

Appendix E
Technology Evaluation

Feasibility of Using Existing Emission Control Technologies for Marine Applications

There are a number of control technologies that have been proven to reduce emissions of oxides of nitrogen (NO_x) and particulate matter (PM) from diesel-fueled engines used in on-road, and off-road, applications. While, in theory many of the control technologies used in land-based applications could potentially be marinized to work in the marine environment, the potential success of these methods when applied to harbor craft will be highly dependent on the specific application. Considerations for applicability include the engine duty cycle, engine placement in the hull, vessel exhaust system configuration, and age of specific harbor craft. Since most marine vessels are custom built and have vastly different engine room configurations with varying capacity for space in which to install after-treatment emission controls, it is unlikely that there will be “off-the-shelf” or “one size fits all” aftertreatment devices available for harbor craft. It is likely that the control devices will also need to be customized to each vessel configuration. Nevertheless, we believe that over the next several years, there will be increased desire to develop control technologies for marine applications to help mitigate the emissions that occur in and around ports and urban centers.

In this appendix, brief descriptions of NO_x and PM emission reduction control strategies currently used in general diesel engine applications will be presented. Some of the control technologies presented have been recently introduced to use in the marine environment. We believe many of the control technologies presented here can be used in the marine environment, but, at this time, there are no control technologies that have been verified for marine applications through the ARB verification procedure.

Descriptions of a number of demonstrations of different control technologies are provided in this appendix as well as the current status of engine replacements that have occurred under the Carl Moyer Memorial Air Quality Standards Attainment Program.

Diesel PM Exhaust After-treatment Emission Controls

The principle exhaust treatment technologies that have been successfully used to reduce diesel PM from diesel-fueled engines used in land-based applications are diesel particulate filters (DPF), diesel oxidation catalysts (DOC), and flow through filters (FTF) (or combinations of technologies). Each of these are briefly described below.

Diesel Particulate Filters

DPFs have been successfully used in many applications, including stationary prime and emergency standby generators, and with both on-road and off-road engines. In general, a DPF consists of a porous substrate that permits the gases

in the exhaust to pass through but traps the diesel PM. DPFs can reduce diesel PM emissions by more than 85 percent. The magnitude of these emission reductions depends on the baseline emissions of the associated engine, and the fuel sulfur content. In addition, up to a 90 percent reduction in carbon monoxide (CO) and a 95 percent reduction in hydrocarbons (HC) can also be realized with DPFs. (Allansson, 2000) Most DPFs employ some means to periodically regenerate the filter, i.e., burn off the accumulated PM. In California, diesel-fueled school buses, emergency backup generators, solid waste collection vehicles, urban transit buses, medium-duty delivery vehicles, people movers, and fuel tanker trucks have been retrofitted with DPFs. These installations have been implemented through a number of voluntary and regulatory mandated programs as well as demonstration programs. DPFs can be either active or passive systems.

Active DPFs use a source of energy beyond the heat in the exhaust stream to induce regeneration. Active DPF systems can be regenerated with electric currents passed through the substrate, fuel burners, microwaves, or the aid of additional fuel injection to increase exhaust gas temperature. Some active DPFs induce regeneration automatically onboard the vehicle or equipment when a specified exhaust back pressure is reached. Others simply indicate when to start the regeneration process. Other active systems collect and store diesel PM over the course of a full day or work shift and are regenerated at the end of the day or shift when the vehicle or equipment is shut off. A number of the smaller filters are then removed and regenerated externally at a "regeneration station." Because active systems have control over their regeneration and are not dependent on the heat in the exhaust, active DPFs have a much broader range of applications and a much lower probability of getting plugged than passive DPFs.

A passive DPF is one in which a catalytic material is applied to the substrate. The catalysts that are used are known as the platinum group metals. These consist of platinum, iridium, osmium, palladium, rhodium, and ruthenium. Platinum is best suited as the catalyst for diesel engine control devices; therefore, it appears that it will be the main catalyst used in diesel catalytic converters. (Kendall, 2002/2003) The catalyst lowers the temperature at which trapped PM will oxidize to a temperature periodically reached in diesel exhaust. No additional source of energy is required for regeneration, hence the term "passive."

Field experience has indicated that the success or failure of a passive DPF is primarily determined by the exhaust temperature profile at the filter's inlet and the rate of PM generated by the engine. These two parameters, however, are determined by a host of factors pertaining to both the details of the application, the duty cycle, the level of engine maintenance, and the type of engine being used. As a result, the technical information that is readily accessible can serve

as a guide, but it may be insufficient to determine whether a passive DPF will be successful in a given application. (ARB, 2002)

With regard to estimating average exhaust temperature in actual use, commonly documented engine characteristics such as the exhaust temperature at peak power and peak torque are insufficient. The exhaust temperature at the DPF's inlet is highly application dependent in that the particular duty cycle experienced plays a prominent role, as does heat loss in the exhaust system. Various application-specific characteristics enter the heat loss equation, such as the length of piping the exhaust must travel through before it reaches the DPF and whether the exhaust is wet cooled or dry cooled. Lower average exhaust temperatures can also be the result of operations of engines oversized for the application or engines run with low or no load applied. (ARB, 2002)

Diesel Oxidation Catalysts

DOCs are currently the most commonly used form of diesel after-treatment technology and have been used for compliance with the PM standards for some on-highway engines since the early 1990s. DOCs are generally referred to as "catalytic converters." DOCs are attached to the engine exhaust system. They have chemicals lining them which catalyze the oxidation of carbonaceous pollutants – some of the soot emissions and a significant portion of the soluble organic fraction. These carbon-containing pollutants are oxidized to carbon dioxide (CO₂) and water.

DOC effectiveness in reducing PM emissions is normally limited to about 30 percent of diesel PM. This is because DOCs only control the soluble organic fraction (SOF) of diesel PM for modern diesel engines and the SOF fraction is typically less than 30 percent of total PM. Additionally, DOCs increase sulfate PM emissions by oxidizing the sulfur in fuel and lubricating oil, reducing the overall effectiveness of the catalyst. Limiting fuel sulfur levels to 15 ppm allows DOCs to be designed for maximum effectiveness (nearly 100 percent control of SOF emissions). DOCs also reduce emissions of HC and CO with reported efficiencies of 76 percent and 47 percent respectively. (Khair, 1999)

DOCs are also very effective at reducing the air toxic emissions from diesel engines. Test data shows that emissions of toxics such as polycyclic aromatic hydrocarbons can be reduced by more than 80 percent with a DOC. (DieselNet, 2002)

Flow Through Filters

Flow through filter (FTF) technology is a relatively new technology for reducing diesel PM emissions. Unlike a DPF, in which only gasses can pass through the substrate, the FTF does not physically "trap" and accumulate PM. Instead, exhaust flows through a medium (such as wire mesh) that has a high density of

torturous flow channels, thus giving rise to turbulent flow conditions. The medium is typically treated with an oxidizing catalyst or used in conjunction with a fuel-borne catalyst. FTFs reduce emissions of PM, HC, and CO. Any particles that are not oxidized by the FTF flow out with the rest of the exhaust and do not accumulate.

The filtration efficiency of an FTF is lower than that of a DPF, but higher than a DOC. In addition, compared to DPFs, the FTF is much less likely to plug under unfavorable conditions such as high PM emissions, low exhaust temperatures and emergency circumstances. The FTF, therefore, is a candidate for use in applications that are unsuitable for DPFs.

Combinations of Technologies

Combinations of more than one technology are also being explored to maximize the amount of diesel PM reduction. For example, fuel-borne catalysts can be combined with any of the three main hardware technologies discussed above: DPF, FTF, or DOC.

NOx Emission Controls

There are various technologies available and in development to provide reductions in NOx. The principal technologies are selective catalytic reduction (SCR), water injection, exhaust gas recirculation, NOx adsorbers, and lean NOx catalysts. These are each briefly described below.

Selective Catalytic Reduction

SCR is an exhaust after-treatment method for controlling NOx emissions up to 90 percent. The SCR process basically works by injecting ammonia (NH₃) or urea into the exhaust gas or the engine in the presence of a catalyst. Ammonia reduces NOx in the presence of the catalyst to produce nitrogen (N₂) and water.

SCR systems have been installed on new marine engines for many years. However, retrofitting SCR systems on existing vessels is challenging. Challenging issues include urea and ammonia storage, safety requirements, and space requirements near the engine. The SCR system is effective only over a narrow range of exhaust temperatures where the catalyst is active. Ammonia slip can also be a problem if the system is not properly optimized. (DieselNet, 2006a) Ammonia slip is caused by injecting more ammonia into the exhaust stream than is needed to reduce the NOx.

Water Injection

Adding water to the combustion chamber absorbs heat when the water vaporizes, lowering the peak combustion temperatures and reducing NOx

emissions. Water can be introduced in a variety of ways: direct water injection, fumigation into the intake air, or emulsified with the fuel. Unmodified engines can use emulsified fuel if the injection systems can handle the extra volume. Other systems require major redesign to include separate water supply tanks, injection lines, fuel pumps, injectors, etc. Generally, a 1 percent increase in water equates to a 1 percent decrease in NO_x emissions. However, HC and CO emissions may increase using water injection strategies. (DieselNet, 2006)

Exhaust Gas Recirculation

Exhaust gas recirculation (EGR) lowers combustion temperatures thereby reducing NO_x formation. EGR displaces some of the engine's intake air with inert materials, which dilute the mixture in the cylinder and absorb heat. PM in the exhaust has the potential to be a source of problems with EGR, including accelerated wear in the engine and turbocharger and deposition on the engine intake system, which can decrease the effectiveness of the turbocharger and/or aftercooler. By reducing combustion temperatures and available air for combustion, EGR may cause incomplete combustion, increases in HC, CO, and PM emissions, and decrease fuel economy. (DieselNet, 2006)

NO_x Adsorber

NO_x adsorbers utilize materials which store NO_x under engine lean conditions, then release and catalytically reduce the stored NO_x under engine rich conditions.

The process entails oxidation of NO to NO₂, usually using a platinum-based catalyst, then oxidizing it again and storing it as a metallic nitrate on the catalyst surface. The most common storage component is barium carbonate (BaCO₃), which can store NO₂ as barium nitrate (Ba(NO₃)₂) while releasing CO₂.

The NO_x adsorber is regenerated by operating for a brief period in an engine rich condition. NO_x is released and subsequently reduced by precious metal catalysts just as a three-way catalyst does today on modern automobiles. NO_x reductions can be in excess of 90 percent if the catalyst is well matched to the exhaust temperature profile. (EPA, 2004)

There are also diesel fuel reformers available that regenerate and desulfinate the NO_x adsorption catalyst. The process consists of an electrically generated plasma and a noble metal catalyst that converts a diesel/air mixture into a hydrogen rich gas. Based on the partial oxidation process, carbon atoms from the fuel are oxidized to CO and the hydrogen is released as hydrogen molecules. This hydrogen rich diesel reformat provides a reducing atmosphere, improves NO_x adsorption and catalyst regeneration, reduces the temperature at which desulfation occurs, and reduces the fuel penalty. (Bromberg, 2003)

Lean NOx Catalyst

Lean NOx catalysts reduce nitrogen oxides through selective catalytic reaction with hydrocarbons. NOx conversion is usually limited to about 10-20 percent due to the relatively low concentrations of hydrocarbons in diesel exhaust. In active lean NOx catalysts, where diesel fuel is injected upstream of the catalyst, NOx conversions of up to 50-60 percent are possible. Conversion rates are dependent on exhaust temperatures. (DieselNet, 2006a)

Engine Design Modification

There are a number of engine modifications that can be employed, generally at the time of an engine rebuild, to reduce emissions. Two examples of engine design modifications that reduce PM emissions are a diesel engine reengineering kit produced by Clean Cam Technology (Clean Cam) and the ECOTIP Superstack Fuel Injectors (ECOTIP) distributed by Interstate Diesel.

Clean Cam consists of specific engine retrofit components, including a proprietary camshaft. The product reduces NOx emissions by increasing the volume of exhaust gas that remains in the combustion chamber after the power stroke. Within the combustion chamber, the residual exhaust gas absorbs heat and reduces the peak combustion temperature, which results in lower NOx emissions. The injection timing can then be adjusted (i.e., advanced) to maximize the diesel PM emission reductions or it can be varied to achieve the desired balance of NOx and PM. The Clean Cam reduced diesel PM and NOx emissions from eleven pre-1993 and four 1994-2000 models of two-stroke diesel-fueled engines manufactured by Detroit Diesel Corporation (DDC). The ARB has pre-certified Clean Cam technology. Clean Cam's Version 2 of the camshaft kit can reduce NOx emissions up to 10 percent beyond the U.S. EPA's Tier 2 Off-road engine NOx emission standards and can reduce PM emissions by 75 percent beyond the U.S. EPA's Tier 2 Off-road engine PM emission standards, depending on the engine's horsepower rating.

Interstate Diesel takes a different approach with the ECOTIP Superstack Fuel Injectors to reduce emissions from existing engines. This product has been shown to reduce diesel PM emissions from engines manufactured by Electro-Motive Division (EMD). The product consists of a fuel injector with a reduced sac [DEFINE SAC] volume and a more consistent fuel injection pressure, compared to average engines. The product improves combustion and reduces diesel PM emissions by minimizing the amount of fuel that drips into the combustion chamber at the end of the fuel injection cycle. The ECOTIP fuel injectors can provide a 2 to 3 percent fuel savings, depending on engine load. The manufacturer states that the overall diesel PM emission reduction can be up to 44 percent. The product is commercially available and has been installed on diesel generator plants, locomotives, and tugboats. (Interstate Diesel, 2006)

Injection timing retardation

Retarding the injection timing has been used for decades for reducing NOx. The effect of injection retardation is to reduce the maximum combustion pressure and hence temperature. A reduction of up to 30 percent can be achieved by this technique however, a penalty of up to 5 percent in standard fuel consumption results, as the engine efficiency is reduced. Increase in injection pressure is used in conjunction with injection timing retard to maintain fuel consumption. Another modification that is used when implementing this strategy is a modification of the engine's compression ratio.

Cleaner Diesel Fuels, Alternative Diesel Fuels, and Alternative Fuels

Diesel PM emission reductions can also be achieved through the use of cleaner diesel fuels, alternative diesel fuels, or alternative fuels (e.g., compressed natural gas). Some marine vessel owner/operators have explored the use of alternative diesel-fuels with some success and others have tried using compressed natural gas, however, there are some limitations when using alternative diesel fuels and alternative fuels. Below we describe some fuel options for marine engines.

Alternative Diesel Fuels

Alternative diesel fuel can be used in a diesel engine without requiring engine or fuel system modifications for the engine to operate, although minor modifications (e.g., recalibration of the engine fuel control) may enhance performance. Examples of alternative diesel fuels include biodiesel, emulsified fuels, Fischer-Tropsch fuels, or a blend of these fuels with CARB diesel fuel. A detailed discussion of these fuels is provided in the Diesel Risk Reduction Plan. (ARB, 2000) These alternatives may result in significant benefits for higher-emitting applications. Synthetic or alternative diesel fuels may also prove to be part of the preferred control strategy for diesel-fueled engines that would otherwise expose people to relatively high risk, or where control retrofit options are very expensive or difficult to implement. The impacts these fuels can have on emissions from diesel-fueled engines can vary. There has not been significant penetration of these fuels into commercial marine engine applications, however biodiesel is being used with some success in some ferries and recreational boats. (von Wedel, 1999; Biodiesel.org, 2006)

Alternative Fuels

Alternative fuels may be an option to reduce emissions from diesel engines, but use of these fuels in marine applications is not as prevalent as in land-based applications. Use of alternative fuels in marine vessels presents a variety of safety issues that the U.S. Coast Guard must address before vessels can be converted such they can use alternative fuels. The passenger ferry *James C. Echols* in Norfolk, Virginia was converted from diesel to compressed natural gas

(CNG) fueled twin Caterpillar 3406_G natural gas engines in 1995 and was emissions tested in 2002. The natural gas engines ran richer than optimum, and adjustments to the fuel-air ratio resulted in a reduction in power. (Wilcox, 2000; Thompson, 2002) The concept of using vent gas from the boil-off of liquefied natural gas (LNG) carriers to fuel propulsion and auxiliary engines has been employed in a Gulf Coast shrimp boat by converting the engines to use CNG. LNG is bunkered and converted to CNG fuel through boil-off before use. (Wilcox,-2000; Acker, 1989)

Repowering

Repowering (i.e., replacing the engine) can be a viable and cost-effective way to reduce emissions when compared to the older, uncontrolled diesel engines they replace. Heavy-duty diesel engines currently being manufactured are significantly cleaner than those built just a short time ago and can provide significant NOx and PM benefits compared to an older engine. (Diesel, 2002a)

The Carl Moyer Memorial Air Quality Standards Attainment Program

Repowering harbor craft has been on-going throughout the state under the auspices of California's Carl Moyer Memorial Air Quality Standards Attainment Program (Moyer) for eight years. As of fiscal year 2003-2004, more than 450 engines have been replaced in approximately 300 harbor craft. The types of vessels that have participated in Moyer are representative of all types of harbor craft; ferries and excursion vessels, tugboats, towboats, commercial fishing vessels, charter fishing vessels, and others.

Moyer provides funds for the incremental cost of cleaner-than-required engines and equipment which result in significant near-term reductions in NOx and PM emissions. Marine vessel repowers in Moyer are required to achieve a minimum of a 15 percent reduction in NOx emissions to be eligible for funding. The average engine replacement cost was approximately \$100,000 and the average Moyer contribution per engine was approximately \$54,000. Emission reductions from marine vessels achieved through Moyer in the first seven years totaled 1,250 tons per year of NOx and 75 tons per year of PM at a NOx-weighted average cost effectiveness of \$1,800 per ton. (ARB, 2006)

Fuel Cells

Fuel cells have captured worldwide attention as a clean power source and have generated interest and enthusiasm among industry, environmentalists, and consumers. In principle, a fuel cell operates like a battery. A fuel cell converts chemical energy directly into electricity by combining oxygen from the air with hydrogen gas. However, unlike a battery, a fuel cell does not run down or require recharging. It will produce electricity as long as fuel, in the form of

hydrogen, is supplied. Fuel cells have been a reliable power source for many years.

There have been some limited applications of fuel cell technologies on marine vessels. Fuel cells on marine vessels have operated for several years as an auxiliary power source. In the summer of 2002, adventurer Kenichi Horie sailed *Malt's Mermaid III* across the Pacific Ocean and derived on-board electricity from a 30-watt direct methanol fuel cell made by Yuasa. In November 2002, a 300 watt fuel cell provided auxiliary power for the *Branec III* in the Route du Rhum yacht race across the Atlantic Ocean from France to Mexico. (Cropper, 2004)

In October 2003, MTU Friedrichshafen and Ballard Power Systems built a 12 meter yacht propelled by a 20 kilowatt (kW) battery/fuel cell system. The compressed hydrogen fuelled yacht has a range of 225 kilometers (km) at 6 kilometers per hour (km/hr) or 25 km at 12 km/hr. (Cropper, 2004)

Also in 2003, a 30-foot, 22 passenger, 6 kW Anuvu fuel cell-powered Duffy Electric Boat, Inc.'s DH30 water taxi was test run in Newport Harbor. The fuel cell extended the operating time of the 15 kW electric motor launch by 6 hours at about 5.5 miles per hour. Aqueous sodium borohydrate (15 percent by weight) was used to generate saturated hydrogen, which does not degrade the proton exchange membrane. The byproducts are water and borate, which is returned to the manufacturer to be reprocessed to sodium borohydrate. The sodium borohydrate was manufactured by a pharmaceutical company and was expensive. The project was not economically viable, but it demonstrated a fuel cell boat could function. (Seaworthy, 2003; CCDoTT, 2003; Seaworthy, 2006)

The San Francisco Bay Area Water Transit Authority (WTA) has plans to build a vessel with a fuel cell-powered auxiliary engine as one element of an Eco-Friendly Power System. That vessel is still in the planning stages. (WTA, 2003)

In-Use Experience with Diesel PM and NO_x Emission Control Strategies on Harbor Craft

Demonstration Projects:

There have been a number of demonstration projects nationwide funded primarily through public agencies to implement installation of aftermarket emission controls for harbor craft. The alternative emission control strategies used in these demonstration projects represent the range of choices a harbor craft owner/operator has when deciding whether to use an after-treatment devices to reduce emissions from their vessel. Brief discussions of some of these demonstration projects are presented below.

Diesel Particulate Filters

U.S. Navy Workboat

In 2006, one of two early 1970's two-stroke Detroit Diesel Corporation (DDC) 12V-71 400 horsepower engines on a U.S. Navy workboat operating in the Suisun Bay was rebuilt. The port engine was rebuilt with Clean Cam Technology System (CCTS), The CCTS engine rebuild replaces the original cam shaft, updates the cylinder liner configuration, and adds a turbocharger to the engine. This rebuild kit is made to reduce NOx and PM emissions from a variety of DDC engines during the normal rebuild cycle.

In addition to the engine rebuild, a Rypos active diesel particulate filter replaced the traditional exhaust muffler. The Rypos diesel particulate filter (DPF) consists of a filter housing, electrical control circuit, and filter cartridges. The Rypos system does not rely on high exhaust gas temperatures for filter regeneration; instead a controller monitors pressure, initiating regeneration when needed. The filters are made of sintered metal, which can be heated electrically for filter regeneration.

The preliminary emissions tests results for each diesel emission control strategy and combined are as follows. The rebuilt CCTS engine reduced PM emissions by over 30 percent and NOx by approximately 70 percent. The Rypos filter achieved a reduction of PM of approximately 70 percent and a small reduction of NOx. Used together, the CCTS and Rypos active DPF achieved over 80 percent reduction of PM and over 70 percent reduction of NOx. Durability testing of the system was completed in late 2006. To date, we have not received the results of those tests.

Selective Catalytic Reduction

Vallejo Ferry

In 2004, the City of Vallejo, California, launched the M/V Solano, a low emissions ferry utilizing urea-based selective catalytic reduction (SCR) made by Steuler GmbH. This ferry is part of the Vallejo Baylink passenger ferry system, which services Vallejo and the North San Francisco Bay. The ferry has two MTU/DDC 16V-4000 engines with rated power of 3100 hp each. The SCR system is designed to reduce NOx by 57 percent. (Baylink, 2006; MARAD, 2003)

In July of 2007, BayLink was experiencing an increase in engine problem alarms. BayLink staff inspected the engines and the SCR unit. They found that a number of the engines in the starboard unit were showing excessive wear. They also examined the starboard SCR unit and found extensive damage. The damage to the SCR unit included corrosion, heat impacts, and mechanical impacts. The

BayLink staff have published a report and continue to look into the potential reasons for the damage to the engine and the SCR unit. (BayLink, 2007)

Staten Island Ferry

Staten Island Ferry (M/V Alice Austen) was retrofitted with selective catalytic reduction and a diesel oxidation catalyst in 2004. The ferry is propelled by two Caterpillar 3516 1,550 horsepower main engines. The system reduces NOx by 50 percent as well as PM by 25 percent. With adjustments to temperature thresholds and one of the main engines rebuilt, the anticipated NOx reduction is about 70 percent. (Bradley, 2006)

The Alice Austen has been operating with SCR since 2005. The vessel is in service during the night runs of the Staten Island Ferry system (9 p.m. to 5 a.m.). A complete circuit of the route the vessel is assigned to takes about an hour. The vessel idles for about 15 minutes during passenger off- and on-loading, makes a twenty minute run to the route's destination, idles for 15 minutes to off-load and on-load passengers, and makes a twenty minute run back to its point of origin. To date, there have been no problems with the SCR system.

San Francisco Bay Area Water Transit Authority (WTA) Ferry

WTA is planning to build two new 149 passenger ferries to be put into service in late 2008 which will include exhaust aftertreatment to reduce NOx emissions by at least 85 percent beyond Tier 2 standards. The ferries are being designed to incorporate a compact SCR system coupled with an oxidation catalyst with the 1410 hp Detroit Diesel propulsion engines. The inclusion of the aftertreatment system will require about six feet to be added to the vessel's overall length. The system was derived from one that has been used on other mobile equipment. The ferries' design includes a dry exhaust with a high exhaust stack. (WTA, 2006)

Hybrid Systems

Foss Tugboat

The Foss Tug Company of Seattle, Washington recently "laid keel" on a Dolphin class hybrid tugboat. The tugboat will be a stern drive vessel used primarily for harbor assist services. The tugboat's electric drive units will be powered by batteries coupled with diesel-fueled generators. The vessel's engine room will be modified to accommodate two 670 horsepower battery packs and two 335 horsepower generators. Although the main engines will have lower horsepower than those found in the existing Dolphin class tugboats (5000 hp), the total horsepower of the hybrid tugboat will be equal to that of the existing Dolphin class tugboats.

Foss anticipates a number of benefits from the use of hybrid technology. These benefits include over a 40 percent reduction in emissions of PM and NO_x, lower fuel consumption, and a reduction in the noise associated with the operation of the vessel. It is anticipated that the vessel will begin operations in 2008.

Humid Air Injection

SCX Ferries, Inc and MARAD tested the emission reduction potential of an air humidification system on a hydrofoil ferry, WaveRider, in San Diego, California. The ferry is powered by four high-speed Detroit Diesel 12V92 engines, each rated at 1050 hp at 2300 rpm, driving two water jets. They installed a water injection (fumigation) system to reduce NO_x by reducing peak combustion temperatures. The system was able to reduce NO_x by about 16 percent. (MARAD, 2003)

References

- (Acker, 1989) Acker, G. Jr., et al. "Experience Using LNG as a Marine Engine Fuel." *Marine Technology Society Journal*. Vol. 23, No. 2, 33-39; 1989.
- (Allansson, 2000) - DPF
- (ARB, 2002) California Air Resources Board. *Staff Report: Initial Statement of Reasons Proposed Regulation for Verification Procedure for In-Use Strategies to Control emissions from Diesel Engines, Appendix B, Diesel Emission Control Technologies*; 2002.
- (ARB, 2006) Joseph Calavita, California Air Resources Board. Personal communication. October 5-6, 2006.
- (Baylink, 2006) Martin Robbins, Baylink Ferry. Personal communication. October 24, 2006. [print e-mail]
- (Baylink, 2007) SCR Project-M/V Solano, June 30, 2007.
- (Biodiesel.org, 2006) "Easier on the Marine Environment." biodiesel.org <http://www.biodiesel.org/markets/mar/> Date accessed: November 1, 2006.
- (Bradley, 2006) M.J. Bradley and Associates. *Staten Island Ferry: Alice Austen Vessel SCR Demonstration Project Final Report*. August 2006.
- (Bromberg 2003) Bromberg, L., et al. "Hydrogen generation from plasmatron reformers: A promising technology for NOx adsorber regeneration and other automotive applications." *Diesel Engine Emission Reduction Workshop*. Newport, RI Aug 24-28, 2003.
- (CCDoTT, 2003) Center for the Commercial Deployment of Transportation Technologies, California State University, Long Beach Foundation. "On Demand Hydrogen Generating System: Phase II—System Demonstration." September 30, 2003. ftp://www.foundation.csulb.edu/CCDoTT/Deliverables/2002/task%202.25/task_2.25_6_FY02.pdf Date accessed: November 1, 2006.
- (Cropper, 2004) Cropper, Mark. "Fuel cells in ocean-going yachts." *Fuel Cell Today*. March 5, 2004. <http://me.queensu.ca/courses/MECH430/Assets/Files/General%20Interest/Fuel%20Cells%20In%20Yachts%20March%202004.pdf> Date accessed October 25, 2006.
- (DieselNet, 2002) DieselNet. *Technology Guide: Diesel Oxidation Catalyst*. <http://www.dieselnets.com>; 2002.

(DieselNet, 2002a) DieselNet. http://dieselnet.com/tech/engine_adv.html

(DieselNet, 2006) DieselNet. *DieselNet Technology Guide. Engine Design for Low Emissions: Water in Diesel Combustion.* http://www.dieselnet.com/tech/engine_water.html; September 29, 2006.

(DieselNet, 2006a) DieselNet, *DieselNet Technology Guide. Diesel Emission Control.* http://www.dieselnet.com/tech/engine_control.html; September 29, 2006.

(EPA, 2004) EPA, *Final Regulatory Analysis: Control of Emissions from Nonroad Diesel Engines Chapter 4*; May, 2004. EPA420-R-04-007

(Interstate Diesel, 2006) Lee Arkus, Interstate Diesel – McBee. Personal Communication. October 20, 2006.

(Kendall, 2002/2003) Kendall, Tom; Johnson Matthey. *Platinum 2002* <http://www.platinum.matthey.com/publications/1051543656.html>; *Platinum 2003*, <http://www.platinum.matthey.com/publications/1059138410.html>; May 2002 and May 2003.

(Khair, 1999) Khair, Magdi, Dale L. McKinnon *Performance Evaluation of Advanced Emission Control Technologies for Diesel Heavy-Duty Engines*, SAE 1999-01-3564; 1999.

(MARAD, 2003) U.S. Department of Transportation Maritime Administration Office of Shipbuilding and Marine Technology. *Energy Technologies. Newsletter No. 04*; Winter 2003-2004. http://www.marad.dot.gov/nmrec/energy_technologies/images/ETNo4Winter0304.htm August 9, 2006.

(Seaworthy, 2003) "Fuel Cell Boat Tested in Newport, California Harbor; Millennium Cell, Seaworthy, Duffy Boat and Anuvu Demonstration Takes to the Water." *Business Wire*. August 21, 2003.

(Seaworthy, 2006) Marty Toyen. Seaworthy Systems. Personal communication. October 27, 2006.

(Thompson, 2002) Thompson, Gregory J., et al. "Evaluation of Exhaust Emissions from Elizabeth River Ferries: Final Report." Department of Mechanical and Aerospace Engineering, West Virginia University. Morgantown, WV July 2002. <http://cafee.wvu.edu/Assets/Documents/Report%20-%20Evaluation%20of%20Exhaust%20Emissions%20from%20Elizabeth%20River%20Ferries.pdf> Date accessed: October 26, 2006.

(von Wedel, 1999) von Wedel, Randall. Technical Handbook for Marine Biodiesel in Recreational Boats. Second Ed. April 22, 1999.
www.cytoculture.com/Biodiesel%20Handbook.htm Date accessed: August 24, 2006.

(Wilcox, 2000) LT Robb Wilcox, CDR Mark Burrows, Sujit Ghosh, Bilal M. Ayyub. "Risk-based Technology Methodology for the Safety Assessment of Marine Compressed Natural Gas Fuel Systems." *International Cooperation on Marine Engineering Systems/The Society of Naval Architects and Marine Engineers*. New York Metropolitan Section Symposium May 22-23, 2000.
<http://www.uscg.mil/HQ/msc/article/cng.paper.pdf> Date accessed: October 26, 2006.

(WTA, 2003) San Francisco Bay Area Water Transit Authority. "Congress Floats Fuel Cell Boat with \$2.5 Million." Press Release. February 20, 2003.
<http://www.watertransit.org/pubs/FuelCellBoat.pdf> October 18, 2006.

(WTA, 2006) San Francisco Bay Area Water Transit Authority. "The SF Bay Area Water Transit Authority is Building Boats." Press Release. May 9, 2006.
<http://www.watertransit.org/pressreleases/pressRelease050906.pdf> October 18, 2006.