Status Report on Clean Mobile Source Diesel Initiatives in The Northeast States and Eastern Canadian Provinces

Acid Rain Steering Committee

Committee on the Environment

New England Governors/Eastern Canadian Premiers Conference

September, 2003

TABLE OF CONTENTS

SUMMARY

In May 2002, the Government of Quebec held a symposium on air pollution and public health under the auspices of the Conference of New England Governors and Eastern Canadian Premiers (NEG/ECP). Much of the conference focused on emerging health data that has demonstrated a cause-and-effect relationship between fine particulate matter (PM) and increased disease and mortality in the US and Canada. Although much of the fine PM is produced by large coal-burning power plants to our west, emissions from less controlled diesel trucks and buses present serious regional and localized problems. In addition to the long-established health effects resulting from diesel PM, recent studies have identified diesel PM to be a likely human carcinogen. In recognition of this growing public health concern, the Governors and Premiers at their August meeting in Quebec City drafted Resolution 27 Concerning the Environment. This resolution requested that the Committee on the Environment report at the next NEG/ECP Conference on state, provincial and federal efforts to reduce diesel emissions from existing sources in their respective jurisdictions.

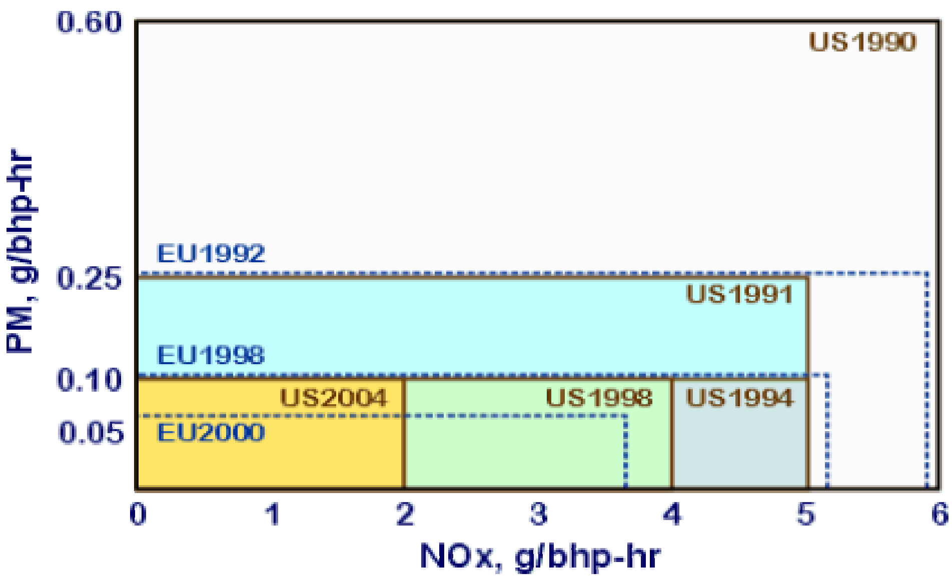
This report, which was prepared by Northeast States for Coordinated Air Use Management (NESCAUM), fulfills the request made in Resolution 27 and provides the background and technical information necessary for effective decision-making on diesel abatement programs from the federal level to the local school district level. The US and Canadian governments have acknowledged the public health and environmental problems associated with diesel engines by focusing on more stringent standards for new engines and lower sulfur fuel requirements for on-highway and nonroad heavy-duty vehicles. Although these programs will begin to be implemented starting in 2006, a large number of existing diesel engines with relatively high emissions will remain in operation. This problem is compounded by the remarkable durability of diesel engines. While the longevity of diesel engines is one of their primary attributes, it means that much of the existing heavy-duty vehicle fleet will remain on the road emitting higher levels of pollution for another 25 to 30 years. Accordingly, this report examines the use of current and developing retrofit emissions control technologies, reformulated fuels and vehicle use restrictions as viable options for reducing harmful emissions from the existing US and Canadian heavy-duty diesel vehicle fleets.

The report begins with an investigation of the types of pollutants that heavy-duty diesel trucks and buses emit, followed by a survey of currently available and emerging emissions control technologies and their estimated emissions reductions, costs, benefits and drawbacks. Since low sulfur diesel fuel is a key component in the selection of various control technologies, the report discusses the current availability of Ultra-Low Sulfur Diesel (ULSD) as well as US and Canadian regulatory requirements for the availability of ULSD beginning in mid-2006. The report also outlines several retrofit and fuel reformulation projects in the US and Canada. In addition, the report evaluates the diesel engine idling issue from several different perspectives, provides a summary of anti-idling programs in the Northeast and offers several alternatives for reducing the excessive emissions associated with unnecessary engine idling.

1. INTRODUCTION

A dichotomy has existed for at least two decades regarding the heavy-duty diesel engine used in commercial transportation applications. On one hand, the diesel engine is a highly efficient and robust power system, with low torque characteristics well suited for heavy-duty on road trucks and buses, and off-highway equipment. On the other hand, the emissions from these engines have a deleterious effect on both air quality and human health. These diverse air quality impacts have been known for a number of years. An increased understanding of the toxicity of diesel exhaust, most notably the particulate matter (PM) component, has resulted in both the US Environmental Agency (EPA) and the California Air Resources Board (ARB) designating diesel exhaust as a hazardous air pollutant[1].

In addition to PM, diesel engines emit significantly greater amounts of Oxides of Nitrogen (NOx) on a per-mile basis, than their gasoline-powered counterparts. NOx is a major contributor to tropospheric ozone, acid rain, estuary nitrification, secondary particulate formation and the destruction of stratospheric ozone. The deleterious effects of NOx and PM emissions from diesel-powered equipment have led to the adoption of stringent new engine emission standards by EPA and ARB.



The newer, more stringent NOx and PM standards for heavy-duty engines have encouraged the development and increased the use of aftertreatment devices to control emissions from diesel engines. This trend will certainly continue as tighter standards take affect over the next five or so years. Many of these devices, such as catalyzed diesel particulate filters, can only be used, or work most effectively, in conjunction with ultra-low sulfur diesel fuel (ULSD), with sulfur levels at a minimum of less than 30 parts per million (PPM), and optimally at less than 15 ppm. US on-highway regulations will account for this by mandating low-sulfur diesel fuel to complement these more stringent exhaust emissions regulations. Current Canadian fuels regulation has

[1] ARB designated diesel particulate matter (PM) a Toxic Air Contaminant (TAC) in 1998 and in October, 2000, established their “Risk Reduction Plan” to promulgate control measures. In 2002, EPA characterized diesel exhaust a likely human carcinogen and used this as a basis for mobile source regulation.

harmonized sulfur content with that of the US at 500 ppm, with plans to mirror the US's 15 ppm mandate for June 2006 implementation.[2]

The robustness and longevity of heavy-duty diesel engines has made them a popular power plant for commercial vehicle applications. Unfortunately, from an emissions perspective, the durability of these engines results in older, higher-emitting diesel equipment remaining in operation for many years. As vehicles age and deteriorate, regulated emissions tend to increase. Additionally, because of their commercial, rather than personal use application, fleets routinely rebuild these older, higher-emitting diesels, further extending their life in-use. Consequently, the benefits of new engine standards for the heavy-duty fleet take longer to be realized since fleet turnover is much slower than for the light-duty fleet.

The need to mitigate the long-lasting exhaust emissions effects of these older higher emitting diesels has prompted a growing interest in in-use retrofit and clean fuels programs and vehicle operating adjustments. By installing these retrofit control devices on the existing diesel fleet, with little or no modification to the base engine or vehicle, substantial emission reductions can be realized at comparatively low costs and with minimal disruption to fleet operations. Similarly, a number of clean-burning fuels are emerging in the market that can be used in diesel engines to reduce in-use emissions. Finally, changes in driver behavior, most notably through idle-reduction measures, can provide significant emissions reductions at very low cost.

This Status Report provides: (1) an overview of retrofit and clean fuel technology options; (2) a summary of retrofit activities in the Northeast states and Eastern Canadian provinces; (3) details regarding several successful retrofit programs in the region; (4) a rationale and overview of anti-idling initiatives; (5) a status update on Canadian diesel fuel regulation.

2. BACKGROUND

NOx and PM are the criteria pollutants of greatest concern from diesel engines. Federal and California new engine regulations target these constituents. Similarly, retrofit technology is geared to NOx and PM reductions. Currently, commercially available, technologically "mature" devices tend to be substantially more effective in reducing PM than NOx. This fact is reflected in the number of past, current and planned programs in the Northeast states and Eastern Canadian provinces targeting PM reductions. Nevertheless, NOx emissions contribute to a host environmental and public health problems and to the extent that the technology to reduce these emissions becomes commercially available and is cost-effective, NOx retrofit technology is likely to be pursued more aggressively in the future. Carbon dioxide (CO_2), the primary greenhouse gas associated with global climate change, is another pollutant of concern that is emitted in significant quantities by those fleets powered with diesel engines.

a) Emissions Constituents – "What are we trying to reduce?"

Diesel engines emit a number of gaseous emissions as well as particulates. Compared to gasoline engines, diesels have considerably lower engine-out levels of CO_2, making them an attractive longer-term alternative for enhanced energy efficiency and greenhouse gas emission reductions. However, diesels emit significantly greater amounts of NOx and PM than gasoline

[2] Actual schedule for implementation: June 1, 2006 for refiners to produce ULSD; July 15, 2006 for terminals to stock ULSD for distribution; September 1, 2006 for retail filling stations and fleet depots to carry ULSD for on-highway vehicle consumption.

engines. In order to maintain the diesel engine as a viable transportation powerplant as emission standards are tightened, engine and aftertreatment strategies are needed to reduce the levels of NOx and PM emitted.

Oxides of Nitrogen (NOx)

NOx is a regulatory term referring to the combination of the gases nitric oxide (NO) and nitrogen dioxide (NO_2). Both of these constituents are undesirable from a public health and atmospheric pollution perspective. NOx reduction retrofit technology is geared at the simultaneous reduction of both constituents.

From a health perspective, NO is a colorless gas that causes eye nose and throat irritation, drowsiness, and can exacerbate heat-related disease. From an air pollution perspective, NO contributes to ground level ozone formation. NO_2 is far more toxic than NO, causing extreme respiratory inflammation, pulmonary distress and, at very high concentrations, can even cause death. Diesel exhaust is composed primarily of NO (85 to 95 percent depending on the engine design).While NO is less toxic, it is easily oxidized in the atmosphere to form NO_2.

Particulate Matter (PM)

Diesel particulate matter contributes to adverse heath and air quality impacts, as noted above. PM is sub-divided into three distinct components, called “fractions”. A general understanding of these three fractions serves as a guide in selecting the proper retrofit technology for a specific application. The three fractions are as follows:

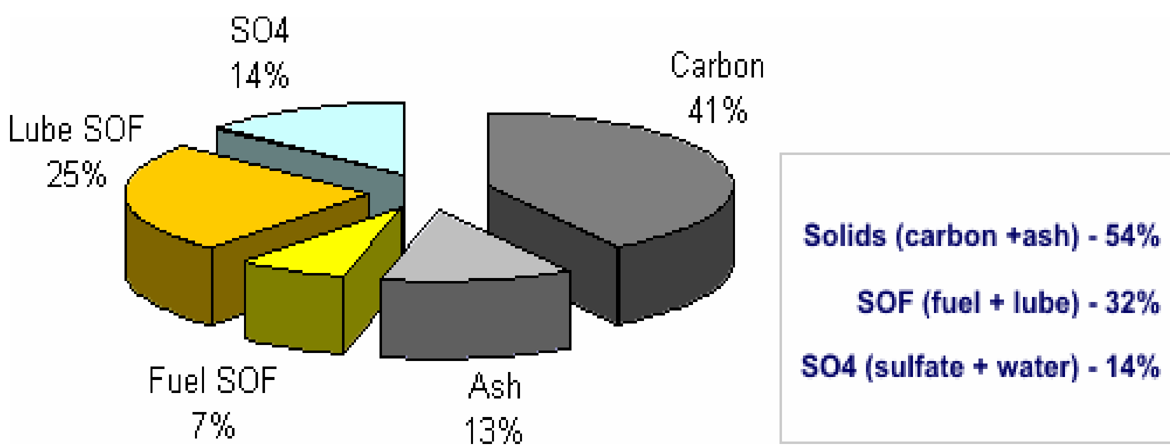
- Solid Fraction
  The solid fraction of diesel PM is often referred to as “elemental carbon” (“EC”) or “black carbon” and also includes ash deposits. The solid fraction of total PM is the primary source of the black smoke associated with heavy-duty diesel engines. Ash, on the other hand, primarily emanates from lubricating oil and metals due to engine wear. As newer engines are developed to produce less EC, the proportion of ash in the exhaust tends to increase. The good news is that high levels of ash are usually effectively removed by diesel particulate filters (DPFs) through physical entrapment. However, ash presents two significant issues: it is quite corrosive and can deteriorate DPF filter material if not properly accounted for in the design of the DPF, and it cannot be completely removed from the DPF through the regeneration process (explained below), requiring periodic DPF removal and cleaning by hand.

- Soluble Organic Fraction (SOF)
  The SOF is composed of organic material from engine fuel and lube oil. It is essentially hydrocarbon deposition forming on the surface of elemental carbon (EC) particles, and is often referred to as “wet PM.” SOF formation is extremely duty cycle dependent, and is present in higher concentrations in diesel exhaust from vehicles that operate under light load, when exhaust temperatures are low. This is especially significant when considering diesel oxidation catalysts (DOCs) as a candidate retrofit device, since they are effective in reducing only the SOF portion of diesel PM. SOF concentrations in the PM of diesel exhaust also tend to be decreasing with newer engines as emission regulation prompts generally higher operating temperatures. While this trend is beneficial, it lessens the effectiveness of the DOC as a strategy for meeting new engine standards

- <u>Sulfate Particles (SO_4)</u>
  SO_4 is a combustion by-product emanating from the sulfur content in diesel fuel forming sulfuric acid and water, and subsequently precipitating under cooling to form sulfate particles. Sulfate formation may also occur as an unintended by-product of the oxidation of sulfur dioxide (SO_2) in a DOC. This chemical reaction, frequently termed "sulfate make", is added to the total PM of an engine, causing elevated levels of PM and adversely affecting DOC conversion efficiency.

It is very important to understand these "fractions" of the total PM, since certain retrofit technologies are only capable of reducing some, but not all of these components of PM. As one would expect, the more sophisticated technologies are able to reduce both the solid fraction and SOF portion (catalyzed diesel particulate filters, for example), but at greater cost and with some implementation challenges.

PM composition for post-1994 engines is illustrated in the chart below:



b) Retrofit Functionality –
"How are emission reductions from these devices quantified?"

Both EPA and ARB operate retrofit technology verification programs. The purpose of these programs is to develop protocols and test candidate retrofit devices in order to assign PM and/or NOx emission reduction values to specific devices. When a verified device is used as part of a pilot retrofit program, the assigned emissions reductions can be credited to the program[3].

An alternative approach is to measure the effectiveness of specific retrofit technologies after they have been installed on the vehicles. Generally, there are two options in developing this in-use testing protocol. In the first, the entire vehicle is installed on a chassis dynamometer that operates the vehicle through a prescribed test cycle and records PM, NOx and other criteria

[3] Details on these programs may be found on these websites:
- EPA – http://www.epa.gov/etv/verifications/verification-index.html
- ARB – http://www.arb.ca.gov/diesel/verifieddevices/verdev.htm

emissions as well as vehicle information such as speed and load, over the course of the cycle[4]. In the second approach, a Portable Emissions Monitoring System or "PEMS" is installed on the vehicle itself and the vehicle is subsequently driven over public roads. Again, emissions are sampled and recorded over the duration of the driving "sequence." While cycle repeatability is difficult if not impossible, this technique better replicates real world driving conditions and set-up and measurement costs are considerably reduced.

3. RETROFIT TECHNOLOGIES – An Overview

Retrofit technologies can be broadly divided into three main categories: (1) "bolt on" devices that primarily reduce PM; (2) "bolt on" devices that primarily reduce NOx; and (3) fuel formulations that reduce PM or NOx, or both, simultaneously. The most effective and commercially viable technologies are those designed to reduce PM emissions. NOx-reducing technologies tend to be in earlier stages of development and have yet to enjoy widespread use in pilot programs. Finally, clean fuel formulations show great promise as an in-use control strategy. ULSD is widely used for PM reductions and will be federally mandated in the US for on-highway use in 2006 and nonroad use in 2010. Emulsified diesel fuel (water emulsions) is being targeted for pilot programs to reduce both NOx and PM. Biodiesel is starting to find more widespread use as a viable approach for reducing regulated air pollutants, and greenhouse gases – and enhancing energy security.

a) Current Retrofit Technologies

Two "bolt on" retrofit technologies that have enjoyed widespread application in retrofit programs are diesel oxidation catalysts (DOCs) and diesel particulate filters (DPFs). A third, Selective Catalytic Reduction (SCR), has enjoyed some success in stationary (e.g. generator set) applications, but is less commercialized than the other two for mobile sources. Nevertheless, SCR shows promise as a NOx-reducing approach and is currently being used in a number of pilot programs.

i) Diesel Oxidation Catalysts

(1) Application and Effectiveness

Diesel oxidation catalysts (DOCs) were one of the first retrofit reduction devices to enjoy widespread use. They are virtually identical in size and shape to the conventional mufflers that they replace, making them a true "bolt on" application with no requirements to modify or adjust engine controls or use a specific fuel type, such as ULSD. However, they tend to be heavier than the mufflers they replace and sometimes require revised, more robust mounting brackets. Costs typically range from $1,000 to $2,000 per vehicle, making them an attractive replacement for the conventional muffler as a low cost PM reduction strategy.

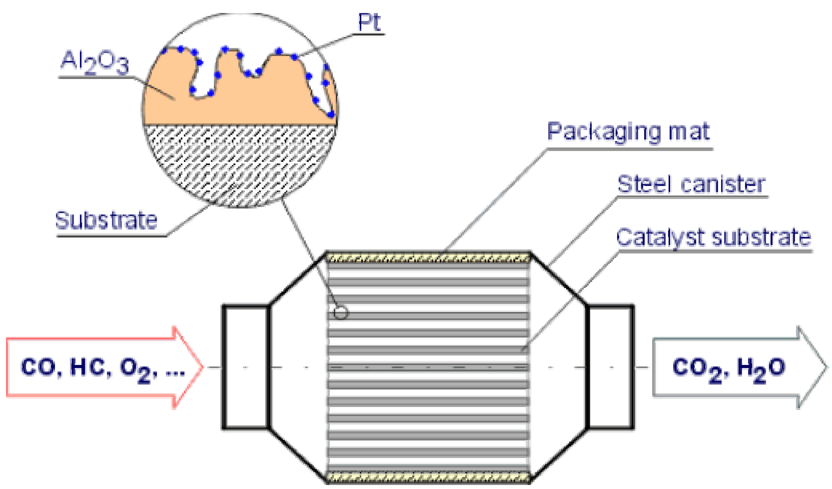
DOCs generally exhibit PM reduction efficiencies of 20 percent, which is modest compared to other, more advanced technologies. However the ease of installation, minimal modification to the vehicle structure or operational parameters (such as engine recalibration or low-sulfur fuel

[4] Test cycles are generally selected to reflect in-use operation for a specific type of vehicle. Two commonly used cycles are the Urban Dynamometer Driving Schedule (UDDS) replicating freeway as well as non-freeway "tractor trailer" and bus operation, and the New York Garbage Truck Cycle (NYGTC) to specifically test refuse collection trucks that operate in urban areas.

substitution), coupled with their low-cost, makes them an ideal PM retrofit technology when used in large-scale applications. It is not surprising, therefore, that most DOC-focused retrofit programs target, on average, installation on 100 or more vehicles to maximize total fleet PM reduction benefits. DOCs are a low-efficiency/high volume retrofit option at a modest price increase over a conventional muffler.

(2) Operating Principle

As the name suggests, the oxidation catalyst "oxidizes", or "adds oxygen" to hydrocarbons in the exhaust, to form carbon dioxide (CO_2) and water. Oxygen is present in diesel exhaust in large quantities, so oxidation occurs naturally; a DOC speeds up the reaction rate. SOF is the hydrocarbon composition on the elemental carbon portion of PM (as discussed above); DOCs oxidize the SOF fraction of PM and this reaction results in PM reductions.



(3) Benefits and Drawbacks

DOCs are effective at reducing HC, CO and the SOF portion of PM. Typical reduction values are 50 – 90 percent for HC, 70 – 90 percent for CO, and 20 – 30 percent for total PM. The PM value is low when compared to DPFs because the SOF portion of diesel PM, which they control, is correspondingly low (refer to pie chart above).

A significant concern with DOCs is their propensity for "sulfate make", as described above. Under certain conditions, the unwanted production of sulfate can outweigh any benefit in total PM reduction. Sulfate make is dependent primarily upon sulfur content in the diesel fuel, the operating conditions of the vehicle (and hence the resultant catalyst temperature) and the formulation of the metal on the catalyst itself. The best defense against sulfate make is to use low-sulfur fuels. DOCs are attractive for retrofits since they are not poisoned by the use of higher sulfur fuels (300 ppm and above) the way many DPFs are. However, higher sulfur content can contribute to sulfate make, and their use with lower sulfur content fuel will ensure minimal sulfate production. Additionally, DOCs are becoming more sophisticated and coating formulations are selectively minimizing sulfate make. Finally, sulfur formation tends to decrease with increasing temperatures above a certain threshold point. As noted earlier, there is a design trend toward higher engine and exhaust temperatures.

DOCs "At A Glance"

Benefits	Drawbacks
1. Moderate total PM reduction performance (20-30%) – benefit if applied in high vehicle volumes. 2. Comparatively low cost. 3. Easy installation – usually direct replacement for muffler. 4. Tolerant of sulfur content in diesel fuel (not "poisoned"). 5. May provide high PM reduction on older engines, especially 2-cycle engines (both have higher SOF concentrations in diesel exhaust).	1. Low PM reduction efficiency – drawback if applied in low vehicle volumes. 2. Ineffective in reducing elemental carbon (i.e. "soot"). 3. Easy installation – but occasionally requires revised brackets to accommodate additional weight over muffler. 4. Potential for sulfate make.

ii) Diesel Particulate Filters

(1) Application and Effectiveness

Diesel particulate filters (DPFs), when used in conjunction with a catalyst ("catalyzed traps") are capable of total PM reductions on the order of 90 percent, making them a very attractive retrofit option. A number of these devices, primarily manufactured by Johnson Matthey and Engelhard, are being used on a pilot basis in a number of fleets in the Northeast. More retrofit initiatives using DPFs are in the planning stages as the benefits and functional acceptability of this technology become better known.

While DPFs are generally designed as a direct replacement for the original muffler – much like a DOC – they tend to be larger and heavier than either of these two and therefore require some engineering to be properly installed on the vehicle. Further, the need for proper exhaust temperature complicates the use of DPFs in retrofit applications. Because DPF regeneration is very exhaust temperature-dependent, data logging instruments are installed to record the vehicle's exhaust temperature "history" prior to DPF retrofit installation. This approach ensures that the exhaust temperature, on average, is sufficiently high to promote timely and consistent regeneration of the DPF. Revised mounting brackets to sustain the increased weight and larger size must be designed, fabricated and installed. Finally, an exhaust backpressure sensor and dashboard-mounted indicator light is installed to ensure consistent regeneration in-use.[5]

DPFs are considerably more technically complicated than DOCs and this is reflected in their cost, which on average is between $6,000 and $9,000 including installation. Furthermore, most systems require the use of ultra low sulfur diesel fuel (ULSD) – typically less than 15 parts per million (ppm) – to facilitate regeneration and/or preclude catalyst poisoning that would permanently render them inoperable. Nevertheless, their per unit effectiveness in reducing PM is very attractive. In comparison to the DOC, DPFs are a "high-efficiency/low volume" retrofit option with attendant cost, installation and operational challenges over the DOC.

[5] Monitoring exhaust gas backpressure (EGBP) ensures that the DPF in not becoming plugged with soot due to insufficient regeneration, which would increase EGBP levels beyond the engine manufacturers' specifications for safe operation of the engine.

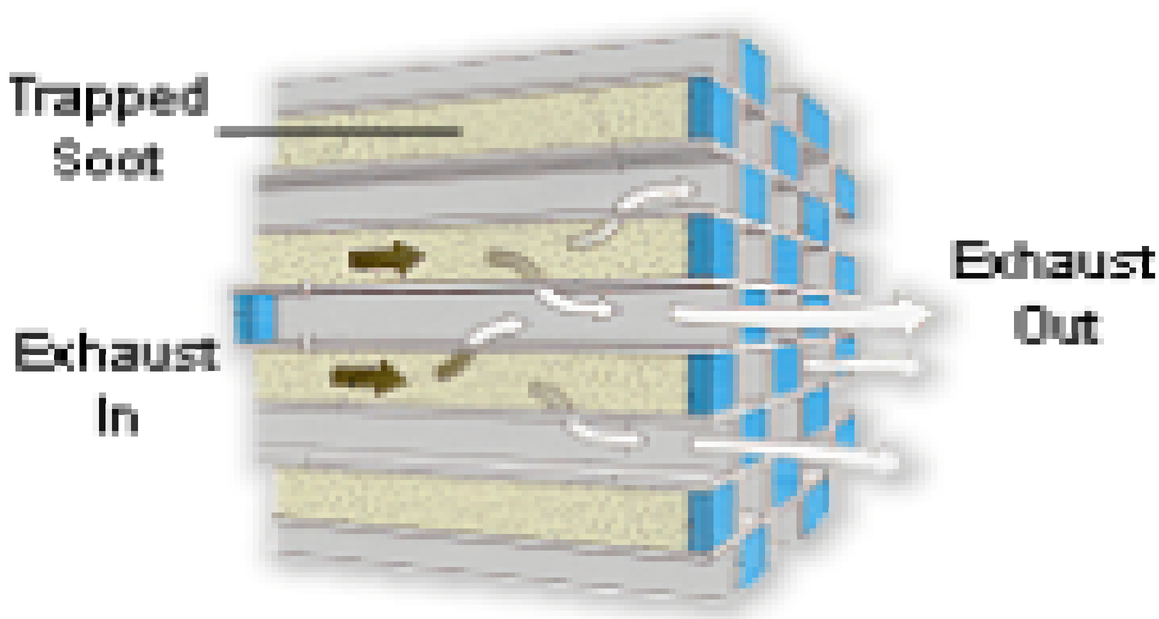
(2) Operating Principles

DPFs have evolved as the most effective method for reducing total PM emissions from diesel engines. DPFs remove PM through a two-stage process. First, the DPF physically entraps the elemental carbon portion of PM. Then, through application of elevated exhaust temperatures, the DPF oxidizes these solid particulates to form gaseous products, primarily CO_2, through a process termed “regeneration.”

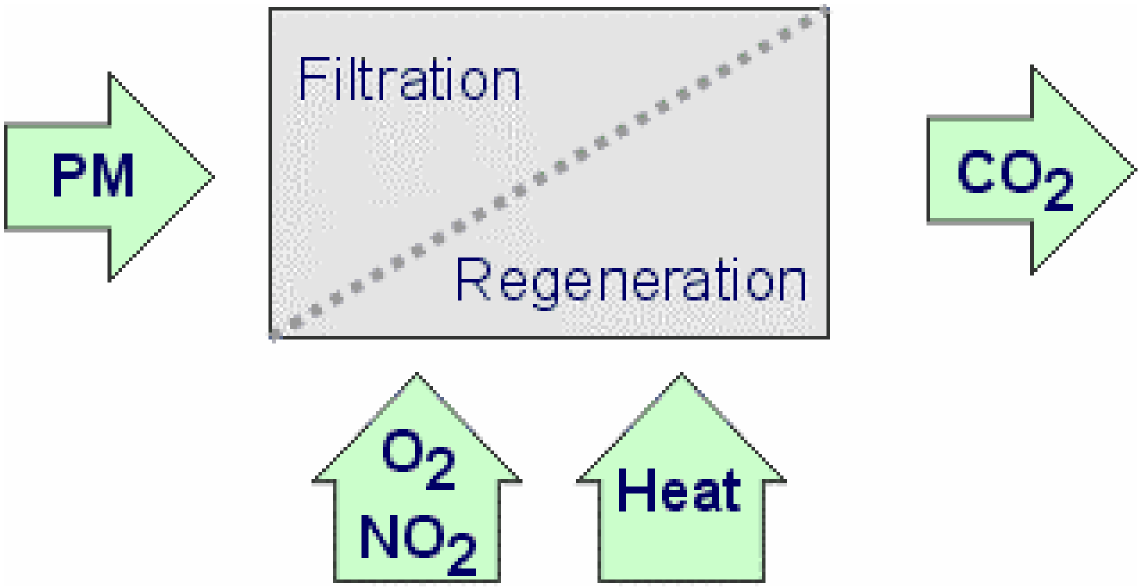
There are two types of DPFs, each designed to effectively promote regeneration. *Passive DPFs* require no outside source of heat; exhaust temperatures are elevated by the increased backpressure in the exhaust as the DPF fills with PM. As this loading increases, the exhaust backpressure and hence the exhaust temperature increase to specific threshold values. When this threshold exhaust backpressure and temperature is reached, the PM is oxidized and removed, and the exhaust temperature subsequently reduces. The DPF starts to trap more PM and the process is repeated. *Active DPFs* employ the same principal, but heat is added by one of a number of external means to promote regeneration – electric heating, injection of diesel fuel into the exhaust, or engine calibration to temporarily raise the exhaust temperature. Active filters are used when the engine exhaust temperature is too low for passive DPF use.

By combining a DPF with an oxidation catalyst, the SOF portion can also be removed, making for impressive total PM reducing efficiency (upwards of 90 percent). Most DPF manufacturers have commercialized these dual-based systems into one container or “can”, using a DPF in tandem with a DOC or applying a catalytic coating to the DPF substrate itself, to facilitate retrofit installation. To date catalyzed DPFs have been used in retrofit projects in the Northeast region to maximize PM fleet reductions.

DPF Operating Principle



DPF Regeneration of Particulates



(3) Benefits and Drawbacks

Catalyzed DPFs are very effective in reducing total PM; coupled with their general "muffler like" configuration, they are an attractive retrofit technology. As noted above and in the table, below, there are a number of challenges to overcome, but pilot projects conducted in the Northeast have demonstrated the viability of DPFs as retrofit technology for heavy-duty vehicles. On-going research and development by DPF manufacturers is mitigating the regeneration issue for passive type DPFs, ULSD is becoming more widely available in the US – and in the Northeast region – and economies of scale will lower costs over time. Similarly, more widespread application for retrofits will attenuate the need for custom made brackets for installations as will efforts by DPF manufacturers to redesign their units into smaller packages for easier retrofit installation.

DPFs "At A Glance"

Benefits	Drawbacks
1. Very high total PM reduction performance (90%). 2. Comparatively easy installation – not as straightforward as the DOC, but it still fits within the space formerly occupied by the muffler. 3. Passive regeneration is unnoticed by the vehicle operator.	1. High cost. 2. Requires ULSD. 3. Requires threshold exhaust temperature to ensure regeneration. 4. Requires periodic (usually yearly) removal and cleaning to remove unregenerated ash deposits.

iii) Selective Catalytic Reduction (SCR)

(1) Application and Effectiveness

SCR is one of two commercially available technologies that show significant promise in reducing NOx from diesel engines (emulsified diesel fuel is the other). For a number of years, SCR systems have been used in stationary applications, such as diesel engines that power generator sets, compressors and pumps. They have also been successfully used in large powerplant and other industrial applications. The lack of mobility and more consistent operating characteristics of stationery engines mitigate some of the substantial challenges of applying SCR systems to mobile applications. These include transporting the requisite supply of ammonia, and ensuring that the engine operates within a rather narrow exhaust temperature band to ensure proper SCR operation.

SCR systems are inherently more complex than the PM-reducing retrofit options discussed above, in that they require an elaborate injection or "dosing" mechanism to provide the correct measure of ammonia into the exhaust stream to reduce engine-out NOx. As a result, the initial unit cost is higher (upwards of $12,000), as are the installation costs. Furthermore, a constant ammonia supply is needed. Finally, with no established ammonia infrastructure along highways in North America, the EPA is wary of promoting a technology that not only relies on the existence of such an infrastructure but also on the diligence of vehicle operators to fill the on-board ammonia storage tank as required.

In spite of these drawbacks, considerable investigation is underway to assess the feasibility and cost of overcoming these obstacles. This effort appears to be warranted given the NOx reduction potential of SCR which ranges from 80 to 90 percent.

(2) Operating Principles

SCR uses an outside agent – in this case ammonia – to convert NOx to harmless nitrogen (N_2) and water. Because ammonia is quite toxic and corrosive in its pure form, a non-toxic substitute, urea, is used. The urea essentially "locks in" ammonia in a non-toxic, easy to handle and commercially available solution. When the injection or "dosing" unit releases the urea into the exhaust, the heat from the exhaust (minimum temperature of 160^{o} C) releases the ammonia component of the urea stimulating the chemical reaction that converts NOx into N_2 and H_2O.

(3) Benefits and Drawbacks

The major benefit of SCR is the ability of this technology to convert large concentrations of NOx – both NO and NO_2 – into harmless nitrogen and water. Until other NOx-reducing technologies are perfected, SCR represents a potentially feasible technology – albeit with considerable challenges. As such, states and provinces should consider further promoting its use in pilot programs to evaluate the longer-term viability of this technology.

In addition to the cost, complexity and infrastructure issues, SCR systems must maintain a careful balance of proper urea dosing and exhaust temperature. Under-dosing of urea results in poor (sometimes zero) NOx reduction. Excessive amounts of urea result in a phenomena known as "ammonia slip", where raw ammonia – recall the earlier comment regarding toxicity – discharges from the exhaust. Similarly, vehicle operation and exhaust temperatures that are too low (generally less than 200^{o} C) can cause "secondary reactions" that can increase NOx formation. SCR, if improperly engineered, will contribute to NOx formation, rather than reducing it. These lower temperatures are often characteristic of light-load vehicle duty cycles such as those associated with transit buses, refuse trucks and other urban fleets that are of concern from a public exposure perspective. States and provinces should weigh these operating characteristics very carefully when considering SCR for pilot NOx reduction programs.

SCR "At A Glance"

Benefits	Drawbacks
1. High total NOx conversion efficiency (70+%). 2. Sulfur tolerant (does not require ULSD). 3. Does not require removal for cleaning.	1. High cost. 2. Requires urea infrastructure. 3. Requires on-board urea injection system. 4. Requires careful urea injection strategy to preclude either poor NOx conversion or "ammonia slip." 5. Requires careful control of exhaust temperature to preclude excessive NOx formation.

b) EMERGING NOx RETROFIT TECHNOLOGIES

With the inherent challenges associated with the use of SCR in mobile source applications, and the need to comply with much more stringent NOx standards in the coming years, the after-treatment industry is striving to develop alternative NOx-reducing technologies. Two promising devices are the lean NOx catalyst and the NOx adsorber. The following section briefly describes their operation and potential for implementation in future retrofit projects.

i) Lean NOx Catalysts

In theory, a lean NOx catalyst operates much like an SCR unit – it selectively reduces NOx through the introduction of an enabling "outside agent." The SCR system uses urea, which must be carried in a separate vessel on-board the vehicle. The lean NOx catalyst injects a "shot of hydrocarbons" into the exhaust – either through direct injection of fuel into the exhaust stream or through late injection of fuel directly into the cylinder of the engine. The direct fuel injection system is costly (for the same reasons as the urea injection system is on SCR), and the in-cylinder injection system promotes cylinder wall wetting, compromising engine durability. Both injection strategies enable the lean NOx catalyst to convert NOx to harmless nitrogen, carbon dioxide and water, but both strategies exact significant fuel economy penalties. Since fuel efficiency and durability are the attributes that attract users to diesel engines, minimizing these adverse impacts will be a focus of catalyst and engine manufacturers' research and development activities.

While the challenges are significant, the capability of the lean NOx trap to employ an activation mechanism already on board the vehicle – diesel fuel – makes it far more attractive than the urea-infrastructure-intensive SCR system. There is some optimism that commercial units may be available within the next few years for use in retrofit programs.

Lean NOx Catalysts "At A Glance"

Benefits	Drawbacks
1. Moderate total NOx conversion efficiency (30 – 50%). 2. Diesel fuel (as enabling "outside reducing agent") already on board the vehicle; diesel fuel infrastructure already in place.	1. High cost. 2. Conversion efficiency significantly less than SCR. 3. Precise control of exhaust temperature required. 4. Prone to sulfur poisoning (needs ULSD). 5. Prone to generating nitrous oxide, a greenhouse gas.

ii) NOx Adsorbers

Of all the NOx-reduction technologies, NOx adsorbers[6] appear to be the most promising, at least for new engine applications. A number of complex processes are involved in the ultimate conversion of NOx to carbon dioxide and water. Basically, NOx adsorber operation involves adsorption and storage of NO_x in the catalyst during lean-fueling driving conditions with subsequent release under rich operation. Then, the released NO_x is catalytically converted to nitrogen in much the same way as in a gasoline, automotive-type catalyst Very close integration with the electronic engine control system is required to make the adsorber work properly. As a result, it is uncertain whether NOx adsorbers will emerge as a viable retrofit option. However, the emission reduction effectiveness of these devices certainly merits further development and evaluation efforts. It is conceivable that in time, commercial manifestations could incorporate a supplemental "electronics kit" that would properly modify the electronic engine management system for in-use engines to optimize adsorber operation, thereby making NOx adsorbers an option for retrofit applications.[7]

NOx Adsorbers "At A Glance"

Benefits	Drawbacks
1. High total NOx conversion efficiency (50 – 70%). 2. Diesel fuel (as enabling "outside reducing agent") already on board the vehicle; diesel fuel infrastructure already in place.	1. High cost. 2. Conversion efficacy good, but less than SCR. 3. Precise control of exhaust temperature required. 4. Prone to sulfur poisoning (needs *very low* ULSD).[8] 5. Prone to generating nitrous oxide, a greenhouse gas.

[6] Adsorption is different from absorption: gases or particles that absorb go into a substance (e.g. water into a sponge); gasses etc that adsorb attach to the surface.
[7] Current regulatory provisions regarding tampering would have to be revisited.
[8] NOx adsorption efficiency decreases even at diesel fuel sulfur levels below 10 ppm. Efficiencies can usually be restored, but at very elevated exhaust temperatures (600+^{o} C) through infusion of diesel fuel. The excess fuel reduces fuel economy, while the high-temperature thermal cycling tends to destroy the adsorber itself.

c) Fuel Formulations

i) Ultra-Low Sulfur Diesel Fuel (ULSD)

ULSD has three properties that make it an important in-use emission reduction strategy. First, it is generally required to enable the operation of the most effective reduction devices such as particle filters. Second, it promotes more effective operation and/or longer operating life for some retrofit devices (poisoning from use of elevated fuel sulfur levels can permanently render some retrofit devices inoperative), and third it reduces engine-out PM emissions and secondary emissions of SO_4, even when used without any other retrofit device.

A major challenge for states and provinces in designing and implementing retrofit programs is the ability to identify fleets that either have ULSD already available, or are amenable to introducing it. Cost differentials may run as high as twelve to fifteen cents per gallon, with availability in some areas being an issue. Additionally, installing a separate fueling station to service that part of the fleet fitted with sulfur-sensitive retrofit devices involves cost, regulatory issues and logistical challenges.

Fortunately for the Northeast, ULSD is usually readily available, with one of the major local distributors actively partnering on a variety of retrofit initiatives in the region. Additionally, some key municipal fleets have already converted to ULSD, effectively providing a "glide path" for facilitating retrofit programs. For example, transit bus fleets in New York City and in the State of New Jersey are completely fueled by ULSD, while the Department of Sanitation of New York is in the process of converting all its depots to ULSD, a process that is scheduled to be completed by late summer 2003. These fleets either have existing retrofit programs, or are slated for programs in the near future.

Finally, Federal regulation for both the on-highway and (proposed) nonroad sectors will have a ULSD requirement to enable low emissions technology for these vehicles. This translates into a nearly all low-sulfur diesel fuel supply, starting in July of 2006.

ULSD "At A Glance"

Benefits	Drawbacks
1. Enabler for advanced PM and NOx aftertreatment technologies. 2. Some PM Reductions.	1. Incremental cost differential (over current sulfur-level diesel fuel). 2. Reduced lubricity. 3. Potential for contamination with higher sulfur fuels (until mandated ULSD takes effect).

II) Water Emulsions (Emulsified Diesel Fuel)

Water emulsions, frequently termed "emulsified diesel fuel", hold considerable promise as a cost-effective strategy for reducing PM and NOx emissions. This option is very user-friendly, in that it involves only "normal" vehicle fill up; no engine modification is required. Furthermore, a commercial supplier in the region distributes a brand of emulsion that is currently undergoing EPA verification through their ETV program and has completed verification for California use under the ARB retrofit program. This product, developed by Lubrizol and blended and marketed by Sun Oil Company under the brand name "PuriNOx", has been verified in the ARB

"Alternative Diesel Fuels Verification Program"[9] to provide, on average, NOx and PM emission reductions of 14 and 63 percent, respectively, for on-highway vehicles, with an emulsion formulation containing 20 percent water content.

Emulsions reduce combustion temperature in the engine cylinder, which lowers NOx emissions. Additionally, the emulsion "leans out" the initial stages of diesel combustion, thereby reducing the amount of soot formed, resulting in the rather impressive PM reductions. The ability to reduce both NOx and PM emissions, coupled with the relatively low cost and ease of implementation, make emulsions a very promising and currently available in-use emission control option.

States in the region are developing proposals for emulsion-based retrofit initiatives. Much of the initial work will focus on dispelling the fears of deleterious effects on the engine associated with earlier emulsion formulations. These issues, which include excessive engine wear, engine power loss and settling of the emulsion in the fuel, have been largely solved. States should be encouraged by these technical developments and actively consider encouraging the use of emulsified diesel in pilot applications.

Emulsions "At A Glance"

Benefits	Drawbacks
1. Significant NOx and PM reductions. 2. No major engine modifications required. 3. No new fuel infrastructure required, such as that required for urea or CNG. 4. No apparent increase in other emissions.	1. Incremental cost differential. 2. Potential engine durability issues with older (pre-1994) engines (corrosion). 3. Fuel stability ("even mix" of water emulsion and base diesel). 4. Reduced engine power ≈ 5 – 10% with a 20% emulsion. 5. Reduced fuel economy.

iii) Biodiesel

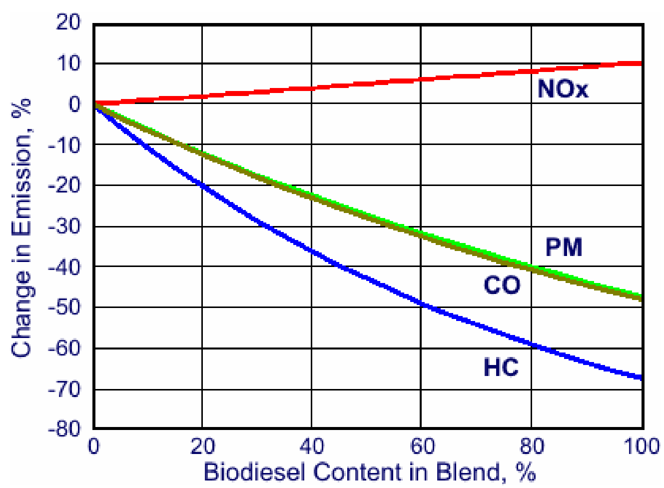
There has been increasing interest in recent years in the use of biodiesel as a substitute for petroleum-based diesel, both for emissions reduction and energy security purposes. Biodiesel fuels may be produced from many types of feedstocks including soybeans, rapeseeds, canola oil, grease, tallow and lard (yellow oil). A common concentration for mixing biodiesel with conventional diesel is in a 20 percent to 80 percent solution ("B20"). shown in the table below, EPA statistically determined that PM, HC and CO emissions decrease and NOx emissions increase slightly with B20 mixtures, when compared with conventional diesel:[10]

[9] http://www.arb.ca.gov/fuels/diesel/diesel.htm
[10] EPA Draft Technical Report, "A Comprehensive Analysis of Biodiesel Impacts on Exhaust Emissions", *EPA-420-P-02-001, October 2002.*

"B20" Biodiesel Emissions

Constituent	Percent change in emissions
NOx	+2.0%
PM	-10.1%
HC	-21.2%
CO	-11.0%

As biodiesel concentrations increase, PM, CO and HC emissions tend to further decline, but at the expense of NOx emissions. Reductions in excess of 45 percent are possible with B100, but with a potential NOx increase of nearly 10 percent, care must be taken in considering 100 percent biodiesel (B100) for retrofit applications. Further, there are adverse operational issues associated with the use of B100 that should be carefully evaluated when considering emission control options. While the exact cause for the NOx increase associated with the use of biodiesel is not understood, it is postulated that the higher oxygen content in biodiesel causes increased oxidation of nitrogen during the combustion process, thereby increasing NOx:



Biodiesel "At A Glance" (B20 compared to #2 diesel)

Benefits	Drawbacks
1. PM, HC and CO emission reductions. 2. CO_2 lifecycle emissions reductions can be over 70% (renewable fuel). 3. Lower aromatics (lower PAHs). 4. Lower sulfur content 5. Renewable fuel. 6. Biodegradable. 7. Better lubricity.	1. NOx "disbenefit". 2. CO_2 tailpipe increase (exact value dependent upon many factors). 3. More corrosive. 4. Higher freezing temperature – cold weather operational issues. 5. Reduced engine power – ≈ 2%. 6. Reduced fuel economy – ≈ 10%.

4. RETROFITS IN THE NORTHEAST U.S. AND EASTERN CANADA – OVERVIEW OF ALL PROGRAMS

Clean diesel retrofit projects have been underway in the Northeast for a number of years and a growing number of programs are being introduced and considered within the region. These programs are summarized in the following table. Details on key specific programs of interest are outlined in the pages following the table:

NORTHEAST STATES AND EASTERN CANADIAN PROVINCES RETROFIT PROJECTS "AT A GLANCE"

COMPLETED OR CURRENT

Shaded Projects Represent Retrofit "Success Stories" – See Text Description

PROJECT NAME	DATES	LOCATION(S)	VEHICLE TYPE	ULSD?	RETROFIT TYPE	EMISS TEST?	PROJ COST	FUNDING SOURCE	STATUS
New England Power	1997 – 1998	Salem (Harbor), MA	Nonroad construction	No	FBC[11], DOC, passive DPF, active DPF	Yes – EPA, Env Can[12]& ROVER	$70K + in kind	NE Power; EPA	Completed
Central Artery ("Big Dig")	1998 – 2002	Boston	Nonroad construction	No	100 DOCs	No	$150K	MA Highway Cmsn; construction contractors	Completed
7 WTC[13]	4Q'01 – June '03	NYC	Nonroad construction	Yes	3 DOCs; 6 more planned	Yes – CATI[14]	$500K	CAC[15] ($300 K of funding)	Completion, 3Q '03
Mack Truck SEP – SCR Component	1999 – 2004	1. NYC (for DSNY[16]) 2. UPS, Stratford, CT	Refuse trucks & Class 8 long-haul trucks	Yes	1. DSNY – 2 SCR 2. UPS – 8 SCR 3. 3 SCR/DPF combo	Yes – 3 vehicles, WVU[17]	$1.41M	Mack (SEP)	Completion, summer '04
Mack Truck SEP – DOC/DPF Component		1. DSNY, NYC 2. Waste Management, 6 NE sites 3. UPS Stratford, CT	Refuse trucks	DSNY – Yes WM -- No	1. 30 DPF at DSNY 2. DSNY – 45 DOCs 3. WM – 105 DOCs	DOC – No DPF – Yes, 3 vehicles @ WVU	$1.31M	Mack (SEP)	DOC – Completed, spring '03; DPF -- Completion, summer '04
Norwich School Bus (CT DEP)	1Q'02 – 3Q'03	Norwich, CT	School buses	Yes	33 DOCs; 9 DPFs	Yes, Env Can	$250K	SEP from CT-based violator (metallurgical Co.); CT DEP	Completion, fall '03
Cummins SEP (DSNY)	4Q '00 – 2004	NYC	Refuse Trucks; CNG Street Sweepers	Yes	1. 70 DPFs 2. 4 CNG Street Sweepers	Yes – WVU	$3.15M	Cummins (SEP)	Completion, 2004

11 FBC = "Fuel Borne Catalyst"
12 Env Can = Environment Canada's portable emissions testing system, "DOES2"
13 WTC = "World Trade Center"
14 CATI = "Clean Air Technologies, Inc."
15 CAC = "Clean Air Communities" (NESCAF)
16 DSNY = "Department of Sanitation New York"
17 WVU = "West Virginia University"

NORTHEAST STATES AND EASTERN CANADIAN PROVINCES RETROFIT PROJECTS "AT A GLANCE"

COMPLETED OR CURRENT (continued)

Shaded Projects Represent Retrofit "Success Stories" – See Text Description

PROJECT NAME	DATES	LOCATION(S)	VEHICLE TYPE	ULSD?	RETROFIT TYPE	EMISS TEST?	PROJ COST	FUNDING SOURCE	STATUS
UPROSE[18] — Clem's Snacks	Feb '03 – June '03	NYC	Delivery trucks ("step vans")	No	DOC	Yes – CATI	$125K	CAC	Completion, June '03
CT DOT Retrofit Program	2001 – present	New Haven, CT	Nonroad	No	24 DOCs	NO	??	??	??
NY MTA[19] Transit Bus Pilot Program – CNG v Diesel		NYC	Transit Buses[20]	Yes	1. Diesel – DPF 2. CNG - none	Yes – Env Cdn	N/A	NYSERDA[21]	Completed
NY MTA "Clean Diesel Demonstration Program"		NYC	Transit Buses[22]	Yes	DPF	Yes – engine and chassis dyno	$2.1M		
Montreal "Biobus" Project	Mar.'02 – Mar.'03	Montreal, Canada	Transit Buses	??	Biodiesel, variety of concentrations and base feed stocks	Yes – Env Can	$1.31M Cdn ≈ $890K US	Canadian Fed Govn't; Quebec Provincial Govn't; Montreal Transit; corporate funding	Completion, Mar.'03; report to follow
Toronto Hydro Biodiesel Project	Pilot, XXX – Sept '01	Toronto	On-highway and nonroad		Biodiesel				
NJ "Executive Order" Retrofit									
MA MBTA Retrofit Program		Boston	Transit Buses	Yes	900 DPFs				

[18] UPROSE = "United Puerto Ricans of Sunset Park"
[19] NY MTA = "New York (City) Mass Transit Authority"
[20] Three DDC series 50 CNG engines; two DDC Series 50 diesel engines w/DPF
[21] NYSERDA = "New York State Energy Research and Development Authority"
[22] DDC Series 50 4-stroke & DDC 6V92 2-stroke engines

5. RETROFITS IN THE NORTHEAST U.S. AND EASTERN CANADA – SUCCESS STORIES

a) Norwich School Bus

i) Overview

There is growing concern over issues of children's health and exposure to emissions from diesel-powered school buses. As noted earlier, exhaust from diesel engines is a significant contributor to air pollution and has been classified as a probable human carcinogen by EPA and a Toxic Air Contaminant by ARB. In addition to the two key criteria emissions of PM and NOx, diesel exhaust also contains 40 other known carcinogens including benzene, 1-3 butadiene, formaldehyde, and acrolein**.** While these toxic components are not yet explicitly regulated by EPA or ARB, overall reduction of the gaseous and PM components of diesel exhaust, through regulation of new vehicles and the retrofitting of existing vehicles, will help reduce these toxic emissions.

In Connecticut nearly 387,000 children ride 6,100 school buses each day. Of those 6,100 buses, 99% are diesel fueled. The amount of time a child spends on the bus every day varies from 20 minutes to several hours per day. Collectively, Connecticut children spend 50 million hours on buses each year. The health issues associated with diesel exhaust are exacerbated with children and Connecticut has made the reduction of diesel emissions in school buses a priority.

The Norwich School Bus project emanated from a settlement between a Connecticut-based industrial manufacturer and the Connecticut Department of Environmental Protection (CT DEP). A provision of the resultant Consent Decree was a Supplemental Environmental Project (SEP) designed to provide near-term emissions reduction benefits. Norwich, CT was selected since the violator was located in that municipality and one of the project goals was to provide a corresponding environmental benefit in the community where the violation occurred. Beginning in January 2002, CT DEP partnered with the City of Norwich, Norwich Public Schools, NESCAUM, First Student Inc., other state and local agencies, and the Mohegan Tribal Nation to develop and implement a diesel technology demonstration project. This project takes a multi-faceted approach to reducing diesel emissions from school buses by incorporating several strategies aimed at reducing diesel emissions. These include adoption of an anti-idling policy, an extensive education and outreach component, and the implementation of school bus retrofits with the use of ULSD.

In order to reduce emissions, maximize the available resources while providing an emissions reduction benefit to each child, and gain experience with different retrofit technologies, the decision was made to utilize both DOCs and DPFs. Thirty-three school buses were fitted with DOCs and nine with DPFs, and the entire fleet has been operating on ultra-low sulfur diesel (ULSD) since September of 2002. This project has involved a number of stakeholders and has proven to be one of the most successful programs of its type in the U.S. The Project started in early 2002 and will be completed by the end of 2003.

ii) Project Details

The primary project goal is to reduce PM emissions from the Norwich school bus fleet to the greatest extent possible, given available resources. In addition to the retrofit installation itself, a number of additional components stand out, making this program a model for future retrofit endeavors. First, an in-cabin assessment of pollution concentrations, before and after installation of the retrofit devices, is being performed to assess the program's effectiveness in reducing student exposure to diesel exhaust. Second, tailpipe emission testing, using Environment Canada's "DOES2" portable emissions measurement system, is being conducted to measure gaseous emissions and PM. Finally, an extensive outreach and educational program is included, to increase public awareness of the harmful impact of diesel school bus emissions and the effectiveness of properly designed retrofit programs.

Project partners, in greater detail, include the Connecticut Department of Environmental Protection (CT DEP) for project oversight; NESCAUM for project development and management; the Connecticut Department of Motor Vehicles (CT DMV) for bus safety; First Student, supplying the fleet vehicles and in-kind mechanical support; and the Norwich Public Schools. The Norwich Public Utilities, US EPA Region I, Manufacturers of Emissions Controls Association (MECA) members and the Mohegan Tribe are also contributing in-kind technical and outreach activities. The Connecticut-based industrial manufacturer that was cited in the Settlement, provided the $250,000 for the SEP as part of that settlement.

iii) Results

As mentioned earlier, this program serves as a model for the development and implementation of school bus retrofit programs. In addition to the novel components of the project, outlined above, its success has depended upon the effective cooperation of all participants. Extremely close interaction was required and continues to be required as the program nears completion. From the complicated logistics in arranging the ULSD fuel supply, to the commitment by participants to develop the educational and outreach components, this program, above all else, is demonstrating the success that can be achieved when partnerships are developed and promoted.

iv) Future Considerations

The growing concern about the impact of environmental exposures to diesel school bus emissions on children's health, as well as increased sources of funding, will likely result in an increase in the number of school bus retrofit programs. The Norwich project serves as a model for future efforts. With thoughtful planning, the coalescing of appropriate partners, and careful implementation and follow-up, effective tailpipe emissions reductions and public health benefits can be achieved in a timely and cost-effective manner.

A number of future mitigating factors suggest a bright future for school bus retrofits. First, the U.S. Federal government is allocating significant funding for this type of program. Second, ULSD is slowly finding its way in U.S. and Canadian diesel market. With Canadian and U.S. mandates starting in 2006, the logistics and associated costs of providing ULSD will disappear. Third, original equipment manufacturers are beginning to produce and market "green" school buses and, over time, the fleet should include greater numbers of cleaner school buses. It is not inconceivable, for example, that the educational and outreach programs from this project will engender interest – perhaps insistence – from parents and school administrators for the clean-up of existing buses and the purchase of clean diesel buses in the future. Finally, the cost of future school bus retrofit projects should decline with the increased production and standardization of retrofit hardware and the growing market for USLD. Further, the need for emission testing and fleet vehicle operational assessments will not necessarily be needed for future projects since this data is being gathered as part of early pilot efforts, such as those described in this paper.

b) Mack SEP – DOC Retrofit of WM and DSNY Fleets

i) Overview

Like the Norwich School Bus project, the Mack retrofit project emanated from a US Department of Justice settlement, in this case with Mack Trucks. A requirement of the Mack Consent Decree, which is mirrored by six other CDs between the major heavy-duty engine manufacturers and the US DOJ, is to provide near-term emissions reduction benefits.

Many of the SEPs, including this one with Mack, involve the installation of retrofit devices to garner emission reductions from existing fleets of trucks, transit buses and school buses.[23] In 1999, NESCAUM partnered with Mack Trucks to fulfill this portion of the SEP through the installation of 150 diesel oxidation catalysts (DOCs).

The decision to install DOCs was predicated on the desire to reduce emissions from a large number of vehicles, while minimizing other requirements – such as the use of ULSD – associated with other retrofit options. With DOCs on average reducing PM by 20 percent, reductions across the participating fleet are projected to be in excess of 1000 lb./year.

This retrofit program targeted refuse collection trucks from both urban and suburban fleets. Refuse fleets are considered a good application of retrofit technology since they tend to operate in a “stop and go” mode that results in high per mile emissions and are used in heavily populated areas. The Department of Sanitation New York (DSNY) provided the urban fleet and Waste Management (WM) provided the suburban refuse trucks. DSNY fleets included vehicles operating in the boroughs of Manhattan and the Bronx. Waste Management fleets encompassed vehicles from six New England municipalities spanning four states.[24] Funding for this project was provided by Mack Trucks as part of the settlement agreement.

All of the DOCs have been installed and their performance has been transparent to both the vehicle operator as well as fleet maintenance and operations personnel. To date, no drivability degradation or excessive maintenance issues have been reported. Assuming they continue to operate effectively, the DOCs will remain on the DSNY and Waste Management fleets for the life of the vehicles.

ii) Project Details

This portion of the Mack Retrofit Project involved installation of 150 DOCs onto Mack refuse trucks. Engelhard Corporation, a major manufacturer of aftertreatment products including

[23] SEP retrofit programs are not limited to on-highway vehicles; the nonroad sector is a very viable candidate for retrofits, as some of these projects in the Northeast attest.
[24] Cranston, RI; Portland, ME; Londonderry and Rochester, NH; Somerville and Woburn, MA.

DOCs and DPFs, was the vendor supplier for the DOCs used in this project. Other project partners, in addition to NESCAUM and Mack Trucks, included:

- Donaldson Company – Manufacturers of exhaust systems, this vendor was responsible for "canning" the DOCs and for providing specialty exhaust piping as needed.

- DSNY and Waste Management – These were the two fleets that generously provided not only their vehicles, but a significant portion of "in-kind" mechanical support.

As mentioned earlier in describing characteristics of DOCs, it was necessary to modify the existing muffler brackets for one of the model Mack trucks, the "MR", to accommodate the extra weight of the DOC (the muffler brackets for the other model Mack Truck used in the project, the "LE", has sufficiently robust brackets, precluding the need for redesign). Mack undertook a rigorous design program to develop these unique brackets. Out of this effort emerged an "installation package" compete with the brackets, clamps, modified exhaust piping, and installation instructions. This effort in developing a "mini production line", to allow Mack dealers to easily install the DOCs, proved invaluable for the comparatively large numbers of units – 150 – that were installed as part of the project. Once these kits were provided, installation of the DOCs was performed by the maintenance crews at DSNY and WM, and also by local Mack dealers.

iii) Results

While actual emissions testing – either in-use with some portable emissions analyzer, or on some type of dynamometer – was not performed as part of the program, a number of factors have provided the project participants, as well as EPA, with a high level of confidence that this retrofit program was a success. First, DOC performance has been established though the rigorous verification programs, describer earlier in this Status Report. Second, DOC deterioration from continuous operation, thermal cycling or use with higher sulfur (300 ppm) fuels is minimal, ensuring consistent performance with corresponding emissions benefits, throughout the life of the DOC and the vehicle in which it is installed. Finally, the transparency with which the DOC performs, without imposing operational burdens, ensures that vehicle drivers or fleet operators will not be inclined to remove them.

iv) Future Considerations

While DOCs, on a per unit basis, are a less effective retrofit option than DPFs, their comparatively easy installation, integration into the operating characteristics of the vehicle, and lack of a ULSD requirement, make them a very attractive retrofit option. Add in their significantly lower cost, and the use of DOCs becomes very attractive. In the longer-term, it is likely that retrofit options such as DPFs will predominate as ULSD becomes more widely available in the U.S. and Canadian markets. But for the shorter term, for fleets that are reasonably large, yet have little or no access to ULSD, the DOC will remain in the suite of retrofit options for the Northeast states and Eastern Canadian provinces.

c) Montreal Biobus Project

i) Overview

In March of 2002, the City of Montreal launched a program to replace the standard diesel fuel in 155 of its downtown urban transit buses with biodiesel. Canada is in agreement with the provisions of the Kyoto protocol, and is seeking methods to reduce greenhouse gas emissions. Biodiesel, mixed in specific concentrations with a diesel fuel "base", has proven to reduce a number of key criteria pollutants including PM, HC and CO. Additionally, the renewable nature of this fuel results in significant CO_2 lifecycle reductions – up to 70 percent for B100 . From the technical discussion outlined earlier in this Status Report, it is clear that biodiesel's benefits in reducing PM, HC, CO and CO_2 emissions well outweigh any drawbacks associated with slightly Incremental cost differential elevated NOx emissions. Furthermore, implementation without any engine or infrastructure disruptions makes this technology a viable candidate for in-use emission reduction projects.

The Montreal Biobus Project involves refueling 155 transit buses with two formulations of biodiesel – B5 which represents a 5 percent concentration and B20, a 20 percent concentration. The operation of this fleet will be evaluated over the course of a year, followed by comprehensive engine emissions testing at Environment Canada's laboratories in Ottawa. The base diesel fuel stock for the biodiesel blends used in this program contains 150 ppm sulfur or less.

ii) Project Details

The primary goal of this project is to reduce CO_2 emissions as well as certain criteria pollutants with which biodiesel is effective – PM, HC and CO. CO_2 reductions with this program are estimated at 1,800 tons per year; fueling the entire 1,600 Montreal transit bus fleet would yield a 19,350 ton reduction. Additional project goals include proving the feasibility of fueling a significantly sized fleet with an alternative fuel; investigating biodiesel's operational characteristics under cold weather conditions; assessing the economic impacts of biodiesel as an alternative fuels source; and characterizing this particular type of biodiesel fuel which is made from agro-industry waste[25], rather than the more common vegetable oil-based blends.

The bus fleet selected for this large-scale pilot program is from the Societe de Transport de Montreal (STM), specifically the Frontenac Terminal which serves the airport and downtown area of the city. The buses are powered by Cummins ISC 8.3 litre engines in both mechanical and electronic controlled configurations[26]. Because biodiesel use has a comparatively small effect upon engine power loss or fuel economy, the STM did not recalibrate or otherwise modify these engines with the biodiesel use.

The total budget for this program is $1.31M Canadian.[27] STM is contributing $370M including the transit bus fleet and fueling infrastructure; the Government of Canada which has established a partnership of other agencies including Natural Resources Canada, Environment Canada, Canada Economic Development and the Climate Change Action Fund to support the effort, $515M; Government of Quebec, $375M; the Rothsay/Laurenco (Maple Leaf Foods) Group who will supply the "straight" (unblended) biodiesel, $37,500; and the Canadian Renewable Fuels Association, $10,000.

The biodiesel blends utilized in the program consist of B5 biodiesel – a 5 percent concentration of biodiesel and a 95 percent concentration of petroleum-based diesel – and B20, with a 20

[25] Non-food-grade vegetable oil, recycled cooking oil and animal fat.
[26] Mechanical and electronic controls are primarily on the engine's fuel injection equipment (FIE). Electronic controls provide the capability to constantly alter the rate that fuel is injected into the engine, in order to optimize for higher power, increase fuel economy or reduce emissions.
[27] About $890M, US.

percent concentration. Then, within these two concentrations, the biodiesel blends were further subdivided, based upon one of three feedstocks – recycled cooking oil, vegetable stock or animal fat.

A key component of the testing portion of the program was a parametric study of the six different biodiesel fuel types and blends that were used in the program. Testing was performed with each fuel type to understand the effect of each unique formulation upon the exhaust emissions of the buses.

The emissions testing for this parametric study was performed with the bus engine removed from the vehicle and installed on an engine dynamometer. This is a different technique from installing the entire bus on a chassis dynamometer. Both techniques have considerable merit and have been used for a number of years to characterize engine exhaust emissions. The selection of the engine dynamometer approach was predicated upon a need to quickly perform the large number of transient tests needed to complete the fuels characterization study. Engines were operated over the US FTP transient test cycle, which is a benchmark exhaust emissions test procedure developed by the USEPA and is the official test cycle required for heavy-duty diesel engine certification in both the US and in Canada.

Emission testing was completed in early spring at the Environment Canada Environmental Technology Centre on two of the ISC Cummins diesel bus engines, one with mechanical controls and the other with electronic controls. In addition to criteria emissions (gaseous and PM), a full complement of speciation analysis was conducted to determine toxics concentrations. Preliminary evaluation of emission test results for criteria pollutants has been completed and is reported below. Analysis of toxics emissions is in process, with a full final report encompassing all emissions testing, due by late summer.

iii) Results

As reflected in the table, below, biodiesel plays a significant role with significant PM reductions. Surprisingly, NOx was comparatively unaffected by biodiesel use – if anything, NOx *reductions* were observed – allaying fears of a NOx "disbenefit" with biodiesel use. Finally, concerns that the lower heating value of biodiesel fuel would result in engine power loss, appear to be unfounded, with minimal loss in maximum engine power experienced from the vehicles participating in this program.

Exhaust Emissions and Engine Power Characteristics Using Biodiesel
(*preliminary* results)

Std Fuel	B 5			B20		
<500 ppm sulfur	Recycled Oil	Vegetable Oil	Animal Fat	Recycled Oil	Vegetable Oil	Animal Fat
Engine power						
TPM[28], Mechanical Engine	-7.6			-21.5	-23	
TPM, Electronic Engine	-5.8	-2.8	-5.2	-15	-14	+2.7
NOx, Mechanical Engine	-0.3			+0.3	+1.1	
NOx, Electronic Engine	-2.0	-0.5	-3.6			-2.9
Results in % Relative to Standard Diesel Fuel Baseline Negative Values Represent Reductions; Positive Values, Increases; Blank Spaces, Data Not Yet Available						

iv) Future Considerations

A comprehensive exhaust emissions analysis is underway encompassing the following: more detailed, final results of all criteria pollutants (NOx, TPM, CO, CO_2 and HC); PM speciation to analyze PM components ($PM_{2.5}$, PM_{10}, SOF, etc.); toxics analysis; and fuel consumption characterization using carbon balance techniques. All these results will be included in the Final Report, which will also document the program, itself – triumphs, lessons learned, and recommendations for future work. Preliminary reports from bus operators, maintenance personnel and others at STM indicate no adverse operation using biodiesel. There is no noticeable power loss, nor any compromises in engine durability. Based upon these observations and the very favorable emissions results, expansion of biodiesel use into other depots within the STM fleet will be seriously considered.

6. Anti-Idling

a) Overview

While pilot retrofit programs have increased in recent years in the Northeast States and Eastern Canadian Provinces, there exist significant challenges hampering their more widespread application, which is necessary to achieve significant diesel emission reductions from the vast numbers of older vehicles that continue to populate the commercial diesel fleet. There are technological hurdles in selecting, matching and often calibrating the most appropriate retrofit technology for a specific fleet application; distribution challenges in providing ultra-low sulfur diesel fuel which is an enabler for the most effective technologies; cost issues associated with many retrofit technologies; fleet owner/operator concerns regarding retrofit impacts upon engine durability, warranty and performance; and the absence to-date, of a fully commercialized retrofit technology capable of significantly reducing NOx emissions.[29] Within this context,

[28] TPM = “Total Particulate Matter”. $PM_{2.5}$ and PM_{10} were analyzed, as well, with results to be included in the late summer Final Report.
[29] As described earlier, Selective Catalyst Reduction (SCR) and water-based fuel emulsions show considerable promise, but neither is in widespread use, and long-term performance and durability issues have yet to be fully explored.

environmental stakeholders have been seeking other avenues to try and reduce emissions from the existing diesel fleet. One of these approaches includes idling restrictions.

Historically, it is quite common to see diesel engines idling for protracted periods of time. Line-haul, Class 8 truck operators idle their engines when parked at rest stops for mandatory rest periods[30]; school bus drivers (as well as urban transit bus drivers) habitually leave their buses idling when picking up and dropping off children during the course of their routes; mid-size delivery vehicles (typically Class 4 through 7 trucks) idle their engines during the delivery of goods even when loading/unloading aids, such as hydraulic lifts, are not being operated. And while many truck and bus operators maintain that idling is necessary, perhaps even beneficial for prolonged engine life, most idling circumstances are totally unnecessary and have been shown to demonstratively increase diesel exhaust emissions.

Many states, not only in the Northeast but throughout the United States, have recognized the benefits of reducing unnecessary idling. While emission reduction of criteria pollutants is paramount, other critical benefits of minimizing unnecessary idling include reducing fuel consumption, prolonging engine life, lowering engine maintenance costs, minimizing adverse health effects from the toxic components of diesel exhaust and diminishing noise pollution.[31] This section of this Status Report briefly explores the idling issue from both a user/driver perspective and an emissions perspective, provides a snapshot of anti-idling programs in the Northeast, and offers alternatives to excessive idling.

b) Idling Issues

i) User Perspective

While many idling scenarios are unnecessary and needlessly contribute to excess emissions – school and urban bus idling during temperate weather conditions, and delivery vehicle idling during pick-up and delivery, for example – many situations do require some sort of power source, usually for electrical supply of heating. Typically power is provided from an idling engine. For example, heavy-duty line haul trucks parked at truck stops need vehicle power for cabin heating or air-conditioning, school buses operating in inclement weather conditions need cabin heating for the health of the transported children, emergency vehicles need continuous power in order for personnel to perform their duties, delivery vehicles may need power to activate hydraulic assist devices for loading and unloading of goods, and cold storage over-the-road trailers need electrical power to operate refrigeration units to maintain proper chilled temperatures.

Unfortunately, there exists considerable misunderstanding in differentiating between these legitimate power needs, and from unnecessary, wasteful and harmful excessive idling. It is a fallacy, for example, that continued idling of diesel engines promotes enhanced engine performance or prolongs engine life. Diesel engines are remarkably robust devices – that so many older units are in continuous widespread use has prompted retrofit interest in the first place. They are designed to be shut down and restarted innumerable times, and will not somehow magically become more durable by endlessly running them under idle. Engine wear

[30] The US Department of Transportation (US DOT) mandates eight hours of rest time for every maximum period of ten hours of driving.

[31] Environmental Justice neighborhoods, where large chain supermarket retail stores and distribution centers are frequently located, may especially benefit from diminished noise resulting from idling restrictions imposed upon supermarket delivery trucks.

is a function of *total operating hours* and the more an engine operates, regardless of the speed or load, the sooner metal components fatigue, bearing coatings wear out, injector nozzles erode, cylinders liners become “scored” and so on – the engine generally wears out sooner.

On the other hand, there may be instances where idling an engine may prove to be the more expedient choice. For example, shutting down an engine only to restart it within a comparatively short timeframe may produce more emissions and waste more fuel during the restarting process, than simply idling the engine for this period of time in the first place. Most state anti-idling programs account for this characteristic by allowing for maximum idling periods, usually of three to five minutes.

ii) Emissions Perspective

While fuel consumption, engine life, noise pollution etc, are key ingredients in the idling stew, diesel exhaust emissions remain paramount, and it is incumbent upon those promulgating anti-idling regulations to try and better understand idling emissions characteristics. Towards this end, EPA’s Office of Transportation and Air Quality (OTAQ), has released a reasonably comprehensive study that not only characterizes engine emissions from idling diesel trucks but compared these emissions to those from auxiliary power units (APUs) and diesel fired heaters (DFHs), to determine if APUs and DFHs truly offer a lower emissions alternative to an idling truck.[32] As described in further detail below (see “The Solution – Idling Alternatives”), APUs provide electrical power for a number of truck accessories including heating and air-conditioning, while DFHs heat truck cabs in cold weather conditions. APUs and DFHs offer two solutions for line-haul trucks that are required to sit at rest stops for eight hours with the driver sleeping/resting on-board, providing they deliver lower emissions than idling truck itself for eight hours.

Engine emissions results from the study provided rather startling values for the amounts of emissions from idling heavy-duty trucks.[33] On average, a single idling Class 8, heavy-duty, over-the-road, line-haul truck emits 144g/hr of NOx, 8224 g/hr CO_2 and consumes 0.82 gal/hour of diesel fuel. The study uses these values from actual tests to predict emissions in the US from idling trucks. While detailed records of fleet idling characteristics for the US are sketchy, nevertheless, by making a few rather conservative assumptions regarding fleet size and daily idling time at truck rest stops, the resultant tons per year of emissions fro idling are compelling: 190,000 tons NOx, 10.9 million tons CO_2 and 960 million gallons of diesel fuel.[34] By estimating the heavy-duty truck fleet for New England and for Eastern Canada, idling emissions can be quantified for these regions, as well.

Even from this limited study (further investigations are underway), it is clear that anti-idling initiatives will provide emissions reductions, not only from the heavy-duty line-haul truck sector, but from school buses, delivery trucks and other diesel-powered sources.

[32] “Study of Exhaust Emissions from Idling Heavy-Duty Diesel Trucks and Commercially Available Idle-Reducing Devices”, *USEPA Technical Report No. EPA-420-R-02-025, October, 2002.*
[33] For the study, the focus was on fuel consumption, NOx and CO_2, though particulate matter (PM) data was taken and will be published later this year.
[34] Assumptions: national truck fleet estimate of 500,000 trucks; trucks idle 8 hours per day, 300 days per year while consuming 0.8 gallons of diesel fuel per hour.

c) States' Programs

Because of the misconceptions surrounding idling, many state initiatives, whether mandatory or optional (sometimes with incentives), incorporate educational components to dispel the types of myths illustrated above. Similarly, while anti-idling initiatives are significantly more cost-effective than the implementation of retrofit technology as an emission reduction approach, idling changes are in and of themselves behavioral changes, and behavior modification may prove as challenging, albeit for different reasons, as the technical challenges of retrofits. Nevertheless, a number of states in the Northeast report considerable success with anti-idling initiatives through education, rather than enforcement, especially for school bus drivers. As of June, 2003, Connecticut, Massachusetts and New Hampshire have anti-idling regulations, while Maine, Rhode Island and Vermont do not. Extending beyond the New England area, New Jersey, New York and Maryland also have anti-idling regulations. A synopsis of anti-idling regulations is shown below:

State	Idling Limit	Applicability	Exemptions Allowed?	Is There Enforcement?	Are There Penalties?
CT	3 mins	Autos, Buses, Trucks, Nonroad Equipment	Yes	Yes	Yes
MA	5 mins, 30 for diesel locomotives	All on-highway vehicles and locomotives	Yes	Yes	Yes
NH	5 mins; 15 mins for temps below 32^{o}F	All heavy-duty on-highway vehicles	Yes		Yes, but rarely enforced
NJ	3 mins, other specialty provisions	All on-highway vehicles	Yes	Yes	Yes, with enforcement
NY City	5 mins	All on-highway vehicles	Yes	Yes	Yes, with enforcement
NY State	5 mins	All heavy-duty on-highway vehicles	Yes	Yes	Yes, with enforcement
MD	5 mins	All on-highway vehicles	Yes	Yes	Yes, but rarely enforced

ME, RI and VT have no anti-idling regulations

Anti-idling regulations for these states have a number of common elements. They all allow a maximum allowable idling time limit, all define on-highway vehicles to include diesel-powered trucks, schools buses and urban transit buses, all provide for specific, similar exemptions, all have some form of enforcement authority though the enforcement agency may differ, and all mandate civil penalties for non-compliance. Unfortunately, enforcement and levying of penalties is a recurring problem for all those states that have promulgated idling regulations. Resource limitations, lack of familiarity with the law by some agencies responsible for enforcement, perceptions that enforcement of idling restrictions is not a major issue when compared to criminal acts, and so on, have conspired to make idling regulation enforcement a challenge for the Northeast States. In contrast, success in *empowering* drivers to reduce idling, as in a number of cases with school bus drivers, appears to be the most effective approach to a successful idle reduction program.

d) Eastern Canadian Programs

In Montreal, an anti-idling regulation has been in place for approximately 20 years. Originally developed as a response to nuisance complaints from emissions from idling trucks and tour buses, it restricts idling time to 4 minutes within 60 meters of a building opening (e.g. doorway, window) or air intake, on the island of Montreal.

Anti-idling policies on school property are being implemented in New Brunswick. Anti-idling initiatives were first piloted at one school in New Brunswick through the New Brunswick Lung Association's Healthy School Program. The pilot was run during the winter of 2002 and confirmed that school bus engine performance and safety features were not diminished when the bus engines were shut-off. As a result, the Department of Education in New Brunswick has recommended to all School Districts within the province that they develop anti-idling policies on school grounds. A number of School Districts in the province have adopted or are planning to implement anti-idling policies. These policies are intended to reduce school bus arrival time to 5 minutes before school is dismissed and to encourage the shutting off of bus engines and other vehicles while on school property in all but extreme weather conditions.

e) The Solution – Idling Alternatives

i) Auxiliary Power Units and Diesel Fired Heaters (APUs and DFHs)

The EPA study characterizing exhaust emissions from idling heavy-duty diesel trucks, referenced above, also investigated potential emissions reductions from APUs and DFHs, when used as a replacement power source for the idling heavy-duty diesel engine. In trying to quantify potential NOx, CO_2 and fuel economy reductions, the study replicated three "real world" operational scenarios: operation of the of the APU to provide assessory power and cabin heating, operation of the APU for truck power and air-conditioning, and operation of a DPH for truck heating alone. Emissions from the APU and DPH under these three scenarios were significantly less than the alternative of idling a Class 8, heavy-duty truck to provide these same power requirements:

Pony Pack APU

Percent *Reductions* Using APU and DPH

Power Unit	Providing…	Fuel Consumption	NOx	CO_2
DPH	Cab Heating	94-95%	99%	94-96%
APU	Assessory Power & Heating	71-81%	94-96%	71-81%
APU	Assessory Power & AC	52-80%	89-94%	52-80%

These are commercially available, well-proven units that offer considerable emissions and fuel-economy benefits, without compromising driver comfort or safety at truck rest stops.

ii) Truck Stop Electrification

An alternative to on-board devices in the truck, such as the APU and DFH, centers around electrification of the truck stop itself. Through installation of a commercially available device that attaches to the passenger window of the truck, all in-cabin functions, as well as other "luxury" functions, such as internet access, can be made available. Companies such as IdleAire have developed these devices and have successfully demonstrated their viability through a number of pilot programs in the Northeast, including truck stops at Hunt's Point, and Syracuse, New York.

IdleAire Module (attaches to truck passenger side window)

A key issue in adjudging this type of device as a viable alternative to the idling truck, is electrical power consumption. It must be shown that a device such as that from IdleAire, for example, will consume substantially less energy and emissions, due to the electrical energy made by the power plant supplying the electrical power to the device, than the energy and emissions from idling a truck. Towards this end, IdleAire and NESCAUM developed an analytical study estimating power plant energy to power the IdleAire device. As with the APU and DPH devices, the IdleAire system reduced energy consumption and emissions in significant levels to qualify it as a meaningful alternative to the idling diesel truck:

Emissions Reductions Achievable Through Truck Stop Electrification (Percent)

Type	NO_X	PM	VOC	CO	CO_2
Idling Emissions (grams/truck/hr)	122	2.19	36.4	118	10,070
Emissions To Generate Equivalent Electrical Power (grams/hr)	6.04	0.035	0.054	0.481	3,014
Percent Emissions Reduction	95.0%	98.4%	99.9%	99.6%	70.1%

Truck stop operators/owners pay for the unit cost and installation costs of the IdleAire device and then lease rest stop space to the operator at a cost equal to, or less than the costs of fuel consumed during idling. Truck driver response has been positive and pilot programs with these types of devices are continuing in the Northeast.

7. Canadian Fuels Regulation

a) Background

Canada enjoys a long history of promulgating heavy duty exhaust emissions regulation harmonious with regulation in the United States, not only from an absolute emission reduction perspective but also because of the large amount of cross border commercial traffic between the two countries. The border traffic situation lends itself to harmonious US-Canadian regulations for two reasons. First, from an environmental perspective, it is counterproductive in striving to reduce overall emissions to have heavy-duty vehicles entering one country with higher emissions (due to less stringent emissions limits) than those in the other country. Second, from an enforcement perspective, it is difficult to keep track of vehicles which comply with differing emissions standards and emit differing amounts of pollutants. This can especially influence roadside inspection and maintenance programs.

Clearly, in light of this significant truck traffic along this very large geographic border, harmonization of heavy-duty on-highway engine emissions regulations is essential. It is not surprising, therefore, that the Canadian and US governments have worked closely together to ensure that emissions regulations are similar in stringency, implementation dates, certification test procedures, vehicle and engine classifications, certification and compliance procedures, etc.

Technological solutions required to meet exhaust emissions regulation have always consisted of two components, the engine and the diesel fuel powering that engine. Furthermore, as emission standards become ever more stringent, the technological solutions required to meet the standards – especially the aftertreatment technologies described earlier – rely upon diesel fuel quality as an enabler to make them perform. Towards this end, a key component of harmonized US and Canadian heavy-duty on-highway engine emission regulations are harmonized diesel fuel quality regulations. While diesel fuel quality is defined by a number of characteristics such as cetane number and index, aromatic content, and cloud point, the most critical parameter is the sulfur content of the diesel fuel (see Section 3.c).i), ULSD, above).

b) US Regulation

The United States has finalized *on-highway* emissions regulations that take effect starting on January 1, 2007, and has also proposed “Tier 4” *nonroad* emissions regulations[35] that would take effect starting in 2008, and continue through 2014 depending on the displacement of the nonroad engine. Similarly, diesel fuel sulfur regulations are geared to follow these implementation timetables. For on-highway engines, all US diesel fuel will be required to contain sulfur levels of 15 parts per million (ppm)[36] or less, beginning June of 2006. This is six months’ in advance of the implementation date for the emissions standards themselves, and is specifically designed in this manner to provide adequate lead time for the low sulfur fuel to be fully implemented and integrated within in the fuel delivery infrastructure.

For nonroad engines, the new proposed nonroad fuels regulations would follow a similar pattern. 500 ppm or less sulfur diesel fuel is being proposed for implementation in 2007, with reductions to 15 ppm in 2010. As with the on-highway regulation, these nonroad diesel fuel sulfur limits will be needed to enable the operation of aftertreatment devices that will be required to meet the nonroad Tier 4 emission standards.

c) Canadian Regulation

Canada’s approach with diesel engine emissions and corresponding diesel fuel sulfur regulations follows this same pattern. For on-highway engines, the following sulfur limits for diesel fuel have been approved:

Throughout Canada, excluding the “Northern Supply Area”[37]:

- 500 mg/kg sulfur limit – throughout Canada until August 31, 2006.
- 15 mg/kg sulfur limit – throughout Canada beginning September 1, 2006.

---

[35] The EPA proposal has been well-received by most stakeholders, and is expected to be promulgated into a Final Rule by the end of this year.

[36] The US specifies “parts per million” (ppm) to describe the sulfur concentration in diesel fuel. Canada specifies “mg/kg”. The two units of measure are equal, so 15 ppm diesel fuel sulfur content = 15 mg/kg diesel fuel sulfur content.

[37] The “Northern Supply Area” includes the Northwest Territories, Nunavut, most of the Yukon, northeast Manitoba, northern Quebec, Labrador, and coastal areas around James Bay and Hudson Bay.

Throughout the "Northern Supply Area" of Canada:

- 500 mg/kg sulfur limit – throughout Canada until August 31, *2007*
- 15 mg/kg sulfur limit – throughout Canada beginning September 1, *2007*

The "northern supply area" of Canada is allowed an additional year for implementation of these diesel fuel sulfur limits, since refueling centers in these areas typically have slow turnover of existing fuel stocks.

Canada's current on-highway fuels standard is the same as that of the US, at 500 ppm (500 mg/kg), and was promulgated as part of the 1999 Canadian Environmental Protection Act (CEPA). Amendments to that act have been finalized and were published in the Canada Gazette[38] on July 17, 2002. These amendments formally change the sulfur level and implementation dates for on-highway diesel fuel in Canada, as described above.

Canada intends to promulgate nonroad engine emissions and fuels regulations that correspond to the EPA's proposed Tier 4 requirements. That process has already started, now that the US nonroad regulations are expected to become final later this year.

8. CONTACTS

a) Author

The reader is invited to contact the author with questions or comments:

Michael Block,
Senior Staff Engineer, NESCAUM
101 Merrimac Street, 10th Floor
Boston, MA 02114
617/367-8540 x 218
617/742-9162
mblock@nescaum.org

b) Acknowledgements

The author wishes to thank the staff from the Northeast states, the staff from NESCAUM and the staff from the municipal, provincial and national governments of Canada for their invaluable contributions to this Status Update.

[38] The Canada Gazette is the official publication of the federal government of Canada and provides a mechanism to inform the public of regulatory activity, and in this sense, is similar to the US Federal Register. The Gazette website for the fuels regulation is: http://canadagazette.gc.ca/partII/tempPdf/g2-13616.pdf

APPENDIX – Glossary of Terms

A

Absorb

The process by which a gas or liquid permeates a solid substance.

Adsorb

The process by which a gas or liquid is deposited or attaches on the surface of a solid substance.

Aftertreatment

General term denoting the installation of a “bolt on” device, usually a DOC or DPF, in the vehicle’s exhaust system, to reduce diesel exhaust emissions, primarily PM and NOx.

Anti-Idling

An approach to reduce diesel engine emissions by limiting the amount of time a diesel-powered vehicle is allowed to run the engine at idle (not moving).

APU

“Auxiliary Power Unit”, generic name given to a device that provides accessory power, heating, and sometimes air-conditioning to the cab of a truck via a separate, much smaller diesel-powered engine in order to reduce idling emissions.

ARB

“Air Resources Board”, part of the California EPA and the diesel engine emissions regulatory body in the State of California.

Ash

Component of the lubricating oil of an engine that promotes enhanced lubrication (“lubricity”). Ash will find its way into the diesel exhaust stream and cannot be removed from a DPF through regeneration, necessitating the periodic cleaning of the DPF at intervals of approximately 12 to 16 months.

B

Biodiesel

Alternative diesel fuel formulation of which a portion is composed of renewable stocks such as those from plants and animal fat.

B5

A Biodiesel blend of 5% renewable stocks.

B20

A Biodiesel blend of 20% renewable stocks.

B100

A Biodiesel blend of 100% renewable stocks. B100 is said to be in "pure form" with no petroleum-based (i.e. diesel fuel) component.

C

CAC

"Clean Air Communities", a non-profit organization affiliated with NESCAUM, dedicated to cleaner air in disadvantaged communities.

Catalyst

A substance that speeds up or otherwise enhances a chemical reaction without changing its own composition or state. Often refers to the "bolt on" device in the vehicle exhaust system that reduces emissions through a catalytic process.

CATI

"Clean Air Technologies, Inc.", manufacturers of a portable emissions measurement (PEMs) instrument.

CEPA

"Canadian Environmental Protection Act", the legal basis behind the Canadian Federal Government's regulation of air pollution. Passed in 1999, it assigned responsibility for mobile source vehicle emissions to the Ministry of the Environment of which Environment Canada is a division.

CNG

"Compressed Natural Gas"

CO

"Carbon monoxide" the odorless, colorless gas that is a minor by-product of diesel combustion.

CO_2

"Carbon dioxide", a more significant by-product of diesel combustion than CO, and a "greenhouse gas" emissions constituent known to contribute to global warming. Though present in greater concentrations than CO due to the oxygen-rich diesel combustion process, diesel engines because of their greater efficiency, emit far less CO_2 than their gasoline-powered counterparts.

Consent Decree

In the context of heavy-duty diesel emissions, an agreement between the seven primary diesel engine manufacturers[39] and the US Department of Justice (US DOJ), mandating engine manufacturer restitution for engine electronic calibration illegalities that resulted in increased "real-world" diesel engine NOx emissions. A key component of the Consent Decree is the Supplemental Environmental Project (SEP).

[39] The seven consent decree companies are: Caterpillar Inc.,, Cummins Engine Company, Detroit Diesel Corporation (DDC), International Truck and Engine, Mack Trucks Inc., Renault Trucks and Volvo Trucks. Each of these seven Consent Decrees contained somewhat different financial penalties and SEP requirements.

CT DEP
“Connecticut Department of Environmental Protection”

CT DMV
“Connecticut Department of Motor Vehicles”

CT DOT
“Connecticut Department of Transportation”

D

DDC
“Detroit Diesel Corporation”, one of the major heavy-duty engine manufacturers in the U.S. now wholly owned by DaimlerChrysler Corporation. DDC is a signatory to a Consent Decree with US DOJ.

E

Env. Can.
“Environment Canada”, Canadian Government agency that, among many activities, performs in-use, on-vehicle emissions testing.

F

FBC
“Fuel Borne Catalyst”, a liquid substance premixed or injected into the diesel fuel supply of a vehicle to promote emissions reduction though catalytic reaction in the engine combustion chamber itself.

Fischer-Tropsch Fuels
A type of diesel fuel manufactured from natural gas and having very low emissions properties.

M

MBTA
“Massachusetts Bay Transit Authority”, transit authority of the State of Massachusetts.

MTA
“Metropolitan Transit Authority”, transit authority of New York City.

N

NOx

“Oxides of Nitrogen”, a term used to describe a group of emissions constituents that is a major by-product in diesel exhaust.

NO

“Nitrogen Oxide”, one of the constituents of NOx, usually present in the greatest concentrations.

NO_2

“Nitrogen Dioxide, another primary constituent of NOx. NO_2 is usually present in NOx in smaller quantities than NO, but is far more toxic.

NYSERDA

“New York State Economic and Research Development Authority”, a branch of the State Government of New York that, among many other functions, provides funding on a grants award basis for New York State-based mobile sources emission reduction projects such as retrofits.

O

OTAQ

“Office of Transportation and Air Quality”, the motor vehicle air pollution division of the US Environmental Protection Agency (EPA).

P

PM

“Particulate matter”, often referred to as “soot”, the carbon-based non-gaseous emissions component of diesel exhaust.

$PM_{2.5}$

Particulate matter whose mean particle diameter is 2.5 microns or less. Often referred to as “fine PM”, $PM_{2.5}$ has a propensity to lodge in the far reaches of the human lung potentially posing an even greater health risk than $PM_{10.}$

PM_{10}

Particulate matter whose mean particle diameter is 10 microns or less. Typically PM_{10} has been the focus of most federal and California diesel engine emissions regulation.

Ppm

“Parts per million” an expression denoting the concentration of one substance within a bigger substance, for liquids or gases. Regarding the sulfur content in diesel fuel for example, ultra-low sulfur diesel (ULSD) is said to contain less than 15 ppm, meaning less than 15 ‘parts’ of sulfur for every million ‘parts’ of diesel fuel.

R

Regeneration

The process by which PM is removed from a DPF. Application of elevated exhaust temperatures oxidizes solid PM to form gaseous products, primarily CO_2.

Retrofit

A general term denoting the application or installation of a device designed to reduce diesel engine exhaust emissions, onto a diesel-powered vehicle. Retrofits may include “bolt on” devices such as diesel oxidation catalysts (DOCs) or diesel particulate filters (DPFs); fuel formulations such as water emulsified diesel or biodiesel; or fuel borne catalysts (FBCs).

Repower

A method of reducing diesel engine emissions by replacing the entire engine of a heavy-duty vehicle with one that emits less emissions. This is made easier because the key areas where the engine is fastened to the vehicle – the engine mounting points on the frame of the vehicle, and the engine mating points to the transmission – are all standardized, hence older, higher-emitting engines can be replaced by new, lower-emitting engines with little difficulty.

ROVER

“Real Onboard Vehicle Emissions Recorder”, a portable emissions monitoring system (PEMs) developed by EPA that is capable of measuring engine emissions on the vehicle while it is in motion, during daily operation. While ROVER is diesel-specific, it is only capable of measuring gaseous emissions and not PM.

S

SCR

“Selective Catalytic Reduction”, an emissions control device that lowers engine-out oxides of nitrogen (NOx) by injecting ammonia into the engine’s exhaust, which converts 80 to 95 percent of the NOx to nitrogen and water. SCR units look like mufflers, and are physically attached to the vehicle’s exhaust system

SEP

“Supplemental Environmental Project” a part of the “Consent Decree” (CD, see above) that mandated environmentally beneficial projects to be undertaken by specific heavy-duty engine manufacturers. Many SEPs involved retrofitting heavy-duty vehicles with aftertreatment devices of some sort.

SO_4

“Sulfate” or “Sulfate Particles.” SO_4 is a combustion by-product emanating from the sulfur content in diesel fuel forming sulfuric acid and water, and subsequently precipitating under cooling to form sulfate particles. In specifying the type of retrofit device that is most appropriate for a specific application, one must avoid the unwanted production of sulfate particles. This phenomena, called “sulfate make” is most often associated with SO_4 formation by DOCs using high sulfur content diesel fuel.

SOF

“Soluble Organic Fraction”, the soluble or “wet” portion of diesel PM, most effectively removed from diesel exhaust by a diesel oxidation catalyst (DOC).

Soot

“Soot” is a generic term that refers to the “black carbon” or “elemental carbon” portion of diesel PM.

T

TAC

“Toxic Air Contaminant’, a term defined by ARB as an air pollutant which may cause or contribute to an increase in mortality or an increase in serious illness, or which may pose a present or potential hazard to human health.[40]

TPM

“Total Particulate Mass” consisting of all the components of particulate including $PM_{2.5}$, PM_{10}, SOF, and sulfate particles.

U

UDDS

“Urban Dynamometer Driving Cycle”, one of a number of test cycles applicable for heavy-duty vehicles tested on a chassis dynamometer. The UDDS cycle replicates city and highway driving.

UPROSE

“United Puerto Ricans of Sunset Park”, a community educational and activist group based in Brooklyn, New York.

Urea

Chemically denoted as $CO(NH_2)_2$, urea is a liquid-state chemical that contains the ammonia used as a reductant to allow SCR systems to convert NOx to harmless nitrogen and water. Because ammonia is toxic and hazard to handle, SCR systems use urea, which is safe and non-toxic.

US DOJ

“United States’ Department of Justice’, the plaintiff in the cases against the seven truck engine manufacturers that resulted in the Consent Decrees.

US DOC

“United States Department of Commerce”

US DOE

“United States’ Department of Energy”

[40] California Health and Safety Code Section 39655a.

US DOT

“United States Department of Transportation”

USFTP

“United States’ Federal Test Procedure”, the official engine-dynamometer-based test cycle required for US EPA certification of a heavy-duty diesel engine.

V

VOCs

“Volatile Organic Compounds”, carbon-containing gaseous compounds that are emitted as a portion of diesel exhaust and subsequently evaporate into the air. VOCs contain toxics and contribute to the formation of smog.

W

Water Emulsions

A type of diesel fuel in which water is blended in a “suspension” with diesel fuel to form a stable mixture, that when burned in diesel engines, provides NOx and PM emissions reductions without engine modifications. The two major emulsified diesel fuel products include TotalFinaElf’s Aquazole™ and Lubrizol’s PuriNOx™. Water emulsions are typically blended one part water to six parts diesel.

WM

“Waste Management”, refuse collection firm that has participated in a number of diesel retrofit projects.

WTC

“World Trade Center” in New York City.

WVU

“West Virginia University” in Morgantown, West Virginia