NYSERDA Clean Diesel Technology Off-Road Demonstration Program Case Study

Final Report 08-24
December 2008

New York State
Energy Research and
Development Authority

NYSERDA New York State Energy Research and Development Authority

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NYSERDA Clean Diesel Technology
Off-Road Demonstration Project
Case Study

Final Report

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NOTICE

This case study, "Case Study: NYSERDA Clean Diesel Technology Off-Road Demonstration Program", is in response to Environmental Protection Agency (EPA) Request for Applications (RFA) No. OAR-CCD-05-14. It does not necessarily represent final EPA decisions or positions, and is intended only to present a technical analysis of issues using currently available data. Such reports are provided to facilitate the exchange of technical information and to inform the public of technical developments.

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ADPF	active diesel particulate filter
BAT	best available technology
CARB	California Air Resources Board
CATI	Clean Air Technologies, Inc.
CCRT	catalyzed continuously regenerating technology
CNG	compressed natural gas
CO	carbon monoxide
CRT	continuously regenerating technology
DOC	diesel oxidation catalyst
DPF	diesel particulate filter
DSNY	Department of Sanitation of New York City
ECT	emission control technology
ECS	Engine Control Systems
EPA	U.S. Environmental Protection Agency
FTF	flow-through filter
FTP	federal test procedure
HP	Horsepower
HC	hydrocarbon
NOx	oxides of nitrogen
NCDC	National Clean Diesel Campaign
NYCDEP	New York City Department of Environmental Protection
NYCMA	New York City Metropolitan Area
NYS	New York State
NYSDEC	New York State Department of Environmental Conservation
NYSERDA	New York State Energy Research and Development Authority
PDPF	passive diesel particulate filter
PEMS	portable emissions monitoring system
PM	particulate matter
SCR	selective catalytic reduction
Southern	Southern Research Institute
ULSD	ultra-low sulfur diesel
VOC	Volatile Organic Compounds

1.0 INTRODUCTION

Diesel engines can be highly energy efficient and durable, yet emissions from diesel engines have historically contributed to a number of serious air pollution problems. Recognizing this, the U.S. Environmental Protection Agency (EPA) has passed regulations to reduce emissions from new diesel engines for on-highway and, more recently, off-road applications. These regulations also require the use of lower sulfur diesel fuel. In on-highway and off-road inventories, however, existing diesel engines will continue to emit higher levels of pollutants, including particulate matter (PM), nitrogen oxides (NOx), carbon monoxide (CO), and air toxics. Within New York State (NYS), diesel emissions significantly affect ambient air quality, which contributes to non-attainment of air quality standards in areas such as the New York City Metropolitan Area (NYCMA).

To address the issues associated with the legacy fleet of diesel engines, several local and state initiatives and laws have been introduced that focus on reducing pollution from existing diesel engines. As more voluntary programs are initiated, regulations enacted, and emission reductions sought, more information about the various strategies for emission reductions is needed. This project provides detailed information to interested stakeholders, including end-users, regulators, and others, about the performance of various emission-control technologies (ECTs) on high-priority off-road equipment operated in the NYCMA. The project was part of a broader Clean Diesel Initiative at the New York State Energy Research and Development Authority (NYSERDA) that supports development of products and technologies to reduce emissions from diesel engines, funding for school buses and other retrofits across NYS, and demonstration and evaluation of various emission reduction strategies.

Concurrent with this project, the U.S. EPA's National Clean Diesel Campaign (NCDC) requested applications for grants intended to demonstrate the applicability and feasibility of verified diesel-emission retrofits in the off-road construction sector. NYSERDA applied for and received funding to acquire and demonstrate the ECTs discussed in this report. This leveraging of the EPA and NYSERDA funds allowed expanded demonstration programs at a significant cost savings to the participants and significantly increased the number of retrofits evaluated under the NYSERDA program.

NYSERDA coordinated the use of EPA funds for purchasing and installing retrofit technologies as a sub-grant program. NYSERDA and their prime contractor, Southern Research Institute (Southern), selected ECTs as part of the NYSERDA-funded project. Once equipment, fleets, and retrofits were selected, the project employed EPA grant monies for the specification, procurement, installation, and evaluation of California Air Resources Board- (CARB) or EPA-verified retrofit ECTs on off-road construction equipment applications in the NYCMA.

1.1. PROJECT GOALS

In initial phases of NYSERDA's Clean Diesel Initiative program, NYSERDA identified diesel construction equipment as the priority off-road equipment sector in NYS based on a baseline emission inventory conducted for calendar year 2002. Both within the NYCMA and across the State, diesel construction equipment dominates the off-road emission inventory, accounting for nearly 50% of all diesel emissions. The NYCMA includes the following 10 counties: New York, Queens, Bronx, Kings, Richmond, Nassau, Suffolk, Rockland, Putnam, and Westchester counties. In addition, nearly 67% of all NOx emissions from construction equipment are generated in the NYCMA. Nine counties in the NYCMA are in severe non-attainment for NOx and Volatile Organic Compounds (VOCs), while New York County is in moderate non-attainment for PM-10. Seven of the counties are also in moderate non-attainment for CO.

The primary demonstration project goal was to provide information to end users and regulators to allow them to determine what the best available technologies (BAT) are for diesel emission reductions in the off-road fleet. A significant driver for this program was the implementation of New York City Local Law 77 of 2003, which requires diesel equipment used in public works construction projects in the NYCMA to use ultra low sulfur diesel (ULSD) and BAT retrofit diesel emission controls. The project data provides information the New York City Department of Environmental Protection (NYCDEP) may use in identifying feasible retrofit technologies and to the regulated community and other users. This information addresses economic, operational, and maintenance impacts of these technologies that have been previously unavailable.

Project objectives included:

- identify off-road equipment that contributes significant emissions in the NYCMA
- evaluate the feasibility of specific verified/certified control strategies on the priority equipment
- demonstrate specific retrofit solutions in real-world applications
- help identify BAT for implementation of NYC Local Law 77-2003
- work with government agencies, technology vendors, equipment owners, and trade associations to disseminate and promote results of the program
- educate equipment owners about the impacts of retrofits and the potential impacts of technologies on their fleets, encouraging them to voluntarily adopt technologies
- obtain quality data to document technology performance and present to stakeholders

1.2. PROJECT PARTNERS

Southern coordinated all field testing and analyses for NYSERDA with the assistance of Environment Canada, EF&EE, E. H. Pechan, Emisstar, and Ecopoint (subcontractors) under NYSERDA Agreement No. 8958. The New

York State Department of Environmental Conservation (NYSDEC) provided and operated the Clean Air Technologies, Inc. (CATI) portable emissions monitoring system (PEMS) for a portion of the tests.

Twelve manufacturers provided 25 ECTs of various types and sizes. The NCDC grant monies contributed to the acquisition of 11 ECTs, as discussed in the following sections. Appendix A provides a list of participants and contact information.

1.3. LAUNCH EVENTS, PUBLICITY, AND OTHER OUTREACH EFFORTS

Southern, NYSERDA, and the ECT vendors have conducted a variety of launch events, publicity, and other outreach efforts for this series of tests. These include press releases, conference presentations, peer-reviewed and other journal articles, posting of final reports on the NYSERDA and Southern internet sites, and one-on-one conversations with clients, regulators, and other stakeholders.

Press releases issued individually and jointly by Southern and NYSERDA, as archived at their respective Internet sites, are important outreach tools (see http://www.southernresearch.org/press/pr20070731.html and http://www.airpollutionnews.com/2007/07/31/12628/southern-research-institute-evaluates-clean-diesel-technologies-for-new-york-state-pr-newswire-via-yahoo-news/). Test participants and ECT vendors have also issued press releases over the course of the project (see http://www.emisstar.com/news_press.php).

Formal public presentations have included invited, peer-reviewed papers at the 2007 and 2008 Coordinating Research Council In-Use Emissions Workshops, a poster presentation at the 2006 Diesel Engines Efficiency and Emissions Research (DEER) conference in Detroit, MI, and the 2007 NYSERDA Environmental Monitoring, Evaluation, and Protection (EMEP) conference.

For more information, see
http://www.nyserda.org/Programs/Environment/EMEP/conference_2007/Hansen_Tim.pdf.

2.0 FLEET SELECTION

To ensure the demonstration program that addressed ECTs that provided the most effective emission reductions, NYSERDA evaluated the construction equipment population and emissions within the NYCMA, as well as the feasibility of various verified retrofit applications. The result of this analysis was the selection of the off-road equipment fleet for testing combined with selected ECTs.

2.1. PRIORITY EQUIPMENT

To identify the highest priority equipment for retrofit demonstration, NYSERDA evaluated a state-wide and NYCMA emission inventory based on calendar year 2002 data. The inventory was evaluated by sector, equipment type, and horsepower range to determine the equipment items that are the sources of the largest amounts of diesel pollution, most populous, and largest fuel consumers. The inventory analysis identified NYCMA construction and mining equipment as the primary sector of interest, accounting for 64% of all state-wide non-road diesel PM and NOx emissions. The construction and mining sector also accounts for nearly 60% of all non-road diesel PM and NOx emissions within the NYCMA. To further narrow the target and identify specific equipment types of interest, an aggregated equipment-level inventory was developed. An initial set of priority equipment was identified for the construction equipment sector in the NYCMA. Five equipment categories were responsible for nearly 50% of all of non-road diesel PM and NOx emissions in the NYCMA. Those equipment categories include the following: Crawler Tractors/Dozers, Excavators, Rubber Tire Loaders, Skid Steer Loaders, and Tractors/Loaders/Backhoes. Table 2.1 lists the top 10 non-road diesel construction equipment emission sources in the NYCMA. Of these equipment types, rubber tire loaders 300 to 600 Horsepower (HP) are the number one ranked NO_X emission source, and tractors/loaders/backhoes 75 to 100 HP are the number one PM and CO source.

Table 2-1. Non-Road Diesel Construction Equipment Emission Sources in the NYCMA

Overall Rank	Equipment Type	Horsepower Range
1	Tractors/Loaders/Backhoes	100 < HP <= 175
2 (No. 1 for CO & PM)	Tractors/Loaders/Backhoes	75 < HP <= 100
3 (No. 1 in population)	Skid Steer Loaders	50 < HP <= 75
4	Skid Steer Loaders	75 < HP <= 100
5 (No. 1 for NOx)	Rubber Tire Loaders	300 < HP <= 600
6	Excavators	100 < HP <= 175
7	Rubber Tire Loaders	175 < HP <= 300
8	Rubber Tire Loaders	100 < HP <= 175
9	Rough Terrain Forklifts	75 < HP <= 100
10	Excavators	175 < HP <= 300

2.2. FLEET IDENTIFICATION

Criteria for selecting fleets included the following: fleet equipment inventory / availability of targeted equipment; equipment activity (fleets with more active equipment were preferred); equipment duties (common duty cycles are more widely applicable); fleet replacement rate (those with high turnover rates were less preferred); locations of work (fleets with equipment located near sensitive populations were preferred); and existence of an Environmental Management System, community based toxics reduction programs, air quality improvement policies, idle reduction policies, extensive O&M practices, or other policies and practices maintained by the fleet with the goal of reducing air emissions from diesel and other sources.

NYSERDA selected the Department of Sanitation of New York City (DSNY) fleet for the demonstration program. DSNY operates citywide, employing 59 district facilities and commanding a fleet of over 5,000 vehicles. DSNY has a large fleet of nearly 300 rubber tire loaders used mainly for lot cleaning, snow removal, and salt loading. These activities occur mainly during colder months, providing a high usage of equipment during these time periods. The equipment available ranged in age from the 1990s to 2004, and included equipment from several manufacturers, including: Caterpillar, Case, Daewoo, and others. DSNY's array of equipment represents different equipment types, ages, engine sizes, manufacturers, and duty cycles. The majority of the equipment is well within its useful life cycle, has significant activity levels, and is owned, operated, and maintained by DSNY. The replacement rate for the equipment is typically around 10 years. DSNY's varied pool of equipment allowed for demonstration of retrofits on a variety of applications in a single, well managed fleet.

Because DSNY is working everyday in every part of the city, the recognizable equipment and vehicles are highly visible and easily identified. Equipment is utilized regularly in current target areas of environmental justice grants and activities related to air pollution and impacts on asthma. DSNY has evaluated various data on their operations, including the proximity of its equipment fleet operations to schools, hospitals, areas with high levels of asthma, and city wastewater treatment plants. Any reduction of emissions from diesel construction equipment would significantly benefit air quality and public health. DSNY was eager to serve as a host and model for other fleets to emulate for emission reduction retrofits that will reduce the possible negative effects of non-road construction equipment for the life of the vehicle and help protect sensitive populations.

In 2005, DSNY was awarded a grant from the U.S. EPA to retrofit 68 garbage collection trucks operating in the South Bronx section of New York City. The retrofits were expected to reduce PM emissions by 33%, CO emissions by 41%, and hydrocarbon emissions by 52%. The South Bronx has been targeted for emission control installations. Asthma mortality rates are three times the national average in this area, and hospitalization rates are seven times higher. Additionally, over 40% of the local population is either under the age of 18 or over the age of 65 - groups that are most vulnerable to the impacts of air pollution.

DSNY has also initiated many voluntary emission control strategies. The DSNY fleet is one of the first in the country to participate in the EPA's Voluntary Diesel Retrofit program. Approximately one third of its fleet is equipped with various advanced diesel exhaust after-treatment technologies. In 2004, DSNY voluntarily switched their entire diesel fleet to ultra-low sulfur diesel fuel, and in 2007 voluntarily converted to a B5 biodiesel blend. They are currently testing B20 Biodiesel on a fleet of vehicles. DSNY also has a fleet of 500 flexible fuel vehicles and 250 hybrid electric vehicles as well as operate 26 compressed natural gas (CNG) powered collection trucks and 29 CNG powered mechanical brooms. DSNY is also participating in a pilot project using hydrogen fuel cells to power a fleet of experimental vehicles and has rigorous operations and maintenance policies they adhere to, with ample shop space for maintaining their fleet. DSNY also recently built a heavy-duty chassis dynamometer facility for performing emissions research on their equipment. These significant activities are a strong indicator of DSNY's commitment to reducing emissions from its fleet through a variety of policies, voluntary programs, and managed practices.

3.0 EMISSION CONTROL TECHNOLOGY EVALUATIONS

The majority of ECT evaluations took place at DSNY's Central Repair Shop located in Woodside, NY. DSNY coordinated ECT installation, gathered in-use performance data, compiled installation and maintenance costs, and assisted with test equipment installation. Additional ECT evaluations took place at the Fresh Kills Landfill located in Staten Island, NY. Table 3-1 lists all of the equipment and ECT combinations included in the NYSERDA Clean Diesel Initiative program. Those ECTs that were eligible for the EPA NCDC evaluation and funded with this grant are marked.

Table 3-1. Equipment and ECTs Evaluated

Equipment Description	Equipment Type	ECT Manufacturer	ECT Type[a]	Field Tested in NYSERDA Clean Diesel Program	EPA NCDC Program Eligible
Case 821	Rubber tire loader	CleanAIR Systems	PDPF	✓	
Case 70XT	Skid steer loader	NETT Technologies	Special Configuration FTF	✓	
Daewoo Mega 200	Rubber tire loader	NETT Technologies	FTF	✓	
Caterpillar D400	Dump Truck	Huss	ADPF	✓	
Caterpillar D400	Dump Truck	JMI	DPF	✓	
Daewoo Mega 200	Rubber tire loader	DCL	FTF	✓	
Bobcat 863	Skid steer loader	AirFlow Catalyst	DOC	✓	
Case 821	Rubber tire loader	NETT Technologies	PDPF	✓	
Case 821	Rubber tire loader	AirMeex	ADPF	✓	
Daewoo Mega 200	Rubber tire loader	ECS	PDPF	✓	
Daewoo Mega 200	Rubber tire loader	Donaldson	PDPF	✓	
Case 821	Rubber tire loader	Extengine	FTF	✓	
Case 821	Rubber tire loader	NETT Technologies	FTF/SCR	✓	
Case 821	Rubber tire loader	DCL	PDPF	✓	
Case 580	Backhoe	NETT Technologies	DOC	✓	
Cat D400	Dump truck	JMI	DPF	✓	✓
Cat D400	Dump truck	Huss	ADPF	✓	✓
Case 821	Rubber tire loader	CleanAIR Systems	DPF	✓	✓
Daewoo Mega 200	Rubber tire loader	ECS	DPF	✓	✓
Daewoo Mega 200	Rubber tire loader	ECS	DPF	✓	✓
Daewoo Mega 200	Rubber tire loader	Donaldson	DPF	✓	✓
Case 821	Rubber tire loader	ECS	DPF		✓
Case 821	Rubber tire loader	Donaldson	DPF		✓
Case 821	Rubber tire loader	ECS	DOC		✓
Case 821	Rubber tire loader	ECS	DOC		✓

[a] ECT nomenclature:
ADPF -- active diesel particulate filter
DPF -- diesel particulate filter (also known as PDPF for passive diesel particulate filter)
DOC -- diesel oxidation catalyst
FTF – flow through filter
SCR – selective catalytic reduction

In-use field tests were performed under auspices of the NYSERDA Clean Diesel Initiative program. This report addresses only those ECTs eligible for the EPA NCDC Program. Detailed results for all field tests will be available in NYSERDA Clean Diesel Technology: Non-Road Field Demonstration Program Final Report, Agreement Number 8958, New York State Energy Research and Development Authority, Albany, NY 2008.

3.1. OFF-ROAD EQUIPMENT AND EMISSION CONTROL TECHNOLOGIES EVALUATED

Off-road equipment used in the EPA NCDC evaluations included dump trucks and rubber-tired loaders. Detailed information about the equipment and ECTs is shown in Table 3-2. All ECTs were monitored for at least six months, with the exception of one ECS DOC. Installation of one ECS DOC was delayed because the unit had to be sent back to the manufacturer for redesign. As such, this unit was only logged for approximately five months. However, an additional ECS DOC unit was logged for at least six months, and most ECTs were logged beyond that.

The following information was collected for each ECT:

- retrofit technology descriptions
  - general information and full technology specifications
- equipment and engines involved
  - specific descriptions of all vehicles and engines involved and their usage
- engine usage during the demonstration
- EPA- or CARB-estimated emissions reductions
- economic analyses, including technology costs, estimated changes in fuel costs, maintenance costs, etc.
- summary of operational impacts and impressions from fleet owners and equipment operators
- problems identified and lessons learned

Estimated fuel consumption for each piece of equipment was one of the tracking parameters specified in the NCDC grant Scope of Work. However, DSNY does not track fuel consumption for individual pieces of equipment. As such, this parameter could not be logged.

Table 3-2. Off-Road Equipment and ECTs Evaluated in the EPA NCDC Program

Equip. Model	Engine Mfr.	Engine Model	Engine Model Year	EPA Engine Family	Type of Equipment	DSNY Vehicle ID	Engine S/N	ECT Mfr.	ECT Type[a]	ECT Install Date[b]	Hrs of ECT Operation Since Install[c]
Case 821	Cummins	6T-830	2000	XX9XL0505AAA	Rubber tire loader	21BH-206	45897196	CleanAIR Systems	DPF	09/23/06	243
Cat D400	Caterpillar	3406	2001	YCPXL14.6ERK	Off-highway truck	66J-103	3406E9AP01573	Huss	ADPF	02/21/07	90
Cat D400	Caterpillar	3406	2001	YCPXL14.6ERK	Off-highway truck	66J-105	34069AP01583	JMI	DPF	05/01/07	369
Mega 200V	Daewoo	DB58TIS	2005	DWXL05.8C0A	Rubber tire loader	21BY-101	404143LB	ECS	DPF	08/28/07	52
Mega 200V	Daewoo	DB58TIS	2005	DWXL05.8C0A	Rubber tire loader	21BY-118	408991LB	ECS	DPF	10/26/07	172
Mega 200V	Daewoo	DB58TIS	2004	DWXL05.8C0A	Rubber tire loader	21BY-014	401598LB	Donaldson	DPF	11/13/07	69
Case 821	Cummins	6T-830	2005	DWXL05.8C0A	Rubber tire loader	21BY-119	408988LB	ECS	DPF	11/23/07	21
Case 821	Cummins	6T-830	1999	VX9505R6DTRA	Rubber tire loader	21BH-106	45623530	Donaldson	DPF	11/30/07	97
Case 821	Cummins	6T-830	2000	XX9XL0505AAA	Rubber tire loader	21BH-204	45906580	ECS	DOC	12/13/07	157
Case 821	Cummins	6T-830	1999	WX9XL0505AAA	Rubber tire loader	21BH-104	45769286	ECS	DOC	01/4/08	71

[a] ECT nomenclature:
ADPF -- active diesel particulate filter
DPF -- diesel particulate filter (also known as PDPF for passive diesel particulate filter)
DOC -- diesel oxidation catalyst
[b] ECT monitoring period ended 05/31/08
[c] Typical hours of operation per year for rubber tire loaders: 200-300 hrs; typical hours of operation per year for off-highway trucks: 500 hrs

3.2. EMISSION CONTROL TECHNOLOGY DESCRIPTIONS AND PERFORMANCE

One criterion for participation in this NCDC project was prior verification of ECT performance. Table 3-3 summarizes the verification status of the selected ECTs and their EPA- or CARB-certified emissions performance.

Table 3-3. Expected Emission Control Technology Performance

Manufacturer and Type[a]	Verification Status	PM Control (%)
JMI CRT/CCRT DPF as Caterpillar-installed unit	CRT: EPA and CARB for on-highway CCRT: EPA for on-highway, pursuing CARB verification	85 – 90%
HUSS MK-Series ADPF (fuel burner)	CARB for on-highway & off-road	85%
CleanAIR Systems DPF, "PERMIT"	CARB for on-highway	85%
ECS DPF, "Purifilter"	EPA & CARB for on-highway	90%
Donaldson DPF muffler	CARB for on-highway	85%
ECS DOC "Purifier" and "Purimuffler"	EPA and CARB for on-highway	40 – 50%

[a] ECT nomenclature:
ADPF -- active diesel particulate filter
DPF -- diesel particulate filter (also known as PDPF for passive diesel particulate filter)
DOC -- diesel oxidation catalyst

The following subsections provide descriptions of each ECT. All technology descriptions are based on information provided by the ECT manufacturers and do not represent information independently verified by Southern or NYSERDA.

3.2.1. JMI Continuously-Regenerating and Catalyzed Continuously-Regenerating Diesel Particulate Filter Technology

The Johnson-Matthey, Inc. CRT/CCRT system is a DOC-DPF system, but with a catalytic coating applied to the DPF. The oxidation catalyst removes CO and HC and oxidizes some of the NO in the exhaust gasses to NO_2. This NO_2 then reacts with the PM trapped in the filter, producing NO and CO_2. Some of the NO is then re-oxidized to NO_2 in the filter, which then reacts with more trapped PM. This enables the system to regenerate in applications with very low exhaust gas temperatures or low NO_X to PM ratios in the exhaust gases.

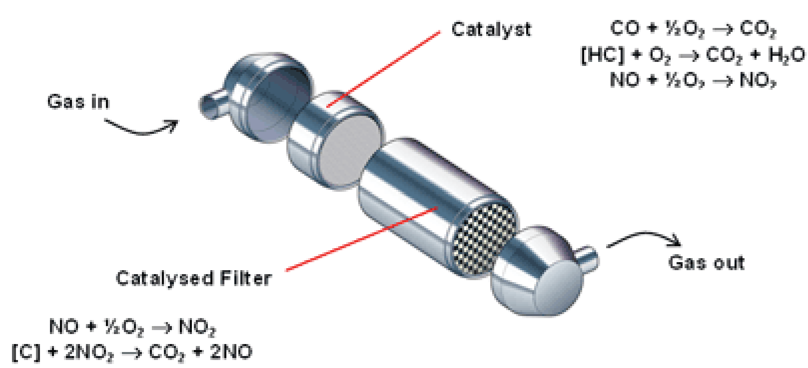

Figure 3-1. Johnson-Matthey CRT/CCRT

The CCRT system is similar to a CRT system, but is able to operate in applications that have exhaust temperatures too low for a CRT system. It has been verified by the U.S. EPA for applications that have temperatures greater than 210 °C for 40 percent of the operating time. It is also able to operate on engines with a NOx to PM ratio that is insufficient for a standard CRT system.

3.2.2. Huss Active Diesel Particulate Filter

The Huss MK system is integrated in the exhaust piping of the vehicle, usually in place of the original muffler. The filter medium is made of silicon carbide. The filter can be used for approximately eight working hours, at which time the maximum allowed backpressure is reached and the filter must be regenerated. During regeneration, the diesel burner is ignited while the engine is shut-down. Depending on the filter size, regeneration takes from five to 35 minutes. Approximately three to 10 ounces of diesel fuel are necessary for each regeneration period. The entire process is supervised by the HUSS electronic control device.

Figure 3-2. Huss ADPF

3.2.3. CleanAIR Systems Passive Diesel Particulate Filter

CleanAIR® Systems manufactures the PERMIT passive DPF, which is designed to control PM, CO, and HC emissions from any size diesel engine. The PERMIT filter is packaged in a 304L stainless steel shell finished by bead blasting, which offers a corrosion-resistant product. The wall-flow design of the CleanAIR PERMIT filter captures diesel PM, reducing PM and visible black smoke. The PERMIT filter's catalyst, incorporated within the wall-flow filter, oxidizes the captured PM into CO_2 while the engine is operating. This results in a passive, self-cleaning (or regenerating) filter without the need for manual intervention. Regeneration is dependent upon exhaust temperature and fuel sulfur level. Emissions of CO and HC are also reduced when exhaust gases interact with the filter's catalyst.

The PERMIT filter is CARB verified for diesel engines. Applications for the PERMIT filter include on-road and off-road equipment such as trucks, buses, construction equipment, mining vehicles, and power generation equipment. The PERMIT filter is available in standard designs, muffler combination, and critical or super-critical grade silencer configurations. In many large diesel engine applications, multiple PERMIT filters can be integrated into a silencer, which can take the place of a standard exhaust silencer.

Regeneration for the PERMIT filter is dependent on exhaust temperature and fuel sulfur content, as follows:

Sulfur Content by Weight	Regeneration Temp.	% Run Time Required
< 15 ppm	280° C (536° F)	>30%
< 500 ppm	360° C (680° F)	>30%
> 500 ppm	390° C (734° F)	>30%

Figure 3-3. CleanAIR Systems PERMIT PDPF

3.2.4. Engine Control Systems Diesel Oxidation Catalyst and Diesel Particulate Filter

Engine Control Systems (ECS) manufactures AZ Purifiers and Purimufflers. They offer 20-40% PM reduction values depending on the application. Both systems employ a zeolite-containing washcoat and precious metal catalyst for better low- temperature performance. They can be combined with the ECS closed crankcase ventilation (CCV) system which increases verified PM reduction to 40% for all 1991 to 2004 medium- and heavy-duty highway engine applications compliant to a 5 or 4 g/hp-hr NOx standard. ECS also offers the DZ and EZ diesel oxidation catalysts supported on a metallic substrate, which affords vibration resistance at low exhaust backpressure. The DZ series features quick release band clamps. This allows the center body to be readily removed for periodic engine-out opacity measurements or for purifier cleaning. These DZ purifiers are also available with modular add-on DMS and DMXS silencers. The EZ purifier offers the same metallic substrate-based catalyst as the DZ purifier but in an all welded purifier to afford a compact size and lower cost.

Figure 3-4. ECS Diesel Oxidation Catalyst Products

The Purifilter diesel particulate filter employs a base and precious metal catalyst impregnated onto a silicon carbide surface to passively oxidize accumulated particulate while complying with CARB NO_2 limits. The silicon carbide filter substrate is formed in a honeycomb design; alternating cells are open on one end and plugged at the outlet end. As the exhaust flow enters the open inlet cells, it is forced to pass through the micro-porous walls to the outlet cells, filtering the diesel particulate from the exhaust. The filter substrate is coated with a proprietary catalytic layer to reduce soot combustion temperatures to a level within the normal exhaust temperature range of diesel engines.

Purifilter displays regeneration balance points between 280 ^{o}C and 325 ^{o}C, varying with both vehicle engine and application. Continuous passive filter regeneration occurs during a vehicle duty cycle when the exhaust temperatures are above 280 ^{o}C for more than 25% of the time. The catalyst also serves to oxidize more than 90 percent of carbon monoxide and hydrocarbons. Purifilter models are available in five different particulate filter muffler types. The modular design allows for 360° rotation of the muffler inlet and outlet sections to provide a range of fit. A backpressure monitor kit is provided with each Purifilter. The Purifilter has been certified under the Swedish Environmental Zones -- Off-Road Engines Program. Results obtained from a Perkins 1004 engine over the ISO 8178 Cycle show that PM was reduced by 91%, HC by 96%, and CO by 99%. Off-Road vehicles suited to the Purifilter include construction vehicles, mining vehicles, and other heavy industrial machines.

Figure 3-5. ECS Purifilter

3.2.5. Donaldson Diesel Particulate Filter

Donaldson recommends the DPF Muffler if the average exhaust temperature is greater than 225 ^{o}C. The CARB-verified system covers 1994 to 2006, 150 to 600 hp, non-EGR diesel engines (0.10 g/bhp-h PM emissions or less), and requires ultra-low sulfur diesel fuel (less than 15 ppm sulfur). The design uses patented flow distribution elements to ensure uniform PM loading and temperature distribution.

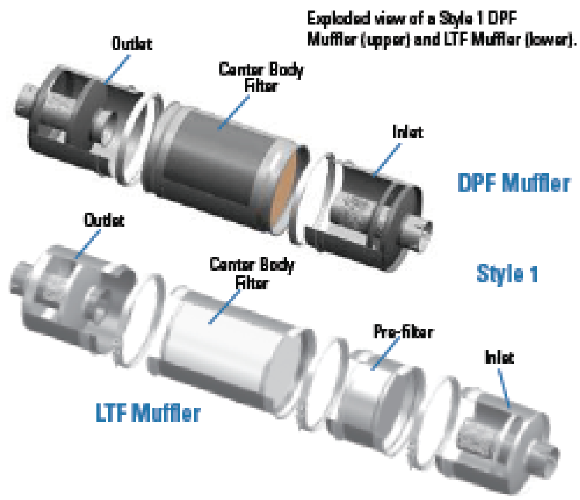

Figure 3-6. Donaldson DPF

3.3. ECT INSTALLATIONS

Figures 3-7 through 3-12 show selected ECT installations as evaluated under the EPA NCDC grant program.

Figure 3-7. Johnson-Matthey DPF installed on a CAT D400 Dump Truck

Figure 3-8. Front View of the Johnson Matthey DPF Mounting Arrangement

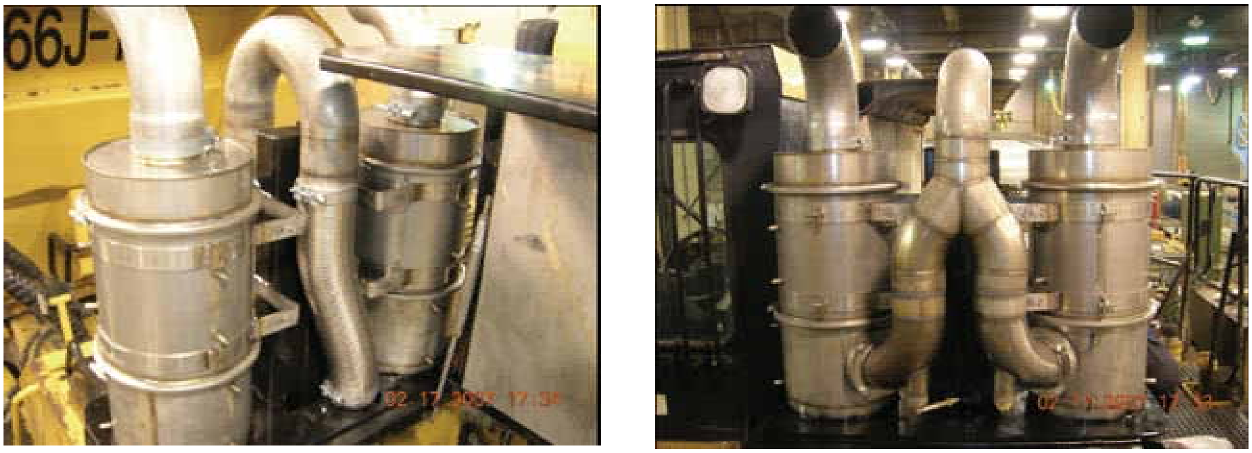

Figure 3-9. Front (left) and Rear (right) View of the Huss ADPF Dual Filter Retrofit Installed on a CAT D400 Dump Truck

Figure 3-10. In-Cab Display of Huss ADPF Control Modules Installed in the CAT D400 Dump Truck

Figure 3-11. CleanAIR Systems PDPF Installed on a Case 821 Rubber Tire Loader and Instrumented for In-Use Emissions Testing

Figure 3-12. Left-Side View of the ECS DPF Installed on a Case 821 Rubber Tire Loader

3.4. ECT COST, INSTALLATION, AND OPERATIONAL PERFORMANCE ANALYSIS

Analysis of ECT costs consisted of collecting and reporting the following cost data:

- capital purchases
- shop labor for installations
- EPA grant funds expended
- installation downtime
- maintenance and repair costs, and downtime
- operations and maintenance issues

Tables 3-4 through 3-6 summarize costs and operational impacts for the 11 ECTs funded through the EPA NCDC grant program.

Table 3-4. ECT Costs and Installation Labor

Equip. Model	Equipment Type	DSNY Vehicle ID	ECT Mfr.	ECT Type[a]	Retail Cost, $	EPA NCDC Funds, $	Labor Hours[b], h				Install cost[c], $	More Info[d]
							A	B	C	D		
Cat D400	Dump truck	66J -105	JMI	DPF	$37123	$4736	unit was installed by Caterpillar dealer @ ≈ 40 h					‡
Cat D400	Dump truck	66J-103	Huss	ADPF	$36498	$8780	30	35	80	80	$17835[e]	†, *, ‡
Case 821	Rubber tire loader	21BH-206	CleanAIR Systems	PDPF	$8948	$7647	8	8	32	--	$5904	†, *
Case 821	Rubber tire loader	21BY-119	ECS	DPF	$7156	$7156	16	--	16	--	$3936	†, *
Case 821	Rubber tire loader	21BH-106	Donald-son	DPF	$7625	$4640	8	--	8	8	$1968	†, ‡
Case 821	Rubber tire loader	21BH-204	ECS	DOC	$3291	$3291	--	--	8	--	$984	*
Case 821	Rubber tire loader	21BH-104	ECS	DOC	$3291	$3291	--	--	8	--	$984	*
Mega 200V	Rubber tire loader	21BY-101	ECS	DPF	$7156	$7156	8	--	8	--	$1968	*
Mega 200V	Rubber tire loader	21BY-118	ECS	DPF	$7156	$7156	16	--	16	--	$3936	†, *
Mega 200V	Rubber tire loader	21BY-014	Donald-son	DPF	$7625	$4690	8	--	8	--	$1968	‡
This ECT has not yet been installed.			ECS	DOC	$3291	$3291	--	--	--	--	--	--
				Total:	*$121685*	*$61834*	--	--	--	--	*$39483*	--

[a] ECT nomenclature:
ADPF -- active diesel particulate filter
DPF -- diesel particulate filter (also known as PDPF for passive diesel particulate filter)
DOC -- diesel oxidation catalyst
[b] Labor description: A = electrician, B = blacksmith, C = mechanic, D = manufacturer's representative
[c] Does not include manufacturer's representative labor. DSNY average labor rate is $123 / h.
[d] See the following tables for more information:
† = brackets, custom parts listed in Table 3-5
* = installation notes in Table 3-5
‡ = maintenance or operations issues described in Table 3-6
[e] Huss currently requires that installation of their device be completed by a Huss technician or a trained and authorized Huss installer, for a cost of $6,260.

Table 3-5. Custom Parts and Installation Notes						
Equip. Model	**Equip. Type**	**DSNY Vehicle ID**	**ECT Mfr.**	**ECT Type**	**Custom Parts**	**Installation Notes**
Cat D400	Dump truck	66J-103	Huss	ADPF	2 brackets; 1 wiring harness; 1 in-cab control box; 1 fuel line; temperature monitor; backpressure monitor	Complicated installation required significant DSNY and manufacturer's representative labor[a].
Case 821	Rubber tire loader	21BH-206	CleanAIR Systems	PDPF	2 brackets; 1 wiring harness; temperature monitor; backpressure monitor; 4" x 4" reinforcement plate; 4' long x 4" dia. flex pipe; 6 elbows, 4" dia.; 6" x 6" bulkhead plate with 4" hole	Extended exhaust pipe from turbocharger outlet to top rear outside of engine cover. Drilled engine cover and made reinforcement plates to secure the unit.
Case 821	Rubber tire loader	21BY-119	ECS	DPF	2 brackets; 1 wiring harness; temperature monitor; back pressure monitor	As-received exhaust inlet and outlet ends on ECT were the wrong size and were replaced. As-received mounting brackets did not fit, so DSNY modified existing brackets on the loader.
Case 821	Rubber tire loader	21BH-106	Donaldson	DPF	1 wiring harness; temperature monitor; back pressure monitor	Used existing brackets on the loader for mounting the ECT.
Case 821	Rubber tire loader	21BH-204	ECS	DOC	--	Easy installation. Used existing brackets on the loader for mounting the ECT.
Case 821	Rubber tire loader	21BH-104	ECS	DOC	--	Easy installation. Used existing brackets on the loader for mounting the ECT.
Mega 200V	Rubber tire loader	21BY-101	ECS	DPF	2 brackets; 1 wiring harness; temperature monitor; back pressure monitor	As-received exhaust inlet and outlet ends on ECT were the wrong size and were replaced. As-received mounting brackets did not fit, so DSNY modified existing brackets on the loader.
Mega 200V	Rubber tire loader	21BY-118	ECS	DPF	2 brackets; 1 wiring harness; temperature monitor; back pressure monitor	As-received exhaust inlet and outlet ends on ECT were the wrong size and were replaced. As-received mounting brackets did not fit, so DSNY modified existing brackets on the loader.
Mega 200V	Rubber tire loader	21BY-014	Donaldson	DPF	1 wiring harness, temperature monitor, back pressure monitor	Used existing brackets on the loader for mounting the ECT.

[a] Huss currently requires that installation of their device be completed by a Huss technician or a trained and authorized Huss installer, for a cost of $6,260.

The majority of the ECTs had little impact on operational performance. Regeneration or other routine ECT functions were generally transparent to the equipment operators. Table 3-6 summarizes the operational performance issues to date. Maintenance and repair records provided by DSNY were the primary data source, supplemented by interviews with DSNY mechanics and technicians.

Table 3-6. Maintenance and Operational Issues							
Equip. Model	**Equipment type**	**DSNY Vehicle ID**	**ECT Mfr.**	**ECT type**	**Problem description and resolution**	**Equip-ment down, days**	**Repairs, approx. h**
Cat D400	Dump truck	66J -105	JMI	DPF	Mounting brackets were too lightly-built for the ECT. They cracked, bent, and were replaced by the Caterpillar dealer.	36	8
Cat D400	Dump truck	66J-103	Huss	ADPF	Operators dislike the regeneration process. The truck cannot operate during the 20 to 25 minute regeneration. The ignition key must be on during regeneration which, if forgotten, can lead to discharged batteries.[a]	--	--
Case 821	Rubber tire loader	21BH-106	Donald-son	DPF	Backpressure alarm - ECT was removed and cleaned off-board.	5	8
Mega 200V	Rubber tire loader	21BY-014	Donald-son	DPF	Backpressure alarm - ECT was removed and cleaned off-board. Mechanics tried various cleaning strategies.	≈ 60[b]	40

[a] The manufacturer recommends running the regeneration process during the operator's lunch break to prevent unnecessary downtime.
[b] Equipment was down for approximately two months, with approximately five days of staff time required for maintenance.

3.5. ECT EMISSION REDUCTION ANALYSIS

Analysts used the EPA's Diesel Emissions Quantifier (Quantifier) to estimate PM emission reductions associated with using the ECTs evaluated in the EPA NCDC program. The Quantifier is an interactive tool for estimating emission reductions for clean diesel projects and is the EPA's recommended tool for preparing diesel emissions data for submission to the EPA. The Quantifier is based on existing EPA tools and uses emission factors from EPA's National Mobile Inventory Model, which includes the MOBILE 6.2 and NONROAD2005 models. The Diesel Emissions Quantifier can be found at the following address: http://cfpub.epa.gov/quantifier/view/index.cfm.

Table 3-7 shows the input data entered in the Quantifier program. The Quantifier has limited input capabilities and therefore some inputs to the program do not represent actual vehicle or ECT specifications. For all cases in Table 3-7 where the actual specifications differ from inputs available in the Quantifier, the actual numbers appear in parentheses and italics. For example:

- The horsepower selected for each vehicle class is based on the horsepower inputs available in the Quantifier, not actual equipment horsepower. Actual equipment horsepower is in parentheses and italics.

- For typical equipment hours of operation per year, analysts used DSNY estimates for each equipment piece. DSNY estimates that rubber tire loaders operate an average of 200 hours per year, and dump trucks operate an average of 500 hours per year. However, analysts also used the actual hours of operation logged during the EPA NCDC monitoring period to extrapolate annual usage. This number appears in parentheses and italics.

Analysts used average fuel consumption data obtained from the in-use testing portion of the NYSERDA Clean Diesel Initiative for fuel usage inputs to the Quantifier. Fuel consumption from the in-use tests (gal/hr) combined with the average hours of operation per year resulted in an average yearly fuel consumption of approximately 490 gal/year for rubber tire loaders and 3,570 gal/year for dump trucks.

Table 3-8 shows the PM, HC, and CO emission reduction estimates from the Diesel Emissions Quantifier. It should be noted that the Quantifier provides only a general estimation of emission reductions. Details of the actual in-use emission reductions measured for the ECTs included in the in-use field testing portion of the NYSERDA Clean Diesel Initiative program will be available in the NYSERDA Clean Diesel Technology: Non-Road Field Demonstration Program Final Report.

The Quantifier estimates that use of the 10 ECTs included in the EPA NCDC Program results in a reduction in PM emissions of 0.09 tons/year, a reduction in HC emissions of 0.08 tons/year, and a reduction in CO emissions of 0.39 tons/year. This translates to a PM reduction of 0.22 kg/day, an HC reduction of 0.2 kg/day, and a CO reduction of 0.97 kg/day. The Quantifier also estimates lifetime emissions reductions for each ECT based on the expected remaining lifetime of the vehicle after the time of ECT installation. The lifetime PM reduction associated with the use of these 10 ECTs is 0.21 tons. The lifetime HC and CO reductions are 0.22 and 1.52 tons, respectively.

Table 3-7. Diesel Emissions Quantifier Inputs

Vehicle Class #	Sector	Vehicle/ Equipment Type	Model Year	Retrofit Year	# of Vehicles	Typical Usage [hrs/year] *(Actual)*	HP Range *(Actual)*	Fuel Type	Typical Fuel Usage [gal/year] *(Actual)*	ECT Type	# of Vehicles Retrofitted	Unit Cost [$]	Installation Cost [$]	Total Project Cost [$]
1	Construction	Rubber Tire Loaders	2000	2007	1	200 *(152)*	175 *(190)*	B5 Biodiesel	497 *(377)*	DPF	1	9000	6000	15000
2	Construction	Off-highway Trucks	2001	2007	1	500 *(76)*	300 *(400)*	B5 Biodiesel	3571 *(540)*	DPF	1	35000	18000	53000
3	Construction	Off-highway Trucks	2001	2007	1	500 *(370)*	300 *(400)*	B5 Biodiesel	3571 *(2638)*	DPF	1	37000	18000	55000
4	Construction	Rubber Tire Loaders	2005	2007	3	200 *(153)*	100 *(143)*	B5 Biodiesel	1450 *(1116)*	DPF	3	7000	4000	33000
5	Construction	Rubber Tire Loaders	2004	2007	1	200 *(149)*	100 *(143)*	B5 Biodiesel	483 *(360)*	DPF	1	5000	2000	7000
6	Construction	Rubber Tire Loaders	1999	2007	1	200 *(232)*	175 *(190)*	B5 Biodiesel	497 *(578)*	DPF	1	5000	2000	7000
7	Construction	Rubber Tire Loaders	2000	2007	2	200 *(316)*	175 *(190)*	B5 Biodiesel	994 *(1569)*	DOC	2	3000	1000	8000

Table 3-8. Diesel Emissions Quantifier Emission Reduction Estimates

Vehicle Class #	Baseline of Retrofitted Vehicles [PM, tons/year]	Percent Reduced [PM, %] *(Verified Level)*	Amount Reduced Per Year [PM, tons/year]	Kilograms Reduced Per Day [PM, kg/day]	Baseline of Retrofitted Vehicles [HC, tons/year]	Percent Reduced [HC, %] *(Verified Level)*	Amount Reduced Per Year [HC, tons/year]	Kilograms Reduced Per Day [HC, kg/day]	Baseline of Retrofitted Vehicles [CO, tons/year]	Percent Reduced [CO, %] *(Verified Level)*	Amount Reduced Per Year [CO, tons/year]	Kilograms Reduced Per Day [CO, kg/day]
1	0.01	85% *(85%)*	0.01	0.02	0.01	90% *(unk.)*	0.01	0.01	0.03	90% *(unk.)*	0.02	0.06
2	0.03	85% *(85%)*	0.03	0.07	0.03	90% *(unk.)*	0.02	0.06	0.1	90% *(unk.)*	0.09	0.22
3	0.03	85% *(90%)*	0.03	0.07	0.03	90% *(95%)*	0.02	0.06	0.1	90% *(85%)*	0.09	0.22
4	0.01	85% *(90%)*	0.01	0.02	0.01	90% *(85%)*	0.01	0.03	0.12	90% *(75%)*	0.11	0.28
5	0	85% *(85%)*	0	0.01	0	90% *(unk.)*	0	0.01	0.04	90% *(unk.)*	0.04	0.09
6	0.01	85% *(85%)*	0.01	0.02	0.01	90% *(unk.)*	0.01	0.01	0.03	90% *(unk.)*	0.02	0.06
7	0.02	20% *(40%)*	0	0.01	0.01	50% *(75%)*	0.01	0.02	0.05	30% *(60%)*	0.02	0.04
Total:	**0.11**	**--**	**0.09**	**0.22**	**0.1**	**--**	**0.08**	**0.2**	**0.47**	**--**	**0.39**	**0.97**

3.6. PROBLEMS IDENTIFIED AND LESSONS LEARNED

The single canister, muffler-type ECTs required the simplest and most straightforward installations. Those listed in Table 3-4 with the shortest installation times were direct muffler replacements and presented no particular installation, operational, or maintenance problems. Emission control technologies which require an in-cab control unit required more complicated installations and more resources from hourly workers.

Some devices have not yet made the transition from on-highway to off-road applications, as shown by inadequate brackets, shapes, and sizes which did not easily fit off-road machines, or other design flaws. Technicians at DSNY were generally able to "work around" such problems, as noted in Tables 3-5 and 3-6. Two as-received ECTs, however, could not be made to fit their designated machine. These two, an Engine Control Systems DOC intended for a Case 580 backhoe, and a Clean Air Systems DPF intended for a Daewoo rubber tire loader, were not part of the EPA grant program and are mentioned here for information only.

Consistent backpressure and exhaust temperature monitoring and operator training for appropriate responses to these parameters will continue to be extremely important. In-house DPF cleaning capability became important to DSNY for their ongoing development of routine maintenance strategies and for quick recovery from backpressure faults.

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NYSERDA Clean Diesel Technology
Off-Road Demonstration Project Case Study

Final Report 08-24

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