

# **CASE STUDIES OF STATIONARY RECIPROCATING DIESEL ENGINE RETROFIT PROJECTS**

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**Manufacturers of Emission Controls Association**

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## 1.0 Introduction

Diesel engines provide important fuel economy and durability advantages for stationary diesel reciprocating engines. Although they are often the power plant of choice for stationary applications, they have the disadvantage of emitting significant amounts of particulate matter (PM) and oxides of nitrogen (NO<sub>x</sub>), and lesser amounts of hydrocarbon (HC), carbon monoxide (CO), and toxic air pollutants.

Stationary diesel engines are significant contributors to air pollution in many cities in the U.S. It is estimated that there are some 600,000 existing stationary diesel engines that are in use nationwide, with electrical generators accounting for more than half of the total. The population of stationary diesel engine is expected to continue to grow. In efforts to address air pollution from stationary diesel engines, the U.S. EPA issued its requirements to reduce emissions of air pollutants from stationary CI engines on June 28, 2006. The standards, known as New Source Performance Standards (NSPS), limit emissions of nitrogen oxides (NO<sub>x</sub>), particulate matter (PM), sulfur dioxide (SO<sub>2</sub>), carbon monoxide, (CO), and hydrocarbons (HC) from stationary diesel engines to the same stringent levels required by EPA's Tier 4 nonroad diesel engine regulations (see [http://www.epa.gov/ttn/caaa/t3/fact\\_sheets/ci\\_nsps\\_fnl\\_fs.html#moreinfo](http://www.epa.gov/ttn/caaa/t3/fact_sheets/ci_nsps_fnl_fs.html#moreinfo)). On September 2009, EPA announced its proposal to reduce greenhouse gas emissions from large facilities that emit over 25,000 tons of greenhouse gases a year. (see <http://www.epa.gov/nsr/actions.html>). In March 2009, EPA proposed national emission standards for hazardous air pollutants for existing stationary reciprocating IC engines that either are located at major sources of hazardous air pollutant emissions. In addition, EPA proposed national emission standards for hazardous air pollutants for existing stationary CI engines greater than 500 brake horsepower that are located at major sources (see <http://www.epa.gov/ttn/atw/rice/ricepg.html>).

In addition, as part of the Diesel Risk Reduction Plan, California Air Resources Board adopted the Airborne Toxic Control Measure (ATCM) for Stationary Compression Ignition Engines on September 9, 2005. Stationary diesel engines emit approximately 950 tons per year of diesel PM in California and the goal of this regulation is to reduce diesel PM and criteria pollutant emissions from stationary diesel engines through stringent emission limits and operational requirements (see <http://www.arb.ca.gov/diesel/statport.htm>). In order to ensure that a particular emission control technology achieves certain level of PM emissions reduction, ARB created a technology verification program. Currently, ARB has 10 PM retrofit technologies verified for stationary diesel engine applications. Majority of the verified technologies are diesel particulate filters (DPFs), with nine systems achieving PM reduction of 85 percent and greater and one system achieving PM reduction of 50 percent or greater. ARB list of verified retrofit technologies for stationary diesel engines can be found at: <http://www.arb.ca.gov/diesel/verdev/vt/stationary.htm>.

The case studies discussed in this paper focus on those projects that have been completed, or are in progress for retrofitting stationary diesel engines with emission controls technologies such as diesel oxidation catalysts (DOCs) and DPFs for controlling diesel PM emissions, and selective catalytic reduction (SCR) catalysts for controlling NO<sub>x</sub> emissions. Many of the projects highlight the feasibility of installing verified on-road technologies on stationary diesel

engines and relate some of the lessons learned that may assist others in planning additional stationary projects. This paper focuses on technology based strategies and where available, provides information on specific type of technology installed on the type of stationary diesel engines, and the emission reduction that was achieved. More basic information on available emission control retrofit technologies is available in MECA's whitepaper, *Retrofitting Emissions Controls on Diesel-Powered Vehicle* ([www.dieselretrofit.org](http://www.dieselretrofit.org)).

## **2.0 Stationary Reciprocating Engine Diesel Retrofit Case Studies:**

### *2.1 Demonstration of Emission Control Technologies on Diesel-Fueled Backup Generators*

The University of California, Riverside (UCR) Bourns College of Engineering – Center for Environmental Research and Technology (CE-CERT), as part of the California Public Interest Energy Research (PIER) Program, conducted research to measure criteria and toxic emissions from a number of uncontrolled diesel-fueled backup generators (BUGs) that were representative of those used in California. The project was later expanded to incorporate a demonstration program of emission control technology. The objectives of this portion of the research were to assess applicable environmental control technologies and conduct field tests of BUGs units and control alternatives.

During the demonstration project, eight PM control technologies were demonstrated, including fuel modification, addition of emissions control retrofit technology and combination of both. The durability time of the technology was set to 167 hours to allow the control technology participants to obtain a conditional verification with ARB. The ARB, the Energy Commission, and UCR chose the emission control devices based on key elements: the technology's state of commercialization; the willingness of the vendor to supply the technology at no cost; and the need for that technology type in the demonstration matrix. The following devices were chosen:

- Water emulsified fuel (20% water emulsification)
- Diesel oxidation catalyst (DOC)
- Active diesel particulate filter (DPF) with online filter regeneration by electrical heating
- Catalyzed DPF (passive DPF)
- DOC with fuel-borne catalyst
- Fuel-borne catalyst with DPF

The engine models that were selected for testing were: 1985 Detroit Diesel (DDC) V92 two-stroke diesel engine installed in a 300 kW generator and 2000 Caterpillar 3406 C four-stroke diesel engine installed in a 350 kW generator.

#### Emulsified Fuel

The emulsified fuel consisted of a blend of water, conventional diesel fuel, and a mixture of special compounds that was added to the fuel to maintain the emulsion, enhance cetane number and lubricity, inhibit corrosion, and protect against freezing. The formulated fuel contained 77 percent diesel fuel, 20 percent water, and 3 percent additive package. This fuel might not be of interest for applications like emergency generators, because the fuel needs to be

circulated in order to prevent the suspension from breaking down into hydrocarbon and water phases. CE-CERT tested the emulsified fuel in two engines, first a modern and post-control (after 1996) unit and second, a unit from 1986 from the same manufacturer. The fuel tested on the modern BUG showed reductions for all load points and an overall reduction in the emission factors of 69 percent and 13 percent for PM and NO<sub>x</sub>, respectively. Test with the second BUG, a 1986 CAT 3406B, showed less of a reduction in both PM and NO<sub>x</sub> with the overall reduction of 25 percent PM and 4 percent NO<sub>x</sub>. Because PM reduction is linked to a reduction in the diesel oil droplet size in the cylinder and to the injection pressure, CE-CERT believes that the much lower injector pressure used on this unit did not provide the same capability of reducing droplet size, leading to the reduce effectiveness in reducing PM and NO<sub>x</sub>.

### Diesel Oxidation Catalyst

Two DOCs, DOC-1 and DOC-2, were installed on a modern CAT 3406C engine. DOCs are not expected to be very effective in reducing the solid or elemental carbon portion of the diesel exhaust associated with PM. Therefore, the overall reduction effectiveness of DOCs depends on the proportion of the PM that is volatile. For DOC-1, PM was reduced by 25 percent and NO<sub>x</sub> was increased by 6 percent. For DOC-2, PM was reduced by 6 percent and showed no change in NO<sub>x</sub>.

### Passive Diesel Particulate Filter

The passive DPF system used during this demonstration comprised of a proprietary platinum-based oxidation catalyst installed upstream of a wall-flow particulate filter typically made of cordierite. The platinum catalyst oxidizes a proportion of the NO in the exhaust stream to form NO<sub>2</sub> and this NO<sub>2</sub> is used to combust the soot trapped in the DPF. Two passive DPFs (DPF-1 and DPF-2) were retrofitted on a MY2000 Caterpillar 3406C diesel generator. Initial emission testing of DPF-1 resulted in control efficiencies for PM of just below 85 percent, which is lower than expected. When the device was opened, black streaks were noted on the white filter, indicating that a leak around the ceramic monolithic filter and housing had occurred. The DPF-1 was repaired. The control efficiency of DPF-2 was measured at 91 percent for PM, 98 percent for non-methane hydrocarbon (NMHC), and 76 percent for CO. Total NO<sub>x</sub> for DPF-2 decreased about 9 percent from the uncontrolled BUG's emissions.

### Active Diesel Particulate Filter

The active DPF system comprised of three silicon carbide diesel particulate filters with an electrical regeneration system designed to provide continuous PM control. The triple filter system provides uninterrupted emission filtration during regeneration by switching the exhaust flow between filters. The components of the system are the ceramic wall-flow filter elements, electronic control unit (ECU), electrical heater system, compressed air blower system, and valve system to switch the exhaust flow between filters. Because the system operates in two distinct modes, soot and regeneration, emission testing was performed in triplicate for both modes. The emission test results show a greater than 99 percent reduction in PM for both modes. Additionally, NMHC was reduced by about 45 percent and NO<sub>x</sub> by 10 percent. Although the PM reduction was very high, this system had two areas of concern: 1) Backpressure levels

measured during durability were higher than expected. The device manufacturer attributes this to differences in engine exhaust flows and exhaust hardware between the Caterpillar 3300 and 3400 Series engines. Presumably, the issue associated with the higher backpressure could easily be addressed during the design phase of stationary source retrofitting. 2) During the intermittent cold start portion of durability cycling, the soot mode was longer than had been indicated by the manufacturer. As a result, filters were not regenerating as often as described during cold start operation and backpressure increased. Because the regeneration system is controlled only by time and not backpressure sensors, this control scheme may need optimization for applications with multiple cold starts.

#### Fuel-borne Catalyst and Diesel Oxidation Catalyst

Originally, a flow-through filter system was retrofitted on a 1985 MY 2-stroke Detroit Diesel V92. This system was a passive, flow-through filter combined with a fuel-borne catalyst to reduce PM emissions. A DOC, also part of the system, reduced CO and HC emissions. However, this system experienced regeneration problems during degreening operation. The exhaust temperatures were not sufficient for regeneration and the flow-through filter clogged. Therefore, the flow-through filter was removed and the DOC, combined with the fuel-borne catalyst, was tested. The fuel-borne catalyst that was used contained 4-8 ppm of cerium and platinum in a petroleum distillate solution. The control efficiency of the DOC and fuel-borne catalyst system was 38 percent for PM and 69 percent for NMHC and NOx increased by approximately 4.8 percent.

#### Fuel-borne Catalyst and Diesel Particulate Filter

The DPF used in this demonstration is an uncatalyzed ceramic wall flow filter combined with a fuel-borne catalyst. This system was installed on a 2000 MY Caterpillar 3406C diesel generator. The system combines a ceramic monolith trap with a fuel-borne catalyst to facilitate regeneration of the DPF. Results from the testing showed that the fuel/emission control device combination reduced PM by more than 99 percent for both the initial test and after the durability testing.

More information on this project is available at:

[http://www.energy.ca.gov/pier/final\\_project\\_reports/CEC-500-2005-049.html](http://www.energy.ca.gov/pier/final_project_reports/CEC-500-2005-049.html).

### *2.2 The Simultaneous Reduction of NOx, PM, HC and CO from Large Stationary Diesel Engines Using SCR and Particulate Filters*

In late 2003, Snow Summit Mountain Resort purchased generators to use during the winter months to make snow. The resort is located at Big Bear Lake and since the area only gets an average of 75 inches of annual snow fall, Snow Summit actually makes an addition 36 to 60 inches of snow to cover the trails. Because the Snow Summit Mountain Resort comes under the jurisdiction of the South Coast Air Quality Management District (SCAQMD), the air permit for the diesel engines required the installation of the Best Available Control Technology (BACT) to

control emissions from these engines. Table 1 below shows the uncontrolled baseline emissions from the purchased diesel engine, the SCAQMD regulated emissions level and the required percent reduction needed.

**Table 1: Diesel Generator Engine Uncontrolled Emissions and SCAQMD Emissions Limits**

| <b>Emission</b> | <b>Baseline Levels</b> | <b>Regulation Levels</b> | <b>% Reduction Required</b> |
|-----------------|------------------------|--------------------------|-----------------------------|
| NOx             | 8.75 g/bhp-hr          | 0.60 g/bhp-hr            | 93.2%                       |
| CO              | 0.72 g/bhp-hr          | 0.60 g/bhp-hr            | 16.7%                       |
| HC              | 0.20 g/bhp-hr          | 0.15 g/bhp-hr            | 25%                         |
| PM              | 0.30 g/bhp-hr          | 0.045 g/bhp-hr           | 85%                         |

The supplier of emissions control devices chose to install a combination of Selective Catalytic Reduction (SCR) for reducing NOx and a diesel particulate filter (DPF) system on two diesel generators. The DPF that was installed on the generators are a passive continuously regenerating filter technology that incorporates platinum regenerated by the oxidization of NO to NO<sub>2</sub>. The NO<sub>2</sub> in turn combusts the soot that is collected in the DPF to regenerate the DPF. The SCR system that was installed uses a two-fluid technology of urea and compressed air.

Emissions Testing Results

Table 2 and Table 3 show emissions test results from each engines.

**Table 2: Test Results from Engine #1**

| <b>Pollutant</b> | <b>SCAQMD Emissions Limit at 15% O<sub>2</sub></b> | <b>Actual Emissions</b>    | <b>% Reduction Targeted</b> | <b>% Reduction Achieved</b> |
|------------------|--|----------------------------|-----------------------------|-----------------------------|
| PM <sub>10</sub> | 0.045 g/bhp-hr                                     | <0.005 g/bhp-hr            | 85%                         | >90%                        |
| NOx              | 50 ppm   | 34.90 ppm                  | 93.2%                       | >94%                        |
| TNMEHC           | 39 ppm<br>0.15 g/bhp-hr                            | 10.80 ppm<br>0.05 g/bhp-hr | 25%                         | >90%                        |
| NH <sub>3</sub>  | 10 ppm   | 0.01 ppm                   |                             | Surpassed                   |

**Table 3: Test Results from Engine #2**

| <b>Pollutant</b> | <b>SCAQMD Emissions Limit at 15% O<sub>2</sub></b> | <b>Actual Emissions</b>   | <b>% Reduction Targeted</b> | <b>% Reduction Achieved</b> |
|------------------|--|---------------------------|-----------------------------|-----------------------------|
| PM <sub>10</sub> | 0.045 g/bhp-hr                                     | <0.005 g/bhp-hr           | 85%                         | >90%                        |
| NOx              | 50 ppm   | 44.27 ppm                 | 93.2%                       | >94%                        |
| CO               | 89 ppm   | 3.62 ppm                  | 16.7%                       | >90%                        |
| TNMEHC           | 39 ppm<br>0.15 g/bhp-hr                            | 3.18 ppm<br>0.02 g/bhp-hr | 25%                         | >75%                        |
| NH <sub>3</sub>  | 10 ppm   | 0.00 ppm                  |                             | Surpassed                   |

The low PM values, combined with the low NOx, CO, and HC emissions at the stack demonstrate that the criteria pollutants from a diesel engine can be simultaneously controlled by the DPF and SCR technologies.

More information on this project is available at:

<http://www.nj.gov/dep/airworkgroups/docs/1chu.attachment5.pdf>.

### 2.3 Diesel Retrofit of Emergency Backup Power Engine in Puerto Rico

In July 2007, Janssen Ortho LLC retrofitted three 2220 hp Cummins KTTA 50-G2 diesel engines at its Gurabo, Puerto Rico research and manufacturing site. The diesel engines provide emergency backup power. Due to space constraints, Janssen Ortho and an emission control device manufacturer arrived at a compact design that allowed all of the emissions control equipment to be installed above the engine. The diesel engines were retrofitted with SCR and DPF systems and achieved the following emission reductions:

| Pollutant | Targeted Emission Limits |    | Achieved (engine range) |               |
|-----------|--------------------------|----|-------------------------|---------------|
|           | g/bhp-hr                 | %  | 50% Load (%)            | 100% Load (%) |
| NOx       | 1.28                     | 90 | 93.4-99.3               | 91-92.4       |
| CO        | 0.33                     | 95 | 94.6-99.2               | 97.8-99       |
| HC        | 0.03                     | 80 | NA                      | NA            |
| PM        | 0.017                    | 85 | >90                     | >90           |

### 2.4 Controlling NOx from Gas Drilling Rig Engines

Due to rapidly expanding natural gas drilling activity in the Pinedale Anticline in Wyoming, the state of Wyoming and the Bureau of Land Management (BLM) requested that all gas drilling companies in the Pinedale Anticline reduce NOx emissions from their drilling rigs. Shell Exploration and Production Company and an emission control device manufacturer worked together to control NOx emissions from Shell's natural gas drilling rigs that are each equipped with three 1476 hp Caterpillar 3512BDITA engines. The natural gas engines were retrofitted with SCR systems. Even in the harsh environment that the engines work in, the SCR system reduced NOx emissions by greater than 90% and maintained ammonia slip of less than 10 ppm throughout the extreme engine load swings of the gas drilling operation.

| Pollutant       | Targeted Emission Level        | Achieved        |
|-----------------|--------------------------------|-----------------|
| NOx             | 90% reduction or 0.70 g/bhp-hr | 91 to 99%       |
| NH <sub>3</sub> | ≤ 10 ppm                       | Average 2-3 ppm |

### 2.5 Kings County, CA, Department of Public Works

Kings County, located in California's San Joaquin Valley, subscribes to an interruptible power program with the local utility in order to save on electricity costs. As a program participant, the county receives a 25 percent lower rate on electricity but must disconnect from utility grid after being given 30-minute notice. If the county fails to disconnect in 30 minutes, it must pay a large penalty. After a period of frequent interruptions during the winter of 2000/2001, the County Council authorized the installation of a large generator to supply backup power to most facilities located in the Government Center in Hanford. A Caterpillar 3516BB engine powers the backup generator and in order to comply with air quality regulations for diesel generators that run during voluntary power interruptions, the county installed a DPF system on the engine. Installation of the filter system was a collaborative effort involving the County, the system supplier, and the filter installer. The generator engine burns ultra-low sulfur diesel fuel.

Engine emissions testing results before and after installation of the DPFs are summarized in the table below. Emissions before DPF system installation were provided by Caterpillar, Inc. and represent emissions for the engine operating at 50 percent load, the average load the engine carries at the Government Center. Engine-out emissions for PM were also reduced by 25 percent as suggested by Caterpillar, Inc. to account for the use of cleaner burning California diesel fuel. The DPF was removed after 556 hours to inspect soot buildup, which would indicate if the DPF was regenerating properly. The inspection results revealed very clean filters, indicating that the engine was reaching and sustaining adequate temperatures to ensure regeneration.

**Emissions Reduction Summary**

| <b>Pollutant</b> | <b>Emission Rate Before Control<br/>(g/bhp-hr)</b> | <b>Emission Rater After<br/>Controls (g/bhp-hr)</b> | <b>Percent Reduction</b> |
|------------------|--|---|--------------------------|
| CO               | 0.84   | 0.084   | 90                       |
| HC               | 0.33   | 0.033   | 90                       |
| PM               | 0.179 <sup>a</sup>                                 | 0.027 <sup>a</sup>                                  | 85                       |
| NOx              | 6.51   | NA <sup>b</sup>                                     | NA <sup>b</sup>          |

<sup>a</sup> PM emission rate reduced by 25% per Caterpillar, Inc. to account for lower PM emissions from CARB diesel fuel

<sup>b</sup> Not applicable

More information on this project is available at:  
[www.nescaum.org/documents/rpt030612dieselgenerators.pdf](http://www.nescaum.org/documents/rpt030612dieselgenerators.pdf).

**2.6 National Steel and Shipbuilding Company (NASSCO)**

NASSCO, located on San Diego Bay, is the largest shipyard engaged in new ship construction on the West Coast and builds commercial ships including oil tankers, ferries, container ships and research vessels. In 2001, NASSCO purchased a Cummins QST30-G1 diesel engine and generator to power Crane Number 16, a 300-ton gantry crane. In order to meet air quality requirements, the engine was equipped with a DPF to control PM and a selective catalytic reduction (SCR) unit to reduce NOx emissions. To keep the exhaust gas temperature high enough for the proper operation of DPF and SCR system exhaust gas heaters were installed ahead of the emission control system. NASSCO uses California #2 diesel fuel to operate Crane Number 16.

Engine emissions before and after installation of emission controls are summarized in the table below. The emissions rates for the engine before the installation of emission control devices are from Cummins, Inc. Emissions reductions are based on the performance claims of the emission control manufacturer and reflect the typical values observed in similar applications. The emission control installer estimates the DPF achieves an 85 percent reduction of PM and the SCR unit achieves a 90 percent reduction of NOx. Source tests were conducted on the crane by World Environmental, Inc. on March 14, 2002 and preliminary source test data confirm the SCR system achieves a >90% reduction in NOx.

**Emissions Reduction Summary**

| <b>Pollutant</b> | <b>Emission Rate Before Controls (g/bhp-hr)</b> | <b>Emission Rate After Controls (g/bhp-hr)</b> | <b>Percent Reduction</b> |
|------------------|---|--|--------------------------|
| CO               | 0.2   | 0.85   | 85                       |
| HC               | 1.1   | 0.10   | 85                       |
| PM               | 0.03 <sup>a</sup>                               | 0.045 <sup>a</sup>                             | 85                       |
| NOx              | 8.1 <sup>b</sup>                                | 0.69 <sup>b</sup>                              | 93                       |

a PM emission rates reduced 25% per Caterpillar, Inc. to account for lower PM emissions from California diesel fuel.

B Nox emission rates reduced 7% per Caterpillar, Inc. to account for lower Nox emissions from California diesel fuel.

More information on this project is available at:

[www.nescaum.org/documents/rpt030612dieselgenerators.pdf](http://www.nescaum.org/documents/rpt030612dieselgenerators.pdf).

*2.7 Pacific Bell-SBC Telecommunications Facility*

In 1994, the Pacific Bell-SBC installed two emergency generators at their high-rise telecommunications facility in San Francisco, CA. To accommodate growth, Pacific Bell replaced a turbine with two Caterpillar 3516 engines and their associated generators. In order to mitigate complaints of smoke and odors, Pacific Bell installed DPF systems on the engines. The installed filter systems are capable of reducing PM emissions by 85% and carbon monoxide and hydrocarbon emissions by 90%. The engine uses regular #2 diesel fuel.

Expected engine emissions before and after installation of the DPFs are summarized in table below.

**Emissions Reduction Summary**

| <b>Pollutant</b> | <b>Emission Rate Before Controls (g/bhp-hr)</b> | <b>Emission Rate After Controls (g/bhp-hr)</b> | <b>Percent Reduction</b> |
|------------------|---|--|--------------------------|
| CO               | 1.17  | 0.12   | 90                       |
| HC               | 0.50  | 0.05   | 90                       |
| PM               | 0.239   | 0.036  | 85                       |
| NOx              | 17.04   | NA   | NA                       |

More information on this project is available at:

[www.nescaum.org/documents/rpt030612dieselgenerators.pdf](http://www.nescaum.org/documents/rpt030612dieselgenerators.pdf).

*2.8 Santa Clara County Building Operations*

Santa Clara County operates a back-up generator in San Jose, CA. The generator provides emergency back-up power to three buildings. In 1998, Santa Clara County purchased the Cummins KTTA50-G2 diesel engine and generator to provide emergency power for the County Service Center. To avoid complaints of smoke and odors, Santa Clara County installed two catalyzed DPFs on the engine exhaust system. The engine uses CARB diesel fuel #2.

Expected engine emissions before and after installation of the filter system on the engine are summarized in the table below. Emissions reductions are based on preliminary source test results provided by the emission control manufacturer for a similar emission control system installed at another facility.

**Emissions Reduction Summary**

| <b>Pollutant</b> | <b>Emission Rate Before Controls (g/bhr-hr)</b> | <b>Emission Rate After Controls (g/bhp-hr)</b> | <b>Percent Reduction</b> |
|------------------|---|--|--------------------------|
| CO               | 2.17  | 0.22   | 90                       |
| HC               | 0.14  | 0.01   | 90                       |
| PM               | 0.083 <sup>a</sup>                              | 0.012 <sup>a</sup>                             | 85                       |
| NOx              | 12.8  | NA   | NA                       |

<sup>a</sup> PM emission rate reduced 25% per Caterpillar, Inc. to account for lower PM emissions from CARB diesel fuel.

More information on this project is available at:

[www.nescaum.org/documents/rpt030612dieselgenerators.pdf](http://www.nescaum.org/documents/rpt030612dieselgenerators.pdf).

*2.9 Sierra Nevada Brewing Company, Chico, CA*

Sierra Nevada Brewing Company (SNBC) purchased two 750 kW generators to provide emergency back-up power for brewery operations in 1997 and 1999. Both generators are powered by Caterpillar 3412 diesel engines. To meet air quality requirements, SNBC installed DPFs on the engines in 1999 and 2000. Two catalyzed DPFs were installed in parallel on each engine. The engines operate on CARB diesel fuel.

Engine emissions before and after installation of the DPFs are summarized in the table below. Emissions before installation of the filter system were provided by Caterpillar, Inc. and are emissions for the engine operating at 75% load. SNBC typically operates their engines at about 80% load, but the emissions data at 80% were not available from Caterpillar, Inc. As suggested by Caterpillar, Inc., uncontrolled engine emissions from NOx and PM were reduced by 7% and 25%, respectively, to account for the use of cleaner burning CARB diesel fuel. ARB performed source tests on SNBC's engines on March 20-24, 2000.

**Emission Reduction Summary**

| <b>Pollutant</b> | <b>Emission Rate Before Controls (g/bhp-hr)</b> | <b>Emission Rate After Controls (g/bhp-hr)</b> | <b>Percent Reduction</b> |
|------------------|---|--|--------------------------|
| CO               | 0.84  | 0.084  | 90                       |
| HC               | 0.33  | 0.033  | 90                       |
| PM               | 0.164 <sup>a</sup>                              | 0.025 <sup>a</sup>                             | 85                       |
| NOx              | 6.69 <sup>b</sup>                               | 5.85   | 12                       |

<sup>a</sup> PM emission rate reduced 25% per Caterpillar, Inc. to account for lower PM emissions from CARB diesel fuel.

<sup>b</sup> NOx emission rate reduced 7% per Caterpillar, Inc. to account for lower NOx emissions from CARB diesel fuel.

More information on this project is available at:

[www.nescaum.org/documents/rpt030612dieselgenerators.pdf](http://www.nescaum.org/documents/rpt030612dieselgenerators.pdf).

2.10 Diesel Retrofit of Rock Crusher and Conveyor

J. Cloud Inc. has a rock crushing operation near San Diego in El Cajon, California, that operates 8 hours a day for five days a week. After receiving complaints of diesel odors and dust, the San Diego Air Pollution Control District (APCD) investigated and found that prevailing winds were responsible for transporting dust and odors to the residences nearby. As a result, J. Cloud was required to remedy the situation by installing emissions control devices. The rock crusher equipment are equipped with 536 hp CAT 3408 and 430 hp CAT 3306 engines. The CAT 3408 drives a hydraulic pump that powers a rock crusher and the CAT 3306 drives a generator that provides power for a conveyor. J. Cloud chose to install a DOC+DPF system. The catalyst eliminated the odor and the filter reduced the PM. Since its installation in September 2005, the DOC+DPF systems have been operated for over 2,000 hours with no problems.

|    | CAT 3408              |                       |             | CAT 3306              |                       |                |
|----|-----------------------|-----------------------|-------------|-----------------------|-----------------------|----------------|
|    | Engine Out<br>g/hp-hr | Guaranteed<br>g/hp-hr | Reduction % | Engine Out<br>g/hp-hr | Guaranteed<br>g/hp-hr | Reduction<br>% |
| PM | 0.2                   | 0.045                 | 85          | 0.3                   | 0.03                  | 85             |
| CO | 1.6                   | 0.52                  | 80          | 2.6                   | 0.32                  | 80             |

2.11 San Joaquin Valley, CA

The San Joaquin Valley Unified Air Pollution Control District (SJVUAPCD) established a certification protocol for add-on emissions control systems installed on agricultural gas engines for compliance with Rule 4702. Rule 4702, as amended in January 2007, regulates air pollution emissions from agricultural engines > 50 hp. To meet ozone non-attainment, the SJVUAPCD recognized the need to control emissions from agricultural engines. Many of these engines are rich burning gas engines that can be easily retrofitted with three-way catalysts and air fuel ratio controllers. The SJVUAPCD instituted an emissions certification process requiring the installation and operation of the catalytic converter and air fuel ratio controllers on a representative engine. A three-way catalytic converter was retrofitted on a Cummins 855A 200 hp engine that is used for water pumping operation on Grimmway Farms. The catalytic converter exceeded the San Joaquin Valley APCD certification requirements and is currently accumulating operating hours required for full verification.

| Pollutant | Converter Inlet<br>lb/hr | Converter<br>Outlet lb/hr | %<br>Reduction | Certification<br>Standard |
|-----------|--------------------------|---------------------------|----------------|---------------------------|
| NOx       | 3.870                    | 0.212                     | 95             | 80                        |
| CO        | 5.405                    | 0.288                     | 95             | 80                        |
| VOC       | 0.094                    | 0.001                     | 99             | 50                        |

2.12 Diesel Retrofit of Portable Electrical Generator

A New England military contractor performs durability tests on each portable electrical generator they produced before they are shipped to Iraq. The generators vary in size from 10 to

200 kW and as many as six generators are tested at a time, with each being run for a minimum of 50 hours. The company also wanted the freedom of testing the engines at various locations at the site. An emission control device manufacturer designed and built a self contained SCR system that is fully portable. The SCR system is skid mounted and contains a NO<sub>x</sub> analyzer for closed loop urea injection control, an air compressor, urea injection system and urea tank. It is designed to handle the exhaust from as many as six engines sized from 10 kW to 200 kW each for a maximum of 1200 kW total. The system is capable of achieving 80 to 90 percent reduction with a maximum ammonia slip of 10 ppm.

### *2.13 Memorial Hospital of Los Banos, Los Banos, CA*

The Memorial Hospital of Los Banos installed a DPF on a 1994 Caterpillar 3406, 519 horsepower engine operating an emergency backup generator. The DPF was installed in 2002 to comply with the San Joaquin Valley Air Pollution Control District emission permit requirements. The hospital runs the engine about 30 minutes per week for maintenance and testing and the exhaust temperature is monitored during the weekly engine test.

### *2.14 Fresno Regional Medical Center, Fresno, CA*

Fresno Regional Medical Center installed a catalyzed DPFs on five 2002 Caterpillar 3516TA, 2680 horsepower engines that power Caterpillar SR4 B emergency backup generators. As part of the San Joaquin Valley Air Pollution Control District permit, the medical center was required to reduce PM emissions. Emission information provided to the medical center stated that a Caterpillar generator produce 0.10 g/bhp-hr of PM without an emission control device. The Caterpillar generator running on CARB diesel and a DPF has PM emissions reported at 0.01 g/bhp-hr.

### *2.15 New Jersey Department of Environmental Protection Stationary Diesel Particulate Filter Project*

The New Jersey Department of Environmental Protection (NJDEP), in collaboration with the Stevens Institute of Technology and an emissions control technology manufacturer, initiated a project to install diesel particulate filters on five 500 kW electric diesel generators located at the Jersey City Total Energy Plant. This energy plant is a co-generation facility that supplies heat and air conditioning. These generators were retrofitted with catalytic diesel particulate filters that continuously regenerate at normal operating temperatures. The DPF is expected to reduce combined PM, CO and HC emissions by at least 85 percent. NJDEP will demonstrate the DPF for six months and develop an inventory of diesel engines in New Jersey with the associated yearly emission estimates. NJDEP will also determine the applicability of DPFs with respect to the New Jersey Inventory of stationary sources in reducing stationary diesel emissions.

## 2.16 Intel Corporation, San Jose, CA

Intel Corporation installed two DPFs on a Caterpillar 3412C, 896 horsepower engine that powers an emergency backup generator. The facilities manager stated that they have not had any problems with the DPF and there is no extra maintenance.

## 2.17 Demonstration of a NOx Control System for Stationary Diesel Engines

The Electric Power Research Institute (EPRI), the California Energy Commission (CEC), and Hawaiian Electric Company (HECO) have partnered to further develop an emerging emission control technology for retrofitting stationary diesel engines. They identified an emissions control device manufacturer having unique technical capabilities and a novel design for a cost effective, regenerative lean NOx trap system capable of greater than 90 percent reduction and an integrated diesel particulate filter.

The manufacturer developed a system which consisted of a fuel processor with a third-party, commercial lean NOx adsorber trap that will achieve greater than 90 percent NOx reduction. The fuel processor converts diesel fuel to reactive reductants, such as H<sub>2</sub> and CO to rapidly and completely regenerate the NOx trap. These reductants convert the trapped NOx to N<sub>2</sub>. This system was demonstrated on a 8.3 liter, 160 kW, Cummins stationary generator set. The demonstration project is planned in three phases: the Technology Demonstration (Phase I), Field Demonstration (Phase II), and Pilot Production (Phase III). The goal of Phase I is to demonstrate a NOx reduction technology on a 160 kW diesel-fueled reciprocating engine that can be scaled up to a size range of 250 to 2,000 kW in Phase II. The measurable objective is to achieve 90 percent NOx removal using the selected emission control technology for 100 hours of base-load operation and to measure the fuel penalty associated with achieving the 90 percent NOx reduction. The Phase I Technology Demonstration was completed in December 2004. In Phase II, an ARB-verified, regenerative diesel particulate filter will be integrated into the system design (consisting of an Emissions System Control Unit (ESCU), a throttle valve, the fuel processor, and lean NOx trap (LNT)) and two units will be developed and installed on two diesel engines for field demonstration testing. The goal of this phase is to achieve 95 percent NOx reduction. Phase II consists of pre-commercial, limited release operation at multiple commercial sites.

### Phase I Technology Demonstration:

*Task 1:* The manufacturer retrofitted the Cummins 8.3 liter, 160 kW generator set with a throttle valve and control system to enable automatic control of the fuel/air mixture.

*Task 2:* The emissions control device hardware was designed and fabricated. Several fuel processor catalyst materials were evaluated and the most suitable were selected.

*Task 3:* Several NOx traps were evaluated for their suitability in the system.

*Task 4:* Demonstrate the feasibility of a greater than 90 percent NOx reduction system for 100 hours on a stationary 160 kW diesel generator set. The measured average fuel penalty for the entire test was approximately 7 percent, but this fuel penalty was not optimized.

During Phase I, the cumulative NO<sub>x</sub> conversion averaged over the entire 100-hour test was 92 percent. During the first 20 hours of the test, average NO<sub>x</sub> conversion dropped below 90 percent several times while the control system was being tuned and refined. After fine-tuning the control system, NO<sub>x</sub> conversion remained between 90 percent and 94 percent with the cumulative time weighted average NO<sub>x</sub> conversion increasing with time after the first 20 hours. The manufacturer discovered that the actual capacity of the full-scale LNTs was significantly less than predicted, based on the sub-scale LNT test results. The LNT vendor suggested that the capacity difference was due to their prototype production process depositing a non-uniform washcoat loading on the full-scale traps. The vendor explained that this performance shortfall would not be expected from commercially manufactured traps. The NO<sub>x</sub> trapping capacity shortfall resulted in the inability of the prototype hardware to maintain 90 percent NO<sub>x</sub> reduction for an extended period of time. As a result, a fourth trap had to be added to the system to meet the performance objectives of the 100-hour test.

The next phase of the project, Phase II development and field trials, will include:

- Integrating the LNT system with an ARB-certified diesel particulate filter and produce two integrated units for field trials with design goals of 95 percent NO<sub>x</sub> and 85 percent diesel particulate matter (PM) removal at minimal fuel penalty. One unit will be sized for a 500 kW engine and the second for a 1,000 kW engine.
- Installing these two units on existing diesel engines at two different locations and operated for 1,000 hours each under normal operating conditions.

At the conclusion of Phase II field demonstration, the results will be analyzed and a decision will be made as to whether to proceed with Phase III, where this NO<sub>x</sub> control technology will be made available to the general public on a limited release basis while the pilot manufacturing details are worked out and preparations are made for a full commercial release. More information on this project is available at:

[http://www.energy.ca.gov/pier/final\\_project\\_reports/CEC-500-2005-129.html](http://www.energy.ca.gov/pier/final_project_reports/CEC-500-2005-129.html).

## *2.18 Evaluation of NH<sub>3</sub>-SCR Catalyst Technology on a Stationary Diesel Genset*

Three technology manufacturers and U.S. Navy, Naval Surface Warfare Center collaborated together to demonstrate “proof-of-concept” of ammonia-selective catalytic reduction (SCR) and diesel oxidation catalyst system on a 250 kW diesel genset. The SCR and DOC were installed on a Caterpillar 3306 diesel generator set engine, rated at 1800 rpm, 250 kW. The catalyst system was a four bank system, each bank with two 5 liter SCRs and one 2.5 liter DOC brick. The emissions testing for the system was conducted by a third party, GE Energy Management Services. During the field testing, the engine was maintained at 90 percent load, using U.S. #2 diesel fuel. Data was collected at different weather conditions by running the engine for 500 hours at 90 percent load. Exhaust gas analysis (NO, NO<sub>2</sub>, CO, CO<sub>2</sub>, and O<sub>2</sub>) was conducted upstream and downstream of the catalytic converter. Secondary emissions of NH<sub>3</sub>, CO, VOCs, and PM were verified by the third party GE Management Services. Results from the emissions testing showed 70 to 80 percent conversion of NO<sub>x</sub> to N<sub>2</sub> at 90 percent load and NH<sub>3</sub>/NO<sub>x</sub> of about 0.8.

More information on this project is available at:  
[http://www1.eere.energy.gov/vehiclesandfuels/pdfs/deer\\_2005/poster2/2005\\_deer\\_malyala.pdf](http://www1.eere.energy.gov/vehiclesandfuels/pdfs/deer_2005/poster2/2005_deer_malyala.pdf).

### *2.19 Additional SCR projects:*

There have also been several projects involving installation of SCR systems on stationary, natural gas fired, reciprocating engines to comply with NOx regulations. For more information on these projects, go to: <http://www.icac.com/i4a/pages/index.cfm?pageid=3356#Multi-p>.

## **3.0 Summary**

As shown by the above case studies, experiences with retrofitting stationary diesel engines with emission control devices are growing. These stationary engine case studies are another example of the successful transfer of diesel retrofit technology originally developed for reducing diesel particulate and/or NOx emissions from on-road diesel engines into off-road diesel engine applications. The availability of ultra-low sulfur diesel (ULSD) fuel for non-road diesel engines will expand significantly now that the national rollout of ULSD for highway applications has been completed. This should facilitate even wider application of retrofit filter technologies on stationary diesel engines. Areas of the country with severe ozone problems are also prime targets for EGR or SCR retrofits on stationary engines for reducing NOx emissions from these sources. The examples cited in this report provide firm evidence that retrofit technologies can be a successful, cost-effective strategy for reducing emissions from stationary diesel engines.