Diesel Engine Retrofits in the Construction Industry:

A How To Guide

Massachusetts Department of Environmental Protection

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About MassDEP

The Massachusetts Department of Environmental Protection (MassDEP) is responsible for ensuring clean air and water for Massachusetts residents. To achieve this mission MassDEP develops and implements regulations, policies and programs aimed at reducing sources of air and water pollution in the state, including managing the recycling of solid and hazardous wastes, ensuring the timely clean up of hazardous waste sites and spills, and preserving wetlands and coastal resources.

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CHAPTER 1 Introduction: *Why Retrofit Diesel Construction Engines?*

The primary reason to retrofit construction engines with emission control equipment is to reduce diesel PM pollution in order to protect the health of construction workers and citizens in the area.

All vehicles produce pollution that affects the quality of the air we breathe. Most of the emissions coming from the tail pipes of cars and trucks are gases – carbon monoxide (CO), carbon dioxide (CO_2), volatile organic compounds (VOCs), and nitrogen oxides (NO_x). These all have negative effects on humans, plants and animals. CO is a poisonous gas, CO_2 is a greenhouse gas that contributes to global warming, and VOCs and NO_x combine in the atmosphere to produce ground level ozone (smog) in the presence of sunlight. Ozone is a respiratory irritant that can cause breathing problems for people with respiratory diseases.

Diesel engines, whether used in on-road trucks or in construction equipment, also produce significant amounts of particulate matter (PM) – minute solid and liquid particles composed primarily of carbon.

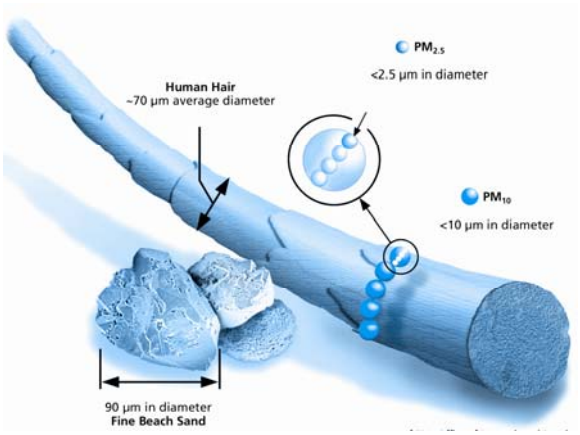
These very small particles can be easily inhaled and pose a significant health risk to humans. Reducing PM pollution from all sources, including construction equipment, is important for the health of workers and the community.

Construction Equipment & Air Quality

Diesel engines produce mostly fine PM with diameters of 2.5 microns or less ($PM_{2.5}$). At about 70 microns, a typical human hair is over 25 times wider than a $PM_{2.5}$ particle. $PM_{2.5}$ presents a serious human health risk because the particles are small enough to get past the body's defenses and lodge deep within the lungs when inhaled. The smallest particles may also enter the bloodstream directly through the lungs.

Construction equipment engines typically produce more PM in a year than on-road trucks and buses because their diesel engines are larger and are not regulated as strictly. Based on new engine standards

Diesel Particulate Matter (PM) Size Compared to Human Hair and Beach Sand



Courtesy of US EPA Office of Research & Development

established by the U.S. Environmental Protection Agency (EPA), a model year 2005 diesel construction equipment engine with 250 horsepower (hp) emits 50% more PM for every gallon of fuel burned than the same size engine installed in an on-road truck. [1] Less powerful off-road engines are allowed to produce even more PM per gallon of fuel.

EPA's new engine standards for both on-road and off-road engines are becoming stricter, but off-road construction engines will not be held to the same PM standards as today's on-road truck engines until the 2011 model year.[2]

Furthermore, even though new engines are becoming marginally cleaner there is still a lot of old construction equipment in use. As emissions from new vehicles are reduced this equipment will emit an ever greater percentage of total diesel PM emissions, both nationally and in Massachusetts.

Diesel Pollution and Your Health

Human exposure to diesel $PM_{2.5}$ can be either short-term (from a few hours to several days), long-term (from one to many years), or both.

Short-term exposure is most harmful for people with existing heart and respiratory problems, including asthma. Short-term exposure to elevated PM levels can aggravate existing lung disease, cause asthma attacks, coughing and acute bronchitis, increase the severity of asthma attacks, and may increase susceptibility to respiratory infections. Short-term PM exposure has also been linked to heart attacks and arrhythmias in people with existing heart disease.

The effect of diesel PM on asthma is of particular concern in Massachusetts since the Asthma Regional Council recently found that one in ten children in Massachusetts has asthma.[3] Children are at increased risk from PM exposure because their lungs are still developing and they breathe more rapidly than adults. They are also typically more active than adults.

Long-term exposure to PM, such as that experienced by people living for years in areas with high PM levels, has been associated with reduced lung function, the development of chronic bronchitis and cardiovascular diseases [4] and even premature death. Many studies show that when particle levels are high, older adults are more likely to be hospitalized and die, often of aggravated heart or lung disease.

In addition, EPA has identified diesel $PM_{2.5}$ as a probable carcinogen due to the demonstrated link between long-term exposure and increased risk of death from lung cancer. The agency has also designated many of the hydrocarbons (i.e. benzene and formaldehyde) in diesel PM as hazardous air pollutants and/or carcinogens.

Finally, studies have not found a "safe" exposure level for $PM_{2.5}$ – meaning that

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[1] EPA, *Control of Emissions of Air Pollution from Nonroad Diesel Engines and Fuel; Final Rule,* Federal Register, 69(124): 38957, June 29, 2004.

[2] Ibid.

[3] Asthma Regional Council, *The Burden of Asthma in New England: A Report by the Asthma Regional Council,* March 2006.

[4] American Heart Association, *American Heart Association Scientific Statement: Air Pollution is Serious Cardiovascular Risk,* June 1, 2004.

even very small amounts have been associated with adverse effects. Virtually all PM created by construction diesel engines is $PM_{2.5}$.

Construction Equipment in Massachusetts

In 2002 there were over 29,000 off-road diesel engines powering construction and mining equipment in Massachusetts.[5] At that time they represented 14% of the diesel engines in the state, but produced 27% — 1,100 tons — of all diesel $PM_{2.5}$ emissions.

Furthermore, the use of construction equipment is growing in this country. According to the U.S. Census Bureau the number of individual companies in the construction industry in Massachusetts grew by over 14% between 1997 and 2002.[6] National surveys conducted by a private research firm between 1999 and 2003 showed that the number of pieces of construction equipment in use nationally increased by 10% in those five years, with the numbers of some types of equipment (excavators and crawlers, for example) increasing by over 40%.[7]

The amount of PM emitted by any individual construction engine in a year, of course, depends on how much it is used. The national survey noted above showed that individual pieces of construction equipment were used between 600 and 2,000 hours per year, with off-highway haulers, bulldozers, and excavators getting the most annual use and concrete pavers and rollers getting the least use.

On average, each construction engine in Massachusetts in 2002 produced 33% more $PM_{2.5}$ per year than the largest tractor-trailer truck, and four times as much as the average school bus.[5]

Massachusetts Air Quality

EPA sets standards for the maximum levels of six different pollutants allowed in the air we breathe (ozone, PM, CO, NO_x, sulfur dioxide, and lead). These National Ambient Air Quality Standards (NAAQS) are designed to protect the public's health.

The entire state of Massachusetts has been designated as being in "nonattainment" of the ozone standard because ozone levels are higher than those allowed by the standards. MassDEP has developed a number of strategies to reduce ozone to comply with the NAAQS standards, including reducing VOCs and NOx emissions from diesel vehicles and other sources. Massachusetts is in attainment for the PM standard adopted in 1997. In 2008 the state will receive its designation for the new PM standard adopted in 2006.

While Massachusetts is in attainment of the NAAQS for PM, PM levels in localized areas near truck corridors, industrial facilities and construction sites may be elevated when diesel activity is high. Indeed, studies have

[5] MassDEP, *The Massachusetts 2002 Diesel Particulate Matter Inventory* , September 2007.

[6] U.S. Census Bureau, *Massachusetts 2002: 2002 Economic Census, Mining, Geographic Area Series, Table 1: Employment Statistics for Establishments by State, 2002*, ECO2-21-A-MA, May 2005; U.S. Census Bureau, *1997 Economic Census: Summary Statistics for Massachusetts, 1997 NAICS Basis*.

[7] McKay & Company, *Construction Equipment, America's Fleet Remains Strong*, August 2003.

shown that operating construction equipment can increase PM concentrations at a construction site by a factor of 16.[8]

MassDEP Diesel Strategies

MassDEP has implemented a number of programs and strategies to reduce diesel PM pollution in Massachusetts in order to better protect the health of the state's residents. Because construction equipment emits such a large portion (27%) of the state's diesel $PM_{2.5}$, MassDEP has focused on reducing emissions from this sector.

The primary diesel reduction strategies for construction equipment are listed below:

- *Reduce Idling:* Decrease engine idling to reduce emissions and save fuel.
- *Replace/Repower/Rebuild:* Retire vehicles or engines "early," and replace them with new, cleaner engines, or rebuild and upgrade engines to incorporate cleaner technologies.
- *Retrofit:* Install retrofit equipment or a muffler replacement device to reduce emissions. These include diesel oxidation catalysts (DOCs) and diesel particulate filters (DPFs), which are discussed in Chapter 3.
- *Refuel:* Use a cleaner diesel fuel.

These strategies take advantage of some of the same technologies used to make new diesel engines cleaner, including changes in the diesel engine itself as well as the use of catalytic after-treatment devices added to the tailpipe. Except for retrofitting, these are the same approaches that have been taken to clean up gasoline-powered cars and light trucks.

MassDEP has carried out these strategies through grant and enforcement programs, regulations, voluntary initiatives, and contract and permit requirements. Contract requirements to reduce diesel pollution, such as those required by MassDEP and several other state agencies, are the focus of this document.

Organization of this Document

This document is a reference manual for construction managers and contractors to help them comply with state agency retrofit requirements. The remainder of the document includes four chapters that cover the following topics:

- *Chapter 2: The specifics of current construction retrofit requirements in Massachusetts state agency contracts*
- *Chapter 3: A description of the retrofit technologies currently available that can reduce PM emissions from diesel construction equipment*
- *Chapter 4: A "road map" for completing a construction equipment retrofit, including how to choose the right technology and how to procure and install a device*
- *Chapter 5: Case studies of several successful retrofit projects that have already been completed in the Northeast*

This document also includes three appendices. The first lists each Massachusetts agency's specific contract language for retrofit requirements. The second is a current list of the retrofit devices that have been verified by EPA and the California Air Resources Board (CARB), as of September 2007. The third lists the Massachusetts-specific contact information for retrofit vendors.

[8] NESCAUM, *Evaluating the Occupational and Environmental Impact of Nonroad Diesel Equipment in the Northeast, Interim Report,* June 9, 2003

CHAPTER 2 Massachusetts State Agency Construction Retrofit Requirements and Recommendations

In recognition of the significant public health benefits of reducing diesel PM emissions from construction equipment, MassDEP has required several agencies or programs that fund public construction projects in Massachusetts to include retrofit requirements in their contracts. These agencies or programs include the Massachusetts Highway Department (MHD), the Massachusetts Bay Transportation Authority (MBTA), and MassDEP's State Revolving Fund (SRF) program. The Massachusetts Division of Capital Asset Management (DCAM) and the Massachusetts Port Authority (MassPort) also have retrofit requirements that they instituted separately from MassDEP.

MassDEP also recommends that development projects being reviewed under the Massachusetts Environmental Policy Act (MEPA) implement strategies to reduce diesel $PM_{2.5}$.

State Agency Requirements

In response to MassDEP's requirements, MHD and MBTA have written specific retrofit requirements into their contract bid specifications. MassDEP instituted this language in its SRF program as well. All winning contract bidders must comply with these requirements in the same way that they must comply with all other bid specifications. The specific language of each agency's retrofit requirements, along with that cited by Massport and DCAM, is listed in Appendix A.

Even if retrofits are not specifically required, construction companies can reap benefits from pro-active voluntary compliance. A commitment to voluntarily clean up construction equipment can help a company foster a reputation as an environmentally friendly company that is interested in the health of its workers and the public.

Retrofit Equipment

While each Massachusetts agency has its own specific contract retrofit language, there are some commonalities across the contracts. For example, all the agencies require contractors to install an emission control device on each piece of diesel construction equipment, to reduce emissions. MHD, MBTA, and MassDEP (regarding MEPA projects) do not specify the type of retrofit equipment to install,

although each agency suggests installing a DOC or DPF. MassDEP's SRF program, DCAM and Massport specifically require that a verified DOC be installed on the equipment. A verified device is a device that has been proven to reduce emissions via standardized testing under an EPA or California Air Resources Board (CARB) program (see Section 3 for a discussion on verification). The MassPort language requires minimum levels of reduction for various pollutants, all of which are easily achievable with a DOC. There are a number of manufacturers who sell EPA-verified devices that can meet these requirements.

New, much more stringent, EPA emissions standards for new construction equipment engines will be phased in between the 2008 and 2014 engine model years. The first new engines to be affected will be those with less than 50 horsepower (hp), beginning in 2008, followed by larger engines between 2012 and 2104. These "Tier 4" standards will require PM reductions of 50 – 90% beyond those achieved in today's new engines, and will likely require DOCs or DPFs as standard equipment on affected engines. Therefore, it is not necessary to retrofit a construction equipment engine certified to EPA Tier 4 standards with an additional emissions control device to comply with Massachusetts state agency construction bid requirements.

Engine Size Requirements

The MBTA currently requires all diesel construction equipment engines, regardless of size or horsepower, to receive retrofits. MassDEP's retrofit recommendations for the MEPA program are not limited to engines of a particular size either.

MHD, DCAM, Massport, and the SRF program limit the retrofit requirements to construction engines of a certain size. MHD limits the requirements to engines with over 50 hp. DCAM restricts the requirements to engines with 50 or more hp that are used on a project for more than 30 days, and the SRF program limits the requirements to engines with 50 or more hp that will be used on a project for 30 or more days. Massport limits the engines to those with 60 or more hp used on a project for over 30 days.

Fuel Requirements

The agencies and programs with retrofit requirements do not require contractors to use specific fuels. Massport and DCAM will, however, allow contractors to use less polluting clean fuels in lieu of a retrofit**.** MassDEP recommends that construction equipment used on MEPA projects operate on ultra low sulfur diesel (ULSD) fuel, which has a fuel sulfur level of 15 parts per million or less.

Reporting Requirements

MHD is the only agency that mandates that the contractor submit a certification form within 14 days, confirming the installation of the retrofit equipment.

Massport and DCAM require contractors to submit an updated list of retrofitted diesel equipment used for each project. The list must indicate the type of retrofit device installed on each engine as well as the use of any clean fuels. Both agencies require contractors to submit monthly reports as well.

The SRF program requires that contractors fill out and file with MassDEP a formal Certification of equipment retrofits, as specified in the plan and specification checklist.

Other Requirements

DCAM and Massport specify that contractors must control nuisance odors from their equipment by turning off their engines and locating engines away from the public.

Massachusetts state law and regulation (310 CMR 7.11) limit idling to five minutes for all on-road and many off-road vehicles, except in certain instances.

DCAM and Massport require contractors to identify each piece of retrofit equipment with markings indicating that it has been retrofitted.

CHAPTER 3 Retrofit Technology: *What is Available?*

This section discusses the retrofit technologies available that can be used to reduce emissions from diesel construction equipment and to meet contractual diesel retrofit requirements. The three most common diesel PM retrofit technologies, in order of increasing effectiveness, are: *diesel oxidation catalysts* (DOC), *flow-through filters* (FTFs), and *active- or passive-diesel particulate filters* (DPFs). These technologies are all potentially applicable to a wide variety of diesel engines.

Because some contract bid language specifies that only devices *verified* by EPA or CARB be used for retrofits this section begins with a discussion of their verification programs. Since some technologies must also use a specific fuel, retrofit fuel requirements are also discussed.

Technology Verification Programs

In order to provide standardized information on the effectiveness of various retrofit technologies and alternative diesel fuels, EPA and CARB operate technology verification programs. Manufacturers who seek verification for their technologies must submit test results from standard emissions tests, along with information on the limitations and special requirements of the technology (e.g., minimum required sulfur level of the fuel). In the EPA program manufacturers must verify a product or technology for each of a number of different engine families and report the actual emissions reductions achieved for NOx, PM, VOC, and CO. Specific products can be verified for onroad engines, nonroad engines, or both.

The CARB verification program separates verified technologies into three levels, based on emissions reduction effectiveness for PM, and reports the level that a product falls into rather than actual PM reductions. The CARB categories include Level 1 (PM reduction of 25% or greater), Level 2 (PM reduction of 50% or greater), and Level 3 (PM reduction of 85% or greater). In the case of technologies that also reduce NOx, the actual NOx control-effectiveness is reported, provided that it exceeds a minimum level.

Some contract language may specify that each retrofit device produce a minimum level of PM reduction (i.e., 25%). This requirement refers to reductions achieved during verification testing; the actual reductions achieved by each verified device are listed on the EPA and CARB websites, and in verification statements that can be provided by the device's manufacturer. These statements can be used to determine whether or not a particular device will meet the contract requirements.

EPA and CARB have slightly different verification requirements, with the CARB requirements somewhat more stringent, especially with respect to mandatory warranty periods. EPA will accept as verified retrofit technologies and fuels that are verified under the CARB program, while CARB does not consider technologies that are verified only under the EPA program to meet its requirements.

EPA and/or CARB have verified a number of commercial products for each of the retrofit technologies discussed here. A current list of the verified devices is presented in Appendix B. Technologies are listed for both on-road and off-road engines. For any changes to this list, please see EPA and CARB's websites, also listed in Appendix A.

Warranties

As a condition of verification any retrofit device verified by CARB must be warranted by the manufacturer to be free of defects and to continue to reduce emissions for the minimum periods shown in the table below. EPA-verified products do not have a mandated minimum warranty period, and warranties may vary by manufacturer. For construction equipment the warranty period is likely to be stated in years and hours of operation. Some products may carry a base warranty of one year.

Minimum Warranty Period for CARB-Verified Off-Road Retrofit Devices

Engine Size	Warranty Period
< 25 hp	3 yrs / 1,600 hrs
25 – 50 hp	4 yrs / 2,600 hrs
> 50 hp	5 yrs / 4,200 hrs

As shown, CARB-verified DOCs, FTFs and DPFs must be warranted by the manufacturer to be free of defects and to continue to reduce emissions for a minimum of three to five years and 1,600 to 4,200 hours of operation, depending on engine size.

Diesel Fuel & Retrofits

Retrofitting construction equipment with DOCs and FTFs requires that the diesel fuel used in the diesel engine have a maximum sulfur level of 500 parts per million (ppm). Required sulfur levels can be even more restrictive for DPFs, depending on whether passive or active DPFs are used. With passive DPFs the fuel can have no more than 50-ppm sulfur while active DPFs can generally tolerate sulfur levels as high as 500 ppm. Contractors should check the EPA or CARB verification statement for a retrofit technology to determine its fuel sulfur requirements.

Until recently the sulfur content of off-road diesel fuel used in construction equipment was unregulated and was typically as high as 3,000 ppm. These high sulfur levels severely limited the ability to retrofit construction equipment with any device to reduce PM emissions, because high sulfur levels degrade the functioning of the catalyst in a DOC or active DPF.

As of June 2007, however, all standard off-road diesel fuel must have no more than 500-ppm sulfur, and in 2010 the maximum sulfur level in off-road fuel will be reduced to 15 ppm. The 500-ppm fuel is known as low sulfur diesel (LSD) fuel while 15-ppm fuel is referred to as ultra-low sulfur diesel (ULSD) fuel.

This change in the fuel sulfur standard means that standard 500-ppm off-road fuel purchased from any supplier can be used successfully with DOCs and FTFs with no negative impact on these devices. Because LSD fuel can be used with DOCs and FTFs, retrofitting with these devices also will not incur any incremental on-going operating costs for fuel.

As mentioned earlier, passive DPFs require fuel with a maximum sulfur level of 50 ppm. On-road ULSD fuel is now available from approximately 90% of retail fuel suppliers across the state, because EPA required on-road diesel vehicles to use ULSD fuel beginning in October 2006. Fuel suppliers can dye and sell this ULSD fuel as off-road fuel for use in a Contractor's off-road engines, and it will receive the same tax treatment as other off-road fuel. It is likely to be more expensive than LSD fuel, due to the cost of the additional processing steps required at the refinery to remove more sulfur. ULSD fuel meeting the 15-ppm sulfur specification, when sold as off-road fuel, may cost anywhere from $0.03 - $0.05 per gallon more than standard LSD off-road fuel.

Contractors who choose to retrofit with DPFs *may* also be able to use LSD fuel, because its actual sulfur level in the next few years may not be even close to the allowable maximum level of 500 ppm, due to issues in the distillate fuel supply chain. The current distillate supply chain was set up to handle the two grades of fuel that have been used for the last 13 years – the 500-ppm sulfur fuel once used in on-road vehicles and the 3,000-ppm sulfur fuel formerly used in off-road diesel equipment and still used for residential heating. This supply system most likely cannot handle a third grade of fuel (i.e., 15 ppm ULSD) without significant investments by fuel suppliers. Therefore, it is likely that most, if not all, of the off-road LSD fuel sold will actually be "off-spec" on-road ULSD – i.e., 15-ppm fuel that has been contaminated by the 3,000 ppm fuel in the supply chain.

Depending on the level of contamination, much of this fuel may have an actual sulfur content of 50 ppm or lower, and could be used in equipment retrofitted with passive DPFs. This means that contractors retrofitting with DPFs *may* be able to use LSD fuel tested at 50 ppm sulfur or lower without incurring an increase in on-going operating costs for fuel.

To determine the suitability of standard LSD fuel for use with DPFs contact your fuel supplier, who maintains records on the actual sulfur level of all fuel sold.

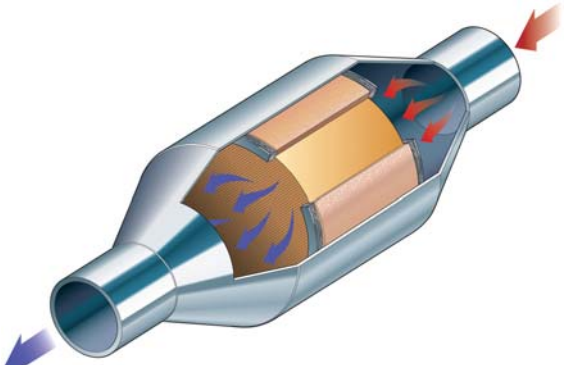
Diesel Oxidation Catalysts

A DOC can be used on virtually any construction diesel engine, and will produce significant emissions benefits. A DOC can reduce VOC and CO emissions from construction equipment by 20 to 75% and PM emissions by 25% or more.[9]

A DOC contains a flow-through metal or ceramic core whose flow channels are coated with a precious metal catalyst such as platinum. This catalyst core is packaged into a metal container similar to an exhaust muffler/resonator. The device

[9] For all technologies the reported range of emissions reductions is from test results reported under the EPA and CARB Technology Verification Programs. See Appendix B for a list of currently verified devices.

Typical Diesel Oxidation Catalyst



Courtesy of Johnson Matthey, Inc

sits in the exhaust stream of a vehicle and, as exhaust flows through it, the catalyst promotes the oxidation of unburned PM, VOC, and CO, producing CO_2 and water.

Fuel Requirements

DOCs do not substantially increase fuel consumption and can operate on standard off-road LSD fuel (maximum 500 ppm sulfur level).

Installation

Some DOCs are designed as a straight replacement for the vehicle's existing muffler/resonator, with the catalyst and a resonator packaged into the same container. Others include only the catalyst core and are designed to be installed in addition to the existing muffler/resonator. Either way, retrofit installation is generally straightforward and takes only a few hours. Space constraints on some equipment would be the only impediment to installation.

Maintenance

DOCs require virtually no on-going maintenance after installation. Since DOCs are usually packaged in stainless steel cans, installed devices usually last for at least six years.

Costs

For a typical construction engine with under 250 hp, a DOC costs from $800 to $3,500, including installation. In general the larger the engine the more expensive the DOC will be. DOCs are usually some of the most cost-effective retrofit devices available - judging by the amount of money it costs to install and maintain them in relation to the emission benefits gained - and are a very good retrofit option for construction equipment. They have been installed on thousands of construction equipment engines throughout the United States.

Limitations

There are very few limitations on the use of DOCs. Very old engines (older than model year 1990), and engines that consume excessive amounts of lubricating oil, may not be good candidates for retrofitting because high oil levels in the exhaust could cause the flow channels of the DOC catalyst core to plug with PM. Virtually all other engines can be retrofit with a DOC.

Flow-Through Filters

FTFs can be used on a wide variety of construction equipment engines and provide even greater emissions benefits than a DOC. An FTF can reduce VOC and CO emissions by 50 to 89% and PM emissions by approximately 50%.

An FTF includes a flow-through catalyst core and is very similar to a DOC, but it uses a different type of core material to hold the catalyst. Different manufacturers use wire mesh, wire fleece, or sintered metal cores, all coated with a precious metal catalyst and packaged into a metal

Typical Flow Through Filter

Courtesy of Fleetguard Emissions Solutions

container similar to those used to package a DOC.

As in a DOC, the catalyst promotes the oxidation of unburned PM, VOCs, and CO in the exhaust passing through the device, producing CO_2 and water. Because of the core configuration individual PM particles typically have greater opportunity for contact with a catalyst site than in a standard DOC, so that an FTF eliminates more PM than a DOC.

Installation

As with a DOC, retrofit installation is generally straightforward and takes only a few hours. Most FTFs are designed to replace a vehicle's existing muffler/ resonator and include a resonator in the package with the catalyst core. While an FTF often is the same size as the vehicle's existing muffler/resonator it may weigh a bit more and require additional or more robust mounting hardware. Space constraints on some equipment would be the only impediment to installation.

Fuel Requirements

Like DOCs, FTFs can operate on standard off-road LSD fuel (maximum 500 ppm sulfur level).

Maintenance

FTFs usually require virtually no on-going maintenance after installation. Since FTFs are usually packaged in stainless steel cans, installed devices usually last at least six years.

Costs

For a typical construction engine with under 250 hp an FTF costs from $3,500 to $5,000, including installation. In general the larger the engine the more expensive the FTF will be.

Limitations

FTFs require a minimum exhaust temperature of greater than 250°C for about 35% of the time to work consistently, and therefore cannot be used in all duty cycles. This somewhat limits their application, as not all construction equipment will routinely produce exhaust temperatures high enough for the devices to work consistently.

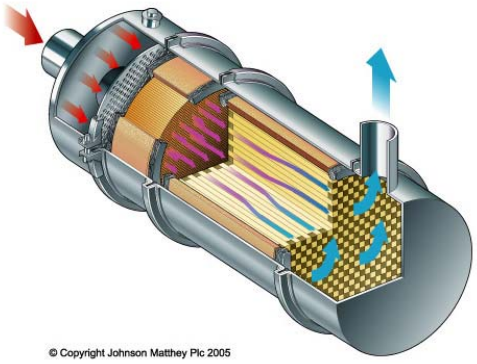
See below for a more in-depth discussion of exhaust temperature limitations, which also apply to passive DPFs. Exhaust temperatures do not need to be as high for an FTF to work as they do for a passive DPF to work, so that FTFs are applicable to a wider range of engines.

FTFs may also increase fuel use by up to one percent because they slightly increase back-pressure on the engine.

Diesel Particulate Filters

Diesel particulate filters can be either "passive" or "active" devices. A passive DPF works without any additional energy input other than the heat in the exhaust coming from the engine. An active DPF

Typical Passive Diesel Particulate Filter



Courtesy of Johnson Matthey, Inc

includes a system to add energy to the exhaust to increase its temperature.

A passive DPF can be used on a wide variety of construction equipment engines, while an active DPF can be used on virtually all diesel engines. Either type of device provides even greater emissions benefits than a DOC or FTF. DPFs, whether passive or active, reduce PM emissions by 85% or more. Passive DPFs that incorporate a catalyst also reduce VOC and CO emissions by 60 to 90%, while non-catalyzed active DPFs will reduce CO emissions by approximately 10% and VOC emissions by approximately 20%.

Passive DPFs

The two types of DPFs share some components but also have significant differences. A passive DPF combines an oxidation catalyst with a porous ceramic, sintered metal, or silicon carbide filter in a metal container similar to an exhaust muffler/resonator.

There are several variations on the design. Some passive DPFs have a separate flow-through catalyst core (essentially a DOC) in a series with an uncatalyzed filter, while others use a filter with the catalyst applied directly to it. Either way, passive DPFs sit in the exhaust stream of the vehicle like a typical muffler/resonator.

The gaseous components of the exhaust pass through the porous walls of the filter section, while the solid PM particles are physically trapped in the filter walls. The catalyst promotes oxidation of the trapped PM at temperatures typical of diesel exhaust, which then exits the filter as gaseous CO_2 and water. The catalyst also oxidizes gaseous VOC and CO in the exhaust like a typical DOC or FTF.

A passive DPF requires a minimum exhaust temperature of 250 – 290^{o}C for approximately 35% of the time to oxidize the collected PM in the filter. This is easily achievable for many construction engines, but certain engines and duty cycles may not have sufficient exhaust temperature to use a passive DPF effectively. In general passive DPFs can be used for duty cycles in which the diesel engine operates for a majority of the time under high loads.

Active DPFs

An active DPF also uses a porous filter to physically remove PM from diesel exhaust. Like a passive DPF, the active DPF may employ a catalyst coating on the filter to lower the temperature at which the collected PM will oxidize out of the filter. However, in order to accommodate a wider range of duty cycles an active DPF also incorporates an "active" system to raise the temperature inside the filter.

The most common method used to raise the filter's temperature is to inject additional diesel fuel into the exhaust stream, downstream of the engine but in front of the filter. As this fuel burns it raises the exhaust temperature.

There is also at least one verified device commercially available for construction equipment that uses only a "bare" uncatalyzed filter on the vehicle, combined with an electric heating element.[10] While the vehicle is operating the filter continually collects PM. At night the user must plug the heating element into a power outlet, which uses electricity to create enough heat to burn all of the collected PM out of the filter in a few hours.

Because they incorporate a method to increase the exhaust temperature as required, or otherwise burn off collected soot, active DPF systems can be used on a much wider range of engines and duty cycles, including virtually all construction equipment.

Fuel Requirements

Passive DPFs require fuel with less than 50-ppm sulfur, so it may not be possible to use standard off-road LSD fuel with retrofit equipment (see *Diesel Fuel & Retrofits*, above). Higher levels of fuel sulfur reduce the oxidation efficiency of collected PM and can result in filter plugging. Active DPF systems that inject diesel fuel into the exhaust generally do not have fuel sulfur restrictions and standard off-road fuel can be used. Vehicles retrofit with active DPFs that use electric heating elements to oxidize collected PM can also use standard off-road LSD fuel.

Installation

Installation of both passive and active DPFs is relatively straightforward and usually takes four to eight hours per vehicle. Active DPF systems take longer to install than passive systems because they include more equipment. Electrically-regenerated active DPF systems typically require access to a 208/240 volt 20 amp electrical outlet for each vehicle, for daily regeneration of the filter.

DPFs, both active and passive, are often slightly larger than the vehicle's existing muffler/resonator and may weigh significantly more. Additional or more robust mounting hardware is nearly always required. Space constraints on some equipment would be the only impediment to installation.

Maintenance

Non-combustible components of lubricating oil collect as ash in the DPF filter over time. Approximately once every 12 to 24 months, depending on the use of the equipment, the filter must be removed from the vehicle and cleaned. This cleaning requires a special machine and can often be done by the engine manufacturer's service representative or another third party for a fee of $200 - $400 per filter. The devices are often designed with the filter section connected to inlet and outlet sections with band clamps, for easy removal of only the filter section for cleaning. This can be done in as little as half an hour.

Since both passive and active DPFs are always packaged in stainless steel cans installed devices usually last at least six years.

Costs

For a typical construction engine with under 250 hp, a passive DPF costs from

[10] This is the Cleaire Horizon; see Appendix B.

$8,500 to $10,000 and an active DPF costs from $14,000 to $20,000 including installation. As with other retrofit devices the larger the engine the more expensive the device will typically be.

Active DPFs that use electric regeneration must be plugged in for up to five hours per vehicle per day, during which time they will consume approximately 15 kilowatt-hours of electricity.[11] At nine cents per kilowatt hour, filter regeneration would cost approximately $1.35 per day.[12]

Limitations

Passive DPFs will not work on all engines. The more PM the engine produces the larger the filter and catalyst must be to work continuously without plugging. For some very old engines (older than model year 1990) it may not be practical to retrofit with a passive DPF, due to cost issues and space constraints.

Certain engines and duty cycles may also not have sufficient exhaust temperature to use a passive DPF effectively. In particular, lightly loaded duty cycles may not be appropriate for passive DPFs. Evaluation of the exhaust temperature profile for the engine/duty cycle is highly recommended before passive DPFs are installed on a vehicle type for the first time (see *Retrofit Roadmap: How to Get it Done,* Chapter 4).

As ash or excess carbon builds up in a DPF filter the backpressure on the engine will rise. Very high engine backpressure can lead to high turbo charger temperatures and progressive engine damage. For this reason all DPFs (both passive and active) should always be used with a backpressure monitoring system that triggers a maintenance light once the backpressure rises above a set threshold. This system consists of a pressure transducer, an electronic control module (ECM), and a maintenance/ warning light mounted in the engine compartment or operator cab. The ECM requires a connection to the vehicle's 12/24-volt power system. These systems are designed to protect the engine.

Passive DPFs may increase fuel use by 1 to 3%. Active DPF systems that inject diesel fuel into the exhaust to raise exhaust temperature could increase fuel use by up to 7%, depending on the engine and duty cycle.

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[11] Based on manufacturer literature for Cleaire Horizon-M; www.cleaire.com/web/products/horizon-m.shtml

[12] According to the US Department of Energy's Energy Information Administration, in 1999 the average price of electricity for commercial customers in Massachusetts was $0.089/kwh (http://www.eia.doe.gov/cneaf/electricity/page/fact_sheets/mass.html).

Comparison of Retrofit Technologies

	DOC	FTF	Passive DPF	Active DPF
PM Reduction	25%	50%	85%	85%
CO, VOC Reduction	20 – 75%	50 – 89%	60 – 90%	Variable*
Cost (< 250 hp)	$800 – $3,500	$3,500 - $5,000	$8,500 - $10,000	$14,000 - $20,000
On-going Maintenance & Costs	None	None	Annual filter cleaning Increased fuel use of 1% - 3%	Annual filter cleaning Increased fuel use of up to 7%. If regenerating electrically requires electric infrastructure
Limitations	None	Minimum exhaust temp required	Minimum exhaust temp required < 50 ppm sulfur fuel required	None

** If the filter is catalyzed reductions will be similar to a passive DPF. With an uncatalyzed filter reductions will be lower.*

CHAPTER 4 Retrofit Roadmap: *How to Get it Done*

Retrofitting a construction diesel engine with a DOC is not hard to do, and will not keep the equipment out of service for long. Retrofitting with an FTF or a DPF is a bit more complicated, and often requires initial exhaust temperature testing, but the actual installation of the devices is straightforward. This section details the three-step process required to successfully retrofit a piece of equipment, from choosing the technology, to buying the device, to installing and keeping it working with ongoing maintenance.

Choosing a Retrofit Technology

There are several factors involved in choosing a technology: the contractual PM reductions and/or specific technology required, feasibility, and cost.

PM Reduction and Technology Requirements

For contractors working on contracts for MHD, MBTA, and MEPA the most important consideration in deciding which retrofit technology to use is how much PM reduction is desired. DOCs reduce PM by about 25%, FTFs by 50%, and active and passive DPFs by 85%.

For contractors bidding on contracts for the SRF Program, which requires DOCs, their decision is simply which DOC to buy. Contractors bidding on the DCAM and Massport contracts must locate the appropriate technology that meets the minimum emission reduction requirements of their contracts.

Feasibility

Contractors must determine if the chosen technology is suitable for their construction engine. DOCs and active DPFs can be used on virtually any piece of construction equipment. FTFs require a minimum level of exhaust temperature, while passive DPFs require both a minimum exhaust temperature and fuel with less than 50-ppm sulfur.

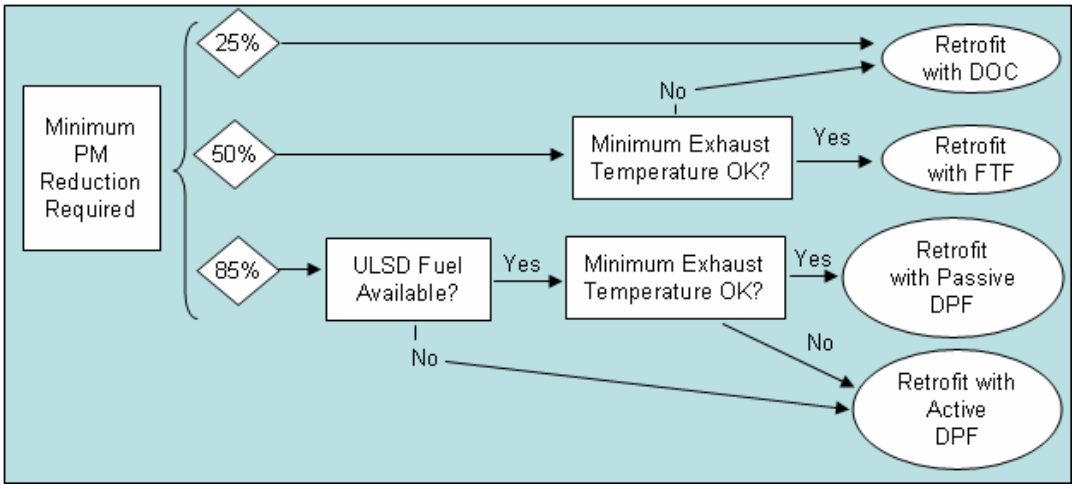
Cost

Whether you retrofit with a DOC, FTF, or DPF, the size and, therefore, the cost of the device will depend on the size and power of the engine (i.e., hp, displacement) being retrofitted. In all cases larger engines require physically larger devices to handle the exhaust flow volume without unacceptably increasing backpressure on the engine or turbo charger. Larger devices require more precious metals in their catalyst formulations, which also increases cost.

Of the available technologies DOCs are the least expensive and active DPFs are the most expensive.

See the flow chart below, which describes the process of choosing a technology.

Construction Equipment Retrofit Decision Process



Purchasing a Retrofit Device

EPA and CARB-verified retrofit devices are listed in Appendix B. [13] Appendix B lists the name of the company that makes each verified device, along with the engines for which they are verified. Appendix C provides a list of contacts at each company.

You can also contact the original engine manufacturer's service representative to determine if they sell verified retrofit devices for your specific engine.

Whether you contact the engine manufacturer's service representative, or the retrofit device manufacturer directly, each will need, at a minimum, the following information to identify the correct device for your equipment:

- Equipment and engine make, model number, and year of manufacture
- Engine hp rating and displacement (liters)
- Size and location of existing muffler/resonator
- Configuration of existing muffler/resonator (i.e., outlet location and orientation in relation to inlet)

If you choose to use a verified technology that combines a retrofit with an alternative fuel, then the vendor will also want to know about your fueling arrangements (i.e., centrally located or mobile fueling).

For many pieces of equipment you should be able to buy a device "off the shelf." For others the vendor may need to adapt an existing design to your piece of equipment (e.g., size, inlet/outlet configuration, supports, connections to exhaust piping).

[13] As of the publication date. Additional devices may have been verified since. See EPA and CARB websites, as noted in Appendix B.

Installing and Maintaining a Retrofit Device

DOC Installation

Installation of a DOC is usually straightforward, requiring only commonly available tools. DOCs that include only a catalyst core and are designed to be installed in addition to the existing muffler/resonator usually take two to four hours to install. DOCs that are designed as a muffler replacement (with a resonator and catalyst core in the same container) may take several hours longer.

In most cases a muffler replacement device will be similar in size to the equipment's existing muffler/resonator while catalyst-only devices will be smaller. With either type of device a vehicle's existing inlet and outlet exhaust piping can usually be re-used with minimal or no modification. Since a DOC is usually of similar weight to the existing muffler/resonator no additional exhaust brackets are usually required.

DOC Maintenance

DOCs do not require any on-going annual maintenance. The exterior "can" in which they are packaged is typically made from stainless steel so that they are much more durable than the standard mufflers/resonators used on construction equipment.

The durability of all retrofit devices will be enhanced by the recent change to off-road fuel sulfur standards, as discussed earlier. Exhaust system corrosion on any vehicle is accelerated by sulfuric acid created in the exhaust from oxidation of fuel sulfur. The recent, significant reductions in off-road diesel fuel sulfur will reduce the amount of sulfuric acid created in the exhaust of construction equipment, and should reduce exhaust system corrosion whether the equipment is retrofitted or not.

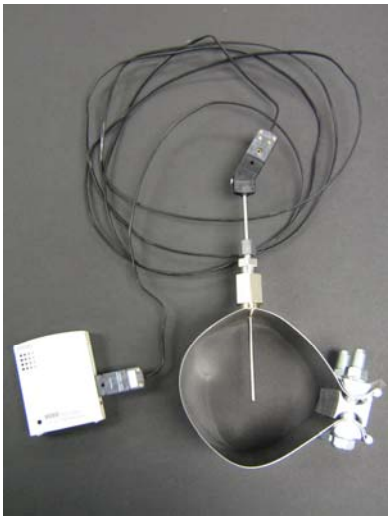
FTF and Passive DPF Data Logging

Both FTFs and passive DPFs require a minimum level of engine exhaust temperature to work reliably. Exhaust temperature can be affected both by the engine and its duty cycle. In general, exhaust temperature will be high when the engine is operating at high power levels and lower when the engine is lightly loaded (i.e., idling).

Because of the minimum exhaust temperature requirements, retrofitting with an FTF or passive DPF is more complicated than retrofitting with a DOC, and requires you to collect exhaust temperature data.

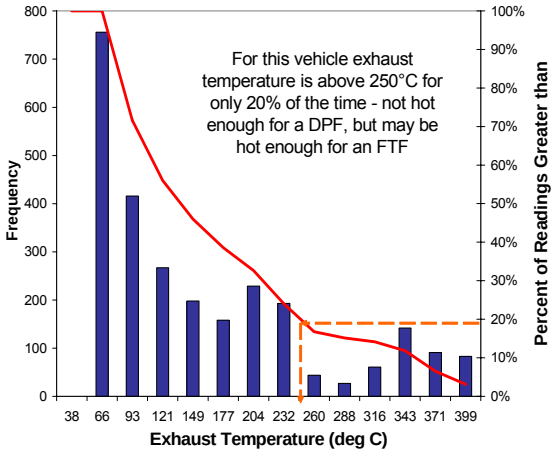
If the particular make and model of equipment that you own has already been retrofitted with an FTF or passive DPF by someone else you should have no problem retrofitting your own vehicle with the

Exhaust Temperature Data Logger & Thermocouple



Thermocouple Installation

Exhaust Temperature Profile - Loader



same type of device, unless you operate your equipment in a very different type of duty cycle (i.e., longer periods of idling, lower average engine load). If your make/model of equipment has never been retrofitted, or if there is any question about its duty cycle, you should collect exhaust temperature data prior to committing to an FTF or passive DPF retrofit.

The required data can be collected with a small, inexpensive, battery-powered data logger and a J-type thermocouple.[14] After installation the equipment is operated in regular service, on its normal duty cycle, for several days. If the vehicle does the same thing every day two days of data is sufficient. If the vehicle does different things every day, then a week's worth of data would be better.

The collected data are then analyzed to see how often the exhaust temperature exceeds certain thresholds. Passive DPFs generally require that the exhaust temperature be above 250 - 290°C for at least 35% of the time. FTFs may have slightly lower temperature or time thresholds.[15]

FTF and Passive DPF Installation

Installation of an FTF or DPF is usually straightforward, requiring only commonly available tools, and is similar to installation of a DOC. Most are designed to replace the vehicle's existing muffler/resonator and are of similar size (or larger) but will be heavier. Due to their increased weight FTFs and DPFs usually require additional or more robust brackets than the existing muffler brackets.

In order to maintain the greatest exhaust temperature inside the device they should also be installed as close to the engine's exhaust manifold as possible, just

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[14] To install the thermocouple you install an exhaust band clamp with a fitting welded to it on the exhaust pipe near where the DPF device would be installed. Then drill a one-eighth inch hole in the exhaust pipe through the fitting, insert the thermocouple through the hole, and tighten the fitting. The wire from the thermocouple is attached to the data logger, which is mounted to a convenient location on the vehicle with clamps or zip ties.

[15] Actual requirements for each device will be listed on the EPA or CARB verification statement.

downstream of the turbocharger. To put the device in this location the existing exhaust piping may have to be modified or replaced. It is also advisable to insulate the exhaust piping between the exhaust manifold and the device to hold in heat.

DPF installations, and sometimes FTF installations, will include a backpressure monitoring system. This consists of a pressure transducer mounted in the DPF inlet section, an electronic control module (ECM), and a maintenance/warning light mounted in the engine compartment or operator cab. The ECM will require a connection to the vehicle's 12/24-volt power system.

Installation of the FTF/DPF and backpressure monitoring system will usually take four to eight hours per vehicle.

Maintenance

Unless there is extended operation with very low exhaust temperatures, or an engine problem, FTFs do not usually require any on-going annual cleaning or maintenance because their construction allows ash to pass through the device. DPFs, however, do require periodic cleaning to remove collected ash.

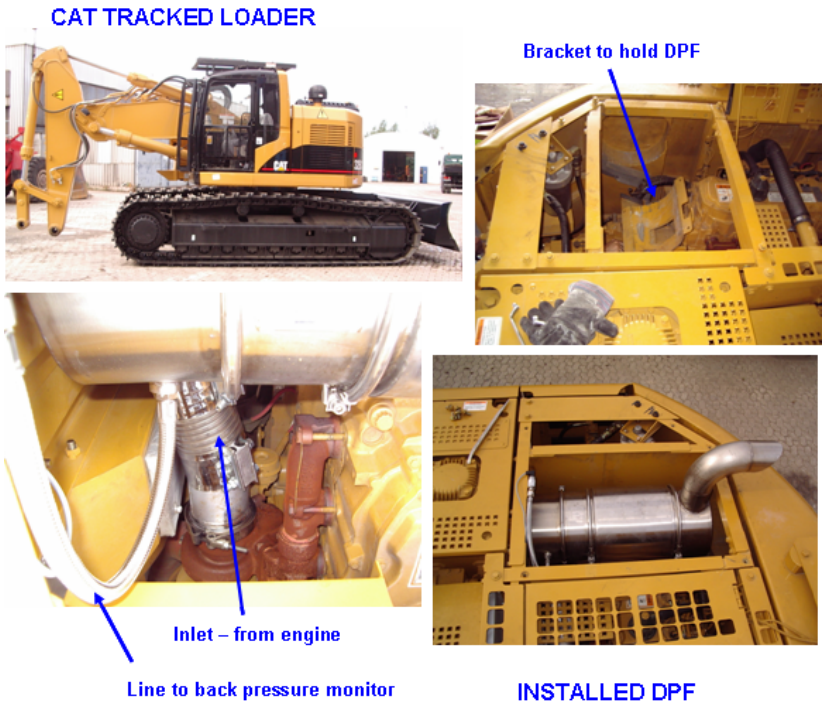
All lubricating oils used in diesel engines contain small amounts of inorganic elements such as potassium, calcium, and phosphorus as additives to control the pH level of the oil. Inevitably some amount of lube oil is burned along with the fuel in even the best maintained engines. This burning lube oil also contributes to the PM produced by a diesel engine.

When the engine is equipped with a DPF virtually all of the PM produced by the engine, most of which is carbon soot, collects in the filter. When the collected carbon soot oxidizes and leaves the filter as gaseous CO_2 the inorganic elements of the burned lube oil cannot oxidize into a gas; they stay behind in the filter as solid ash. More and more of this ash collects over time, and it must be periodically removed or it will eventually plug the filter.

How often the filter element of a DPF needs to be cleaned of ash depends on how much the engine gets used, how much lube oil it burns, and how much inorganic additive is in the lube oil. On-road trucks and buses that operate for 50,000 miles per year or more typically require filter cleaning every twelve to twenty-four months. It is expected that DPFs installed on construction equipment will have a similar ash cleaning interval, though equipment that does not get used very often may require even less frequent cleaning, and equipment that burns a lot of lube oil will require more frequent cleaning.

Lube oil requires pH additives primarily because of sulfuric acid created by oxidation of diesel fuel sulfur during combustion. Without additives the lube oil would become more acidic over time as this acid collected in it. The recent, significant reduction in sulfur levels in off-road fuel, as discussed above, means that less acid will form during combustion

DPF Installation Process



Photos Courtesy of Johnson Matthey, Inc.

DPF Installation Process

Photos Courtesy of NESCAUM

and less will end up in the lube oil. Diesel construction equipment can therefore now use "low ash" lube oils that contain fewer additives. The use of low ash lube oils in equipment retrofit with DPFs will extend the required DPF cleaning interval.

The ash cleaning process is relatively simple, but it requires a special machine that can blow air through the filter and apply heat at the same time, while collecting the removed ash for disposal. The engine manufacturer's service representative, or another third party cleaning company, can clean DPF filters for a fee of $200 to $400 per filter.

Most DPFs are constructed in three sections (inlet section, filter section, outlet section) held together with v-band clamps. They are designed this way so that the filter section can be easily removed for cleaning while leaving the inlet and outlet sections connected to the vehicle's exhaust piping. Depending on the mounting location filter removal and replacement could take half an hour to an hour. In some designs there are graphite gaskets between the sections that must be replaced when the filter is removed for cleaning.

DPF Filter Cleaning Process

Courtesy of Cleaire, Inc

Occasionally a DPF filter will plug up with accumulated soot that cannot be oxidized quickly enough to keep the filter clear, which increases the backpressure on the engine. This is most likely to happen if the vehicle is operated for an extended period in a duty cycle with very cool exhaust temperatures (i.e., left to idle for hours at a time), or if there is some kind of major engine problem that increases the amount of PM produced (i.e., leaking injectors, turbo failure).

If this happens the backpressure monitoring system installed with the DPF should set a maintenance/warning light well before any permanent damage is done to the filter or engine. This light indicates that the filter must be cleaned.

In this instance the accumulated soot may be "wet" so that it cannot be removed with the normal ash cleaning process, and will require a supplemental cleaning process that involves "baking" the filter for an extended period in a special high-temperature oven (up to 1,100ºF). During this cleaning process the temperature of the oven and the air flow are carefully controlled to allow the accumulated carbon to oxidize without damaging the filter substrate. Device manufacturers and third party cleaning companies may refer to this procedure as a "Level 2" cleaning.

In rare cases FTFs might also clog with accumulated wet ash due to an engine problem. If so, they can also be cleaned with a Level 2 procedure as described above.

Active DPFs

For the same size engine active DPFs will be a similar size and weight as passive DPFs, if not larger. Installation of these devices is similar to installation of passive DPFs, but may take longer because they will generally include additional equipment (for example a diesel fuel pump and injector for those that regenerate with diesel fuel, and electrical connections for those regenerated electrically). These devices will also always include a backpressure monitoring system as part of the installation.

As with passive DPFs the filter element will need to be cleaned periodically.

CHAPTER 5 Case Studies

Boston's "Big Dig" Central Artery Construction Project

Boston's Central Artery/Tunnel project was under construction for over 15 years beginning in 1991. One of the largest construction projects in the country, it was designed to bury the existing 7.5 mile, six-lane elevated portion of I-93 running through central Boston. The $14 billion project included construction of 160 lane miles of new highways, 80 lane miles of new tunnels - including a four-lane tunnel under Boston Harbor - and a ten-lane cable-stayed bridge over the Charles River. The work included moving over 13 million cubic yards of excavated material and placing four million cubic yards of concrete.

Construction required the continuous use of several hundred pieces of construction equipment over many years for excavation, underpinning, roadway and tunnel construction, and street surfacing. To minimize the impact of this equipment on the air quality of surrounding Boston neighborhoods, the project sponsor, the Massachusetts Turnpike Authority, in collaboration with other government and private organizations, implemented a construction equipment retrofit program beginning in 1998. This was the first large-scale construction equipment retrofit program ever undertaken, and by the time the Big Dig was complete over 200 pieces of construction equipment had been retrofitted with DOCs.

Involvement with construction retrofits on the Big Dig was helpful to our company because it gave us a jumpstart in this area. We have since seen other agencies add retrofit requirements to their contracts, so we have continued to retrofit our own equipment with oxidation catalysts. We've done more than one hundred major pieces of equipment – almost 85% of our fleet. We've had a few nuisance maintenance issues with the retrofit devices, but nothing major. Initially, the biggest problem was some catalyst clogging early on, when we were still burning high sulfur fuel. Now that sulfur levels have been reduced in off-road fuel we anticipate these problems will go away. Also, as we do more retrofits, we've made sure to account for a couple of issues where the retrofits are different from the regular muffler; that some machines require slightly modified fit-ups, and there is a longer lead time between order and delivery.

– John McAteer
Equipment Manager
J.F. White Contracting Co.

Because it was the first program of its kind the retrofits were completed in three phases. During the first phase eight pieces of equipment from three different contractors were retrofitted. These included both large and small excavators and large and small front-end loaders from several different manufacturers. Installation took less than two hours on each piece of equipment.

When this pilot phase proved that equipment could be easily retrofitted without causing excessive down time or ongoing operational problems the program was extended to another 60 pieces of equipment. In the third phase retrofit requirements were put into the final 23 contracts let for the project, resulting in an additional 150 pieces of equipment being retrofitted.

A wide variety of construction equipment – from lifts to cranes to excavators to bulldozers – was retrofitted. The cost of each retrofit device ranged from $500 to $3,500 depending on the size of the engine, with an average price of $2,500. The contractors reported that the retrofits on some equipment took up to five hours, but did not cause any operational problems – no loss of power, and no additional fuel consumption. Some contractors experienced minor nuisance maintenance issues on some equipment (for example cracking of muffler supports) but nothing that caused excessive equipment down time, or resulted in major maintenance costs. At least one contractor also experienced some plugging of catalyst devices early on, when fuel sulfur levels were high (approximately 3,000 ppm). They report that once the maximum allowable sulfur level in off-road fuel fell below 500 ppm these problems went away.

Photo courtesy of Massachusetts Turnpike Authority

Big Dig Construction Equipment Sample Retrofits – Phase 1 & 2

Type	Make/Model	Year	Engine HP	Retrofit Technology	Number of Retrofits
Lift	Nichi/ISR602	1994 -2000	90	DOC	5
Lift	Nichi/ISR700	2000	80	DOC	1
Lift	CAT/7H83	1999	90	DOC	3
Lift	SIC/600SJC	2000	66	DOC	1
Lift	Terex/TX77 45R	1999	105	DOC	2
Lift	JLG/3513	1999	105	DOC	1
Crane	Mantis/10010	1998 - 2000	215	DOC	2
Excavator	Gradal/XL5200	1999-2000	174	DOC	3
Dozer	Deere/850C	2000	192	DOC	1
Dozer	CAT/953C	1999	121	DOC	3

New York City Department of Sanitation

The New York City Department of Sanitation (DSNY) is responsible for handling the residential trash of over eight million city residents, and for salting roadways and clearing city streets of snow during the winter. On-road equipment is used for trash collection and road salting, but off-road equipment is used to perform maintenance at the Fresh Kills Landfill on Staten Island and for snow clearing city-wide. These operations require approximately 400 pieces of off-road construction equipment - everything from front-end loaders, to tracked loaders, to excavators and off-road dump trucks.

In December 2003 the New York City Council passed Local Law 77, which mandated PM reduction retrofits on all off-road diesel equipment over 50 hp owned by city agencies, or used by private contractors on city-funded construction projects, beginning in 2005. To comply with this law DSNY began to retrofit its off-road equipment in 2004. To date the Department has retrofitted over 200 pieces of equipment, including front-end loaders of various ages from three different manufacturers, with engines ranging in size from 138 hp to 235 hp.

DSNY has been experimenting with DPF retrofits, but to date most equipment has been retrofitted with DOCs. If the few DPFs now in service prove to be reliable over time the Department will begin to retrofit additional equipment with these devices to increase total PM reductions.

Complying with the requirements of Local Law 77 has not been as difficult as some thought it would be. Our experience with retrofitting off-road equipment has been very positive. For the most part we have been able to buy direct-replacement DOCs from the vehicle OEMs. Installation is easy and they have not caused us any operational problems. DPFs are a bit more challenging, and more expensive, but the early results with them are also positive.

- Spiro Kattan
Supervisor of Mechanics
DSNY

The DOC retrofits to date have cost between $1,300 and $2,800 per unit. In most cases installation has taken less than two hours per vehicle – most have been purchased from the vehicle original equipment manufacturer (OEM) and have been designed as a direct replacement for the existing muffler/resonator. The DPFs were significantly more expensive, costing as much as $17,000 per unit and requiring up to 16 hours to install.

DSNY has had no operational problems with the devices that it installed. They have been reliable and have not increased equipment down time or on-going maintenance costs.

NYC Department of Sanitation Equipment Retrofits

Equipment Type	Make/Model	Year	Engine HP	Retrofit Technology	Number of Retrofits
Loader	Case/6T-590	1994 - 2002	138	DOC	90
Loader	Case/59 CPL 2071	1998	138	DOC	24
Loader	Daewoo DB58TIS	2005 - 2006	143	DOC	66
Loader	Daewoo DB58TIS	2006	143	DPF	2
Loader	Case/6T-830	1998-2000	198	DOC	32
Loader	Case/6T-830	2000	198	DPF	1
Loader	Caterpillar/3306	2002	235	DPF	3

Installed DPF

Daewoo Loader

Photos courtesy of DSNY

I-95 New Haven Harbor Crossing Corridor Improvement Program

Begun in 2002, the New Haven Harbor Corridor Crossing Improvement Program is a major road project along seven miles of the I-95 corridor in southern Connecticut. Project work includes the widening of I-95 between New Haven and Branford, CT; reconstruction of the I-95/I-91/I-34 interchange in New Haven; and replacement of the existing Pearl Harbor Memorial Bridge over New Haven Harbor with a new ten-lane bridge. Construction is divided into five contract phases. Work on the first contract was completed in June 2004 and the entire project is expected to be completed by 2014.

The project sponsor, the Connecticut Department of Transportation, began planning for construction equipment retrofits in October 2000, one year before the first contract was bid. The Connecticut Clean Air Construction Initiative was developed with the participation of the Connecticut Construction Industries Association and other groups.

Under this program contractors were required to either retrofit their equipment with DOCs or use alternative clean fuels. These requirements were put into the contract bid specifications so that contractors could plan for the costs and include them in their bids.

To date all contractors have chosen the retrofit option. Six different contractors have already installed DOCs on 100 pieces of equipment used on the project. Everything from cranes to sweepers to rollers to excavators to man lifts have been included. Before the project is complete it is expected that up to 150 pieces of equipment will be retrofitted with DOCs.

O&G's experience with the Connecticutt Clean Air Construction Initiative was a positive one. This program was well managed, giving us ample time to adjust to the new retrofit requirements and still meet contractual obligations. O&G is proud to be a part of a program resulting in lower emissions to the enevironment.

- Jim Zambero
Maintenance Director
O&G Industries

The retrofit costs for individual pieces of equipment have ranged from $750 to $7,000, with prices generally higher the larger the engine. Installation was usually straightforward. Retrofit of individual pieces of equipment usually took less than two hours; installing devices on some larger pieces of equipment took up to 15 hours. Some of these DOCs have now been in use on site for over 45 months, and have accumulated over 5,000 hours of service with few complaints from the contractors about increased fuel use, down-time, or increased maintenance costs.

I-95 Corridor Improvement Program Construction Equipment Retrofits

Type	Make/Model	Year	Retrofit Technology	Number of Retrofits
Backhoe	Badger 1085D	2001	DOC	1
Backhoe	Kobelco 250	2003	DOC	4
Backhoe	John Deere 410E	1997	DOC	1
Compressor	IR 185 CFM		DOC	4
Compressor	Sullivan 185	2003	DOC	1
Crane	Grove 22T		DOC	1
Crane	Grove RT745		DOC	3
Crane	Manitowoc 3900		DOC	1
Crane	Lorain LRT 445		DOC	1
Dozer	Cat D3		DOC	3
Dozer	Cat D4		DOC	5
Dozer	John Deere 650H	2001	DOC	1
Dozer	New Holland DC-180	2001	DOC	1
Excavator	Cat M318		DOC	6
Excavator	Cat 330L		DOC	4
Excavator	Gradall XL5100	1998		1
Excavator	John Deere 370C		DOC	1
Excavator	Komatsu PC300	1997 - 2002	DOC	3
Excavator	Volvo EC360LC	2001	DOC	1
Fork Lift	Gradall 534C		DOC	2
Grader	John Deere 770		DOC	1
Hammer	ICE 216,416,612		DOC	3
Loader	Cat 950E		DOC	4
Loader	Komatsu 380	1996	DOC	2
Manlift	JLG 80HX	2006	DOC	5
Sweeper	Elgin Pelican	1992	DOC	1
Roller	Bomag		DOC	1
Roller	Cat CS563D		DOC	3
Roller	IR SD110D	1999	DOC	1

Dana-Farber Yawkey Center for Cancer Care

The Dana-Farber Yawkey Center for Cancer Care is a 275,000 square foot clinical research and treatment facility being constructed in the heart of the Longwood Medical Area in Boston. The completed facility, which will take five years to construct, will include seven levels of underground parking and a 13-story tower rising out of a densely packed neighborhood.

As a leader in cancer research and treatment it was an obvious choice for Dana-Farber to enact a requirement for emissions retrofits on the diesel construction equipment used on the project.

The prime contractor, Walsh Brothers, Inc., partnered with Dana-Farber and the local EPA office to write Diesel Emission Reduction requirements into all subcontracts. The specifications include a strict no-idling policy, encourage the use of electric-powered equipment where feasible, and require minimum pollutant reductions of 42% for VOCs, 31% for CO, and 23% for PM. Subcontractors were encouraged to use a combination of retrofit technologies and cleaner fuels (ie., PuriNox or ULSD fuel) to meet these contract specifications.

For most involved – including all subcontractors on-site to date – this was their first time participating in a diesel emissions reduction program. Working collaboratively with EPA, Walsh Brothers created and distributed pre-mobilization worksheets to the subcontractors to ensure that all equipment was retrofitted prior to arriving.

SWP's compliance with the DFCI Oxidation Catalyst Specifications has been a good experience. We have retrofit our diesel equipment to reduce diesel emissions in order to preserve the environment and the air we breathe. The requirements were known well in advance and we were able to plan the retrofit without any impacts to our work.

- Jeff Taylor, Project Manager
Slurry Wall Partners, JV

Meeting the emissions requirements set forth by the construction project at the Dana-Farber Cancer Institute was a positive experience for our company. So far the utilization of the retrofits has had no problems. It was a huge step for our company to be able to get involved in a complex project like this while being mindful of the environment at the same time.

– Dave Howe, Owner
J. Derenzo, Co.

Under the program eight pieces of equipment have already been retrofitted with DOCs. Another nine, which will not be required on site until June 2008, are currently in the process of being retrofitted. By the end of the project it is expected that a total of 25 to 30 pieces of construction equipment will have emissions reduction technology installed. All retrofit equipment will also use ULSD fuel while on site.

The retrofitted equipment ranges from loaders, to slurry pumps, to specialized cranes. The DOCs that have been installed to date cost between $800 and $7,000 each, with most purchased for under $3,600. In general the larger the

engine the more expensive the device. Subcontractors have not reported any changes to equipment operation or fuel consumption after being retrofitted.

To date, the only hurdle to implementing the retrofits was some additional machine support required to accommodate the size and shape of the DOC in some cases.

Yawkey Center for Cancer Care Construction Equipment Retrofits

Type	Make/Model	Year	Engine HP	Technology	Number
Crane	Manitiwoc 777	1997	340	DOC+ULSD	1
Crane	Manitiwoc 10000	2006	332	DOC+ULSD	1
Crane	Soilmec SC-120	2007	700	DOC+ULSD	1
Crane	Tadano TR400E	1989	223	DOC+ULSD	1
Excavator	CAT M318	1997	170	DOC+ULSD	1
Loader	Case 821C	2006	204	DOC+ULSD	1
Pump	Gorman Rupp	1985	60	DOC+ULSD	1
Pump	Thompson	1995	80	DOC+ULSD	1
Excavator*	Komatsu PC700	1997	454	DOC+ULSD	1
Excavator*	Komatsu PC600	2007	429	DOC+ULSD	1
Excavator*	CAT 345	2006	345	DOC+ULSD	2
Excavator*	CAT 321	2004	147	DOC+ULSD	2
Excavator*	CAT 375	1997	513	DOC+ULSD	1
Gradall*	XL-5200	2004	174	DOC+ULSD	1
Crawler Carrier*	IHI-IC-45	2000	99	DOC+ULSD	1
**The subcontractor is in the initial stages of retrofit. This equipment will arrive on site in June, 2008*					

Photos courtesy of Dana-Farber and Walsh Brothers, Inc.

New South Ferry Terminal Project

The South Ferry Terminal project was the first lower Manhattan reconstruction project following the attacks of September 11, 2001, and the first major subway tunnel and station construction/expansion project within New York City in 100 years.

Construction began in 2005 and is scheduled to be finished in 2008. Deep tunnel excavation, and construction of the concrete structural box, required a significant deployment of equipment; at any given time there were 70 - 100 pieces of diesel equipment in use on the site, including generator sets, cranes, air compressors, excavators and bulldozers, and boring machines.

Coordinating agencies implemented a set of Environmental Performance Commitments (EPCs) to minimize the environmental impacts of rebuilding on lower Manhattan. The EPCs required, among other things, the implementation of emission control measures on all diesel costruction equipment used for the South Ferry Terminal project. All diesel equipment deployed on the site was required to use ULSD fuel and to be retrofitted with the "best available technology" (BAT) to reduce emissions. The BAT methodology required a DPF to be used unless it was not technically feasible to do so, in which case a DOC could be used instead.

A significant variety of equipment was ultimately retrofit with DPFs, including compressors, generators, excavators, and track drills. Retrofit equipment was equipped with engines ranging in size from 60 to over 500 hp.

As the first project in lower Manhattan to require such a large deployment of clean vehicles the project managers and contractors faced some initial challenges, and there was a learning curve for field managers. Initial confusion led to accidental deployment of non-retroft equipment to the site, as well as contractors retrofitting the wrong pieces of equipment. These initial problems were resolved by implementing a quality assurance program to verify retrofit part numbers against engine serial numbers and issuance of a "clean emissions" registration number and site sticker for all retrofit equipment.

Selected New South Ferry Terminal Construction Equipment Sample Retrofits

Type	Make/Model	Year	Engine HP	Retrofit Technology	Number of Retrofits
Excavator	CAT/M322C	2004	164	DPF	1
Skid Steer	CAT/262B	2004	75	DPF	1
Compressor	Yanmar/185WIR	2004	61	DPF	1
Generator	John Deere/G330	2004	525	DPF	1
Track Drill	Klemm/807		178	DPF	4
Compressor	Sullair/1150 xh		525	DPF	4

Photo courtesy of MTA New York City Transit

MassDEP Contact

For more information about construction retrofit requirements in Massachusetts, environmental benefits of diesel retrofits, and funding/assistance available to Massachusetts contractors please contact:

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Massachusetts Department of Environmental Protection

One Winter Street, Boston, Massachusetts

(617) 556-1101

Acknowledgements

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Appendices: *Resources*

APPENDIX A: Retrofit Requirements of State Agencies

Massachusetts Highway Department:

3.041 Certification of Construction Equipment Standard Compliance Requirement.

The Contractor shall certify that any and all large non-road diesel construction equipment (greater than 50 horsepower) used on this contract have emission control devices installed, such as oxidation catalysts or particulate filters, on the exhaust system side of the diesel combustion engine equipment.

The Certification of Construction Equipment Standard Compliance form shall be sent with the notification of award to the successful bidder, who shall execute and deliver the said form within 14 days after the date of the notice of the award.

Should the successful bidder fail to execute the said form, MassHighway may, at its option, determine that the Contractor has abandoned the Contract, and shall take action in accordance with the Standard Specifications for Highways and Bridges, Subsection 3.06—Failure to Execute Contract.

Massachusetts Bay Transportation Authority:

All Off-Road Diesel Construction equipment must have emission control devices installed, such as oxidation catalysts or particulate filters on the exhaust system side of the diesel combustion engine equipment.

MassDEP State Revolving Fund:

MASSACHUSETTS DIESEL RETROFIT PROGRAM (MDRP)

The Department of Environmental Protection has developed the Massachusetts Diesel Retrofit Program (MDRP) in response to increasing public health concerns with the emissions from diesel engines and vehicles. To control these emissions, the MDRP has identified oxidation catalyst retrofits as the control technology of choice. These retrofits consist of either an in-line replacement engine muffler system or an add-on control device. Compliance with the MDRP is technology based, such that installation of an EPA-certified (or equivalent) control device will constitute full compliance.

As of January 1, 2008 only those construction engines 50 or more horsepower (hp) and which will be used on a project site for 30 or more days are required to be retrofit.

Massachusetts Department of Capital Asset Management:

1.1 DIESEL EQUIPMENT EMISSION CONTROLS

A. All motor vehicles and construction equipment shall comply with all pertinent local, state, and federal regulations covering exhaust emission controls and safety.

B. All Contractor and Sub-Contractor diesel-powered non-road construction equipment with engine horsepower (HP) ratings of 50HP and above, which are used on the Project Site for a period in excess of 30 calendar days over the course of the construction period on the Project Site, shall be retrofitted with Emission Control Devices in order to reduce diesel emissions.

C. The reduction of emissions of volatile organic compounds (VOCs); carbon monoxide (CO) and particulate matter (PM) from diesel-powered equipment shall be accomplished by installing Retrofit Emission Control Devices.

D. Acceptable Retrofit Emission Control Devices for the Project shall consist of oxidation catalysts or other comparable technologies that are (1) included on the US Environmental Protection Agency (EPA) *Verified Retrofit Technology List* and/or the California Air Resources Board (CARB*) Currently Verified Technologies List*; and (2) are verified by EPA or CARB, to provide a minimum emissions reduction of 50 percent for VOCs, 40 percent for CO and 20 percent for PM. Attainment of the required reduction in PM emissions can also be accomplished by using less polluting Clean Fuels. Verified technologies can be identified on the following websites:

EPA: http://www.epa.gov/otaq/retrofit/retroverifiedlist.htm

CARB: http://www.arb.ca.gov/diesel/verdev/verifiedtechnologies/cvt.htm

E. The emission control equipment can be procured through the Statewide Contract #VEH71 that has fixed costs associated with retrofitting of diesel emission control devices. The following are the vendors listed on the Statewide Contract:

OSD: http://www.comm-pass.com

F. Construction shall not proceed until the Contractor has submitted a certified list of the non-road diesel-powered construction equipment subject to this specification, which either are or will be retrofitted with emission control devices. The list shall include (1) the equipment number, type, make, and Contractor/Sub-Contractor name; and the emission control device make, model, and EPA verification number. Contractors shall also submit a receipt or other documentation from a manufacturer or installer that verifies that appropriate equipment has been installed. The Contractor shall also identify any vehicles that will use Clean Fuels. Equipment that has been retrofitted with an emission

control device shall be stenciled or otherwise clearly marked as "Low Emission Equipment".

G. The Contractor shall submit monthly reports, updating the same information stated in Paragraph F above, including the quantity of Clean Fuel utilized. The addition or deletion of non-road diesel equipment shall be indicated in the report.

H. The Contractor shall use methods to control nuisance odors associated with diesel emissions from construction equipment including but not limited to the following: (1) turning off diesel combustion engines on construction equipment not in active use and on trucks that are idling for five minutes or more; and (2) locating diesel equipment away from the public and sensitive receptors.

I. All costs associated with implementation of the diesel equipment emissions control shall be borne by the respective Contractor or subcontractor and included in their cost for performing the work of the Contract.

Massport

All Contractor and Sub-Contractor diesel-powered non-road construction equipment with engine horsepower (HP) ratings of 60 HP and above, which is used on the project for a period in excess of 30 days, shall be retrofitted with Emission Control Devices in order to reduce diesel emissions. In addition, all motor vehicles and construction equipment shall comply with all pertinent local, state and federal regulations covering exhaust emission controls and safety.

The reduction of emissions of volatile organic compounds (VOCs), carbon monoxide (CO), and particulate matter (PM) from diesel-powered equipment shall be accomplished by installing Retrofit Emission Control Devices.

The acceptable Retrofit Emission Control Devices for the project shall consist of oxidation catalysts that (1) are included on the Environmental Protection Agency (EPA) Verified Retrofit Technology List; and (2) are verified by EPA or certified by the manufacturer to provide a minimum emissions reduction of 42 percent for VOCs, 31 percent for CO and 23 percent for PM. Attainment of the required reduction in PM emissions can also be accomplished by using less polluting Clean Fuels (e.g. PuriNOx).

Construction shall not proceed until the Contractor has submitted a certified list of the non-road diesel-powered construction equipment that will be retrofitted with emission control devices. The list shall include (1) the equipment number, type, make and Contractor/Sub-Contractor name; and (2) the emission control device make, model and EPA verification number. The Contractor shall also identify any vehicles that will use Clean Fuels. Equipment that has been retrofitted with an emission control device shall be stenciled or otherwise clearly marked as “Low Emission Equipment”.

The Contractor shall submit monthly reports, updating the same information stated above, including the quantity of Clean Fuel utilized. The addition or deletion of non-road diesel equipment shall be indicated in the report.

In addition to installing the required emission control devices, the Contractor shall use methods to control nuisance odors associated with diesel emissions from construction equipment including without limitation the following: (1) turning off diesel combustion engines on construction equipment not in active use, and on trucks that are idling while waiting to load or unload material for five minutes or more; (2) locating diesel equipment away from the general public and sensitive receptors (e.g., fresh air intakes, air conditioners and windows); and (3) utilizing electronically-powered scissor/man lifts.

Any costs associated with implementing the dust controls and diesel equipment emissions controls as specified in this section shall be included in the general cost of the contract.

APPENDIX B: Currently Verified Retrofit Technologies

EPA Technology Verification Program

(Products specifically certified for offroad engines highlighted in RED)

Manuf.	Name	Tech	Applicability	Reductions (%)			
				PM	CO	NOx	HC
Caterpillar	Catalyzed Converter/ Muffler (CCM)	DOC	Highway, heavy-heavy and medium-heavy duty, 4 cycle, non-EGR, model year 1998 - 2003, turbocharged or naturally aspirated engines	20	20	n/a	40
Caterpillar	Diesel Particulate Filter	DPF	Off-road, 4 cycle, non-EGR equipped, model year 1996-2005, turbocharged engines with power ratings 130 ≤ KiloWatts < 225 (174.2 ≤ Horsepower < 301.5)	89	90	n/a	93
Caterpillar	Emissions Upgrade Group	DOC + Engine mods	Caterpillar model 3306 diesel engines for off-road applications with model years from 1988 to 1995 with mechanical direct fuel injection	15	3	27	61
Clean Diesel Tech-nologies	Platinum Plus Purifier System	DOC + Fuel Borne Catalyst	Highway, medium-heavy- and heavy heavy-duty, 4 cycle, model year 1988 - 2003, turbocharged or naturally aspirated engines	25-50	16-50	0-5	40-50
Clean Diesel Tech-nologies	Platinum Plus Wire Mesh Filter System	FTF + Fuel Borne Catalyst	Highway, medium heavy-duty, 4 cycle, model year 1991 - 2003, non-EGR, turbocharged or naturally aspirated engines	55-76	50-66	0-9	75-89
Cummins Emission Solutions	Cummins Filtration DOC + CCV	DOC + closed crank case filter	Highway heavy-heavy & medium-heavy duty, 4-cycle non-EGR, model year 1991-2003, turbocharged or naturally aspirated engines	30	50	n/a	74

Manuf.	Name	Tech	Applicability	Reductions (%)			
				PM	CO	NOx	HC
Donaldson	Series 6000 + Spiracle	DOC + closed crank case filter	Highway, heavy heavy- and medium heavy-duty, 4 cycle, non-EGR, model year 1991 - 2003, turbocharged or naturally aspirated engines	25-33	13-23	n/a	50-52
Donaldson	Series 6100	DOC	Highway, heavy heavy- and medium heavy-duty, 4 cycle, non-EGR, model year 1991 - 2003, turbocharged or naturally aspirated engines	20-26	38-41	n/a	49-66
Donaldson	Series 6100 + Spiracle	DOC + closed crank case filter	Highway, heavy-heavy- and medium heavy-duty, 4 cycle, non-EGR, model year 1991 - 2003, turbocharged or naturally aspirated engines	28-32	31-34	n/a	42
Engelhard	DPX	DPF	Highway, heavy-duty, 4 cycle, model year 1994 - 2002, turbocharged or naturally aspirated engines	60	60	n/a	60
Engelhard	CMX Catalyst Muffler	DOC	Highway, heavy-duty, 2 cycle engines	20	40	n/a	50
Engine Control Systems	Purifilter	DPF	Highway, heavy and medium heavy-duty; Urban Bus; 4 cycle; model years 1994 - 2003; turbocharged or naturally aspirated; non-EGR engines	90	75	n/a	85
Engine Control Systems	AZ Purimuffler	DOC + closed crank case filter	Highway, heavy-duty, 4 cycle, mechanically or electronically injected, turbocharged or naturally aspirated, originally manufactured from 1991 through 2004 engines	40	60	n/a	75

Manuf.	Name	Tech	Applicability	Reductions (%)			
				PM	CO	NOx	HC
Engine Control Systems	AZ Purimuffler	DOC	Highway, medium heavy-duty, 4 cycle, model years 1991 - 2003 Cummins and Navistar/International engines originally manufactured with no aftertreatment, turbocharged or naturally aspirated, non-EGR engines	40	40	n/a	70
Engine Control Systems	AZ Purimuffler	DOC	Highway, heavy heavy-duty, 4 cycle, model years 1991 - 1993 Cummins engines originally manufactured without exhaust aftertreatment, turbocharged or naturally aspirated, non-EGR engines	35	40	n/a	70
Engine Control Systems	AZ Purimuffler	DOC	Highway, heavy duty, 2 cycle engines	20	40	n/a	50
Engine Control Systems	AZ Purimuffler	DOC	Highway, heavy duty, 4 cycle engines	20	40	n/a	50
International Truck & Engine Corp.	Green Diesel Technology	DOC + Engine mods	Highway, light heavy-duty, 4 cycle, Navistar/International engines, model years 1999 - 2003 in the following families: XNVXHO444ANA YNVXHO444ANB 1NVXHO444ANB 2NVXHO444ANB 3NVXHO444ANB	0-10	10-20	25	50
Johnson Matthey	CCRT	DPF	Highway, heavy-duty, urban bus, 4 cycle, non-EGR model year 1994 - 2006, turbocharged or naturally aspirated engines.	90	85	n/a	95

Manuf.	Name	Tech	Applicability	Reductions (%)			
				PM	CO	NOx	HC
Johnson Matthey	CRT	DPF	Highway, heavy-duty, 4 cycle, model year 1994 - 2006, turbocharged or naturally aspirated engines	90	85	n/a	95
Johnson Matthey	CEM™ Catalytic Exhaust Muffler	DOC	Highway, heavy-duty, non-urban bus, 4 cycle, non-EGR model year 1991 - 2003, turbocharged or naturally aspirated engines	20	40	n/a	50
Johnson Matthey	CEM Catalyst Muffler	DOC	Highway, heavy-duty, 2 cycle engines	20	40	n/a	50
Lubrizol	PuriNOx	Emul-sified Diesel Fuel	Highway & Non-road, heavy-duty, 2 & 4 cycle	16-58	-35 to 33	9 - 20	-30 to -120
Paceco Corporation	MES	DPF	Pre-1996 off-road, 4-cycle, heavy-duty diesel engines in the 225 - 450 kW (NR7) power range in electrical generation applications	39	90	n/a	95
PUREM	PMF Green-Tec	DPF	Highway, medium-heavy duty up to 280 hp, 4 cycle, non-EGR, model year 1998-2003, turbocharged or naturally aspirated engines	90	85	n/a	90
Various	B20 Biodiesel	Biodiesel Fuel	Highway, heavy-duty, 2 & 4 cycle	9	21	n/a	10
Various	B5 Biodiesel	Biodiesel Fuel	Highway, heavy-duty, 2 & 4 cycle	2	5	n/a	2
Various	Cetane Enhancer	Fuel Additive	Highway, heavy-duty, 4 cycle, non-EGR-equipped engines	n/a	n/a	0 - 5	n/a

The above list of verified technologies was updated on May 21, 2007. Please see the most current list at:

http://www.epa.gov/otaq/retrofit/retroverifiedlist.htm

California Air Resources Board Technology Verification Program

(Products specifically certified for offroad engines highlighted in RED)

PM Level	Manuf.	Product Name	Technology Type	Reduction		Applicability
				PM	NOx	
Level 3	Cleaire	Horizon	DPF (active)	85%	N/A	Most on-road engines through 2006 model year; 15 ppm sulfur diesel; CARB diesel. Conditionally verified for off-road engines.
	Cleaire	Longview	Lean NOx Catalyst + DPF	85%	25%	1993-2003 model year on-road; 15 ppm sulfur diesel.
	Clean Air Systems	PERMIT	DPF	85%	N/A	Stationary emergency and prime generators; 15 ppm sulfur diesel.
	Donaldson	DPM	DPF	85%	N/A.	1993-2004 on-road; 15 ppm sulfur diesel.
	EGR Technologies LLC	CleanAIR System	DPF+EGR	85%	50%	Conditional verification for stationary prime and emergency standby generator sets and pumps ≤ 600 hp and ≤ 0.4 g/bhp-hr PM
	Engine Control System	Purifilter (low load)	DPF	85%	N/A	1994-2003 on-road; 15 ppm sulfur diesel
	Engine Control System	Purifilter (high load)	DPF	85%	N/A	1994-2003 on-road; 15 ppm sulfur diesel
	Engine Control System	Combifilter	DPF	85%	N/A	1996-2007 off-road; 15 ppm sulfur diesel; CARB diesel
	HUSS Umwelttechnik	FS-MK	DPF (active)	85%	N/A	Most on-road and off-road diesel engines through 2006 model year.
	International Truck & Engine Corporation	DPX	DPF	85%	N/A.	1994-2003 on-road Navistar (International); 15 ppm sulfur diesel.
	Johnson Matthey	CRT	DPF	85%	N/A.	Stationary emergency and prime generators. Conditionally verified for stationary pumps.
	Johnson Matthey	EGRT	DPF+EGR	85%	40%	2000 International DT-466, 2000 Cummins ISM, 2001 Cummins ISB, 1998-2002 Cummins ISC, 2001 Cummins ISL, 2001 MY DDC - 50, and 2001 DDC - 60. on-road; 15 ppm sulfur diesel.
	MIRATECH Corporation	combiKat	DPF	85%	N/A	Stationary emergency and prime generators with a PM emission rate of 0.2 g/bhp-hr or less.
	Süd-Chemie Inc	EnviCat	DPF	85%	N/A	Stationary prime and emergency standby generators and pumps; 15 ppm sulfur diesel.

PM Level	Manuf.	Product Name	Technology Type	Reduction		Applicability
				PM	NOx	
Level 2	Donaldson		Flow Through Filter	50%	N/A	1991-2002 on-road; 15 ppm sulfur diesel.
	Lubrizol	PuriNOx	Emulsified Fuel	50%	15%	1988-2003 on-road.
	Environmental Solutions Worldwide	Particulate Reactor	Flow Through Filter	50%	N/A	Select model years 1991-1997
	Engine Control System	AZ Purimuffler/ Purifier	DOC + Alt Fuel	50%	20%	1996-2002 off-road; PuriNOx
	Thermo King	PDPF	Flow through filter	50%	N/A	1985 -1998 Isuzu D201 transport refrigeration unit engines; 15 ppm sulfur diesel
	Rypos	ADPF	DPF (active)	50%	N/A	1996-2002 stationary engines; CARB diesel.
Level 1	Donaldson	DCM 6000	DOC	25%	N/A	1988-1990 on-road; 15 ppm sulfur diesel; CARB diesel.
	Donaldson	DCM 6000 + Spiracle	DOC + crankcase filter	25%	N/A	1988-2002 on-road; 15 ppm sulfur diesel; CARB diesel.
	Donaldson	DCM 6100 + Spiracle	DOC + crankcase filter	25%	N/A	1991-2002; CARB diesel.
	Donaldson	DCM 6100	DOC	25%	N/A	1994-2002; 15 ppm sulfur diesel.
	Donaldson	DCM 6000 + Spiracle (off-road)	DOC + crankcase filter	25%	N/A	Off-road port equipment; 15 ppm sulfur diesel; CARB diesel.
	Extengine		DOC + SCR	25%	80%	1991-1995 Cummins 5.9 liter off-road; 15 ppm sulfur diesel or CARB diesel.
	Engine Control System	AZ Purifier & Purifmuffler	DOC	25%	N/A	1991-2003 Cummins and Navistar on-road; 15 ppm sulfur diesel. 1973-1993 DDC 2 stroke; CARB diesel.1991-2002 HHD certain model Cummins and DDC; 15 ppm sulfur.
	Engine Control System	AZ Purifier & Purifmuffler	DOC	25%	N/A	1996-2002 off-road; 15 ppm sulfur diesel.
	Paceco Corporation		DPF	25%	N/A	Pre-1996 model year or Tier 1, 2, or 3 certified off-road diesel engines on rubber-tired gantry cranes.

The above list of verified technologies was updated on May 23, 2007. Please see the most current list at: **http://www.arb.ca.gov/diesel/verdev/vt/cvt.htm**

APPENDIX C: Retrofit Vendors

This list of contact information for retrofit vendors is the most current available at the time of publishing. It is arranged by retrofit manufacturer, as listed in the EPA and CARB verified lists above. In some cases a specific manufacturer's verified products may be available from more than one source (directly from the manufacturer or through an engine manufacturer's service representative). If so, all identified sources have been listed.

Company	Address	Contact	Phone/email
Caterpillar, Inc.		Jeffrey A. Jacobs Northeast Territory Manager	(860) 658-3438 Office (860) 810-2622 Mobile jacobs_jeffrey_a@cat.com
Cleaire	Cummins Northeast 101 Railroad Ave Albany, NY 12205	Glenn Havens	(518) 459-1710 Glenn.c.havens@cummins.com
Clean Air Systems	P. O. Box 23449 Santa Fe, NM 87502	Direct Sales (Tom Mosley)	(505) 474-4120 TMosley@CleanAIRsys.com
Clean Diesel Technologies	300 Atlantic Street, Suite 702 Stamford, CT 06901	Sales	(203) 327-7050 Office (203) 323-0461 Fax
Cummins NorthEast, Inc.	100 Allied Drive Dedham, MA 02026	Brian Beaulieu Territory Manager	(781) 751-1215 Office (508) 962-0976 Cell brian.b.beaulieu@cummins.com
Donaldson Company, Inc.	Bloomington, MN Preventative Maintenance 4 Dollar Avenue Wilbraham, MA Foley Marine 200 Summer Street Worcester, MA 01604	To get more sales information. Michael Richards Jay Foley	(866) 675-2847 emissions@mail.donaldson.com (413) 596-5018 (508) 753 2979
EGR Technologies, LLC	1756 53rd Loop SE Tumwater, Washington 98501	Fred Burke	(360) 250-2730
Englehard (BASF)	101 Wood Avenue Iselin, NJ 08830		(732) 205-5000 info-ec@basf.com
ESW	335 Connie Crescent Concord, Ontario L4K 5R2, Canada	Frank Haas Sales	(905) 695-4141 x255 fhaas@eswcanada.com

Company	Address	Contact	Phone/email
Engine Control Systems	165 Pony Drive Newmarket, Ontario L3Y 7V1 Canada	David Secord Regional Sales Mgr	(905) 952-2439 dvsc@EngineControlSystems.com
Extengine	Extengine Transport Systems, LLC 83 Ide Rd. Williamstown, MA 01267	Lee Harrison Eastern Region	(413) 441-2321 ExtengineEast@verizon.net
HUSS Umwelttechnik	351 W 57th St, #2A New York, NY. 10019	Peter Bruenke Sales Rep, North America	(212) 247-1721 Peter.bruenke@huss-filters.com
International Truck & Engine Corporation	Green Diesel Technology	John Taylor Regional Manager	(508)-405-2499 Office (508)-405-2599 Fax John.Taylor@Nav-International.com
Lubrizol	29400 Lakeland Boulevard Wickliffe, Ohio USA 44092-2298	Elizabeth DiSanto	(440) 943-4200 nasales@lubrizol.com
Johnson Matthey, Inc.	Bell Power Systems 34 Plains Road Essex, CT 06426 Milton CAT 101 Quarry Drive Milford, MA 01757 Cummins Emission Solutions	Alex Bell Adam Belanger Machine Sales Judy Murphy	(800) 225-8669 (860)767-7502 Alex@Bellpower.com 508-634-3400 x5574 608-877-3829 judy.l.murphy@cummins.com
MIRATECH Corporation	All New England Sales, Inc. P. O. Box 1443 Littleton MA 01460	Peter Dunn Sales	(978) 486-8151 P33Dunn@yahoo.com
PUREM	13400 Outer Drive West Mailcode A16 Detroit, MI 48239-4001	Larry Dimitrievski	(313) 592-5883
Rypos	260 Hopping Brook Road Holliston, MA 01746	Sales directly	(508) 429-4552 Phone (508) 429-4553 Fax sales@rypos.com

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