FINAL REPORT

Scoping Study to Evaluate Locomotive Emissions Operating in New Haven, Connecticut and Potential Control Options

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1. INTRODUCTION

1.1. Overview

Diesel powered locomotives emit a number of pollutants of concern to public health officials and air quality regulators. These include fine particulate matter ($PM_{2.5}$), oxides of nitrogen (NOx), hydrocarbon (HC), carbon monoxide (CO), and compounds designated as hazardous air pollutants by the U.S. Environmental Protection Agency (EPA).[1] Although more stringent federal standards will go into effect for locomotive engines over the next few years, nationwide thousands of in-use locomotives will continue to emit large amounts of pollution for the foreseeable future, absent further control measures. In addition, locomotive engines are under-regulated relative to other mobile sources of air pollution. Consequently, a variety of cost-effective emissions control measures could achieve significant reductions in this sector.

The locomotive fleet in and around New Haven, Connecticut includes line-haul freight, commuter, intercity rail, and switch locomotives. To better characterize pollution from locomotives operating in and around New Haven, NESCAUM has developed a preliminary inventory of locomotive emissions in the New Haven area, and has evaluated potential control options to reduce locomotive pollution. This report presents the findings of this work. This report focuses on emissions in New Haven and Fairfield since most of the rail activity in Connecticut takes place in these two densely populated counties. This study is intended to provide the Connecticut Department of Environmental Protection (CT DEP) with information on approaches to reduce locomotive emissions.

Some locomotive operators in the New Haven area are undertaking initiatives to reduce locomotive and switcher emissions. For example, the Connecticut Department of Transportation (CT DOT) is planning to retire and replace thirteen pre-Tier 2 diesel locomotives with state-of –the art emissions compliant locomotives, and to replace eight diesel locomotives with electric multiple-unit locomotives. To reduce emissions from switcher idling and promote fuel efficiency, the Providence and Worcester Railroad is seeking opportunities to purchase a hybrid switcher locomotive in addition to the use of auto-shut off technologies. Strategies such as these considered by the State and P&W could ultimately reduce emissions up to 40%.

The report is divided into four sections: Section 1 provides background information on the health impacts of diesel exhaust, locomotive engines and operations, and federal regulations to control locomotive emissions; Section 2 provides a summary of the New Haven locomotive emissions inventory; Section 3 provides an overview of emissions control options for locomotives and recommendations on emissions control strategies; and Section 4 provides information regarding effective methods for outreach and policy implementation.

[1] EPA has designated 21 compounds as mobile source air toxics. Diesels emit particulate, formaldehyde, acetaldehyde, and others that are included in this list.

1.2. Background

1.2.1. Health Impacts of Diesel Exhaust

Diesel engine exhaust consists of a complex mixture of hundreds of constituents in either a gas or particle form. Diesel engine NOx and HC emissions contribute to elevated ground level ozone. Ozone is a highly irritating gas that produces acute effects including coughing, shortness of breath, and reductions in lung function. Because of the adverse effects of ozone, the EPA established a daily 8-hour average standard of 80 parts per billion (ppb) in 1997. Particulate matter is associated with both cancer and non-cancer health effects and long-term and acute public health effects. Diesel exhaust has been designated a potential carcinogen by the EPA. Diesel particulate has been designated a toxic air contaminant by the California Air Resources Board (CARB). Public health concern regarding fine particle exposure (i.e., particles with an aerodynamic diameter less than 2.5 µm) is based on a series of well-conducted epidemiological studies. Recent studies have shown that current levels of particulate air pollution are associated with excess morbidity and mortality among the general population and has furthered concern about the risk of diesel exhaust.[2] In 2004, the city of New Haven was designated a non-attainment area for $PM_{2.5}$ by EPA. Health and air quality impacts associated with exposure to fine particles are of special relevance because diesel exhaust is virtually all in the fine particle size range. Therefore, it is a potentially important contributor to ambient levels of fine particle pollution, especially in urban areas. For this reason, reducing diesel engine emissions will be an important part of state efforts to reach air quality and public health goals.

1.2.2. Background - Locomotive Engines and Operations

The diesel electric locomotive has been in use in the United States since 1925, primarily for freight transportation. Currently, only 5% of all locomotives in the U.S. are used for the transportation of people. The design of the diesel electric locomotive allows the speed or power of the diesel engine to be decoupled from the speed/power of the train. That is, the train can be traveling 80 mph while the diesel engine is at 10% of its power capacity, or the train can be traveling at 10 mph while the diesel motor is operating at 80% of its power. The diesel electric locomotive does not directly transmit power from the engine to drive the wheels. Rather, the engine is used to drive an alternator, which then supplies electricity for "traction motors" which in turn drive the wheels. In very simplistic terms, the diesel engine of a diesel electric locomotive is a very large generator of electricity, whose power is used to propel the train. Because of this characteristic, a locomotive engine does not necessarily experience the amounts of stress associated with truck engines when climbing an incline.

The power output of the engine is set at 8 discrete power levels or traction modes, which are governed by throttle notches. Throttle notch positions are numbered 1-8, with

[2] The American Journal of Respiratory and Critical Care Medicine, March 15, 2006.

1 being the least powerful and 8 the most powerful. Locomotives employ medium speed large bore diesel engines. Unlike other diesel engines, locomotive engines only experience transient conditions when moving between throttle notches to change to another constant speed/load condition. At most times, they run at steady states.

Both 2-stroke and 4-stroke engines can be found in the diesel electric locomotive marketplace. These machines can accumulate up to 250,000 miles in a year and have an average total life of approximately 40 years.[3] As a result, the turnover rate of locomotive engines is very slow. Approximately 400-500 new locomotives are manufactured each year. Locomotive engines are designed to be remanufactured five to six times during their total life. Approximately 2,000-3,000 locomotive engines are remanufactured each year. The rebuilding of locomotive engines provides the opportunity for emission control upgrades. There are a variety of other options for reducing locomotive emissions including: auto and anti-idling technologies; engine rebuild upgrades, in-use maintenance; clean fuels, and emission control technologies. The age, type, activity, and engine characteristics of locomotive engines must be carefully evaluated in order to determine which control strategy is optimal.

Freight rail companies are classified as either Class I, regional, or local depending on company annual revenues. Freight rail operations use both line haul and switch locomotives. Line haul locomotives operate long distances at relatively constant speeds and are generally characterized as steady state operation. Switch locomotives assemble and disassemble trains in a local switchyard and tend to have more transient operational characteristics. Switch engines are primarily older line-haul or rebuilt engines. Passenger locomotive operations are more similar to line-haul freight operations. On a national basis, 73 percent of the freight industry's vehicle miles traveled (VMT) are from line-haul operations, regional freight haulers represent about 15 percent of the VMT, and local haulers about 12 percent of the VMT. Local railroads include switching and terminal operations and small line-haul operators. Switch locomotives assemble and disassemble trains at local rail yards.

The following rail lines operate in the New Haven area: passenger rail includes Shore Line East, New Haven Line[4] and Amtrak; and freight rail includes CSX and Providence and Worcester. While line-haul freight trains are the largest national source of locomotive emissions, commuter and switching operations may have significant local impact on air quality and public health. In some northeast states, over half of locomotive emissions come from commuter and passenger rail operations.[5]

1.2.3. Federal Locomotive Emissions Standards

EPA finalized locomotive emissions standards in 1997, which became effective in 2000.[6] Three separate sets of emission standards were established, with applicability of

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[3] Personal communication with Mr. Peter Hutchins of the USEPA, Office of Mobile Sources.
[4] The New Haven Line consists of the New Haven Line operated by CTDOT and Metro North, a contract operator for the State of Connecticut's Commuter Rail Service.
[5] NESCAUM, "Nonroad Engine Emissions in the Northeast" 1999
[6] Federal Register vol. 63, No. 73 "Emissions Standards for Locomotives and Locomotive Engines, Final Rule" April 16, 1998

the standards dependent on the date a locomotive is first manufactured. The first set of standards (Tier 0) apply to locomotives and locomotive engines originally manufactured from 1973 through 2001, at any time they are remanufactured. The second set of standards (Tier 1) apply to locomotives and locomotive engines originally manufactured from 2002 through 2004. These locomotives and locomotive engines will be required to meet the Tier 1 standards at the time of manufacture and at each subsequent remanufacture. The final set of standards (Tier 2) apply to locomotives and locomotive engines manufactured in or after 2005. Tier 2 locomotives and locomotive engines will be required to meet the applicable standards at the time of original manufacture and at each subsequent remanufacture. Electric locomotives, historic steam powered locomotives, and locomotives originally manufactured before 1973 do not contribute significantly to the emissions problem, and thus, are not regulated. Tables 1, 2, and 3 provide the Tier 0, Tier 1, and Tier 2 locomotive emission standards in grams per gallon of fuel (g/gal).[7]

Table 1: Tier 0 Locomotive Standards

	NOx (g/gal)	**PM (g/gal)**	**HC (g/gal)**	**CO (g/gal)**
Line-Haul	270	6.7	10	26.6
Switch	362	9.2	21	38.1

Table 2: Tier 1 Locomotive Standards

Estimated Controlled Emission Rates for Locomotives Manufactured in 2002-2004 (Tier 1)				
	NOx (g/gal)	**PM (g/gal)**	**HC (g/gal)**	**CO (g/gal)**
Line-Haul	139	6.7	9.8	26.6
Switch	202	9.2	21	38.1

Table 3: Tier 2 Locomotive Standards

Estimated Controlled Emission Rates for Locomotives Manufactured after 2004 (Tier 2)				
	NOx (g/gal)	**PM (g/gal)**	**HC (g/gal)**	**CO (g/gal)**
Line-Haul	103	3.6	5.4	26.6

As can be seen from Tables 1, 2, and 3, the new regulation will - when fully implemented - result in substantial reductions in locomotive engine emissions. Since locomotive emissions had not been regulated before 2000, it was necessary for EPA to create a comprehensive program, including not only emission standards, but also test procedures and a full compliance program. The 1997 rulemaking affected railroads, locomotive manufacturers, and locomotive re-manufacturers. A unique feature of the rule is the regulation of the engine remanufacturing process, including the remanufacture of locomotives originally manufactured prior to the effective date of this rulemaking. Standards that only applied to locomotives manufactured after the effective date of the rule would not achieve significant emissions reductions in the near term, since

[7] EPA “Technical Highlights, Emission Factors for Locomotives" EPA420-F-97-051, December 1997”

locomotives remain in service for decades. Regulation of the remanufacturing process is critical because of the practice of rebuilding locomotive engines during their service lives.

In 2004, EPA finalized a rule that requires the locomotive fuel sulfur level to be reduced to 500 parts per million (ppm) in 2007 and 15 ppm in 2012. This rule, when implemented, will reduce PM emissions from locomotives and facilitate the introduction of emission control devices in this sector.[8]

2. RESULTS OF THE EMISSIONS INVENTORY

This section describes the method and provides results for the New Haven area locomotive inventory. The inventory method is described in section 2.1 and the inventory results in section 2.2.

2.1. Inventory Method

An emissions inventory of NOx, PM, CO, and HC was generated for all of the line hauls, switchers, commuter and passenger/inner-city rail that operate in New Haven. The study relied on fuel usage, track mileage, published information on emission factors, as well as recent emissions inventory data. In this section, the method is given for the New Haven locomotive emissions inventory. The section is divided three sub-sections: Section 2.2.1 describes the different locomotive types and operational characteristics; Section 2.2.2 provides information on how data was obtained for each rail line; and Section 2.2.3 describes how emissions were estimated.

As a first step, NESCAUM collected information on the following types of locomotives:

Line Haul/Freight **–** The line haul/freight locomotive companies are Providence and Worcester and CSX. Both line haul companies transfer cargo from coal products, fuel, food and other commercial items.

Switcher Locomotives **–** The New Haven Line operates switcher locomotives in the rail yard. Switchers mainly provide assistance moving cars in and around the rail yard.

Commuter /Passenger Rail **–** Shore Line East, New Haven Line and Amtrak provide commuter transportation services to the public. In total, the New Haven Line includes a 72 mile multiple track route extending from New Haven, Connecticut to Grand Central Terminal in New York. The passenger service operates with 344 electric multiple unit (EMU) cars, serviced by push-pull locomotives with coaches for service on some branch lines. Shore Line East provides a commuter service for passengers traveling from New London to New Haven, Monday through Friday, with some service through Stamford. The New Haven Line operates diesel as well as dual mode (diesel and electric)

[8] EPA "Clean Air Nonroad Diesel Rule," May, 2004

locomotives. Lastly, Amtrak operates both electric and diesel powered locomotives in Connecticut.

2.1.1. Data Acquisition

NESCAUM interviewed railroad operators on specific key operating parameters in order to obtain adequate information on each locomotive for the emissions inventory. Specific operating parameters were identified for two reasons: (1) to calculate emissions and (2) to determine the best method to reduce diesel emissions from the locomotive type. The operating parameters included the following:

- Locomotive function;
- Annual fuel consumption;
- Engine characteristics (Make and Model);
- Number of main engines;
- Horsepower of the main engine(s);
- Number of head end power unit(s);
- Horsepower of head end power unit(s);
- Track miles in the State of Connecticut, New Haven County, and Fairfield County.

The information collected for this inventory was collected in meetings with locomotive operators or by phone, email, or fax. In one case, NESCAUM was not able to collect all of the information needed to estimate emissions for the rail line. To estimate emissions for this operator, NESCAUM used inventory data from a previous emissions inventory completed in 1999.

2.1.2. Emissions Calculation

The basic steps taken to calculate locomotive emissions are listed below. Detail on each of these steps in provided later in this section.

1) Multiply the annual number of gallons of fuel consumed by main engines in a given operator's fleet by the emission factor for a given pollutant.
2) Convert grams per year to tons per year.
3) Multiply the emissions (tons per year) by the ratio of track miles in New Haven plus Fairfield counties divided by track miles in Connecticut for that operator.
4) Estimate the annual hours of use per year for head engine power units (HEPs).
5) Multiply hours of use by an emission factor, a load factor, and horsepower.
6) Convert to tons.
7) Repeat steps 1 through 4 for each operator and sum the emissions.
8) Repeat steps 1 through 5 for each pollutant.

Main Engine Emissions

The formula used for calculating main engine emissions is as follows:

Emissions = G * EF

Where:

G = annual gallons consumed

EF = emission factor for a particular pollutant

This equation yields emissions in grams per year. Grams are converted to tons by dividing by 908,800.

Emission factors for locomotive engines are available from EPA in grams per gallon of fuel (g/gal) for NOx, PM, hydrocarbon (HC), and carbon monoxide (CO). To calculate each operator's emissions in tons per year for these pollutants, annual fuel consumed (gallons) is multiplied by the emission factor for each pollutant.

The emission factors used by NESCAUM are presented below in Table 4.

Table 4: Emission Factors Used in This Analysis

	NOx (g/gal)	**PM (g/gal)**	**HC (g/gal)**	**CO (g/gal)**
Line-haul/ commuter	316	7.95	15.5	32.35
Switch	362	9.2	21	38.1

The emission factors are based on Table 1 (Tier 0 emission standards) shown on page 5. However, there is a difference between the EPA Tier 0 emission standards and the ones NESCAUM used. Line haul and switch locomotive emission factors differ due to the different work the locomotives perform. Based on conversations NESCAUM had with staff at national laboratories and other experts, we decided to average emissions for switch and line-haul to calculate line-haul engine emissions. This resulted in higher emission factors for line haul engines. We did this rather than use the EPA emission factors as they are listed in Table 1. The reason for doing this is the test cycle used to estimate locomotive emissions (the FTP) for line-haul engines is less rigorous than the demands made on the engine during normal use, and thus result in emission factors that are typically lower that real world emissions. In addition, the FTP-based emission factors do not take into account deterioration in emissions that occurs over time. Since locomotive engines are in service for many years between rebuilds, some emissions deterioration takes place. Because of this, in-use emissions are likely higher than the emission factors presented in Table 1. Table 2 shows that line-haul emission factors are averaged with switch from Table 1, while switch remain the same as in Table 1.

This calculation provided emissions in the state of Connecticut for each operator. In order to estimate emissions in New Haven and Fairfield counties, we divided the number of track miles in New Haven plus track miles in Fairfield county by track miles in Connecticut. This approach could over or under estimate emissions in the two counties given different terrain and duty cycles in different parts of the state. In addition, this approach assumes that miles traveled by locomotives are distributed evenly across all track miles in the state. This may not be the case as some parts of the state may have much more traffic than others. However, this was the best option available to us in this study.

Head Engine Power Units (HEPs) Emissions

Unlike line haul engines, head engine power units are smaller engines of approximately 500 horsepower. Since the emission factors for line haul engines were developed from testing much larger engines, NESCAUM used the emission factors developed by EPA for smaller land-based nonroad engines. These emission factors are found in the EPA's nonroad engine rule of 1998 and are shown in Table 5.[9]

Table 5: Emission Factors for Engines Less Than 1,000 HP

	NMHC + NOx (g/hp-hr)	**PM (g/hp-hr)**
Head End Power Unit (HEP)	4.8	0.15

For HEPs, emissions were calculated using the following formula typically used to estimate emissions from nonroad land-based diesel engines:

Emissions = HP * LF * A * EF

Where:

HP = horsepower
LF = load factor
A = hours used per year
EF = emission factor

NESCAUM used the EPA load factor in the NONROAD model. The load factor used for line haul engines was approximately 29% and for switchers approximately 10%.[10]

For HEPs, data on hours of use was needed in order to estimate emissions using the equation for land-based nonroad engines. Since data on hours of use per year was not available to NESCAUM, the following conversion factor was used to convert fuel consumption to hours of use:

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[9] Federal Register, Vol. 63, No.205 "Control of Emissions of Air Pollution from Nonroad Diesel Engines, Final Rule," October 23, 1998.
[10] http://www.epa.gov/oms/nonrdmdl.htm

HP-hrs = G x BTU/gal x thermal efficiency x hp-hr/BTU

Where:
G = gallons
BTU/gal = 138,690
Thermal efficiency = 40%
Hp-hr/BTU = 3.93×10^{-4}

The above conversion yields an estimate for activity that can be used in the emissions formula for nonroad land-based engines.

For one operator, Amtrak, fuel consumption was not available. However, emissions from Amtrak locomotives in Connecticut had been estimated as part of a 1999 emissions inventory conducted by NESCAUM for the Northeast states. We used the emissions inventory data from the 1999 report in the absence of more recent fuel consumption data.

2.2. Inventory Results

This section provides NOx, PM, HC, and CO emissions calculated in tons per year for each operator in the New Haven area. Table 6 provides emissions for each operator for the entire state of Connecticut and Table 7 provides emissions for New Haven and Fairfield counties only.

Table 6: Annual Emissions by Locomotives (Connecticut State Total)

Rail Line	NOx (tons per year)	PM (tons per year)	CO (tons per year)	HC (tons per year)
Commuter Lines				
Shoreline East	88.2	3.1	9.0	4.3
New Haven Line	360.7	11.3	37.3	19.1
Amtrak	868.2	26.0	110.2	37.1
Line Haul				
CSX	70.5	1.8	7.2	3.5
Providence & Worcester	98.8	2.5	10.1	4.8
Total State-wide Emissions	**1,486.4**	**44.7**	**173.8**	**68.7**

Table 6 includes state annual emissions for line haul, commuter rail and switcher locomotives. As described above, NESCAUM estimated emissions in the New Haven area by calculating a percent of track miles in New Haven plus Fairfield counties as compared to Connecticut total track miles. This approach has several shortcomings. The first is that different terrain in the state of Connecticut results in emissions that are likely different from area to area. This estimation does not take that factor into account.

Second, this estimation assumes that miles traveled by locomotive are distributed evenly across track miles.

Table 7: Locomotive Emissions in the New Haven Area (New Haven and Fairfield Counties)

Rail Line	**NOx (tons per year)**	**PM (tons per year)**	**CO (tons per year)**	**HC (tons per year)**
Commuter Lines				
Shoreline East	88.17	3.13	9.03	4.32
New Haven Line	360.7	11.3	37.3	19.09
Amtrak	498.2	14.9	63.1	21.2
Line Haul				
CSX	70.5	1.8	7.2	3.5
Providence & Worcester	20.7	0.52	2.12	1.02
Total Statewide Emissions	**1,038.3**	**31.6**	**118.7**	**49.1**

Table 7 includes New Haven and Fairfield annual emissions for line haul, commuter rail and switcher locomotives. As can be seen from Table 7, the majority of emissions from locomotive activity in Connecticut occur in New Haven and Fairfield counties. CSX has a total of 70 miles of track in Connecticut - all located in Fairfield and New Haven counties - and thus all of CSX's locomotive emissions take place in those two counties. This is unlike Providence & Worcester, which operates throughout the state. Passenger trains produce the majority of emissions in the two counties - 83 percent of total locomotive emissions in Fairfield and New Haven counties are emitted from the Shore Line East and the New Haven Line. The New Haven Line operates trains from Grand Central Terminal in New York City to New Canaan, Danbury, and Waterbury - all located within New Haven and Fairfield counties.

Emissions from head engine power units are presented in Table 8. All HEPs in Connecticut are located in the New Haven area. Emission from HEPs shown in Table 8 are in addition to the emissions shown in Tables 6 and 7 for NOx and non-methane hydrocarbons (NMHC). Emissions are expressed in NOx plus non-methane hydrocarbons.

Table 8: Head Engine Power Unit Emissions

Rail Line	**NMHC+NOx (tons/year)**
Head End Power Units (HEP)	
Shoreline East	29.20
New Haven Line	69.57
Total Emissions	**98.77**

HEP emissions for PM are calculated with main engine emissions in Table 7. Table 8 shows that emissions from HEPs are significant.

3. EMISSIONS CONTROL TECHNOLOGY OPTIONS

This section provides an overview of strategies to control emissions from locomotives.

Description of Emissions Control Technology Options

NESCAUM evaluated available emission control options that may be suitable for the rail lines that operate in New Haven. It is important to distinguish the different types of locomotives as recommendations for emission control options are considered. The three types of locomotives include: diesel, electric, and dual-mode.[*] The control options may differ depending on the type of locomotive.

The simplest and least expensive way to reduce PM emissions from existing diesel engines is to ensure that they are properly maintained. Proper maintenance and tuning can significantly improve emissions by ensuring the fuel is completely burned during combustion, rather than being emitted as exhaust PM. Proper maintenance and tuning, performed regularly, can also reduce operating costs by improving fuel economy, eliminating unnecessary maintenance, and extending engine life.

Rebuild Tier 0 and Tier 1 to Tier 2 Standards

Rebuilding older, higher emitting engines to newer engine emissions standards can provide emissions benefits. As can be seen from Tables 1, 2, and 3 on page 5 - Tier 2 emission standards reduce locomotive emissions by more than 50 percent over Tier 0 standards. Rebuilding engines reduces emissions by improving combustion through in-cylinder and fuel injection modifications.

Idle Minimization Technologies

There are six idle minimization technologies that are available to reduce idling from locomotives. The six technologies include: automatic engine stop-start controls (AESS); auxiliary power unit (APU); diesel-driven heating systems (DDHS); shore power plug-in unit, hybrid switching locomotive and a Gen-Set locomotive.

1. AESS - With an AESS control, the engine is shut down after a set idle time. This technology monitors water temperature, brake pressure and charges the battery. If any of the engine parameters are out of range, the engine is restarted. The engine stays on below 40 degrees F.

2. APU - An APU has the ability to shut off and restart the engine. It provides heat to the water and oil and also heats the main cab area. Similar to the AESS system, it maintains the brake air pressure and keeps the batteries charged.

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[*] A *diesel locomotive* runs on a diesel engine and generator. An *electric locomotive* can only use electricity from an external source, either a third rail or catenary overhead wire. A *dual-mode locomotive* can use a diesel gen-set as well as electric from a third rail or catenary overhead wire.

3. DDHS - A DDHS heats water and oil with waste heat. The technology charges batteries and powers the cab heaters. DDHS can be used in conjunction with a stop-start system.

4. Shore Power Plug In Unit - Generally used by commuter and passenger locomotives, a shore power system can be used to supply power to the cabin of locomotive in addition to keeping the engine at a safe operational temperature in cooler climates.

5. Hybrid Switching Locomotives – A hybrid locomotive replaces a 2,000 horsepower switcher and uses a 125 horsepower diesel engine to supply energy to 60,000 pounds of sealed lead-acid batteries. The batteries are expected to have a life span of ten to fifteen years. Hybrid locomotives utilize power from batteries and a diesel gen-set.

6. Gen-Set Locomotive – Unlike a hybrid that uses batteries for power, a Gen-Set locomotive uses non-road certified engines rather than rail engines. Gen-Set locomotives are certified to non-road emission standards.

Regenerative Braking

All locomotives are able to save power through regenerative braking. Most locomotives shunt this power to registrar grids where it is lost as heat. Electric and Dual-mode locomotives can feed this regenerative power back into the wires, where hybrids store the power in the batteries.

Use of Cleaner Fuels

Refueling involves substituting existing diesel fuel with cleaner fuels. The use of low sulfur diesel fuel (500 ppm or less) could provide immediate and cost effective PM emissions reductions in the New Haven locomotive fleet for both the main locomotive engine and the head end power unit (HEP). Studies show that a decrease in fuel sulfur from 3,000 ppm to 500 ppm results in an approximate 10 percent reduction in PM emissions (this percentage is higher in engines with “dry” exhaust) at a cost of 1 to 3 cents per gallon. Cleaner fuels will be required beginning in 2007 (500 ppm fuel) but early introduction could provide emissions benefits at a relatively low cost.

Other fuels are available that have been tested and verified by EPA and CARB for emissions performance. EPA and CARB have verified cleaner fuels for onroad applications but nonroad. Though not verified for nonroad applications, there are a number of alternative fuels such as ultra low sulfur diesel (15 – 50 ppm), bio-diesel, emulsified fuel, and oxygenated diesel can reduce emissions from locomotives. There are some issues surrounding the use of certain alternative fuels such as engine wear concerns with bio-diesel; unknown and untested durability issues with emulsified fuel with 2 stroke engines; and issues with supply and lubricity with alternative fuels that need special consideration. Emulsified fuel reduces power somewhat. This can be an issue for engines that operate at full power during the duty cycle.

Repower with Tier 2 Engine

Though a more costly option, the replacement of just the engine in diesel powered locomotive, "repowering," may be appropriate where a fleet operator has a locomotive with a useful body life that is longer than the useful life of the engine itself. Locomotive owners and operators could consult the original equipment manufacturers to ensure that the torque and horsepower of replacement engines are properly matched to the original application to prevent damage to the vehicle or equipment. In the case of a catastrophic engine failure, replacing an entire Tier 0 or Tier 1 engine with a Tier 2 engine may be possible.

EPA's 1997 locomotive standards do not require passenger locomotives to be rebuilt to Tier 0 standards until 2007. Since rebuilds are infrequent (sometimes only once every decade) ensuring that passenger locomotives undergoing a rebuild before 2007 are rebuilt to Tier 0 standards could provide important benefits.

Replace Entire Vehicle or Equipment

Replacing the entire vehicle or equipment may be the best, most cost effective option for some of the oldest engines. If equipment is replaced, it should be replaced with electric and hybrids rather than conventional equipment. In some cases, the retirement and replacement of older diesel equipment and engines may provide the most practical and cost effective emissions improvements for a particular fleet. Replacement enables fleet operators to replace the emissions profile of their oldest and worst emissions performers with state of the art technology.

Retrofit with Emissions Control Technologies

In Boston, the MBTA, EPA and M.J. Bradley Associates are testing the use of a diesel oxidation catalyst on a commuter rail train. The completion of this pilot project will provide valuable information and practical experience to locomotive operators and state air quality regulators that would like to explore this option. Diesel oxidation catalyst retrofit of locomotive engines holds the potential to significantly reduce the soluble organic fraction of PM emissions, and substantially reduce hydrocarbon emissions (including highly toxic polyaromatic hydrocarbons, formaldehyde, and acetaldehyde), as well as CO emissions.

Recommendations

In this section, recommendations for potential control options are given for all rail lines inventoried for New Haven. Appendix A provides detailed information for the rail lines that operate in the New Haven and Fairfield area.

1. Rebuild to Tier 2

Rebuild line-haul and switch engines to Tier 1 and Tier 2 rather than Tier 0. This option may help save money for the operator with five year return on investment requirement. The upgrade may be a zero cost option and a highly cost effective emission reduction strategy.[11] A Tier 2 engine emits approximately 60 percent less NOx and 47 percent less PM than a Tier 0 engine. If all Tier 0 or pre-control locomotives were rebuilt to Tier 2 emissions levels, a substantial reduction in emissions could be achieved. Operators could evaluate the schedule for rebuilding locomotive and switch engines, consult with engine manufacturers, and plan to upgrade the engines that are scheduled for rebuild.

2. Idle Minimization

All locomotives could utilize idle minimization technologies with a good return on investment. The return on investment occurs because operators save on fuel costs given that reducing idling reduces fuel consumption. Idle minimization technologies could include automatic engine stop-start controls (AESS), auxiliary power units (APU), and diesel-driven heating systems (DDHS). A fleet could start with ten locomotives each year as a revolving loan fund, with fuel savings potentially funding the subsequent locomotives. Another idle minimization technology is a hybrid or Gen-Set locomotive for switch applications. Combining idle minimization strategies with emission control technologies like a diesel oxidation catalyst will help reduce PM emissions.

3. Cleaner Fuels

All locomotives can be operated on low sulfur diesel fuel with a sulfur content of 500 parts per million in both the main engines and HEP units. The use of low sulfur fuel facilitates other controls, reduces sulfur dioxide (SO2) and PM emissions, and reduces component corrosion from sulfuric acid. As mentioned previously, approximately 10 percent of particulate emissions can be reduced by switching from high sulfur fuel to 500 ppm fuel. A ten percent reduction in PM emissions from locomotives operating in the New Haven area would amount to approximately 3 tons of PM reduced annually.

4. Replace with Tier 2 Locomotives

When considering the purchase of a new locomotive, operators could consider buying new Tier 2 locomotives as best available control technology. Operators could also consider combining this strategy with idle minimization technologies and retrofitting with a diesel oxidation catalyst.

5. Retrofit with Diesel Oxidation Catalyst (DOC)

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[11] In EPA's 1997 locomotive rule, the Agency estimated the average cost-effectiveness of the standards to be about $163 per ton of NOx, PM and HC.

Recent retrofits of locomotives with oxidation catalysts have shown that for some engines this technology is feasible. Where possible, operators should consider further retrofitting line-haul and switch locomotives with DOCs for 25% to 50% PM emission reductions. Space and other constraints need to be taken into consideration when evaluating retrofit with DOCs. Recent work to retrofit locomotives with DOCs has shown promise to overcome some of issues such as space constraints.

6. Retire and Phase Out Old Locomotives

Operators should phase out old locomotives and destroy for scrap steel rather than selling old locomotives to another operator.

4. OUTREACH AND POLICY OPTIONS

4.1. Overview

Since full implementation of the more stringent locomotive emissions standards will take many years, the use of incentives and voluntary actions to reduce diesel emissions from locomotives are critical in order to achieve near-term emissions reductions. There are various approaches that can be taken to promote diesel emissions reduction programs in the locomotive sector. This section provides recommendations on how to encourage diesel emissions reduction programs through means of education and outreach, policy implementation and partnership development.

4.2. Education and Outreach

Education and outreach campaigns can effectively promote voluntary diesel emissions reduction programs. A number of outreach programs have been administered by EPA through the Voluntary Diesel Retrofit Program. One of the more successful programs is the Clean School Bus USA program. EPA has worked with state agencies to reach out to school districts and school bus operators to participate in reducing diesel emissions from school buses. A number of workshops and seminars have been carried out to better inform public and private school bus companies and superintendents on importance of reducing diesel emissions from school buses. Workshops and seminars provide an opportunity for schools, school bus operators, and local and state officials to discuss strategies to reduce diesel emissions. Workshop materials have been developed to provide background information on air quality and diesel pollution and its effects on public health; available EPA verified emission control technologies; and implementing a retrofit program. A similar approach can be taken with locomotive companies.

On January 26, 2006, the New England Railroad Club and NESCAUM, on behalf of the Northeast Diesel Collaborative, organized a "green technologies" panel at the Railroad Club membership meeting. The panel was called "Saving Fuel and Reducing Emissions with 'Green' Locomotive Technologies" and included presentations on the Northeast Diesel Collaborative, fuels and technologies, and a retrofit demonstration project with the Massachusetts Bay Transportation Authority's commuter rail. In addition, The New England Railroad Club and the Northeast Diesel Collaborative hosted a special seminar at the 2006 New England Rail Expo & Forum. This seminar examined key issues facing railroad operators today, including:

- new and emerging technologies that can save fuel and reduce emissions;
- upcoming fuel regulations and their effects on the rail industry in the Northeast;
- funding opportunities - including low interest loans;
- New York Container Terminal's choice to use on-dock hybrid locomotives;
- The Port Authority of New York & New Jersey's regional rail improvement program.

Informational sessions such as these provide key information to operators on the benefits of undertaking emission reduction programs. These benefits include: noticeable reduction in costs and fuel consumption; improved maintenance and operations; improved air quality for workers and the surrounding community; and improved relations with the community.

4.3. Policy Options

There are various incentive programs and policy options that can be utilized to promote the reduction of diesel emissions from rail lines in New Haven.

4.3.1. Incentivized Programs

Federal, State, and Local Grant Programs

Through grant programs, equipment owners can receive direct funding to purchase cleaner equipment, cleaner engines, emission control technologies and cleaner fuels. Oftentimes, grant programs elicit funding to cover incremental costs of lower emissions technology. Grants distributed for diesel emissions reduction programs are run by EPA, states, regional air quality districts, cities, and ports.

The most successful grant program to reduce diesel emissions is EPA's Voluntary Diesel Retrofit Program. Programs within this grant program include; Clean School Bus USA, West Coast Collaborative, Northeast Diesel Collaborative, Diesel Retrofits to Benefit Sensitive Communities and Diesel Retrofit Grants. Equipment owners that apply for any of the above grants are required to meet set criteria established by EPA.

State Implementation Plans (SIPs)

States with areas that do not meet National Ambient Air Quality Standards (NAAQS) are required under the Clean Air Act Amendments (CAAA) of 1990 to submit to EPA State Implementation Plan that demonstrates how the non-attainment areas will achieve NAAQS within a set time period. Locomotive operators that participate in diesel emissions reduction programs can provide states with credit toward required SIP emissions reductions. This incentive applies to state air quality agencies rather than private operators.

Supplemental Environmental Projects (SEPs)

A SEP is an environmentally beneficial project that a company agrees to undertake in settlement of an enforcement action by EPA. SEPs have been used more frequently in the recent years. As part of one recent SEP, a total of $20 million dollars was administered for the retrofit of 2,500 school buses. SEPs could be used to fund locomotive emission reduction projects.

Tax Incentives

Tax incentives are used by governments to influence the behavior of individuals and corporate entities. Governments reduce the cost of items or activities by reducing or eliminating taxes on certain items or activities. Several states have participated in tax incentives that are aimed to promote diesel emissions reduction programs. There are three categories for tax incentives; tax exemptions; tax deductions and tax credits. For example, tax incentives have been used recently to spur the introduction of hybrid electric passenger cars.

4.3.2. Environmental Stewardship and Non-incentivezed Programs

There are ways that the government can offer incentives other than those that are monetary. Locomotive companies may want to take steps to reduce emissions with the goal of improving operation efficiency or improving environmental stewardship. Companies are increasingly finding that it makes good business sense to proactively participate in environmental stewardship programs. The government can help to encourage these actions by providing guidance, education, and recognition. Some of the ways which state and federal governments can encourage environmental stewardship include:

- providing public recognition for companies that undertake environmental stewardship programs;
- providing outreach materials to reduce diesel emissions;
- providing guidance on voluntary actions to access current emissions and how to plan for improvements;
- act as a facilitator to create opportunities for information exchange and to leverage additional funding.

Environmental Management System (EMS)

One way for companies to take part in environmental stewardship is by the development of an Environment Management System (EMS). An EMS plan allows companies to integrate environmental decision making into an organization's day-to-day operations. Some of the benefits of developing an EMS include:

- Improved community relations and public image
- Cost savings
- Improved internal communication
- Increased competitiveness and market opportunities

CONCLUSIONS

Locomotive emissions in the New Haven area are significant totaling over 1,000 tons of NOx, 31 tons of PM, 119 tons of CO and 49 tons of HC. Locomotives used in passenger operations contributed the majority of emissions in New Haven and Fairfield counties. These and other locomotives operate in densely populated areas and thus reducing emissions from these engines is important in reducing public exposure to diesel emissions. While control options for this sector are not as numerous as for other types of diesel engines – given space and other constraints, a number of emission control options exist and should be considered. Switching to cleaner fuels, using idling reduction technologies, and retrofitting locomotive engines could reduce emissions and public exposure to locomotive pollution in the New Haven area.

Some operators are undertaking initiatives to reduce locomotive and switcher emissions. For example, the Connecticut Department of Transportation (CT DOT) is planning to retire and replace thirteen pre-Tier 2 diesel locomotives with state-of –the art emissions compliant locomotives, and to replace eight diesel locomotives with electric multiple-unit locomotives. To reduce emissions from switcher idling and promote fuel efficiency, the Providence and Worcester Railroad is seeking opportunities to purchase a hybrid switcher locomotive in addition to the use of auto-shut off technologies. Strategies such as these considered by the State and P&W could ultimately reduce emissions up to 40%.

APPENDIX A
New Haven Fleet Inventory

New Haven Rail Lines	# of Engines	Engine Type	Engine HP
Commuter Lines			
Shoreline East			
Main Engine	6	GP40/ EMD	3000
Head End Power Unit (HEP)	6	Cummins	500
New Haven Line			
Main Engine			
Type 1	6	Diesel/Elec FL9M	1750
Type 2	4	Diesel/Elec Genesis	3200
Head End Power Unit (HEP)	6	Caterpillar	500
Switcher Engine	2	EMD 645 Roots Blown Engine GP 35M	2000
Shuttle Wagon High Rail Car Mover	2	Cummins Diesel	175
Metro-North (CTDOT contract)			
Main Engine	1	Electric (344 EMUs)	
Switcher Engine	2	EMD 645 Roots GP 35M	2000
Amtrack			
Main Engine			
Vermonter	1	GE/P40	4000
Hartford Locos	2	GE/P40	4000
Regional (Boston to D.C.)	1	Electric	
Acela Express (New Haven to NYC)	1	Electric	
Line Haul			
CSX			
Main Engine	4	EMD 645/GP40	3000
Providence & Worcester			
Main Engine	5		
P&W 1		GE/ EMD P40-7	4000
P&W 2		GM/EMD B-23-7	2300
P&W 3		GE/EMD GP38-EMD	2000
P&W 4		GE/EMD B36-7	3600
P&W 5		GE/EMD B36-7	3600