

Title: MASSACHUSETTS DEPARTMENT OF TRANSPORTATION DIESEL RETROFIT  
PROGRAM FOR NON-ROAD CONSTRUCTION EQUIPMENT

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## **ABSTRACT**

Since 2005, the Massachusetts Department of Transportation (MassDOT) has required, through a contract specification, contractors and sub-contractors working on Highway Division job sites to have emission control devices such as Diesel Oxidation Catalysts (DOC) or Diesel Particulate Filters (DPF) installed on all non-road construction equipment greater than 50 horsepower. The purpose of MassDOT's diesel retrofit program is to help achieve diesel emission reductions from non-road construction equipment that result in beneficial air quality improvements, specifically particulate matter, for construction workers and the general public. Since the program began, over 1,200 pieces of non-road construction equipment have been inspected and certified by MassDOT as being in compliance with its diesel retrofit requirement. This type of diesel retrofit program within Massachusetts started in 1998 during the construction of the Central Artery/Tunnel Project in Boston.

The main objective of this paper is to discuss and present the specifics of MassDOT's diesel retrofit specification for retrofitting non-road diesel powered construction equipment over 50 horsepower, including its development, implementation, and lessons learned. The paper also provides an overview of non-road diesel emission regulations along with the benefits of reducing diesel emission particles.

## INTRODUCTION

The need for reducing emissions from heavy-duty diesel engines is clear. The diesel engine has been a workhorse of the 20<sup>th</sup> century. It is reliable, fuel-efficient, durable, easy to repair, and inexpensive to operate. However, due to its high pressures and temperatures, it produces significantly higher amounts of particulate matter (PM) and nitrogen oxides (NOx) emissions than gasoline engines. This made diesel exhaust a growing health concern worldwide.

During the last few years, emissions from such engines in the Northeast accounted for roughly 30% of the NOx and 80% of the PM emitted by all mobile sources. In addition, since diesel engines that power construction equipment emit more pollution than equivalent diesel engines for normal highway use (due to the lack of any emission controls until 1996), the reduction of these emissions has not only the potential to improve ambient air quality for the region, but more importantly, it has significant air quality benefits to those who live or work in or adjacent to construction zones.

In order to reduce the effects of diesel exhaust on workers and abutters, the Central Artery/Tunnel Project in Boston (under the direction of the former Massachusetts Turnpike Authority), implemented in 1998 an emission reduction diesel retrofit program for off-road construction equipment using oxidation catalysts<sup>(1,2)</sup>. This program was designed in conjunction with the Massachusetts Department of Environmental Protection (MDEP) and the Northeast States for Coordinated Air Use Management (NESCAUM). Initially, it started as a pilot program, however, it was later expanded to include all off-road equipment on more than 20 contracts, retrofitting over 200 pieces of construction equipment.

In 2005, MassDOT developed a diesel retrofit specification that has been included in all Highway Division contracts advertised for bid. This includes all roadway, highway, and bridge construction work as well as all roadway and bridge maintenance work. The specification requires emission control devices, such as a Diesel Oxidation Catalyst (DOC) or a Diesel Particulate Filter (DPF), be installed on the exhaust-system side of the diesel combustion engine equipment. Under the contract, the contractor is responsible for purchasing and installing the retrofit device and as well as ensuring that the emissions control device is operated, maintained, and serviced as recommended by the manufacturer.

## U.S. ENVIRONMENTAL PROTECTION AGENCY (EPA) NON-ROAD DIESEL EMISSION REGULATIONS

The first federal standards (Tier 1) for new non-road diesel engines were adopted in 1994 for engines over 37 kW (50 hp), to be phased in from 1996 to 2000. In 1996, a Statement of Principles (SOP) pertaining to non-road diesel engines was signed between the U.S. Environmental Protection Agency (EPA), the California Air Resource Board and engine makers (including Caterpillar, Cummins, Deere, Detroit Diesel, Deutz, Isuzu, Komatsu, Kubota, Mitsubishi, Navistar, New Holland, Wis-Con, and Yanmar). On August 27, 1998, the EPA signed the final rule reflecting the provisions of the SOP. The 1998 regulation introduced Tier 1 standards for equipment under 37 kW (50 hp) and increasingly more stringent Tier 2 and Tier 3 standards for all equipment with phase-in schedules from 2000 to 2008. The Tier 1-3 standards were met through advanced engine design, with limited or no use of exhaust gas after treatment

(oxidation catalysts). Tier 3 standards for NO<sub>x</sub>+HC were similar in stringency to the 2004 standards for highway engines; however, Tier 3 standards for PM were never adopted.

A major step in reducing diesel emissions was taken in May 2004 with the approval of the EPA Clean Non-Road Diesel Rule, which introduced Tier 4 emission standards. They are to be phased in over the period of 2008-2015 [69 FR 38957-39273, 29 Jun 2004]. The Tier 4 standards require that emissions of PM and NO<sub>x</sub> be further reduced by about 90%. Such emission reductions can be achieved through the use of control technologies—including advanced exhaust gas after treatment—similar to those required by the 2007-2010 standards for highway engines.

## NON-ROAD DIESEL FUEL REQUIREMENTS

At the Tier 1-3 stage, the sulfur content in non-road diesel fuels was not limited by environmental regulations. The average in-use sulfur level is about 3,000 ppm. To enable sulfur-sensitive control technologies in Tier 4 engines—such as DPFs and NO<sub>x</sub> absorbers, the EPA mandated reductions in sulfur content in non-road diesel fuels as follows:

- 500 parts per million (ppm) effective June 2007 for non-road, locomotive and marine (NRLM) diesel fuels,
- 15 ppm (ultra-low sulfur diesel) effective June 2010 for non-road fuel, and June 2012 for locomotive and marine fuels.

Since all of these regulations apply only to new engines, there is still a need to reduce emissions from the existing fleet of equipment manufactured before the Tier 3 and 4 standards came into effect. The diesel engine retrofit program discussed in this paper targets Tier 1, 2, and 3 engines which forms the construction industry fleet, focuses on add-on emission reduction equipment such as diesel oxidation catalysts and diesel particulate filters.

## DIESEL OXIDATION CATALYST

A Diesel Oxidation Catalyst (DOC) is similar to an automobile's catalytic converter in that it is installed on the exhaust system side of a diesel engine. Inside a DOC is a honeycomb-type flow-through core that is coated with a precious metal such as platinum. When installed as part of the diesel engine's exhaust system, a DOC can reduce diesel particulate emissions (PM) by 20%, carbon monoxide (CO) emissions by 40%, and volatile organic compounds (VOC) by 50%. DOCs are manufactured two ways: a catalyst that is installed after the machine's muffler (Figure 1), or as a catalyst/muffler that replaces the machine's original equipment muffler (Figure 2). In either case, suppliers of DOCs can readily accommodate a wide range of diesel equipment applications at an average cost of \$1,000 per unit for catalysts, and an average cost of \$2,000 to \$4,000 per unit for a catalyst/muffler<sup>(3)</sup>.

**Figure 1: Diesel Oxidation Catalyst**



**Figure 2: Diesel Oxidation Catalyst/Muffler**



## DIESEL PARTICULATE FILTER

Like a DOC, a Diesel Particulate Filter (DPF) is also installed on the exhaust system side of a diesel engine (Figure 3). DPFs operate in a similar fashion as a DOC; however, they are much more efficient in lowering PM emissions from diesel exhaust--at least an 85% reduction in most cases. In order to achieve these emission reductions, DPFs require exhaust temperature profiles to be above 210 degrees Centigrade for at least 40% of the time, and the  $\text{NO}_x$ /PM ratio to be greater than 20%, preferably greater than 30%. Old non-road construction equipment engines typically have extremely low  $\text{NO}_x$ /PM ratios; essentially, they are emitting more PM. In addition, they were designed for a higher sulfur fuel, which presents additional hurdles for the proper functioning of DPFs.

**Figure 3: Diesel Particulate Filter/Muffler**



*Photo Courtesy of Milton CAT*

Unlike DOCs, which require very little maintenance, the filter in a DPF has to be removed and cleaned. The frequency at which DPF filters have to be cleaned can vary significantly depending on the age of the engine and the percentage of idle time of the equipment. If a machine idles for long periods of time, the filter in a DPF may require additional cleaning. Another difference between a DPF and DOC is cost. On average, the cost of a DPF is approximately \$8,000 to \$10,000 per unit for passive DPFs and \$14,000 to \$20,000 for active DPFs <sup>(3)</sup>.

#### MAIN ASPECTS OF MASSDOT'S RETROFIT SPECIFICATION

Under MassDOT's diesel retrofit specification, contractors have the option to install either a DOC or DPF that has been verified by the Environmental Protection Agency (EPA) or the California Air Resources Board (CARB) for use with "non-road" engines. If a "non-road"-verified device is not available for the piece of equipment being retrofitted, then the contractor has the option to install either a DOC or DPF that has been verified by the EPA or CARB for use with "on-road" engines, provided that the diesel fuel used for the equipment has no more than 15 parts per million (ppm) sulfur content (i.e., Ultra Low Sulfur Diesel (ULSD) fuel). If neither a "non-road" or "on-road" DOC or DPF is available for the piece of equipment being retrofitted, then a contractor has a third option under MassDOT's specification, which is to install a non-verified EPA or CARB DOC or DPF, given that it has been certified by the manufacturer to meet or exceed minimum emission reductions of 20% for PM, 40% for carbon monoxide, 50% for volatile organic compounds for DOCs, and 85% for PM for DPFs.

For non-road construction equipment that meets the latest EPA particulate matter Tier 4 emission standards, no additional retrofit devices have to be installed under MassDOT's diesel retrofit specification.

In order to ensure compliance with MassDOT's diesel retrofit specification, contractors must submit a signed certification form, prior to starting work, which states that all non-road diesel construction equipment above 50 horsepower used on the job site will meet the latest EPA particulate matter (PM) Tier emission standards in effect or will have a DOC or DPF installed. A sample certification form that contractors submit is shown in Figure 4. In addition to the certification form, contractors are also required to submit a data sheet listing the non-road construction equipment that will be used on the job site. For each piece of equipment, detailed information relative to the construction equipment type, equipment make and model, equipment serial number, equipment model engine, the year it was manufactured, its horsepower rating, and the fuel type used in the machine needs to be provided. Also listed on the equipment data sheet is information specific to the emission control devices installed on the construction equipment. Information such as the type of retrofit device installed, the manufacturer of the retrofit device, the retrofit device make and model, and installation date. If a non-verified DOC or DPF is used, contractors are also required to obtain a certification from the DOC or DPF manufacturer stating that the non-verified device will meet the minimum emission reductions for the machine it is installed on. If questions arise regarding a manufacturer emission reduction certification, MassDOT can request supporting test data for the device. If test data does not exist, or if it is of questionable sources, MassDOT can reject the DOC or DPF from use.

#### **Figure 4: Certification of Construction Equipment Standard Compliance Form**

Contract Number: \_\_\_\_\_  
Description: \_\_\_\_\_  
Location (City/Town): \_\_\_\_\_

*I, \_\_\_\_\_ authorized signatory for \_\_\_\_\_ whose principal place of business is at \_\_\_\_\_ do hereby certify that any and all large non-road (greater than 50 brake horsepower) diesel construction equipment (DCE) to be used in this contract meets the EPA particulate matter (PM) Tier emission standards in effect for non-road diesel engines for the applicable engine power group or has emission control devices such as, oxidation catalysts or particulate filters, installed on the exhaust system side of the diesel combustion engine equipment. Said equipment or devices meet the requirements of this specification.*

*I am submitting on behalf of \_\_\_\_\_ a list of said diesel construction equipment, labeled "Diesel Retrofit Data" that will be used in connection with this contract. The said list includes, but is not limited to the number of vehicles subject to this certification and the number of vehicles retrofitted by vehicle type. The said list shall also be signed, certifying that the information is correct and accurate as of the date of signature and is signed under pains and penalty of perjury.*

*I acknowledge that this certificate is being furnished as a requirement under this contract and is subject to applicable State and federal laws, both criminal and civil.*

Signature \_\_\_\_\_ Date \_\_\_\_\_

Title: \_\_\_\_\_

Company: \_\_\_\_\_

Due to the different types of equipment contractors need to operate on a job site and, in some cases, the short time frame in which they need to use them, MassDOT's diesel retrofit specification allows contractors to use rented equipment up to 30 cumulative days without having to be retrofitted. If a rented machine is used for more than 30 cumulative days on a job site, then MassDOT's specification requires that the rented machine be retrofitted. If, however, a machine is contractor owned, the machine must be retrofitted, regardless of the length of time it is used on a job site. This will prevent a potential loophole that will allow a machine from being moved from job site to job site without being retrofitted.

In special cases, such as cranes that are involved with heavy (critical) lifts, MassDOT's diesel retrofit specification provides an exemption for large cranes. The reason being is that cranes may idle for extended periods before performing a lift.

Also, MassDOT's diesel retrofit specification allows Resident Engineers (RE) who are in charge of work performed on a job site to exempt a machine if there is a compelling emergency need to use diesel vehicles or engines that do not meet the contract conditions for emission controls. Examples include the need for rescue vehicles or other equipment to prevent or remedy harm to workers or the general public or additional equipment needed to address an emergency such as structure collapse or imminent collapse.

In order to ensure compliance with MassDOT's diesel retrofit specification, MassDOT conducts regular inspections of equipment operating at jobs sites for the installation of diesel retrofit devices. Inspections are conducted without prior notice to the contractor. If a piece of equipment is found to be in non-compliance, the contractor is directed to retrofit the machine within 15 calendar days. Failure to comply with MassDOT's diesel retrofit requirement can result in non-compliance penalties, consisting of either withholding contractor payments (i.e., pay estimates) or a daily monetary deduction of \$2,500 imposed for each calendar day the deficiency continues. Once the deficient equipment is brought into compliance, contractor payments are reinstated. However, the \$2,500 daily monetary deduction is irrevocable and is not reimbursed.

In some cases, a machine cannot be retrofitted within 15 days. In this instance, MassDOT will allow a contractor to provide documentation, such as a purchase order for a DOC or DPF, and an installation date as justification that the machine will be retrofitted. If the machine is not retrofitted by the date specified by the contractor, then monetary penalties, as indicated above, would be imposed.

Upon confirming that a non-road piece of equipment has the requisite retrofit device installed, MassDOT will issue a non-transferable compliance label (i.e., sticker) for the machine. The compliance sticker as shown in Figure 5, has a unique number assigned to it and is non-transferable. For each compliance sticker issued, MassDOT records the location where the sticker was issued, the MassDOT contract number where the machine was working, the name of contractor who owns the machine, the type of equipment the sticker was assigned to (i.e., loader, excavator, backhoe, grader, compressor, etc.), and the manufacturer of the equipment along with its serial number. Machines that have compliance stickers issued can be reissued a new compliance sticker should the need arise. Compliance stickers will stay with the machine if the machine is sold and the retrofit device is not removed.

**Figure 5: Diesel Retrofit Compliance Sticker**



Lastly, under MassDOT’s diesel retrofit specification, all costs associated with the installation of diesel retrofit devices are the responsibility of the contractor and are considered incidental to the cost of the contract. As such, MassDOT provides no additional compensation to the contractor for installing and/or maintaining either a DOC or DPF. By doing so, contractors have no grounds for submitting a monetary claim as a result of having to comply with MassDOT’s diesel retrofit specification.

#### EMISSION REDUCTION BENEFITS – HEALTH AND GLOBAL PERSPECTIVE

While most carbon in motor vehicle fuels is oxidized to gaseous CO<sub>2</sub> during the combustion process, diesel engines also produce particles in their exhaust as a result of incomplete combustion. Exposure to diesel exhaust emissions exacerbates existing asthma and allergy symptoms, leading the EPA to conclude that long-term inhalation exposure is likely to pose a lung cancer hazard to humans, and to damage lungs in other ways. This conclusion has made a very strong case for the reduction of diesel emissions over the last two decades.

PM emitted from combustion engines is primarily composed of elemental/black carbon (BC), organic carbon (OC) and sulfates. BC particles convert sunlight into infrared heat, accelerate the melting process of snow, ice, and glaciers, and exert a heating effect in the atmosphere. The light OC and sulfate particles increase cloud reflectivity, exerting a cooling effect in the atmosphere. The net balance of these two opposing effects has been the subject of scientific discussions on the role of aerosols on climate change for the last decade <sup>(4, 5, 6, 7, 8)</sup>.

Extensive global simulations by the scientific community in recent years concluded that the effects of diesel-related BC, due to the small particle size, is much more widespread than previously anticipated and a considerable trans-boundary problem.

Today there seems to be an emerging agreement in the scientific community that BC could be responsible for up to 15% of the global warming effect, second only to carbon dioxide (CO<sub>2</sub>).

Diesel BC particles are in the 30-300 nanogram (10<sup>-9</sup> grams) range and comprise 50-70% of PM; this implies more dark particles than light ones, and more time airborne, which seems to favor the scientific consensus that BC particles from diesel exhaust have a net warming effect in the atmosphere, and the effect of their reduction will have an immediate beneficial impact on climate change.

As part of the National Clean Diesel Campaign (NCDC), EPA has developed a list of diesel retrofit technologies that EPA has approved for use in engine retrofit programs<sup>(9)</sup>. The list also indicates the percentage emission reduction for PM, CO, VOC and NOx (of verified or tested levels) that EPA will recognize for emission reductions for each technology. Currently there are approximately 33 technologies (products) on the list, of which only 3 are tested and certified for non-road equipment, making the process of retrofitting construction equipment a challenge when installing DPFs.

The NCDC also provides the Diesel Emissions Quantifier (Quantifier), which is an interactive tool that can help evaluate clean diesel projects by estimating emission reductions, cost effectiveness, and health benefits<sup>(10)</sup>. The tool can help in the preparation process of applications for EPA or other funding-assistance programs. The Health Benefits Module estimates health benefits from the reduction of fine particulate matter under specific retrofit scenarios.

Emission reduction estimates rely on emission factors and other information from EPA's National Mobile Inventory Model as well as user inputs for specific fleets and strategies.

At the time of this writing, the authors are compiling emission data for each piece of equipment being certified and plan to do an emission of the reductions achieved by the program for future information.

## **LESSONS LEARNED**

Since the beginning of MassDOT's diesel retrofit program, more than 1,200 pieces of non-road construction equipment have been inspected and issued compliance stickers across Massachusetts. The equipment consists of a wide range of machines and horsepower ratings consisting of earth-moving machines such as backhoes, excavators, skid steers, loaders, dozers, articulated trucks, to road paving machines such as cold planers, pavers, rollers, to supporting equipment such as compressors, generators, lifts, pile drivers, and cranes. This equipment represents a significant number of pieces of equipment within the Commonwealth.

The vast majority of equipment retrofitted to date opted for installing DOCs. The main reason for using DOCs were ease of installation and cost advantages versus the difficulties encountered when installing DPFs in equipment which was not designed to work with a DPF. For the limited number of DPFs that were installed on machines, contractors discovered that excessive cleaning of the DPF filter had to be performed. If filters were not cleaned on a regular basis, operational issues with a machine engine could occur.

The success of MassDOT's diesel retrofit program is contributed to several critical lessons learned. The first lesson dealt with short-term equipment being moved in and out of a job site. Since work activities at a construction site can vary on a short-term basis, contractors will constantly move equipment in and out of a construction site. When equipment is moved from job site to job site on a frequent basis, MassDOT's specification requires contractor and subcontractor-owned equipment to be retrofitted, regardless of the amount of time the equipment is on a job site. This prevents equipment from being moved from job site to job site and never being retrofitted. However, for rented equipment, contractors have a 30-cumulative-day grace period for the equipment being used. Time periods less than 30 days are very difficult to track.

Another lesson dealt with the limited amount of EPA and CARB-verified retrofit devices available to the wide range of construction equipment. Due to a limited number of verified DOC and DPF devices available for non-road construction equipment, MassDOT learned that contractors would not be able to readily obtain appropriate DPF or DOC devices for some of their machines. In order to ensure that the retrofit program moved forward, MassDOT allows three retrofit options to be available as part of its diesel retrofit specification. These options are as follows:

1. use emission control technology verified by EPA or CARB for use with "non-road" engines, or
2. use emission control technology verified by EPA or CARB for use with "on-road" engines provided that such equipment is operated with Ultra Low Sulfur Diesel Fuel, or
3. use emission control technology certified by manufacturers to meet or exceed emission reductions provided by either "on-road" or "non-road" emission control technology verified by EPA or CARB. Minimum emission reductions of 20% particulate matter, 40% carbon monoxide, 50% volatile organic compounds for DOCs, and 85% particulate emission for DPFs are required. Allowing non-verified devices will allow equipment to be retrofitted in a timely manner.

In addition to the above three options, a fourth option was made available to contractors whose equipment engines met the EPA's particulate matter Tier 3 and 4 emission standards in effect for non-road diesel engines. This option allows contractors with equipment that meets EPA Tier 3 emission limits for particulate matter, to forgo installing a retrofit device on a machine until the EPA Tier 4 emission limit requirements go into effect for the effective horsepower range.

As an example, if a contractor is granted a two-year roadwork contract and one of the machines used on the job is Tier 3 rated (e.g., Tier 3 being in effect) and its horsepower rating is 279, MassDOT's specification does not require the contractor to install a retrofit device at the start of the job. However, when EPA Tier 4 emission limits for 279 horsepower rated machines go into effect, the 279 Tier 3 horsepower machine has to be retrofitted with a DOC or DPF at that time. If a contractor retrofits a machine at the start of the job, the machine would be "grandfathered" when Tier 4 emission limits go into effect.

## CONCLUSION

MassDOT's diesel retrofit specification demonstrates that a successful diesel retrofit program for non-road construction equipment can be implemented without jeopardizing construction schedule or cost and provide significant benefits in terms of emission reductions. As a result, contractors are more than willing to install emission reducing retrofit devices on their machines given that devices are readily available and reasonably priced. As such, a diesel retrofit specification should be written which gives contractors choices for retrofitting their equipment. It should also be written to include the requirement for emission control equipment as part of the contract's bid package. By doing so, the cost of the retrofit equipment can be included as part of the overall contract cost, which for DOCs are estimated to be less than 1 percent of a total contract cost.

When these programs started over a decade ago, the main reason for their development and implementation was to mitigate and reduce the adverse health effects on workers and residents who lived near large construction areas. At that time, it was thought that PM and BC was mostly a localized health and visibility problem.

Today, based on the known effects that diesel BC emissions have on global warming and the immediate benefits that will result from their reductions, there is a strong case for including these diesel emissions reduction programs as one of the many climate-change strategies.

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