Results of implementing aggressive PM reduction on non-road construction equipment at two Lower Manhattan project sites.

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Abstract

The Metropolitan Transportation Authority, Capital Construction Company in New York is managing the construction of two projects in Lower Manhattan, funded via federal government post-9/11 recovery allocations. Lower Manhattan is one of the largest business districts in the nation, and the two projects – the South Ferry Terminal Station and the Fulton Street Transit Center – will improve transit access to, and help to revitalize, downtown Manhattan.

With dozens of large-scale projects in the planning and construction stages in Lower Manhattan, many having lengthy and overlapping construction periods, MTA CC has aggressively implemented Environmental Performance Commitments (EPCs), developed in conjunction with other agencies building in Lower Manhattan. Heightened community awareness of air quality issues in Lower Manhattan has made the clean diesel emissions program one of the most important of the EPCs to implement. The U.S. EPA is using MTA CC's clean diesel emissions program as a model of success to induce its implementation in other areas of the country.

The clean diesel emissions program includes use of Ultra Low Sulfur Diesel (ULSD) fuel, use of Tier 2 engines and diesel particulate filters (DPF) on all off-road construction engines of 50 horsepower (hp) or greater. MTA CC worked closely with retrofit vendors, equipment/engine dealers, rental agencies, and contractors to implement and manage this program. Between the two projects almost 150 pieces of equipment have been eligible for the retrofit technology and an approximate 86 percent compliance rate has been maintained. Given that these measures reduce particulate matter emissions by more than 90 percent, and that construction diesel equipment is a significant contributor to poor air quality, the program provides significant air quality benefits to Lower Manhattan.

This paper reviews MTA CC's clean diesel emissions program, describes the challenges faced to implement the program, and describes the results including compliance statistics and cost factors.

MTA CC's Lower Manhattan Transportation Recovery Projects

MTA CC is constructing a new South Ferry Terminal Station at a cost of approximately $489M, which consists of a structural box (approximately 1700' by 50') beneath Battery Park at the tip of Manhattan. Construction has included installing mini piles to support two active train tunnels, relocation of utilities, removal of over 180,000 cubic yards of rock and 110,000 cubic yards of soil (via drill-and-blast and mechanical excavation), pouring concrete and installation of station finishes. The completed station will consist of an upper level, housing NYCT personnel and material, and a lower level of two subway tracks with a single island platform.

At Fulton Street, a multi-level Transportation Center will be built to serve as a focal point for entry into the 12 subway lines that serve lower Manhattan, most of which date back to the early 1900s. Underground concourses will be constructed to connect the subway lines and link the Transit Center to

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the New Jersey PATH system and the World Trade Center site. Currently work is underway on the Dey Street concourse, to be completed by April 2008 at a cost of $171M. The total cost of the Fulton Street Transit Center project is approximately $888M.

Environmental Performance Commitments

In addition to MTA CCs projects, a number of other projects are under construction or planned for development in Lower Manhattan, including the permanent PATH Station, the WTC Transportation Hub, Route 9A Reconstruction, and the WTC Redevelopment and Memorial Center. Working with the Federal Transit Administration (FTA) of the Lower Manhattan Recovery Office, an advance set of mitigation measures called Environmental Performance Commitments (EPCs) were developed and are being implemented by the project sponsors -- MTA CC, the Port Authority of New York and New Jersey (PANYNJ), the New York State Department of Transportation (NYSDOT), and the Lower Manhattan Development Corporation (LMDC) -- to minimize cumulative environmental impacts during construction. The EPCs include requirements related to dust, noise, vibration, traffic control, and disruption to businesses and residents, in addition to clean diesel emissions controls, which is the subject of this paper.

Regulatory Diesel Emissions Controls

Under the Clean Air Act, National Ambient Air Quality Standards (NAAQS) have been established for particulate matter with an aerodynamic diameter of less than or equal to 2.5 micrometers and 10 micrometers ($PM_{2.5}$ and PM_{10} respectively) and sulfur dioxide (SO_2), pollutants that are of concern during construction since they result from the combustion of fossil fuels. New York City has been designated as a non-attainment area for both PM_{10} and $PM_{2.5}$, both of which can act as a substrate for the adsorption of other pollutants, often toxic and some likely carcinogenic compounds. $PM_{2.5}$ is of particular concern since the smaller fraction of the particle size range has the ability to reach the lower regions of the respiratory tract. The U.S. EPA estimates that construction equipment contributes about a third of annual mobile PM emissions in the U.S., the second largest source behind total highway at 40 percent. While there are around two million off-road construction vehicles in the U.S. compared to around 200 million cars and trucks, a typical 175-horsepower bulldozer emits as much particulate matter as 500 cars. The September 11, 2001 events heightened community concerns and awareness related to the potential health effects of particulate matter, so minimizing particulate matter diesel emissions became extremely important for the downtown construction projects.

The first tier of a four-tier progression of U.S. EPA emissions standards for new off-road diesel engines was phased in (by horsepower rating) from 1996 to 2000. Prior to the 1996 regulations, off-road engine emissions were unregulated (and much more polluting). Emission controls on these pre-1996 unregulated diesel engines remains voluntary. Subsequently, more stringent Tier 2 standards were introduced from 2001 to 2006 and yet more stringent Tier 3 standards phased in from 2006 to 2008. PM values for 175 horsepower Tier 2 and Tier 3 engines are 62 percent better than Tier 1. (Note that while the PM standard is the same for Tier 2 and Tier 3 engines, NO_x values for Tier 3 engines are about 38 percent better than Tier 2 for 175 horsepower engines).

The U.S. EPA issued a diesel sulfur rule affecting highway fuel in early 2001 and, in 2004, finalized the diesel sulfur rule for off-road fuel. U.S. EPA's highway rule involves a phase-in of ULSD fuel by requiring that, beginning in 2006, 80 percent of highway fuel produced in refineries be 15-ppm sulfur, and the remaining 20 percent at the 500-ppm standard (called Low Sulfur Diesel fuel). By 2010, all highway diesel fuel will be 15-ppm. The non-road rule utilizes a "two step" approach, phasing non-road fuel to 500 ppm initially, then to 15-ppm in 2010 in conjunction with the highway diesel requirements. Compliance with the rule contains some "hardship provisions" that allow some small refiners to continue

producing off-spec diesel for several years, particularly off road fuel. Although all diesel fuel will be ULSD by 2010, the U.S. EPA does not yet require service stations and truck stops to sell ULSD fuel and its current availability is market driven.

The New York State Environmental Conservation Law was amended in February 2007 to include a new section 19-0323 that requires the use of ULSD and best available retrofit technology for both on- and off-road heavy duty diesel vehicles for all state projects.

Table 1: non-road diesel engine emission standards for pm (g/bhp-hr)

Model Year	Tier 1 PM	HP Range	Tier 2 PM	Model Year
2000	0.75	Less than 11	0.60	2005
2000	0.60	11 - 25	0.60	2005
1999	0.60	25 - 50	0.45	2004
1998	----	50 - 100	0.30	2004
1997	----	100 - 175	0.22	2003
1996	0.40	175 - 300	0.15	2003
1996	0.40	300 - 600	0.15	2001
1996	0.40	600 - 750	0.15	2002

Source: U.S. EPA

Clean Diesel Emission Control Program

The Clean Diesel Emission Control Program that has successfully been implemented by MTACC at the South Ferry Terminal Station and Fulton Street Transit Center projects includes the following:

1. Use of Tier 2-compliant equipment for all off-road engines greater than 50 hp;
2. Use of ULSD in off-road equipment with engine rating of 50 hp and above;
3. Use of DPF in off-road equipment to further reduce emissions unless technically not feasible, in which case a Diesel Oxidation Catalyst (DOC) is considered.

In addition to these measures, idling times are limited to no more than three minutes, and engines are located away from fresh air intakes whenever possible.

Tier 2 Benefits

Aside from the significantly better performance of Tier 2 engines, PM "loading" on the filters is less likely to occur with Tier 2 equipment as compared to older engines since Tier 2 engines generate less PM emissions to begin with. Also, poor maintenance tends to be more of a problem with the older equipment, which also causes elevated PM emissions that would contribute to "loading". With non-tier engines, the order of magnitude of PM generation is so much higher that retrofit manufacturers might decline to offer a passive DPF, because of the danger of PM overload in the filter.

The requirement of Tier 2 engines motivated contractors to replace aging equipment. Very quickly contractors and sub contractors became aware of engine tier requirements and started asking for Tier 2 engine equipment. Market preparedness by the rental agencies and equipment dealers helped respond to the need.

ULSD Benefits

Unlike on-road diesel engines, construction engines were not regulated until recently and therefore used diesel fuel of any sulfur level. ULSD offers up to 13 percent reduction in PM as well as significant reductions in sulfur and other pollutants. When ULSD is used with DPF the reductions are over 90 percent for PM. ULSD also reduces corrosion and wear of exhaust system components and engine parts and offers more flexibility in the selection of retrofit technology.

USLD can cause older engines to malfunction. Problems cited with older engines include:

- Seal leak: USLD contains less aromatics that cause seals to shrink. Aged nitrile rubber seals tend to lose elasticity and are unable to adapt to lower aromatics in ULSD and can leak.
- Lubricity: Naturally occurring lubricity agents in diesel fuel are removed during the process of reducing sulfur to 15 ppm, which can cause engine problems. However, to overcome the lubricity issue, ASTM adopted lubricity specification D975 for all diesel fuels and this standard went into effect from January 1, 2005
- Fuel economy: processing ULSD reduces aromatics content and density resulting in up to one percent less energy per gallon. However, these reductions are negligible for fuel economy and horsepower in off-road engines.

DPF Benefits

On MTA CC projects, only "passive" DPFs were used, because "active" DPFs were not available at the time of program inception.[2] Passive DPFs filter more than 90 percent of the PM emissions from engines of all horsepower.

Challenges to Implementation

Challenge 1: Education

Educating the contractors and sub contractors about the diesel emission control requirements was found to be extremely important so that the best possible equipment (within the contractor's means) could be in operation at the earliest possible time. *A*lmost two years prior to construction, MTA CC communicated with rental agencies, dealers, and manufacturers of the upcoming need for machines with Tier 2 engines in Lower Manhattan. MTA CC also made contractors aware of the new requirements and shared a preliminary copy of the specifications with the industry. Commitments from United Rental Agency and equipment dealers were obtained that ensured Tier 2-engines would be included in their annual procurement for the most commonly anticipated equipment types.

Initially some contractors confused DPFs with DOCs. A DOC is a catalytic converter that promotes the oxidation of carbon monoxide, hydrocarbon and soluble organic fraction portion of particulate matter. It also oxidizes sulfur dioxide to sulfate. DPFs are preferable to DOCs because they are much more effective in reducing PM emissions. There was also confusion about verified technology, which is described below under *Challenge 3*.

[2] The passive DPF uses the heat of the exhaust gas to burn-off PM from the filter, thus regenerating the filter capacity. Active systems, on the other hand, are not dependant on the exhaust gas temperature for filter regeneration but use an auxiliary means to generate heat (e.g. a diesel burner integrated in the exhaust system). Active DPFs are used on equipment such as cranes, because the application does not generate enough heat to burn off the PM. We employed DOCs on equipment such as cranes, since passive DPFs are not applicable and active DPFs were not available.

Introducing these new specifications required MTA CC personnel to take on additional roles including: being available as a single-point help resource; offering to research and provide practical solutions to the contractor; being a coach; and following-up on issues. DPF suppliers were knowledgeable and helpful in providing information about their products. They were also willing to work with the contractors and agencies to ensure their products satisfied the requirements of the program.

Challenge 2: Resistance to Change Standard Practices

Some manufacturers and their dealers initially did not agree to allow DPF installation on their machines, citing the dangers of potential backpressure caused by PM "loading" despite a backpressure monitor in the cabs. The backpressure monitors serve as an early warning system to cab operators if an unsafe backpressure condition should arise. High backpressure or no backpressure during engine use could mean either that the filter was blocked or that it was ruptured, respectively. It should be noted that none of these conditions were experienced.

Engine warranties with respect to DPFs were initially a subject of great debate because of equipment owner's fear of damage to engine from high back pressure and the lack of endorsement to the use of DPF from the original equipment manufacturer (OEM). Generally equipment and engine manufacturers allow use of auxiliary devices, for example Caterpillar's warranty states that when other manufacturers auxiliary devices, accessories, and consumables are used on Caterpillar equipment, the Caterpillar warranty is not affected simply because of such use Finally, it should be noted that no engine failures have been reported.

Contractors were also resistant to using ULSD, claiming that they would need equipment specifically designated to the Lower Manhattan work that could not be used elsewhere due to a fear of cross contamination of ULSD with regular diesel with higher sulfur content. This fear proved to be unfounded since off road equipment dedicated to Lower Manhattan sites remained on site for a considerable period of time and were fueled on site. Irrespective of horsepower all diesel engines received only ULSD fuel. Additionally, even though MTA NYCT Clean Fuel buses program had already created a market for ULSD fuel, it was originally only available from a single supplier. It is now readily available in the New York metropolitan region.

Challenge 3: Availability of Quality DPFs

Retrofits for non-road engines are custom made. Unlike off-the-shelf parts, retrofit procurement has to be planned at least 4 to 6 weeks before construction equipment is deployed. Many retrofit suppliers were more interested with large volume production and not with customization for our off-road equipment. As a result, the supplier base for off-road retrofit is not as extensive as for on-road retrofits.

The U.S. EPA and California Air Resources Board (CARB) publish a list of verified commercially ready retrofit technologies. The U.S. EPA has a DPF verification program where products undergo a standardized test protocol; generally a 4-cycle ISO8178 test. The program eliminates the need for project sponsors to self-qualify vendors' products. In the northeast, there was only one manufacturer of U.S. EPA verified products that was willing to serve the off- road market. In order to expand the available supplier list, VERT-certified suppliers (a European certification process) were included as acceptable. Information on approved manufacturers of DPFs is available on the U.S. EPA[3] and CARB[4] web sites

[3] EPA- http://www.epa.gov/etv/verification/verification-index.html

[4] ARB - http://www.arb.ca.gov/diesel/verdev/verdev.htm

MTA CC took actions to ensure the availability of verified DPFs by making sure that retrofit manufacturers were aware of the future need in Lower Manhattan. In addition, MTA CC acted as a liaison between the retrofit filter manufacturers and the rental agencies and equipment dealers, provided contact information to contractors, kept tabs on orders placed, and followed through with the installation. These steps were necessary to ensure the timely implementation of the controls.

Challenge 4: DPF Installation

The first DPFs used on our projects were larger than the actual mufflers in the equipment and required some extra fittings, such as piping and clamps, for initial installation. Poorly installed DPFs resulted in leaky joints, which became evident within a few days of operation because a black ring would form on the outside of the filter. Dealers, rental companies and some contractors who used off-site maintenance shops for the installation were typically more successful. Today's custom designs allow for DPF installation within the confines of the engine compartment as a muffler replacement. This innovation makes installation safer, easier and more effective.

Challenge 4: Enforcement and Monitoring Compliance.

Despite the proactive educational measures described above, a certain amount of flexibility had to be afforded to contractors at outset of each contract, particularly for smaller subcontractors. A request for a waiver from the Tier 2 requirement was possible, although not encouraged. MTA CC follows the following guidelines in making allowances for hardship claims made by the contractor:

Accept:	Tier 2 + dpf or Tier 1 (waiver submitted) + dpf
Consider:	Tier 2 + dpf (ordered from manufacturer/will be installed within a specified timeframe)
Avoid:	Tier 1 +dpf (ordered from manufacturer/will be installed within a specified timeframe)
Disallow:	Non-tier engines + dpf
	Non tier engines

Verifying the tier of the equipment brought on site was particularly problematic, since engine data plates are not standardized, do not state tier level directly, and in many instances the information on the engine data plates had to be researched for tier status. Additionally, access to engine data plates within the tight confines of the engine compartment was typically available only when the engine was running, which made recording data difficult.

Initially, tracking fuel consumption and quality was difficult because contractors purchased fuel from different distributors and different contractors on the same site had equipment models that were the same. It was difficult to match equipment to fuel distributor to contractor to gallons of ULSD. To resolve the difficulties with tracking compliance, a simple but effective solution was implemented, where the prime contractor negotiated a fuel contract with a single fuel distributor. The fuel distributor was asked to bar code each piece of equipment filled on site and provide an automated report that captured the date, time, quantity and quality of fuel supplied. An unexpected benefit to this solution was that the fuel reports served as a cross check to the machine inventory on site.

DPF verification was based on physical inspection at site. Once verified for compliance, equipment received a very visible numbered green sticker stating 'Low Emission' that served as an easy means to communicate to those unfamiliar with the details of the program.

Program Results/Conclusion

As of December 2006, data from Fulton Street and South Ferry projects indicate that there have been almost 185 pieces of equipment operated on the sites of which 147 pieces were eligible for the Clean Diesel Emissions Controls (i.e. 50 horsepower and above). Of the 147 pieces, about 86 percent were Tier 2 engines and 13 percent were Tier 1 engines. Of the 147, approximately 72 percent were Tier 2 DPF-retrofitted and eight percent were Tier 1 DPF-retrofitted. Another six percent was a combination of Tier 1 or Tier 2 engines with DOCs.

The DPFs varied in cost according to horsepower, ranging from about $6,000 to $9,000 for engines between 84 and 155 horsepower. For engines between 210 and 800 horsepower, the cost of a DPF ranged from about $10,000 to $33,000. These costs exclude the cost of installation.

ULSD fuel was used exclusively, with no negative implications to the contractor's equipment or equipment fleet. The cost difference at the rack between ULSD and the low sulfur diesel fuel alternative was as little as $0.04 rising up to $0.40, with an average value of $0.17. Between South Ferry and Fulton Street Transit Center, as of December 2006, approximately 380, 000 gallons of ULSD fuel was consumed at a cost, resulting in an incremental cost of roughly $65,000.

Positive feedback on the Clean Diesel Emissions Program was received from construction workers and, in particular, the equipment operators (who are around machines eight hours per day), who appreciated breathing cleaner air as a result of the program. Positive press articles were generated and community support for the projects was enhanced because of the program.

FIG 1: Excavator with Low-Emission Sticker

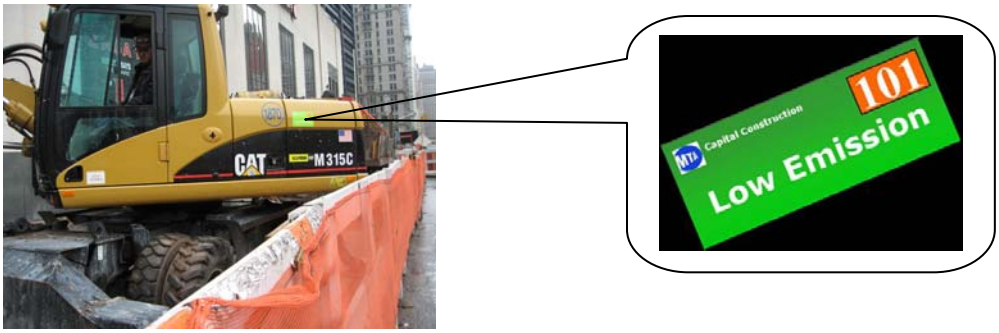

FIG 2: Excavator with DPF