Case Studies of the Use of Exhaust Emission Controls on Locomotives and Large Marine Diesel Engines

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1.0 Introduction

Diesel engines provide important fuel economy and durability advantages for large heavy-duty trucks, buses, and nonroad engines. Although they are often the power plant of choice for heavy-duty applications, they have the disadvantage of emitting significant amounts of particulate matter (PM) and oxides of nitrogen (NOx), and lesser amounts of hydrocarbon (HC), carbon monoxide (CO), and toxic air pollutants.

Locomotive and marine diesel engines are significant contributors to air pollution in many cities, ports, and regions across the U.S. Due to relatively modest emission standards that are currently in place, current locomotive and marine diesel engines emit large amounts of NOx and PM and emissions of these air pollutants are expected to grow due to the anticipated future growth in the use of these engines. U.S. EPA estimates that by 2030, without new emission controls, locomotive and marine diesel engines will contribute about 27% of the national mobile source NOx and 45% of the national mobile source fine diesel particulate matter ($PM_{2.5}$) emissions. Therefore, the reduction of diesel emissions from locomotive and large marine engines has the potential to significantly improve air quality throughout the nation, as well as for those who live or work in or adjacent to ports and railyards.

Many of the diesel emission control technology options first developed for light-duty passenger cars, heavy-duty highway vehicles, and stationary engines (for application on both new vehicles and retrofits on existing vehicles) are now seeing limited application or are involved in feasibility studies on locomotive and large marine diesel engines. The experience with these diesel emission control technologies on highway vehicles provides an important experience and technology base for extending their application to locomotive, marine diesel, and other non-road diesel engines. These technologies include diesel oxidation catalysts (DOCs) and diesel particulate filters (DPFs) for controlling diesel particulate matter (PM) emissions, and lean NOx catalysts and selective catalytic reduction (SCR) catalysts for reducing NOx emissions.

The extensive international experience base of SCR for controlling NOx emissions from stationary sources has been used over the past 15 years to develop NOx emission control solutions for mobile sources. Hundreds of SCR retrofit systems have been installed in the U.S. and Europe on large highway trucks since 1995. Operating experience exceeding 350,000 miles has been generated on some vehicles. SCR-equipped trucks using a urea-based reductant are now commercially available in Europe where tens of thousands of units are operating on the roads to comply with Euro 4 and Euro 5 heavy-duty engine emission regulations. SCR is expected to be introduced on diesel passenger cars and heavy-duty trucks operating in the U.S. over the next three years to comply with EPA’s Tier 2 light-duty regulations and EPA’s 2010 heavy-duty highway diesel emission regulations. These mobile source SCR systems can be designed to give significant reductions in NOx (75-90%), as well as reductions in HC (80%) and PM (20-30 %) emissions.

The operation of locomotive engines is quite different from on-road diesel trucks. Unlike trucks, long haul locomotives have powerful engines designed to operate at low speeds without the frequent transients experienced in on-road applications. In some ways, they more closely resemble stationary or marine engines in both displacement and operating cycle. SCR has been used to control NOx from stationary sources and large marine diesel engines for over 15 years. A recent example of a large stationary retrofit of a diesel-powered generator incorporating both particulate control and SCR was presented at a conference in December 2005 (see www.nj.gov/dep/airworkgroups/docs/1chu.attachment5.pdf). The engines in this demonstration were 2900 hp, 78 liter in size and were equipped with a catalyst-based, continuously regenerating particulate filter and SCR using a urea-based reductant. With more than 2000 hours of operation, these systems achieved reductions of greater than 90% PM, 94% NOx, 90% CO, and 75% HC, with less than 0.01 ppm ammonia slip. Many other stationary diesel engines have successfully achieved significant reductions in NOx emissions with properly designed SCR systems. Additional information on marine SCR experience is discussed in this report.

These, as well as other examples, clearly demonstrate that the NOx reduction technology originally developed for stationary engines has been successfully adapted to on-road vehicles and marine applications in Europe and suggests that emissions reductions from locomotive and marine engines would significantly benefit as well from the use of these same emission control technologies.

In an effort to address diesel air pollution from locomotives and marine diesel engines, EPA issued an Advanced Notice of Proposed Rulemaking (ANPRM) in May 2004. In this ANPRM, EPA announced its intentions to consider adoption of more stringent emission standards for new and existing locomotives and new commercial and recreational marine diesel engines based on the types of technologies that will be used to control emissions from new on-road heavy-duty engines in the 2007-2010 timeframe and new non-road diesel engines in the 2011-2015 timeframe. The growing list of examples of the application of advanced diesel emission controls to locomotive and marine diesel engines outlined in this report provides technical support for significantly tighter emission standards for these important mobile emission sources.

A formal EPA proposal with the next stage of emission standards for locomotive and marine diesel engines is expected in early 2007 (see: www.epa.gov/otaq/regs/nonroad/420f04041.htm) and will likely be finalized by the agency in early 2008. In addition, as part of EPA's nonroad diesel rule (see: www.epa.gov/nonroad-diesel/2004fr.htm) that was adopted in May 2004, EPA has reduced the sulfur limit of diesel fuel used by locomotives and marine diesel engines to 15 ppm maximum starting in mid-2012. The use of ultra-low sulfur diesel fuel in locomotive and marine engines is an important enabler to allowing the use and maximizing the performance and durability of all available diesel emission control options for these engines. Given the health and environmental concerns associated with diesel engines and because the non-road engines make up a significant percentage of diesel pollution emitted, there is an increasing interest in retrofitting older non-road diesel engines.

Concurrent with efforts made by EPA, the California Air Resources Board (ARB) is also making strides in reducing diesel air pollution from locomotive and marine diesel engines. In December 2005, ARB adopted regulations for oceangoing auxiliary engines to reduce emissions from diesel PM, NOx, and SOx from vessels operating within 24 nautical miles of the California coastline. Currently, ARB is in the process of developing regulations to reduce diesel PM and NOx emissions from commercial harbor craft in California. This regulation will likely be met through retrofitting the vessels with verified diesel emission control devices and engine replacements. In addition, ARB has signed an agreement with the railroad industry and the EPA to implement an averaging program in the South Coast region, where locomotives meeting the 2005 EPA standards will be in place by 2010. California's aggressive goods movement related initiatives include significant focus on mediating emissions from ports and railyards, including emission reductions from locomotives and marine diesel engines (see: www.arb.ca.gov/gmp/gmp.htm).

The case studies discussed in this paper focus on those projects that have been completed, or are in progress, that utilize emission control technology on locomotive and marine engines. Many of the projects highlight the feasibility of installing verified on-road retrofit technologies on locomotive and marine engines and relate some of the lessons learned that may assist others in planning additional locomotive and marine engine projects. The limited range of experience with retrofits on locomotive and marine engines summarized in this report also serves to point out the need for expanding the range of verified retrofit technology options for nonroad diesel applications in general, and locomotive and marine engines in particular. This paper focuses on technology-based strategies and, where available, provides information on the specific type of technology installed on the type of locomotive and marine engines, and the emission reductions that were achieved or are expected. For more detailed descriptions of available diesel exhaust emission control technologies that can be retrofit on existing on-road and nonroad diesel engines, please see MECA's companion white paper, *Retrofitting Emission Controls On Diesel-Powered Vehicles* (available on the MECA website at: www.meca.org or the MECA diesel retrofit website at: www.dieselretrofit.org).

2.0 Locomotive Case Studies

2.1 California Emissions Program (CEP)

In 2001, the California Air Resources Board (ARB), Union Pacific Railroad (UP), and BNSF Railway (BNSF) entered into a voluntary agreement to evaluate the feasibility of installing diesel particulate filter (DPF) technology in locomotives. With direction from ARB, the Association of American Railroads (funded by UP and BNSF) has overseen the California Emissions Program (CEP), with Southwest Research Institute (SwRI) leading the effort to evaluate candidate retrofit DOC and DPF systems. The engine that was chosen for retrofit is a 2,000 hp roots blown (i.e., non-turbo charged), 2-stroke, EMD 16-645E switcher locomotive engine. Below is a summary of SwRI's work:

- SwRI has screened commercially available cylinder kits to identify those that offered the lowest lubricating oil consumption. Rebuilding the EMD engines with cylinder kits that use less lubricating oil will produce lower engine-out PM emissions, reduce the burden on any retrofit system, and will reduce the lubricating oil ash loading on the retrofit device.
- CEP focused on evaluating DOC and DPF systems for locomotives using conventional non-synthetic lubricating oil and low oil-consumption power assemblies. SwRI screened more than 14 DOC and DPF candidates on the engine.

- SwRI tested for engine performance and 500-hour system durability for three candidate retrofit systems in an engine test cell.
- SwRI has performed emissions testing in a test cell and will conduct in-use emissions testing.
- CEP screening test showed that an actively regenerated DPF technology that utilizes a diesel burner for soot regeneration and SiC flow through filter elements was the best currently available device.
- The first two 1,500 hp switchers that will be retrofitted with the selected, active DPF technology are scheduled for revenue testing (testing in actual freight service instead of on a test track) in southern California in July 2006. In addition to the active DPF systems, these switcher locomotives will also be installed with automatic stop/start devices that will reduce the PM output of the locomotives during engine operation at idle. If the initial two installations are successful, BNSF and UP have committed to retrofitting two more locomotives with the DPFs.

More information on this project is available at: www.arb.ca.gov/railyard/rrsubmittal/dpf_sum.pdf.

2.2 DPF Applications for New and Retrofit Locomotives in Switzerland and Europe

Switzerland has initiated a program to install DPF technologies on its fleet of diesel-hydraulic freight locomotives. The primary focus in Switzerland was the application of DPFs for new, low horsepower (2,000 hp) switcher locomotives. Switzerland has also retrofitted six existing 1,200 hp engines with DPF systems. Swiss rail freight is operated by SBB (the Swiss Federal Rail System). Of the 603 total locomotives used to move freight in Switzerland, 113 are diesel powered, and, of those, 73 new, low horsepower units are fitted with DPFs, while 6 of the 40 existing low hp units have been retrofitted with DPFs.

Vossloh 1700 Series Locomotive (Am843 in Switzerland)

Vossloh Locomotive Gmbh (Vossloh) is the major diesel-hydraulic locomotive manufacturer in Europe and produces the MaK1700 series locomotive (identified as Am843 in Switzerland) that is powered by a Caterpillar 3512 4-stroke diesel engine (1,500kW/2,000 hp). In 2004, SBB started delivery of new 73 Am843 locomotives and required that all locomotives in this series be equipped with DPFs. Only synthetic engine lube oil (low ash) can be used with this engine and low-sulfur (<300 ppm) diesel fuel is used. No in-use exhaust emissions testing was performed or was required, so it is difficult to assess the actual reductions achieved.

Vossloh Am841 Locomotives

The 1,200 hp Am841 locomotive is the smaller predecessor to the Am843 and is equipped with MTU 396 engines without DPFs. Currently, there are 40 of these locomotives operating in Switzerland. SBB recently retrofitted 6 of the units with actively regenerated DPFs (burner-based regeneration): for the first three prototypes, the DPFs were added to the roofs of the locomotives, downstream of the existing muffler; for the next three retrofits, the DPF was packaged within the carbody, replacing the mufflers. Only synthetic engine lube oil (low ash) can be used with this engine and low-sulfur (<300 ppm) diesel fuel is used. No in-use DPF exhaust emissions testing is planned for these locomotives retrofitted with the DPFs.

New Vossloh 2000 Prototype Locomotive

The MaK2000BB is a new prototype for high horsepower (3,600 hp) locomotives equipped with an MTU 20V-400 engine that was built with an actively regenerated DPF integrated into the carbody. The locomotive has a DPF integrated into the original design that replaces the muffler and two burners are used to regenerate the filter. No emissions test has been performed. The DPF is offered as an option on this new locomotive in selected European markets and, to date, none have been ordered.

More information on this project is available at: www.arb.ca.gov/railyard/rrsubmittal/dpf_sum.pdf.

2.3 Union Pacific DOC Demonstration Project

Through collaboration with the U.S. EPA, Union Pacific is providing a 3,800 hp EMD SD60M locomotive that was built in January 1992 to serve as the first freight locomotive in North America to be equipped with a set of DOCs. Installation and exhaust emissions testing were scheduled to occur in February 2006. SwRI will modify the locomotive and install the DOCs. After the installation, SwRI will perform EPA locomotive emission tests to verify the PM emission reductions. Afterwards, Union Pacific will relocate the locomotive to the Los Angeles Basin for at least a year of regular service with the DOC to test real-life conditions operating in over-the-road freight service.

More information on this project is available at: www.uprr.com/newsinfo/releases/environment/2006/0417_emissions.shtml.

2.4 Massachusetts Bay Transportation Authority (MBTA) Locomotive Demonstration Project

In 2004, as part of the Locomotive Demonstration Project, the MBTA installed a diesel oxidation catalyst (DOC) on a diesel-powered commuter rail locomotive as a replacement for the sound attenuator. The DOC was installed on a GM EMD 645E3, 16 cylinder two-stroke diesel locomotive engine. The goals of this project were:

- To show that a DOC can reduce PM emissions from heavy-duty diesel locomotive engines;
- Quantify baseline exhaust emissions and emissions following the application of cleaner fuel and the DOC;
- Assess the durability of a DOC for normal use in locomotive operations; and
- Determine the steps needed to commercialize the use of catalysts in locomotive operations.

Emissions testing was conducted and showed that the DOC reduces HC emissions by 16% and PM emissions by 47%. However, three weeks after putting the retrofitted locomotive back into service, engine problems emerged. After removing the DOC, it was found that the DOC was plugged with wet soot, which led to back pressure on the engine and operational problems that caused more PM emissions and further plugging ("cascade" failure).

In October 2005, the commuter locomotive was retrofitted with a close-coupled oxidation catalyst. The DOC was placed within the exhaust manifold between the engine and turbocharger, where the exhaust temperature is substantially higher and the exhaust pressure is greater and less sensitive to backpressure. The DOC is expected to reduce PM emissions by 25% to 45%. In December 2005, the locomotive was taken out of service for normal maintenance and to check the DOC. After 900 hours of durability testing, the DOC showed no signs of plugging, but the thermal and vibration stress cause some physical degradation on the DOC. In January 2006, the redesigned catalyst was installed and ran for 45 days. Emission testing was conducted in March 2006. From this demonstration project, it was shown that a DOC can be located between the engine and turbocharger. During early 2006, continued emissions testing was conducted to evaluate the impact of lube oil contaminant on the catalyst and to verify emission performance beyond 900 hours. During mid-2006, durability issues will be addressed to optimize physical design of the catalyst, the location within the engine, and eliminate catalyst fouling or poisoning agents. In early-2007, tests will be conducted to verify long term physical durability and long term catalytic activity. In addition, the catalyst will be optimized in combination with low NOx components, such as injectors and power assemblies.

More information on this project is available at: www.northeastdiesel.org/pdf/EPA-NE-RR-Jan-2006.pdf.

2.5 California Advanced Locomotive Emission Control System Project

Placer County Air Pollution Control District, with other partners, including the U.S. EPA, the Sacramento Municipal Air Quality Management District, Union Pacific Railroad, and Advance Cleanup Technologies, has initiated a project to employ selective catalytic reduction (SCR) technology on locomotives operating at the Roseville, California railyard (near Sacramento). This project was initiated to demonstrate an Advanced Locomotive Emission Control System (ALECS) at the Roseville railyard to control diesel emissions from locomotives. The initial project emissions mitigation plan will make use of stationary air pollution control devices to capture and treat emissions from stationary locomotives that are idling or undergoing engine load tests. The project aims to demonstrate the effectiveness of stationary air pollution control devices (primarily flue gas scrubbers + SCR) in reducing PM, NOx, SOx, and VOC emissions from locomotive engines. The project is developing a locomotive-specific interface (an exhaust bonnet on a moveable overhead rail system) for capturing the locomotive engine exhaust and directing it through the emission control system. First tests of this system using stationary and slow-moving locomotives to evaluate the effectiveness of the control device began in August 2006. The project is being implemented over two phases: 1) The first phase, initiated in September 2005, was to develop the locomotive interface design, test location definition and design, develop test protocols, and acquire locomotive interface hardware. 2) The second phase shipped the ALECS to the Roseville railyard, erected the ALECS on the test site, started-up the

ALECS equipment, begin testing two different locomotive types using the developed test protocols, and will prepare a final report. The final report expected to be issued in late 2006. More information on this project is available at: www.arb.ca.gov/railyard/ryagreement/071306placer.pdf.

A similar approach has been implemented at a railyard on the outskirts of Paris by the French national rail company, SNCF. In this system, a combined DPF + urea-SCR stationary system has been installed with an overhead exhaust bonnet set-up to capture and treat the exhaust of locomotives as they start-up and idle before beginning service. Diesel locomotives that operate out of the Paris-East rail station are shuttled from Paris-East by an electric switcher locomotive to the facility on the outskirts of Paris where the emission control system is located to lower emissions in the vicinity of the densely populated Paris-East station. The DPF + SCR system provides reductions in hydrocarbons, CO, PM, and NOx for the locomotives engines that are started-up at this facility. This system was put in place and began operating in the spring of 2006. Details of the SNCF emission control system near Paris are available at: www.arb.ca.gov/railyard/ryagreement/071306fritz2.pdf.

The use of a stationary emission control treatment facility that employs DPFs and urea-SCR has also been discussed for reducing emissions from large marine vessels docked at a port facility. Again, in this port scenario, a barge equipped with or dockside location of an emission control system could be employed with an exhaust capture bonnet to reduce ship emissions associated with auxiliary engines operated onboard the ship when it is docked at a wharf. This port clean-up concept would be especially well suited to deal with port emissions from existing ships that may be difficult to retrofit with emission control technologies because of space constraints onboard the vessel. The ALECS technology under evaluation at the Roseville railyard will also be evaluated at the Port of Long Beach for reducing emissions from large ships berthed at the port in late 2006 into early 2007.

2.6 Retrofit of Head End Power Units on Commuter Rail Locomotives

On February 24, 2005, the Sacramento Metropolitan Air Quality Management District (SMAQMD) received a grant under the National Clean Diesel Campaign to install emission control devices on two commuter rail locomotives owned by Amtrak that run between Oakland and Sacramento, CA.

The goal of this project is to install an air pollution control retrofit technology in an innovative application in order to achieve significant emission reductions from a locomotive heavy-duty diesel application. This demonstration project will retrofit 13 Head End Power (HEP) engines in passenger cars used in the Capitol Corridor service that have very large heating/ventilation/air conditioning electrical loads, as well as significant lighting, power strip, and concession stand power demands. The Capitol Corridor HEPs are Tier 1 Caterpillar 3412 engines rated at 1080 horsepower, operating 5,000 hours per year at an average of 300 kW load, resulting in emissions of NOx+PM+VOC totaling 12.08 tons per year per engine. The retrofit technology that will be installed on the HEP engines will be a device that is ARB verified for on-road applications. The retrofit device consists of a lean NOx catalyst and a DPF that is verified to reduce PM by 85% and NOx by 25% for on-road diesel engine applications. This project will demonstrate the innovative use of the ARB verified diesel retrofit technology in a non-verified application and will assist in demonstrating the commercial viability of the retrofit technology for locomotive applications. It is estimated that the retrofit of the 13 HEP engines will achieve a total of 217 tons of NOx+VOC+combustion PM for a five-year project life.

More information on this project is available at: www.westcoastdiesel.org/files/meetings/2005-03-21/5a - Locomotives.ppt.

3.0 Large Marine Engine Case Studies

3.1 New York Harbor Private Ferry Emissions Reduction Program

Due to the resurgence of ferry ridership in the New York City harbor area and the region's designation as a NOx non-attainment area, there is a pressure on the ferry operators to reduce air pollution emissions. As a result, the New York State Energy Research and Development Authority (NYSERDA) has initiated a $6.8 million program to collaborate with private ferry operators to demonstrate emission reduction technologies. Currently, there are approximately 50 private passenger ferries operating in the harbor. In September 2003, Seaworthy Systems, Inc. was awarded with a prime contract to oversee the implementation of the demonstration program, with assistance from Environment Canada, Northeast States Coordinated Air Use Management (NESCAUM), and ESI International. The goals of this project are to:

- Reduce private ferry fleet emissions
- Focus on NOx reduction as well as particulate matter ($PM_{2.5}$)
- Aim at near term results instead of new boat construction
- Ultimate widespread deployment

Three local ferries that are participating are: New York Waterways, Inc.; Seastreak, Inc.; and New York Water Taxi, Inc. The scope for Phase I of the project consists of fleet characterization; emissions control technology analysis, ranking, down-selection; and demonstration of three to five selected technologies. Phase 2 consists of providing an estimated $5 million for incentivizing the private fleets to install the selected technologies. This multi-year program will help to provide credible information on the costs, benefits, and feasibility of a wide range of possible emissions control options from private ferry fleets, as well as real-world experience with the use of the identified "best choice" emissions control technologies.

Technologies that are selected for demonstration are:

- DOC plus fuel-borne catalyst installed on CAT 3412E vessels. It is estimated that this would achieve NOx reductions of 5% with ULSD and PM reductions of 50%.
- SCR plus DOC installed on Cummins KTA50M2 engines. It is estimated that this would achieve NOx reductions of 70% and PM reductions of 25%.
- DOC on Detroit Diesel Series 60 engines. It is estimated that this would achieve PM reductions of 40%.

- DOC plus Continuous Water Injection System installed on CAT 3406E or 3412C engines. It is estimated that this would achieve NOx reductions of 25% and PM reductions of 40%.

More information on this project is available at: www.northeastdiesel.org/pdf/Technical-NYSERDA.pdf.

3.2 Staten Island Ferry Emissions Reduction Demonstration Project

The Port Authority of New York and New Jersey, in collaboration with the New York City Department of Transportation, has initiated an innovative pilot project to demonstrate emissions reduction technologies on a Staten Island Ferry. The focus of this project was on NOx reduction and, of the available NOx emission control technologies, SCR was judged to meet the criteria that were set for the project: 1) potential for significant NOx reductions of greater than 70%; 2) an end-of-pipe control system with no intrusion into the main engines; and 3) a proven commercial catalyst technology with more than one vendor to allow for a competitive bid process. SCR, as an aftertreatment device, is completely separate from the engine and is a commercial technology used in several countries, including the U.S. While the focus of the project was on NOx reduction, there was also a desire to reduce particulate matter, volatile organic compound (VOC), and carbon monoixide (CO) emissions as well. Therefore, the *MV Alice Austen* was retrofitted with SCR and DOC systems on its two main CAT 3516A propulsion engines. The Alice Austen Staten Island Ferry vessel was selected for this demonstration project because it is a "relatively" small vessel within the fleet and is equipped with the Caterpillar 3516A four-stroke main engines. In the past, SCR has been successfully installed on several hundred of these specific engines in both marine and power generation applications.

West Virginia University and M.J. Bradley & Associates conducted the emissions test program on the Staten Island Ferry Alice Austen vessel during April 2005 and issued a report summarizing these emission results in August 2006. The emission testing observed on the ferry showed an overall trip reduction of NOx ranging from 68.6% to 81.2% using the installed SCR system. NOx reductions during ferry cruise modes with urea injection operational typically exceeded 94%. The DOC was shown to reduce CO production by 80% to 95%. No clear conclusions on the effects of the SCR on PM can be made without additional testing because the bulk of the PM was produced during transient engine operation and because the number of PM tests was limited. More information on this project is available at: www.mjbradley.com/documents/Austen_Alice_Report_Final_31aug06.pdf.

3.3 Vallejo Ferry Demonstration Project

The city of Vallejo, CA, operates a passenger-only, fast-ferry system serving Vallejo and North Bay residents with service to and from downtown San Francisco. The city has purchased a low emissions ferry that utilizes urea-based selective catalytic reduction (SCR). The new ferry is equipped with a pair of IMO-compliant MTU/DDC 16V-4000 series diesel engines producing a total driving power of 4,500 kW. The SCR device is expected to reduce NOx emissions by 50%, along with 10% reductions in total hydrocarbon (THC), carbon monoxide (CO), and PM emissions. More information on this project is available at: www.marad.dot.gov/nmrec/energy_technologies/images/ETNo4Winter0304.htm.

3.4 Blue and Gold Ferry Demonstration Project

San Francisco-based Blue & Gold Ferry has retrofitted one of their ferries with a lean NOx catalyst and DPF system on new main propulsion engines. The system is expected to achieve more than 30% reduction in NOx and more than 85% reduction in PM. After installation of the emission control devices, there have been some issues with high back pressure and exhaust temperature. ARB is currently working with the Bay Area Air Quality Management District and the vendor to resolves these issues. More information on this project is available at: www.arb.ca.gov/msprog/offroad/marinevess/presentations/032304/demos.pdf.

3.5 ARB Harbor Craft Demonstration Project

ARB plans to finalize regulations in late 2006 for controlling PM and NOx emissions from existing harbor craft operating in California waters. The use of retrofit diesel emission controls is one of the compliance options that will be a part of these regulations. ARB plans to demonstrate the use of selected diesel retrofit technologies, such as DOCs or DPFs, on a few marine vessels in late 2006 and into 2007 as part of this rulemaking effort. Details on ARB's harbor craft regulatory process are available at: arb.ca.gov/msprog/offroad/marinevess/harborcraft.htm.

3.6 U.S. Navy Work Boat/Barge

The California ARB and the U.S. Navy have initiated a demonstration project to reduce diesel emissions from a U.S. Navy work boat/barge. Two 2-stroke DDC 12V-71 engines have been rebuilt with an engine rebuild kit provided by Clean Cam Technology (CCT) Systems. These engines have also been retrofitted with active DPFs and use low sulfur diesel fuel. Preliminary results from emission testing show a 28% reduction in PM and 71% reduction in NOx emissions were achieved with just the engine modifications; a 76% reduction in PM and small reduction in NOx emissions with only the active DPF installed; and an 85% reduction in PM and 74% reduction in NOx emissions with engine modifications + DPF. Durability and final emission testing will be conducted during the fall 2006. More information on this project is available at: www.arb.ca.gov/msprog/offroad/marinevess/presentations/091206/091206tech.pdf.

3.7 Holland America Seawater Scrubbing Technology Feasibility Study

Holland America plans to conduct a feasibility study of a new seawater scrubbing technology to reduce emissions from seagoing vessels. During spring 2007, a scrubber will be equipped and evaluated on the ms Zaandam cruise ship. The study results and final report are planned for June 2008. Results from this study will help determine if the technology could be installed on new ocean-going vessels as well as retrofitting existing vessels. The scrubber technology is expected to partially reduce NOx emissions, almost eliminate sulfur dioxide (SO_2) emissions, and significantly reduce particulate matter (PM). This $1.2 million project is funded by a $300,000 grant from U.S. EPA's West Coast Collaborative and a $100,000 contribution from the Puget Sound Clean Air Agency. Other project partners include Environment Canada, the Port of Seattle, the Port of Vancouver, and Caterpillar. More information on this project is available at: www.marinelink.com/Story/ShowStory.aspx?StoryID=204159.

3.8 Marine Experience in Europe and Asia

In addition to these marine vessel demonstration projects, a significant number of large vessels (more than 200), operating primarily in northern Europe, have been equipped with SCR systems over the past ten years. Experience with SCR on these large marine vessels in Europe includes car ferries, passenger ships, cargo transport vessels, and naval vessels. Some ferries operating in Hong Kong have also been equipped with SCR systems. Applications include both new and retrofitted main marine engines and/or auxiliary engines that range from 2000 to 10,000 bhp. These SCR systems have demonstrated 90-99% NOx reduction, 80-90% hydrocarbon and CO reduction, and 30-40% soot reduction on steady-state operating conditions that match exhaust temperature design windows of the SCR catalysts used in these applications. SCR catalyst design life in these large marine applications can be 40,000 hours or longer depending on total catalyst design volume and the fuel quality used in the application. Separate oxidation catalyst modules can also be included as a part of marine SCR systems. Additional details on the European experience with SCR catalysts on large marine vessels is available in presentations given at the July 26, 2002 ARB Maritime Air Quality Technical Working Group Meeting (see: arb.ca.gov/msprog/offroad/marinevess/presentations.htm#091906).

There have been some limited applications of DOCs on large marine engines including some luxury yachts and passenger ferries operating in Hong Kong. Burner-based, active DPF designs similar to those used in Swiss locomotive applications have also been installed on sight-seeing ships operating on some of the large lakes in Switzerland for significant reductions in PM emissions.

4.0 Summary

As shown by the above case studies, experience with the application of emission control technologies on locomotive and marine diesel engines is growing. Many of the locomotive and marine diesel engine projects discussed in this report have been focused on demonstrating the feasibility of applying verified, on-road retrofit emission control technology on locomotive and marine engines and quantifying the diesel emission reductions achieved. Many of the projects have been initiated by the state, local, and federal agencies to promote interest in retrofitting locomotive and marine engines and facilitate other retrofit projects that may build on the successes and challenges learned from previous projects. The availability of ultra-low sulfur diesel (ULSD) fuel for nonroad diesel engines will expand significantly as the rollout of ULSD for highway applications expands nationwide in the second half of 2006. Emerging on-road verified retrofit technologies, such as actively regenerated DPFs and flow-through particulate filters, should also find applications in nonroad diesel engines and provide more options for significant reductions in diesel particulate emissions from locomotive and marine engines. Similarly, verified retrofit technologies that provide reductions in NOx emissions, such as lean NOx catalysts and SCR systems, will also migrate into the nonroad sector and see greater attention on locomotive and marine engines in the future. The locomotive and marine engine segments require an expanded range of verified retrofit technologies to provide broader application coverage for the range of engines that are currently part of the existing fleet.

The growing experience base with DOCs, DPFs, and SCR on locomotive, marine, and stationary diesel engines indicates that these technologies are feasible for use on new locomotive and marine engines and can provide significant reductions in PM and NOx emissions from these sources compared to their current emission standards. MECA strongly recommends that EPA move forward with a proposal on the next round of emission standards for locomotive and diesel marine engines that uses the same approaches, strategies, and regulatory framework that EPA has successfully put in place to significantly reduce PM and NOx emissions from highway heavy-duty diesel engines (EPA's 2007-2010 heavy-duty highway diesel engine emission regulations) and nonroad diesel engines (EPA's Tier 4 nonroad diesel emission regulations).