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IMPLEMENTATION OF RETROFIT/CLEAN FUEL PROGRAMS FOR DIESEL EQUIPMENT DURING THE CONSTRUCTION PHASE OF TWO LARGE TRANSPORTATION PROJECTS

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ABSTRACT

This paper describes the diesel engine retrofit/clean fuels programs undertaken during the construction phase of the Central Artery/Tunnel (CA/T) Project in Boston, Massachusetts, and the I-95 New Haven Harbor Crossing Improvement Program (I-95 NHHC) in Southern Connecticut. It includes the implementation process along with tests results using the emulsified diesel fuel and the oxidation catalysts in the CA/T project; and the development of final specifications, cost/emission benefits estimates, and the information process conducted to educate contractors and prospect bidders for the Connecticut I-95 program.

The CA/T project includes a four lane tunnel under Boston Harbor, a 10-lane cable stayed bridge crossing the Charles River, and an eight to ten lane underground highway that will replace the existing six lane elevated expressway through downtown Boston. Project construction started in 1992, and during 1998 the project in conjunction with Massachusetts Department of Environmental Protection (MDEP) and the Northeast States for Coordinated Air Use Management (NESCAUM) implemented an emission reduction diesel retrofit program for off-road construction equipment using oxidation catalysts. Initially, it started as a pilot program, later it was expanded to include all off-road equipment on more than 20 remaining contracts to be awarded. This will result in well over 100 pieces retrofitted. The project also examined the use of an emulsified diesel fuel, which reduces nitrogen oxides (NOx) and black smoke when compared to regular diesel.

The (I-95 NHHC) includes the reconstruction of I-95 from Exit 46 in New Haven to Exit 54 in Branford, and the replacement of the Pearl Harbor Memorial Bridge. The construction of the 7.2-mile corridor is expected to start during 2002 and take close to twelve years to complete. The I-95 NHHC implemented a diesel vehicle emissions control program, which requires diesel powered construction equipment to either retrofit the engine with emission control devises and/or use clean fuels.

INTRODUCTION

Emissions from heavy-duty engines in the Northeast States accounts for approximately 33 percent of the nitrogen oxides (NOx) and 80 percent of the particulate matter (PM_{10}) emitted by mobile sources. The approximately 200,000 pieces of construction equipment operating in the region accounts for close to 8% of NOx and 25% of the PM_{10} emissions from all sources. Since diesel power construction equipment has higher emissions than equivalent diesel engines for highway use due to the lack of any emission controls until 1996, the reduction of these emissions has not only the potential to improve ambient air quality for the region, but more important, it has significant air quality benefits to abutters and workers adjacent to large construction areas.

The diesel engine retrofit programs discussed in this paper started as a way to reduce diesel emissions before cleaner fuels and cleaner engines become part of the standard manufacturing process five to ten years from now, when national regulations will make construction equipment engines as clean as heavy duty highway vehicles.

Currently, three are a series of emission reduction technologies for diesel engines at different stages of development and/or production. The most commonly known technologies can be grouped on three main categories:

- Fuel modifications: including synthetic diesel, water-in-diesel emulsions, biodiesel, and ultra low sulfur diesel.
- Engine Design/fuel modifications: including exhaust gas recirculation (EGR), dimethyl ether, and natural gas.

- After Treatment /add-on pollution control devices: including oxidation catalysts, diesel particulate filters (DPF), lean catalysts, and selective catalytic reduction (SCR).

Given the advance stage of design and construction of these two projects, the diesel emission control programs discussed in this paper focused on add-on pollution control devises with the option of cleaner diesel fuels. Today, there are several areas within the US where these types of programs are being evaluated and/or implemented. The experience of these two large transportation projects can serve as a road map toward implementation of these programs in other areas.

CA/T Project Overview

The CA/T Project administered by the Massachusetts Turnpike Authority (MTA) consist of a new third harbor tunnel (named the Ted Williams Tunnel) which opened to commercial traffic in 1996 linking downtown Boston to Logan Airport in East Boston, and a new underground eight to ten-lane Central Artery, which will replace Boston's current elevated north-south expressway, and a ten-lane cable stayed bridge crossing the Charles River. The existing elevated Central Artery built in the 1950' with a capacity of 75,000 vehicles per day is currently operating at close to 180,000 vehicles per day making it one of the most congested segments of the interstate highway system in the country.

When completed in 2005, the Project will consist of a total of 161 lane miles of new highway in a 7.5-mile long corridor, of which approximately one half will be in tunnels. Construction includes approximately 13 million cubic yards of excavated earth material and 4 million cubic yards of concrete, which will be hauled by more than a half of million truckload trips[(1)]. During mainline construction hundreds of pieces of heavy construction equipment are being used 24 hours a day, including large excavators, front-end loaders, bulldozers, cranes, cement trucks, and both 10 wheel and 18 wheel dump trucks.

The CA/T Project is located within a non-attainment Ozone (O_3) transport region. Since NO_x and HC components of diesel emissions are precursors for O_3, one of the objectives of the program was to assist the region toward attainment of the ambient air quality standards for O_3 by voluntary reduction of emissions from off-road diesel construction equipment.

Connecticut I-95 NHHC Overview

The I-95 NHHC administered by the Connecticut Department of Transportation (CONNDOT) consists of the construction of a new State Street Commuter Railroad Station, the widening of I-95 from Exit 46 in New Haven to Exit 54 in Branford, the replacement of the existing Pearl Harbor Memorial Bridge (Q Bridge) with a new 10 lane bridge, and the reconstruction of the I-95/I-91/Route 34 Interchange. The existing Q Bridge built in 1958 to carry in both directions, 40,000 vehicles per day, was operating in 1993 at a level over 120,000 per day. An estimate of 140,000 to 150,000 vehicles per day in 2015 has been forecasted.

Construction of the 7.2-mile corridor is divided in five phases under four major contracts. The first roadway construction phase, Contract "D", is scheduled to be awarded in the spring of 2002.

Project construction will span over a ten to twelve year period. It is estimated that during the construction of all the I-95 NHHC projects, more than 200 pieces of diesel powered construction equipment will be operating within the alignment.

The I-95 Project is located in the municipalities of New Haven, East Haven and Branford, which are a serious non-attainment area for O_3, and non-attainment for PM_{10} for the New Haven area only.

CA/T AIR QUALITY MITIGATION DURING CONSTRUCTION PHASE

Given the urban setting of the CA/T Project, with close proximity of construction activities to residential communities, medical facilities, businesses, and other sensitive abutters along the project alignment, stringent dust and odor control measures were implemented to protect public health.

As part of the mitigation measures the CA/T project established a dust control specification, outlining the necessary measures and requirements that the contractors must follow in order to control on- and off-site nuisance dust. These included: reducing the number of truck entrances and exits from a site within the contract; providing a crushed stone base for the dump truck in the on-site loading area; and creating embankments between stockpiles and haul roads. These particular measures were implemented to manage and reduce dirt tracking. To evaluate the effectiveness of these measures, and assist enforcement of them, the Project undertook a PM_{10} monitoring program in 1992, which will continue until Project completion. The annual ambient PM_{10} monitoring program included the use of portable monitors located at sidewalks during the summer season measuring 24-hout PM_{10} levels twice a week at 5 to 10 locations per year, tracking emissions at the largest construction areas. A field dust inspection program was also implemented to verify contractor's compliance with the specification requirements.

The results of these programs concluded that most of the PM_{10} increases were localized, and confined to areas close to the major CA/T construction activities. The observations of the inspection program also concluded that the single most significant source of the high PM_{10} levels was re-suspended dust from construction trucks entering and exiting the construction areas. A full description of these programs was presented at the AWMA 2000 Annual Meeting by Dolan, Schattanek, and Wan [(2)].

CA/T CONSTRUCTION EQUIPMENT EMISSION CONTROL

Due to the extremely close proximity of CA/T work zones and nearby residential communities, hospitals, office buildings, and pedestrians walking near construction work zones, the majority of complaints received by project personnel are the result of diesel odors from CA/T construction equipment.

In order to minimize odors and diesel smoke impacts from CA/T construction equipment, the Project developed a Construction Odor Control Specification[(3)]. The specification requires that CA/T contractors working on the project keep their equipment properly maintained. In addition, contractors are required to minimize diesel pollutant impacts by:

- Turning off diesel construction equipment not in active use and dump trucks that are idling while waiting to load or unload material for five minutes or more,
- Establishing a staging zone for trucks that are waiting to load or unload material at the work zone in a location where diesel emissions from the trucks will not be noticeable to the public, and
- Locating construction equipment away from sensitive receptors such as fresh air intakes to buildings, air conditioners, and operable windows.

In addition, a voluntary diesel retrofit program was implemented in the fall of 1998 by the MTA. The program consisted of retrofitting large off-road diesel construction equipment with a catalytic-type piece of equipment called oxidation catalysts.

CA/T DIESEL RETROFIT PROGRAM

Retrofit Technology Selected

The CA/T project chose to use oxidation catalysts in retrofitting off-road equipment over available diesel particulate filters due to the following reasons:

- The reduction in HC that are associated with diesel odors as well as carbon monoxide (CO) and PM_{10} provided by an oxidation catalyst,
- Ease of installation and maintenance, and
- Cost of an oxidation catalyst versus a diesel particulate filter (e.g., $2,500 per unit versus $13,000 unit, respectively), allowed more pieces of equipment to be retrofitted for the available funds.

In addition, oxidation catalysts are the most broadly applied technology currently certified by EPA with the Urban Bus Retrofit/Rebuild Program as part of the Voluntary Measures Retrofit Program (VMEP). The technology is well proven, since it is estimated that more than 2 million highway vehicles have been retrofitted with oxidation catalysts, and over 1 million are in circulation to date. Oxidation catalysts reduce diesel emissions by oxidizing diesel pollutants such as particulate matter, hydrocarbons, and carbon monoxide to less harmful emissions such as H_2O and CO_2. Also, toxics such as formaldehyde and benzene may also be reduced by as much as 70 percent.

Program Phases

The diesel equipment retrofit program originated in September 1998 as a two-phased program. The first phase consisted of retrofitting ten pieces of off-road equipment with oxidation catalysts contributed by equipment manufacturers under the Manufacturer's of Emission Control Association (MECA). CA/T contracts that were targeted for the Phase 1 program were those that were located near sensitive receptors such as residential communities and/or hospitals. Three different CA/T contractors were asked to participate in the Phase 1 program. The main goal of the Phase 1 program was to see how easily the equipment could be retrofitted without resulting in excessive "downtime" for the equipment being retrofitted. The type of equipment targeted for retrofitting under the Phase 1 program were both large and small excavators as well as large and small front-end loaders manufactured by both domestic and foreign companies. If Phase 1 succeeded, the CA/T project would implement a Phase 2 retrofit program, which would consist of retrofitting up to an additional sixty pieces of off-road construction equipment at an allocated funded cost of $100,000.

Equipment Retrofit Costs

The CA/T retrofit program used catalytic oxidizers manufactured by Engelhard Corporation. The cost of this type of unit can range from $1,000 to $3,000 per unit, depending on the engine horsepower (HP) rating of the unit being retrofitted. Because the project chose to retrofit larger off-road pieces of construction equipment, the average cost per oxidation catalyst was $2,500, translating in an approximate cost of $8/HP of equipment retrofitted. The installation cost was absorbed by the contractors using their own mechanics. Given an estimated cost of $250,000 for an off-road piece of construction equipment, the cost of $2,500 for an oxidation catalyst is relatively small for achieving an effective means of diesel emissions reductions.

Results of Phase 1 and Phase 2 Retrofit Programs

Under the CA/T's Phase 1 program ten pieces of non-road equipment were slated to be retrofitted with oxidation catalysts. However, due to potential engine warranty concerns, two of the ten pieces of equipment were not retrofitted. Of the eight that were retrofitted, each installation was performed within a 2-hour time-period, which resulted in a minimum downtime for the equipment being retrofitted. Because of the successful implementation of the Phase 1 program, the MTA moved to implement the Phase 2 portion of the retrofit program.

Under the Phase 2 program, the same sitting criteria as implemented under the Phase 1 program was followed (i.e., equipment located near sensitive receptors). In addition, the project also targeted equipment that was slated to remain on the project work site for the longest duration of the contract life. The purpose of the additional criteria was to help ensure that the air pollution benefits obtained from the oxidation catalysts would be applied to the metropolitan Boston area.

At the end of the CA/T's Phase 1 and 2 programs, more than 50 pieces of equipment were retrofitted with oxidation catalysts. However, due to the amount of below grade (i.e., in-tunnel) construction work that contractors have been performing, and the need for worker health and safety; additional equipment has been retrofitted with oxidation catalysts. As a result, slightly more than 100 pieces of CA/T construction equipment have been retrofitted.

In addition, the MTA extended the CA/T diesel retrofit program to all remaining contracts to be awarded, requiring that all non-road diesel powered equipment be retrofitted with oxidation catalysts.

By having this requirement in the final remaining contracts (i.e., approximately 23 contracts), it is estimated that an additional 75 to 100 pieces of off-road construction equipment will be retrofitted with oxidation catalysts. Thus, when combined with those retrofitted under the Phase 1 and 2 portions of the program, and with those retrofitted for in-tunnel worker health and safety considerations, the total number of off-road pieces of construction equipment used during the construction of the CA/T project will be approximately 200.

Equipment Performance

According to contractor experience, the equipment retrofitted with oxidation catalysts has not experienced any adverse operational problems such as loss of power or additional fuel consumption. In addition, contractors have not had to perform any additional maintenance on the equipment outside of the routine maintenance currently being performed. To date, some of the oxidation catalysts have been in operation for more than two years.

Currently several oxidation catalysts that have been extensively used on CA/T diesel equipment are being sent to a third party monitoring laboratory to evaluate emissions reductions performance.

While a number of papers have been published on the long-term durability of oxidation catalysts used in highway diesel applications, relatively few data are available on the durability of catalysts used in nonroad construction machines. The emission reductions achieved in non-road machines has been shown initially to be comparable to reductions seen in highway applications. However, higher sulfur levels found in nonroad fuel and other factors may affect the long-term function of the units differently than their counterparts used in highway applications. The purpose of this test is to examine catalysts installed on CA/T equipment to determine the long-term effectiveness of the units to reduce pollution.

We anticipate emission reduction results prior to the presentation of the paper.

Estimated Emission Reductions

The methodology used to estimate the emission reductions from the diesel retrofit program followed the general procedures for State Implementation Plan (SIP) credit calculations recommended by NESCAUM[(4)].

The general procedures used for this program include the following steps:

- Estimation of baseline emission factors for CO, HC, NOx and PM_{10} by equipment type in grams per brake horsepower hour,
- Estimation of baseline emissions (tons/year) base on equipment type, usage, and hours of operation,
- Estimation of emission reductions for each type of equipment retrofitted for applicable pollutants, and
- Estimation of total emission reductions for the list of equipment already retrofitted.

Today the estimation of emission reductions can be easily calculated by using the Environmental Protection Agency (EPA) electronic calculator included in the EPA Verified Retrofit Technology List. However, since in-use emission data for the variety of non-road construction equipment is was not available then, the engine emission rates were based on the USEPA Report N^0. NR-

009A[5]. Appendix C of the report provides emission factors for non-road engines operating under different conditions that the steady state ISO-C1 testing procedure. It includes the cycle specific results for individual engines by application category converting a vast list of equipment tested to the equivalent mode of operation of an agricultural tractor, a backhoe, or a dozer. The average emission factor for CO, HC, NOx and PM in grams per horsepower hour (g/hp-hr) per application type was used to determine the base emission rate for each type of construction equipment.

A list of construction equipment for each CA/T contract retrofitted was prepared, including equipment type, engine horsepower, hours of weekly operation, percent of operation/idle time, and percent of power use during operation or idle conditions.

Baseline emission estimates were determined by multiplying the engine horsepower, by the hours of operation per day (adjusted by the percentage of full operation to idle), by the engine load factor during operation, and by the emission factor in g/hp-hr. The hours per day were based on a double shift schedule six days per week. The equipment utilization was assumed to be operating 90% of the working hours and idling the remaining 10% of the time. The load factor was based on 75% of full power during operation and 20% of full power during idling. Table 1 provides baseline emission estimates in kilograms/day for each piece of equipment retrofitted, with total emission for one of the contracts.

Emission reductions were based on percentage reductions for each pollutant from the estimated baseline emission levels. Currently, there are several retrofit technologies that have obtained EPA certification and most of these technologies have been used for highway on-road vehicles. For this assessment, it was assumed that oxidation catalysts would achieve a minimum of 20% reductions for PM_{10}, 40% reductions for CO, and 50% reductions for HC in all heavy-duty engines. These are the minimum eligible credits without administrative or peer review. They are also the allowable credits posted in the EPA emission reductions calculator under the EPA s' Voluntary Diesel Retrofit Program. Table 2 provides the emission estimates for each type of equipment retrofitted as of year 2000, and the total emission reductions for the same contract evaluated in Table 1.

The emission reductions estimated in these tables do not include the additional PM_{10} pollutant reductions due to the use of lower sulfur fuel. Because of logistical refueling operations, all equipment on site used on-road diesel fuel instead of non-road diesel fuel. Current national regulations limit the sulfur content of on-road diesel fuel to less than 0.05% by mass (normal use is approximately 0.035%), while non-road diesel fuel is exempt of this limitation and normally contains 0.33% of sulfur by mass.

The results of the evaluation for the five contracts indicate that the current diesel equipment retrofit program will reduce approximately 90 Kg/day of CO, 30 Kg/day of HC, and 7.4 Kg/day of PM_{10} during the year 2000[6/7].

The emission reductions for the future years are anticipated to increase to twice the level estimated for the year 2000 by 2002 when construction is at its peak, and slowly fall back to the year 2000 level by 2004 when the project is near completion.

CA/T ALTERNATIVE DIESEL FUEL TEST PROGRAM

The CA/T Project had explored the possibility of lower diesel emissions even further by replacing the diesel fuel used to power construction equipment in the project with a cleaner alternative.

The LUBRIZOL Corp. (Ohio) manufactures a low NOx emission blend of diesel fuel marketed as PuriNOx™. It consists of a mixture of diesel fuel, water, and an additive to maintain the emulsified mixture stable and avoid water droplets from becoming in contact with engine parts. As water atomizes and converts into steam it lowers engine temperature reducing NOx and PM formation. Test demonstration projects have achieved 10-30% NOx reductions and 10-50% PM reductions. California Air Resources Board (CARB) had certified in January 2001 that PuriNOx™ could reduce NOx emissions by 14% and PM emissions by 62.9%, and that no net increase in toxic emissions and hydrocarbons where found.

Emissions and Performance Tests

A performance test was performed on a model year 2000 Caterpillar 311B excavator owned by a contractor during February 2001. The 311B excavator uses a four cylinder 79 horsepower diesel engine. Emission and opacity tests were performed under a series of low and high idle conditions using No. 2 diesel fuel and a winter blend of PuriNOx™. After the initial test, a performance test using PuriNOx™ was conducted by allowing the excavator to operate 16 hours per day, five days per week for a period of three weeks, consuming approximately 600 gallons of PuriNOx™.

Tests Results

The emission and opacity tests conducted under typical operating conditions indicated that PuriNOx™ reduced NOx emissions between 24.5 and 30.5 %. Smoke reductions for the same operating period were reduced by 93 to 96.8 %[8].

The only performance problems reported by the operator were that it required slightly more power in deep mud conditions, and slightly more fuel consumption. Lubrizol also indicated that an increase on fuel consumption in the 7 to 10% range could be expected since water has no caloric power. In addition, a performance test was done using a mixture of 50% PuriNOx™ and 50% diesel fuel. The operator reported no problems with the 50% mixture.

CONNECTICUT I-95 NHHC DIESEL EMISSION CONTROL PROGRAM

Due to the length of the construction period, and proximity to the city of New Haven, every effort will be made to implement measures to minimize emissions during the construction period. As a result, CONNDOT started to look at the possibility of a retrofit program linked to the I-95 New Haven Harbor Crossing Improvement Program (NHHC).

In October 2000, CONNDOT formed an air quality working group which would investigate the benefits and costs of implementing a diesel emission control program. The group included personnel from various offices within CONNDOT, and experts from the consulting team (Parsons Brinckerhoff), NESCAUM, Connecticut Department Environmental Protection (CONNDEP), Department of Motor Vehicles (DMV), and Connecticut Construction Industries Association (CCIA).

CONNDOT and CONNDEP sent representatives to visit the CA/T Project to obtain an overview of the ongoing diesel retrofit program implemented by the MTA. The CA/T experience not only provided a good starting point for the I-95 NHHC, but also provided the opportunity to interview contractors and get members of CONNDOT's construction services more familiar with the issues.

It also was determined that the I-95 NHHC had more avenues that could be pursued because the projects were still in their engineering design stages, and contract documents wouldn't be finalized for several months, as opposed to the CA/T Project where the retrofit program started when construction was already ongoing for a few years. As a consequence, the first order of business was to evaluate which technologies could be appropriate for this project, their emission reduction potential, and the cost of implementing them.

It was decided early on that the I-95 NHHC would only apply to non-road diesel powered equipment, since highway diesel vehicles are already regulated by the DMV under the heavy-duty diesel emissions opacity test regulation.

The DMV Program[(9)] specifies that only diesel-powered commercial motor vehicles consisting of the following characteristics should be tested:

- Vehicles over 26,000 lbs. GVWR
- Vehicles designed to transport sixteen or more passengers
- Vehicles transporting hazardous material and those required to be placarded

The tests are preformed in conjunction with any safety or weight inspection at any official weighing area or other location designated by the Commissioner. Roadside tests have been in operation for 2 years, the failure rate is averaged at 16-18 percent. Vehicles that fail are subject to a potential $300 fine, and must submit proof of repairs. Second encounters with previously failed vehicles show a drastic reduction in smoke opacity. For the year 2000, a total of 1221 vehicles were tested out of which 263 exceeded the states opacity standards.

Once Contract D is awarded, CONNDOT will arrange with the DMV for a pre-construction opacity test for all contractors and sub-contractors.

Technologies Evaluated in the I-95 NHHC

Four different scenarios (technologies) that could be implemented to reduce air emissions during construction were identified. Two included diesel engine retrofit technologies, oxidation catalysts, and/or four way catalysts; while two others included the use of cleaner fuels, Biodiesel B-20 Blend™ and/or PuriNOx™. Any of these four technologies could be applied partially and in combination with the others. All have logistical and cost advantages and disadvantages that were evaluated prior to implementation[10/11].

The methodology used to estimate the emission reductions from the diesel retrofit and/or clean fuels program followed the same procedure presented for the CA/T Project, i.e.:

- Estimation of baseline emission factors for CO, HC, NOx and PM_{10} by equipment type in grams per brake horsepower hour.
- Estimation of baseline emissions (tons/year) based on equipment type, usage, and hours of operation.
- Estimation of emission reductions for each type of equipment retrofitted and/or type of fuel for applicable pollutants.

Retrofit Technologies: Emission Reduction Potential and Cost.

Oxidation catalysts. At the time of the evaluation for the I-95 Program, the CA/T Project had already installed approximately 70 oxidation catalysts on a variety of construction equipment with positive results. It was assumed then, that oxidation catalysts would achieve a minimum of 20% reductions for PM_{10}, 40% reductions for CO, and 50% reductions for HC in all heavy-duty diesel engines.

An average cost of $8/HP was used for this assessment. It was anticipated that these costs would decrease in the future.

Four Way Catalysts. At the time QuadCAT™ manufactured by Ceryx Inc. was the only equipment of this kind that can reduce NOx as an afterburner retrofit for mobile source diesel engines (oxidation catalysts reduce CO, VOC and PM but not NOx). QuadCAT™ planned to go through EPA certification using the same test data required by CARB. There were several units in operation, but it was not yet an “off the shelf“ type of equipment.

Based on manufacturers data, it was assumed that QuadCAT™ would achieve a minimum of 60% reductions for PM_{10}, 80% reductions for CO, and 80% reductions for HC, and 25% reductions for NOx.

The cost of QuadCAT™ ranges from $ 2,500 to $ 7,500 depending on the displacement of the engine retrofitted. An average cost of $ 25/HP was used for this assessment. It was also expected that once this type of equipment enters into full production mode it could be more competitive with oxidation catalysts.

Clean Fuels: Emission Reduction Potential and Cost.

PuriNOx™, which is manufactured and distributed by Lubrizol Corp. in Ohio, was considered as a good alternative to reduce NOx and PM_{10}.

The cost of PuriNOx™ was approximately 16-cents per gallon above the cost of N°2 diesel fuel according to the Massachusetts distributor. Since PuriNOx ™ contains close to 20% of water, the relative cost differential depends on the wholesale cost of diesel fuel (i.e. the higher the diesel fuel cost the lower the differential).

Biodiesel, is a generic name for a variety of ester-based oxygenated fuels made from soybean or other vegetable oils or animal fats. The concept is more than a century old, and it can be used in any diesel engine without modification. It is a proven safe and cleaner burning fuel. It is biodegradable, contains no sulfur, and produces a lot less carbon dioxide than petroleum based fuels. The most commonly used is the B-20 Blend™ (20% Biodiesel and 80% petro-diesel). Pure (100%) Biodiesel has the disadvantage that it freezes at higher temperatures than diesel fuel, creating potential storage problems in cold weather areas.

B-20 Blend™ Biodiesel certification data indicates that its use could achieve a 20% reduction for PM_{10}, 30% reduction for HC, and 20% reduction for CO. It also could increase NOx emissions by 5% or more.

The cost of B-20 Blend™ oscillates between 15 to 30 cents per gallon above the cost of diesel fuel depending on market conditions. A 25-cents per gallon increase was assumed for the analysis.

Technology comparison.

Tables 3 and 4 provide a summary of the technology benefits and costs evaluation for each contract. Table 3 includes retrofit options and Table 4 includes cleaner fuel options. Each table provides the total number of units for each contract, total engine horsepower (HP), and annualized HP hours of utilization. The reductions in tons/year and projected costs represent an upper limit, since they assume that all units would be retrofitted, or that the cleaner fuels will be use exclusively for all operations. This may not be the case, since a partial and/or combination of the different technologies might be more desirable given the large differences in periods of time that construction equipment could remain in a contract area.

The results presented in these tables should be only used as broad indicators, since there is a high degree of uncertainty in these projections, and more so when costs of these technologies are considered. The cost of oxidation catalysts and four way catalysts could drop substantially if their use for non-road equipment becomes more widespread. The price of cleaner fuels is also subject to market fluctuations, making two to five year predictions very uncertain.

From the analysis performed, it can be concluded that oxidation catalysts appear to be more cost effective for equipment to remain on site during long periods of time (i.e. contracts which range in duration from one to several years), while cleaner fuels could have an economic advantage on equipment that will remain on site for shorter periods of time (one year or less).

Development of Diesel Vehicle Control Specification

The air quality working group had to address the following issues before making a decision concerning the requirements that would be incorporated into a contractor specification for this program:

Selected technologies. Considering that this was a voluntary pilot program for CONNDOT, it was decided to use the most widely accepted and the least expensive emission reduction options.

As such, the following methodologies were selected:

- Oxidation catalysts due to the low cost and proven experience,
- PuriNOx^{TM} to provide the contractors more flexibility in situations where equipment would not remain on site for long periods of time.

It was also decided that the program would include the option of either retrofitting with oxidation catalysts or using an emulsified diesel fuel such as PuriNOx^{TM}. Four way catalysts were considered to be too experimental and too costly for a pilot program. The use of Biodiesel was rejected because of the possible NOx increases.

Equipment size applicability and length of time on site. An evaluation of the emission benefits, as a function of HP-hours of operation and fuel consumption for each contract, indicated that if all equipment with engine size over 60 HP were retrofitted, more than 98% of the emission benefits of retrofitting all equipment would be achieved. As a result, 60 HP became the smallest engine size that will require retrofitting. In terms of duration of the equipment on the construction site, the main issue was how exempt specialized equipment that is only needed for some special operation, and how to deal with rental equipment without limiting the contractor's options. The minimum time limit required for exemption started at 100 days and was latter shortened to 30 days, in order to limit the possibility that contractors will rotate equipment to avoid complying with the program.

Payment options. Current CONNDOT standard specifications related to environmental compliance are in the form of either "incidental" or "pay" items.

- Pay items are those that the contractor bids a unitary price for, can be measured on site, and once verified by an inspector, are paid for according to the contract's unitary price. This payment method is common for such items as the application of calcium chloride, water for dust control, and/or fences for wind or erosion control. The contractor has to perform these tasks in order to get paid.
- Incidental items are those where that the cost is included in a contractor's overall bid price, and not specifically identified. One of the critical issues associated with incidental items is enforcement (i.e., what monies are retained for non-compliance). CONNDOT has a 24-hour provision normally used for environmental aspects, where once the contractor is notified of not performing a contractual task, the Department can have the task performed by a third party, with the cost billed to the contractor.

It was decided that the retrofit program would be included in project contracts as an incidental item, with some special enforcement provisions.

Form of the specification. Current CONNDOT standard specifications related to airborne emissions include 1.10.04 Air quality Control, 9.42 Calcium chloride for dust control, and 9.43 Water for dust control. CONNDOT also has the requirement that modifications to existing specifications must be issued as special provisions for at least one year before incorporation into the contracts. This allows modifications to new requirements once they are tested in construction areas. As a consequence the retrofit/clean fuel program was issued as a Notice to Contractors (NTC) in the bid package for the first contract.

Notice to Contractors - Diesel Vehicle Emissions Controls Specification

The final form of the specification for Contract D can be summarized as follow:

- All diesel powered construction equipment with engine horsepower (HP) ratings of 60 HP and above, that are on the project or are assigned to the contract for a period in excess of 30 days shall be retrofitted with Emission Control Devices and/or use Clean Fuels in order to reduce diesel emissions. In addition, all motor vehicles and/or construction equipment shall comply with all pertinent State and Federal regulations relative to exhaust emission controls and safety.
- The reduction of emissions of CO, HC, NOx, and PM_{10} will be accomplished by installing retrofit emission control devices or by using less polluting clean fuels.
- The retrofit equipment shall consist of oxidation catalysts, or similar retrofit equipment control technology that is included in the EPA Verified Retrofit Technology List, and certified to provide a minimum of emission reductions of 20% PM_{10}, 40% CO, and 50% HC.
- The Clean Fuels shall consist of PuriNOx^{TM}, or other low NOx and PM emission diesel fuel that can be used without engine modification, and it is certified to reduce the emission of NOx, and PM by more than 10% and 30% respectively when compared to N^{o}2 diesel fuel as distributed and sold in the State.
- Construction shall not proceed until the contractor submits a certified list of the diesel powered construction equipment that will be retrofitted with emission control devices or that will use Clean Fuels. The list shall include (1) the equipment number, type, make, and contractor/sub-contractor name; (2) the emission control device make, model and EPA certification number; and/or (3) the type and source of fuel to be used.
- The contractor shall submit monthly summary reports, updating the same information stated above, and include certified copies of the clean fuel delivery slips for the report time period, noting which vehicles received the fuel. The addition or deletion of diesel equipment shall be included on the monthly report.
- The contractor shall establish truck-staging zones that are waiting to load or unload material at the contract area. Such zones shall be located where the diesel emissions from the trucks will have minimum impact on abutters and the general public.
- Idling of delivery and/or dump trucks, or other diesel powered equipment shall not be permitted during periods of non-active use, and it should be limited to three minutes in accordance with Regulations of Connecticut State Agencies 22a-174-18, subsection (a)(5).
- A Diesel Emissions Mitigation plan will be required for areas were extensive work will be performed in close proximity (i.e. less than 50 feet) to sensitive receptors.
- If a diesel equipped vehicle is found to be in non-compliance with this specification, the contractor will be issued a Notice of Non-Compliance and given a 24-hour period in which to bring the vehicle into compliance or remove it from the project.

Contractor Information Process

Once the requirements for the diesel vehicle control specification were determined, the air quality working group started the preparations for a contractor information and dissemination program. This program focused on how to explain the benefits and requirements of the Connecticut I-95 Diesel Emission Control Program to contractors and prospective bidders. One of the main purposes was to acquaint contractors with specification requirements and with vendors of emission control devices and clean fuel distributors. Several presentations were made at the CONNDOT training facility with information and invitations distributed by Connecticut Construction Industries Association.

These presentations included speakers from CONNDEP, EPA, NESCAUM, Caterpillar, CONNDOT, DMV, and the CA/T retrofit program. Emission control vendors and clean fuel distributors were also invited to set up booths with their products. The presentations lasted a full morning which included an overview of federal and state regulations, the experience obtained through the CA/T retrofit program, engine manufacturers points of view, the specification requirements, and a demonstration of the smog opacity test performed by DMV on heavy-duty vehicles.

CONCLUSION

The CA/T diesel construction retrofit program has proven that retrofitting construction equipment with oxidation catalysts is very feasible, and that it has significant benefits in terms of emission reductions, odor control, and visible smoke. When considering that the costs of the oxidation catalysts are on the order of one percent of the total cost of the construction equipment to be retrofitted, this Program is a very effective way to reduce diesel emissions and odor. The Connecticut I-95 Program started from the CA/T experience, and achieved a few improvements in the planning and public information process, which allowed the development of a more flexible and targeted specification.

The lessons learned from both experiences can be summarized as follows:

The experience of the CA/T Project showed that when implementing a retrofit program for off-road construction equipment, it is best to include the requirement for emission control equipment as of the contract's bid package. By doing so, the cost of the retrofit equipment can be included as part of the overall contract cost, thus avoiding the use of economic incentives to bring contractors into the program.

The two major concerns expressed by contractors who participated in the CA/T's retrofit program were:

- The potential affects on equipment warranty as well as the potential affects on equipment performance. Owners of off-road diesel equipment wanted written assurances from their equipment (engine) manufacturers that engine warranties will not be affected once a retrofit is installed; and

- Assurances from the manufactures of emission control equipment that the equipment performance will not be affected.

The I-95 NHHC had the advantage of the CA/T experience as well as almost one year of lead-time before contract documents had to be ready for the advertising of the first contract. The most positive aspect of initiating the retrofit program was the creation of an air quality working group that met on a regular basis (every six weeks). The group was able to convince all of the affected parties to buy into the retrofit program. It was very important to obtain a clear understanding of the program benefits, costs, who was going to pay, and how the concept would be translated into a required specification as part of the bid documents early on in the program. Once those issues were resolved, the rest of the program required the effort of technical experts to develop the necessary language for the construction specifications.

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KEY WORDS

1. Oxidation catalyst
2. Diesel exhaust
3. Emission Control
4. Clean Fuels
5. Pollutant reduction
6. Construction equipment

TABLE 1

CA/T Project - Daily Baseline Emissions of CO, NOx, HC, and PM10 from Affected Construction Equipment

		Number of Units	HP of Each Piece of Equipment	Total Utilized HP	Pollutant Emission Factors Under Baseline Conditions				Baseline Conditions Daily Emissions (kg/day)			
Type	Model	#			CO	NOx	HCs	PM10	CO	NOx	HCs	PM10
			Hp	hp-hr/day	g/hp-hr	g/hp-hr	g/hp-hr	g/hp-hr	kg/day	kg/day	kg/day	kg/day
Nichi Lift	ISR602 1994	1	90	1,001	2.77	7.88	0.66	0.47	2.8	7.9	0.7	0.5
Nichi Lift	ISR602 1999	2	90	2,002	2.77	7.88	0.66	0.47	5.5	15.8	1.3	0.9
Nichi Lift	ISR602 2000	2	70	1,557	2.77	7.88	0.66	0.47	4.3	12.3	1.0	0.7
Nichi Lift	ISR700 2000	1	80	890	2.77	7.88	0.66	0.47	2.5	7.0	0.6	0.4
Mantis Crane	10010 1998	1	215	2,391	2.77	7.88	0.66	0.47	6.6	18.8	1.6	1.1
Mantis Crane	10010 2000	2	215	4,782	2.77	7.88	0.66	0.47	13.2	37.7	3.2	2.3
Crane	RT5223 2000	1	130	1,446	2.77	7.88	0.66	0.47	4.0	11.4	1.0	0.7
CAT Lift	7H83 1999	1	90	1,001	2.77	7.88	0.66	0.47	2.8	7.9	0.7	0.5
CAT Lift	TH83 1999	2	90	2,002	2.77	7.88	0.66	0.47	5.5	15.8	1.3	0.9
SIC Lift	600SJC 2000	1	66	734	2.77	7.88	0.66	0.47	2.0	5.8	0.5	0.3
Terex Lift	TX77 45R 1999	2	105	2,335	2.77	7.88	0.66	0.47	6.5	18.4	1.5	1.1
JLG Lift	3513 1999	1	105	1,168	2.77	7.88	0.66	0.47	3.2	9.2	0.8	0.6
Gradal Excavator	XL5200 1999	2	174	3,870	5.04	8.21	1.56	0.79	19.5	31.8	6.0	3.1
Gradal Excavator	XL5200 2000	1	174	1,935	5.04	8.21	1.56	0.79	9.8	15.9	3.0	1.5
Deere Dozer	850C 2000	1	192	2,135	2.77	7.88	0.66	0.47	5.9	16.8	1.4	1.0
CAT Dozer	953C 1999	3	121	4,037	2.77	7.88	0.66	0.47	11.2	31.8	2.7	1.9
Total Number of Units		**24**										
Total Emissions Under Baseline Conditions (kg/day)									**105.4**	**264.2**	**27.2**	**17.6**

Source: Massachusetts. Turnpike Authority, Technical Memorandum – Emission Reduction Estimates from the Construction Equipment Diesel Retrofit Program. November 2000

TABLE 2
CA/T Project - Daily Emission Reductions Under Diesel Engine Retrofit Program

Equipment		Number of Units	Total Utilized HP	Oxidation Catalyst Daily Emissions (kg/day)			
Type	Model			CO	NOx	HCs	PM10
			hp-hr/day	kg/day	kg/day	kg/day	kg/day
Nichi Lift	ISR602 1994	1	1,001	1.7	7.9	0.3	0.4
Nichi Lift	ISR602 1999	2	2,002	3.3	15.8	0.7	0.8
Nichi Lift	ISR602 2000	2	1,557	2.6	12.3	0.5	0.6
Nichi Lift	ISR700 2000	1	890	1.5	7.0	0.3	0.3
Mantis Crane	10010 1998	1	2,391	4.0	18.8	0.8	0.9
Mantis Crane	10010 2000	2	4,782	7.9	37.7	1.6	1.8
Crane	RT5223 2000	1	1,446	2.4	11.4	0.5	0.5
CAT Lift	7H83 1999	1	1,001	1.7	7.9	0.3	0.4
CAT Lift	TH83 1999	2	2,002	3.3	15.8	0.7	0.8
SIC Lift	600SJC 2000	1	734	1.2	5.8	0.2	0.3
Terex Lift	TX77 45R 1999	2	2,335	3.9	18.4	0.8	0.9
JLG Lift	3513 1999	1	1,168	1.9	9.2	0.4	0.4
Cradal Excavator	XL5200 1999	2	3,870	11.7	31.8	3.0	2.5
Cradal Excavator	XL5200 2000	1	1,935	5.9	15.9	1.5	1.2
Deere Dozer	850C 2000	1	2,135	3.5	16.8	0.7	0.8
CAT Dozer	953C 1999	3	4,037	6.7	31.8	1.3	1.5
Total Number of Units		**24**					
Total Emissions (kg/day)				**63.2**	**264.2**	**13.6**	**14.1**
Total Emissions Reductions Under Diesel Engine Retrofit Program (kg/day)				**42.1**	**0.0**	**13.6**	**3.5**

Source: Massachusetts. Turnpike Authority, Technical Memorandum – Emission Reduction Estimates from the Construction Equipment Diesel Retrofit Program. November 2000

TABLE 3
I-95 New Haven Harbor Crossing Project Construction Phase
Projected Emission Reductions and Cost of Diesel Engine Retrofit Program

Contract	Total Number of Units	Total Tota Engine HP	Total Utilized Annual Hp-hr	Annual Emission Reductions							Total Projected Cost (1)	
				Oxidation Catalyst			Four Way Catalyst QUADCAT ™				Oxidation Catalyst	QUADCAT ™
				CO	HCs	PM10	CO	NOx	HCs	PM10		
	#	hp	hp-hr/yr	tons/year	tons/year	tons/year	tons/year	tons/year	tons/year	tons/year	(dollars)	(dollars)
Contract B	71	18,999	17,255,587	29.3	11.1	2.5	58.7	37.6	17.7	7.5	151,992	474,975
Contract C	62	15,817	14,212,442	24.2	9.0	2.0	48.5	31.1	14.4	6.1	126,536	395,425
Contract D	31	8,367	7,781,314	14.3	5.4	1.2	28.5	17.1	8.7	3.5	66,936	209,175
Contract E	58	15,592	14,070,826	25.6	9.7	2.1	51.3	31.0	15.5	6.4	124,736	389,800

1. Total projected cost is based on all units retrofitted at an average of 8 dollars per HP for oxidation catalyst equipment and 25 dollars per HP for QUADCAT™ equipment.

Source: Guido Schattanek, Technical Memorandum – I-95 Q-Bridge Project – Projected Air Pollution Benefits and Costs of Diesel Retrofit and/or Clean Fuels Program For Construction Phase, Connecticut. Department of Transportation, December 4, 2000

TABLE 4

I-95 New Haven Harbor Crossing Project Construction Phase

Projected Emission Reductions and Cost of Clean Fuels Program

Contract	Total Number of Units	Total Engine HP	Total Utilized Annual Hp-hr	Annual Emission Reductions					Total Projected Cost (1)	
				PuriNOx™		BIODIESEL				
				NOx	PM10	CO	HCs	PM10	PuriNOx™	BIODIESEL
	#	hp	hp-hr/yr	tons/year	tons/year	tons/year	tons/year	tons/year	(dollars)	(dollars)
Contract B	71	18,999	17,255,587	30.0	2.5	14.7	6.7	2.5	138,045	215,695
Contract C	62	15,817	14,212,442	24.9	2.0	12.1	5.4	2.0	113,700	177,656
Contract D	31	8,367	7,781,314	13.7	1.2	7.1	3.2	1.2	62,251	97,266
Contract E	58	15,592	14,070,826	24.8	2.1	12.8	5.8	2.1	112,567	175,885

1. Total projected cost is based on total annualized hp-hr of equipment used, fuel consumption rate of 0.05 gal per hp-hr, and additional over diesel fuel cost 0.16 dollars and 0.25 dollars per gallon for PuriNOx™ and BIODIESEL program, respectively.

Source: Guido Schattanek. Technical Memorandum – I-95 Q-Bridge Project – Summary of Projected Air Pollution Benefits and Costs of Diesel Retrofit and/or Clean Fuels Program For Construction Phase, Connecticut. Department of Transportation, December 7, 2000