NYC Private Ferry Fleet Emissions Reduction Technology Study and Demonstration

Final Report 06-15
September 2006

New York State
Energy Research and
Development Authority

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Final Report

Prepared for the

New York State Energy Research and Development Authority

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NYSERDA Report 06-15 | NYSERDA 7931 | September 2006

NOTICE

ABSTRACT AND KEY WORDS

The objectives of this project were to characterize the vessels that comprise the New York City (NYC) harbor private ferry fleet, select technologies with the potential to reduce exhaust constituents, and to demonstrate selected technologies on representative vessels to determine their effectiveness. In order to complete these objectives it was first necessary to characterize the NYC harbor private ferry fleet with regard to vessel type, passenger capacity, installed power, propulsion system, fuel, fuel consumption, operating profile and emissions signature. It was determined that the ferry fleet and its subsequent emissions could effectively be classified according to the scheduled routes and modes of operation. The routes were classified as short, intermediate and long haul with single leg distance being the determining factor. Additionally, three different modes of ferry operation were identified: cruise, push, and maneuvering.

After the fleet and its associated emissions were characterized, a variety of applicable emissions control technologies were researched and assessed for in use demonstrations and potential fleetwide deployment. The assessment focused on emissions control technologies that could be demonstrated on private ferry vessels and contained a substantial potential for marked decreases in NO_x and PM 2.5 emissions. From these analyses and the vessel load profiles the following technologies were demonstrated on the representative vessels: a diesel oxidation catalyst (DOC) and fuel-borne catalyst (FBC) combination, plus two additional DOCs. A selective catalytic reduction (SCR) system and water injection system (WIS) were analyzed as emissions control solutions, but both were withdrawn from the program before implementation.

The final objectives of this project were to conduct baseline emissions tests utilizing the previously developed vessel load profiles, and to demonstrate various selected emissions control devices on representative vessels. In order to complete these objectives, two phases were established. Phase I consisted of baseline emissions measurements in which normal low sulfur diesel fuel (No. 2 LSD, 500 ppm S) was compared with ultra-low sulfur diesel fuel (No. 1 ULSD, <50 ppm S). Additional fuel test trials were conducted on a similarly rated marine diesel engine test bed, in a more controlled environment, where the effects of No. 2 LSD, No. 1 ULSD and No. 2 ULSD fuels were more effectively compared and quantified. The purpose of Phase II was to demonstrate and evaluate the effects of the selected emissions control devices. This was accomplished by measuring relevant emission constituents before and after the implementation of the emission control technology. Finally, from the data collected in Phases I and II, conclusions were drawn with regard to individual vessels, treatment devices, and potential fleetwide emissions reductions. This study confirmed that effective exhaust emissions control devices can be fitted to the representative vessels and similar ferries without adversely affecting their performance and safety, or creating an undue maintenance issue for their operators.

Key Words: NYC, Marine, Ferry, Fuel, Emissions, Exhaust, Treatment, Control, Technology

ACKNOWLEDGEMENTS

Seaworthy Systems, Inc. would like to express its gratitude to NESCAUM, Environment Canada and ESI for their assistance in the execution of this task. For their management of the project and guidance, Seaworthy would also like to acknowledge gratitude to the NYSERDA project management team of Mr. Frank Ralbovsky, Ms. Janet Joseph and Ms. Ellen Burkhard, as well as the NYCDOT project management team of Mr. Lou Calcagno, Mr. Mark Simon and Mr. Anthony Di Guglielmo. Thanks also to the private ferry vessel operators, NY Waterway, NY Water Taxi, SEA STREAK, and BillyBey Ferry, and especially to Mr. Reichenberg and Mr. James Silecchia of NY Watertaxi, who volunteered to be part of this program, provided essential fleet data, and made their vessels available for the data logging and their crews available for the tests. In addition, acknowledgements are due to the Project Advisory Group, consisting of many participating organizations, including the U.S. Environmental Protection Agency, the Port Authority of NY and NJ, the New York State Department of Transportation, the New York State Department of Environmental Conservation, the New Jersey Department of Transportation, the U.S. Department of Transportation Maritime Administration, the U.S. Coast Guard, and Environmental Defense. Finally, Seaworthy would like to express gratitude to the U.S. Department of Transportation, Federal Transit Administration, and Federal Highway Administration for providing the primary funding for this project.

TABLE OF CONTENTS

Section Page

TABLE OF CONTENTS – cont'd

Section Page

TABLE OF CONTENTS – cont'd

Section | Page

APPENDICES

FIGURES

Section 2

FIGURES Cont.

Section 2 Cont.

Section 3

Section 4

FIGURES Cont.

Section 4 Cont.

Figure Page

Section 5

Figure Page

FIGURES Cont.

Section 5 Cont.

TABLES

Executive Summary

Section 2

TABLES Cont.

Section 2

Section 3

Section 4

TABLES Cont.

Section 4

Section 5

TABLES Cont.

Section 5

Section 6

EXECUTIVE SUMMARY

INTRODUCTION

New York City is experiencing a rapid growth in the use of ferries as a means of mass transit within New York Harbor. Although these privately operated ferries present a viable means of public transportation they are not without drawbacks. Air emissions from the ferry diesel engines are generally less regulated than other sources and are responsible for introducing significant amounts of nitrogen oxides (NO_X), particulate matter (particularly PM 2.5), and other pollutants into the New York City air shed.

This study and demonstration project is the initial element of an overall program to mitigate marine emissions in New York Harbor. The objective of the project is to identify, quantify, and demonstrate those emission reduction technologies that are the most suitable for the private ferries providing commuter service in the Harbor. Successful demonstrations are planned to provide the basis for a subsequent incentive-based emission reduction program, aimed at full deployment of the most effective technologies throughout the private ferry fleets. The funding for this project has been provided by the U.S. Department of Transportation, Federal Transit Administration and Federal Highway Administration, New York State Energy Research and Development Authority (NYSERDA), and New York City Department of Transportation (NYCDOT).

TASK APPROACH

To achieve the overall goals of this study the following tasks were completed:

1. **Identification of the Problem:**
    a. **Vessel and Fleet Characterization:** The characteristics of each vessel in the private ferry fleet were documented including vessel physical parameters, propulsion and engine parameters, vessel space constraints, and other factors that would effect the applicability of various emissions reduction technologies.
    b. **Development of Ferry Operating Profiles:** Operating profiles were developed for selected ferry routes utilizing data recorders and a Global Positioning System (GPS). The data collected included vessel speed, vessel position, indications of propulsive power and other operating parameters for each route.
    c. **Preliminary Phase I Emissions Testing:** Phase I emissions testing was preformed on selected vessels operating in normal service.
    d. **Development of a Private Ferry Fleet Air Emissions Inventory:** Based on vessel, fleet and route characteristics and on preliminary emissions testing, an inventory of the emissions from the existing private ferry fleet was developed.

2. **Selection of the Emission Reduction Technologies:** Commercially available diesel engine emission reduction technologies were identified, evaluated, compared and down-selected. This resulted in a ranked list of the most feasible technologies for the private ferry fleet.
3. **Demonstration of Selected Emission Reduction Technologies:** Selected reduction technologies were installed and tested on representative private ferries.
4. **Determination of Harbor Effects:** Results of emission reduction technology demonstrations were used to project the harbor wide emissions reductions possible with a full deployment of the most effective technologies.

IDENTIFICATION OF THE PROBLEM

Vessel and Fleet Characterization: A detailed survey of the private ferry fleet was completed. The hull types were monohulls and catamarans propelled by propellers and/or waterjets. Most of the vessels had been constructed since 2000 and their engines met EPA Tier 1 emissions. Tables S.1 and S.2 characterized the NYC harbor private ferry fleet.

Table S.1. Comparison of Ferry Vessels by Hull Type.

Hull Type	Construction Material	Maximum Speed, knots	Length, ft.	Passenger Capacity	Quantity
Monohull, Small	Aluminum	30	65	97	6
Monohull, Medium	Aluminum	15	62	146	1
Monohull, Large	Aluminum	15	87-102	396-402	11
Catamaran, Small	Aluminum	25	65	75	6
Catamaran, Medium	Aluminum	27-32	78.5-89.6	149	15
Catamaran, Large	Aluminum	37-42	114-141	349-400	6

Table S.2. Distribution of Propulsion Systems.

Main Engine Manufacturer	Main Engine Model	BHP @ rpm	Propulsion Type (P=propeller, WJ=water jet)	IMO Compliant	Quantity of Engines in NYC Fleet
Caterpillar	3406E	550 @ 1800	P	Y	2
Caterpillar	3406E	600 @ 2100	P & WJ	Y	74
Caterpillar	3412C	764 @ 2100	P	N	20
Caterpillar	3412E	720 @ 1800	P	Y	2
Caterpillar	3412E	1150 @ 2100	P	Y	2
Cummins	KTA50 M2	1875 @ 1900	WJ	Y	16
Detroit Diesel	Series 60	600 @ 2100	P	Y	12
Deutz	TBD616	1285 @ 2100	WJ	Y	2
MTU	16V396	2672 @ 2100	WJ	N	4

The vessels are further categorized based on the length of a round trip. Routes varied in length from 1.5 NM to 50 NM and were separated into three lengths: short haul (<2 km), medium haul (2-10 km), and long haul (>10-50 km).

Development of Operating Profiles: After compiling the fleet inventory and categorizing the vessels by route length, four (4) representative vessels were selected and fitted with data logging equipment to determine route and load profiles of the vessels in normal service. The vessels were selected based on the commonality of their power trains and to provide at least one example of each type of route.

Data logging equipment was installed to record engine load indications and other parameters that were needed to determine the applicability of emission control equipment. Global positioning system (GPS) information was logged to correlate the vessel's position and speed and the engine operating data. Load curves were generated that depict the operating profile of each vessel. Operational time was divided into three (3) modes; push, cruise and maneuver.

Baseline Emissions Testing with Low Sulfur Diesel: In-service baseline testing with the vessels' normal No. 2 low sulfur diesel fuel (LSD ~500 PPM sulfur) was performed to establish current emissions levels and to gather operational data. These tests were used to develop an accurate emissions inventory and to provide input for the down selection of emission reduction technologies. The emissions test load points were those determined from the actual vessel load profile. Additional emissions tests were performed using No. 1 ultra-low sulfur diesel fuel (ULSD ~30 PPM sulfur), since some of the anticipated emissions control devices require ULSD. The tests also were used to determine if significant reductions in emissions, particularly PM 2.5 could be obtained by simply changing fuel.

Development of a Private Ferry Fleet Air Emissions Inventory: Utilizing route information, load profiles and measured emissions the total contribution of the fleet to the NYC air emissions inventory was calculated. Previous emissions inventory calculations generally used the EPA E3 test cycle power distributions to establish engine power profiles and corresponding emission rates. The realistic operating profiles established by this study are significantly different than this standard test cycle. The new operating profiles provide a more realistic picture of ferry operations and more accurately estimate emission rates from the NY Harbor private ferry vessels.

SELECTION OF THE EMISSION REDUCTION TECHNOLOGIES

Using the results of the vessel characterization and the initial baseline emissions testing, a study was undertaken to identify and evaluate potential means to reduce air emissions from the ferry fleet. A technology review was performed to eliminate experimental or pre-production technologies and focus on commercially available products that promised significant reductions of NO_X and PM 2.5 for the specific operating conditions of these diesel engines. Emission control proposals were solicited from a number of vendors whose products were either on the EPA's list of verified technologies or whose product had a sufficiently long track record.

Initially it was thought that there would be a large selection of emissions control technologies applicable to these vessels. All of the engines have land based counterparts and it was assumed that emissions control devices for these applications would be readily adaptable. Unfortunately, the marine market is very small when compared to the land based market and the manufacturers have not generally adapted land based emissions control to marine engines.

Cost effective NO_X reduction technologies proved particularly difficult to find. The most effective NO_X solution, selective catalytic reduction (SCR) systems, significantly increases operating cost. Since the subsequently-planned fleet-wide deployment program funding allows the payment of capital but not operating costs, owners generally opted for controls that do not increase operating costs. An exception was the SCR system selected by SeaStreak. Unfortunately SeaStreak later withdrew from the program due to business reorganization issues. Although fuel-borne catalysts increase operating expenditures they were included because of possible fuel consumption reductions.

The data collected on vessel characteristics and operating profiles in the previous phase had a significant impact on the emission control selection process. For example, exhaust temperature profiles which are a direct function of engine load, were critical for evaluating the effectiveness of passive diesel particulate filters (DPF's) and selective catalytic reduction (SCR) systems. These systems depend on heat in the engine exhaust for effective operation. Information on available space was important in the selection of acceptable technologies.

Based on responses from potential suppliers and the results of fleet characterization, a matrix was developed in which each technology was applied to a composite ferry vessel to determine if it would be effective in this marine application. Evaluation factors included:

- reduction effectiveness for targeted emissions,
- the effect on non-targeted emissions,
- experience in similar applications,
- annualized cost,
- operational factors,
- safety, and
- field support

Emission reduction technologies evaluated included diesel oxidation catalysts, diesel particulate filters (active and passive), low pressure exhaust gas recirculation, selective catalytic reduction (SCR) systems, lean NO_X catalyst, intake air fumigation, fuel changes, fuel-borne catalysts, EPA Tier 2 engines, other engine modifications, and many combinations of the above.

Following the selection of technologies for the general case of ferry vessel applicability, vessel-specific matrices were created to apply the emission control technologies to individual demonstration vessels. The emphasis was on the annualized cost per unit of NO_X or PM 2.5 reduction. It was also necessary that the vessel operator accept the technology chosen, based on recurring operating costs, space constraints and perceived risk levels. The final selected technologies and demonstration vessels are shown in Table S.3.

Table S.3. Vessel ECT Demonstration.

Vessel	Emissions Control Device(s)	Manufacturer
MV PORT IMPERIAL MANHATTAN	No. 1 ULSD	SPRAGUE ENERGY
	DOC	CDTI
	FBC	CDTI
MV FATHER MYCHAL JUDGE	No. 1 ULSD	SPRAGUE ENERGY
	DOC	JOHNSON-MATTHEY
	WIS	MA TURBO
MV ED ROGOWSKY	No. 1 ULSD	SPRAGUE ENERGY
	DOC	JOHNSON MATTHEY
MV SEASTREAK WALL STREET	No. 1 ULSD	SPRAGUE ENERGY
	SCR	Combustion Components, Assoc.

DEMONSTRATION OF SELECTED EMISSIONS CONTROL TECHNOLOGIES

The emissions control devices were purchased in the fall of 2005. Based on the results of the Phase I emission tests, test protocols for the emission reduction demonstration tests were modified as follows;

- Based on demonstrated problems with fuel flow measurement, a Coriolis Effect mass flow meter was utilized. Coriolis meters measure mass flow directly and are not subject to the effects of fluid density, viscosity and temperature.
- A strain gage shaft torsion meter was utilized to definitively establish developed engine power.
- Additional test points were taken for the push and cruise modes.
- The transit mode test was modified to be consistent for all vessels.
- Tests were performed with the vessels out of service, allowing more controlled test conditions.
- The electrical generator set test was eliminated since emissions from the main propulsion engines were the primary target of the program.

A number of modifications were made to the original emission reduction technologies selected in the last section.

- The water injection system (WIS) technology demonstration was withdrawn from the project due to a combination of perceived risk from the ferry operators and a lower efficiency estimate of system performance during cold-weather conditions.
- Financial and reorganization issues caused the owners of the MV SEASTREAK WALL STREET to withdraw from program participation.

Results of the demonstration emissions tests had the following results:

- For the diesel oxidation catalysts (DOC's), PM, CO and HC decreased significantly and in one case, so did the NO_X. PM 2.5 reductions were less than projected from the diesel oxidation catalysts but still in a range of economic viability.
- The Platinum Plus fuel-borne catalyst appeared to enhance the performance of the DOC, although the anticipated fuel economy gains were not realized. Both results were within the range of testing error uncertainty bands. Since these gains were realized in more controlled EPA testing (EPA voluntary diesel retrofit program verification testing), it is assumed that the optimal dosing or engine break-in may not have been attained during the projects in-use testing. Therefore, further testing is warranted before the validity of performance can be established in a marine application.
- While the fuel economy impact of a Tier 2 engine have yet to be determined, they are expected to be positive. The manufacturer's published literature of the selected engine "will meet all current (Tier 2) emissions requirements without compromising fuel efficiency."

A summary of the results of testing along with projected reductions for SCR's and Tier 2 re-engining are presented in Table S.4. Table S.5. presents more detailed trial results from each demonstration vessel.

Table S.4. Summary Results of Emission Control Demonstrations.

Owner	New York Waterway	New York Watertaxi	BillyBey Ferry Company	New York Waterway & BillyBey
Applicable Vessels	11	6	12	9
Engines	CAT 3406E, 3412E	Detroit Diesel Series 60	CAT 3406E	CAT 3412C
Technology	Diesel Oxidation Catalyst	Diesel Oxidation Catalyst	Diesel Oxidation Catalyst	Re-engine Tier 2 + Diesel Oxidation Catalyst
Supplier	Clean Diesel Technologies	Johnson Matthey Catalysts	Johnson Matthey Catalysts	TBD
Anticipated NO_X Reduction, %	0.0%	0.0%	0.0%	25.0%
Actual NO_X Reduct., % (± 95% C.I.)	-1.06% (±2.18%)[1]	-6.28% (±8.21%)[1]	-2.38% (±1.99%)[1]	22.7% (±5.60%)
Actual NO_X Reduct., Tons (± 95% C.I.)	-2.27 (±4.67)[1]	-2.02 (±2.64)[1]	-3.42 (±2.86)[1]	19.1 (±4.81)
Anticipated PM 2.5 Reduction, %	40.0%	15.0%	15.0%	56.3% [3]
Act. PM2.5 Reduct., % (± 95% C.I.)	41.3% (±2.84%)	32.5% (±2.31%)	60.1% (±3.56%)	84.0% (±2.17%)[2]
Act. PM2.5 Reduct., Tons (± 95% C.I.)	0.577 (±0.037)	0.192 (±0.013)	1.25 (±0.648)	0.998 (±0.0199)[2]
Anticipated HC Reduction, %	50.0% to 90.0%[4]	70.0%	80.0%	81.3%[3]
Actual HC Reduction % (± 95% C.I.)	52.8% (±2.94%)	64.7% (±8.46%)	42.1% (±4.31%)	62.2% (±10.8%)
Actual HC Reduction Tons (± 95% C.I.)	28.9 (±1.49)	4.23 (±0.494)	17.45 (±1.75)	5.60 (±0.82)

Table S.4 Notes:

1. No significant change in NO_X emissions was anticipated for the Diesel Oxidation Catalysts. Although some changes have been observed in previous installations, the magnitude of the increase in NO_X observed in this field study is statistically insignificant with respect to no change in NO_X concentrations based on 95% confidence intervals (C.I.).
2. This reported actual value is based on the anticipated reductions as modeled for a single Tier 2 engine and propagated throughout all vessels chosen for Tier 2 engine replacement consideration.
3. It is believed that a higher assumed reduction can be assumed for the Tier 2/DOC combination in that the engine and DOC manufacturers will have the opportunity to carefully engineer and balance the interaction of the two units.
4. No manufacturer data was available for HC reduction by employing this DOC. Reported values reflect the general range expected from the majority of DOC manufacturers.

Table S.5. Detailed Results of Emission Control Demonstrations (Per Engine)

MV GEORGE WASHINGTON Pre / Post Tier 2 Engine Harbor Load Cycle Emissions.									
							Reduction (%)		
									Cruise (±95% C.I.)
									29.4% (1.17%)
									50.8% (6.93%)
									65.6% (14.5%)
MV PORT IMPERIAL MANHATTAN Pre / Post FBC Harbor Load Cycle Emissions, Without DOC.									
							Reduction (%)		
									Cruise (±95% C.I.)
									-0.217% (1.69%)
									-1.56% (14.1%)
									27.1% (11.8%)
MV PORT IMPERIAL MANHATTAN Pre / Post DOC Harbor Load Cycle Emissions, Without FBC.									
							Reduction (%)		
									Cruise (±95% C.I.)
									0.233% (1.61%)
									9.50% (12.3%)
									74.1% (13.5%)
MV PORT IMPERIAL MANHATTAN Pre / Post DOC Harbor Load Cycle Emissions, With FBC.									
							Reduction (%)		
									Cruise (±95% C.I.)
									7.47% (1.55%)
									10.2% (3.88%)
									75.7% (15.2%)
MV FATHER MYCHAL JUDGE Pre / Post DOC Harbor Load Cycle Emissions.									
							Reduction (%)		
									Cruise (±95% C.I.)
									-1.73% (2.81%)
									27.2% (14.5%)
									35.8% (14.5%)
MV JOHN KEITH Pre / Post DOC Harbor Load Cycle Emissions.									
							Reduction (%)		
									Cruise (±95% C.I.)
									-19.7% (1.94%)
									33.2% (5.22%)
									65.7% (8.93%)

$^{+}$Estimated value for Caterpillar C18 engine, derived from Caterpillar 3412E data.
$^{\#}$Maneuvering PM 2.5 values displayed in above Table are measurements from the transit operation mode.

The results from the demonstrations prove that the use of emissions control technologies on ferries operating in NY harbor is feasible. Properly selected, the devices have the potential to significantly reduce the emission of PM 2.5, HC and CO from the vessels engines. Replacing older engines with Tier 2 engines can also significantly reduce NO_X emissions. The results further proved that the devices do not impose significant any limitations on the vessels.

The errors associated with the reported Phase II data are reasonable in the face of the constraints imposed upon the field testing, and are displayed in Table S.5. The major sources of the error may be linked to environmental factors and the dynamic vessel operation under all operating modes, especially maneuvering. The purpose of this test was to develop the capacity to calculate emissions as a sum of component parts. This was not entirely successful, and it was deemed necessary to estimate the maneuvering portion of the emissions rate. The maneuvering emissions rates and subsequent errors for gaseous emissions were calculated using the time dependent emission rates measured during the vessel transits. Due to the propagation of errors and the high variability in maneuvering, the errors associated with this mode are significantly higher than the other modes of operation. The maneuvering PM 2.5 emission rates and associated errors were calculated using straight forward approach by simply using the measured transit test rate. For all maneuvering calculations, the emission rates resulted in greater uncertainty and are only an estimated value. These maneuvering mode errors are the source for the majority of the error reported in the composite values.

There are a number of improvements that can be made to improve the testing and reduce errors. Increasing the control over the vessels' operation would significantly limit the source of many errors. For future emissions tests a possible solution is either to create a transient mode whereby the vessel is accelerated and decelerated at a predetermined rate for more precise measurements. Another solution would be to perform more transit samples so that the results can be averaged with a greater set of data. This would increase the degrees of freedom associated with the data and subsequently decrease the propagation of errors. These approaches would result in more accurate emission rates.

The errors associated with the field demonstration testing are presented below in Table S.5. This table summarizes the propagation of errors that results from applying the field data to the NY harbor ferry fleet. Confidence intervals (C.I.) are given on a single standard deviation about the mean which represents a 68.27 percent C.I. Doubling the single standard deviation gives a C.I. of 95.45 percent. The relative deviations and time weighted percentages are also located in Table S.5. The errors are presented in this fashion because finite and definitive values do not exist, and all reported errors are estimated values based on the data measured. Additionally, it should be noted that the error in these emission rates is at least +/- 5.0 % of the reported mean value as per the sampling system.

ULTRA-LOW SULFUR DIESEL (ULSD) FUEL TEST FIELD TRAILS

In-use emissions tests were performed using No. 1 ultra-low sulfur diesel fuel (ULSD ~30 PPM sulfur), since ULSD can extend the maintenance periods of exhaust aftertreatment devices. In addition, the tests were also used to determine if significant reductions in emissions, particularly PM 2.5 could be obtained by simply changing fuel. The in-use vessel testing using No. 1 ultra-low sulfur diesel fuel (ULSD ~30 PPM sulfur) revealed several unexpected results. The NO_X levels decreased while CO, and PM levels and fuel consumption increased. The literature strongly suggests that PM levels should decrease, not increase and that on a btu/kw basis the fuel rate should not change. The difference in fuel consumption in particular was of concern to the vessel operators and owners.

The unexpected results warranted additional testing in a more controlled environment. Environment Canada undertook additional testing under laboratory conditions. The original fuels (No. 2 LSD and No. 1 ULSD) were duplicated to the extent possible and an additional fuel, a ULSD fuel made from No. 2 diesel fuel was added to the mix. Although the results were not identical, the NO_X values decreased while the PM 2.5 and CO values increased. The fuel rate for No.1 ULSD did not increase to the same degree as measured in the onboard tests and the fuel rate for No.2 ULSD actually decreased. The differences in fuel rates were 2-3%, significantly lower than indicated by onboard testing. These smaller differences are assumed to be a result of differences in fuel properties such as Cetane number which effects ignition, and possibly viscosity, which may affect injector operation. The unexpected increase in PM emissions for both versions of ULSD in both tests remains unexplained.

HARBOR IMPACTS

The results of the technology demonstration emissions testing were then used to project overall New York City Harbor emission reductions that would result with a full deployment of the most successful technologies. The results of full deployment are presented in Appendix AB, and are subject to the errors reported in Table S.5 for similar vessels propagated throughout the fleet.

The installation of these emissions control devices was relatively straightforward. However, installing these units on a vessel does create some design issues that are not necessarily found on land based units. For one, the units are fairly large and only exacerbate the space limitations found in most small vessel engine rooms. For another, the limited ventilation of the vessel engine rooms means that the units must be leak free and heavily insulated. Finally, because these units are installed on passenger vessels, there are heightened safety requirements that must be met.

The estimated cost of each installation is listed below in table S.6. The costs include the design, hardware, installation and operating costs. These are the actual costs charged for the demonstration installations and projected for one year of operation. It is anticipated that there will be a decrease in unit cost for follow on and multiple installations.

Table S.6. ECT Installation Costs and Annual Emission Reduction for Demonstration Vessels.

Vessel	ECT Desc.	Vendor	Annual Cost				Annual Reductions		
			Hard-ware	Install	Cons	Total	NO_X ton/yr	PM 2.5 lb/yr	HC ton/yr
MV PORT IMPERIAL MANHATTAN	DOC	Clean Diesel Tech.	$6642	$10727	$0.00	$17369	0.70	32.02	5.24
MV PORT IMPERIAL MANHATTAN	DOC+ FBC	Clean Diesel Tech.	$6642	$10727	$5900	$23269	0.70	16.69	5.24
MV FATHER MYCHAL JUDGE	DOC	Johnson Matthey	$7065	$17719	$0.00	$24784	-0.18	88.02	2.68
MV JOHN KEITH	DOC	Johnson Matthey	$11625	$10627	$0.00	$22252	-0.39	68.36	0.98

The program has successfully identified and proven the feasibility of emission reduction technologies that can significantly reduce emission from the private ferry fleet in the New York Harbor area at reasonable costs without interfering with the operation of the system or causing an undo burden on the operators.

ACCOMPLISHMENTS OF THE PROGRAM

The accomplishments of the program include the following.

- Successfully completed what is the largest and most extensive onboard emission test program ever performed on a fleet of operating ferries.
- Identified and demonstrated technologies applicable to a majority of ferries operating in New York Harbor with the potential, with full deployment, of reducing emission of NO_X by 12.2 tons/year (+/- 7.48 tons), PM 2.5 by 3.02 tons/year (+/- 0.073 tons/year), and HC by 56.2 tons/year (+/- 2.38 tons).
- Conducted the first onboard demonstration of a DOC on a ferry nationwide
- Conducted the first onboard demonstration of a fuel-borne catalyst on a ferry nationwide
- Conducted the first onboard demonstration of ULSD on a ferry nationwide
- Made significant progress in the development of successful methods of testing emissions on board ferry vessels including a number of lessons that will be of use in future testing.

LESSONS LEARNED

This program is the largest and most extensive onboard emission test program ever performed on a fleet of operating ferries. In many areas, the learning curve was steep and significant effort was required to complete the project successfully. A number of lessons were learned that may be of use to those who undertake similar programs in the future.

- Well-developed and proven on-road emission control technologies can not just be seamlessly applied to a marine environment. Operational and space considerations can change the effectiveness of control devices and can present installation challenges. The program did however prove that most of these challenges can be overcome and emissions can be effectively reduced.
- DOC's resulted in somewhat higher back pressures though when properly sized these pressures could be kept within limits. No measurable increase in fuel consumption was noted.
- Onboard testing proved to be quite challenging requiring many replications to obtain meaningful data. Factors such as current, wind, sea state and operator idiosyncrasies made duplication of results, particularly for tests separated by significant periods of time difficult to correlate.
- Whenever possible the vessel should be taken out of service so that conditions can be controlled purely based on the needs of testing.
- Proper instrumentation is essential. The use of Coriolis effect mass flow meters and strain gauge torsion measurement on the later tests provided means to clearly establish and crosscheck operating conditions.
- Obtaining reliable data during the transient maneuvering phase of vessel operation is particularly challenging. Obtaining meaningful data during these periods of rapidly changing power and propeller operating conditions has proven very difficult. Although in many cases the contribution of these periods is small when compared to the overall operational cycle, in ferry operation with shorter runs and frequent docking the proportion of maneuvering can become significant. The topic warrants further investigation and test.

RECOMMENDATIONS

Based on the successful results of the technology evaluations and demonstrations, project staff recommends that the program proceed to the next phase, which consists of funding the deployment of the successful technologies throughout the NY Harbor private ferry fleets.

This planned deployment phase is expected to consist of providing funds to repower that portion of the fleet having unregulated (Tier 0) engines with the newest, cleanest, EPA Tier 2 marine diesel engines, and to retrofit all participating vessels with diesel oxidation catalysts.

Section 1
Introduction

New York City has experienced a rapid growth in the use of ferries as a means of mass transit within New York Harbor. Although these privately operated ferries present a viable means of public transportation they are not without drawbacks.

Diesel engine propulsion system emissions from the NYC private ferry fleets are responsible for significant amounts of nitrogen oxides (NO_X), particulate matter (particularly PM 2.5) and other pollutants into the New York City air shed. As these emissions sources are mostly unregulated, it became apparent that the City and/or State would have to develop an incentive program to produce the desired emissions reductions from the ferry operators. The priority and urgency of addressing these sources of unregulated emissions is underscored by the reported doubling of private ferry services since the events of September 11th, juxtaposed on a transportation-sensitive, highly populous area already in ozone non-attainment.

To address the problem, the New York City Department of Transportation (NYCDOT) secured FHWA CMAQ (Federal Highway Administration Congestion Mitigation Air Quality) funds for an initial diesel ferryboat emissions reduction evaluation and demonstration program and small pilot deployment program. Subsequently, the U.S. Department of Transportation Federal Transit Administration (FTA) provided additional funding to expand the demonstration and deployment phases. To assist in project management, NYCDOT enlisted the participation of the New York State Energy Research and Development Authority (NYSERDA), to provide the primary source of overall project management. Through a competitive procurement, NYSERDA enlisted Seaworthy Systems, Inc. (SSI) as the project prime contractor.

The objectives of the overall program were three-fold:

1) To obtain credible information on the costs, benefits, and feasibility of a wide range of possible emissions control options for private ferry fleets and the subsequent identification of a group of "best choices";
2) To obtain real-world experience with the use of the identified "best choice" emissions control technologies in private ferry fleets operating in New York's Harbor through a field demonstration initiative; and
3) To achieve ultimate widespread deployment of successful technologies within the NYC private ferry fleets to achieve maximum reduction of NO_x, particulates, and additional emissions.

This report documents the activities and results of the first phase of the program, comprising the first two elements listed above – technology evaluation and demonstration. Based on these efforts and results, the project is proceeding to the third objective through a separate fleet-wide emissions control deployment initiative. The technology evaluation and demonstration portion of the project, described in this report, consisted of several discrete tasks, which are describe in the following sections of the report:

Section 2. Vessel Characterization

The characteristics of each vessel in the private ferry fleet were documented including vessel physical parameters, propulsion and engine parameters, vessel space constraints, and other factors that would affect the applicability of various emissions reduction technologies. Operating profiles were developed for selected ferry routes utilizing data recorders and a Global Positioning System (GPS). The data collected included vessel speed, vessel position, indications of propulsive power and other operating parameters for each route. Initial emissions testing was preformed on selected vessels operating in normal service. Based on vessel, fleet and route characteristics and on preliminary emissions testing, an inventory of the emissions from the existing private ferry fleet was then developed.

Section 3. Emissions Control Technology Review and Selection

A wide range of commercially available diesel engine emission reduction technologies were identified, evaluated, compared and down-selected. This resulted in a ranked list of the most feasible technologies for the private ferry fleet.

Section 4. Fuel Economy and Emissions Effects of ULSD and LSD Fuel

In-service baseline testing with standard No. 2 low sulfur diesel fuel (LSD ~500 PPM sulfur) was performed on four individual ferries to establish current emissions levels and to gather operational data. In-use emissions tests were also performed on the vessels using No. 1 ultra-low sulfur diesel fuel (ULSD ~30 PPM sulfur), since ULSD can extend the maintenance periods of exhaust aftertreatment devices. Unexpected results from the in-use tests warranted additional testing in a more controlled environment. The original fuels (No. 2 LSD and No. 1 ULSD) were duplicated to the extent possible and an additional fuel, a ULSD fuel made from No. 2 diesel fuel was added to the additional laboratory test activity.

Section 5. Field Demonstrations and Evaluations

The selected emissions reduction technologies were installed and tested on three representative private ferries and comprehensive emissions tests were conducted to determine the effectiveness of the control technologies.

Section 6. Conclusions

The results of the technology demonstration emissions testing were then summarized by control technology and vessel type, and then used to project overall New York City Harbor emission reductions that would result with a full deployment of the most successful technologies. Overall project accomplishments and lessons learned are also summarized.

Section 2
VESSEL CHARACTERIZATION

FLEET IDENTIFICATION

At the time of the investigation, the NYC private ferry vessel fleet consisted of forty-five (45) passenger ferry vessels operating on scheduled routes around the NYC harbor. The route lengths varied from 1.5 nautical miles (NM) to 50 NM. The three operators who managed the vessels that made up this fleet when the project was started were NY Waterway, Inc., NY Water Taxi, Inc., and SeaStreak America, Ltd. The vessels included in this study were those wholly owned by the operators as of December 2003.

The vessels have a variety of hull configurations, propulsion systems, main machinery ratings, and equipment and engine manufacturers. The dominant hull form was catamaran, and the dominant propulsion system was the 4-cycle, direct-injected, turbocharged diesel engine driving waterjets. Table 2.1 provides a comparison of the ferry vessels in the private NYC fleet identified by hull type. Each vessel has two to four engines, with each engine driving a propeller or waterjet. Most of the engines had some degree of electronic control and met International Maritime Organization (IMO) emissions standards. Thirteen vessels were propelled with pre-IMO mechanically injected engines. As of December 2003, 11 of those vessels were scheduled to be refitted with IMO or U.S. Environmental Protection Agency (EPA) Tier 2 engines, depending upon the date of purchase. These plans were subsequently put on hold due to the financial condition of the vessels' owner. Each of the propulsion engines averaged 860 brake horsepower (bhp and ranged from 550 bhp to 1875 bhp. Table 2.2 shows propulsion engines listed by manufacturer and model, while Table 2.3 provides IMO emission rates for the ferry engines. All engines consumed No. 2 low sulfur diesel (LSD) fuel, which had a nominal sulfur content of 300–500 parts per million (PPM). Table 2.4 provides the current and future EPA and MARPOL (marine pollution) Convention standards for marine diesel engine emissions.

Table 2.1. Comparison of Ferry Vessels by Hull Type.

Hull Type	Construction Material	Maximum Speed, knots	Length, ft.	Passenger Capacity	No. of Vessels	No. of Propulsion Engines
Monohull, Small	Aluminum	30	65	97	6	18
Monohull, Medium	Aluminum	15	62	146	1	2
Monohull, Large	Aluminum	15	87-102	396-402	11	22
Catamaran, Small	Aluminum	25	65	75	6	12
Catamaran, Medium	Aluminum	27-32	78.5-89.6	149	15	58
Catamaran, Large	Aluminum	37-42	114-141	349-400	6	20

Table 2.2. Distribution of Propulsion Engines by Manufacturer and Model.

Main Engine Manufacturer	Main Engine Model	BHP @ rpm	Propulsion Type (P=propeller, WJ=water jet)	IMO Compliant	No. of Engines in NYC Fleet
Caterpillar	3406E	550 @ 1800	P	Y	2
Caterpillar	3406E	600 @ 2100	P & WJ	Y	74
Caterpillar	3412C	671 @ 2100	P	N	18
Caterpillar	3412E	720 @ 1800	P	Y	2
Caterpillar	3412E	1150 @ 2100	P	Y	2
Cummins	KTA50 M2	1875 @ 1900	WJ	Y	16
Detroit Diesel	Series 60	600 @ 2100	P	Y	12
Deutz	TBD616	1285 @ 2100	WJ	Y	2
MTU	16V396	2672 @ 2100	WJ	N	4

Table 2.3. NYC Ferry Vessel IMO NO_X Emission Rates.

Engine Model (year)	Rating, bhp @ rpm	IMO NO_X Emissions Rate, g/kW-hr (g/bhp-hr)	Number of Engines In NYC Fleet
3406E (2000)	550 @ 1800	10.05 (7.49)	2
3406E (2001)	600 @ 2100	9.8 (7.31)	74
3412C (1992)	671 @ 2100	NA	18
3412E (2002)	720 @ 1800	10.05 (7.49)	2
3412E (2002)	1150 @ 2100	9.8 (7.31)	2
Series 60 (2003)	600 @ 2100	9.8 (7.31)	12
KTA 50 M2 (2003)	1875 @ 1950	9.89 (7.38)	16
TBD 616 (2003)	1285 @ 2100	9.8 (7.31)	2
16V396 (1995)	2672 @ 2100	NA	4

Table 2.4. EPA Diesel Engine Emissions Standards

Marine Diesel Engine Emissions Standard, g/kw-hr						
Emission Standard		Start Year	HC	NOx	CO	PM
MARPOL Annex VI	<130 rpm	2000	-	17.0	-	-
	130<rpm<2000			17.0-9.8		
	rpm>2000					
EPA Locomotive	Tier 0	2000-2001	1.3	12.7	6.7	0.80
	Tier 1	2002-2004	0.7	9.9	2.9	0.60
	Tier 2	2005	0.4	7.4	2.0	.27
			HC+NOx		CO	PM
EPA On Road	MD	2002	2.5			0.10
	HD		2.0			0.10
EPA Non Road	Tier 1	2000	1.3 (HC) 9.0 (NOx)		11.4	0.54
	Tier 2	2001-2006	6.4-6.6		3.5	0.20
	Tier 3	2008-2010	4.0		3.5	0.20
EPA Marine	Tier 1	2000	Marpol Limits			
	Tier 2 (note 1)	2004-2006	7.2 7.5		2.0 3.5	0.20 0.30
	Tier 3 (note1)	2008-2010	4.0 4.5		2.0 3.5	0.20 0.30
Note: Limits and implementation years on marine Tier 2 and Tier 3 engines are based upon cylinder displacement.						

All the vessels identified were constructed of aluminum and built in accordance with U.S. Coast Guard subchapter T or K regulations. The maximum passenger capacity ranged from 75 to 450 persons. The age of the vessels varied from 16 years old to less than one year. The average vessel age was 4.7 years with an average remaining life of 23.2 years. The expected service life was provided by each ferry vessel operator for each vessel type and ranged from 15 to 30 years.

All the vessels identified were also equipped with one or two small diesel-powered generator sets (DG) to provide electrical power to the vessel while underway. Vessels equipped with two generators typically operated with only one generator at any given time, with the second unit acting as an emergency backup or as means to alternate operating hours between the two installed units. The DG sets ranged from 15 kWe to 95 kWe. The engines powering these generators included both 2- and 4-cycle, naturally aspirated and turbocharged units. The relative emissions contribution of these engines as compared to the main propulsion engines was minimal. However, they were included in the fleet characterization to ensure completeness of the emissions study.

FLEET OPERATIONS

The characterization of the fleet's operating profile was performed according to the type of ferry service routes. Routes varied in length from 1.5 NM to 50 NM and were separated into three distinct lengths: short haul, medium haul, and long haul. Depending on the length of the route, a vessel may be scheduled to dock at one landing (pier) and then return to its point of origin, or it may make several landings and then complete the route by returning to its point of origin. Therefore, by definition, a route is identified as the departure from point of origin, docking at destination landing(s), and returning to the point of origin; in essence a round-trip. The round-trip distances determine the placement of that route in one of the three defined route categories. Short haul was defined to include ferry routes where the round-trip distance was less than 2 NM, medium haul to include ferry routes where the round-trip distance was between 2 and 10 NM, and long haul to include ferry routes where the round-trip distance was between 10 and 50 NM.

A typical ferry vessel route consists of periods of time at the dock to load/unload passengers, periods of time to accelerate or decelerate the vessel as it departs or approaches the dock, and a period of high-speed steady state operation between the scheduled landings. These three distinct periods of time are further characterized by three modes of operation: pushing, maneuvering, and cruising. Each route is made up of two or more periods of operation in each mode. For example, the modes of operation for the round-trip between Port Imperial, Weehawken, and 38th Street, NYC, can be described as follows: (1) vessel in push mode while unloading/loading passengers at the Port Imperial landing; (2) vessel in maneuvering mode while backing away and accelerating away from landing; (3) vessel in cruise mode as it reaches steady state speed/rpm while crossing the Hudson River to 38th Street; (4) vessel in maneuvering mode as it decelerates and approaches the 38th Street landing; (5) vessel in push mode as it loads passengers at 38th Street; (6) vessel in maneuvering mode as it backs away and accelerates away from the landing; (7) vessel in cruise mode as it reaches steady state speed/rpm while crossing the Hudson River to Port Imperial; (8) vessel in maneuvering mode as it decelerates and approaches the Port Imperial landing; and (9) vessel in push mode at Port Imperial to unload/load passengers.

Due to the relative light weight of the ferry vessels, a minimal amount of time is needed for accelerating the vessel from stop to full speed and decelerating from full speed to stop as it approaches or departs from a dock. If the vessel is a bow (front-loading) passenger configuration, the operator applies forward thrust while situated at the dock to keep the bow pressed firmly against the pier. This operating mode is called "pushing." The act of '"pushing" forces the propulsion system into what is known as a bollard pull condition. A bollard pull condition has a minimal effect upon the engine load at a given rpm for a waterjet propelled vessel, but it causes a propeller-driven vessel's engine to operate at a higher load condition for a given engine speed. The propeller-driven engine is said to be operating at a heavier load line in the bollard pull situation.

The percentage of a vessel's operating time at maximum speed, with correspondingly high exhaust temperatures, is a critical factor in determining the appropriate emissions control device (ECD) technology application for PM as well as NO_X control. To function effectively, most ECDs rely upon a sufficiently high exhaust temperature for a minimum period of time during each hour of operation. As the operational data of the ferry vessels were collected and analyzed, however, it became apparent that all of the NY Water Taxi vessels and a majority of the NY Waterway vessels were utilized on scheduled round-trip routes that did not provide sustained periods of high speed and high exhaust temperature operation. Observed distances between loading points varied between <1 and 10 NM. The actual operational data indicated that each ferry vessel spent approximately the same amount of time pushing, maneuvering, or cruising.

The vessels from both the SeaStreak and NY Water Taxi fleets were, individually, of the same respective class and performance capability. The vessels that comprise the NY Waterway fleet, however, were varied with regard to size, speed, and passenger capacity. Moreover, any vessel could be placed on any particular run provided it met the speed and capacity requirement that the operator needed to maintain the ferry schedule.

FLEET INVENTORY DEVELOPMENT

The Seaworthy Systems, Inc. (SSI) team initially received a list of vessels categorized by NYSERDA. The first step in the characterization process was to determine which vessels would be included in this project. Vessel operators are constantly in the process of adding to or reducing their fleets in response to future passenger capacity requirements. This is accomplished by either purchasing or selling new/used vessels or by chartering existing vessels. For the purposes of this study, the fleet was defined as only those vessels wholly owned by the respective ferry vessel operators and regularly engaged on scheduled point-to-point ferry runs for the entire calendar year. Excursion, dinner, or other passenger type vessels were excluded. A December 2003 cutoff date was also used since the ferry fleet was in a state of contraction due to the impending resumption of service to the PATH train transportation system, which had been interrupted by the attacks of September 11, 2001.

Questionnaires were issued to each ferry vessel operator to determine a representative vessel inventory through December 31, 2003. Other requested information included the following:

- propulsion plant configuration,
- vessel particulars,
- vessel construction date,
- expected vessel service life,
- vessel hull configuration,
- daily fuel consumption,

- engine rating,
- hull material,
- passenger capacity,
- operational information, and
- engine maintenance information.

Once the information was received, it was reviewed for completeness. Follow-up calls were made to each operator and field visits were made to verify the information on the questionnaire. Engine manufacturers were contacted to see if any pertinent emissions information was available on each engine. SSI also performed an investigation of the relevant emissions standard of each engine. Once the information was compiled, it was placed in a matrix format. The results are contained in Tables 2.5 and 2.6**.** A copy of the questionnaire may be found in Appendix C.

SSI obtained fleetwide GPS data from NY Waterway and NY Water Taxi. Supplemental GPS data were obtained by riding the ferry vessels and logging the speed/position data with a hand-held GPS receiver. GPS data for SeaStreak were collected by SSI personnel with the use of a hand-held GPS receiver. The GPS data provided the time and position of each vessel while traveling on their respective routes. The GPS information was utilized in the same time frame as the data acquisition equipment to obtain time-aligned data between engine parameters and vessel position for the four prospective demonstration vessels. The database was then used to develop the fleetwide operating profile and for tabulating route emission rates found in Tables 2.22, 2.23, and 2.24.

TEST VESSEL CANDIDATES

The overall composition of the fleet was reviewed to determine the best potential candidates for the installation of data logging equipment, in order to provide the best fleet representation. Based on the current and near future fleet makeup, four vessels were chosen for data logging purposes. They were the MV PORT IMPERIAL MANHATTAN, MV FATHER MYCHAL JUDGE, MV ED ROGOWSKY and MV SEASTREAK WALL STREET. While at least one vessel was selected from each operator, vessels were chosen to give the best representation of the fleetwide installed propulsion systems. For example, the propulsion system used in the MV FATHER MYCHAL JUDGE is identical in configuration to those found in 20 other vessels (73 other engines). This meant that the operating parameters and emissions output could be applied to those vessels, provided the vessels achieved nearly the same operating profile.

One engine and generator from each vessel was fitted with a data logger as well as the sensors necessary to collect the operating parameters according to the methodology found in "Protocols For On Board Marine Vessel Data Logging For Implementing Emissions Reduction Strategies," by West Virginia University and M.J. Bradley & Associates (Appendix B). An assumption was made that the multiple engines found on each vessel operated at the same load, such that only one engine needed to be equipped with data logging instrumentation.

VESSEL DATA LOGGING

In order to determine how the ferry vessels were operated, it was necessary to record various performance parameters for an extended period of time. From the pool of available ferry vessels, four representative vessels were chosen, one each from SeaStreak and NY Water Taxi and two from NY Waterway. The selected vessels represented those used on the short-, medium-, and long-haul routes described earlier. Combined, the selected vessels represented over 80% of the propulsion system engine/drive combinations in use. Data-logging equipment was installed on each vessel to measure engine rpm, exhaust temperature and pressure, fuel flow, and intake manifold pressure and temperature. Data were logged in accordance with the "Protocols For On Board Marine Vessel Data Logging For Implementing Emissions Reduction Strategies" developed by West Virginia University and M.J. Bradley & Associates (Appendix B). The ferry vessel operators assisted in the collection of operating data by providing vessel transit information such as route description and vessel speed and position. Other information was collected by riding each vessel and noting the operating patterns, in conjunction with data from on-board and/or hand-held global positioning satellite (GPS) systems. Finally, each vessel's exhaust emissions were measured using a portable emissions analyzer, plus a mobile dilution tunnel type emissions collection system for the purpose of collecting PM samples.

The data were collected over a period of three to five days of normal weekday vessel operation. The engine operating data were collected at 1-second intervals. The vessel position data were collected at 30- to 60-second intervals. The engine parameters were downloaded into a database, averaged over 10-second intervals, and time-aligned with the vessel position data. In this way it was possible to determine in what mode the vessel was operating at any specific point in time. Assumptions were made regarding the engine load and rpm for the pushing and cruise modes based on the GPS and fuel consumption data. Direct engine load data were not taken, either through shaft-mounted load cells or the engine electronic control unit (ECU), because there was no way to guarantee a steady continuous data stream from those devices over the time interval. Employing simple filtering methodology, with respect to engine rpm and vessel speed parameters, made it possible to obtain data sets that were representative of the vessel operations under pushing, maneuvering, and cruise conditions. The data were then used to construct operating curves for the engines and histograms depicting the percentage of time the engines were operating at any particular load, fuel flow, rpm, exhaust temperature, etc. Additionally, the data were used to determine the dominant engine load for each operating mode and formed the basis for the emissions test points.

Following the operating data analysis, baseline emissions testing was performed on each vessel. The baseline emissions tests followed the protocols set forth in "Emission Measurement Protocols For On-

Board Marine Vessels For Implementing Emissions Reduction Strategies; Staten Island Ferry Emissions Reduction Program Emission Measurement Protocol," developed by West Virginia University and M.J. Bradley & Associates (Appendix G) and applicable sections of the Code of Federal Regulations (CFR) 40. The emissions tests included gaseous sampling for NO_X, O_2, CO, and CO_2, and particulate sampling for PM 10 and PM 2.5. The testing was conducted during commercial passenger service operation, as well as during times with no passengers on board, as allowed by the ferry vessel operators. The emissions were collected under the three modes of operation: pushing, maneuvering, and cruising.

Data from the emissions collection and the engine load profile were used to construct an emissions signature of each representative vessel. Since the propulsion systems tested during the emissions test represented over 80% of the systems in use, the results could be extrapolated with a high degree of certainty that they would be representative of the emissions of the entire fleet.

CHARACTERIZATION MATRICES

The data were collected during the week of 15 January 2004 so as to represent each vessel's operation during a normal workweek. The time period also coincided with good weather so that there were no delays or cancellations of scheduled routes.

The results of the data logging and emissions testing activities are presented in the vessel characterization matrices. These matrices characterize the fleet's vessel population, physical and route profiles, and current total fleet emission rates of the installed engines. This characterization aided in identifying the limiting factors, operating parameters, and constraints of the various engines and machinery spaces and assisted in determining which control technologies would be most suitable for ferryboat application. Characterization of the fleet emission rates is vital to determining the emissions contribution of the private ferry fleet to the New York City air shed. Moreover, it was supplied to project management in both hard copy and in the form of a spreadsheet that can be manipulated as the routes, vessels, emissions numbers, and ultimately the effectiveness of the emissions control devices change.

Table 2.5 provides detailed information on the vessel particulars of the ferry fleet. It also includes propulsion machinery performance ratings, and maintenance requirements. Table 2.6 contains the particulars for the diesel generators installed onboard the vessels. Table 2.7 profiles the scheduled routes that are operated by each of the three ferry operators involved in this study. This table identifies the route by description of where the vessel originates from, where it stops and the final destination prior to returning to its origin. Each route is based on a round-trip length and is categorized as applicable in the table. The routes are presented in descending order of route length by each respective operator. It provides specific information regarding the operating profiles and emission rates for the various ferry routes. Most importantly it provides the basis for a single source compilation of the real and potential emissions contributors found in the NYC private ferry vessel fleet.

Table 2.5. Vessel Main Propulsion System Particulars

OPERATOR	VESSEL PARTICULARS											PROPULSION		MAIN ENGINES										
												PROPULSOR	GEARING						MAIN ENGINE HOURS SUMMARY					
																				HOURS TO NEXT OVERHAUL [3]				
OPERATOR	CLASS/BUILDER: VESSEL	USCG NUMBER	YEAR BUILT	REMAINING SERVICE LIFE YEARS	HULL TYPE: MH = MONOHULL, C=CATAMARAN	LENGTH OVERALL, FEET	SERVICE SPEED, KNOTS	MAXIMUM SPEED, KNOTS	HOURS OPERATED/DAY	CREW	PASSENGER CAPACITY	P = PROPELLER: NO. x D" x P" x BLADES WJ= WATERJET: NO. x MODEL	RG = RED. GEAR: MFG / MODEL / RATIO DD = DIRECT DRIVE	MANUFACTURER/ NO. INSTALLED x MODEL/ RATING/ TOTAL INSTALLED BHP / E3 CYCLE EMISSION RATES, g/BHP-HR	FUEL TYPE/ CONSUMPTION RATE @ MAX. BHP, GPH	EXHAUST TYPE: W = WET, D = DRY	YEAR INSTALLED	SCHEDULED REPOWER	MFG. OVERHAUL INTERVAL, HOURS	MAIN ENGINE #1	MAIN ENGINE #2	MAIN ENGINE #3	MAIN ENGINE #4
New York Water Taxi	MURPHY / DERECKTOR:																							
	MICKEY MURPHY	1129770	2002	24	CAT	53.3	20	25	12.5	3	75	P: 2x 29.5 x 33.5 x 3	RG: Twin Disc / 5114A / 1.92:1	DETROIT DIESEL / 2 x Series 60 / 600 bhp @ 2100 rpm / 1200 bhp / *NOx = 5.73, CO = .20, HC = 0.068, PM = 0.079*	No. 2D / 28	D	2002	N/A	10,000	9,901	6,445	N/A	N/A
	MICHAEL MANN	1132284	2002	24	CAT	53.3	20	25	12.5	3	75	P: 2x 29.5 x 33.5 x 3	RG: Twin Disc / 5114A / 1.92:1		No. 2D / 28	D	2002	N/A	10,000	5,942	6,784	N/A	N/A
	CURT BERGER	1133350	2002	24	CAT	53.3	20	25	12.5	3	75	P: 2x 29.5 x 33.5 x 3	RG: Twin Disc / 5114A / 1.92:1		No. 2D / 28	D	2002	N/A	10,000	5,942	5,947	N/A	N/A
	JOHN KEITH	1143410	2003	25	CAT	53.3	20	25	12.5	3	75	P: 2x 29.5 x 33.5 x 3	RG: Twin Disc / 5114A / 1.92:1		No. 2D / 28	D	2003	N/A	10,000	8,136	8,133	N/A	N/A
	ED ROGOWSKY	1145216	2003	25	CAT	53.3	20	25	12.5	3	75	P: 2x 29.5 x 33.5 x 3	RG: Twin Disc / 5114A / 1.92:1		No. 2D / 28	D	2003	N/A	10,000	8,770	8,770	N/A	N/A
	SCHUYLER MEYER JR.	1145217	2003	25	CAT	53.3	20	25	12.5	3	75	P: 2x 29.5 x 33.5 x 3	RG: Twin Disc / 5114A / 1.92:1		No. 2D / 28	D	2003	N/A	10,000	8,503	8,504	N/A	N/A
SeaStreak	NEW YORK/ GLADDING-HEARN:																							
	NEW YORK	1105798	2001	12	CAT	141.0	38	42	8	6	400	WJ: 4x Kamewa A50	RG: Reintjes WVS 730D	CUMMINS / 4 x KTA50-M2 / 1875 bhp @ 1950 rpm / 7500 bhp / *NO_X = 6.44, CO = 1.66, HC = 0.14, PM = N.A.*	No. 2D / 350	D	2001	N/A	18,000	9,065	9,036	8,980	9,030
	NEW JERSEY	1118507	2001	12	CAT	141.0	38	42	8	6	400	WJ: 4x Kamewa A50	RG: Reintjes WVS 730D		No. 2D / 350	D	2001	N/A	18,000	10,592	10,700	10,535	10,535
	WALLSTREET	1145690	2003	14	CAT	141.0	38	42	8	6	400	WJ: 4x Kamewa A50	RG: Reintjes WVS 730D		No. 2D / 350	D	2003	N/A	18,000	16,999	17,001	16,997	16,996
	HIGHLANDS	1151440	2004	15	CAT	141.0	38	42	8	6	400	WJ: 4x Kamewa A50	RG: Reintjes WVS 730D		No. 2D / 350	D	2004	N/A	18,000	N/A	N/A	N/A	N/A

NOTES:

N/A = Not Applicable; N.A. = Not Available

(1) Representative emission values not available, due to age/model of engine

(2) CAT 3412E: 720 bhp @ 1800 rpm: NOX = 6.51, CO = 0.903, HC = 0.05

(3) Engine hours with negative values indicate engine is overdue for overhaul

Table 2.5. Vessel Main Propulsion System Particulars, continued

OPERATOR	CLASS/BUILDER: VESSEL	USCG NUMBER	YEAR BUILT	REMAINING SERVICE LIFE YEARS	HULL TYPE: MH = MONOHULL, C=CATAMARAN	LENGTH OVERALL, FEET	SERVICE SPEED, KNOTS	MAXIMUM SPEED, KNOTS	HOURS OPERATED/DAY	CREW	PASSENGER CAPACITY	PROPULSOR: P = PROPELLER: NO. x D" x P" x BLADES WJ= WATERJET: NO. x MODEL	GEARING: RG = RED. GEAR: MFG / MODEL / RATIO DD = DIRECT DRIVE	MANUFACTURER/ NO. INSTALLED x MODEL/ RATING/ TOTAL INSTALLED BHP / E3 CYCLE EMISSION RATES, g/BHP-HR	FUEL TYPE/ CONSUMPTION RATE @ MAX. BHP, GPH	EXHAUST TYPE: W = WET, D = DRY	YEAR INSTALLED	SCHEDULED REPOWER	MFG. OVERHAUL INTERVAL, HOURS	HOURS TO NEXT OVERHAUL [3]: MAIN ENGINE #1	MAIN ENGINE #2	MAIN ENGINE #3	MAIN ENGINE #4
New York Waterway	**HUDSON / GLADDING-HEARN:**																						
	ROBERT FULTON	990941	1993	20	MH	92.0	12	15	16	3	397	P: 2x 42 x 38	RG: ZF/ BW 195 2.571:1	CATERPILLAR / 2 x 3412 / 671 bhp @ 1800 rpm / 1342 bhp / [1]	No. 2D / 60	D	1993, 2001	2005 [2]	10,000	-3,607	808	N/A	N/A
	TOBIN / ALLEN MARINE:																						
	AUSTIN TOBIN	1119246	2001	28	MH	64.9	24	30	16	2	97	WJ: 3 x Hamilton Jet HJ362	DD	CATERPILLAR / 3 x 3406E TA / 600 bhp @ 2100 rpm / 1800 bhp / *NOX = 6.68, CO = 0.431, HC = 0.08, PM = N.A.*	No. 2D / 80	W	2001	N/A	10,000	1,927	1,934	2,037	N/A
	MOIRA SMITH	1121370	2001	28	MH	64.9	24	30	16	2	97	WJ: 3 x Hamilton Jet HJ362	DD		No. 2D / 80	W	2001	N/A	10,000	2,393	2,431	2,467	N/A
New York Waterway	**LAGUARDIA / ALLEN MARINE:**																						
	CONGRESSMAN ROBERT A. ROE	1137118	2003	30	CAT	78.5	22	27	16	3	150	WJ: 4 x Hamilton Jet HJ362	DD	CATERPILLAR / 4 x 3406E TA / 600 bhp @ 2100 rpm / 2400 bhp / *NOX = 6.68, CO = 0.431, HC = 0.08, PM = N.A.*	No. 2D / 200	W	2003	N/A	10,000	6,366	6,508	6,302	6,298
	JERSEY CITY	1137610	2003	30	CAT	78.5	22	27	16	3	150	WJ: 4 x Hamilton Jet HJ362	DD		No. 2D / 200	W	2003	N/A	10,000	6,258	6,166	6,179	6,172
	GOVERNOR THOMAS H. KEAN	1137612	2003	30	CAT	78.5	22	27	16	3	150	WJ: 4 x Hamilton Jet HJ362	DD		No. 2D / 200	W	2003	N/A	10,000	6,192	6,191	6,195	6,212
	ADMIRAL RICHARD E. BENNIS	1138601	2003	30	CAT	78.5	22	27	16	3	150	WJ: 4 x Hamilton Jet HJ362	DD		No. 2D / 200	W	2003	N/A	10,000	7,215	8,317	7,240	7,170
	BAYONNE	1138602	2003	30	CAT	78.5	22	27	16	3	150	WJ: 4 x Hamilton Jet HJ362	DD		No. 2D / 200	W	2003	N/A	10,000	6,408	6,414	6,406	6,437

NOTES:

N/A = Not Applicable; N.A. = Not Available

(1) Representative emission values not available, due to age/model of engine

(2) CAT 3412E: 720 bhp @ 1800 rpm: NOX = 6.51, CO = 0.903, HC = 0.05

(3) Engine hours with negative values indicate engine is overdue for overhaul

Table 2.5. Vessel Main Propulsion System Particulars, continued

OPERATOR	VESSEL PARTICULARS											PROPULSION		MAIN ENGINES									
												PROPULSOR	GEARING							MAIN ENGINE HOURS SUMMARY			
																					HOURS TO NEXT OVERHAUL [3]		
OPERATOR	CLASS/BUILDER: VESSEL	USCG NUMBER	YEAR BUILT	REMAINING SERVICE LIFE YEARS	HULL TYPE: MH = MONOHULL, C=CATAMARAN	LENGTH OVERALL, FEET	SERVICE SPEED, KNOTS	MAXIMUM SPEED, KNOTS	HOURS OPERATED/DAY	CREW	PASSENGER CAPACITY	P = PROPELLER: NO. x D" x P" x BLADES WJ= WATERJET: NO. x MODEL	RG = RED. GEAR: MFG / MODEL / RATIO DD = DIRECT DRIVE	MANUFACTURER/ NO. INSTALLED x MODEL/ RATING/ TOTAL INSTALLED BHP / E3 CYCLE EMISSION RATES, g/BHP-HR	FUEL TYPE/ CONSUMPTION RATE @ MAX. BHP, GPH	EXHAUST TYPE: W = WET, D = DRY	YEAR INSTALLED	SCHEDULED REPOWER	MFG. OVERHAUL INTERVAL, HOURS	MAIN ENGINE #1	MAIN ENGINE #2	MAIN ENGINE #3	MAIN ENGINE #4
New York Waterway	**GULF CRAFTS / GULF CRAFT, INC.**																						
	MANHATTAN	916221	1987	30	MH	102.3	12	15	16	3	492	P: 2 x 38 x 36	RG: ZF/ BW 195 / 2.03 : 1	CATERPILLAR / 2 x 3412E TA/ 720 bhp @ 1800 rpm / 1440 bhp / *NO_X = 6.51, CO = 0.903, HC = 0.05, PM = N.A.*	No. 2D / 60	D	2003	N/A	10,000	8,720	8,720	N/A	N/A
	NEW JERSEY	928331	1988	15	MH	87.3	12	15	16	3	304	P: 2 x 36 x 28	RG: ZF/ BW 195 / 2.03 : 1	CATERPILLAR / 2 x 3412 / 671 bhp @ 1800 rpm / 1342 bhp / [1]	No. 2D / 60	D	2002	2004 [2]	10,000	3,921	5,533	N/A	N/A
	GEORGE WASHINGTON	948900	1989	16	MH	87.3	12	15	16	3	396	P: 2 x 36 x 30	RG: ZF/ BW 195 / 2.03 : 1		No. 2D / 60	D	1989, 2002	2005 [2]	10,000	7,679	7,327	N/A	N/A
	THOMAS JEFFERSON	948901	1989	16	MH	87.3	12	15	16	3	396	P: 2 x 36 x 30	RG: ZF/ BW 195 / 2.03 : 1	CATERPILLAR / 2 x 3406E TA / 550 @ 2100 rpm / 1100 bhp / *NO_X = 6.68, CO = 0.431, HC = 0.08, PM = N.A.*	No. 2D / 60	D	2001	N/A	10,000	7,825	-2,223	N/A	N/A
	ALEXANDER HAMILTON	948902	1989	16	MH	87.3	12	15	16	3	396	P: 2 x 36 x 30	RG: ZF/ BW 195 / 2.03 : 1	CATERPILLAR / 2 x 3412 / 671 bhp @ 1800 rpm / 1342 bhp / [1]	No. 2D / 60	D	1989	2005 [2]	10,000	5,614	6,076	N/A	N/A
	ABRAHAM LINCOLN	948903	1989	16	MH	87.3	12	15	16	3	396	P: 2 x 36 x 30	RG: ZF/ BW 195 / 2.03 : 1		No. 2D / 60	D	2003	2005 [2]	10,000	7,355	7,378	N/A	N/A
	WEST NEW YORK	957551	1989	17	MH	62.0	12	15	16	3	146	P: 2 x 36 x 28	RG: ZF/ BW 195 / 2.03 : 1	CATERPILLAR / 2x 3406E TA / 600 bhp @ 2100 rpm / 1200 bhp / NOX = N.A., CO = N.A., HC = N.A., PM = N.A.	No. 2D / 60	D	2003	N/A	10,000	8,720	8,720	N/A	N/A

NOTES:

N/A = Not Applicable; N.A. = Not Available

(1) Representative emission values not available, due to age/model of engine

(2) CAT 3412E: 720 bhp @ 1800 rpm: NOX = 6.51, CO = 0.903, HC = 0.05

(3) Engine hours with negative values indicate engine is overdue for overhaul

Table 2.5. Vessel Main Propulsion System Particulars, continued

OPERATOR	VESSEL PARTICULARS: CLASS/BUILDER: VESSEL	USCG NUMBER	YEAR BUILT	REMAINING SERVICE LIFE YEARS	HULL TYPE: MH = MONOHULL, C=CATAMARAN	LENGTH OVERALL, FEET	SERVICE SPEED, KNOTS	MAXIMUM SPEED, KNOTS	HOURS OPERATED/DAY	CREW	PASSENGER CAPACITY	PROPULSION: PROPULSOR (P = PROPELLER: NO. x D" x P" x BLADES; WJ= WATERJET: NO. x MODEL)	PROPULSION: GEARING (RG = RED. GEAR: MFG / MODEL / RATIO; DD = DIRECT DRIVE)	MAIN ENGINES: MANUFACTURER/ NO. INSTALLED x MODEL/ RATING/ TOTAL INSTALLED BHP / E3 CYCLE EMISSION RATES, g/BHP-HR	FUEL TYPE/ CONSUMPTION RATE @ MAX. BHP, GPH	EXHAUST TYPE: W = WET, D = DRY	YEAR INSTALLED	SCHEDULED REPOWER	MAIN ENGINE HOURS SUMMARY: MFG. OVERHAUL INTERVAL, HOURS	HOURS TO NEXT OVERHAUL [3]: MAIN ENGINE #1	MAIN ENGINE #2	MAIN ENGINE #3	MAIN ENGINE #4
New York Waterway	**FINEST / DERECKTOR :**																						
	FINEST	1044082	1996	23	CAT	114.1	34	37	8	5	349	WJ: 2 x MJP 650	RG: ZF/ BW 755 / 1.77 : 1	MTU / 2 x 16V396TE74L / 2672 BHP	No. 2D / 170	D	2004	N/A	10,000	9,746	2,872	N/A	N/A
	BRAVEST	1044083	1996	23	CAT	114.1	34	37	8	5	349	WJ: 2 x MJP 650	RG: ZF/ BW 755 / 1.77 : 1	MTU / 2 x 16V396TE74L / 2672 BHP	No. 2D / 170	D	2004	N/A	10,000	10,000	10,000	N/A	N/A
	LARGE CATAMARAN / GLADDING-HEARN & YANKS MARINE:																						
	MONMOUTH	1036356	1995	22	CAT	77.2	24	30	14	3	149	WJ: 2 x MJP 550	RG: ZF 1.7 : 1	2 x Deutz 616V16	No. 2D / 240	W	2002	N/A	10000	6,381	6,384	N/A	N/A
	MIDDLETOWN	1100671	2000	27	CAT	89.6	26	32	14	3	150	WJ: 4 x Hamilton Jet HM521	RG: Reintjes WVS 334L 1.645:1	CATERPILLAR / 4 x 3412E / 1200 bhp @ 2100 rpm / 4800 BHP / NOX = 6.51, CO = 0.903, HC = 0.05, PM = N.A.	No. 2D / 160	D	2003	N/A	10,000	8,059	8,058	8,060	8,059
Billy Bey Ferry Company, Inc.	**HUDSON / GLADDING-HEARN:**																						
	HENRY HUDSON	989554	1992	19	MH	92.0	12	15	16	3	397	P: 2x 42 x 38	RG: ZF/ BW 195 2.571:1	CATERPILLAR / 2 x 3412 / 671 bhp @ 1800 rpm / 1342 bhp / [1]	No. 2D / 60	D	1992	2004 [2]	10,000	-12,580	-10,664	N/A	N/A
	EMPIRE STATE	997922	1993	21	MH	92.0	12	15	16	3	397	P: 2x 42 x 38	RG: ZF/ BW 195 2.571:1		No. 2D / 60	D	1999, 2002	2004 [2]	10,000	5,363	-6,001	N/A	N/A
	GARDEN STATE	1022780	1994	21	MH	92.0	12	15	16	3	397	P: 2x 42 x 38	RG: ZF/ BW 195 2.571:1		No. 2D / 60	D	1994	2004 [2]	10,000	-1,410	-488	N/A	N/A
	JOHN STEVENS	1048895	1996	24	CAT	92.0	12	15	16	3	397	P: 2x 42 x 38	RG: ZF/ BW 195 2.571:1		No. 2D / 60	D	1997	2005 [2]	10,000	44	-1,110	N/A	N/A

NOTES:

N/A = Not Applicable; N.A. = Not Available

(1) Representative emission values not available, due to age/model of engine

(2) CAT 3412E: 720 bhp @ 1800 rpm: NOX = 6.51, CO = 0.903, HC = 0.05

(3) Engine hours with negative values indicate engine is overdue for overhaul

Table 2.5. Vessel Main Propulsion System Particulars, continued

OPERATOR	CLASS/BUILDER: VESSEL	USCG NUMBER	YEAR BUILT	REMAINING SERVICE LIFE YEARS	HULL TYPE: MH = MONOHULL, C=CATAMARAN	LENGTH OVERALL, FEET	SERVICE SPEED, KNOTS	MAXIMUM SPEED, KNOTS	HOURS OPERATED/DAY	CREW	PASSENGER CAPACITY	PROPULSOR: P = PROPELLER: NO. x D" x P" x BLADES WJ= WATERJET: NO. x MODEL	GEARING: RG = RED. GEAR: MFG / MODEL / RATIO DD = DIRECT DRIVE	MANUFACTURER/ NO. INSTALLED x MODEL/ RATING/ TOTAL INSTALLED BHP / E3 CYCLE EMISSION RATES, g/BHP-HR	FUEL TYPE/ CONSUMPTION RATE @ MAX. BHP, GPH	EXHAUST TYPE: W = WET, D = DRY	YEAR INSTALLED	SCHEDULED REPOWER	MFG. OVERHAUL INTERVAL, HOURS	HOURS TO NEXT OVERHAUL (3): MAIN ENGINE #1	MAIN ENGINE #2	MAIN ENGINE #3	MAIN ENGINE #4
Billy Bey Ferry Company, Inc.	**TOBIN / ALLEN MARINE:**																						
	FATHER MYCHAL JUDGE	1121369	2001	28	MH	64.9	24	30	16	2	97	WJ: 3 x Hamilton Jet HJ362	DD	CATERPILLAR / 3 x 3406E TA / 600 bhp @ 2100 rpm / 1800 bhp / *NOX = 6.68, CO = 0.431, HC = 0.08, PM = N.A.*	No. 2D / 80	W	2001	N/A	10,000	8,666	1,961	2,078	N/A
	DOUGLAS B. GURIAN	1121371	2001	28	MH	64.9	24	30	16	2	97	WJ: 3 x Hamilton Jet HJ362	DD		No. 2D / 80	W	2001	N/A	10,000	2,633	2,635	2,726	N/A
	ENDURING FREEDOM	1127372	2002	29	MH	64.9	24	30	16	2	97	WJ: 3 x Hamilton Jet HJ362	DD		No. 2D / 80	W	2002	N/A	10,000	4,558	4,552	4,572	N/A
	FRED V. MARRONE	1127373	2002	29	MH	64.9	24	30	16	2	97	WJ: 3 x Hamilton Jet HJ362	DD		No. 2D / 80	W	2002	N/A	10,000	4,776	4,765	4,807	N/A
	LAGUARDIA / ALLEN MARINE:																						
	FIORELLO LAGUARDIA	1091256	1999	27	CAT	78.5	22	27	16	3	150	WJ: 4 x Hamilton Jet HJ362	DD	CATERPILLAR / 4 x 3406E TA / 600 bhp @ 2100 rpm / 2400 bhp / *NOX = 6.68, CO = 0.431, HC = 0.08, PM = N.A.*	No. 2D / 200	W	(3ea.) 2001 (1ea.) 2003	N/A	10,000	2,372	4,167	3,142	3,522
	FRANK SINATRA	1091257	2000	27	CAT	78.5	22	27	16	3	150	WJ: 4 x Hamilton Jet HJ362	DD		No. 2D / 200	W	2002	N/A	10,000	8,720	-3,059	4,564	4,548
	YOGI BERRA	1091258	1999	27	CAT	78.5	22	27	16	3	150	WJ: 4 x Hamilton Jet HJ362	DD		No. 2D / 200	W	2002	N/A	10,000	286	-4,075	5,138	5,285
	CHRISTOPHER COLUMBUS	1100520	2000	27	CAT	78.5	22	27	16	3	150	WJ: 4 x Hamilton Jet HJ362	DD		No. 2D / 200	W	2002	N/A	10,000	-4,408	5,159	3,152	8,720
	GIOVANNI DAVERRAZANO	1109244	2001	28	CAT	78.5	22	27	16	3	150	WJ: 4 x Hamilton Jet HJ362	DD		No. 2D / 200	W	2003	N/A	10,000	8,046	8,720	8,666	8,720
	U.S. SENATOR FRANK R LAUTENBERG	1125842	2002	29	CAT	78.5	22	27	16	3	150	WJ: 4 x Hamilton Jet HJ362	DD		No. 2D / 200	W	2003	N/A	10,000	3,316	3,316	3,353	3,346
	BROOKLYN	1125849	2002	29	CAT	78.5	22	27	16	3	150	WJ: 4 x Hamilton Jet HJ362	DD		No. 2D / 200	W	2003	N/A	10,000	3,527	3,361	3,391	3,376
	HOBOKEN	1128485	2002	29	CAT	78.5	22	27	16	3	150	WJ: 4 x Hamilton Jet HJ362	DD		No. 2D / 200	W	2003	N/A	10,000	3,793	3,765	3,787	3,776

NOTES:

N/A = Not Applicable; N.A. = Not Available
(1) Representative emission values not available, due to age/model of engine
(2) CAT 3412E: 720 bhp @ 1800 rpm: NOX = 6.51, CO = 0.903, HC = 0.05
(3) Engine hours with negative values indicate engine is overdue for overhaul

Table 2.6. Vessel Generator System Particulars

DIESEL GENERATORS							
OPERATOR	CLASS / BUILDER: VESSELS	MANUFACTURER / NO. INSTALLED MODEL / KW / RPM / VOLTS / HERTZ D2 CYCLE EMISSION RATES, g / bhp hr	YEAR INSTALLED	SCHEDULED REPOWER	DG HOURS SUMMARY: RECOMMENDED OVERHAUL INTERVAL, HOURS	HOURS TO NEXT OVERHAUL: DG SET NO.1	HOURS TO NEXT OVERHAUL: DG SET NO.2
New York Water Taxi	**MURPHY / DERECKTOR:**						
	MICKEY MURPHY	NORTHERN LIGHTS / 1 x M984K / 33 / 1800 / 120-240 / 60 / (1)	2002	N/A	9,000	5,132	N/A
	MICHAEL MANN		2002	N/A	9,000	5,787	N/A
	CURT BERGER		2002	N/A	9,000	5,567	N/A
	JOHN KEITH	NORTHERN LIGHTS / 1 x 20CR / 20 / 1800 / 120-240 / 60 / NO_X = 3.87, CO = .708, PM = .113	2003	N/A	9,000	6,915	N/A
	ED ROGOWSKY		2003	N/A	9,000	7,601	N/A
	SCHUYLER MEYER, JR.		2003	N/A	9,000	7,346	N/A
SeaStreak	**NEW YORK / GLADDING-HEARN:**						
	NEW YORK	CUMMINS / 2 x 6BT5.9 / 95 / 1800 / 120-240 / 60 / (1)	2001	N/A	18,000	8,136	8,528
	NEW JERSEY		2001	N/A	18,000	10,068	11,068
	WALL STREET		2003	N/A	18,000	16,821	16,703
	HIGHLANDS		2004	N/A	18,000	N/A	N/A

NOTES:

N/A = Not Applicable; N.A. = Not Available

NG = No gauge installed for hours

(1) Representative emission values not available, due to age/model of engine

Table 2.6. Vessel Generator System Particulars, continued

DIESEL GENERATORS							
					DG HOURS SUMMARY		
						HOURS TO NEXT OVERHAUL	
OPERATOR	CLASS / BUILDER: VESSELS	MANUFACTURER / NO. INSTALLED MODEL / KW / RPM / VOLTS / HERTZ D2 CYCLE EMISSION RATES, g / bhp hr	YEAR INSTALLED	SCHEDULED REPOWER	RECOMMENDED OVERHAUL INTERVAL, HOURS	DG SET NO. 1	DG SET NO. 2
New York Water Way	**HUDSON / GLADDING-HEARN:**						
	ROBERT FULTON	DETROIT DIESEL / 2 x 371 / 40 kW / 75 kVA / (1)	1993	2005	10,000	NG	NG
	TOBIN / ALLEN MARINE:						
	AUSTIN TOBIN	NORTHERN LIGHTS / 1 x P844k / 20 / 1800 / 120-240 / 60 / NO_X = *3.87, CO = .708, PM = .113*	2001	N/A	9,000	5,299	N/A
	MOIRA SMITH		2001	N/A	9,000	6,165	N/A
	LAGUARDIA / ALLEN MARINE:						
	CONGRESSMAN ROBERT A. ROE	NORTHERN LIGHTS / 2 x M32C / 32 / 1800 / 120-240 / 60 / (1)	2003	N/A	9,000	4,766	4,778
	JERSEY CITY		2003	N/A	9,000	4,729	5,513
	GOVERNOR THOMAS H. KEAN		2003	N/A	9,000	4,536	5,411
	ADMIRAL RICHARD E. BENNIS		2003	N/A	9,000	5,615	6,151
	BAYONNE		2003	N/A	9,000	4,933	5,378
	GULF CRAFTS / GULF CRAFT:						
	MANHATTAN	NORTHERN LIGHTS / 2 x M673 / 40 / 1800 / 120-240 /	2003	N/A	9,000	7,641	7,798
	NEW JERSEY	DETROIT DIESEL / 1 x 371 / 60 kW / 75 kVA PERKINS 1 x 4108 (1)	1988	2004	10,000	NG	NG
	GEORGE WASHINGTON		1989	2005	10,000	NG	NG
	THOMAS JEFFERSON		1989	2005	10,000	NG	NG
	ALEXANDER HAMILTON		1989	2005	10,000	NG	NG
	ABRAHAM LINCOLN		1989	2005	10,000	NG	NG
	WEST NEW YORK		1990	2004	10,000	NG	NG
	FINEST / DERECKTOR:						
	FINEST	NORTHERN LIGHTS / 2 x M439 / 55kW (1)	1996	N/A	9,000	6,647	8,638
	BRAVEST		1996	N/A	9,000	7,623	6,909
	HEARN & YANKS MARINE:						
	MONMOUTH	NORTHERN LIGHTS / 2 x 40 (1)	1995		9,000	6,887	2,902
	MIDDLETOWN	CATERPILLAR / 2 x 3304 / (1)	2000		10,000	NG	NG

NOTES:

N/A = Not Applicable; N.A. = Not Available

NG = No gauge installed for hours

(1) Representative emission values not available, due to age/model of engine

Table 2.6. Vessel Generator System Particulars, continued

DIESEL GENERATORS							
OPERATOR	CLASS / BUILDER: VESSELS	MANUFAC TURER / NO. INSTALLED x MODEL / KW / RPM / VOLTS / HERTZ / D2 CYCLE EMISSION RATES, g / bhp - hr	YEAR INSTALLED	SCHEDULED REPOWER	DG HOURS SUMMARY: RECOMMENDED OVERHAUL INTERVAL, HOURS	HOURS TO NEXT OVERHAUL: DG SET NO. 1	HOURS TO NEXT OVERHAUL: DG SET NO. 2
Billy Bey Ferry Company, Inc.	**HUDSON / GLADDING-HEARN:**						
	HENRY HUDSON	DETROIT DIESEL / 2 x 371 / 40 kW / 75 kVA / (1)	1992	2004	10,000	NG	NG
	EMPIRE STATE		1994	2004	10,000	3,693	7,772
	GARDEN STATE		1994	2004	10,000	NG	NG
	JOHN STEVENS		1997	2005	10,000	6,540	7,079
	TOBIN / ALLEN MARINE:						
	FATHER MYCHAL JUDGE	NORTHERN LIGHTS / 1 x P844k / 20 / 1800 / 120-240 / 60 / NO_X = 3.87, CO = .708, PM = .113	2001	N/A	9,000	5,983	N/A
	DOUGLAS B. GURIAN		2001	N/A	9,000	6,406	N/A
	ENDURING FREEDOM		2002	N/A	9,000	8,209	N/A
	FRED V. MARRONE		2002	N/A	9,000	7,482	N/A
	LAGUARDIA / ALLEN MARINE:						
	FIORELLO LAGUARDIA	NORTHERN LIGHTS / 2 x M32C / 32 / 1800 / 120-240 / 60 / (1)	2000	N/A	9,000	3,562	2,798
	FRANK SINATRA		2000	N/A	9,000	4,531	4,533
	YOGI BERRA		2000	N/A	9,000	5,047	3,956
	CHRISTOPHER COLUMBUS		2000	N/A	9,000	5,151	6,096
	GIOVANNI DAVERRAZANO		2001	N/A	9,000	8,051	7,681
	U.S. SENATOR FRANK R LAUTENBERG		2002	N/A	9,000	874	2,797
	BROOKLYN		2002	N/A	9,000	1,774	2,082
	HOBOKEN		2002	N/A	9,000	1,121	2,574

NOTES:

N/A = Not Applicable; N.A. = Not Available
NG = No gauge installed for hours
(1) Representative emission values not available, due to age/model of engine

Table 2.7. Ferry Vessel Routes

Route No.	Route Origin / Destination / End	Operator	Route Description	Route Distance	Routes per Day	Days per Week	Routes per Year	Vessel Class	GPS Data Source Vessel	Propulsion Engine Type	No. of Propulsion Engines	Propulsion Power, per engine	Propulsion Power, per vessel	Time at Push, per route	Time at Manuever, per route	Time at Cruise, per route	Total Time, per route
				NM								(hp)	(hp)	(hrs)	(hrs)	(hrs)	(hrs)
1	Belford, NJ to Pier 11 to Belford, NJ	NY Waterway	Long Haul	45.8	14	5	3,640	Large Cat	Middletown	Caterpillar 3412E	4	1200	4800	0.154	0.194	1.062	1.410
2	Port Liberte to Pier 11 to Port Libete	NY Waterway	Medium Haul	9.4	7	5	1,820	Lauguardia	Roe	Caterpillar 3406E	4	600	2400	0.192	0.260	0.261	0.713
3	Pier 11 to Port Liberte to Pier 11	NY Waterway	Medium Haul	9.4	10	5	2,600	Lauguardia	Roe	Caterpillar 3406E	4	600	2400	0.165	0.223	0.267	0.655
4	Hoboken-South to (via WFC & Pier 11) WFC to Hoboken-South	NY Waterway	Medium Haul	7.7	12	5	3,120	Gulf Craft	Lincoln(1)	Caterpillar 3412(2)	2	671	1342	0.213	0.154	0.335	0.702
5	38th Street to (via Newport & Harborside) Colgate to 38th Street	NY Waterway	Medium Haul	7.6	23	5	5,980	Tobin	Tobin	Caterpillar 3406E	3	600	1800	0.178	0.148	0.344	0.669
6	38th Street to (via Newport) Harborside to 38th Street	NY Waterway	Medium Haul	6.7	17	5	4,420	Tobin	Tobin	Caterpillar 3406E	3	600	1800	0.110	0.097	0.291	0.497
7	38th Street to (via Harborside) Newport to 38th Street	NY Waterway	Medium Haul	6.7	6	5	1,560	Tobin	Tobin	Caterpillar 3406E	3	600	1800	0.110	0.109	0.275	0.495
8	38th Street to Harborside to 38th Street	NY Waterway	Medium Haul	6.6	6	5	1,560	Tobin	Tobin(1)	Caterpillar 3406E	3	600	1800	0.081	0.062	0.231	0.374
9	Liberty Harbor to Pier 11 to Liberty Harbor	NY Waterway	Medium Haul	5.8	24	5	6,240	Laguardia	Bayonne	Caterpillar 3406E	4	600	2400	0.083	0.120	0.132	0.335
10	38th Street to Newport to 38th Street	NY Waterway	Medium Haul	5.6	17	5	4,420	Tobin	Tobin(1)	Caterpillar 3406E	3	600	1800	0.077	0.089	0.172	0.338
11	Hoboken-South to WFC to Hoboken-South	NY Waterway	Medium Haul	5.0	63	5	16,380	Gulf Craft	Lincoln	Caterpillar 3412(2)	2	671	1342	0.104	0.065	0.193	0.362
12	38th Street to (via Lincoln Harbor) Hoboken North to 38th Street	NY Waterway	Medium Haul	3.1	28	5	7,280	Laguardia	Kean	Caterpillar 3406E	4	600	2400	0.136	0.144	0.053	0.332
13	Hoboken-North to 38th Street to Hoboken-North	NY Waterway	Medium Haul	2.4	29	5	7,540	Laguardia	Kean	Caterpillar 3406E	4	600	2400	0.136	0.082	0.056	0.274
14	38th Street to Lincoln Harbor to 38th Street	NY Waterway	Medium Haul	2.4	26	5	6,760	Gulf Craft	Hamilton	Caterpillar 3412(2)	2	671	1342	0.097	0.091	0.071	0.258
15	Port Imperial to 38th Street to Port Imperial (weekdays)	NY Waterway	Short Haul	2.0	89	5	23,140	Gulf Craft	Manhattan	Caterpillar 3412E	2	720	1440	0.110	0.092	0.127	0.329
16	Port Imperial to 38th Street to Port Imperial (saturdays)	NY Waterway	Short Haul	2.0	52	1	2,704	Gulf Craft	Manhattan	Caterpillar 3412E	2	720	1440	0.125	0.059	0.153	0.337
17	Port Imperial to 38th Street to Port Imperial (sundays)	NY Waterway	Short Haul	2.0	49	1	2,548	Gulf Craft	Manhattan	Caterpillar 3412E	2	720	1440	0.128	0.081	0.129	0.338

Table 2.7. Ferry Vessel Routes, continued

Route No.	Route Origin / Destination / End	Operator	Route Description	Route Distance	Routes per Day	Days per Week	Routes per Year	Vessel Class	GPS Data Source Vessel	Propulsion Engine Type	No. of Propulsion Engines	Propulsion Power, per engine	Propulsion Power, per vessel	Time at Push, per route	Time at Manuever, per route	Time at Cruise, per route	Total Time, per route
				NM								(hp)	(hp)	(hrs)	(hrs)	(hrs)	(hrs)
18	Colgate to WFC to Colgate	NY Waterway	Short Haul	1.6	63	5	16,380	Gulf Craft	New Jersey	Caterpillar 3412[2]	2	671	1342	0.097	0.059	0.107	0.263
Totals, NY Waterway					**535**		**118,092**										
19	Port Imperial to (via Hoboken-North, WFC) Pier 11 to (via WFC, Hoboken-North) Port Imperial	Billy Bey	Long Haul	13.1	6	5	1,560	Laguardia	Lautenberg/ Brooklyn[1]	Caterpillar 3406E	4	600	2400	0.206	0.237	0.373	0.816
20	Port Imperial to Pier 11 to Port Imperial	Billy Bey	Long Haul	12.8	25	5	6,500	Lauguardia	Brooklyn	Caterpillar 3406E	4	600	2400	0.118	0.124	0.411	0.654
21	Pier 11 to 38th Street to Pier 11	Billy Bey	Long Haul	11.8	8	5	2,080	Laguardia	Brooklyn[1]	Caterpillar 3406E	4	600	2400	0.118	0.124	0.285	0.527
22	Port Imperial to (via Hoboken-North) WFC to Port Imperial	Billy Bey	Medium Haul	8.0	8	5	2,080	Lauguardia	Lautenberg	Caterpillar 3406E	4	600	2400	0.110	0.139	0.231	0.481
23	WFC to (via Hoboken-North) Port Imperial to WFC	Billy Bey	Medium Haul	8.0	8	5	2,080	Lauguardia	Lautenberg	Caterpillar 3406E	4	600	2400	0.109	0.149	0.237	0.495
24	Hoboken-South to Pier 11 to Hoboken-South	Billy Bey	Medium Haul	7.4	61	5	15,860	Lauguardia	Lauguardia	Caterpillar 3406E	4	600	2400	0.149	0.113	0.240	0.502
25	38th Street to Colgate to 38th Street	Billy Bey	Medium Haul	7.4	13	5	3,380	Tobin	Freedom	Caterpillar 3406E	3	600	1800	0.167	0.122	0.213	0.501
26	38th St. to (via Newport Hoboken-South) Hoboken-North to 38th St.	Billy Bey	Medium Haul	6.2	8	2	832	Hudson	Stevens	Caterpillar 3412[2]	2	671	1342	0.207	0.231	0.340	0.778
27	38th St. to (via Hoboken North & Hoboken South) Newport to 38th St.	Billy Bey	Medium Haul	6.2	15	2	1,560	Hudson	Stevens	Caterpillar 3412[2]	2	671	1342	0.167	0.225	0.349	0.741
Totals, Billy Bey Ferry Company					**152**		**35,932**										
28	East 34th St. to Pier 11 to Highlands to Atlantic Highlands to Pier 11 to East 34th St.	Seastreak	Long Haul	50.0	15	5	3,900	New York	Wall Street	Cummins KTA50-M2	4	1875	7500	0.479	0.638	1.106	2.224
29	East 34th St. to Pier 11 to Highlands to Pier 11 to East 34th St.	Seastreak	Long Haul	48.0	4	2	416	New York	Wall Street	Cummins KTA50-M2	4	1875	7500	0.346	0.388	1.056	1.790
30	Pier 11 to South Amboy to Pier 11	Seastreak	Long Haul	45.0	9	5	2,340	New York	Wall Street	Cummins KTA50-M2	4	1875	7500	0.279	0.221	0.923	1.423
Totals, Seastreak					**28**		**6,656**										

Table 2.7. Ferry Vessel Routes, continued

Route No.	Route Origin / Destination / End	Operator	Route Description	Route Distance	Routes per Day	Days per Week	Routes per Year	Vessel Class	GPS Data Source Vessel	Propulsion Engine Type	No. of Propulsion Engines	Propulsion Power, per engine	Propulsion Power, per vessel	Time at Push, per route	Time at Manuever, per route	Time at Cruise, per route	Total Time, per route
				NM								(hp)	(hp)	(hrs)	(hrs)	(hrs)	(hrs)
31	Various weekday routes [3]	NY Water Taxi	Medium Haul	-	9hrs/day operation [3]	5 vessels, 5 days/ week [3]	1,300	Murphy	Rogowsky	DD Series 60	2	600	1200	4.050	1.323	3.627	9.000
32	Various weekend routes [3]	NY Water Taxi	Medium Haul	-	9hrs/day operation [3]	3 vessels, 2 days/ week [3]	312	Murphy	Rogowsky	DD Series 60	2	600	1200	4.050	1.323	3.627	9.000
Totals, New York Water Taxi					**-**		**1,612**										
Grand Totals, New York City Harbor					**715**		**162,292**										

Notes: (1): GPS data for respective route was unavailable for specific route; therefore route times estimated from vessels operating on similar routes.

(2): Emission data for mechanically controlled Caterpillar 3412 engines from PANY report dated April 2001

(3): Because NY Watertaxi vessels do not typically complete a closed circuit route the operating profile of the three modes of operation are presented as the total time in hours in each mode during the typical 9 hours of daily operation as determined during data logging. Therefore, route definitions and frequency are presented as various and on a hrs/day basis.

DATA ACQUISITION SYSTEM

During January 2004, the engine operating data from the four prospective demonstration vessels was collected using a data acquisition system. Appendix D contains details of the data logging system and equipment. Each vessel was fitted with a data logger unit and the necessary sensors for the selected operating parameters. The data logger was capable of monitoring up to 40 channels and could be configured for thermocouple, voltage, 4-20mA, or frequency inputs. The units were powered by a 12-volt battery that was kept charged while the vessel was underway or on shore power. Each unit had sufficient memory storage to collect over 10 days of data continuously, logged at 1-second intervals. The measured parameters, where available, included engine rpm, fuel flow, exhaust temperature, exhaust back pressure, intake manifold pressure (turbocharged engines only), engine intake manifold temperature (turbocharged engines only), and ambient air temperature. The monitored parameters were logged at 1-second intervals for the duration of the data collection. Each vessel's operating parameters were logged for periods of three to five days of normal weekday commuter operation. For those locations on the engine and/or exhaust system where the bosses normally used to collect exhaust data were fitted with engine instrumentation, the exhaust temperature was monitored with a surface temperature probe. A limited number of actual engine exhaust temperatures were measured utilizing a Testo 350 portable exhaust analyzer.

The data acquisition system was housed in a 17.5" x 15.5" x 6.3" fiberglass electrical enclosure. The enclosure contained a Datataker DT800 42-channel data acquisition and logging instrument, a 12-volt sealed regulated lead acid battery, a 115-130 VAC battery charger with charging state indication, fuel flow display gauges for FloScan Fuel Meters, and requisite terminal strips, wiring, and switches. A schematic is shown in Figure 2.1, and the actual system housing is shown in Figure 2.2. The data acquisition system housing had several sensor instrumentation cables, which were connected to various sensing points on one main engine and one auxiliary engine.

Each data logging unit had been bench tested prior to installation. Bench testing consisted of comparing the measured signal as recorded by the Datataker 800 with a calibrated analog input signal. For instance, a pressure transducer would be connected to the Datataker 800 and a pressure source. The pressure source would be measured by a calibrated gage (+/- 2% accuracy). The calibrated gage reading would then be compared to the reading given by the Datataker 800 display. The pressure would be increased or decreased to verify that the pressure as read by the Datataker was accurate.

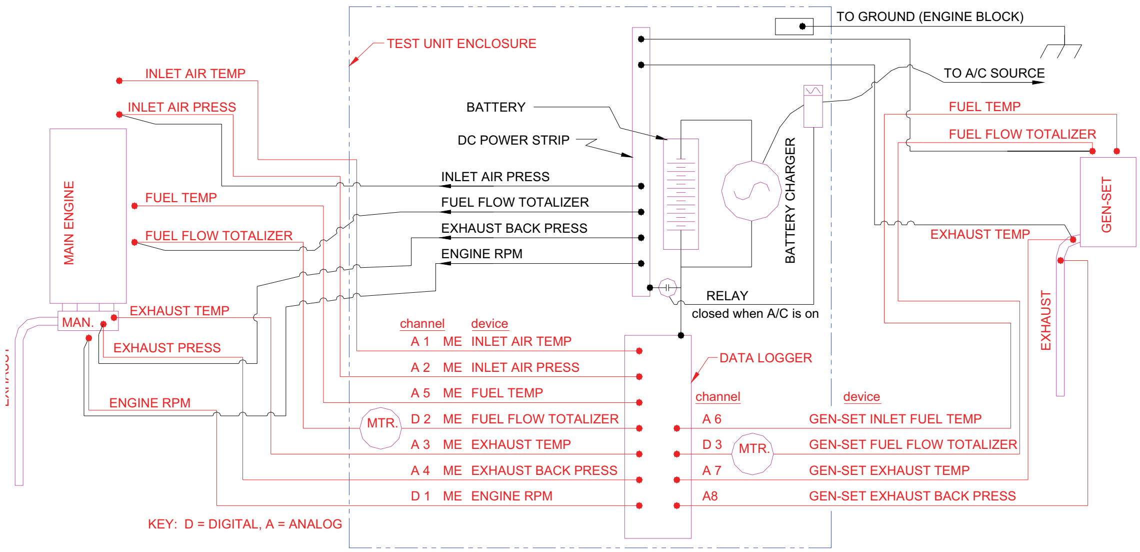

Figure 2.1. Data Acquisition System Schematic.

Figure 2.2. Data Acquisition System.

Pre-installation visits were conducted on the representative vessels to locate available test ports for installation of the various sensors. The SSI team identified which instruments could utilize existing ports and fittings in order to avoid the need for any permanent modification to engine piping or components. In some cases up to 13 sensors/test instruments were installed on the vessel. Table 2.8 presents information on the various test points.

Table 2.8. Data Acquisition System Sensor List.

Test Point	Parameter	Sensor	Data Channel	Location
1	Date / Time	Datataker 800	(Internal / None)	Data Logger
2	Main Engine (ME) Intake Temperature	Omega T/C P/N: TJ36-CASS-18U-12	Analog 1	Intake Manifold
3	ME Intake Pressure	Setra Pressure Sensor Model 209	Analog 2	Intake Manifold
4	ME Exhaust Temperature	Omega T/C P/N: TJ36-CASS-18U-12	Analog 3	Exhaust Piping
5	ME Exhaust Back Pressure	Setra Pressure Sensor Model 209	Analog 4	Exhaust Piping
6	Engine Speed	Monarch Optical Sensor	Digital 1	Engine Flywheel
7	ME Fuel Flow	FloScan P/N 86TMP-6DC-2K	Digital 2	Fuel Supply and Return Line
8	ME Fuel Temperature	Omega T/C P/N: SA1-K	Analog 5	Fuel Supply Line
9	Generator Fuel Flow	FloScan P/N 850MP-201-2K	Digital 3	Fuel Supply and Return Line
10	Generator Exhaust Temperature	Omega T/C P/N: SA1-K	Analog 7	Exhaust Piping
11	GPS / Vessel Location	Furnished by vessel operators; SeaStreak GPS via hand-held units from SSI Personnel	None	Bridge
12	Engine NO_X (PPM)	Testo 350 Gas Analyzer	None	Exhaust Outlet

Temperature Measurement

Intake manifold, exhaust, and fuel temperatures were logged by the DT 800 via thermocouples. These temperatures were recorded to assist with the evaluation of the type and size of the exhaust after treatment devices. The majority of temperature measurement sensors were two-wire Type K thermocouples Probes were installed in existing ports utilizing pipe fittings of the appropriate type and size for the application. This approach was utilized for the fuel temperature and some of the exhaust temperature measurements. The DT 800 logged the analog output from the temperature probes. Figure 2.3 shows the installation of a thermocouple probe installed on New York Waterway's MV FATHER MYCHAL JUDGE, measuring main engine intake manifold temperature.

Pressure Measurement

Intake manifold and exhaust backpressure was logged by the Datataker (DT) 800 via pressure sensors to determine engine loads as well as the type and size of the exhaust after treatment devices. The pressure sensors were of the sealed gage transducer type, excited by 12 VDC, with a 4-20 mA output signal. All pressure sensors were installed in existing ports utilizing appropriate type and sized pipe fittings, and the DT 800 logged the analog output. Figure 2.3 shows a pressure sensor installed on New York Waterway's MV FATHER MYCHAL JUDGE, measuring main engine intake manifold pressure.

Figure 2.3. Thermocouple and Pressure Sensor Installation.

Speed Measurement

Main engine speed was recorded in order to determine the load profiles of the engines. Engine speed (rpm) was measured utilizing a light emitting diode remote optical sensor (ROS)mounted in proximity to the engine's flywheel. The ROS, powered by a 12-volt direct current source, detected a reflected pulse from a target consisting of reflective tape attached to the flywheel. The digital output pulse was then logged by the DT 800. Figure 2.4 shows the installation of an engine rpm sensor installed on the MV SEASTREAK WALL STREET port aft main engine.

Figure 2.4. Engine RPM Sensor and Reflective Tape, MV SEASTREAK WALL STREET Port Aft Main Engine.

Fuel Flow Measurement

Fuel flow measurement sensors were installed on the fuel supply and return lines to display net flow rate and total fuel consumption. This parameter was used to assist with the determination of the engine load calculations. The turbine style flow meters used in the data acquisition system were manufactured by FloScan Instrument Company. FloScan has over 25 years of experience in marine fuel flow monitoring. FloScan's Series K diesel fuel flow sensors measured the supply and return fuel flows (see Appendix D for additional details). A microprocessor computer then converted the raw data to a net rate of flow or the fuel consumption.

The heart of the FloScan system is an "opto-electronic" turbine-type flow sensor, which uses an infrared light source to count rotations of the turbine. A signal generator reports this information to the meter heads microprocessor to calculate fuel flow and total fuel used; it sends a digital output pulse to the DT 800 to be logged. The temperature-compensated meters have a stated accuracy of ±2% with a repeatability within 0.25%. The design of the sensor eliminates any possibility of fuel blockage in the highly unlikely event that the turbine rotor is jammed due to debris in the fuel system. The supply meter was installed downstream of the RACOR fuel filters to further reduce the chance of any foreign matter or debris blocking the ports of the flow sensors.

Pre-installation visits were conducted on the representative vessels to properly size the flexible hoses installed on the inlet and outlet ports of the supply and return fuel meters. The flexible braided steel "Aeroquip"-manufactured hoses, with their appropriately sized sleeve and threaded hose ends, were assembled by an authorized Aeroquip fabrication shop utilizing FC-234 hose rated at 1250–1500 psi and marked USCG Type A1. The hoses were connected to existing fittings without disruption to the vessels' permanent hard piping and fittings by utilizing appropriately sized 37^{o} flare/NPT steel Aeroquip adapters. On some installations, the existing flexible hoses connecting the hard piping to the engine were utilized to join to either the supply or return fuel sensors, either from the engine or from the hard piping, while maintaining a flexible connection between the engine and hard piping. All flexible fuel lines and fuel sensors were adequately supported and secured using hangers/straps designed to eliminate potential damage to the fuel lines. Additionally, fuel hoses were protected from chafing where necessary. Figure 2.5 shows installation of fuel flow supply meter on the main engine of New York Waterway's MV FATHER MYCHAL JUDGE.

Figure 2.5. FloScan Fuel Supply Meter, MV FATHER MYCHAL JUDGE Main Engine.

Shaft power was purposely avoided as a measured parameter. The portable shaft power measuring instrumentation, being battery powered and wireless, would not be able to measure power for the time periods that were being logged. Also there was a limited amount of space in which to install the equipment. For the purpose of this testing, the fuel flow versus engine rpm curve was deemed equally good as shaft power at depicting the engine load, and measurements made in the cruise mode could be correlated to the manufacturer's design curves. By calculating the emissions on a fuel-consumed basis, the emissions rate is more easily estimated with the available information. Moreover, the operators do not record their vessel power levels so this data is not common; however, they do record fuel consumption.

DATA ACQUISITION SYSTEM INSTALLATION AND DATA RETRIEVAL

With the consent and assistance of the vessels' operators, the systems were installed during non-operating hours while the ferries were located at the operators' facilities. The SSI team completed the process in accordance with safety and regulatory requirements. Once installed, the system sensor calibrations were made with the engines off and then checked for communication between all channels with the engines running in idle mode. Checks on the integrity of the fuel connections were also done at that time. The data collection process was initiated once the system commissioning was satisfactorily completed.

Within a few days of commencement of data collection, the subject vessels were visited to download data from the DT 800 memory card and to check on integrity of system and communication of all channels. Thereafter, data were downloaded from the DT 800 on a periodic basis, dependent upon the total length of the test period. Downloaded data were reviewed and summarized for use in fleet characterization as well as in determination of appropriate emissions reduction technology and equipment.

DATA REDUCTION

After the data acquisition systems were in use for a nominal week of normal ferry vessel operation, the data were collected by using a serial connection or by removing the memory card and downloading to a laptop computer. The software supplied with the units provided for conversion of the raw data to Excel-formatted spreadsheets. Even so, the enormous quantity of data made it necessary to compress the information to a more manageable size so that common software programs (e.g. Excel) could be used for analysis. Excel has a row limitation of approximately 65,000 lines. The 1,000,000 lines of data in each download would require approximately 15 work sheets. This issue was alleviated by creating an Access database, which averaged the data over 10- second intervals and then exported the reduced data to an Excel workbook file . Deleting data recorded during time intervals when the engines were not running further reduced the quantity of data. These techniques reduced five continuous days of data to approximately 15,000 rows. Figure 2.6 depicts a 1-Hz data sample of approximately 4 hours duration.

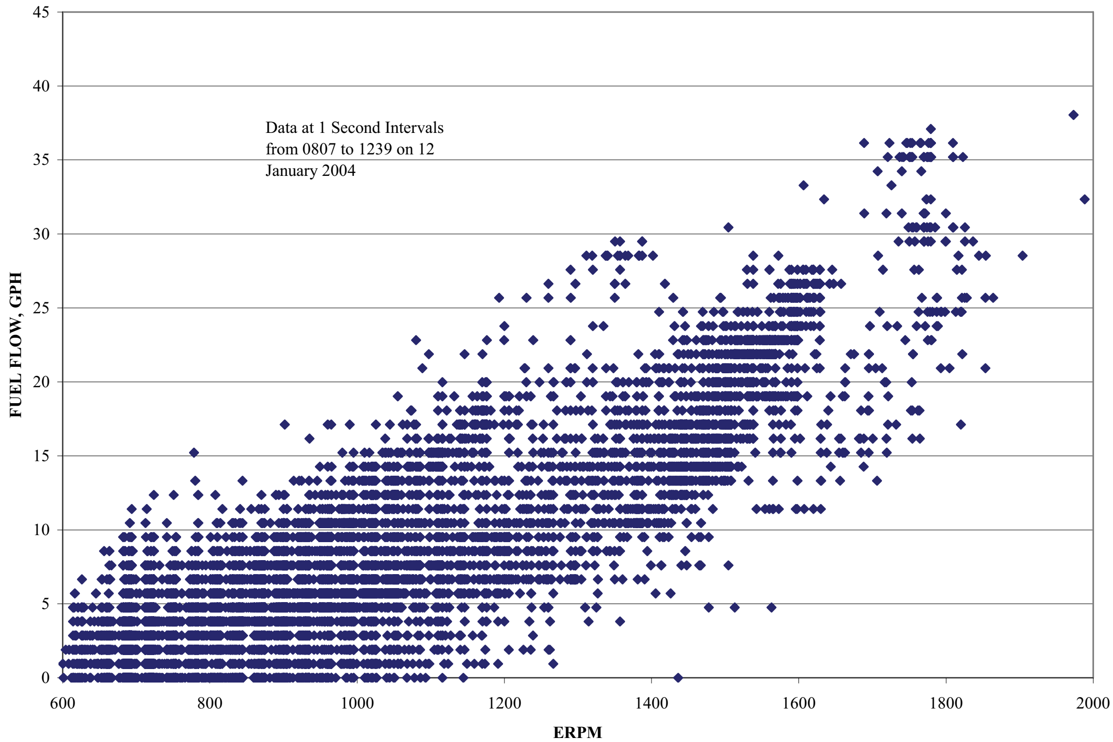

Figure 2.6. Representative 1 Hz Data Sample

Where available, GPS data were supplied by the operators and logged over a nominal 30-second interval. The GPS data acquired included the vessel position, date and time, distance traveled, direction, and speed. Longer logging intervals were found to exist where the ferry vessel was close to or alongside the dock. The GPS data were also recorded using a different clock. Each GPS device received a time signal from the satellite it tracks, but each engine data logger had an internal clock. This resulted in GPS data that was not exactly synchronized with the engine data. Nevertheless, the GPS data time was rounded to the nearest 10 seconds and then synchronized with the engine data in the database. An example of the synchronized data may be found in Figure 2.20. Graphic depictions of this type were used to verify the relationship between vessel speed and position, and the vessel's power output and engine speed (ERPM). The resultant ±10-second differential was deemed insignificant for the purpose of the data collection and analysis. The data were collected for periods that represented the normal workday schedules and passenger loads. The vessel routes were held constant throughout the data collection period.

DATA ANALYSIS

The data were analyzed after the complete data set for each ferry vessel was created. The first step in the analysis was determining the loading of the engine while the ferry vessel was in operation. This was completed utilizing truth tables to determine the operational mode for each ferry vessel. Truth tables are sets of numerical questions that can be used to filter and select data subsets. The truth tables were based upon each vessel's synchronized speed/fuel flow/ERPM vs. time curve. The truth tables filtered the data with regard to the vessel's speed and engine rpm. Generally, it was observed that certain ranges of speeds and engine rpms were unique to the mode in which the vessel was operating. For example, if the speed was zero, then it could be assumed that the vessel was at or near a dock. Each ferry vessel's passenger load and course were also incorporated into the analysis. Firsthand observations were used to determine how the vessels are operated while in service.

As noted earlier, each ferry vessel operates in three distinct modes of engine load: pushing, maneuvering, and cruising. The pushing portion of any ferry vessel's run was considered to be where the ferry vessel was actually stopped against the dock and unloading/loading passengers with the engine providing thrust in the forward direction to hold the vessel against the dock. The amount of thrust applied to hold the vessel to the dock was highly dependent upon the weather, tide, and the personal preference of the vessel's captain. The maneuvering portion of any ferry vessel's run was considered to be where the ferry vessel was accelerating away from or decelerating towards the dock and shifting ahead and astern. Maneuvering consists of a mixture of pushing and cruising. Actual thrust direction was not monitored. The cruising portion of any ferry vessel's run was considered to be any part where the speed was relatively constant in the forward direction. Each ferry vessel transited from one point to the next at the highest speed necessary to maintain its schedule. The ferry vessel would then slow as it approached and closed in on the dock. Bow-loading ferry vessels nose into the dock, and a certain amount of thrust is then applied to hold the ferry vessel to the pier face while the passengers disembark and embark. The ferry vessels then back away from the dock, rotate, and proceed to the next dock.

The data analysis also depended upon the method of propulsion. Propeller-driven vessels have a very different load profile than the waterjet vessels. Propeller propulsion systems are designed to operate in the forward direction with the vessel moving close to the speed of advance of the propeller. The direction of the thrust is determined by the shaft rotation or propeller direction. Propeller thrust is normally depicted as a cubic curve in which the power absorbed by the propeller varies by the cube of the rpm. However, when the same propeller operates in a bollard pull condition, as when the vessel is pushing against the dock, the propeller and engine loading is much higher. The propeller curve generated in a bollard pull condition is also a cubic function but with a larger coefficient. In order to determine the operating mode of the propeller and engine (cruising or pushing), it was necessary to first graph a curve that included all of the data points and then select data above and below this curve. The selected data were then re-graphed to represent the pushing and cruising regimes. This was evident in the data collected on the MV PORT IMPERIAL MANHATTAN and the MV ED ROGOWSKY, the two vessels utilizing propellers rather than waterjets. On both of these vessels, the engine load was comparable to the rated load curve of the engine when the vessel was cruising in open water. However, the engine load was significantly higher when the vessels were pushing against the dock. This situation was also apparent on the fuel flow and air manifold pressure vs. engine rpm curves.

Waterjet-powered vessels have a load profile that also varies by the cube of the rpm. However, the waterjet absorbs and the engine produces virtually the same amount of power whether the vessel is moving or stationary. The thrust direction is controlled by the position or angle of the control buckets relative to the longitudinal axis of the vessel.

The collected data were graphed with the engine fuel flow and exhaust temperature plotted in relation to the engine rpm. Each data set was regressed, and the optimum curve fit for the data was assigned from the options available within the spreadsheet charting software. Engine power was not measured and therefore not graphed; however, it can be inferred that fuel flow is equivalent to engine power and is the specific basis for the emissions measurements. Frequency distribution histograms were also created for fuel flow, engine rpm, and exhaust temperature to percentage of rated (where applicable). These curves for the MV PORT IMPERIAL MANHATTAN, MV FATHER MYCHAL JUDGE, MV ED ROGOWSKY and MV SEASTREAK WALL STREET are shown in Figures 2.20 through 2.25, 2.31 through 2.36, 2.41 through 2.45, and 2.50 through 2.55.

The engine operating curves were then compared to manufacturer performance curves. In general, the cruise mode fuel flow (power) to engine rpm relationship was very close to that provided by the manufacturers' documentation. Other operating parameters were observed to follow expected curve shape and slope in relation to the engine rpm and load. The engine manufacturers did not make available the actual test bed values for any parameters other than fuel flow and power.

Some erroneous data points were unavoidable due to the highly transient nature of ferry vessel operations. Filtering was necessary to discard the irrational data points. By collecting the data over a long time period the effects of weather, passenger load, tides, and currents were attenuated, resulting in more accurate curves. Some data collection points, such as exhaust temperature and backpressure, did not have a suitable measurement point and thus were not available to the data logging equipment. Supplemental data for these points was collected during the baseline emissions test or when the portable emissions test equipment was used to obtain an emissions snapshot. Other instrumentation (e.g. surface thermocouples) did not have the necessary accuracy for exhaust temperature and were used for comparative purposes only.

EMISSIONS TESTING

Following analysis of the data and in conjunction with the Phase I Low Sulfur Diesel (LSD)/Ultra-low Sulfur Diesel (ULSD) fuel test, baseline emissions values were established for each of the four demonstration vessels. Emissions were measured with the vessels operating on LSD using the test modes that were developed from the previously logged data. During February 2004, each vessel was tested at the dominant load for the cruise and push modes. The results were used to calculate the maneuvering mode and then used to calculate an overall emissions number based on the percentage of time each vessel operates in each mode. Environment Canada, in association with personnel from SSI and Northeast States Consortium for Coordinated Air Use Management (NESCAUM), coordinated and conducted the testing. Concurrent with each emissions test, engine operating parameters were collected utilizing the same data logging equipment used for developing the vessel operating profiles. Additionally, a hand-held GPS receiver was employed to provide vessel speed and position data while the tests were conducted. Each vessel was operated at loads that simulated the normal operating profile

The "Staten Island Ferry (SIF) Emissions Reduction Program Emissions, Emissions Reduction" protocol (Appendix J) as well as International Standards Organization (ISO) protocol 8178 "Reciprocating Internal Combustion Engines – Exhaust Emission Measurement" were adhered to as closely as possible during the testing. The goal of the testing protocol was to capture emissions data based on engine speed to brake horsepower (ERPM/BHP) load profiles that were representative of typical ferry operation on a given route. However, the actual load profiles of these vessels in service are dissimilar from the E3 certification test cycle in Part 4 of ISO 8178, applicable to these classes of vessels. Most of the testing was undertaken during off-hire trips by the ferries under steady state operation

In each set of trials the following modes of operation were tested for each vessel:

- propulsion engines
  - pushing
  - maneuvering
  - cruising
- genset engines -- diesel generator (DG) operating at constant electrical load (kWe).

The SIF emissions data logging protocol (Appendix B) specifies how the emissions should be measured in terms of the test set-up, instrumentation, accuracy, and test duration. For the baseline emissions tests a continuous portable sampling and analyzing system (mini-dilution system for particulate collection, SMART 2000, ECOM, and Horiba NO_X gas analyzers) was employed to sample and record emissions constituents. Both engine performance data and regulated emissions (e.g. NO_X, CO, CO_2, and PM) were recorded during transit and steady-state conditions along each vessel's route. By combining the emissions measurements with the engine data, it was possible to determine the amount of fuel used during each test and to calculate the amount of exhaust compared to the fuel burned, on a mass basis.

Emissions Measurement

The emissions measurement system uses a partial flow dilution method with multiple filters for PM 10 and PM 2.5 measurements. Total exhaust gas mass and volume were determined using fuel flow measurements combined with carbon balance calculations. Both of these methods are acceptable as defined in ISO Standard 8178-2.

For detailed emissions measurements a mini-dilution system was installed to facilitate the collection of particulate samples, along with two portable continuous emissions analyzer systems for the dilute and raw exhaust concentrations of NO_X, CO, CO_2, and O_2. This mini-dilution system was developed by the Environment Canada (EC) Environmental Research and Measurement Division (ERMD). It is correlated to a full exhaust emissions dilution and sampling system that is employed by the ERMD for the certification of engine emissions according to EC and U.S. Environmental Protection Agency (EPA) test protocols (Code of Federal Regulations, Schedule 40 Part 86) and closely adheres to the requirements of the SIF emissions measurement protocol. The emissions constituents were analyzed as follows:

- carbon monoxide: Non-Dispersive Infrared Detection (NDIR)
- carbon dioxide: Non-Dispersive Infrared Detection (NDIR)
- oxides of nitrogen: Electrochemical and direct insertion zirconia ceramic sensor
- particulate matter: PM 2.5 and PM 10 via Cyclones and Gravimetric Procedure.

The primary function of the mini-dilution system was to collect a known quantity of raw exhaust (partial flow) from the exhaust system of an engine and to mix this with a known quantity of ambient dilution air so that a "dry" particulate sample could be obtained. Diluting the raw exhaust with ambient air (while maintaining a constant temperature and flow velocity) conditions the sample and minimizes condensation, a major obstacle to particulate matter collection in the field. This technique was used in order to determine average weighted emission rates over defined periods of operation.

During operation, a ferry engine functions under various speed and load conditions. As a result, the volume of exhaust varies, as does the concentration of the pollutants. In marine and similar applications, the best results are obtained when the engine is operating under steady state conditions. In order to reliably measure exhaust emissions under steady state conditions, previous experience indicates that iso-kinetic sampling was not required[1]. However, dilution of each sample was required in order to maintain a condition above the dew point temperature. This was accomplished by establishing a flow rate of the dilution air that permits the collection of a "dry" particulate sample with sufficient mass accumulating on the collection media.

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[1] Emission Measurement Protocols for On-Board Marine Vessels for Implementing Emissions Reduction Strategies, prepared by West Virginia University September 4, 2003

The emissions analyzers and associated reference calibration gases were set up in close proximity to the engines to be tested.

The outputs from the two analyzers and the Horiba NO_X sensor were recorded on laptop computers. These data were analyzed and combined with simultaneously recorded engine operating data in order to report mass emission rates.

Emissions Test Equipment

Figures 2.7 through 2.15 show the various components of the portable exhaust emissions sampling system.

Figure 2.7. Mini-Dilution Tunnel (Total Length 82 inches).

Figure 2.8. Flow Control for Sample and Dilution (side).

Figure 2.9. Pump Box.

Figure 2.10. Flow Control for Sample and Dilution (top).

Figure 2.11. Dilute Gas Analyzer

Figure 2.12. Raw Exhaust Analyzer

Figure 2.13. Horiba NO_X / Air Fuel Sensor.

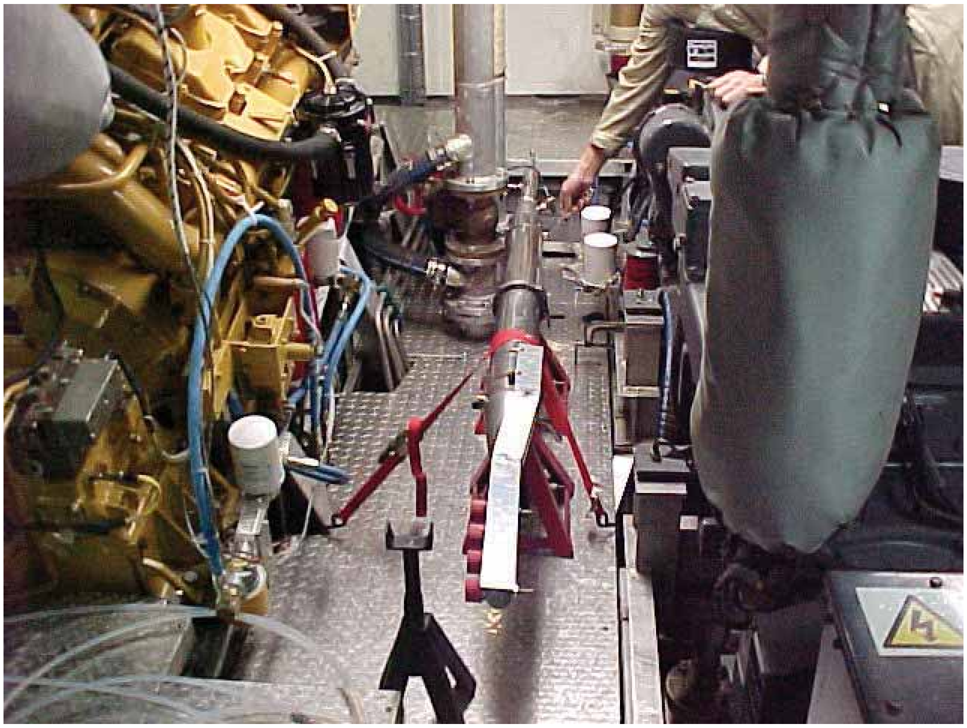


Figure 2.14. Dilution Tunnel in Engine Room of the MV PORT IMPERIAL MANHATTAN.

Figure 2.15. Particulate Sampling Setup Showing PM 2.5/PM 10 Cyclone Separators.

DATA LOGGING AND INITIAL EMISSIONS TESTING RESULTS

The results of the data logging and baseline emissions testing, conducted during January and February 2004, are discussed separately for the four vessels studied. These tests were performed on one short-haul, two medium-haul, and one long-haul vessel. The test results are presented as summary sheets and graphs.

The main engine summary sheet for each vessel (shown in Tables 2.10, 2.13, 2.16, and 2.19) delineates the percentage of time the vessel spent in each operating mode during the course of its normal operating profile. The graph of engine speed (ERPM), speed over the ground (SOG), and fuel flow vs. time (shown in Figures 2.20, 2.31, and, 2.50) depicts the relationship between the indicated parameters and the time they were recorded. As can be seen in every case, the engines and vessels accelerate and decelerate fairly quickly. On each curve the R^2 for the data fit is printed. The higher the number (1 being a perfect fit), the better the curve is able to represent the data. The fuel flow vs. ERPM graph (shown in Figures 2.21, 2.32, 2.42 and, 2.51) depicts the relationship between the fuel flow and the engine rpm when each vessel is operating in the cruising and pushing modes compared to the rated fuel curve from the engine manufacturer. Note the dissimilarities between these curves for a propeller-driven vessel (MV PORT IMPERIAL MANHATTAN) versus a water-jet vessel (MV FATHER MYCHAL JUDGE**)** The fuel flow vs. ERPM data for the propeller-driven vessel (shown in Table 2.21) resolves into two distinct power curves (push and cruise), whereas for a waterjet-driven vessel (shown in Figure 2.32), there is no distinction between the push, maneuvering, and cruise modes. The engine exhaust temperature vs. ERPM curve (shown in Figures 2.22, 2.33, 2.43 and, 2.52) depicts the change in exhaust temperature in relation to the engine rpm for the push and cruise operating modes. The ERPM histogram (shown in Figures 2.23, 2.34, 2.44 and, 2.53) depicts the percentage of time the vessel's engine operates at any particular rpm during the normal operating profile. The exhaust temperature histogram (shown in Figures 2.25, 2.36, 2.46 and, 2.55) depicts the percentage of time each exhaust temperature is achieved during the course of a normal operating profile. All of this information is used in determining the load profile and the emissions profile of each vessel. The exhaust temperature histograms are particularly important to the emissions control technology vendors and were used to assess the viability of the potential technologies for the demonstration.

Table 2.9 displays information on the properties of the LSD fuel used by each ferry vessel during the trials. The fuel properties are necessary to calculate the emissions and to determine what corrections may be necessary for the engine fuel consumption. The engines are rated for specific fuel and environmental conditions.

Table 2.9. Properties of LSD Fuel Used in Ferry Vessel Emissions Tests February 2004

PROPERTY	MV PORT IMPERIAL MANHATTAN	MV FATHER MYCHAL JUDGE	MV ED ROGOWSKY	MV SEASTREAK WALL STREET
Fuel Type	LSD	LSD	LSD	LSD
Specific Gravity	0.8641	0.8648	0.8684	0.8638
Sulfur ppm	412	405	362	426
Higher Heating Value Btu/gal	140,676	140,741	141,181	140,681
Aromatic Content %vol	38.7	37.0	41.5	36.3
Cetane Index	43.3	42.8	42.0	44.4
Cloud Point ◦F	10	12	10	12
Carbon %w	86.58	86.6	84.78	87.12
Hydrogen %w	13.33	13.31	12.71	11.78
Lubricity MM@75◦C	0.63	0.64	0.69	0.65

Short-Haul Vessel

The MV PORT IMPERIAL MANHATTAN is a monohull vessel powered by twin Caterpillar 3412E engines driving propellers through reduction gears. The vessel was originally constructed in 1986 but was significantly rebuilt in 2003, at which time the engines were replaced. Figure 2.16 shows the present configuration of the vessel. The MV PORT IMPERIAL MANHATTAN is capable of carrying in excess of 450 passengers and has a top speed of 17 knots. Its physical size and reserve speed made it well suited for NY Waterway's Weehawken, NJ, to 38th Street, NYC, ferry route shown in Figure 2.17.

Figure 2.16. MV PORT IMPERIAL MANHATTAN.

For this testing, the MV PORT IMPERIAL MANHATTAN was operating on the route shown in Figure 2.17. During a normal working day, it would be in operation approximately 14 hours. The vessel started its service at 7:00 AM and did not stop, save briefly for crew changes and a midday layover period, until nearly 10:00 PM. During rush hour service (7:00-9:00 AM and 5:00-7:00 PM) the vessel, along with a complimentary vessel, was on a 20-minute round-trip schedule. Between rush hours, the MV PORT IMPERIAL MANHATTAN operated on a 15-minute round-trip schedule, and the other vessel was shifted to a different route or placed in off-hire status.

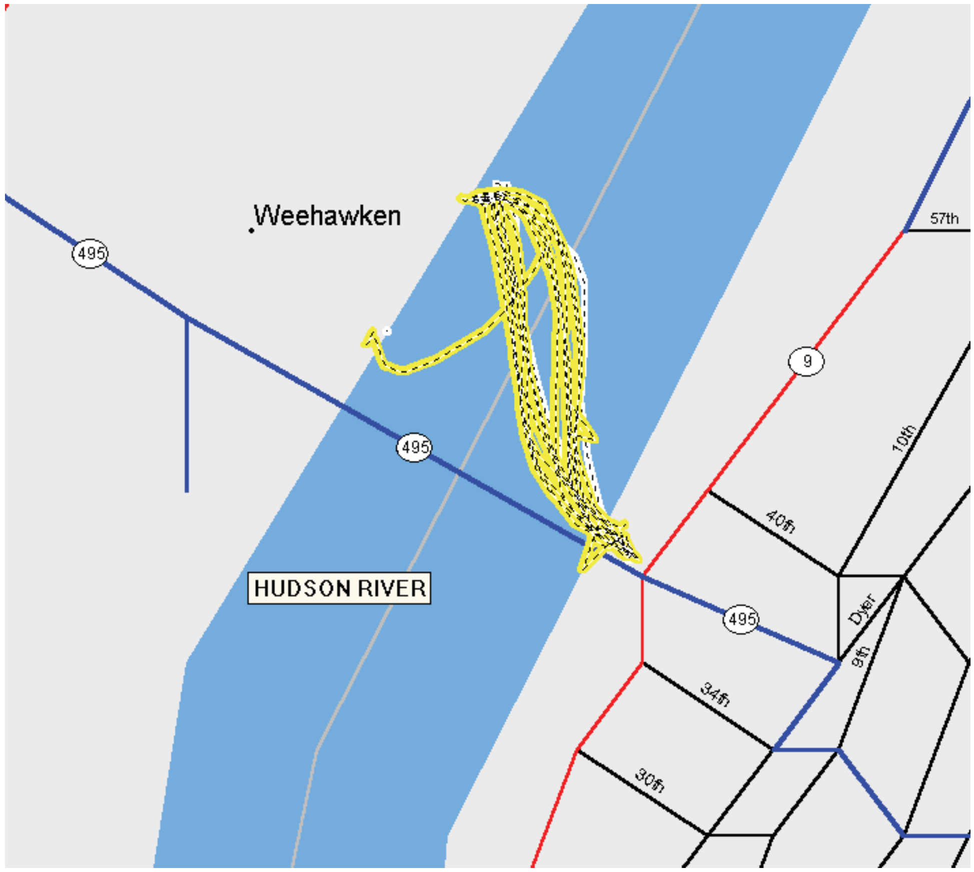


Figure 2.17. MV PORT IMPERIAL MANHATTAN Route Map.

As previously described, each round trip could be broken into three distinct operating modes: pushing, maneuvering, and cruising. The percentage of time the vessel spent operating in each regime is listed in the Table 2.10. The distance that the vessel covered for each round trip was approximately 0.8 NM. The actual time the vessel achieved steady state operation was approximately 4 minutes, each way. Due to the short distance, the vessel did not require more than 10-11 knots to maintain the schedule. Because of the low speeds, the engines were not operated near the maximum rated power levels and the exhaust temperatures were low.

From the collected data it is possible to determine the operating profile and exhaust emissions of this vessel or any other similarly powered vessel that is placed in this service. Though the vessels are theoretically interchangeable, the primary type used on the short-haul runs is the large monohulls. These vessels simply do not have the speed reserve necessary to effectively replace the faster catamarans in the longer NY Waterways route system. Furthermore, the small monohulls used on some of the longer runs do not have the passenger capacity to effectively replace the large monohulls in the short-haul service.

Table 2.10 MV PORT IMPERIAL MANHATTAN Main Engine Summary (January 12-16, 2004)

Mode	Time, hrs	% of Time	ERPM	Est. BHP	Fuel Flow, GPH	Fuel Temp, °F	Speed, KNOTS	Exh Temp, °F	ME Exh BP, IWC	Air Manifold Temp, °F	Air Manifold Press. PSIG
Pushing	22.7	37.8	936.0	N/A	9.8	69.6	0.4	513.6	15.8	159.7	3.2
Maneuvering	14.5	24.2	824.7	N/A	5.4	68.1	4.2	464.3	15.5	162.7	1.1
Cruising	22.7	38.0	1114.5	187.9	9.8	70.2	10.2	524.3	16.1	165.2	3.5
All Points	60.0	100.0	976.6	N/A	8.7	69.5	7.5	505.5	15.8	162.5	2.8

The relatively low exhaust temperatures and the overall amount of time at these temperatures make it challenging to apply off-the-shelf emissions technologies to vessels in the short-haul service. The engine room on the MV PORT IMPERIAL MANHATTAN is fairly spacious, and an exhaust treatment device could be fitted in either the main engine room or in the lazarette. The exhaust system of this vessel as well as those of the other large monohull vessels is a dry type. The dry type system consists of a large resonance chamber (silencer) into which the exhaust from the engine is ducted. The exhaust is then routed outside of the vessel through the transom. Figure 2.18 shows this arrangement. In either the engine room or the lazarette, the actual space available within which to fit any after treatment device is a box approximately 54” high and 30” square.

A larger emissions control device would have a significant negative impact on the ability to service and maintain the engine. Figure 2.19 shows the typical clearances around the engines on the MV PORT IMPERIAL MANHATTAN. Soft patches (easily removable deck sections), located in the main deck above the main engines, could be removed to permit installation of the equipment. The normal engine access requirements are met through a 30” personnel doorway and ladder. The only access to the lazarette is by means of an 18” personnel access hatch. There are no soft patches in the deck above the lazarette. Unless it could fit through the hatch, any exhaust treatment device installed in this space would require a hole to be cut and then re-welded in the deck of the vessel. Tables 2.10, 2.11, and 2.12 and Figures 2.20 through 2.25 depict the actual operating profile and emissions rate of this vessel. The collected data were modified so that the operating data represents only the time when the main engines were running.

Figure 2.18. MV PORT IMPERIAL MANHATTAN Exhaust System in Lazarette.

Figure 2.19. MV PORT IMPERIAL MANHATTAN Port Main Engine.

Table 2.11. MV PORT IMPERIAL MANHATTAN Diesel Generator Engine Summary

Mode	DG Fuel Flow, GPH	DG Load, kWe	DG Exhaust Temp, F	DG Exhaust Pressure, IWC
Pushing	1.0	10.0	514.3	3.5
Maneuvering	1.0	10.5	532.4	3.5
Cruising	0.8	7.9	475.2	3.5
All Points	0.9	9.8	513.5	3.5

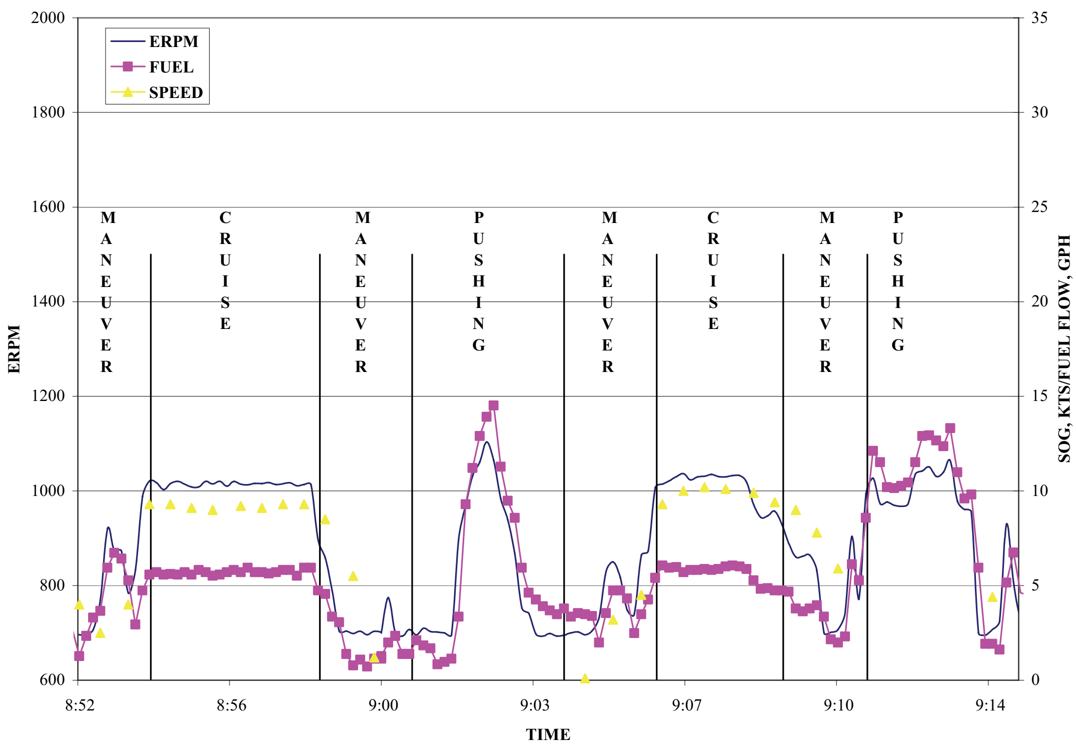


Figure 2.20. MV PORT IMPERIAL MANHATTAN Engine Speed (ERPM), Speed Over Ground (SOG), and Fuel Flow vs. Time.

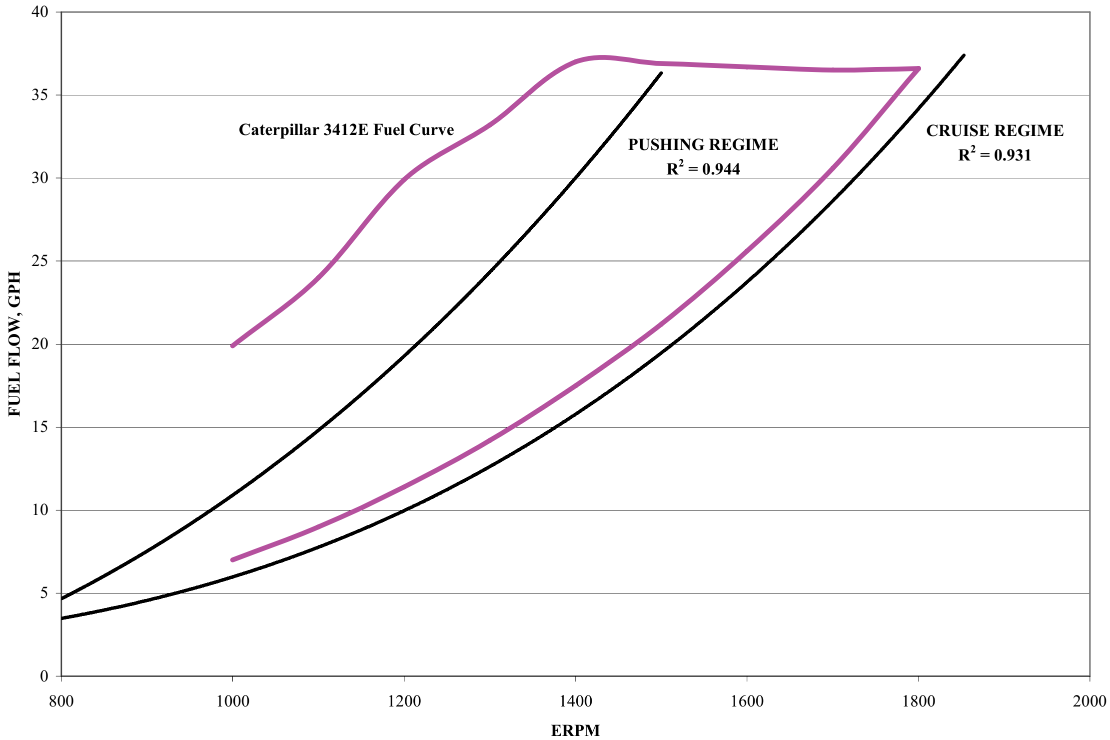


Figure 2.21. MV PORT IMPERIAL MANHATTAN Fuel Flow vs. ERPM.

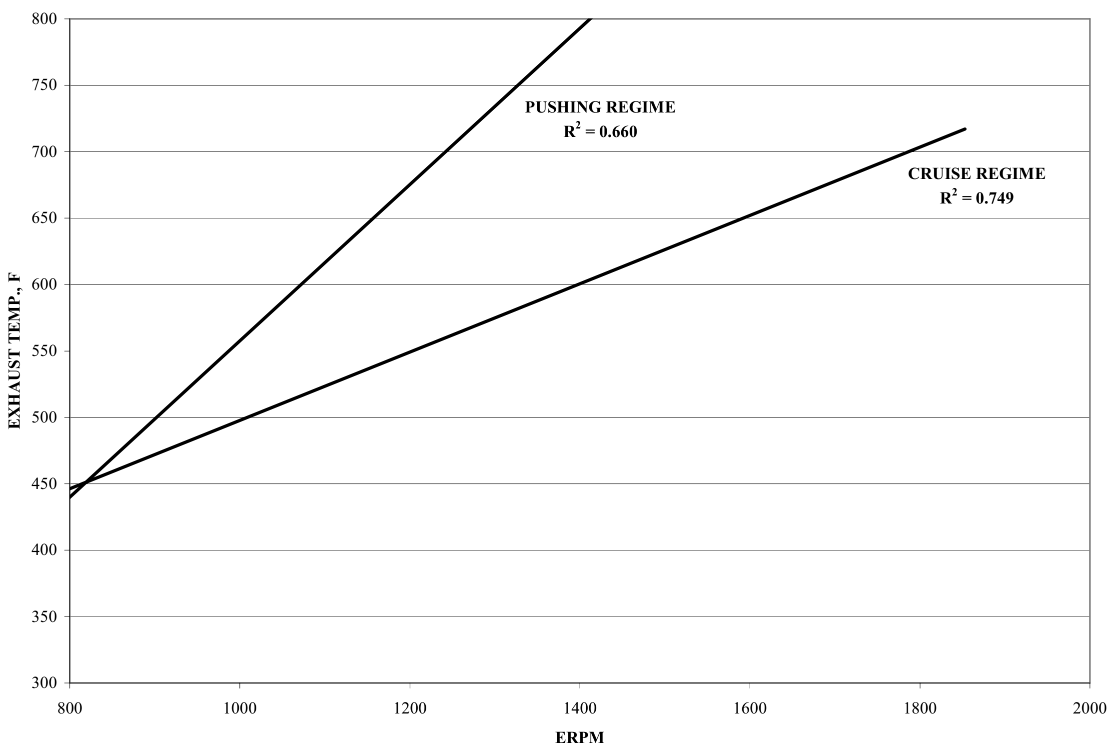


Figure 2.22. MV PORT IMPERIAL MANHATTAN Exhaust Temperature vs. ERPM.

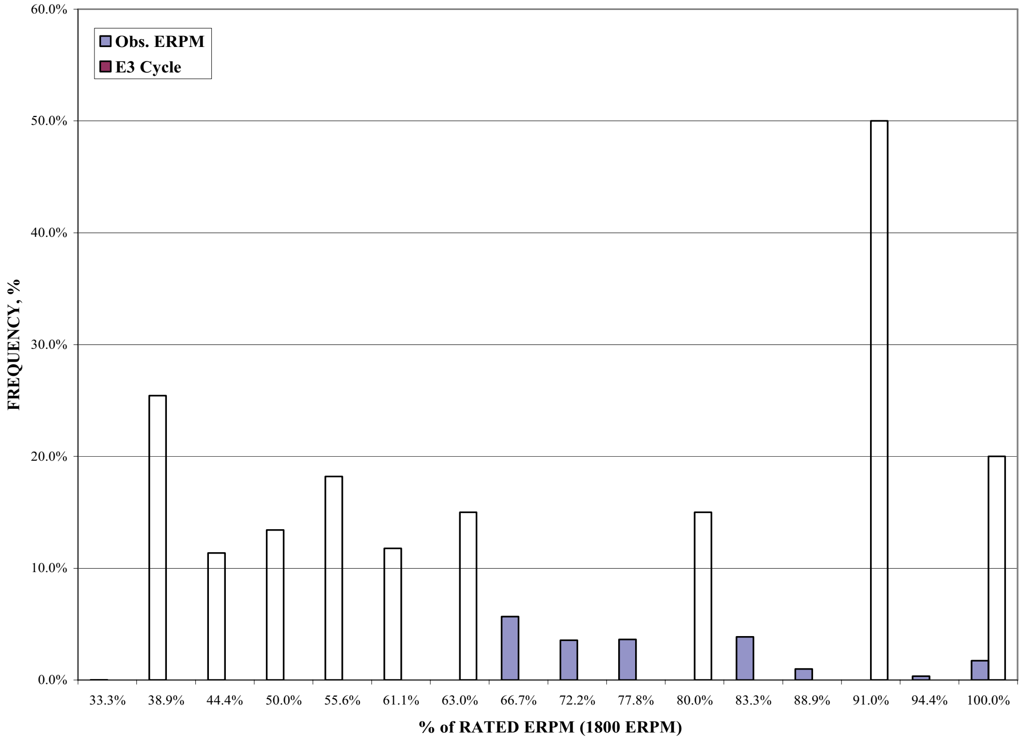


Figure 2.23. MV PORT IMPERIAL MANHATTAN ERPM Histogram

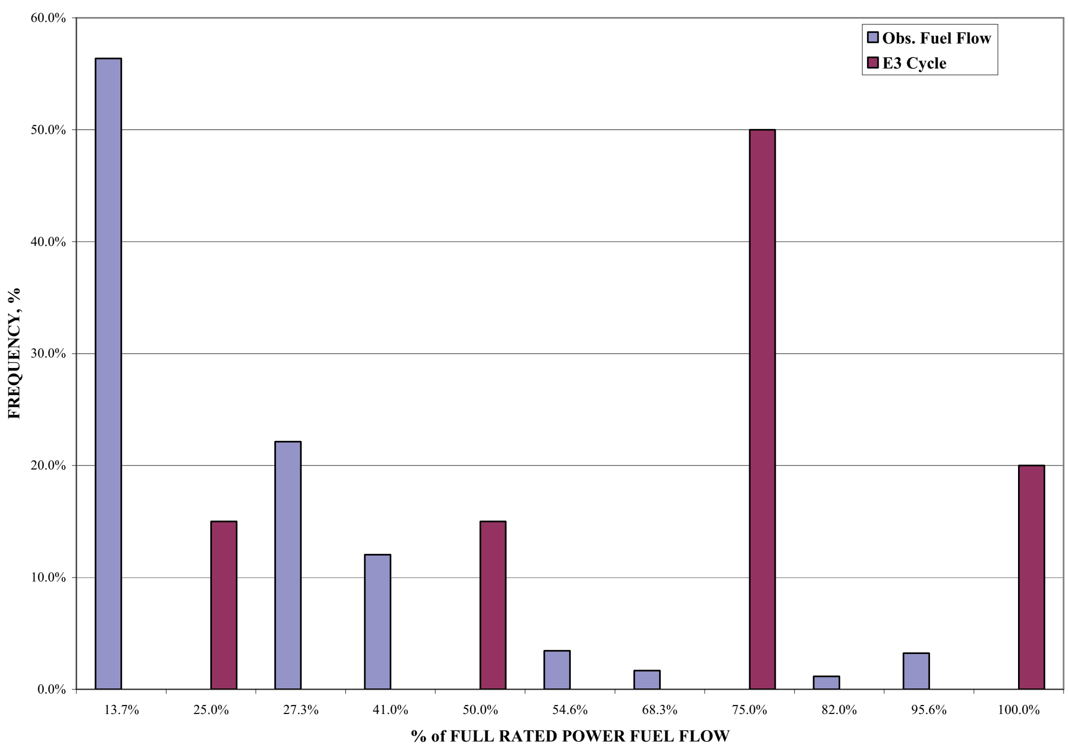


Figure 2.24. MV PORT IMPERIAL MANHATTAN Fuel Flow Histogram

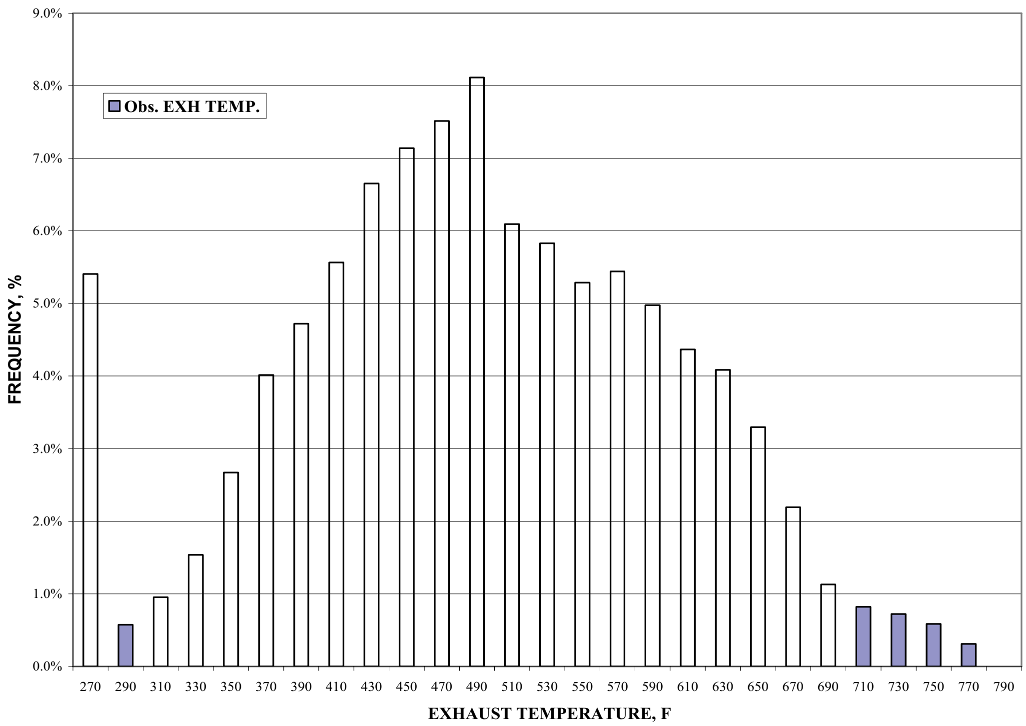


Figure 2.25. MV PORT IMPERIAL MANHATTAN Exhaust Temperature Histogram

Table 2.12. MV PORT IMPERIAL MANHATTAN Baseline Emission Rates February 2004

											PM 10
											[g/gal]
Push	2.41	0.08	101.6	2.91	3.27	9.8	246.1	8.5	10.4	0.30	0.33
Maneuver	1.26	0.04	56.1	2.34	2.48	5.4	233.5	8.0	10.4	0.43	0.46
Cruise	2.16	0.07	101.9	5.59	5.75	9.8	220.8	7.5	10.4	0.57	0.59
Genset	0.17	0.03	9.9	3.43	3.35	1.0	180.2	35.7	10.4	3.61	3.53
OVERALL EMISSION RATES											
Per Engine	2.04	0.07	90.70	3.79	4.02	8.7	233.45	8.02	10.38	0.43	0.46
Total Propulsion	4.08	0.14	181.40	7.58	8.04	17.47					
Per Vessel	4.25	0.17	191.3	11.01	11.39	18.4	230.7	9.4	10.4	0.60	0.62

Medium-Haul Vessels

The MV FATHER MYCHAL JUDGE is a monohull vessel powered by three Caterpillar 3406E engines driving waterjets. Electric power is provided by a 20 kWe Northern Lights generator set. The vessel was originally constructed in 2001. It is capable of carrying in excess of 60 passengers and has a top speed of 32 knots. Figure 2.26 shows the outboard profile of the MV FATHER MYCHAL JUDGE. The physical size and reserve speed of the vessel make it well suited for the Pier 11 to Harborside, NJ, route shown in Figure 2.27, with intermediate stops at Newport and Hoboken. It is also well suited for the NY Waterways Colgate to 38th Street NYC ferry route. The shortest leg for either route is approximately 0.4 NM, and the longest (Colgate to West 38th Street) is approximately 3.4 NM. The round trip times vary from 30 minutes to 1 hour. The stops that comprise the routes change routinely depending on the passenger loading and the number of other vessels that are in operation.

Figure 2.26. MV FATHER MYCHAL JUDGE.

For this testing, the MV FATHER MYCHAL JUDGE was operated on NY Waterway's Pier 11 to Harborside, NJ, ferry route. Normally the vessel began service at 6:00 AM and did not stop, save for crew changes and a midday layover period, until nearly 10:00 PM. During the data logging phase, the vessel averaged approximately 10 hours per day of normal operation. Figure 2.27 shows the GPS vessel track data for the MV FATHER MYCHAL JUDGE while operating on this route.

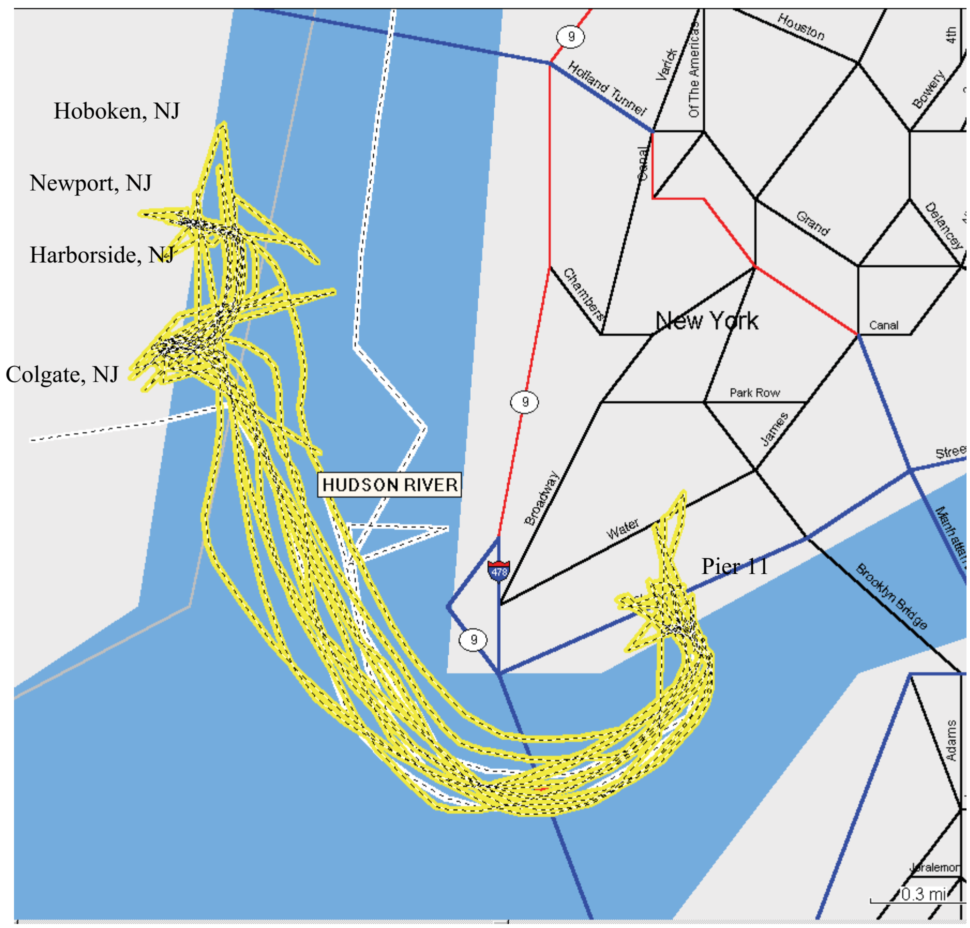


Figure 2.27. MV FATHER MYCHAL JUDGE Route Map.

As with the other vessels, each round trip could be broken into pushing, maneuvering, and cruising modes. The percentage of time the vessel spent operating in each regime is listed in Table 2.13. The total distance that the vessel covered for each round trip was approximately 5.1 NM. The actual time the vessel achieved steady state operation was approximately 10 minutes of each round trip of 30 minutes. During the steady state operation, the vessel achieved speeds above 26 knots. The balance of the round trip was spent either pushing or maneuvering. The short distances between the intermediate stops (approximately 0.5 NM) do not require high-speed operation. On these routes the MV FATHER MYCHAL JUDGE makes numerous speed and direction changes. As noted earlier, when bow-loading vessels dock, a certain amount of propulsive power is used to hold the vessel firmly at the pier face while embarking and disembarking the passengers. The amount of power used in these situations varies depending on the weather conditions and water current.

From the collected data it is possible to determine the operating profile and exhaust emissions of this vessel or any other similarly powered vessel that is placed in this service. The primary type of vessel used on the

NY Waterway medium-haul runs are the small, fast monohulls. These vessels simply do not have the passenger capacity to be employed on high passenger traffic routes (e.g. Weehawken to West 38th Street), but they do have the speed reserve necessary to operate on routes with longer distances between stops.

While the relatively higher exhaust temperatures and the increased amount of time at these temperatures make it possible to utilize a larger variety of emissions technologies, the lack of space in the engine room makes it difficult. Figures 2.28 and 2.29 show how cramped the machinery space is on the vessel. Also, the exhaust system of MV FATHER MYCHAL JUDGE as well as those of the catamaran and other small monohull vessels is a wet type. The wet type exhaust system consists of a large resonance chamber into which the exhaust from the engine is ducted. This chamber or wet muffler is shown in Figure 2.30. A raw water stream from the engine's raw water cooling system is also piped into the exhaust stream before the chamber to cool the exhaust. In this system particulates and other exhaust components mix with the water, and the combined water and gas flow helps to silence the exhaust. From the chamber, the exhaust is directed overboard above the vessel's waterline. The actual space available to fit any after treatment device is approximately 54" high and 30" square. A larger size will have a significant negative impact on ability to service and maintain the engine. The MV FATHER MYCHAL JUDGE is equipped with soft patches that can be removed in the main deck to provide access to the engines. Normal engine servicing requirements are achieved through a 22" personnel access hatch.

Figure 2.28. MV FATHER MYCHAL JUDGE Port Engine Looking Forward.

Figure 2.29. MV FATHER MYCHAL JUDGE Engine Room Aft.

Figure 2.30. MV FATHER MYCHAL JUDGE Wet Muffler.

Tables 2.13 through 2.15 depict the actual operating profile and emissions rate of this vessel. The collected data were modified so that the operating data represents only the time when the main engines were running.

Table 2.13. MV FATHER MYCHAL JUDGE Main Engine Summary (January 13-16, 2004).

Mode	Time, hrs	% of Time	ERPM	Est. BHP	Fuel Flow, GPH	Fuel Temp F	Speed KNOTS	Exh Temp F	ME Exh BP, IWC	Air Manifold Temp, F	Air Manifold Press. PSIG
Push	8.01	34.7	1228.8	N/A	5.5	62.3	0.4	555.5	-1.5	54.1	3.4
Maneuver	6.58	28.5	1088.6	N/A	3.5	63.4	9.3	516.6	-1.3	55.0	2.4
Cruise	8.49	36.8	1914.1	423.4	20.5	62.4	26.5	724.6	3.4	65.0	17.9
All Points	23.1	100	1440.8	N/A	N/A	62.7	17.9	606.6	0.4	58.4	8.5

Table 2.14. MV FATHER MYCHAL JUDGE Diesel Generator Engine Summary.

Mode	DG Fuel Flow, GPH	DG Load, kWe	DG Exhaust Temp, F	DG Exhaust Pressure, IWC
Pushing	0.9	9.1	NA	NA
Maneuvering	0.9	9.1	NA	NA
Cruising	1.0	10.1	NA	NA
All Points	0.9	9.7	NA	NA

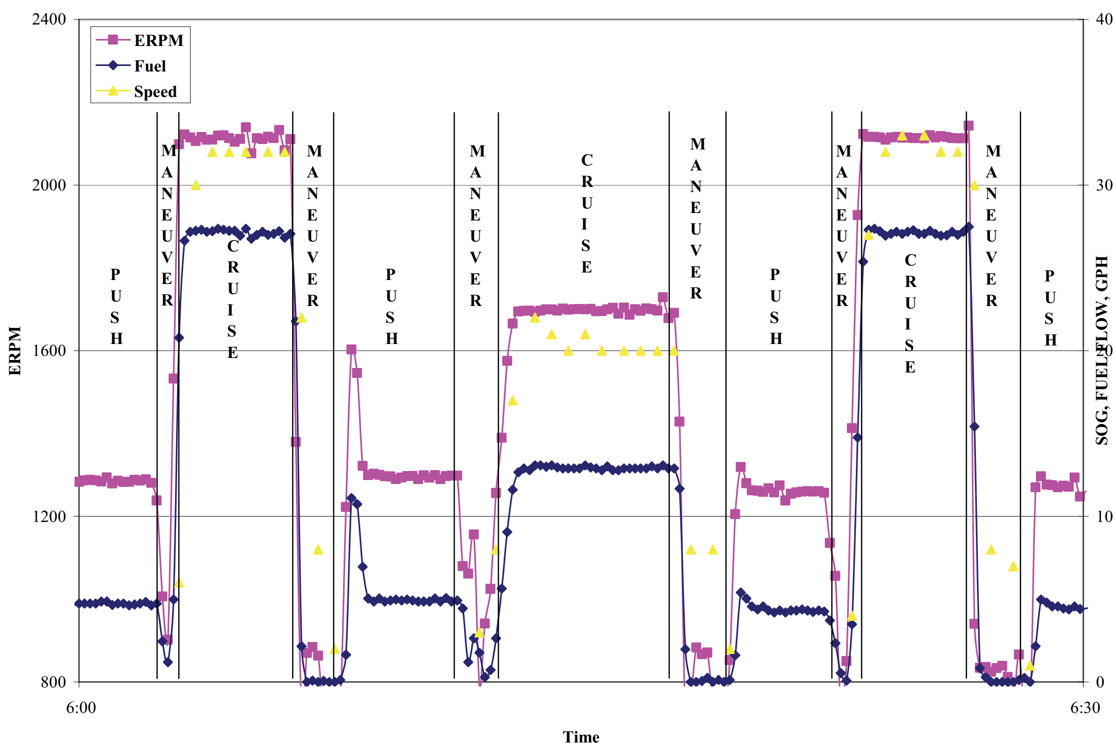


Figure 2.31. MV FATHER MYCHAL JUDGE ERPM, Fuel Flow, and SOG vs. Time.

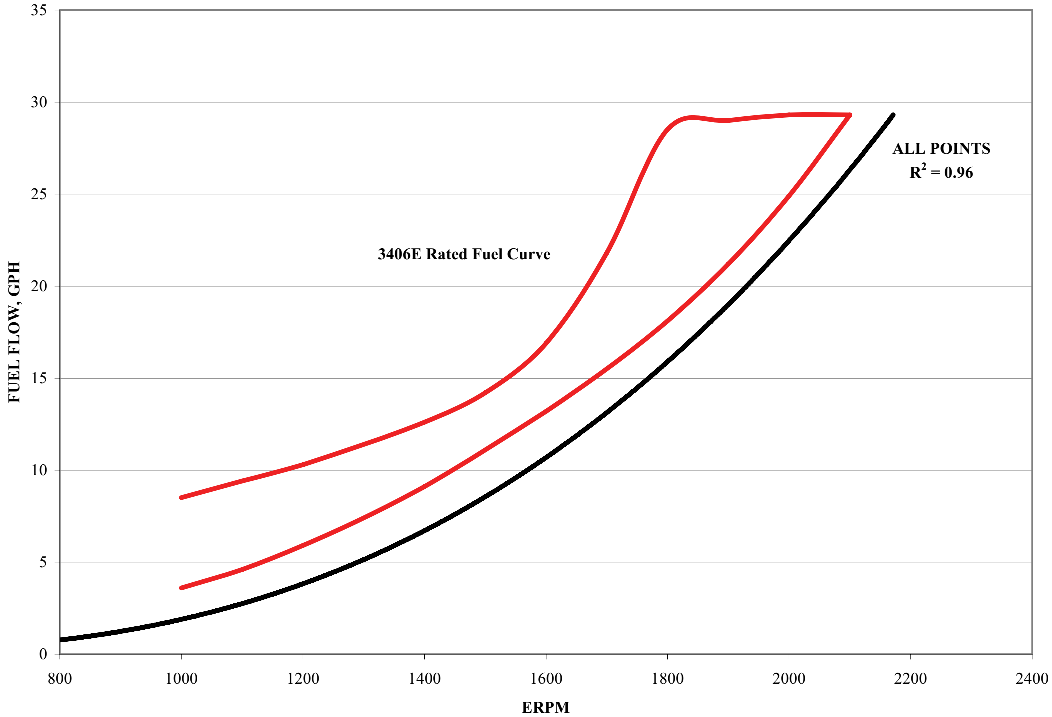


Figure 2.32. MV FATHER MYCHAL JUDGE Fuel Flow vs. ERPM.

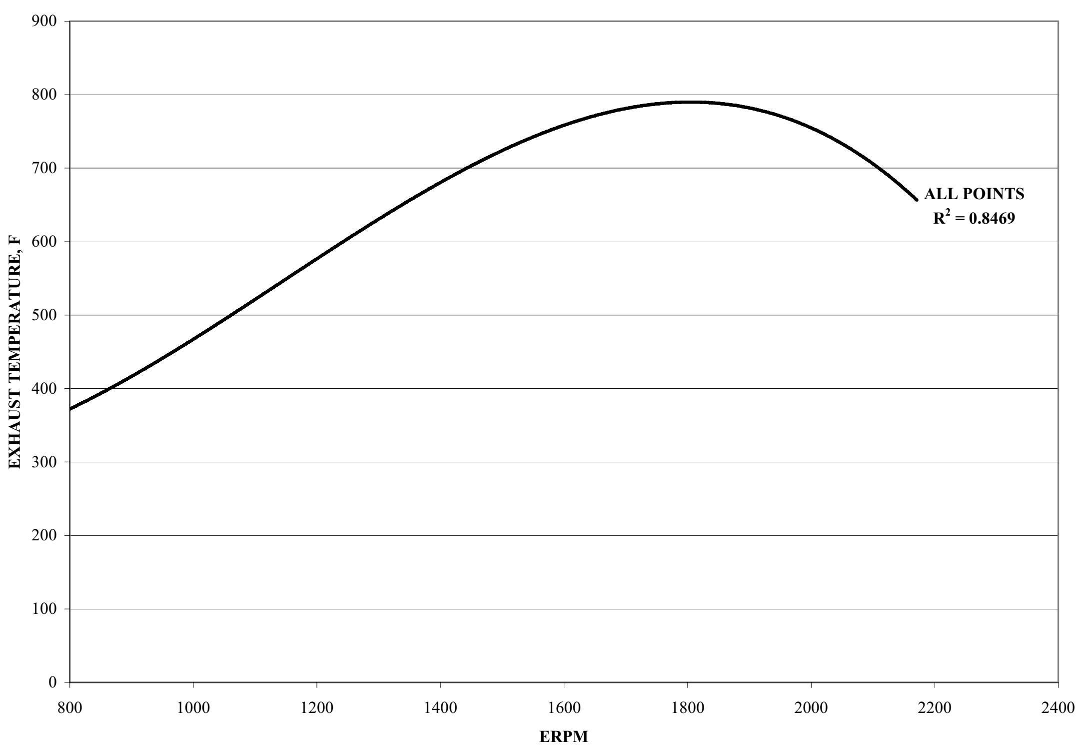


Figure 2.33. MV FATHER MYCHAL JUDGE Exhaust Temperature vs. ERPM.

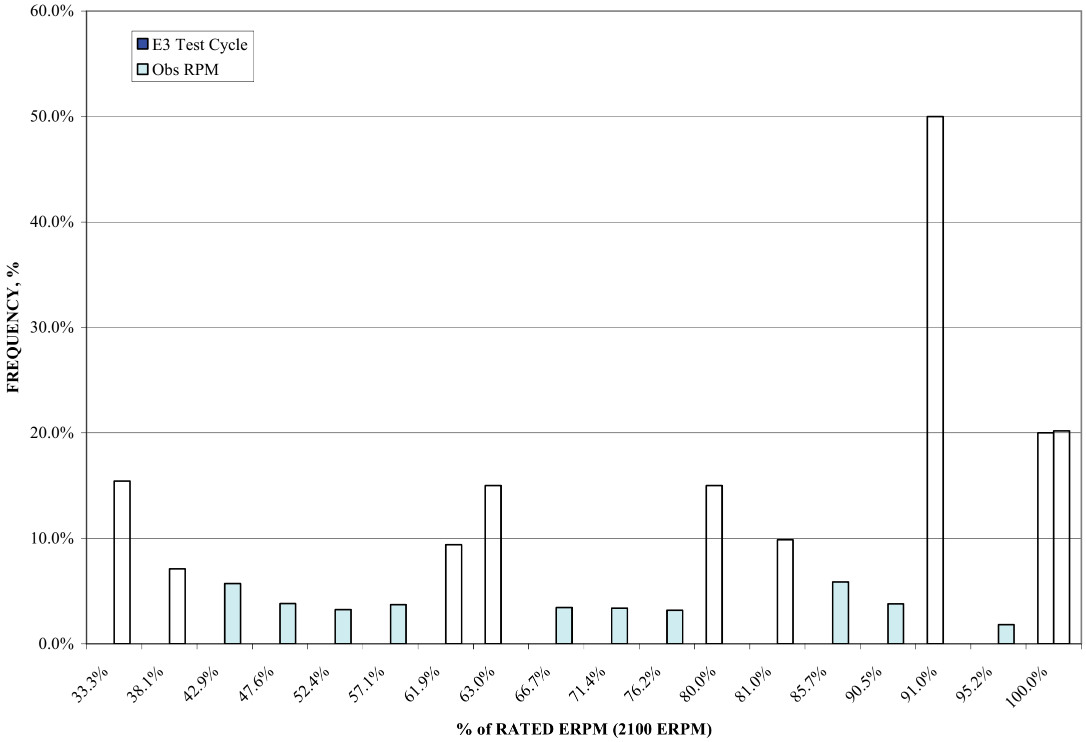


Figure 2.34. MV FATHER MYCHAL JUDGE ERPM Histogram.

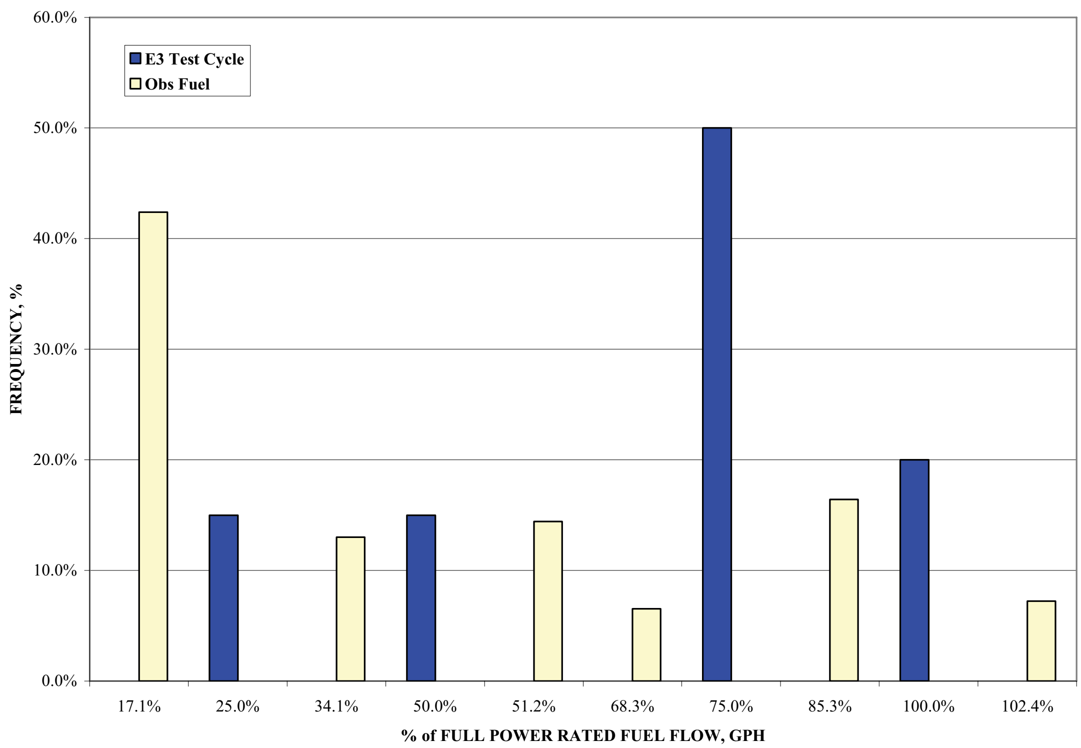


Figure 2.35. MV FATHER MYCHAL JUDGE Fuel Flow Histogram.

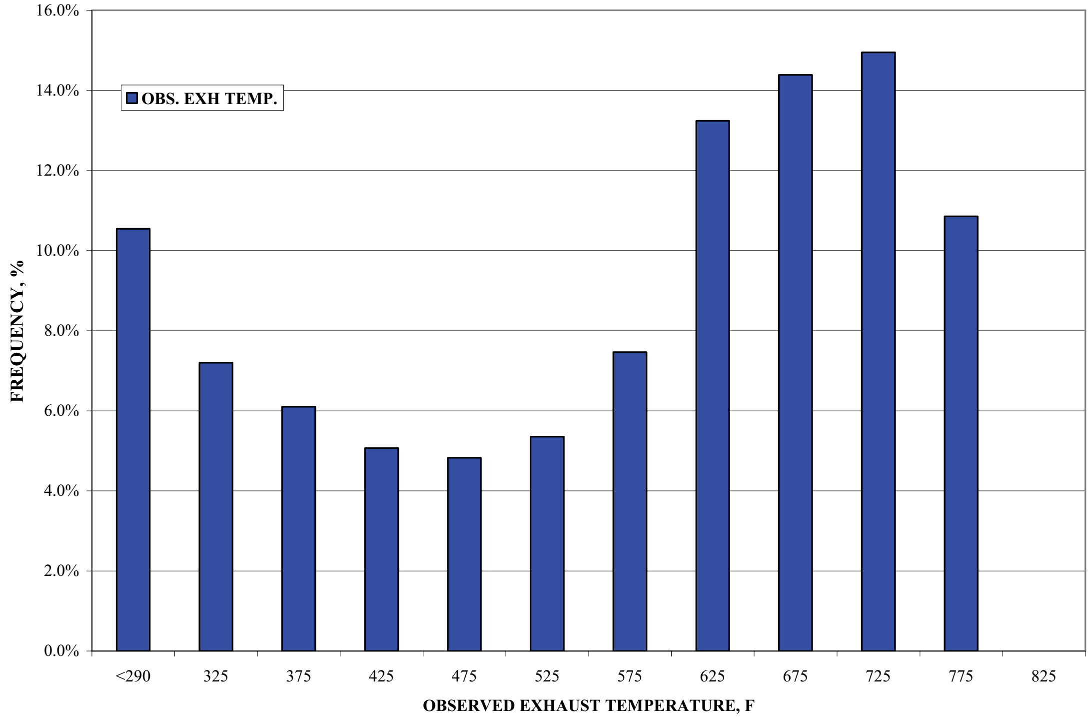


Figure 2.36. MV FATHER MYCHAL JUDGE Exhaust Temperature Histogram.

Table 2.15. MV FATHER MYCHAL JUDGE Baseline Emission Rates (February 2004).

											PM 10
						gal/hr	[g/gal]				[g/gal]
Push	1.72	0.07	57.2	7.26	6.99	5.5	312.3	12.8	10.4	1.32	1.27
Maneuver	2.68	0.35	126.2	23.06	21.47	3.5	237.4	15.7	10.4	1.50	1.36
Cruise	3.33	0.38	213.2	34.54	29.73	20.5	162.5	18.7	10.4	1.69	1.45
OVERALL EMISSION RATE											
Per Engine	2.59	0.26	134.3	21.80	19.48	10.5	247.5	25.2	12.8	2.09	1.86
Per Vessel	7.76	0.79	402.8	65.41	58.44	31.4					

A second medium-haul vessel was included in this study. The MV ED ROGOWSKY is a catamaran vessel powered by two Detroit Diesel Series 60 engines driving conventional propellers through a gearbox. It is shown in Figure 2.37. Electric power is provided by a single 20-kWe Northern Lights diesel generator set. The MV ED ROGOWSKY was constructed in 2003 and is capable of carrying in excess of 60 passengers at a top speed of 25 knots. While the physical size and reserve speed make this vessel well suited for water taxi service, it is also considered a medium-haul vessel for the purposes of this study. The service route ranges from E 90th Street to W 44th Street, NY, with stops at Hunter's Point, E 34th Street, Fulton Ferry Landing, Pier 11, Whitehall, Battery Park, W 23rd Street and the Brooklyn Army Terminal. The distances between the stops range from 0.5 NM to 4 NM. The round-trip times vary because the vessel does not typically complete a closed circuit during the entire time it is in operation. During the data logging phase, the vessel ran on intermediate short loops on one side of Manhattan or the other, and then it occasionally made runs from one side of the island to the other. The round trip times ranged from 30 minutes to 1.5 hours depending upon the number of stops and length of time spent at each stop.

Figure 2.37. MV MICKEY MURPHY, Sister Vessel to MV ED ROGOWSKY.

For the duration of the testing the MV ED ROGOWSKY was operated on the same ferry route. All vessels in the NY Water Taxi fleet are sister ships with identical hull and machinery systems. Normally the vessel began service at 6:00 AM and did not stop, save for crew changes and a midday rest period, until nearly 8:00 PM. During the data logging phase, the vessel averaged approximately 9 hours per day of normal operation. Figure 2.38 depicts the range of operation for the vessel.

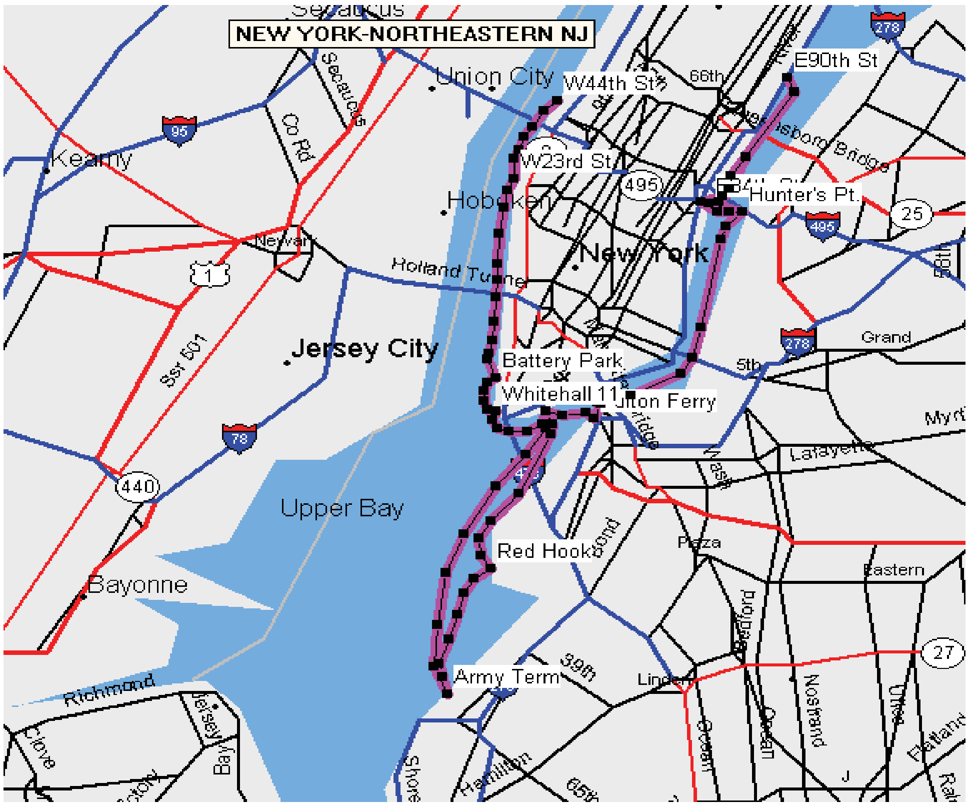


Figure 2.38. MV ED ROGOWSKY Route Map.

As with the other vessels, each round trip could be broken into three (3) discreet propulsion modes: pushing, maneuvering, and cruising. The percentage of time the vessel spent operating in each regime is listed in the Table 2.16. The distance covered by the MV ED ROGOWSKY for each round trip was approximately 5.1 NM. The actual time the vessel achieved steady state operation was approximately 10 minutes out of each 30-minute round trip. Based upon the GPS data received from the operator, the vessel achieved an average speed of 11 knots. However, during the steady state operation emissions tests the vessel achieved speeds above 20 knots at the same engine speeds. This discrepancy can probably be found in the calculations performed by the vessel tracking GPS system because the calculated speeds, when using the recorded times and positions, are in line with those that were recorded during the emissions tests. The balance of the time the vessel was either pushing or maneuvering, and there were numerous speed and direction changes. The short distances between many of the intermediate stops (approximately 0.5 NM) did not require high speed operation. As a bow-loading vessel, the MV ED ROGOWSKY applied propulsive power to hold the vessel to the dock while embarking and disembarking the passengers. From the collected data it was possible to determine the operating profile and exhaust emissions of this vessel.

Figure 2.39. MV ED ROGOWSKY Engine Room Looking Aft.

The low exhaust temperatures logged by the MV ED ROGOWSKY make it challenging to incorporate a number of emissions reduction technologies. The situation is compounded by the fact that the engine room is very cramped (see Figures 2.39 and 2.40). The exhaust system of this vessel is a dry type that ducts exhaust directly from the turbocharger outlet to the silencer and then out through an opening in the ship's side. The system is very short and compact. The actual space available within which to fit any after treatment device is approximately 54" high and 24" square. A larger size would significantly impair the ability of personnel to access the engine for maintenance and service. There are no soft patches that could be removed in the main deck. Normal engine servicing requirements are achieved through a 22" personnel access hatch.

Figures 2.41 through 2.45 and Tables 2.16 through 2.18 depict the actual operating profile and emissions rate of this vessel. The collected data were modified so that the operating data represents only the time when the main engines were running.

Figure 2.40. MV ED ROGOWSKY Engine Room Looking Forward.

Table 2.16. MV ED ROGOWSKY Main Engine Summary (January 16-22, 2004).

Mode	Time, hrs	% of Time	ERPM	Est. BHP	Fuel Flow, GPH	Fuel Temp F	Speed KNOTS	Exh Temp F	ME Exh BP, IWC	Air Mani. Temp, F	Air Mani. Press. PSIG
Pushing	11.4	45.0	856.1	N/A	5.0	40.5	0.1	NA	NA	40.1	3.3
Maneuvering	3.72	14.7	1019.7	N/A	6.8	39.8	0.0	NA	NA	41.2	4.1
Cruising	10.2	40.3	1893.5	473.5	22.4	39.2	11.1	547.3	NA	49.2	24.6
All Points	25.3	100.0	1298.3	N/A	12.3	39.9	8.7	NA	NA	43.9	12.0

Table 2.17. MV ED ROGOWSKY Diesel Generator Engine Summary.

Mode	DG Fuel Flow, GPH	DG Load, kWe	DG Exhaust Temp, F	DG Exhaust Pressure, IWC
Pushing	0.8	8.8	NA	NA
Maneuvering	0.8	9.0	NA	NA
Cruising	0.8	9.9	NA	NA
All Points	0.8	9.3	NA	NA

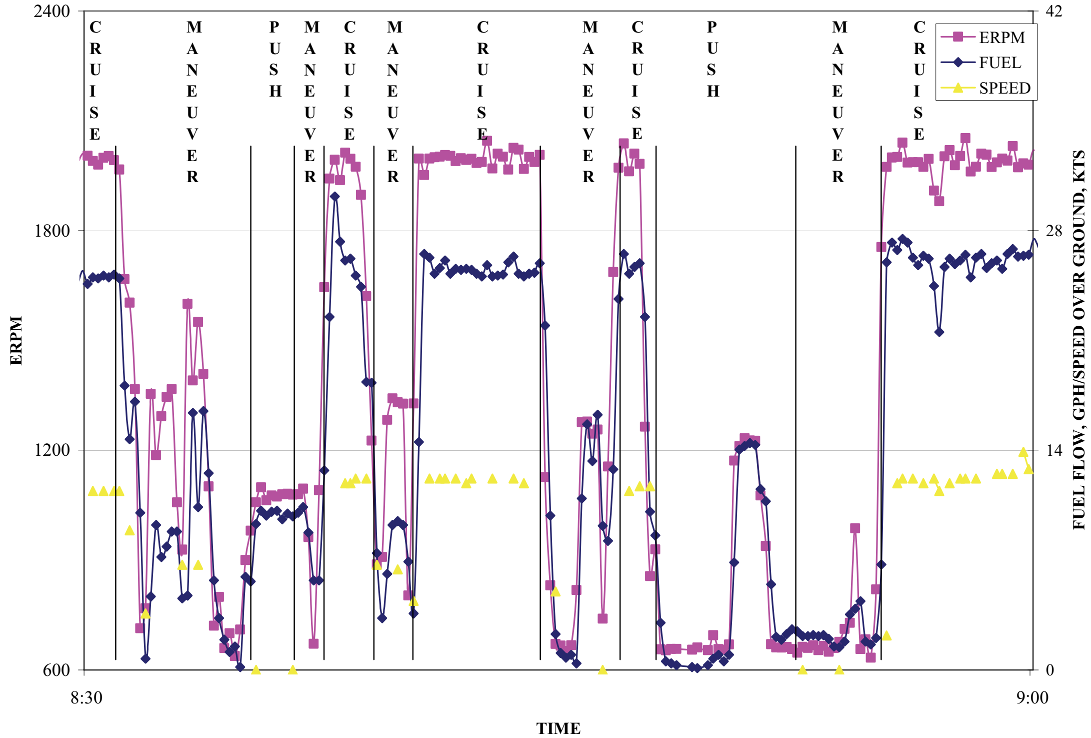


Figure 2.41. MV ED ROGOWSKY ERPM, Fuel Flow, and SOG vs. Time.

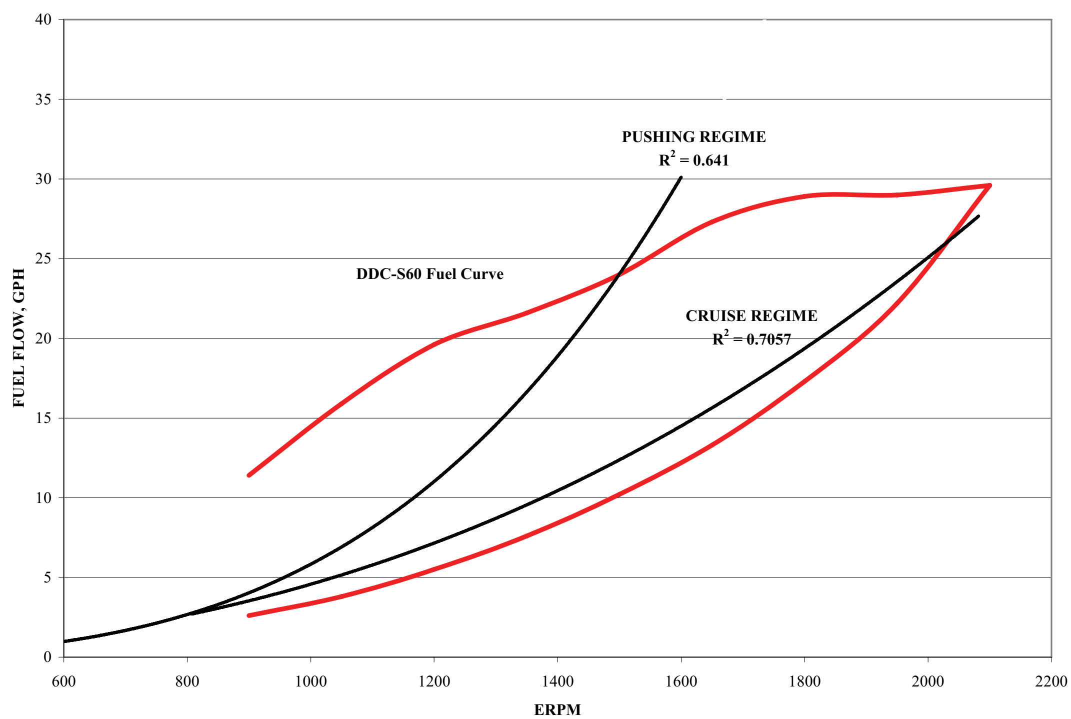


Figure 2.42. MV ED ROGOWSKY Fuel Flow vs. ERPM.

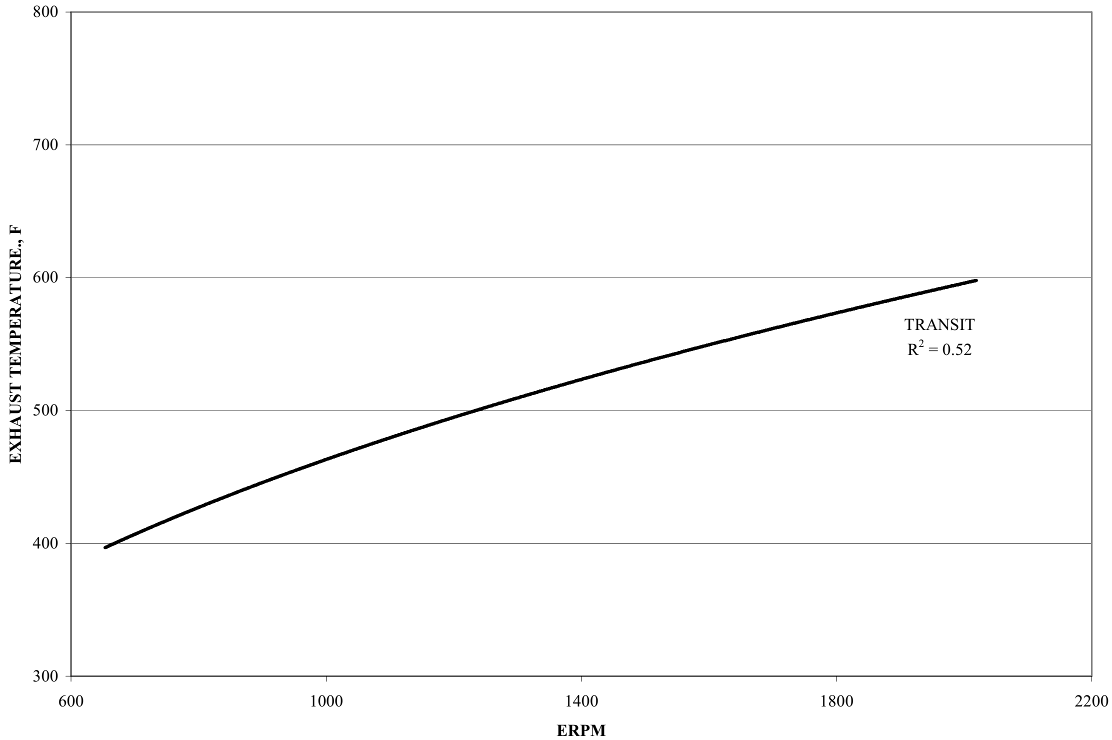


Figure 2.43. MV ED ROGOWSKY Exhaust Temperature vs. ERPM.

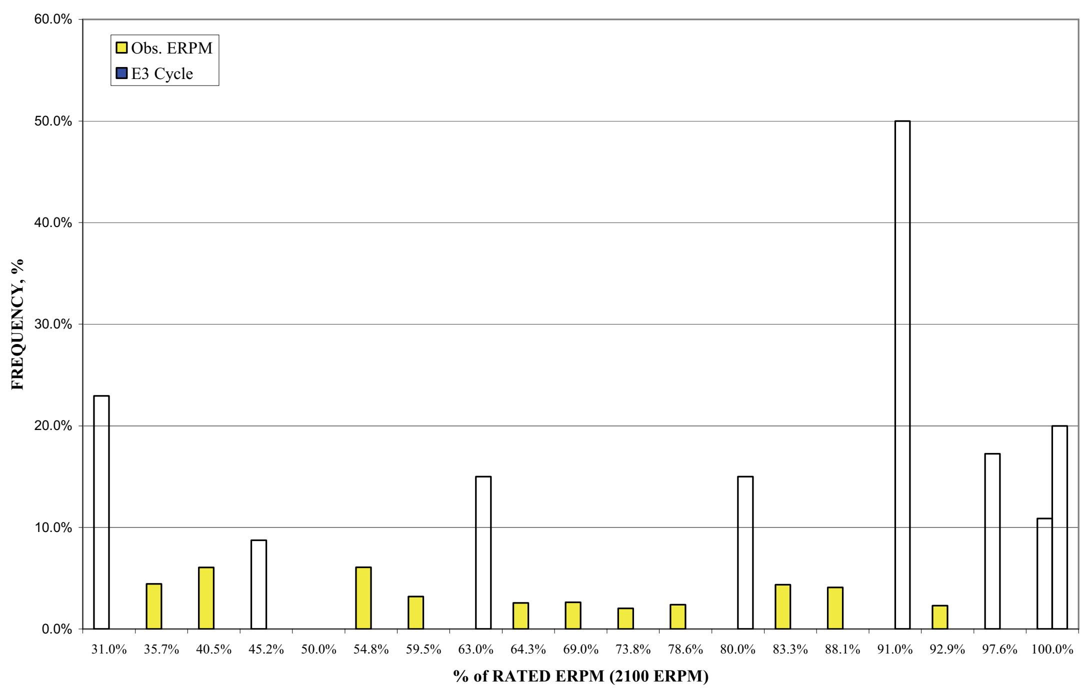


Figure 2.44. MV ED ROGOWSKY ERPM Histogram.

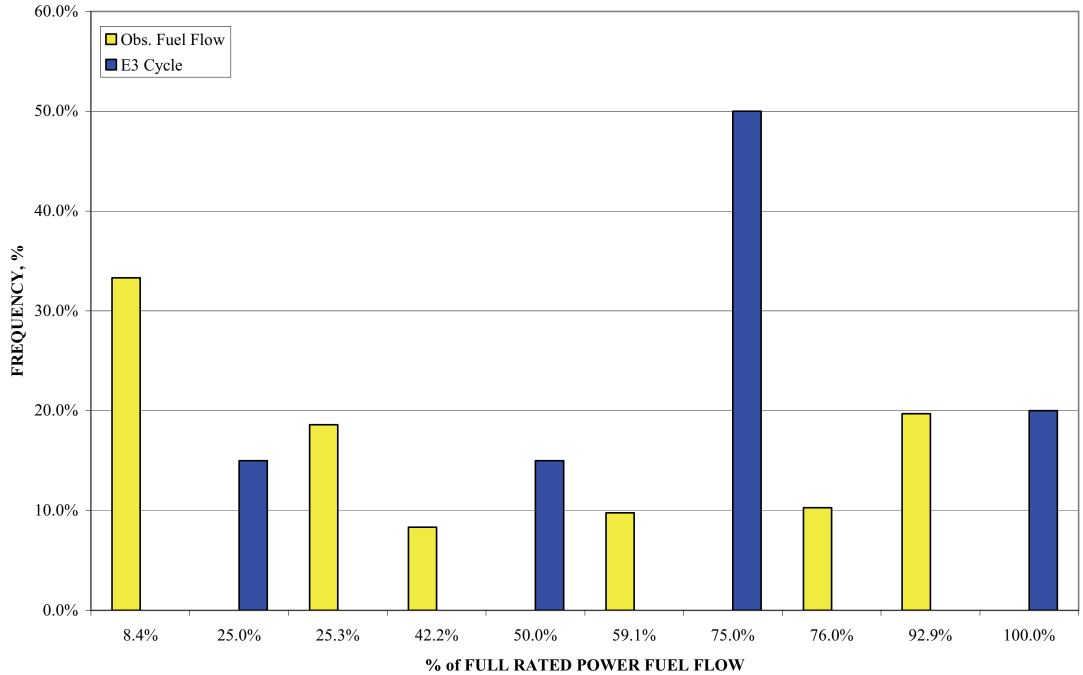


Figure 2.45. MV ED ROGOWSKY Fuel Flow Histogram.

Table 2.18. MV ED ROGOWSKY Baseline Emission Rate February 2004

						gal/hr	[g/gal]				PM 10 [g/gal]
Push	0.79	0.49	50.5	6.82	6.27	5.00	158	97.1	10.1	1.36	1.25
Maneuver	0.98	0.38	69.2	13.65	12.80	6.80	144	55.8	10.2	2.01	1.88
Cruise	2.89	0.33	230.0	59.40	56.26	22.40	129	14.5	10.3	2.65	2.51
Genset	0.05	0.02	8.2	3.10	3.39	0.80	67	26.7	10.2	3.87	4.24
OVERALL EMISSION RATE										
Per Engine	1.66	0.41	125.6	29.01	27.38	12.28	135.5	33.0	10.2	2.36	2.23
Total Propulsion	3.33	0.81	251.2	58.02	54.75	24.55					
Per Vessel	3.38	0.83	259.3	61.12	58.14	25.35	133.3	32.8	10.2	2.41	2.29

Long-Haul Vessel

The MV SEASTREAK WALL STREET, shown in Figure 2.46, is a catamaran hull vessel powered by four Cummins KTA50 M2 engines driving waterjets. Electric power is provided by two 65 kWe Cummins 6 BT 5.9 generator sets. The vessel was originally constructed in 2003 and is capable of carrying 400 passengers at a top speed of over 35 knots. These characteristics make it well suited for the Pier 11 to the NJ Highlands route shown in Figure 2.47, with intermediate stops at E. 34th Street. The shortest leg of its route is approximately 0.4 NM and the longest (Pier 11 to the N.J. Highlands) is approximately 22 NM. The round trip voyages are approximately 2 hours. The vessel does not operate on weekends and has a layover period between the hours of 10:00 AM and 1:00 PM during each day of normal operation.

Figure 2.46. MV SEASTREAK WALL STREET.

For this testing the MV SEASTREAK WALL STREET was operated on SeaStreak America's Pier 11 to the N.J. Highlands ferry route (see Figure 2.47). Normally the vessel began service at 6:00 AM and did not stop (except for the midday layover) until nearly 8:00 PM. During the data logging phase, the vessel averaged approximately 10 hours per day of normal operation.

Each round trip was made up of three distinct modes: pushing, maneuvering, and cruising. The percentage of time the vessel spent operating in each mode is listed in Tables 2.19 and 2.20. The distance that the vessel covered for each round trip was approximately 45 NM. The actual time the vessel achieved steady state operation was approximately 80 minutes out of each 120-minute round trip. During the steady state operation, the vessel achieved speeds above 35 knots; during the balance of the time it was either pushing or maneuvering. The short distances between the intermediate stops (approximately 0.5 NM) did not require high-speed operation. The MV SEASTREAK WALL STREET is normally used as a bow-loading ferry, but it is also capable of receiving passengers from the sides. When the vessel docks bow in, factors such as the weather conditions or current will determine the amount of propulsive power necessary to hold the vessel to the face of the pier while embarking and disembarking the passengers. (Side docking vessels use less propulsion; the engines are in idle mode.)

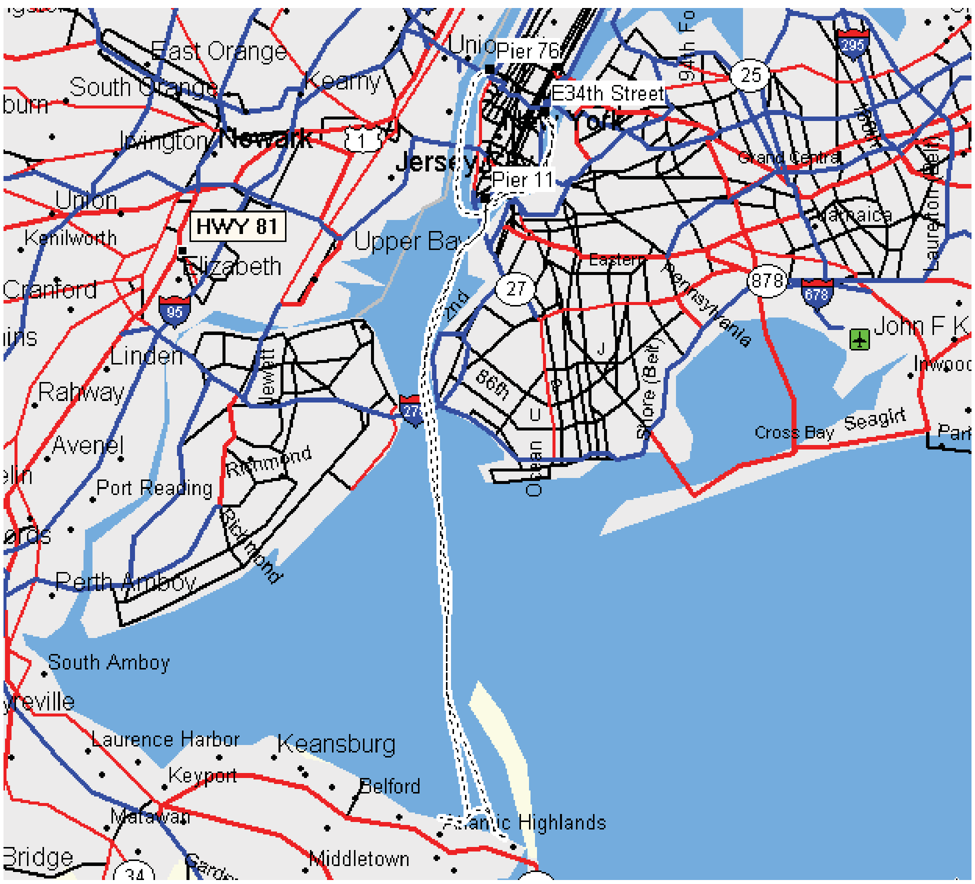


Figure 2.47. MV SEASTREAK WALL STREET Route Map.

From the collected data it is possible to determine the operating profile and exhaust emissions of the MV SEASTREAK WALL STREET or any other similarly powered vessel that is placed into this service. These vessels, because of their somewhat large size and high levels of installed propulsion power, are ill suited for all but the long-haul runs.

Figure 2.48. MV SEASTREAK NEW YORK sister vessel to MV SEASTREAK WALL STREET Aft Engine.

This vessel's relatively high exhaust temperatures and the significant amount of overall time at these temperatures permit the consideration of a number of emissions reduction technologies. However, as with the other vessels, the engine room space on the MV SEASTREAK WALL STREET is very cramped. Each catamaran hull contains two propulsion engines and a generator set. The width of each hull limits personnel access to only one side of each engine. Figures 2.48 and 2.49 show the compact nature of this situation. The exhaust system is a dry type consisting of a large resonance chamber into which the exhaust from the engine is ducted. From the chamber the exhaust is routed through the waterjet room and then directed overboard above the vessel's waterline. The actual space available to fit any after treatment device (less the required exhaust ducting) within this compartment is approximately 65" in length and 30" square. A larger size emissions device will significantly impair the ability to service and maintain the engines. There are also concerns about the potential need for installation of an excessive amount of exhaust ductwork above that already in place. The MV SEASTREAK WALL STREET is equipped with soft patches that can be removed in the main deck to access the engines. However, the construction of the vessel is such that the superstructure is isolated from each catamaran hull, and a portion of the superstructure deck must be removed to access the soft patches. Normal engine servicing requirements are achieved through two 22” personnel access hatches.

Figure 2.49. MV SEASTREAK NEW YORK sister vessel to MV SEASTREAK WALL STREET Forward Engine.

Figures 2.50 through 2.54 and Tables 2.19 through 2.21 depict the actual operating profile and emission rate of this vessel. The collected data were modified so that the operating data represents only the time when the main engines were running.

Table 2.19. MV SEASTREAK WALL STREET Main Engine Summary (January 12-16, 2004).

Mode	Hours	% of Time	Avg RPM	Est. BHP	ME Fuel Flow, GPH	ME Fuel Temp F	Speed, mph	ME Exh Temp*	ME Exh Press., PSIG	ME Int Manifold Pressure, PSIG	ME Int Manifold Temp, F
Push	14.1	26.9	753	NA	6.2	64.8	NA	554	NA	1.9	141.8
Maneuver	11.9	31.8	1230	NA	29.4	64.4	NA	639	NA	9.1	142.8
Cruise	18.3	41.2	1896	1636	79.9	64.3	38.5	786	NA	28.3	159.1
All Points	44.3	100.0	1366	NA	43.7	64.5	38.5	664	NA	15.0	149.4

* From Baseline Emissions Test

Table 2.20. MV SEASTREAK WALL STREET Diesel Generator Engine Summary.

	DG Int Manifold Press., PSIG	DG Int Manifold Temp., F	DG Fuel Flow, GPH	DG Load, kWe	DG Exhaust Temp, F
Push	4.7	100.5	3.7	46.6	528.7
Maneuver	4.7	101.4	3.7	46.6	528.7
Cruise	4.7	100.2	3.7	46.6	528.7
All Points	4.7	100.6	3.7	46.6	528.7

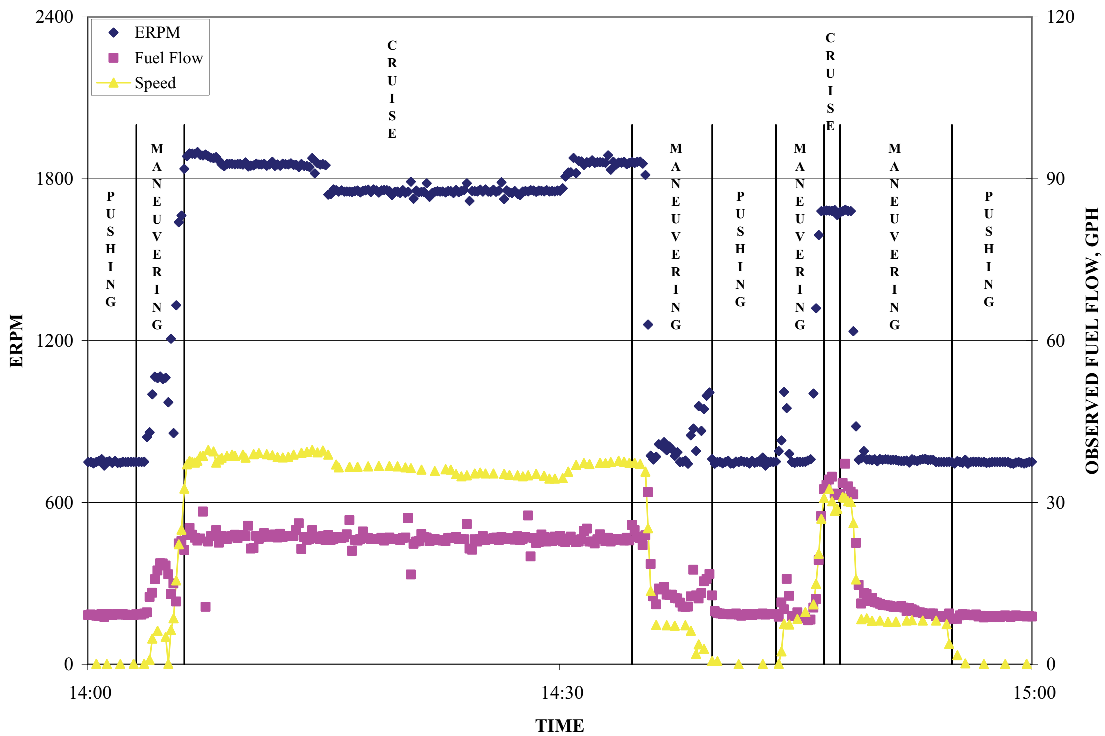


Figure 2.50. MV SEASTREAK WALL STREET ERPM, Fuel Flow, and SOG vs. Time.

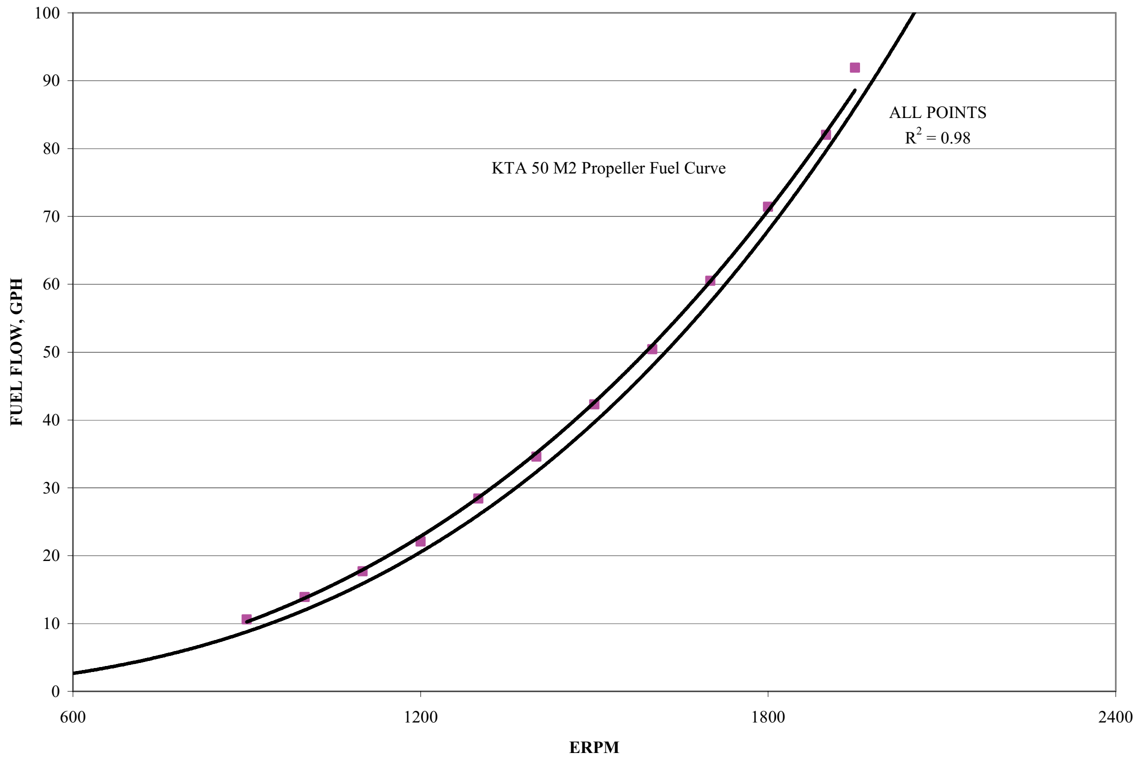


Figure 2.51. MV SEASTREAK WALL STREET Fuel Flow vs. ERPM.

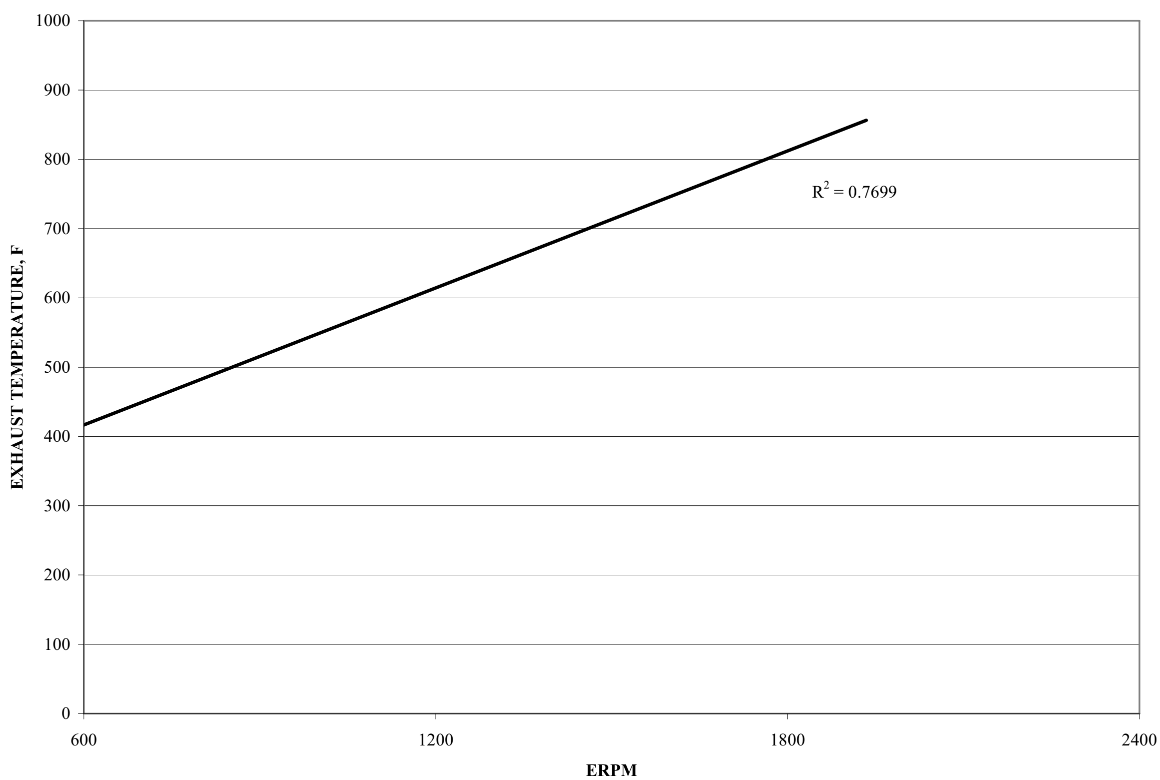


Figure 2.52. MV SEASTREAK WALL STREET Exhaust Temperature vs. ERPM.

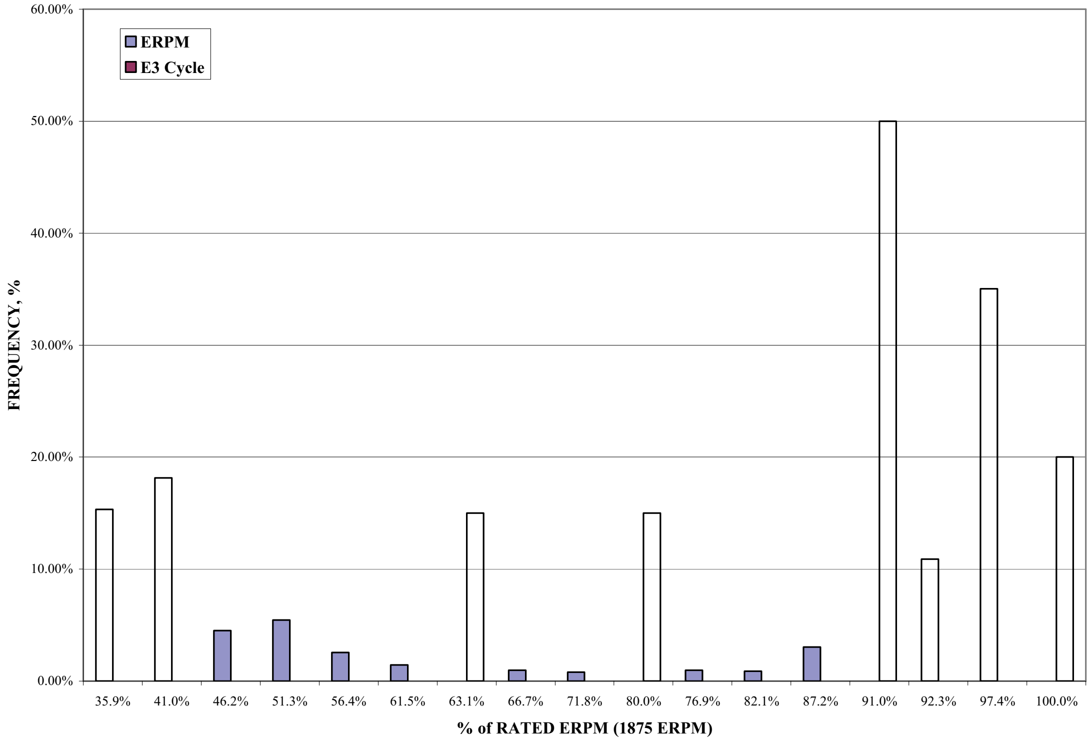


Figure 2.53. MV SEASTREAK WALL STREET ERPM Histogram.

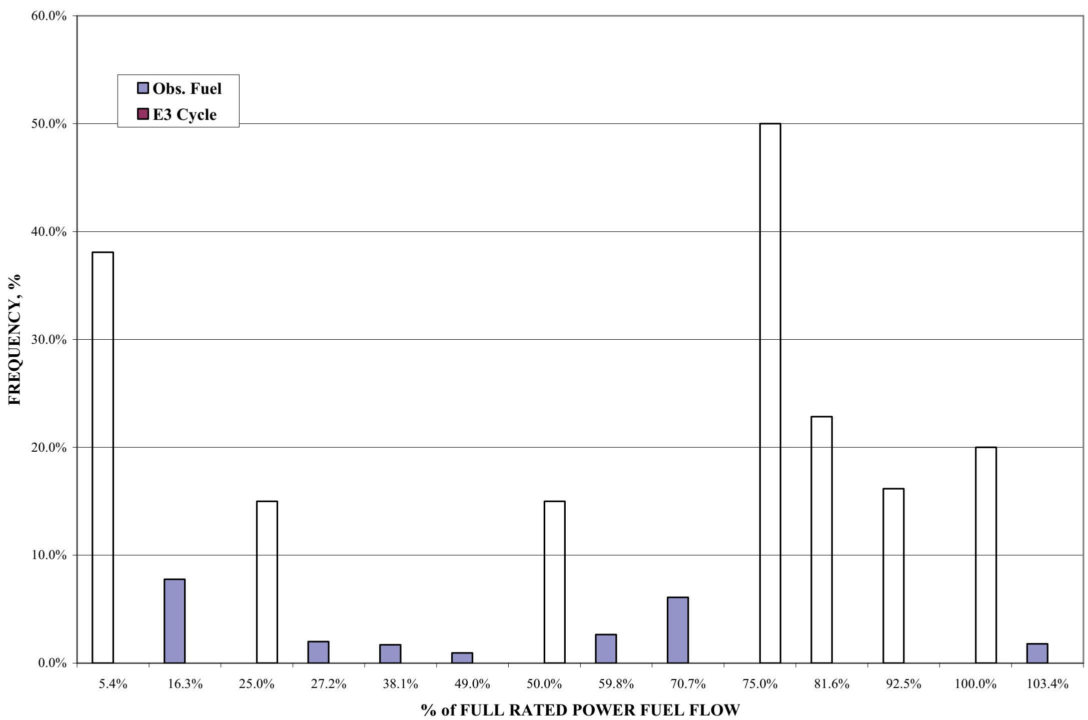


Figure 2.54 MV SEASTREAK WALL STREET Fuel Flow Histogram.

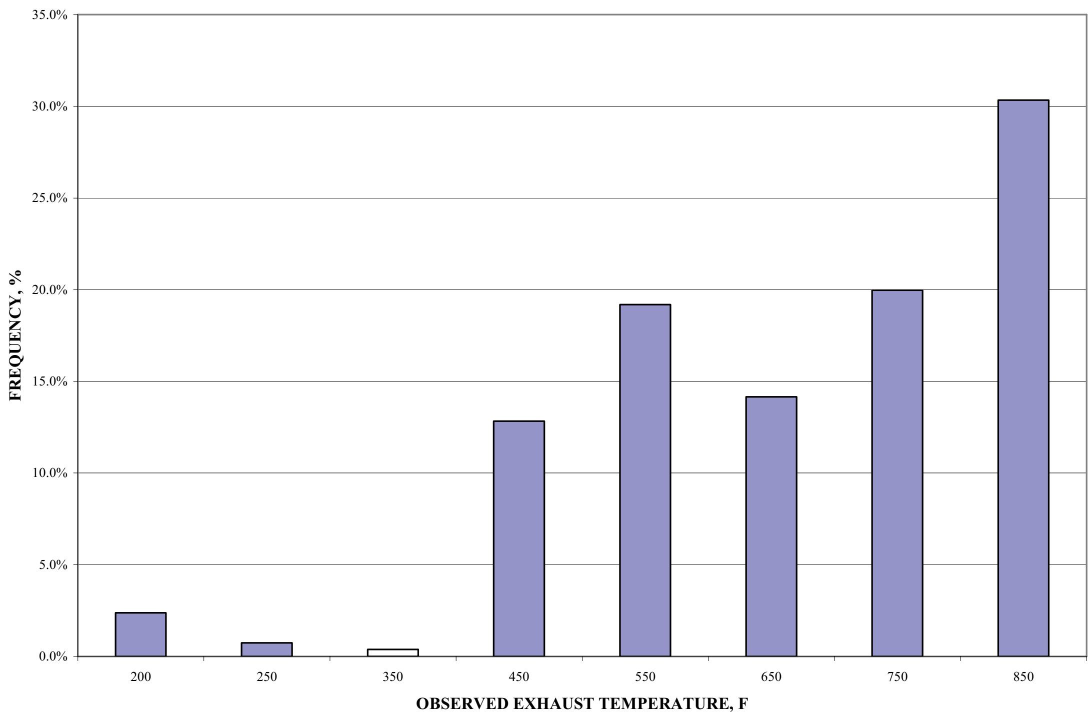


Figure 2.55. MV SEASTREAK WALL STREET Exhaust Temperature Histogram.

Table 2.21. MV SEASTREAK WALL STREET Baseline Emission Rates (February 2004).

											PM 10
						gal/hr	**[g/gal]**				**[g/gal]**
Push	0.65	0.09	61.4	18.2	17.5	6.2	104.33	15.13	9.90	2.94	2.82
Maneuver	3.19	0.47	291.1	62.7	60.8	29.4	108.67	16.10	9.90	2.13	2.07
Cruise	9.03	1.36	791.0	106.3	105.2	79.9	113.00	17.07	9.90	1.33	1.32
Genset	0.14	0.28	39.0	71.4	69.6	3.98	34.00	70.60	9.80	17.95	17.49
OVERALL EMISSION RATE											
Per Engine	4.9	0.74	435.0	68.6	67.4	43.9	108.14	15.98	9.90	2.23	2.16
Total Propulsion	19.6	2.95	1739.9	274.5	269.5	175.7					
Per Vessel	19.8	3.23	1778.9	345.9	339.1	179.7	110.03	17.98	9.90	1.92	1.89

NYC HARBOR PRIVATE FERRY FLEET EMISSIONS

In order to calculate overall fleet emissions for the entire NYC harbor, a set of spreadsheets was developed utilizing the calculated emission rates for the representative vessels. Each representative ferry vessel's emission rate was applied to the routes taken from each operator's published route schedules. The ferry vessels were selected for each route based on their applicability to long-, intermediate-, or short-haul usage and propulsion system commonality. The spreadsheets are capable of being manipulated as ferry routes, schedules, and vessels change in response to the operators' needs.

Initially the emissions were derived from the results of the baseline emissions test conducted during the initial LSD fuel test. The emission rates were calculated by first testing each of the targeted vessels at its dominant load points and then determining its emissions as mass per volume of fuel consumed. From the data logging results in this task, the average fuel flow and percentage of time a vessel spent at each operating mode were determined. Multiplying the fuel flow times the emission per volume of fuel times the percentage of time in each mode resulted in a time-based emission rate for each mode. The rates for each mode were then added and multiplied by the hours of operation for each vessel to obtain an annual emission rate. [These calculations were repeated for each emissions constituent.]

Fuel Flow(GPH@cruise) x g (NO_X@cruise)/gal x % time at cruise = g/hr NO_X (cruise)
Fuel Flow(GPH@push) x g (NO_X@push)/gal x % time at push = g/hr NO_X (push)
Fuel Flow(GPH@maneuver) x g (NO_x@maneuver)/gal x % time at maneuver = g/hr NO_X (maneuver)

g/hr NO_X (cruise) + g/hr NO_X (push) + g/hr NO_x (maneuver) = g/hr NO_X

g/hr NO_X x Annual Hours of Operation x No. of Engines = NO_X /year

The generator engines were included in the total vessel emissions. Where a specific engine was not tested, published emissions factors were used or, in the case of any engine built after 2000, the corresponding IMO emissions factors were used.

It was assumed that vessels not tested for emissions operated in the same manner as those tested, whether they were short-, medium-, or long-haul vessels. This means that the MV YOGI BERRA, which has 3406E and waterjets for its propulsion, was assumed to have the same emission rate per hour per engine as the MV FATHER MYCHAL JUDGE since both vessels are classed as medium haul and have the same propulsion system. The same assumptions were used for SEASTREAK and NY Water Taxi because these companies operate fleets of identical vessels, which are totally interchangeable.

During the Phase II demonstration tests, the baseline and post-treatment emissions values were recalculated for the MV PORT IMPERIAL MANHATTAN, MV FATHER MYCHAL JUDGE, and MV JOHN KEITH. The MV JOHN KEITH is a sister ship of the MV ED ROGOWSKY and was substituted when the MV ED ROGOWSKY was sold. In addition HC emissions were also measured. These recalculated rates were used to evaluate the changes to the harbor emissions with the deployment of emissions control devices.

Ferry Vessel Route Data

The earlier Table 2.7 profiles the scheduled routes that are operated by each of the three ferry operators involved in this study. This table helps define the information provided in Tables 2.22 through 2.24. It identifies the route by description of where the route originates from, where it stops, and where its final destination is prior to its return to origin. As discussed in previous sections, each route is categorized in the table as short-, medium-, or long-haul based on round-trip length. The routes are presented in descending order of length by each respective operator. Table 2.7 provides specific information regarding the operating profiles and emission rates for the various ferry routes. Most importantly it provides the basis for a single source compilation of the real and potential emissions contributors found in the NYC private ferry vessel fleet.

NO_X Emission Rates

Table 2.22 identifies the NO_X emission rates for each route identified in Table 2.7. The rates presented are those measured during Phase I emissions testing on each engine for each mode of operation. The per route NO_X emission rates are calculated for the total number of propulsion engines installed aboard the typical vessel on its respective route. Also presented in this table are the emissions from the diesel generator. The sum of the emissions during each mode of operation and the diesel generator emissions are multiplied by the total routes per year to determine the total annual NO_X per year for the respective route. Total annual NO_X is presented in kilograms per year (kg/year), pounds per year (lbs/year), and short tons per year (short tons/year). Calculations were made for each scheduled route for each operator. Totals are presented for each operator, and these totals are summed to provide the grand total of annual NO_X emissions for the NYC Harbor.

PM 2.5 Emission Rates

Table 2.23 identifies the PM 2.5 emission rates for each route identified in Table 2.7. The rates presented are those measured during Phase I emissions testing on each engine for each mode of operation. The per route PM 2.5 emission rates are calculated for the total number of propulsion engines installed aboard the typical vessel on its respective route. Also presented in this table are the emissions from the diesel generator. The sum of the emissions during each mode of operation and the diesel generator emissions is multiplied by the total routes per year to determine the total annual PM 2.5 per year for the respective route. Total annual PM 2.5 is presented in kilograms per year (kg/year), pounds per year (lbs/year), and short tons per year (short tons/year). Calculations were made for each scheduled route for each operator. Totals are presented for each operator, and these totals are summed to provide the grand total of annual PM 2.5 emissions for the NYC Harbor.

Table 2.22. NO_X Emission Rates.

Route No.	Route Origin / Destination / End	Operator	Route Description	Route Distance	Propulsion Engine Type	NOx EMISSION RATES										
						NOx at Push, per Engine	NOx at Manuever, per Engine	NOx at Cruise, per Engine	Generator Nox at Constant kWe Load	Generator Nox at Constant kWe Load, per vessel	NOx at Push, per vessel	NOx at Manuever, per vessel	NOx at Cruise, per vessel	Total Annual NOx, per route	Total Annual NOx, per route	Total Annual NOx, per route
				NM		(kg/hr)	(kg/hr)	(kg/hr)	(kg/hr)	(kg/route)	(kg/route)	(kg/route)	(kg/route)	(kg/yr)	(lbs/yr)	(short tons/yr)
1	Belford, NJ to Pier 11 to Belford, NJ	NY Waterway	Long Haul	45.8	Caterpillar 3412E	2.41	1.26	2.16	0.75	1.06	1.49	0.98	9.18	46,235	101,932	51.0
2	Port Liberte to Pier 11 to Port Libete	NY Waterway	Medium Haul	9.4	Caterpillar 3406E	1.72	2.68	3.33	0.05	0.04	1.32	2.79	3.47	13,863	30,563	15.3
3	Pier 11 to Port Liberte to Pier 11	NY Waterway	Medium Haul	9.4	Caterpillar 3406E	1.72	2.68	3.33	0.05	0.03	1.14	2.39	3.55	18,490	40,763	20.4
4	Hoboken-South to (via WFC & Pier 11) WFC to Hoboken-South	NY Waterway	Medium Haul	7.7	Caterpillar 3412(2)	0.99	1.38	4.51	0.38	0.26	0.42	0.42	3.02	12,895	28,428	14.2
5	38th Street to (via Newport & Harborside) Colgate to 38th Street	NY Waterway	Medium Haul	7.6	Caterpillar 3406E	1.72	2.68	3.33	0.05	0.03	0.92	1.19	3.43	33,323	73,465	36.7
6	38th Street to (via Newport) Harborside to 38th Street	NY Waterway	Medium Haul	6.7	Caterpillar 3406E	1.72	2.68	3.33	0.05	0.02	0.57	0.78	2.90	18,888	41,642	20.8
7	38th Street to (via Harborside) Newport to 38th Street	NY Waterway	Medium Haul	6.7	Caterpillar 3406E	1.72	2.68	3.33	0.05	0.02	0.57	0.88	2.75	6,587	14,521	7.3
8	38th Street to Harborside to 38th Street	NY Waterway	Medium Haul	6.6	Caterpillar 3406E	1.72	2.68	3.33	0.05	0.02	0.42	0.50	2.31	5,060	11,155	5.6
9	Liberty Harbor to Pier 11 to Liberty Harbor	NY Waterway	Medium Haul	5.8	Caterpillar 3406E	1.72	2.68	3.33	0.05	0.02	0.57	1.29	1.76	22,676	49,991	25.0
10	38th Street to Newport to 38th Street	NY Waterway	Medium Haul	5.6	Caterpillar 3406E	1.72	2.68	3.33	0.05	0.02	0.40	0.71	1.72	12,587	27,749	13.9
11	Hoboken-South to WFC to Hoboken-South	NY Waterway	Medium Haul	5	Caterpillar 3412(2)	0.99	1.38	4.51	0.38	0.14	0.21	0.18	1.74	37,068	81,721	40.9
12	38th Street to (via Lincoln Harbor) Hoboken North to 38th Street	NY Waterway	Medium Haul	3.1	Caterpillar 3406E	1.72	2.68	3.33	0.05	0.02	0.93	1.54	0.71	23,280	51,324	25.7
13	Hoboken-North to 38th Street to Hoboken-North	NY Waterway	Medium Haul	2.4	Caterpillar 3406E	1.72	2.68	3.33	0.05	0.01	0.94	0.88	0.74	19,408	42,787	21.4
14	38th Street to Lincoln Harbor to 38th Street	NY Waterway	Medium Haul	2.4	Caterpillar 3412(2)	0.99	1.38	4.51	0.38	0.10	0.19	0.25	0.64	7,946	17,518	8.8
15	Port Imperial to 38th Street to Port Imperial (weekdays)	NY Waterway	Short Haul	2	Caterpillar 3412E	2.41	1.26	2.16	0.17	0.06	0.53	0.23	0.55	31,621	69,711	34.9
16	Port Imperial to 38th Street to Port Imperial (saturdays)	NY Waterway	Short Haul	2	Caterpillar 3412E	2.41	1.26	2.16	0.17	0.06	0.60	0.15	0.66	3,977	8,768	4.4
17	Port Imperial to 38th Street to Port Imperial (sundays)	NY Waterway	Short Haul	2	Caterpillar 3412E	2.41	1.26	2.16	0.17	0.06	0.62	0.20	0.56	3,659	8,067	4.0
18	Colgate to WFC to Colgate	NY Waterway	Short Haul	1.6	Caterpillar 3412(2)	0.99	1.38	4.51	0.38	0.10	0.19	0.16	0.96	23,205	51,158	25.6
Totals, NY Waterway														**340,767**	**751,263**	**375.6**

Table 2.22. NO_X Emission Rates (continued).

Route No.	Route Origin / Destination / End	Operator	Route Description	Route Distance	Propulsion Engine Type	NOx EMISSION RATES										
						NOx at Push, per Engine	NOx at Manuever, per Engine	NOx at Cruise, per Engine	Generator Nox at Constant kWe Load	Generator Nox at Constant kWe Load, per vessel	NOx at Push, per vessel	NOx at Manuever, per vessel	NOx at Cruise, per vessel	Total Annual NOx, per route	Total Annual NOx, per route	Total Annual NOx, per route
				NM		(kg/hr)	(kg/hr)	(kg/hr)	(kg/hr)	(kg/route)	(kg/route)	(kg/route)	(kg/route)	(kg/yr)	(lbs/yr)	(short tons/yr)
19	Port Imperial to (via Hoboken-North, WFC) Pier 11 to (via WFC, Hoboken-North) Port Imperial	Billy Bey	Long Haul	13.1	Caterpillar 3406E	1.72	2.68	3.33	0.00	0.00	1.42	2.54	4.97	13,923	30,694	15.3
20	Port Imperial to Pier 11 to Port Imperial	Billy Bey	Long Haul	12.8	Caterpillar 3406E	1.72	2.68	3.33	0.05	0.03	0.81	1.33	5.48	49,774	109,734	54.9
21	Pier 11 to 38th Street to Pier 11	Billy Bey	Long Haul	11.8	Caterpillar 3406E	1.72	2.68	3.33	0.05	0.03	0.81	1.33	3.79	12,404	27,347	13.7
22	Port Imperial to (via Hoboken-North) WFC to Port Imperial	Billy Bey	Medium Haul	8	Caterpillar 3406E	1.72	2.68	3.33	0.05	0.02	0.76	1.49	3.08	11,133	24,544	12.3
23	WFC to (via Hoboken-North) Port Imperial to WFC	Billy Bey	Medium Haul	8	Caterpillar 3406E	1.72	2.68	3.33	0.05	0.02	0.75	1.59	3.16	11,499	25,351	12.7
24	Hoboken-South to Pier 11 to Hoboken-South	Billy Bey	Medium Haul	7.4	Caterpillar 3406E	1.72	2.68	3.33	0.05	0.03	1.03	1.21	3.20	86,513	190,727	95.4
25	38th Street to Colgate to 38th Street	Billy Bey	Medium Haul	7.4	Caterpillar 3406E	1.72	2.68	3.33	0.05	0.03	0.86	0.98	2.13	13,491	29,743	14.9
26	38th St. to (via Newport Hoboken-South) Hoboken-North to 38th St.	Billy Bey	Medium Haul	6.2	Caterpillar 3412(2)	0.99	1.38	4.51	0.38	0.29	0.41	0.64	3.07	3,667	8,084	4.0
27	38th St. to (via Hoboken North & Hoboken South) Newport to 38th St.	Billy Bey	Medium Haul	6.2	Caterpillar 3412(2)	0.99	1.38	4.51	0.38	0.28	0.33	0.62	3.15	6,830	15,058	7.5
Totals, Billy Bey Ferry Company														**209,234**	**461,282**	**230.6**
28	East 34th St. to Pier 11 to Highlands to Atlantic Highlands to Pier 11 to East 34th St.	Seastreak	Long Haul	50	Cummins KTA50-M2	0.65	3.19	9.03	0.47	1.05	1.25	8.14	39.95	196,505	433,220	216.6
29	East 34th St. to Pier 11 to Highlands to Pier 11 to East 34th St.	Seastreak	Long Haul	48	Cummins KTA50-M2	0.65	3.19	9.03	0.47	0.84	0.90	4.95	38.15	18,653	41,123	20.6
30	Pier 11 to South Amboy to Pier 11	Seastreak	Long Haul	45	Cummins KTA50-M2	0.65	3.19	9.03	0.47	0.67	0.73	2.83	33.33	87,863	193,704	96.9
Totals, Seastreak														**303,021**	**668,047**	**334.0**
31	Various weekday routes (1)	NY Water Taxi	Medium Haul	-	DD Series 60	0.79	0.98	2.89	0.05	0.45	6.40	2.59	20.96	39,528	87,144	43.6
32	Various weekend routes (1)	NY Water Taxi	Medium Haul	-	DD Series 60	0.79	0.98	2.89	0.05	0.45	6.40	2.59	20.96	9,487	20,915	10.5
Totals, New York Water Taxi														**49,015**	**108,059**	**54.0**
Grand Totals, New York City Harbor														**902,038**	**1,988,651**	**994.3**

Notes: (1): Because NY Watertaxi vessels do not typically complete a closed circuit route the operating profile of the three modes of operation are presented as the total time in hours in each mode during the typical 9 hours of daily operation as determined during data logging. Therefore, route definitions and rates are presented as various and on a hrs/day basis.

(2): Emission data for mechanically controlled Caterpillar 3412 engines from PANY report dated April 2001

Table 2.23. PM 2.5 Emission Rates.

Route No.	Route Origin / Destination / End	Operator	Route Description	Route Distance	Propulsion Engine Type	PM2.5 at Push, per Engine	PM2.5 at Manuever, per Engine	PM2.5 at Cruise, per Engine	Generator PM2.5 at Constant kWe Load	Generator PM2.5 at Constant kWe Load, per vessel	PM2.5 at Push, per vessel	PM2.5 at Manuever, per vessel	PM2.5 at Cruise, per vessel	Total Annual PM2.5, per route	Total Annual PM2.5, per route	Total Annual PM2.5, per route
				NM		(g/hr)	(g/hr)	(g/hr)	(g/hr)	(g/route)	(g/route)	(g/route)	(g/route)	(g/yr)	(lbs/yr)	(short tons/yr)
1	Belford, NJ to Pier 11 to Belford, NJ	NY Waterway	Long Haul	45.8	Caterpillar 3412E	2.91	2.34	5.59	1.34	1.89	1.80	1.81	23.75	106,469	235	0.12
2	Port Liberte to Pier 11 to Port Libete	NY Waterway	Medium Haul	9.4	Caterpillar 3406E	7.26	23.06	34.54	3.10	2.21	5.58	24.00	36.00	123,379	272	0.14
3	Pier 11 to Port Liberte to Pier 11	NY Waterway	Medium Haul	9.4	Caterpillar 3406E	7.26	23.06	34.54	3.10	2.03	4.79	20.60	36.82	167,020	368	0.18
4	Hoboken-South to (via WFC & Pier 11) WFC to Hoboken-South	NY Waterway	Medium Haul	7.7	Caterpillar 3412(2)	126.80	176.70	578.80	26.80	18.81	53.97	54.39	387.80	1,606,662	3,542	1.77
5	38th Street to (via Newport & Harborside) Colgate to 38th Street	NY Waterway	Medium Haul	7.6	Caterpillar 3406E	7.26	23.06	34.54	3.10	2.08	3.88	10.20	35.61	309,612	683	0.34
6	38th Street to (via Newport) Harborside to 38th Street	NY Waterway	Medium Haul	6.7	Caterpillar 3406E	7.26	23.06	34.54	3.10	1.54	2.39	6.71	30.11	180,119	397	0.20
7	38th Street to (via Harborside) Newport to 38th Street	NY Waterway	Medium Haul	6.7	Caterpillar 3406E	7.26	23.06	34.54	3.10	1.53	2.39	7.57	28.54	62,447	138	0.07
8	38th Street to Harborside to 38th Street	NY Waterway	Medium Haul	6.6	Caterpillar 3406E	7.26	23.06	34.54	3.10	1.16	1.76	4.30	23.95	48,616	107	0.05
9	Liberty Harbor to Pier 11 to Liberty Harbor	NY Waterway	Medium Haul	5.8	Caterpillar 3406E	7.26	23.06	34.54	3.10	1.04	2.41	11.09	18.22	204,440	451	0.23
10	38th Street to Newport to 38th Street	NY Waterway	Medium Haul	5.6	Caterpillar 3406E	7.26	23.06	34.54	3.10	1.05	1.67	6.15	17.84	118,063	260	0.13
11	Hoboken-South to WFC to Hoboken-South	NY Waterway	Medium Haul	5.0	Caterpillar 3412(2)	126.80	176.70	578.80	26.80	9.71	26.45	22.97	223.30	4,626,195	10,199	5.10
12	38th Street to (via Lincoln Harbor) Hoboken North to 38th Street	NY Waterway	Medium Haul	3.1	Caterpillar 3406E	7.26	23.06	34.54	3.10	1.03	3.94	13.24	7.36	186,140	410	0.21
13	Hoboken-North to 38th Street to Hoboken-North	NY Waterway	Medium Haul	2.4	Caterpillar 3406E	7.26	23.06	34.54	3.10	0.85	3.95	7.60	7.68	151,436	334	0.17
14	38th Street to Lincoln Harbor to 38th Street	NY Waterway	Medium Haul	2.4	Caterpillar 3412(2)	126.80	176.70	578.80	26.80	6.91	24.52	32.05	81.73	981,670	2,164	1.08
15	Port Imperial to 38th Street to Port Imperial (weekdays)	NY Waterway	Short Haul	2.0	Caterpillar 3412E	2.91	2.34	5.59	3.43	1.13	0.64	0.43	1.42	83,690	185	0.09
16	Port Imperial to 38th Street to Port Imperial (saturdays)	NY Waterway	Short Haul	2.0	Caterpillar 3412E	2.91	2.34	5.59	3.43	1.16	0.73	0.28	1.71	10,475	23	0.01
17	Port Imperial to 38th Street to Port Imperial (sundays)	NY Waterway	Short Haul	2.0	Caterpillar 3412E	2.91	2.34	5.59	3.43	1.16	0.75	0.38	1.44	9,494	21	0.01
18	Colgate to WFC to Colgate	NY Waterway	Short Haul	1.6	Caterpillar 3412(2)	126.80	176.70	578.80	26.80	7.04	24.52	20.96	123.52	2,883,470	6,357	3.18
Totals, NY Waterway														**11,859,396**	**26,145**	**13.07**

Table 2.23. PM 2.5 Emission Rates (continued).

Route No.	Route Origin / Destination / End	Operator	Route Description	Route Distance	Propulsion Engine Type	PM2.5 at Push, per Engine	PM2.5 at Manuever, per Engine	PM2.5 at Cruise, per Engine	Generator PM2.5 at Constant kWe Load	Generator PM2.5 at Constant kWe Load, per vessel	PM2.5 at Push, per vessel	PM2.5 at Manuever, per vessel	PM2.5 at Cruise, per vessel	Total Annual PM2.5, per route	Total Annual PM2.5, per route	Total Annual PM2.5, per route
				NM		(g/hr)	(g/hr)	(g/hr)	(g/hr)	(g/route)	(g/route)	(g/route)	(g/route)	(g/yr)	(lbs/yr)	(short tons/yr)
19	Port Imperial to (via Hoboken-North, WFC) Pier 11 to (via WFC, Hoboken-North) Port Imperial	Billy Bey	Long Haul	13.1	Caterpillar 3406E	7.26	23.06	34.54	0.00	0.00	5.99	21.82	51.55	123,801	273	0.14
20	Port Imperial to Pier 11 to Port Imperial	Billy Bey	Long Haul	12.8	Caterpillar 3406E	7.26	23.06	34.54	3.10	2.03	3.44	11.47	56.83	479,396	1,057	0.53
21	Pier 11 to 38th Street to Pier 11	Billy Bey	Long Haul	11.8	Caterpillar 3406E	7.26	23.06	34.54	3.10	1.63	3.44	11.47	39.32	116,179	256	0.13
22	Port Imperial to (via Hoboken-North) WFC to Port Imperial	Billy Bey	Medium Haul	8.0	Caterpillar 3406E	7.26	23.06	34.54	3.10	1.49	3.21	12.85	31.90	102,848	227	0.11
23	WFC to (via Hoboken-North) Port Imperial to WFC	Billy Bey	Medium Haul	8.0	Caterpillar 3406E	7.26	23.06	34.54	3.10	1.53	3.18	13.72	32.74	106,437	235	0.12
24	Hoboken-South to Pier 11 to Hoboken-South	Billy Bey	Medium Haul	7.4	Caterpillar 3406E	7.26	23.06	34.54	3.10	1.56	4.33	10.39	33.16	783,956	1,728	0.86
25	38th Street to Colgate to 38th Street	Billy Bey	Medium Haul	7.4	Caterpillar 3406E	7.26	23.06	34.54	3.10	1.55	3.63	8.42	22.08	120,602	266	0.13
26	38th St. to (via Newport Hoboken-South) Hoboken-North to 38th St.	Billy Bey	Medium Haul	6.2	Caterpillar 3412(2)	126.80	176.70	578.80	26.80	20.85	52.60	81.49	393.58	456,373	1,006	0.50
27	38th St. to (via Hoboken North & Hoboken South) Newport to 38th St.	Billy Bey	Medium Haul	6.2	Caterpillar 3412(2)	126.80	176.70	578.80	26.80	19.86	42.40	79.44	403.89	851,119	1,876	0.94
Totals, Billy Bey Ferry Company														**3,140,711**	**6,924**	**3.46**
28	East 34th St. to Pier 11 to Highlands to Atlantic Highlands to Pier 11 to East 34th St.	Seastreak	Long Haul	50.0	Cummins KTA50-M2	18.20	62.70	106.50	14.80	32.91	34.90	160.04	471.20	2,726,270	6,010	3.01
29	East 34th St. to Pier 11 to Highlands to Pier 11 to East 34th St.	Seastreak	Long Haul	48.0	Cummins KTA50-M2	18.20	62.70	106.50	14.80	26.49	25.19	97.34	449.90	249,150	549	0.27
30	Pier 11 to South Amboy to Pier 11	Seastreak	Long Haul	45.0	Cummins KTA50-M2	18.20	62.70	106.50	14.80	21.07	20.33	55.53	393.07	1,146,592	2,528	1.26
Totals, Seastreak														**4,122,012**	**9,087**	**4.54**
31	Various weekday routes [(1)]	NY Water Taxi	Medium Haul	-	DD Series 60	6.82	13.65	53.86	3.10	27.90	55.24	36.12	390.70	662,948	1,462	0.73
32	Various weekend routes [(1)]	NY Water Taxi	Medium Haul	-	DD Series 60	6.82	13.65	53.86	3.10	27.90	55.24	36.12	390.70	159,108	351	0.18
Totals, New York Water Taxi														**822,056**	**1,812**	**0.91**
Grand Totals, New York City Harbor														**19,944,175**	**43,969**	**21.98**

Notes:

(1): Because NY Watertaxi vessels do not typically complete a closed circuit route the operating profile of the three modes of operation are presented as the total time in hours in each mode during the typical 9 hours of daily operation as determined during data logging. Therefore, route definitions and rates are presented as various and on a hrs/day basis.

(2): Emission data for mechanically controlled Caterpillar 3412 engines from PANY report dated April 2001

PM 10 Emission Rates

Table 2.24 identifies the PM 10 emission rates for each route identified in Table 2.7. The rates presented are those measured during Phase I emissions testing on each engine for each mode of operation. The per route PM 10 emission rates are calculated for the total number of propulsion engines installed aboard the typical vessel on its respective route. Also presented in this table are the emissions from the diesel generator. The sum of the emissions during each mode of operation and the diesel generator emissions is multiplied by the total routes per year to determine the total annual PM 10 per year for the respective route. Total annual PM 10 is presented in kilograms per year (kg/year), pounds per year (lbs/year), and short tons per year (short tons/year). Calculations were made for each scheduled route for each operator. Totals are presented for each operator, and these totals are summed to provide the rand total of annual PM 10 emissions for the NYC Harbor.

HC Emission Rates

Recognizing the need to present HC emissions and their potential reduction while utilizing any emissions control devices, Table 2.25 has been added. Table 2.25 identifies the HC emission rates for each route identified in Table 2.7. HC emissions were not measured during the Phase I testing; the rates here are those measured during Phase II baseline testing. The per route HC emission rates are calculated for the total number of propulsion engines installed aboard the typical vessel on its respective route. Also presented in this table are the emissions from the diesel generator. The sum of the emissions during each mode of operation and the diesel generator emissions is multiplied by the total routes per year to determine the total annual HC per year for the respective route. Total annual HC is presented in kilograms per year (kg/year), pounds per year (lbs/year), and short tons per year (short tons/year). Calculations were made for each scheduled route for each operator. Totals are presented for each operator, and these totals are summed to provide the grand total of annual HC emissions for the NYC Harbor. It should be noted that the SeaStreak vessel had been pulled out of the project before the HC measurements were performed during the Phase II testing.

Annual Emissions for NYC Harbor

Finally Table 2.26 summarizes the annual emissions from each operator and its respective fleet as short tons per year for each pollutant.

Table 2.24. PM 10 Emission Rates.

Route No.	Route Origin / Destination / End	Operator	Route Description	Route Distance	Propulsion Engine Type	PM10 EMISSION RATES										
						PM10 at Push, per Engine	PM10 at Manuever, per Engine	PM10 at Cruise, per Engine	Generator PM10 at Constant kWe Load	Generator PM10 at Constant kWe Load, per vessel	PM10 at Push, per vessel	PM10 at Manuever, per vessel	PM10 at Cruise, per vessel	Total Annual PM10, per route	Total Annual PM10, per route	Total Annual PM10, per route
				NM		(g/hr)	(g/hr)	(g/hr)	(g/hr)	(g/route)	(g/route)	(g/route)	(g/route)	(g/yr)	(lbs/yr)	(short tons/yr)
1	Belford, NJ to Pier 11 to Belford, NJ	NY Waterway	Long Haul	45.8	Caterpillar 3412E	3.27	2.48	5.75	1.34	1.89	2.02	1.92	24.43	110,148	243	0.12
2	Port Liberte to Pier 11 to Port Libete	NY Waterway	Medium Haul	9.4	Caterpillar 3406E	7.34	21.47	27.35	3.39	2.42	5.64	22.35	28.51	107,215	236	0.12
3	Pier 11 to Port Liberte to Pier 11	NY Waterway	Medium Haul	9.4	Caterpillar 3406E	7.34	21.47	27.35	3.39	2.22	4.84	19.18	29.16	144,030	318	0.16
4	Hoboken-South to (via WFC & Pier 11) WFC to Hoboken-South	NY Waterway	Medium Haul	7.7	Caterpillar 3412(2)	132.20	184.20	603.50	26.80	18.81	56.26	56.70	404.35	1,672,668	3,688	1.84
5	38th Street to (via Newport & Harborside) Colgate to 38th Street	NY Waterway	Medium Haul	7.6	Caterpillar 3406E	7.34	21.47	27.35	3.39	2.27	3.92	9.50	28.20	262,488	579	0.29
6	38th Street to (via Newport) Harborside to 38th Street	NY Waterway	Medium Haul	6.7	Caterpillar 3406E	7.34	21.47	27.35	3.39	1.69	2.41	6.25	23.84	151,122	333	0.17
7	38th Street to (via Harborside) Newport to 38th Street	NY Waterway	Medium Haul	6.7	Caterpillar 3406E	7.34	21.47	27.35	3.39	1.68	2.42	7.05	22.60	52,631	116	0.06
8	38th Street to Harborside to 38th Street	NY Waterway	Medium Haul	6.6	Caterpillar 3406E	7.34	21.47	27.35	3.39	1.27	1.77	4.01	18.96	40,576	89	0.04
9	Liberty Harbor to Pier 11 to Liberty Harbor	NY Waterway	Medium Haul	5.8	Caterpillar 3406E	7.34	21.47	27.35	3.39	1.14	2.44	10.32	14.43	176,772	390	0.19
10	38th Street to Newport to 38th Street	NY Waterway	Medium Haul	5.6	Caterpillar 3406E	7.34	21.47	27.35	3.39	1.15	1.69	5.73	14.13	100,286	221	0.11
11	Hoboken-South to WFC to Hoboken-South	NY Waterway	Medium Haul	5	Caterpillar 3412(2)	132.20	184.20	603.50	26.80	9.71	27.58	23.95	232.83	4,816,706	10,619	5.31
12	38th Street to (via Lincoln Harbor) Hoboken North to 38th Street	NY Waterway	Medium Haul	3.1	Caterpillar 3406E	7.34	21.47	27.35	3.39	1.13	3.98	12.32	5.83	169,354	373	0.19
13	Hoboken-North to 38th Street to Hoboken-North	NY Waterway	Medium Haul	2.4	Caterpillar 3406E	7.34	21.47	27.35	3.39	0.93	4.00	7.08	6.08	136,355	301	0.15
14	38th Street to Lincoln Harbor to 38th Street	NY Waterway	Medium Haul	2.4	Caterpillar 3412(2)	132.20	184.20	603.50	26.80	6.91	25.57	33.41	85.21	1,021,503	2,252	1.13
15	Port Imperial to 38th Street to Port Imperial (weekdays)	NY Waterway	Short Haul	2	Caterpillar 3412E	3.27	2.48	5.75	3.35	1.10	0.72	0.46	1.46	86,452	191	0.10
16	Port Imperial to 38th Street to Port Imperial (saturdays)	NY Waterway	Short Haul	2	Caterpillar 3412E	3.27	2.48	5.75	3.35	1.13	0.82	0.29	1.76	10,823	24	0.01
17	Port Imperial to 38th Street to Port Imperial (sundays)	NY Waterway	Short Haul	2	Caterpillar 3412E	3.27	2.48	5.75	3.35	1.13	0.84	0.40	1.48	9,823	22	0.01
18	Colgate to WFC to Colgate	NY Waterway	Short Haul	1.6	Caterpillar 3412(2)	132.20	184.20	603.50	26.80	7.04	25.57	21.85	128.79	3,001,485	6,617	3.31
Totals, NY Waterway														**12,070,435**	**26,611**	**13.31**

Table 2.24. PM 10 Emission Rates (continued).

Route No.	Route Origin / Destination / End	Operator	Route Description	Route Distance	Propulsion Engine Type	PM10 EMISSION RATES										
						PM10 at Push, per Engine	PM10 at Manuever, per Engine	PM10 at Cruise, per Engine	Generator PM10 at Constant kWe Load	Generator PM10 at Constant kWe Load, per vessel	PM10 at Push, per vessel	PM10 at Manuever, per vessel	PM10 at Cruise, per vessel	Total Annual PM10, per route	Total Annual PM10, per route	Total Annual PM10, per route
				NM		(g/hr)	(g/hr)	(g/hr)	(g/hr)	(g/route)	(g/route)	(g/route)	(g/route)	(g/yr)	(lbs/yr)	(short tons/yr)
19	Port Imperial to (via Hoboken-North, WFC) Pier 11 to (via WFC, Hoboken-North) Port Imperial	Billy Bey	Long Haul	13.1	Caterpillar 3406E	7.34	21.47	27.35	0.00	0.00	6.05	20.32	40.82	104,817	231	0.12
20	Port Imperial to Pier 11 to Port Imperial	Billy Bey	Long Haul	12.8	Caterpillar 3406E	7.34	21.47	27.35	3.39	2.22	3.47	10.67	45.00	398,847	879	0.44
21	Pier 11 to 38th Street to Pier 11	Billy Bey	Long Haul	11.8	Caterpillar 3406E	7.34	21.47	27.35	3.39	1.79	3.47	10.67	31.14	97,907	216	0.11
22	Port Imperial to (via Hoboken-North) WFC to Port Imperial	Billy Bey	Medium Haul	8	Caterpillar 3406E	7.34	21.47	27.35	3.39	1.63	3.24	11.96	25.26	87,556	193	0.10
23	WFC to (via Hoboken-North) Port Imperial to WFC	Billy Bey	Medium Haul	8	Caterpillar 3406E	7.34	21.47	27.35	3.39	1.68	3.21	12.77	25.93	90,664	200	0.10
24	Hoboken-South to Pier 11 to Hoboken-South	Billy Bey	Medium Haul	7.4	Caterpillar 3406E	7.34	21.47	27.35	3.39	1.70	4.38	9.67	26.26	666,190	1,469	0.73
25	38th Street to Colgate to 38th Street	Billy Bey	Medium Haul	7.4	Caterpillar 3406E	7.34	21.47	27.35	3.39	1.70	3.67	7.84	17.48	103,730	229	0.11
26	38th St. to (via Newport Hoboken-South) Hoboken-North to 38th St.	Billy Bey	Medium Haul	6.2	Caterpillar 3412(2)	132.20	184.20	603.50	26.80	20.85	54.84	84.95	410.38	475,089	1,047	0.52
27	38th St. to (via Hoboken North & Hoboken South) Newport to 38th St.	Billy Bey	Medium Haul	6.2	Caterpillar 3412(2)	132.20	184.20	603.50	26.80	19.86	44.21	82.82	421.12	886,084	1,953	0.98
Totals, Billy Bey Ferry Company														**2,910,883**	**6,417**	**3.21**
28	East 34th St. to Pier 11 to Highlands to Atlantic Highlands to Pier 11 to East 34th St.	Seastreak	Long Haul	50	Cummins KTA50-M2	17.50	60.80	105.20	14.80	32.91	33.56	155.19	465.45	2,679,690	5,908	2.95
29	East 34th St. to Pier 11 to Highlands to Pier 11 to East 34th St.	Seastreak	Long Haul	48	Cummins KTA50-M2	17.50	60.80	105.20	14.80	26.49	24.22	94.39	444.41	245,235	541	0.27
30	Pier 11 to South Amboy to Pier 11	Seastreak	Long Haul	45	Cummins KTA50-M2	17.50	60.80	105.20	14.80	21.07	19.55	53.84	388.27	1,129,597	2,490	1.25
Totals, Seastreak														**4,054,523**	**8,939**	**4.47**
31	Various weekday routes (1)	NY Water Taxi	Medium Haul	-	DD Series 60	6.27	12.80	50.75	3.39	30.51	50.79	33.87	368.14	628,298	1,385	0.69
32	Various weekday routes (1)	NY Water Taxi	Medium Haul	-	DD Series 60	6.27	12.80	50.75	3.39	30.51	50.79	33.87	368.14	150,792	332	0.17
Totals, New York Water Taxi														**779,090**	**1,718**	**0.86**
Grand Totals, New York City Harbor														**19,814,932**	**43,684**	**21.84**

Notes: **(1): Because NY Watertaxi vessels do not typically complete a closed circuit route the operating profile of the three modes of operation are presented as the total time in hours in each mode during the typical 9 hours of daily operation as determined during data logging. Therefore, route definitions and rates are presented as various and on a hrs/day basis.**

(2): Emission data for mechanically controlled Caterpillar 3412 engines from PANY report dated April 2001

Table 2.25. HC Emission Rates.

Route No.	Route Origin / Destination / End	Operator	Route Description	Route Distance	Propulsion Engine Type	HC EMISSION RATES										
						HC at Push, per Engine	HC at Manuever, per Engine	HC at Cruise, per Engine	Generator HC at Constant kWe Load	Generator HC at Constant kWe Load, per vessel	HC at Push, per vessel	HC at Manuever, per vessel	HC at Cruise, per vessel	Total Annual HC, per route	Total Annual HC, per route	Total Annual HC, per route
				NM		(g/hr)	(g/hr)	(g/hr)	(g/hr)	(g/route)	(g/route)	(g/route)	(g/route)	(g/yr)	(lbs/yr)	(short tons/yr)
1	Belford, NJ to Pier 11 to Belford, NJ	NY Waterway	Long Haul	45.8	Caterpillar 3412E	173.88	90.73	698.06	0.00	0.00	107.39	70.26	2965.93	11,442,617	25,227	12.61
2	Port Liberte to Pier 11 to Port Libete	NY Waterway	Medium Haul	9.4	Caterpillar 3406E	230.00	150.01	744.32	0.00	0.00	176.64	156.13	775.88	2,017,729	4,448	2.22
3	Pier 11 to Port Liberte to Pier 11	NY Waterway	Medium Haul	9.4	Caterpillar 3406E	230.00	150.01	744.32	0.00	0.00	151.80	133.99	793.44	2,805,991	6,186	3.09
4	Hoboken-South to (via WFC & Pier 11) WFC to Hoboken-South	NY Waterway	Medium Haul	7.7	Caterpillar 3412(2)	301.25	32.08	106.93	0.00	0.00	128.21	9.87	71.65	654,364	1,443	0.72
5	38th Street to (via Newport & Harborside) Colgate to 38th Street	NY Waterway	Medium Haul	7.6	Caterpillar 3406E	230.00	150.01	744.32	0.00	0.00	122.96	66.38	767.46	5,721,668	12,614	6.31
6	38th Street to (via Newport) Harborside to 38th Street	NY Waterway	Medium Haul	6.7	Caterpillar 3406E	230.00	150.01	744.32	0.00	0.00	75.62	43.65	648.90	3,395,316	7,485	3.74
7	38th Street to (via Harborside) Newport to 38th Street	NY Waterway	Medium Haul	6.7	Caterpillar 3406E	230.00	150.01	744.32	0.00	0.00	75.76	49.23	614.95	1,154,320	2,545	1.27
8	38th Street to Harborside to 38th Street	NY Waterway	Medium Haul	6.6	Caterpillar 3406E	230.00	150.01	744.32	0.00	0.00	55.61	27.99	516.03	935,438	2,062	1.03
9	Liberty Harbor to Pier 11 to Liberty Harbor	NY Waterway	Medium Haul	5.8	Caterpillar 3406E	230.00	150.01	744.32	0.00	0.00	76.45	72.12	392.70	3,377,566	7,446	3.72
10	38th Street to Newport to 38th Street	NY Waterway	Medium Haul	5.6	Caterpillar 3406E	230.00	150.01	744.32	0.00	0.00	52.92	40.01	384.51	2,110,301	4,652	2.33
11	Hoboken-South to WFC to Hoboken-South	NY Waterway	Medium Haul	5	Caterpillar 3412(2)	132.20	184.20	603.50	0.00	0.00	27.58	23.95	232.83	4,657,706	10,268	5.13
12	38th Street to (via Lincoln Harbor) Hoboken North to 38th Street	NY Waterway	Medium Haul	3.1	Caterpillar 3406E	230.00	150.01	744.32	0.00	0.00	124.75	86.10	158.69	2,690,281	5,931	2.97
13	Hoboken-North to 38th Street to Hoboken-North	NY Waterway	Medium Haul	2.4	Caterpillar 3406E	230.00	150.01	744.32	0.00	0.00	125.21	49.44	165.54	2,565,034	5,655	2.83
14	38th Street to Lincoln Harbor to 38th Street	NY Waterway	Medium Haul	2.4	Caterpillar 3412(2)	132.20	184.20	603.50	0.00	0.00	25.57	33.41	85.21	974,762	2,149	1.07
15	Port Imperial to 38th Street to Port Imperial (weekdays)	NY Waterway	Short Haul	2	Caterpillar 3412E	173.88	90.73	698.06	0.00	0.00	38.36	16.68	176.89	5,366,685	11,832	5.92
16	Port Imperial to 38th Street to Port Imperial (saturdays)	NY Waterway	Short Haul	2	Caterpillar 3412E	173.88	90.73	698.06	0.00	0.00	43.50	10.71	213.89	724,934	1,598	0.80
17	Port Imperial to 38th Street to Port Imperial (sundays)	NY Waterway	Short Haul	2	Caterpillar 3412E	173.88	90.73	698.06	0.00	0.00	44.55	14.72	179.96	609,543	1,344	0.67
18	Colgate to WFC to Colgate	NY Waterway	Short Haul	1.6	Caterpillar 3412(2)	132.20	184.20	603.50	0.00	0.00	25.57	21.85	128.79	2,886,164	6,363	3.18
Totals, NY Waterway														**#####**	**119,249**	**59.62**

Table 2.25. HC Emission Rates (continued).

Route No.	Route Origin / Destination / End	Operator	Route Description	Route Distance	Propulsion Engine Type	HC EMISSION RATES										
						HC at Push, per Engine	HC at Manuever, per Engine	HC at Cruise, per Engine	Generator HC at Constant kWe Load	Generator HC at Constant kWe Load, per vessel	HC at Push, per vessel	HC at Manuever, per vessel	HC at Cruise, per vessel	Total Annual HC, per route	Total Annual HC, per route	Total Annual HC, per route
				NM		(g/hr)	(g/hr)	(g/hr)	(g/hr)	(g/route)	(g/route)	(g/route)	(g/route)	(g/yr)	(lbs/yr)	(short tons/yr)
19	Port Imperial to (via Hoboken-North, WFC) Pier 11 to (via WFC, Hoboken-North) Port Imperial	Billy Bey	Long Haul	13.1	Caterpillar 3406E	230.00	150.01	744.32	0.00	0.00	189.70	141.97	1110.82	2,250,281	4,961	2.48
20	Port Imperial to Pier 11 to Port Imperial	Billy Bey	Long Haul	12.8	Caterpillar 3406E	230.00	150.01	744.32	0.00	0.00	108.84	74.58	1224.55	9,151,797	20,176	10.09
21	Pier 11 to 38th Street to Pier 11	Billy Bey	Long Haul	11.8	Caterpillar 3406E	230.00	150.01	744.32	0.00	0.00	108.84	74.58	847.33	2,143,958	4,727	2.36
22	Port Imperial to (via Hoboken-North) WFC to Port Imperial	Billy Bey	Medium Haul	8	Caterpillar 3406E	230.00	150.01	744.32	0.00	0.00	101.57	83.58	687.45	1,815,013	4,001	2.00
23	WFC to (via Hoboken-North) Port Imperial to WFC	Billy Bey	Medium Haul	8	Caterpillar 3406E	230.00	150.01	744.32	0.00	0.00	100.65	89.22	705.61	1,862,607	4,106	2.05
24	Hoboken-South to Pier 11 to Hoboken-South	Billy Bey	Medium Haul	7.4	Caterpillar 3406E	230.00	150.01	744.32	0.00	0.00	137.17	67.56	714.54	14,579,761	32,143	16.07
25	38th Street to Colgate to 38th Street	Billy Bey	Medium Haul	7.4	Caterpillar 3406E	230.00	150.01	744.32	0.00	0.00	114.89	54.77	475.84	2,181,769	4,810	2.40
26	38th St. to (via Newport Hoboken-South) Hoboken-North to 38th St.	Billy Bey	Medium Haul	6.2	Caterpillar 3412(2)	132.20	184.20	603.50	0.00	0.00	54.84	84.95	410.38	457,741	1,009	0.50
27	38th St. to (via Hoboken North & Hoboken South) Newport to 38th St.	Billy Bey	Medium Haul	6.2	Caterpillar 3412(2)	132.20	184.20	603.50	0.00	0.00	44.21	82.82	421.12	855,108	1,885	0.94
Totals, Billy Bey Ferry Company														**#####**	**77,819**	**38.91**
28	East 34th St. to Pier 11 to Highlands to Atlantic Highlands to Pier 11 to East 34th St.	Seastreak	Long Haul	50	Cummins KTA50-M2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0.00
29	East 34th St. to Pier 11 to Highlands to Pier 11 to East 34th St.	Seastreak	Long Haul	48	Cummins KTA50-M2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0.00
30	Pier 11 to South Amboy to Pier 11	Seastreak	Long Haul	45	Cummins KTA50-M2	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0	0	0.00
Totals, Seastreak														**0**	**0**	**0.00**
31	Various weekday routes [1]	NY Water Taxi	Medium Haul	-	DD Series 60	73.75	41.96	351.68	0.00	0.00	597.35	111.02	2551.10	4,237,309	9,342	4.67
32	Various weekday routes [1]	NY Water Taxi	Medium Haul	-	DD Series 60	73.75	41.96	351.68	0.00	0.00	597.35	111.02	2551.10	1,016,954	2,242	1.12
Totals, New York Water Taxi														**#####**	**11,584**	**5.79**
Grand Totals, New York City Harbor														**#####**	**208,651**	**104.33**

Notes: **(1): Because NY Watertaxi vessels do not typically complete a closed circuit route the operating profile of the three modes of operation are presented as the total time in hours in each mode during the typical 9 hours of daily operation as determined du**

(2): Emission data for mechanically controlled Caterpillar 3412 engines from PANY report dated April 2001

Table 2.26. Annual Harbor Emissions Based on Phase I Emissions Testing.

Vessel Operator/Owner	No. of Vessels	NOx, tons/year	PM 2.5 tons/year	PM 10 tons/year	HC tons/year[1]
NY Waterway, Inc	20	375.63	13.07	13.31	59.62
Billy Bey Ferry Co. Inc	15	230.64	3.46	3.21	38.91
NY Water Taxi, Inc.	6	54.03	0.91	0.86	5.79
SeaStreak, Ltd.	4	334.02	4.54	4.47	0.00

Note 1: HC was not tested for during the Phase I emissions tests. The HC values are from the Phase II tests.

Section 3

EMISSIONS CONTROL TECHNOLOGY REVIEW & SELECTION

INTRODUCTION

This section discusses the portion of the study that utilized the vessel characterizations described in Section 2 to develop a means to select the most suitable emission control technology(s) for demonstration and potential fleetwide deployment. This information will be used as the basis to select the emissions control technologies to be used for Section 5, Phase II, of this project. In Phase II, selected emissions control technologies were installed and analyzed aboard the demonstrative ferries. One of the results of the Phase I fuel test demonstration was the decision not to restrict the technology demonstration to the use of Ultra-low Sulfur Diesel fuel (ULSD). This will provide more flexibility and will reduce the resistance of the ferry operators to participation in this program.

Seaworthy Systems, Inc., and its team performed this task by:

- Reviewing and assessing the currently available diesel engine emissions control technologies used in the marine, on-road, or off-road markets including relative performance, installation cost, operating cost, availability, and safety.
- Constructing an emissions control technology evaluation matrix whereby each potential technology would be evaluated according to weighted categories and graded on its applicability to the ferry vessels.
- Contacting the various emissions control technology manufacturers and vendors to determine whether they could provide the hardware necessary for the Phase II demonstration.
- Contacting the ferry vessel engine manufacturers to determine whether installing emissions control equipment would have any impact upon the operation and warranty of the engines.
- Issuing request for proposals (RFPs) to the various emissions control technology manufacturers and vendors to obtain budgetary, schedule, and performance information for their respective products.
- Identifying the technology most likely to provide the requisite emissions performance for each of the demonstration vessels based on the operating profiles developed in the first section of this report.
- Presenting the available technologies to each ferry vessel operator to obtain authorization to proceed with the execution of a purchase order.
- Estimating the demonstration cost of using the chosen technology for each subject vessel.

- Requesting a quote from each of the selected emissions control technology vendors to provide the equipment necessary to conduct the demonstration.

DIESEL ENGINE EMISSIONS

Diesel engines emit a variety of complex chemical compounds. The species of greatest concern are nitrogen oxides (NO_X), which includes nitrogen dioxide (NO_2) and nitrogen oxide (NO). These, along with volatile organic compounds (VOCs), contribute to the formation of ozone and particulate matter (PM). The amount, size, and composition of diesel particles will depend upon a number of factors including the fuel formulation, lubricating oil, engine parameters, and after treatment device, as well as the temperature, sunlight intensity, and composition of particles and gases in the atmosphere.

Ozone is a highly oxidative molecule that can form high in the atmosphere (stratosphere) as part of the beneficial ozone layer. It can also form in the lower atmosphere from photochemical reactions involving NO_X and VOCs. Its presence in the lower atmosphere causes health concerns because of its association with respiratory irritation, aggravating asthma, and reducing lung function. The New York metropolitan region has been designated by the EPA as not attaining the 8-hour standard; and the region needs to come into attainment by 2010.

Because ozone is not directly emitted from tailpipes or smokestacks, ozone is referred to as a secondary pollutant. NO_X and VOCs may be referred to as ozone precursors or primary pollutants. The anthropogenic sources of NO_X and VOCs are mostly fuel combustion. Nationwide, mobile sources (on-road and non-road) are responsible for approximately 40% of the NO_X and VOC emissions (North American Research Strategy for Tropospheric Ozone, 2000).

Particulate matter (PM) is a mixture of solid, semi-solid, and liquid aerosols. It is both a primary and secondary pollutant. Aerosol particles are a heterogeneous mix of trace metals, elemental carbon, organic carbon, sulphate, and nitrate. PM is regulated by size in two categories: those particles smaller than an aerodynamic diameter of 10 um and those smaller than 2.5 um.

Health concerns with particulate matter depend on its size and composition. The smaller particles are able to travel deeper into the lungs, and therefore have a greater potential to cause problems. A great deal of research has focused on the trace metals, polycyclic-aromatic hydrocarbons, sulphate, and other components of PM to explain the epidemiological findings associating PM with cardiovascular and respiratory disease and mortality. Several state, national, and international agencies have identified diesel exhaust as a probable lung carcinogen (Health Effects Institute report).

NO_X is a regulatory term referring to the combination of the gases NO and NO_2. Both of these constituents are undesirable from a public health and atmospheric pollution perspective. NO is a colorless gas that causes irritation of the eyes, nose, and throat and drowsiness, and it can exacerbate heat-related disease. NO also contributes to ground-level ozone formation. NO_2 is far more toxic than NO, causing extreme respiratory inflammation, and pulmonary distress; at very high concentrations, it can even cause death.

The EPA considers NO_X and PM emissions the criteria pollutants from diesel engines; these are therefore the predominant focus of emission reduction strategies. Hydrocarbons (HC) and carbon monoxide (CO), the other two regulated criteria pollutants, are emitted from diesel engines in sufficiently low concentrations to be of little concern. Low HC and CO concentrations result from the characteristically lean combustion of the diesel, in which the engine operates with excess air that oxidizes HC and CO to form carbon dioxide (CO_2) and water. While CO_2 is not a criterion/regulated pollutant, it is nevertheless measured as a representation, or "marker," for the fuel consumption of an engine and is widely accepted as a greenhouse gas. While CO_2 formation predominates over CO formation in diesel engines due to the excess air and lean combustion described above, overall CO_2 emissions from a diesel engine are significantly less than from its gasoline counterpart, due to diesel's superior fuel efficiency. This is the reason why the diesel engine is frequently cited as a viable approach for reducing greenhouse gas (GHG) emissions.

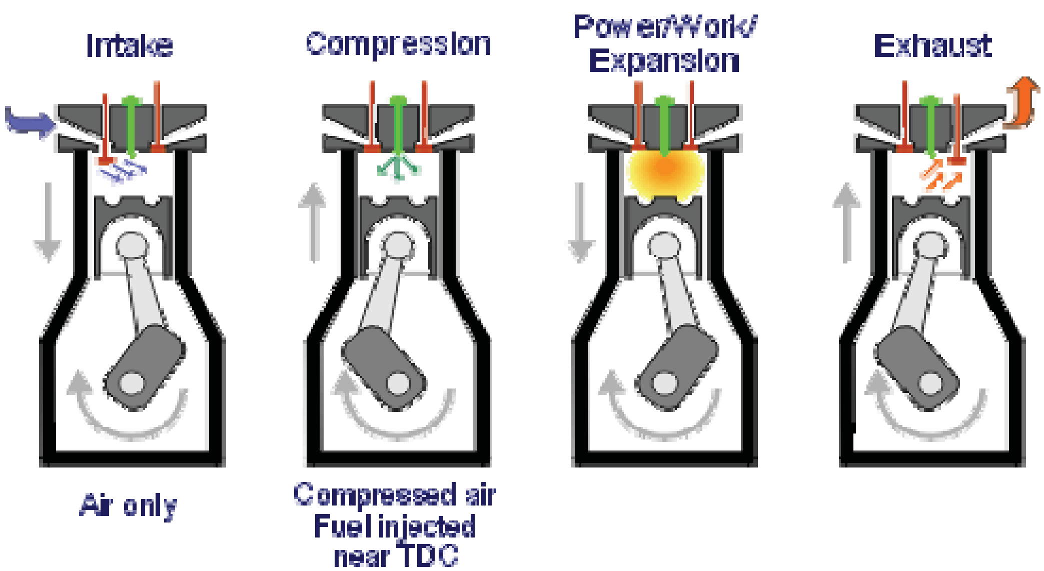


Figure 3.1. Diesel Four-Cycle Steps.

The diesel engine was invented in the late nineteenth century and commercialized in the early twentieth century by Dr. Rudolph Diesel, a German inventor and scientist of French birthright. Developed at approximately the same period in history as the gasoline engine, the diesel exhibited superior thermal energy efficiency, which translates into superior performance and exemplary fuel economy. Conceptually, gasoline and diesel engines operate according to similar thermodynamic principles, over four distinct cycles or "strokes." Diesel four-stroke engine cycles include the intake stroke, the compression stoke, the power stroke, and the expansion stroke, as shown schematically in Figure 3.1.

In the intake stroke air is inducted, through the air filter and inlet manifold, into the uppermost part of the engine cylinder, where the piston resides. Imbedded in the top of the piston is the combustion chamber, and it is here that the engine derives its power. At this point the piston is near the bottom of the cylinder. As the compression stroke begins, the piston starts to accelerate to the top of the cylinder, compressing the air that is trapped in the cylinder. This compression process rapidly heats the air to an extremely high temperature. By now, the piston is near the top of the cylinder, in a position approaching top dead center (TDC). At this point in the compression stroke, fuel is delivered by the fuel injector at very high pressure (10,000 to 30,000 pounds per square inch, or PSI) into the combustion chamber. This injected fuel is ignited by the pressurized and heated air already in the combustion chamber, and the generation of power associated with the diesel engine begins.

The ignition of the air/fuel mixture releases great quantities of heat energy, which pushes down on the piston/combustion chamber assembly, forcing it down the cylinder. This process is called the power stroke, since it generates the engine's power. The piston is now near the bottom of the cylinder, in a position approaching bottom dead center, opposite top dead center. Finally, the piston starts to rise up the cylinder again, forcing any combustion products that have not been consumed during the power stroke out of the engine. This is the exhaust stroke, and at this point PM, NO_X, hydrocarbons (HC), carbon monoxide (CO), carbon dioxide (CO_2), and other emissions constituents are exhausted from the engine into the exhaust system and into the atmosphere. It is these exhaust products that are the object of concern, and the reason NYSERDA and its colleagues are pursuing projects to reduce these emissions.

Only one part of this four-stroke process, – the top of the compression stroke after fuel is injected into the cylinder – is the focus of fuel and on-engine modification strategies to reduce emissions. The physical and chemical properties of the fuel, air mixing, and subsequent ignition at this stage are all prospects for modification strategies. Except for engine repowering or replacement, all of the eleven fuel and on-engine emission reduction strategies in the ECT matrix discussed in Section 5 strive to control or influence this ignition activity at the top of the compression stroke.

<u>Emission Formation</u>

Emission formation in the diesel engine involves two diesel combustion processes: air-fuel mixing at the beginning of the intake stroke, and ignition and combustion of this mixture on the compression stroke. The effectiveness of any fuel technology or on-engine technology is entirely predicated upon its effectiveness to properly "form" this air-fuel mixture as a means of providing proper combustion.

Mixing air with fuel is the heart of the combustion process, and failure to properly develop the air-fuel mixture results in increased NO_X and/or PM emissions. The good news is that the twelve strategies discussed later in this report are all effective, in varying degrees, in reducing NO_X or PM. The bad news is that the strategies that reduce NO_X (by lowering the temperatures and pressures in the diesel engine's combustion chamber) typically increase PM, and vice versa (with some exceptions, such as emulsified diesel fuels). Scientists and engineers referred to this phenomenon as the "NO_X/Particulate tradeoff."

A brief description of this mixture/flame formation will be useful in understanding the mechanisms by which technologies control NO_X and/or PM formation. Figure 3.2 shows diesel fuel spray formation and the beginning of combustion in the combustion chamber. Heat release is the end product of combustion; this heat energy provides the work that moves the piston, which turns the rest of the engine's rotating components to provide power to the vessel propeller shafts. Air that has been ingested into the engine on the intake stroke is compressed as the piston moves upward during the compression stroke (see Figure 3.1). This compression heats up the combustion chamber to the point where ignition will occur, once fuel is injected. At this juncture, no fuel has been injected. Near the top of the compression stroke, the fuel injector injects diesel fuel at very high pressure and ignition begins.

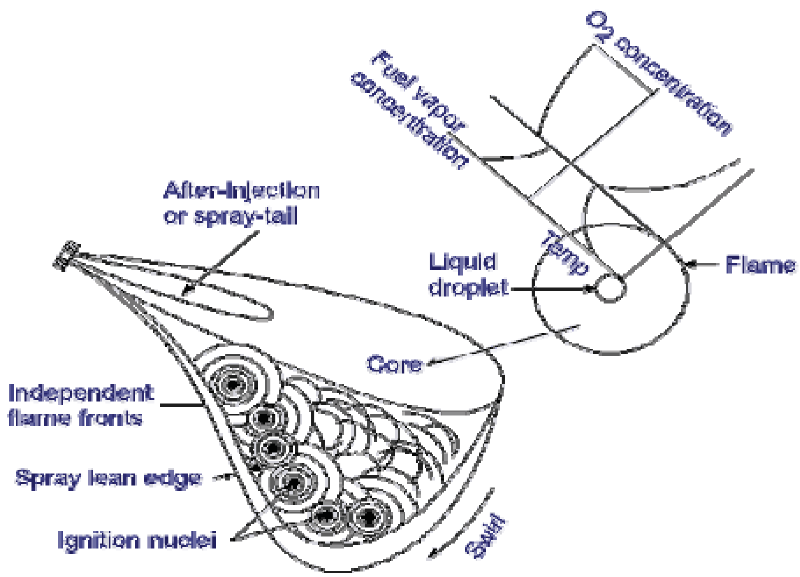


Figure 3.2. Diesel Flame Illustration, Beginning of Combustion.

This point in the cycle is called the start of injection, or SOI, as shown in Figure 3.3. The fuel atomizes into small droplets and penetrates into the combustion chamber. The atomized fuel absorbs heat from the surrounding heated compressed air, vaporizes, and mixes with the high-temperature, high-pressure air. The time that the fuel and air are mixing, but no ignition or subsequent combustion is occurring, is called the ignition delay period. This phase is critical to emissions formation. As the piston continues to move closer to the top of the cylinder the mixture reaches the fuel's ignition point, and ignition of the mixture occurs.

This is called the start of combustion. This initial ignition of the mixture, and resultant combustion, is the premixed combustion (or flame) phase, as described above and shown in Figure 3.2. As combustion continues, premixed combustion causes a rapid rise in cylinder pressure. The subsequent rate of burning is controlled by the rate of mixing between the remaining fuel and air. This is the diffusion combustion phase, so named because additional combustion is caused by the pre-mixed flame diffusing into the remaining air in the combustion chamber, causing ignition.

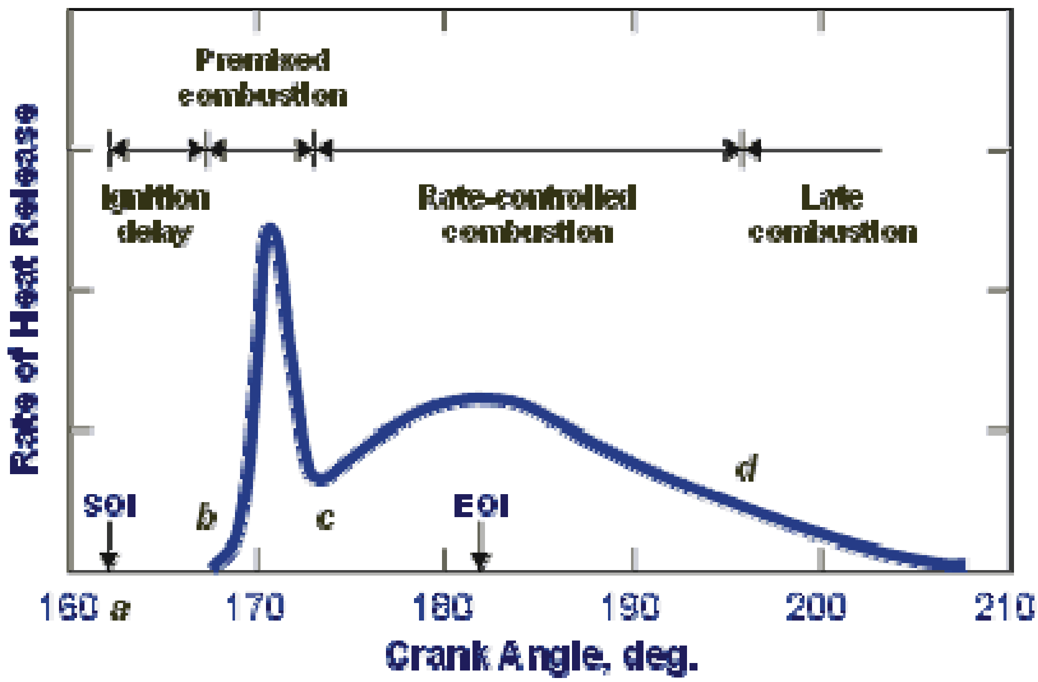


Figure 3.3. Crank-Angle Diagram.

The longer the ignition delay, the longer the amount of time the injected fuel mixes with the air in the combustion chamber before ignition. Greater mixing increases the fuel content of the mixture, which will increase the intensity of the resultant pre-mixed combustion flame. This means a "hotter" flame, and higher combustion temperatures and pressures. As a result, combustion is more complete, which reduces PM emissions. On the other hand, the higher temperatures and pressures cause NO_X to increase – the NO_X/particulate tradeoff discussed earlier. The formation of NO_X is controlled chemically by the amount of nitrogen and oxygen present in the combustion process itself, and physically by both the temperature of combustion and in-chamber residence time. Therefore, fuel options and on-engine modification options generally seek to alter one or more of these factors to reduce NO_X formation in the exhaust. Conversely, a decrease in the amount of pre-mix time results in cooler mixture and lower pressures. Combustion is less complete so PM increases, but combustion is cooler so NO_X decreases. Again, the effect of the thermodynamic NO_X/particulate tradeoff. Thus, to recapitulate:

- Longer ignition delay allows more time for the air in the combustion chamber to mix with the injected fuel.

- This greater time for mixing will result in a hotter flame, once combustion starts.
- This hotter flame will result in higher temperatures and pressures.
- Result: more complete combustion, PM goes down, but NO_X goes up.
- Fuel type, fuel composition, and on-engine emissions control strategies all do one thing – they affect the time of ignition delay, which in turn affects combustion temperatures and pressures, which influence the amount of NO_X and PM formation in the exhaust.

It should be noted that prior to the focus on emissions, diesel engines, fuels, and auxiliary equipment were all designed to provide an economical source of power. In general, previous engines were tuned to maximize thermal efficiency at the expense of increased NO_X formation. One of the simplest methods of NO_X reduction is to retard the fuel injection timing so that the fuel is injected later in the cycle. This will reduce NO_X, but it will also lead to lower fuel efficiency and higher PM.

This part of the study focused on exhaust aftertreatment emissions devices. The engines comprising the New York harbor private ferry fleet are, by and large, emissions certified, and any internal engine modifications may void the manufacturers' warranties and thus be economically unattractive to ferry vessel operators. The aftertreatment options include an array of commercially available fuels, selective catalytic reduction, diesel particulate filters, diesel oxidation catalysts, fuel-borne catalysts, humid air motors, lean NO_X catalysts, and any combination of these options. Generally, it was found that each option was good at reducing either NO_X or PM but not necessarily both. In order to significantly reduce the emissions of both pollutants, a combination of technologies would be needed. The following discussion provides a brief overview of each basic emissions control technology currently available. Table 3.1 is a summary of the emissions control devices and their effectiveness that were studied. During this study, these devices were found to be commercially available with a high potential for successful application to the NY harbour private ferry vessels. It should be noted that the engines and ratings required for many of the Tier 2 engine replacement strategies will not be available until 2007. This is because these engines will most likely have a cylinder displacement in excess of 3 liters.

Table 3.1. Emissions Control Devices.

ECT	Cost	Effectiveness, % Reduction				EPA Verified	Vendor
Alternative Fuels		NO_X	PM	HC	CO		
ULSD	$0.10-$0.25/gal premium	0	5-15	0	0	Y	Sunoco, BP, Valero, Exxon
Oxygenated Diesel Fuel	$0.10-$0.15/gal premium	5	40	0	25	Y	O2D, PureEnergy
Biodiesel 20%	$0.30-$0.40/gal premium	-2 to -10	15-70	10-40	10-50	Y	Various
Emulsified Diesel	$0.25-$0.40/gal premium	20	6.8	-30	3.4	Y	Lubrizol
Fischer-Tropsch Fuels (Synthetic Diesel Fuels)	$3.00/gal premium	5	30	22	58	Y	Sasol, Shell
Fuel-borne Catalysts	$0.05/gal premium	0--5	29	52	13	Y	Clean Diesel Technologies
On-Engine Emission Controls Devices							
FIE Optimization for NO_X	$50K	20	20	0	0	N	Original Engine Manufacturer
Ceramic Coating of Engine Components	$20K	0	20-50	0	0	N	Aftermarket
Exhaust Gas Recirculation	$20K	40	50	0	0	Y	STT Emtec
Humid Air Motor	$25K	20	0	0	0	N	MA Turbo
Closed Crankcase Ventilation	$700	0	15-20	0	0	Y	Donaldson, Fleetguard
Exhaust Aftertreatment Emission Control Devices							
Diesel Oxidation Catalysts	$5K	0	20-30	50-90	70-90	Y	Johnson Matthey, Englehard, Argillon
Diesel Particulate Filters	$10K	0	20-30	50-90	70-90	Y	Rypos, Johnson Matthey
Lean NO_X Catalysts	$20K	30-50	0	0	0	Y	Cleaire
Selective Catalytic Reduction	$75K	70-90	0	0	0	Y	Johnson Matthey, Combustion Components Associates
Wet Scrubbers	$100K	0	90	0	0	N	Marine Exhaust Solutions
ECT Combinations	$30-$75K	30-90	50-70	0	0	Y	Aftermarket
Other Methods							
Operating Cycle Change	0	5-10	5-10	5-10	5-10	N	N/A
Engine Replacement: Tier 2 Engine	$75-100K	25	25	25	0	Y	Original Engine Manufacturer

FUELS

The properties of the fuel used in a diesel engine have a profound effect upon the thermal efficiency, power, and emissions. The wrong fuel can easily destroy an engine by not having enough lubricity to keep the fuel injection equipment lubricated or by promoting pre-ignition, which could easily damage pistons, piston rings, bearings, and other components due to the high peak pressures. With the emphasis on lower emissions, regulations now mandate fuels with reduced sulfur concentrations. During the study, low sulfur diesel (LSD) of 500 ppm sulfur was the primary on-road fuel available in the NY metropolitan region and was the fuel of choice for the ferry vessel operators. Ultra-low sulfur diesel fuel (ULSD), with sulfur content of less than 15 ppm, will be mandated as a highway fuel by October 2006. This will help reduce sulfur compound emissions, reduce PM, and enable the emission control device manufacturers to utilize more effective catalysts in their equipment without the danger of sulfur poisoning.

Table 3.2. Diesel Fuel Regulated Sulfur Limits, in ppm.

Implementation Year	Fuel Use			
	Highway	Non-Road	Marine	Rail
1993	500	N/A	N/A	N/A
2006	15	N/A	N/A	N/A
2007	15	500	500	500
2010	15	15	500	500
2012	15	15	15	15
2014	15	15	15	15

Ultra-low Sulfur Diesel Fuel

Ultra-low sulfur diesel fuel is a petroleum distillate that undergoes hydro-desulfurization at the refining level to eliminate more than 99% of its sulfur content. Sulfur, a component of all petroleum-based feedstocks and grades, serves the primary role of engine lubricant, though undesirably so because it creates corrosive combustion by-products, releases sulfur oxides into the environment, and increases deposits on fuel injectors and combustion components. The hydro-desulfurization process works by passing a heated mixture of feedstock and hydrogen through a catalyst-laden reactor to remove sulfur as hydrogen sulfide and other impurities from gases or petroleum distillates. This creates a virtually sulfur-free fuel containing from 5 to 25 ppm sulfur, on average.

The movement to use ultra-low sulfur diesel widely in the United States is prompted by EPA regulations mandating that the fuel arrive at the retail and wholesale level for all on-highway applications by October 2006 (with some exceptions). Setting sulfur fuel standards at 15 ppm facilitates the adoption of emission control technologies that will enable diesel engine manufacturers to meet the more stringent diesel engine standards of 2007. The newer standards require a dramatic reduction in pollutants from heavy-duty diesel vehicles. Engine manufacturers aim to meet this standard using a combination of engine design improvements and exhaust aftertreatment, including exhaust gas recirculation and active diesel particulate filters. These technologies necessitate the 2006 fuel standard. Current EPA on-highway regulations set sulfur levels at 500 ppm for diesel fuel, although most on-road low sulfur diesel tests in the 350-450 ppm range at the retail pump. By contrast, non-road fuel grades contain sulfur in fuel levels of up to 3000 ppm. Even higher levels can be found in industrial boiler and marine applications. Future non-road regulations will bring these higher sulfur levels down to 2006 on-highway levels starting with non-road applications in 2010 and finishing with marine and locomotive fuels in 2012.

Ultra-low sulfur diesel is used primarily for reduction of PM and secondary emissions of sulfate particles (SO_4), even when used without any retrofit devices. Ultra-low sulfur diesel is often referred to as an "enabling technology" as its adoption by the industry will enable the use of aggressive emissions control technologies. Regionally, markets for ultra-low sulfur diesel are already being served by one or more providers. This is especially true in markets where attainment of EPA's proposed fine particulate matter standard (PM 2.5) will be a major focus. In the U.S., these regions currently include the NY metropolitan area, Ohio/Illinois, Texas, and California.

The removal of virtually all sulfur in a more highly refined fuel with an innocuous lubricity additive eliminates unwanted sulfur and sulfate formation in the combustion chamber and exhaust. As incomplete combustion leads to engine exhaust emissions of these particles, minimizing the introduction of such compounds at the source of formation in the combustion chamber serves to reduce particulate emissions by 5-15% on average, on a mass basis. Less in equals less out.

By late 2006 ultra-low sulfur diesel will be a reliable product. Until that time, however, product integrity issues remain foremost in controlling the level of fuel sulfur delivered to end-user locations. Storage, segregation, and contamination issues will continue to play a role as the fuel is stored and transported. The introduction of ultra-low sulfur diesel to the market may cause near-term pricing inefficiencies and irregularities until the majority of refiners and suppliers convert to ultra-low sulfur diesel production. EPA economic models project an ultra-low sulfur diesel price premium of 6.5 to 7.2 cents per gallon during the period 2007-2011.

Using ultra-low sulfur diesel as a fuel for the ferry vessels should not impose many difficulties providing the fuel supplier can meet the engine manufacturer's fuel property requirements. The operators will have to bear the cost differential over their current low sulfur diesel fuel. However, during the study period, the ultra-low sulfur diesel available in the NY metropolitan area was refined from No. 1 diesel fuel. No. 1 diesel fuel typically has a volumetric heating value that is approximately 3% lower than a comparable No. 2 fuel. This alone will cause a commensurate fuel use increase. No. 1 diesel fuel also has a significantly lower viscosity. This may affect the quality of the fuel injection, especially in the older, mechanically fuel injected vessels. Moreover, the No. 1 ultra-low sulfur diesel has a flash point lower than that required by the U.S. Coast Guard for many of the private ferry vessels. A complete comparison between No. 1 ULSD and No. 2 LSD fuels was performed in Phase I and is presented in Section 4.

Oxygenated Diesel Fuel

Oxygenated diesel fuel (O2D) is a diesel fuel blend using oxygenated ethanol and a stabilizing proprietary additive. Manufacturers of oxygenated diesel fuels claim a significant reduction in PM and visible smoke along with some NO_X and CO reductions. The product is fully fungible with all diesel fuels and can be blended effectively with any diesel fuel.

Using oxygenated diesel fuel for the ferry vessels should not impose many difficulties providing the fuel supplier can meet the engine manufacturer fuel property requirements. The operators will have to bear the cost differential of approximately \$0.10-\$0.15/gal over their current low sulfur diesel fuel. However, the oxygenated diesel fuel has a volumetric heating value that is approximately 3% lower than a comparable No. 2 fuel. This alone will cause a commensurate fuel use increase. Moreover, the oxygenated diesel fuel can have a flash point less than that required by the USCG for many of the private ferry vessels.

Biodiesel Fuel

Biodiesel fuel is a both a cleaner burning fuel and a fuel additive, if mixed in concentration with petroleum diesel. It is biologically derived from domestic, renewable sources such as fats and vegetable oils. Biodiesel refers to the pure fuel ("neat") before blending with diesel fuel. Blends are denoted as "BXX," with "XX" representing the percentage of biodiesel contained in the blend; B20 is 20% biodiesel, 80% petroleum diesel. Pure biodiesel (B100) is biodegradable, non-toxic, and virtually free of sulfur and aromatics.

Biodiesel is produced through process called transesterification, in which a fat undergoes reaction with an alcohol (such as methanol) in the presence of a catalyst (usually sodium or potassium hydroxide) to yield mono-alkyl esters (biodiesel) and glycerin. Biodiesel conforms to ASTM D6751 specifications for use in diesel engines and is attractive as a "renewable" fuel due to its potential greenhouse gas lifecycle benefits. It is used primarily as alternative to conventional diesel to achieve PM, CO, HC, and polycyclic-aromatic hydrocarbon (PAH) reductions and by state and federal fleets to conform to certain renewable energy requirements.

Most U.S. biodiesel is soybean based, due to abundant supply of this feedstock. Therefore, the current supply nucleus centers around those heartland states with abundant soybean production, such as Missouri, Nebraska, Iowa, Illinois, and Minnesota, although the fuel is available in all 50 states and production capacity is expanding along the Eastern seaboard.

The effectiveness of biodiesel in reducing emissions varies with BXX %. Generally, there is a modest application-specific NO_X penalty of between 2 and 10 percent associated with the use of biodiesel. Increasing the level of biodiesel in the fuel blend increases NO_X with a proportionally greater reduction in PM. Reduction in CO and HC improves linearly with the addition of biodiesel, according to the literature. This is indicative of more complete combustion, thought to be promoted by the increased content of oxygen in the fuel.

Fueling with biodiesel will reduce the solid or carbonaceous fraction of the PM, which cannot be removed by an oxidation catalyst. The use of biodiesel in combination with a catalyzed, continuously regenerating trap and selective catalytic reduction system would remove even more of the solid PM component from the exhaust; it would also provide an opportunity to oxidize the soluble fraction stemming from engine lubricant and to address NO_X reductions..

There will definitely be a place in the diesel economy for biodiesel, primarily because of the fuel's attractive properties as a renewable fuel and its cleaner emissions profile, though the extent of its long term use and overall market share remains difficult to predict. Commercialization will continue as demand warrants, with limited probability of success without greater regulatory incentives. The probability of success in this application, however, is high. Recently the fuel outperformed ultra-low sulfur diesel and emulsified diesel fuel in an engine dynamometer study by the New York State Department of Environmental Conservation (NYSDEC). Overall, the biodiesel ratio will dictate the overall emission reduction potential and corresponding technology deployment strategy.

This fuel should not pose many difficulties providing the fuel supplier can meet the engine manufacturer's fuel property requirements. The operators will have to bear the cost differential of approximately $0.30-$0.40/gal over their current low sulfur diesel fuel. Biodiesel diesel fuel has a volumetric heating value that is approximately 3% lower than a comparable No. 2 fuel, which will cause a commensurate fuel use increase. Additionally, the fuel has a tendency to gel up in cold weather.

Emulsified Diesel Fuel

Emulsified diesel fuel (EDF) is a petroleum distillate that undergoes emulsification, a process in which one liquid is suspended within another. A proprietary chemical agent is added to suspend water micro-droplets in the fuel, typically in the following proportions: 77% diesel, 20% water, and 3% emulsifying agent. Water content can range from 5 to 40%, depending on the production specification and end user application.

The practice of emulsifying fluids in diesel is not new. The science of using additive chemistry and blending techniques to specifically address the air quality characteristics of diesel exhaust emissions is evolving, however, with a number of U.S.-based and international companies taking a lead role in its advancement. Key to this practice is the suspension of sub-micron sized water droplets in the fuel, a process accomplished by using additives that encapsulate and suspend the droplets during the blending process, thereby creating a secure, stabilized product ready for delivery, storage, and combustion.

The principle effect of water in fuel is to lower the combustion temperature, i.e. to reduce the peak flame temperature within the combustion chamber to modify the combustion process itself and mitigate the formation of NO_X emissions. NO_X formation in the diesel combustion engine is influenced by N_2, O_2, the temperature of combustion, and the residency time. Water emulsions reduce NO_X formation and thus emissions by lowering the overall temperature of combustion.

Water also serves to alter fuel flow properties and injection characteristics, which has the benefit of reducing PM emissions. By increasing liquid column penetration during pre-mixed combustion, water facilitates more entrainment and less PM formation. It also promotes a larger flame light off length, resulting in a less rich combustion process and thus lower PM emissions (especially at higher loads).

The emission reduction effectiveness percentages cited in Table 3.1 apply to non-road engines of greater than 300 hp, using summer PuriNOx blend, as provided by the EPA – retrofit technology verification page located in Appendix K. Actual mission reductions achievable using EDF are highly variable; they depend on the engine, test cycle, emulsification process, water content, baseline diesel fuel properties, and peak torque vs. torque loss comparison (less work per composite duty cycle). There is conflicting data in the literature concerning PM mitigation/production with EDF. In some engines, longer flame length may lead to excess PM creation due to emulsified diesel fuel "splashing" on the combustion bowl during incomplete combustion. More PM is then expelled during the exhaust stroke. CO, HC, and toxic air contaminants have a propensity to increase with emulsion, some by factor of 2 or more though not in quantities above regulatory standards, due to inherently low emissions output.

The market for emulsified diesel fuel in the U.S. is supported by several factors. Counties designated as non-attainment have an immediate need for an alternative to diesel that addresses both NO_X and PM reductions simultaneously. Support also comes from demonstration projects in those areas and others throughout the country, and by the EPA's Environmental Technology Verification (ETV) Program, which has verified and approved emulsified diesel fuel for use in diesel engines. There is significant question as to the future commercialization and probability of success with emulsified diesel fuel, primarily due to economic factors and secondarily to potential engine performance factors. It is unclear if a national market for this product will emerge, especially with the EPA mandated ultra-low sulfur diesel requirements in 2006.

Emulsified diesel fuel should not impose many difficulties providing the fuel supplier can meet the engine manufacturer's fuel property requirements. The operators will have to bear the cost differential of $0.25-$0.40/gal over their current low sulfur diesel fuel. Significant losses in fuel economy have been experienced with emulsified diesel fuel, on the order of 10-30%. This varies due to the water-in-fuel percentage, on-road vs. off-road engine application, and the age of the engine (whether it is mechanically vs. electronically controlled). The emulsified diesel fuel also has a very significant volumetric heating value that is approximately 30% lower than a comparable No. 2 fuel. Lower fuel economy will cause a commensurate fuel use increase and will possibly cause a high end power limitation. The fuel has a finite shelf life, plus it has a tendency to separate and freeze in cold weather.

Fischer-Tropsch Fuel

Fischer-Tropsch is a term used to characterize clean fuels derived from natural gas, coal, and low value refinery products using the Fisher-Tropsch reaction. In this process, the raw materials are partially oxidized in the presence of air or oxygen to produce CO and H (synthesis gas, or "syngas"), converted to light hydrocarbons using catalysts and appropriate conditions (FT catalysis), and further processed by hydrocracking and isomerization to produce diesel (post-processing). The end result of the Fisher-Tropsch process, as detailed in Figure 3.4, is a diesel fuel with no detectable aromatics or sulfur, low olefins, and improved lubricity over conventional diesel.

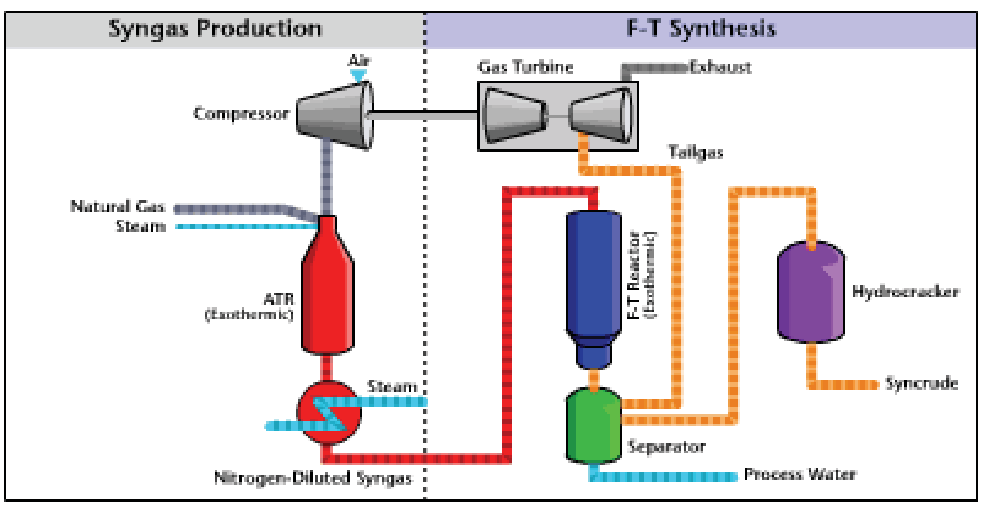


Figure 3.4. Fischer-Tropsch "Syngas" Production Process.

Fischer-Tropsch (FT) fuels were named after the German coal researchers Franz Fischer and Hans Tropsch, who discovered the process for synthesizing hydrocarbons. They are widely used in South Africa today and have been blended with crude oil-derived fuels in the U.S. to meet California's diesel fuel quality standards. Synthetic diesel fuels have not been widely used in the U.S. to date, although Syntroleum is expanding its land- and sea-based gas-to-liquid conversion technology using the Fischer-Tropsch syngas method to produce a competitive alternative to ULSD.

The absence of virtually all aromatics and sulfur compounds in Fischer-Tropsch fuels lessens the combustion emissions for both regulated and non-regulated pollutants, especially compared to either conventional or ULSD diesel. Engine and chassis dynamometer testing at South West Research Institute (SWRI) San Antonio, TX, demonstrates a decreasing trend in NO_X, PM, HC, CO, air toxics, and overall greenhouse gases with decreasing aromatic and sulfur content in fuel. In addition, the higher cetane value of Fischer-Tropsch fuels improves auto-ignition tendency, thereby attaining 2-5% additional NO_X reduction. This synthetic diesel could very well become the gold standard for the compression ignition engine, against which the resultant emissions profiles for all other petroleum-derived alternative fuels will be measured.

Until recently Fischer-Tropsch fuels have enjoyed little commercial development aside from South America, although that is all changing with the movement of global refining giants into the gas-to-liquid conversion market in Qatar and other developing nations. Worldwide expansion into Fischer-Tropsch fuel production will be accelerated by high crude petroleum prices, universally abundant gas and coal supplies, more cost-effective syngas production processes, and a move to cleaner emissions forms of diesel.

For the private ferries demonstration, the probability of success with this fuel is extremely high. The fuel will outperform all other alternatives in this category – including biodiesel, ultra-low sulfur diesel and emulsified diesel fuel – by a wide margin. This prediction is supported by SWRI and NYSDEC research. In the near term, uncertainty remains about regional availability, pricing, and demand, but the future outlook is improving rapidly for the long term availability of synthetic FT diesel.

Fuel-borne Catalysts

Fuel-borne catalysts (FBC) are utilized as a pre-combustion fuel system dosing technique.
Noble/precious metal based catalysts, typically platinum and cerium (4–8 ppm), are pre-mixed with diesel at a 1500:1 gallon ratio. Fuel-borne catalysts act to promote more complete in-cylinder combustion, thereby minimizing engine emissions of HC, CO, and PM. The enhanced combustion also increases engine power and significantly improves fuel economy. Fuel-borne catalysts are a scientific formulation of metal additives blended with diesel detergent and a petroleum distillate “carrier” to make a complete additive package. Typically the metal additives are platinum or some other noble metal. However, the health effects of the emissions common to fuel-borne catalyst usage are only recently being studied. The long term health effects are not known. Use of noble metal based catalysts may be restricted in the future due to the associated emissions of nanoparticles of cerium and platinum, the very elements that make these products effective.

On their own, fuel-borne catalysts are claimed to lower PM and HC emissions up to 30% while delivering significant fuel economy improvement – especially in stationary generator, marine, and locomotive engines. EPA has recognized and verified the "Platinum Plus" Fuel-borne catalysts from Clean Diesel Technologies as providing certain minimum and potentially even higher emissions reduction levels when used in combination with diesel oxidation catalysts, diesel particulate filters, or catalyzed wire mesh filters. Although other FBCs exist and offer similar emissions reduction claims, at the time of this study "Platinum Plus" was the only EPA verified FBC. Therefore, this Clean Diesel Technologies product was the only FBC considered within the framework of this section and the remainder of the report.

Usage on the ferry vessels would be unrestricted. A minimal amount of operator intervention would be required to add the fuel treatment. Batch treatment is possible so that a prescribed amount of fuel additive would be added each time the vessel fuels.

ON-ENGINE MODIFICATIONS

On-engine modifications are those technologies that are installed directly on the engine or changes made to engine components. These modifications range from fuel injection equipment modifications to aftermarket exhaust gas recirculation and humid air motor systems. Some are methods available to improve the performance of engines that have been deemed too costly for the engine manufacturers to incorporate into their products. Others are aftermarket versions of equipment installed by the manufacturers on on-road and off-road vehicles that have not been employed in the marine market because of cost constraints. A number of modifications would not be feasible without the manufacturers' input. The engines used in the NY harbor private ferry vessel fleet are EPA certified, so it would be against the law to tamper with components that affect emissions. However, if there were a market and a means, engines could be recertified with modified components in place.

Fuel Injection Equipment (FIE)

The fuel injection system is often referred to as the heart of the diesel engine simply because it is such an integral part of its proper operation. It is the most important component in determining the proper air/fuel mixture. From the earlier discussion regarding air/fuel mixture preparation, it is clear that proper mixture preparation determines the concentrations of NO_X and PM emanating from the engine's exhaust. In addition to delivering fuel to the engine, this system serves two additional key functions:

- It determines when in the combustion cycle the fuel will be injected – injection timing.
- It determines the amount of fuel injected during the engine cycle – injection metering.

Increasingly sophisticated systems have been developed that perform considerably more functions than simple injection timing and injection metering. These additional functions include the following:

- **Pilot-injection** – a “pre” injection of a small quantity of fuel, before the main injection event. Pilot injection tends to keep the extent of pre-mixed combustion lower than with a “full squirt” from a main injection event. This lowers combustion chamber temperatures and pressures, thus lowering NO_X levels.
- **Post-injection** – a second injection after the primary injection event, often used to increase exhaust temperatures and promote diesel particulate filter regeneration.
- **Multiple injections** – injection strategy comprised of a number of strategically developed injections for each four-stroke combustion cycle, designed to optimize engine performance (power and low emissions) over different operating regimes.
- **“Boot” injection** – a graduated flow of fuel in which the rate of fuel injection starts out low and increases as the injection proceeds. Boot injection is single “squirt” of fuel as opposed to multiple injections.

Each of these features affects exhaust emissions at different operating regimes of the diesel-powered vehicle. The goal is to specifically design the injection strategy such that it minimizes both NO_X and PM formation, while not affecting (or affecting as little as possible) engine power and fuel economy. This goal has been accomplished through electronic controls for two fuel injection equipment types: unit injection and common rail. Armed with both “boot” and multiple injection capabilities, these types of systems can tailor fuel injection to maximize power and minimize emissions.

The most flexible fuel injection systems have two distinguishing characteristics: they can deliver fuel at very high pressures for maximum spray atomization and most efficient burning in the combustion chamber, and they can do so, essentially on demand, for any engine speed and load throughout the engine’s operating range. There are three major types of fuel injection systems. They are, in approximate order of sophistication, pump-line-nozzle (P-L-N), unit injection (UI), and common rail (CR). Each is successively more effective in reducing exhaust emissions, since each can provide higher injection pressures than the previous, and each exhibits a greater degree of precise control over the fuel injection metering. This provides a mechanism for the precise “tailoring” of the fuel injection illustrated previously in Figures 3.1 and 3.2.

Regardless of which design is employed, at the end of each system resides the injector nozzle. It is mounted on top of the engine, protruding into the combustion chamber where it delivers a specified quantity of diesel fuel. Descriptions of the three types of fuel injection equipment (FIE) are provided in the following paragraphs.

Pump-Line-Nozzle (P-L-N). Pump-Line-Nozzle systems are the oldest design and have been on diesel engines almost since their inception in the early 1900s. The P-L-N design is illustrated in Figure 3.5. It uses a central injection pump driven off the engine camshaft to feed fuel at comparatively high pressures to the injectors located on top of the engine, one for each engine cylinder. Fuel injection pressures for P-L-N systems are limited by two constraints. First, pressure is dependant upon engine speed, being reasonably high at high engine speeds but dropping off considerably at lower speeds. Second, maximum pressure is limited by the fuel line connecting the high-pressure pump to the injector, due to hydrodynamic friction losses within the line. Both limit injection strategy flexibility. P-L-N systems exist in both mechanical and electronically controlled configurations, the latter more effective in controlling injection and thereby reducing emissions.

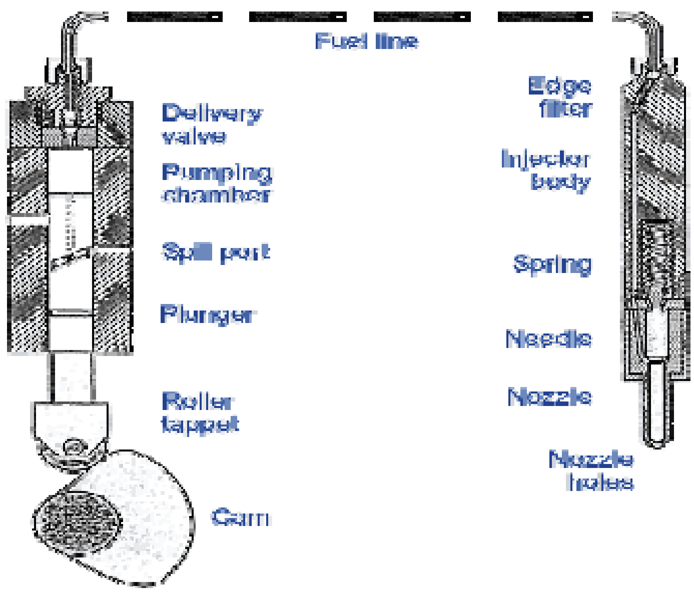


Figure 3.5. Pump Line Nozzle System.

Electronic Unit Injector (EUI). Unit injectors incorporate the injection pump and the injector itself as one device, or unit, as shown in Figure 3.6. The injector is mounted directly on top of the engine, with the nozzle portion inserted into the engine's combustion chamber. The upper part of the unit is directly connected to the engine's camshaft, which pumps the injector to provide the necessary fuel pressure. Because of the absence of fuel lines from a separate pump as with P-L-N designs, as well as the overall compact design, fuel injection pressures are considerably higher, aiding in fuel spray atomization and generally helping to reduce engine emissions. Almost all UI systems are electronic (hence EUI for electronic unit injection), contributing to the ability to develop effective injection strategies. And while injection pressures are higher than P-L-N systems, a critical limitation shared by both of these FIE systems is the dependence of fuel injection pressure upon engine speed.

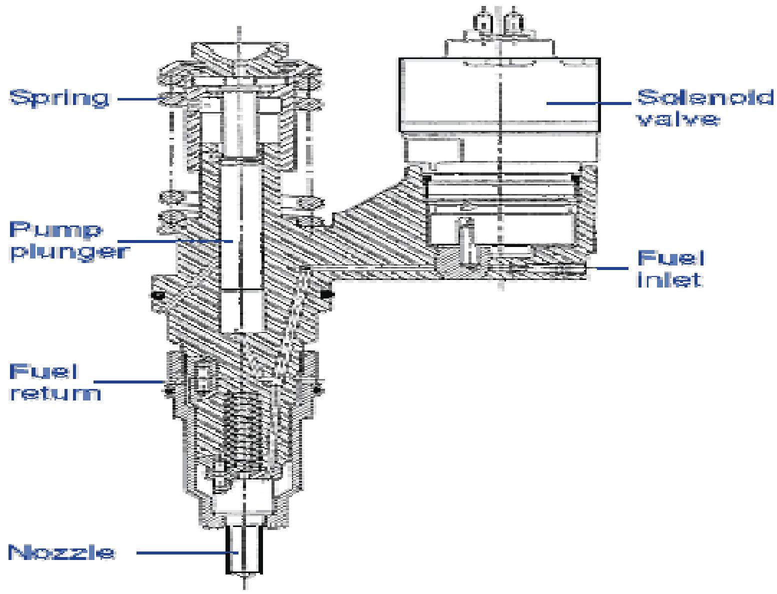


Figure 3.6. Electronic Unit Injector.

Common Rail (CR). Common rail systems use a high pressure pump, usually driven via direct mechanical drive off of the engine, to provide very high fuel line pressures. As shown in Figure 3.7, fuel is fed into a common rail mounted alongside the engine block, and from the rail to one injector for each of the engine's cylinders (e.g. 8 cylinder engine = 8 injectors). Pressure is built up in this common rail and is maintained regardless of engine speed or load. High pressure fuel is therefore available at any time and at any engine speed, providing enormous flexibly in designing an overall injection strategy to maximize engine power and torque and minimize exhaust emissions and fuel consumption.

Figure 3.8 summarizes the relationship between injection pressure and the three different FIE systems discussed above. The figure depicts the fuel injection pressure as a function of engine speed for the three different systems. Note the broad band of maximum injection pressure across the entire engine speed range (RPM) with the common rail system (green horizontal line). For the purposes of this study, a mechanical P-L-N system is used as the performance baseline for fuel injection engines. Electronic versions of the P-L-N, as well as electronic EUI and CR systems are considered viable "on-engine modification" emission control technologies (ECTs).

Given the complexity of electronic FIE systems (P-L-N, EUI, or CR) as well as the differing quantifiable effects of injection optimization with engine model, type, and duty cycle (route) undertaken by a specific vessel, it is impossible to provide exact emissions reduction values for a specific optimization scheme. However, some general engine emission trends are provided graphically in Figure 3.9, as a function of key FIE optimization approaches:

- **Increasing Injection Pressure** – Referring to Figure 3.9, increasing injection pressure reduces smoke (green line) and PM (blue line), since increased injection pressures “shoot” more fuel deeper into the combustion chamber, enhancing fuel atomization and vaporization to fully utilize the air in the engine’s combustion chamber. This results in a hotter pre-mixed flame and more complete combustion. Not shown is the obvious disadvantage of increased NO_X emissions.
- **Pilot Injection** – Introducing pilot injection will reduce NO_X by reducing the temperature of the pre-mixed flame; this is only possible with electronically controlled FIE, and accomplished most precisely with common rail systems. Given the NO_X/PM tradeoff, it is not surprising to see an increase in smoke (used here as an illustrative surrogate for PM).
- **Start of Injection (SOI)** – Advancing SOI reduces PM and HC, but rapidly increases NO_X formation, according to the mechanisms explained earlier in this section. Conversely, it is beneficial to retard fuel injection timing, which effectively delays SOI, as the most feasible mechanism for NO_X reduction (as explained earlier in Emissions Formation). However, care must be taken to limit the amount of retardation to approximately 5 or 6 degrees from the engine manufacturer’s recommended baseline specification, to avoid excessive PM, HC, and smoke emissions as well as increased fuel consumption.

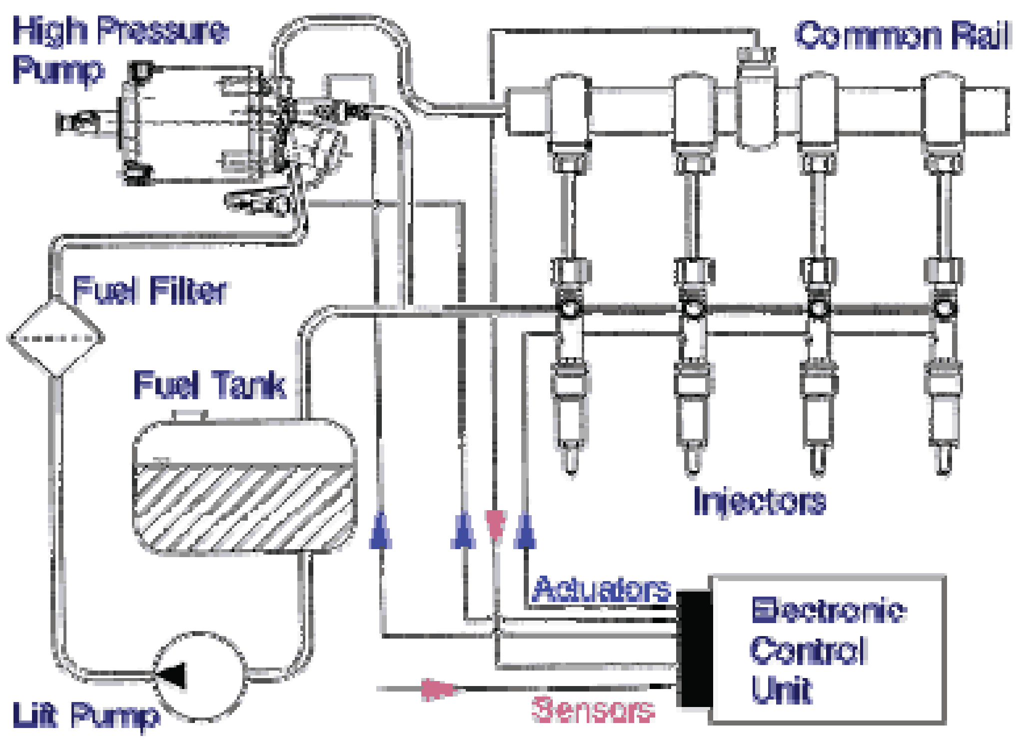


Figure 3.7. Common Rail System.

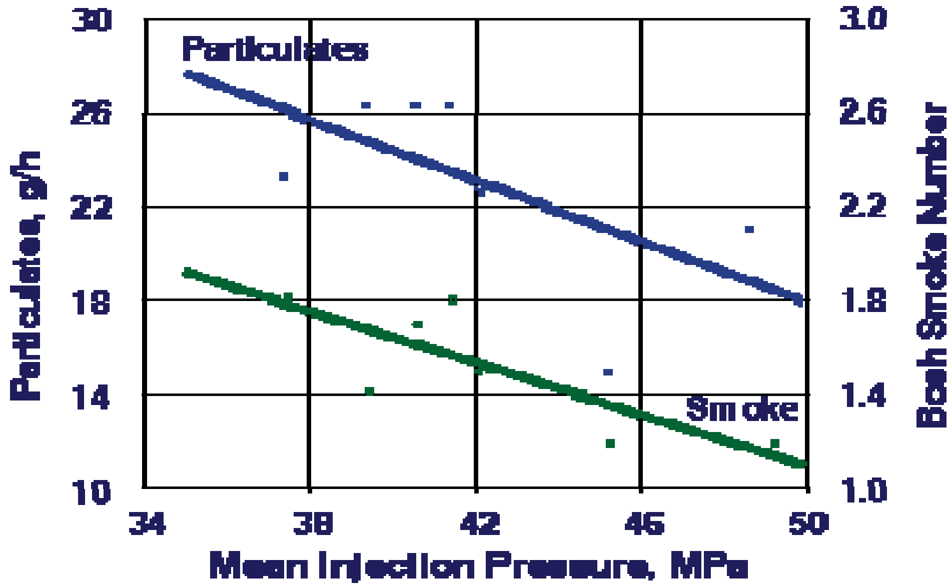


Figure 3.8. Fuel Injection Pressure vs. Engine Speed.

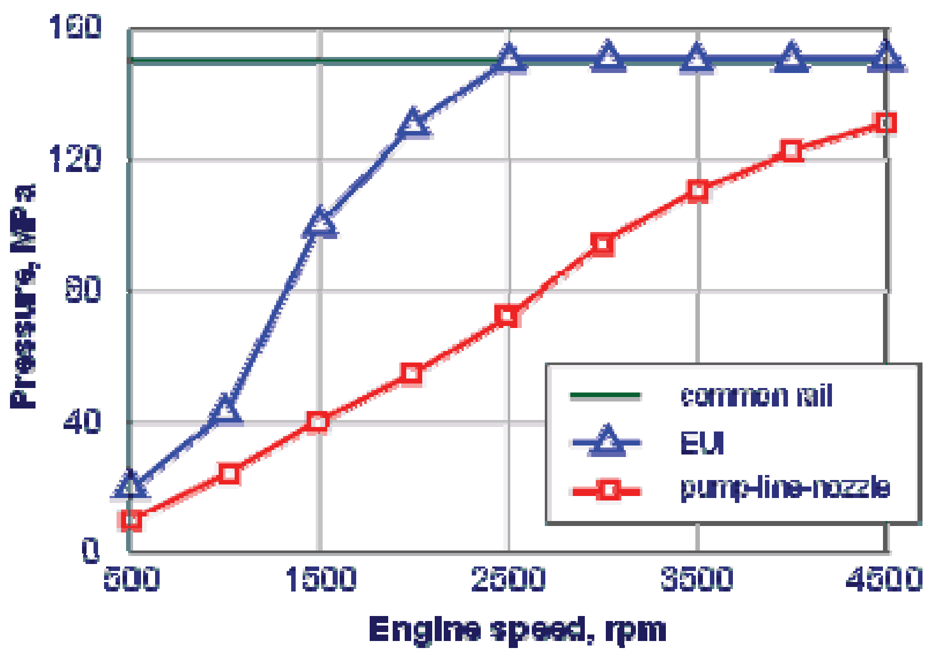


Figure 3.9. Effect of Injection Pressure.

Modifying the fuel injection equipment on the ferry vessels to reduce emissions is feasible, and there would be little if any impact to the vessel's operations in any way. However, any changes to components, timing, and electronic control map would have to be done by the engine manufacturer because these engines are EPA certified. Any unauthorized modifications would constitute tampering. In order to make significant changes, it would be necessary to recertify the engine once the changes were made. This would be an extensive and costly process, and the ultimate gains probably would not match the emissions performance of marine Tier 2 certified engines.

Diesel Ceramic Coatings

Thermal barrier coatings (TBCs) have been employed for 22 years in all types of diesel engines. TBCs have been used to reduce corrosion of pistons and valves, improve fuel efficiency, reduce pollution, allow use of lower quality fuels, improve cold start capability, reduce maintenance costs, improve power, and improve lubricating oil life.

Diesel TBCs are plasma-applied ceramic coatings, which insulate combustion components such as pistons, valves, and fire decks from thermal transmission and shock. The insulation reduces the heat flow to the water jackets and through the piston crown into the lubricating oil. This means that more heat energy is retained and available in the cylinder to work on the piston.

The ability to reduce emissions is best explained by how TBCs work within the diesel combustion process itself. The diesel combustion process occurs in two zones. There is a "pre-mix" zone where fuel oil is injected and mixed with air, as shown earlier in Figure 3.3. Toward the end of this process fuel oil and air detonate, causing a sharp high pressure and temperature spike recognizable by the familiar "diesel knock." The formation of NO_X occurs primarily at the high temperatures associated with detonation. In the quieter diffusion combustion zone that forms after the diesel knock has occurred, the fuel oil burning rate is controlled by the need to find oxygen. This diffusion zone provides the time needed to burn soot formed in the pre-mix zone. Diesel TBCs, with their ability to radiate heat for longer periods, aid in this soot-burning process.

Diesel engine components coated with diesel TBCs force two major changes in the combustion process. First, there is a reduction of the ignition delay between the start of fuel injection and ignition of the fuel oil. Second, there is a major reduction in the combustion spikes. These result in a decrease in NO_X and unburned HC, more complete oxidation of soot, reduced exhaust particulate emissions, and reduced smoke. This improved combustion efficiency translates into substantial fuel savings and many other additional benefits. Seaworthy Industrial Systems, Inc. (SIS) of Essex, Connecticut, has reported some major successes in emissions reduction and improved engine performance with the use of diesel TBCs. A 22-year study conducted by SIS on ceramic thermal barrier coatings in diesel applications demonstrated the following potential benefits:

- Fuel savings, 5% maximum
- Longer engine life, 20% maximum
- Increased power, 10% maximum
- Reduced particulate emissions, 20% to 50% maximum
- Reduced stack opacity, 75% maximum
- Reduced ignition delay, 3^{o} CA (crankshaft angle) maximum
- Lubricating oil savings, 15% maximum
- Reduced engine noise, 3dB maximum
- Increased cold-start reliability at low temperatures
- Reduced part temperatures by 100^{o} C (180^{o} F)
- Longer exhaust valve life, 300% maximum
- Reduced maintenance costs, 20% maximum

Although they have been an integral part of aerospace technology for many decades, it is only recently that TBCs have been modified and tested for safe use in diesel engines. Major differences exist between TBCs in aircraft and diesel engines. Although diesel engines operate at lower temperatures than aircraft engines, their TBCs are subjected to much greater compressive loads and more frequent thermal shock than their aircraft engine counterparts. In addition, diesel engine TBCs must cope with the contaminants often found in lower grade diesel fuels. The differences between aircraft TBCs and diesel TBCs are often ignored by coating applicators, resulting in premature failure of the coating.

TBCs are applied by a thermal spray plasma process. The process calls for the application of a metallic bond coat followed by a ceramic topcoat. Thickness control is critical to the success of the application. If the total coating thickness is not tightly controlled to within .003", spallation can occur due to the uneven heating and cooling of the ceramic topcoat. To control thickness, TBCs are applied using robotics. Eddy current probes are used to measure thickness and correlated to physical measurement standards. As a final confirmation of the thickness, control tabs are TBC-coated with the component and viewed under a microscope.

The bond coat material is comprised of various combinations of nickel, cobalt, and chromium, with additions of aluminum and yttrium. The combination of nickel, cobalt, and chromium provides the high melting temperature (+2,800 degrees F/1,538 degrees C) of the coating alloy, while the aluminum and yttrium protect the alloy from oxidation by forming a thin, adherent layer of aluminum oxide. Aluminum also generates an exothermic reaction during the process, which enhances the bond strengths of the coating (+8,000 psi). The top ceramic coat is almost always comprised of zirconia (partially stabilized zirconium oxide) due to its high melting temperature (4500°F/2480°C) and its low thermal conductivity (1.3W/mK). Over the years, various stabilizers have been added to the zirconia to achieve greater high-temperature performance.

Use of TBC in the ferry vessels would be unrestricted. The ceramic coating would not have any impact upon the vessel's operation. Some gains, 3%, could be expected in fuel efficiency and up to a 20% increase in overhaul intervals. Also, there would be a visible reduction in smoke production. In order to utilize the ceramic coatings to control emissions they would have to be combined with an FIE optimization, simply because the net result of the coatings is to keep more heat in the combustion chamber therefore increasing peak temperatures. However, it is unlikely that these coatings could be applied to any of the certified engines in the NY harbor private ferry fleet without consultation with the EPA and possible engine recertification.

Exhaust Gas Recirculation

Used for NO_X reduction, exhaust gas recirculation systems return a portion of the engine exhaust gases back into the engine. These essentially inert (non-reactive) exhaust gases reduce combustion temperatures and pressure in the engine, thus lowering NO_X. Two processes employing exhaust gas recirculation to reduce combustion temperatures and pressures include:

- Dilution of the intake air with inert exhaust gases decreases oxygen content in the combustion process, and
- Heat absorption by the exhaust gas recirculation stream through the heat absorbing capacity of CO_2 (thermal effect) and dissociation of CO_2 (chemical effect).

High-pressure exhaust gas recirculation systems are the most common and effective systems for retrofit application. Such systems "siphon off" a portion of the engine exhaust gases and direct them back into the engine before the turbocharger, talking advantage of the manifold depression upstream of the turbocharger to "suck" the exhaust gases into the engine (see Figure 3.10). These systems require a clean exhaust supply to ensure that the turbocharger is not damaged by what would otherwise be soot-laden exhaust. This is accomplished through the installation of a diesel particulate filter (DPF), which removes PM. The exhaust is drawn off after the DPF and re-enters the engine via the EGR system, through the turbocharger. EGR systems typically have a cooler in line with the recirculated gas so that the charge air doesn't get too hot.

EGR is a proven method to reduce NO_X and is in widespread use in on-road vehicles. Use in the ferry vessels would be unrestricted, as long as the engine contains or can be fitted with a DPF so that the exhaust gas that is being recirculated does not contain PM. The EGR system would reduce fuel efficiency by 3-5%, and the dilution of the charge air with exhaust gas may impose a limit on the engine's rated power.

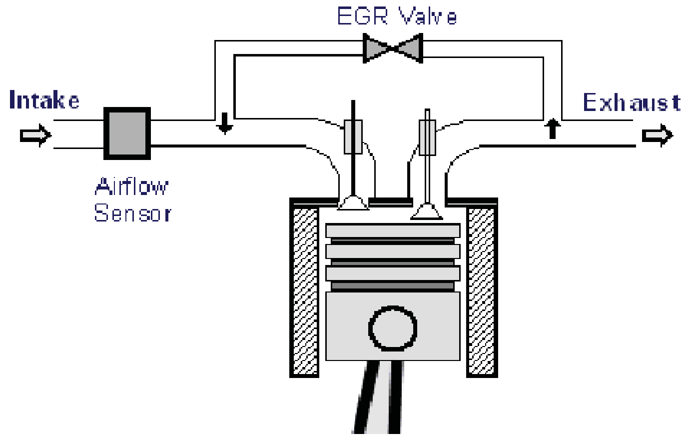


Figure 3.10. Exhaust Gas Recirculation Schematic.

<u>**Humid Air Motor**</u>

It has long been demonstrated that the addition of water into the diesel engine combustion process is an effective means of reducing NO_X on relatively large engines. Three methods exist to introduce water in diesel combustion: water emulsified diesel fuels (discussed above under Fuels), inlet fumigation, and direct water injection. These three techniques for creating a humid air motor are shown in Figure 3.11.

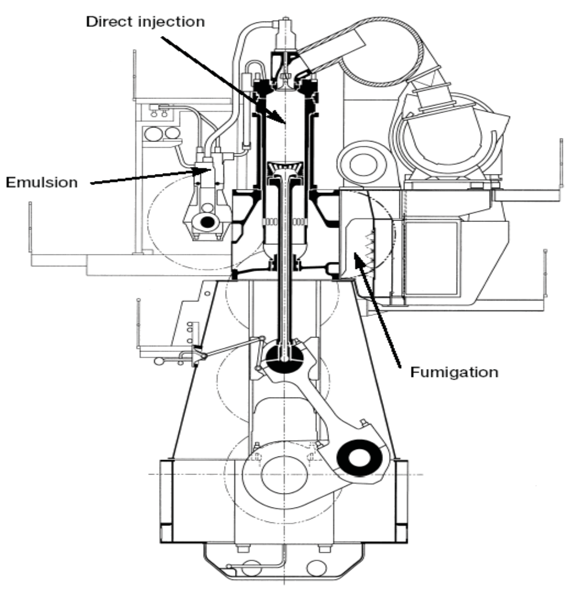


Figure 3.11. Humid Air Motor Techniques.

Inlet fumigation is the simplest method of introducing water into diesel engine combustion. This method "sprays" the water into the intake manifold, where it enters the engine and is mixed with the incoming combustion air. The fumigation system is an electronically actuated system, separate from any other electronically actuated system on the engine. It generally sprays water droplets at a steady, constant rate (i.e., the rate and timing of water injection is constant, and cannot be altered to suit the real-time, instantaneous operating characteristics of the engine). The inability to respond to changing engine conditions limits theoretical NO_X reductions.

Water addition to the diesel combustion process reduces NO_X emissions by lowering the combustion temperatures and pressures that are the cause of excessive NO_X formation. However, water addition may also decrease or have minimal effect on PM formation (depending on the technology used), or upon fuel economy. While no definitive mechanism has been conclusively accepted, the prevailing theory is as follows. The addition of water promotes enhanced mixing by improving the atomization of the fuel/air mixture. This enhanced mixing results in accelerated mixture formation and increased ignition delay, which in turn increases pre-mixed combustion. The additional pre-mixed combustion causes a higher rate of heat release, higher combustion pressures, and, in general, more complete combustion. Typically, these effects promote PM reductions and NO_X increase, but water also reduces peak combustion temperatures in the engine, thereby reducing NO_X formation. As a result, water addition reduces NO_X formation while at the same time having little PM effect (fumigation or direct injection), or actually reducing PM (emulsified diesel fuel).

Use of humid air motor technologies in the ferry vessels would be problematical. The separate water injection and metering pump needed for direct injection would require substantial modification to the engine cylinder heads at high cost. These modifications may not be feasible since the cylinders heads on the ferry engines are relatively small, and the only available spaces are taken up by the fuel injector and valves. Moreover, careful design of the whole system would be critical to prevent water from impinging on the cylinder walls or compromising the cylinder lubrication. The alternative method, inlet fumigation, is simpler but less effective. The amount of NO_X reduction depends upon the amount of water available to reduce the temperature in the combustion chamber. The air entering the cylinders is only capable of holding a finite amount of water vapor. Any additional water in liquid form will enter the combustion chamber.

The overall impact on the ferry vessel's operation would be minimal with either system. The vessels do not have to make their own water and they are off line each day so that a small water tank could provide enough water for a day's operation. One significant advantage is that the system could be turned off at any time without affecting the engine's operation.

Closed Crankcase Ventilation (CCV)

Crankcase emissions are created as a by-product of the diesel combustion process. A certain percentage of engine exhaust gases passes by the piston rings and valve seals and finds its way into the crankcase (oil sump and oil pan assembly) of the engine. Typically, these exhaust products vent into the atmosphere and include PM, gaseous products (HC, CO, NO_X, etc.), and toxics. Closed crankcase ventilation (CCV) systems do not allow these blow-by gases to be vented into the atmosphere. Rather, CCV systems recirculate crankcase exhaust gases back into the engine for subsequent "re-combustion." To effectively and safely perform this recirculation operation, the CCV requires a vapor separator, filtration process, and recirculating device similar to the system shown in Figure 3.12. The service unit displayed in Figure 3.12 performs the separation, filtration, and means to recirculate the crankcase emissions.

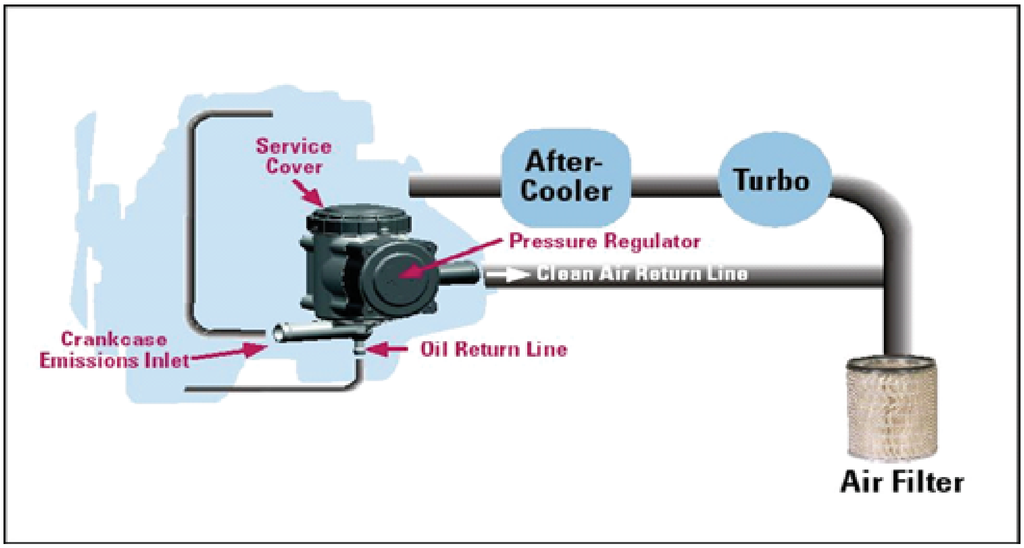


Figure 3.12. Closed Crankcase Ventilation.

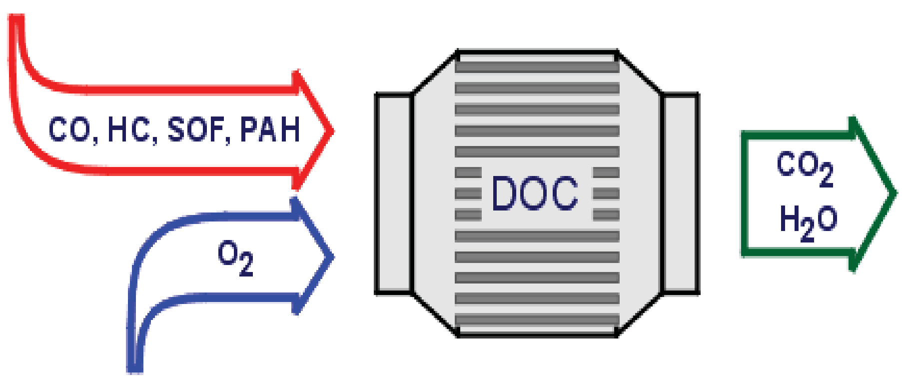
Use of this device on the ferry vessels would be unrestricted. In fact, most of the vessels already have a means to control crankcase vapor emissions by collecting and reintroducing the vapors into the intake tract. The units have minimal effect upon the NO_X emissions simply because NO_X isn't formed in the crankcase of the engines. The reduction of PM is the result of reburning the PM emissions generated in the crankcase. The other benefit is in consolidating all of the potential emissions sources and passing them out the engine exhaust system, as opposed to venting the crankcase emissions to the atmosphere.

EXHAUST AFTERTREATMENT

The exhaust aftertreatment modifications are those that are installed in line with and designed to process the engine exhaust. These modifications typically consist of diesel oxidation catalysts, diesel particulate filters, selective catalytic reactors, and/or lean NO_X catalysts. These devices are installed directly in the exhaust gas piping from the engines; they process the exhaust gas to remove the targeted pollutants. They may be used in place of the exhaust silencers. These devices may require the use of an active agent or catalyst to reduce NO_X, and all require that the engine be in good mechanical condition. The devices also may require a certain exhaust temperature range or a specified amount of time at a given temperature to operate properly. Operator intervention may be required, either for maintenance or refilling reduction agent tanks. Since it is the exhaust that is being processed, there is little impact upon the engine control systems. However, some engines may benefit from improved performance because they can be allowed to increase their NO_X output, as it will be removed by the exhaust aftertreatment device.

Diesel Oxidation Catalyst

Diesel oxidation catalysts (DOCs) were some of the first retrofit emissions reduction devices to enjoy widespread use. They are virtually identical in size and shape to the conventional mufflers that they replace, making them a true "bolt on" application with no requirements to modify or adjust engine controls or to use a specific fuel such as ULSD. However, they tend to be heavier than the mufflers they replace and sometimes require revised, more robust mounting brackets.



$$\text{Hydrocarbons} + O_2 = CO_2 + H_2O$$

$$CO + \frac{1}{2} O_2 = CO2$$

Figure 3.13. Diesel Oxidation Catalyst.

Diesel oxidation catalysts are a low-efficiency/high volume retrofit option at a modest price increase over a conventional muffler. DOCs can generally reduce PM emissions up to 20%, which is modest compared to other, more advanced technologies. However, their ease of installation, with minimal modification to the vehicle structure or operational parameters (such as engine recalibration or low-sulfur fuel substitution), coupled with their low cost, make them an ideal PM retrofit technology when used in large-scale applications. It is not surprising, therefore, that diesel oxidation catalyst retrofit programs are most useful when they involve large numbers of vessels to maximize total fleet PM reduction benefits. Diesel oxidation catalysts will also significantly reduce hydrocarbon and CO emissions.

As the name suggests, the oxidation catalyst oxidizes, or "adds oxygen" to hydrocarbons through the removal of electrons associated with carbon atoms in the hydrocarbons to form CO_2 and water. Carbon dioxide, CO_2, is fully oxidized and is not very reactive or flammable, but it is a widely recognized as a major greenhouse gas. Oxygen is present in diesel exhaust in large quantities, so oxidation occurs naturally; a diesel oxidation catalyst speeds up the reaction rate. Diesel oxidation catalysts oxidize organic carbon, a hydrocarbon derivative referred to as the soluble organic fraction (SOF) of PM. This reaction results in PM reductions.

Usage of diesel oxidation catalysts on the ferry vessels would be unrestricted. These units are essentially passive and require very little outside intervention to operate effectively. However, the degree of catalysis will be dependent upon the amount of sulfur in the fuel. High amounts of sulfur in the fuel can lead to sulfate PM formation. Diesel oxidation catalysts will achieve the best results using ULSD fuels, even though such fuels are not required for their use.

Diesel Particulate Filters

Diesel particulate filters, when used in conjunction with a catalyst ("catalyzed traps"), are capable of total PM reductions on the order of 90%, making them a very attractive retrofit option. A number of these devices are being used on a number of truck fleets in the Northeast. More retrofit initiatives using diesel particulate filters are in the planning stages, as the benefits and functional acceptability of this technology are becoming better known.

Diesel particulate filters (DPF) have evolved as the most effective method for reducing total PM emissions from diesel engines. These units remove PM through a two-stage process. First, the filter physically entraps the elemental carbon portion of PM. Then, through elevated exhaust temperatures, the diesel particulate filter oxidizes these solid particulates to form gaseous products (primarily CO_2), through a process termed "regeneration."

There are two types of diesel particulate filters, each designed to effectively promote regeneration. Passive units require no outside source of heat. Exhaust temperatures are elevated by the increased backpressure in the exhaust as the unit fills with PM. As this loading increases, the exhaust backpressure along with the exhaust temperature increase to a specific threshold value. When this threshold value is reached, the PM is oxidized and removed, and the exhaust temperature subsequently drops. The DPF starts to trap more PM and the process is repeated.

An active diesel particulate filter employs the same principal, but heat is added (see Figure 3.14) by one of several external means to promote regeneration: electric heating, injection of diesel fuel into the exhaust, or engine calibration to temporarily raise the exhaust temperature. Active filters are used when the engine exhaust temperature is too low for passive diesel particulate filters to function properly.

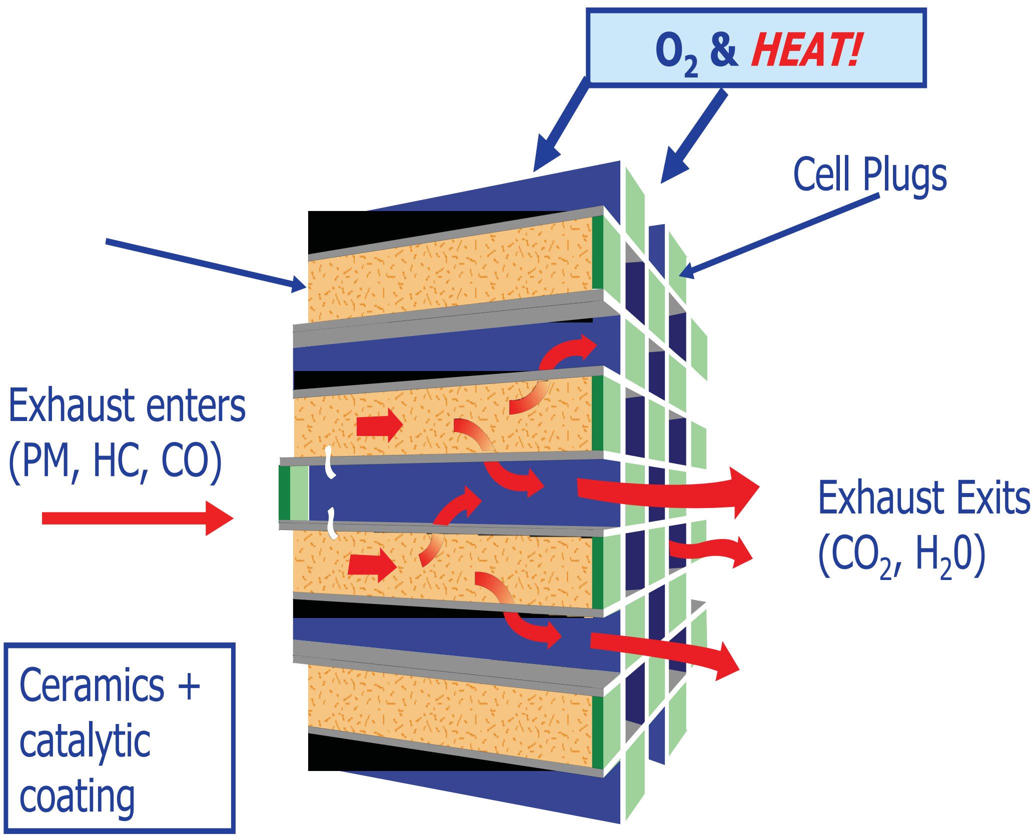


Figure 3.14. Diesel Particulate Filter Schematic.

By combining a diesel particulate filter with an oxidation catalyst, the soluble organic fraction of PM can also be removed, making for impressive total PM reductions (upwards of 90%). Most diesel particulate filter manufacturers have commercialized these dual systems into one container or "can," using a diesel particulate filter in tandem with a diesel oxidation catalyst or applying a catalytic coating to the unit's substrate. Figure 3.15 illustrates a diesel particulate filter element of a dual system.

Diesel particulate filters are considerably more technically complicated than diesel oxidation catalysts and this is reflected in their cost, which on average is between $6,000 and $9,000 (including installation). Furthermore, most systems require the use of ULSD, typically less than 15ppm, to facilitate regeneration and/or preclude catalyst poisoning that would permanently render them inoperable. Nevertheless, their per-unit effectiveness in reducing PM is very attractive. In contrast to diesel oxidation catalysts, diesel particulate filters are a high-efficiency/low volume retrofit option with higher costs and greater installation and operational challenges than the diesel oxidation catalyst.

Figure 3.15. Diesel Particulate Filter Element.

Usage on the ferry vessels would be unrestricted, except for the need for proper exhaust temperature. Because regeneration is very exhaust temperature-dependent, data logging instruments would need to be installed to record the vessel's exhaust temperature history prior to the installation. This approach would ensure that the exhaust temperature, on average, is sufficiently high to promote timely and consistent regeneration of the unit. Finally, an exhaust backpressure sensor and dashboard-mounted indicator light would need to be installed to ensure consistent regeneration in-use. Monitoring exhaust gas backpressure would ensure that the unit did not becoming plugged with soot due to insufficient regeneration. The plugging of a diesel particulate filter would impose a severe operating restriction and could cause engine damage.

Lean NO_X Catalyst

Lean NO_X catalyst systems selectively reduce NO_X through the introduction of an enabling "outside agent." These systems inject diesel fuel into the exhaust, either through direct injection of fuel into the exhaust stream or through the late injection of fuel directly into the cylinder of the engine via the fuel injection system. A depiction of typical lean NO_X catalyst systems is located below in Figure 3.16.

Oxides of nitrogen combine with hydrocarbons (typically diesel fuel sprayed into the exhaust stream) to form atmospheric nitrogen, carbon dioxide, and water:

$$\{HC\} + NO_X = N_2 + CO_2 + H_20$$

The direct fuel injection system is costly. The in-cylinder injection system is less expensive, but it promotes cylinder wall wetting, compromising engine durability. While the challenges are significant and the cost high, the capability of the lean NO_X trap to employ an activation mechanism already on board the vehicle (diesel fuel) makes it far more attractive than other exhaust aftertreatment processes employing different active agents not typically found on ferries.

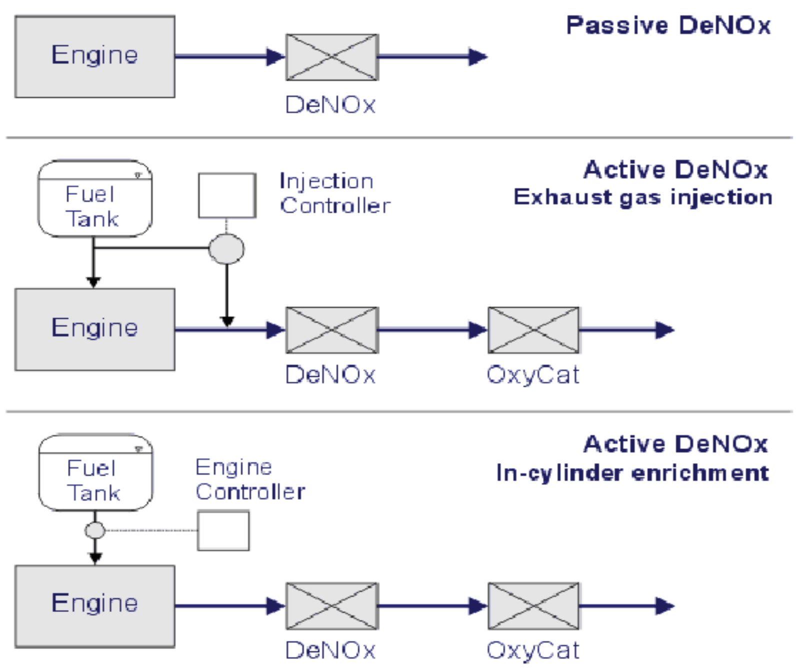


Figure 3.16. Lean NO_X Catalyst Systems.

Usage on the ferry vessels would be unrestricted; however, a significant fuel penalty would be incurred for the additional fuel required to reduce the NO_X. The design is attractive because it is a viable method to reduce NO_X, also because the systems could replace the existing silencers so only moderate redesign of the exhaust systems would be required. The systems typically use their own control systems and operate independently of the engines.

Selective Catalytic Reduction

Selective catalytic reduction (SCR) uses an outside agent, ammonia, to convert NO_X to harmless nitrogen gas (N_2) and water. Because ammonia is quite toxic and corrosive in its pure form, a nontoxic substitute – urea – is used. Urea essentially "locks in" ammonia into a nontoxic, easy to handle, and commercially available solution. When the injection or "dosing" unit releases urea into the exhaust, the heat from the exhaust (minimum temperature of 160^{o} C) releases the ammonia component of the urea, stimulating the chemical reaction that converts NO_X into N_2 and H_2O. The urea must have a certain residence time within the exhaust stream for it to break down into ammonia prior to the reaction. An open-loop selective catalytic reduction system is shown in Figure 3.17. The reactions in which ammonia plus NO_X are converted into N_2 and H_2O is shown in Figure 3.18.

Along with emulsified diesel fuel and lean NO_X catalysts, selective catalytic reduction is one of three commercially available technologies that demonstrate significant reductions of NO_X from diesel engines. For a number of years, selective catalytic reduction (SCR) systems have been used in stationary applications, such as diesel engines that power generator sets, compressors, and pumps. They have also been successfully used in large power plants and other industrial applications. The lack of mobility and more consistent operating characteristics of stationery engines mitigate some of the substantial challenges of applying these systems to truck or ferry engines. These challenges include transporting the requisite supply urea and ensuring that the engine operates within a rather narrow exhaust temperature band. However, the less transient duty cycle of many marine applications, as well as central-fueling of vessels typical of the ferry industry, make these units an attractive NO_X reduction option since the ferry engine(s) operate at a relatively steady load for longer periods of time which the SCR would be designed for and the activation mechanism (urea) could be readily resupplied when the vessel refuels.

Selective catalytic reduction systems are large, bulky, and inherently more complex than other NO_X reduction strategies and typical PM-reducing retrofit options such as diesel particulate filters and catalysts., In addition to the catalyst itself (which is typically installed in series with the engine's muffler), they require an elaborate injection or dosing mechanism to provide the correct measure of urea (ammonia) into the exhaust stream to reduce NO_X emissions. The dosing unit costs of the injector and attendant electronic controls, and it usually requires air assist to aerate the injected urea. As a result of this complexity, the initial unit cost is higher, as are the installation costs. Furthermore, a constant ammonia/urea supply is needed, and care must be taken to ensure operators maintain the supply in a specified separate urea storage tank.

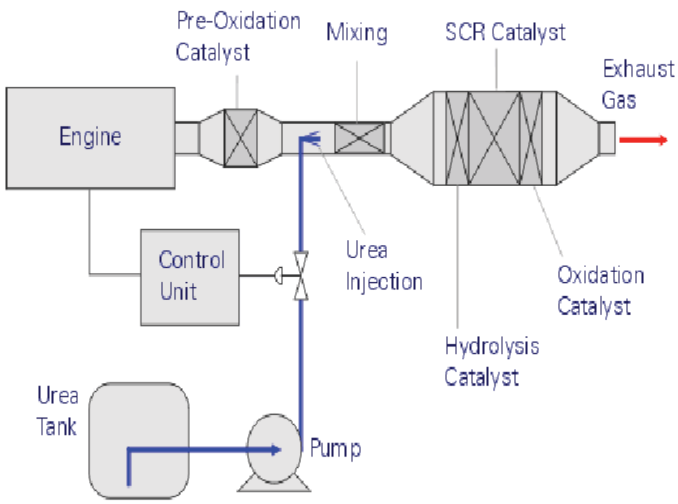


Figure 3.17. Open Loop Selective Catalytic Reduction System.

$$6NO + 4NH_3 = 5N_2 + 6H_2O$$
$$4NO + 4NH_3 + O_2 = 4N_2 + 6H_2O$$
$$6NO_2 + 8NH_3 = 7N_2 + 12H_2O$$
$$2NO_2 + 4NH_3 + O_2 = 3N_2 + 6H_2O$$
$$NO + NO_2 + 2NH_3 = 2N_2 + 3H_2O$$

Figure 3.18. Selective Catalytic Reduction NO_X Reaction.

Usage of SCR systems in the ferry vessels would be unrestricted. However, their large size and cost make it unlikely that any operator would install them without a regulatory requirement or cost incentive. In addition to the installation costs, the operator would have to bear a significant recurring urea cost equal to about 3% of their fuel cost.

Exhaust Gas Scrubbers

These devices are placed between the engine exhaust outlet and the vessel's hull. Primarily marketed as a means to reduce emissions of sulfur oxides (SO_X), exhaust gas scrubbers are also effective in reducing PM emissions. They work by spraying seawater into the exhaust gas as is passes from the engine to the atmosphere. The seawater absorbs the SO_X emissions and knocks down the PM. The system's disadvantages are that the equipment is very large and relatively large pumps are used in the process.

Extensive modifications would be necessary to the electric system on any of the ferry vessels in the harbor to make this system work.

Exhaust Aftertreatment Device Combinations

Using two or more aftertreatment technologies enhances the ability to achieve the desired emissions goals. As stated before, the formation of NO_X is the result of a combustion process that reduces PM and other controlled emissions, and the opposite is true as well. The following combinations have the potential to meet the project goal of a NO_X reduction of 30% and a PM reduction value of 50% assuming they are synergistic and additive:

- exhaust gas recirculation (low pressure) and diesel particulate filter,
- selective catalytic reduction and diesel particulate filter,
- lean NO_X catalyst and diesel particulate filter,
- humid air motor and diesel particulate filter with fuel injection equipment,
- exhaust gas recirculation (high pressure) and diesel oxidation catalyst,
- emulsified fuel and diesel particulate filter,
- ceramic coatings with fuel injection equipment, and
- emulsified fuel and diesel oxidation catalyst.

Each technology alone would meet one or the other goal but not both. Moreover, in a number of cases, the first technology requires the second. With exhaust gas recirculation (low pressure), a diesel particulate filter is required to clean up the exhaust gas that passes back into the engine. The combined technologies are assumed to be used with ULSD fuel so that catalyst poisoning is minimized.

It is also assumed that the combinations that utilize FIE will have the fuel injection systems optimized for emissions control. FIE optimization will most likely result in NO_X reduction at the expense of increased CO and PM emissions and increased fuel consumption. As explained previously, NO_X removal from the exhaust stream is far more difficult than removing CO and PM. Moreover, it is assumed that the exhaust temperatures are sufficiently high and sustained for a long enough duty cycle to permit efficient catalyst operation and regeneration.

TIER 2 REPLACEMENT ENGINES

Another option for emissions control consists of replacing the existing ferry engines with those that meet the EPA marine Tier 2 emissions regulations. Engines will probably be replaced with a like unit from the same manufacturer. The manufacturers realize that engine replacement is a viable alternative to vessel owners for reasons other than emissions abatement; consequently, they offer engines that are similar in ratings, dimensions, and other system requirements. Also, changing from one engine brand to another may increase the costs of the conversion because the auxiliary systems may need more extensive modification. In addition, the regulatory agencies such as the U.S. Coast Guard will be more involved if a different engine brand is used.

A comparison of the EPA Tier 1 and Tier 2 regulations reveals that the NO_X level requirement is reduced by nearly 25%. Other emissions, PM and THC, are also regulated under Tier 2 regulations, whereas the original Tier 1 or MARPOL requirement focused only on NO_X.

The Tier 2 engines will typically be electronically controlled and will have features conducive to controlling emissions over their operating range, such as higher injection pressures and better control of intake air temperature, charge air pressure, and fuel timing. However, the actual emissions benefit of a Tier 2 engine over a Tier 1 cannot be directly ascertained simply by comparing the regulations. Many Tier 1 engines will have emissions that are comparable to those found from Tier 2 engines, and only by testing can the true emissions reduction be quantified. The data sheet for one of the Tier 2 propulsion engines used on the ferry vessels indicated a 20-fold decrease in PM emissions when compared to published representative values for Tier 1 mechanically injected diesel engines. It is believed that the electronically controlled Tier 2 engines from other manufacturers will have similar PM reductions.

The MARPOL Annex VI (1997) emissions limits only target NO_X; they are calculated based upon rated speed as shown in Table 3.3. The rated rpm of the vessels used for the tests ranged from 1800 to 2000 rpm. The MARPOL NO_X limits range from 10.05 g/kWh (7.5 g/bhp-hr) to 9.84 g/kWh (7.34 g/bhp-hr).

Table 3.3. MARPOL and EPA Tier 1 Marine Engine Emissions Limits.

Engine Speed (n, RPM)	NO_X Limit, g/kWh	NO_X Limit, g/bhp-hr
$n < 130$	17.0	12.7
$130 \le n \le 2000$	$45 \times n^{-0.2}$	$33.6 \times n^{-0.2}$
$n > 2000$	9.8	7.3

The Tier 2 emissions limits target NO_X, total hydrocarbons (THC), PM, and CO, and they will be fully implemented by 2007. The implementation year depends upon engine displacement and power output, as shown in Table 3.4.

Table 3.4. EPA Tier 2 Marine Engine Emissions Limits.

Engine Category	Power, P (kW)	Displace., D, liters	NO_X+THC,		PM		CO		Implementation Year
			g/kW-hr	g/bhp-hr	g/kW-hr	g/bhp-hr	g/kW-hr	g/bhp-hr	
1	P≥37	0.9>D	7.5	5.6	0.40	0.30	5.0	3.73	2005
		0.9≤D<1.2	7.2	5.4	0.30	0.22	5.0	3.73	2004
		1.2≤D<2.5	7.2	5.4	0.20	0.15	5.0	3.73	2004
		2.5≤D<5.0	7.2	5.4	0.20	0.15	5.0	3.73	2007
2	P≥3300	5.0≤D<15	7.8	5.8	0.27	0.20	5.0	3.73	2007
		15≤D<20	8.7	6.5	0.50	0.37	5.0	3.73	2007
		15≤D<20	9.8	7.3	0.50	0.37	5.0	3.73	2007
		20≤D<25	9.8	7.3	0.50	0.37	5.0	3.73	2007
		25≤D<30	11.0	8.2	0.50	0.37	5.0	3.73	2007

The propulsion engines used by the NY harbor private ferry vessel fleet all fall into category 1. Their cylinder displacements range from 2.3 to 3.1 liters per cylinder. Some of the generator engines also fall into category 1 since their rated power outputs are above 37 kW (50 bhp) and their cylinder displacements are above 0.9 liters. As of January 2006, only one engine manufacturer had an engine that met EPA Tier 2 emissions levels and had a sufficiently high rating and duty cycle that could replace the majority of the engines in the fleet. Operators using engines from other manufacturers would be reluctant to change their engine brand without a regulatory requirement or other financial incentive.

The Tier 2 engines would most likely replace any older mechanically fuel injected engines. Unfortunately reliable and accurate emissions data is difficult to find if not nonexistent for these replacement engines. For the purposes of this study, the emissions benefit of a replacement EPA Tier 2 engine is therefore taken as the difference between the Tier 1 and Tier 2 standards.

OPERATING PROFILE CHANGES

Another way to reduce emissions is to operate ferry vehicles at slower speeds, which reduces fuel consumption and thus reduces ferry emissions. Using less power in the push mode of operation is another possible change in vessel operating profile. If a decreased load is placed on a ferry's engines when operating in a push mode, then the fuel consumption and subsequent emissions will be reduced. Table 3.5 shows that as fuel consumption is reduced, emissions are reduced by the same percentage. The operating profile changes shown in Table 3.5 are mainly illustrative in nature. With the high cost of fuel, the vessel owner/operators can be expected to make significant changes to their operating profiles that reduce fuel consumption, such as reducing vessel speed. However, speed reductions can only go so far before the ferry schedules become affected.

Table 3.5. Operating Profile Emissions Reductions.

Operating Profile Change						
Operational Change		Fuel Consumption/Emission Reduction Effectiveness (%)			Estimated Cost Savings	
Operating Mode	Change	Overall Fuel Consumption Decrease	NO_x	PM	$/day	Schedule Effect
Short Transit	Reduce transit speed 5%	-8.1%	-8.1%	-8.1%	~$22	Adds 15 seconds to each round trip transit period
Medium Transit	Reduce transit speed 5%	-7.5%	-7.5%	-7.5%	~$28	Adds 36 seconds to each round trip transit period
Long Transit	Reduce transit speed 5%	-5.9%	-5.9%	-5.9%	~$51	Round trip time increases 5 minutes.
Long Transit	Transit with 2 vs. 4 engines	-66%	-66%	-66%	$1,500	Round trip time increases 20 minutes
Short Transit Vessel Pushing	Reduce pushing rpm 5%	7%	-7%	-6%	~$12	No effect
Medium Transit Vessel Pushing	Reduce pushing rpm 5%	2.5%	-2.5%	-2.5%	~$10	No effect
Long Transit Vessel Pushing	Reduce pushing rpm 5%	1%	-1%	-1%	~$18	No Effect
All	Reduce electric load 1 kWe	<1%	neg	neg	~$0.50	No Effect

EMISSION CONTROL TECHNOLOGY MATRICES

The Emission Control Technology (ECT) Matrices in Appendices J through L rank the fuel and engine technologies described at the beginning of this section in Table 3.1 and listed below in Table 3.6. Each considered technology must have a proven record in the marine, on-road, or off-road markets. Verifiable results must be available for each technology, and each technology should be listed with either the California Air Resources Board (CARB) or EPA. Each can be adapted to marine vessels, as long as the design and construction of the devices and their auxiliary systems meet the strength requirements to stand up to marine environments and meet the requirements of the regulatory agencies. Finally, each device is graded as to its annual cost per unit weight of reduced emissions constituent, whether or not its cost outweighs the benefits.

Appendix M shows the preliminary ECT matrix, which grades the relative merits of each of the exhaust control technologies applied to a composite ferry vessel. The composite vessel has two electronically controlled, turbocharged direct injected diesel engines driving propellers. The ferry consumes approximately 150,000 gallons of fuel per year. The vessel's lifespan is assumed to be 20 years, and it is further assumed that the emissions control device will need replacement at year 10. The hardware and installation costs are net present value, assuming a cost of money of 5% and a 20-year amortization period. The operating costs are for the first year.

Following the evaluation of the technologies using this preliminary matrix, the devices that received higher than a 70% normalized grade were selected as prime candidates to use for the demonstration. A request for proposal was drafted and sent along with the data collected during the vessel characterization to the various manufacturers and vendors of these selected.

A second matrix was created to evaluate each demonstration vessel. Each responder furnished technology performance information for NO_X and PM based on the data collected during the vehicle characterization portion of this project and on cost. The annual emissions from each vessel were calculated using the baseline factors developed during the vessel characterization. These values were entered into the vessel's specific matrix to generate a final annual cost per emissions constituent. The top candidates from this matrix were used to determine which technologies would be considered for demonstration. The demonstration technologies were presented to the vessel operators as the final determinant of what technology would be demonstrated and on which vessel. The ferry vessel operators had the last say simply because the equipment would be installed on their vessels and they would be incurring the operational burden should the equipment require undue maintenance or vessel downtime.

Evaluation Criterion Categories

Four primary criterion categories were used to evaluate each of the control technology and strategy options. Within each one of the four primary categories are applicable subcategories. Each subcategory was assigned a weighted grade and was then added to the weighted grades of the other subcategories. The total grade for the respective category was then weighted again based upon its overall impact on the final selection and deployment of the chosen technology or strategy. A brief discussion of the primary categories and their respective subcategories is presented below. Within each category's discussion is an identification of the grading and weighting methodology applied to the respective criterion.

Experience and Performance (40%). The experience and performance category was given the highest percent of weighting (40%) due to the impact it has on the main focus of this study; the evaluation of control technologies and strategies designed primarily for the remediation of NO_X and to a lesser extent, particulate matter (specifically PM 2.5) emissions. Within this category are four subcategories {list/describe here}. These subcategories evaluate a control technology's past experience and potential results regarding the actual remediation of emissions. The subtotal score was calculated as follows:
$(2 \times NO_X + PM + O + E)*(.40)$

Annualized Costs. Because this project involved an economic as well as a technological analysis, the annualized costs category was given the second highest weighting (30%). Within this category are three subcategories. These subcategories evaluate a control technology's costs with regard to the purchase, installation, and operation of the technology. The subtotal score was calculated as follows: $(P + I + O)*(0.30)$. The costs were annualized to a figurative vessel that operates 3,500 hour per year and consumes 150,000 gallons per year of fuel. This operating profile is compilation of the profiles for each of the three vessels participating in this study.

Design and Operation. The design and operation category was given a weighting of 15%. Within this category are two subcategories. These subcategories evaluate the reality of installing a particular technology onboard a vessel. Considerations are made within this category for physical installation requirements as well as operator willingness to modify their vessels and take on additional operating burdens. The subtotal score was calculated as follows: $(S + A)(0.15)$.

Safety and Field Support. The Safety and Field Support category was also given a weighting of 15%. Within this category are three subcategories. {list/describe here}. The subtotal score was calculated as follows: $(S + C + F)*(0.15)$. Prudent marine engineering, along with regulatory body requirements, dictates that whenever a vessel's system is installed or modified, its impact on safety requirements, crew utilization, and vendor support be reviewed. The Safety and Field Support category of the evaluation matrix addresses these areas of concern.

Fatal Flaw. A final category was added for which there could be no score. Each technology has some impact on the vessel on which it is installed. In order to screen products that would not be acceptable for use on the NYC private ferry vessels, a "fatal flaw" category was inserted. The fatal flaw need not be something that would adversely the performance, safety, or any other criteria, just something that would preclude its use on these vessels. The fatal flaw category was strictly acceptable or unacceptable.

The four category scores of each emissions control technology were totalled and normalized to a 0 to 100% basis. The highest scores, above 70%, were selected for use in the remainder of the project.

Emission Control Technology Request for Proposal

Following the grading of the various technologies using the matrix described above, a request for proposal was sent out to over 50 companies that specialize in emissions control devices, either as manufacturers or reseller. Each vendor was required to submit a proposal for installing its equipment on any or all of the demonstration vessels. The proposal included the performance of the device(s) on the criteria pollutants and the installation costs. The installation costs included the hardware, installation, vessel modifications, consumable material, design, and commissioning costs. This information was then inputted into a matrix for each vessel to evaluate each technology on a cost per annual unit weight of pollutant (NO_X and/or PM) removed. The emissions reduction information was taken from each vendor's proposal, while the emissions contribution for each demonstration vessel was derived from the emissions testing that took place in February of 2004.

Vessel Specific ECT Selection Matrix

Following the receipt of the ECT proposals, a second vessel-specific ECT selection matrix was constructed. The purpose of this matrix was to determine the best emissions control technology to be used for demonstration and possible future deployment on a specific vessel. These vessel-specific matrices are presented in Appendices M, N, O, and P. The selection categories for the vessel specific matrix include the following:

- Uncontrolled annual emissions (calculated annual vessel emissions of NO_X and PM)
- Assumed ECT reduction, %
- Projected annual ECT treatment emissions reduction
- Post ECT treatment emissions output
- Purchase and installation cost –(based on 20 years net present value and 5% cost of money)
- Operating and renewal – (based on present cost of consumable items and replacement of ECT at year 10. It is assumed that the cost of the unit will have dropped to 50% of the original cost due to technological innovations.)
- Total cost (summation of the purchase, installation, operating, and renewal costs.)

- Specific emissions reduction cost (total cost divided by the annual emission reduction of NO_X or PM as applicable.)

The equipment that provided the best emissions control on an annual dollar per unit weight basis was then discussed as they would apply to each vessel with a large emphasis placed upon two facets. These two critical factors included the vessel owner's acceptance of the ECT and the effect upon overall harbor emissions when implemented fleetwide.

One of the original goals of this project was not only to find emissions control technologies that could be applied to the representative private ferry vessels, but also to assist in the selection of these devices for purchasing and installing fleetwide. The goal of the fleetwide adoption was to realize an overall harbor emissions reduction of 30% NO_X and 50% PM with the limited amount of funds available. In order to achieve these harborwide reductions in emissions it was found to be more cost effective to target the large producers of NO_X and utilize SCR technologies for these, rather than to install SCRs fleetwide. Also, a large emphasis was placed upon acceptance of the technology by the ferry vessel operators. This premise made it possible to include EPA Tier 2 certified engines as an alternative to SCRs for the smaller vessels even though the Tier 2 engines would cost significantly more.

SELECTION RESULTS

The general ECT evaluation matrix ranked the emissions control technologies that would be considered for use on the ferry vessels. This list was presented to the ferry vessel operators. Each technology and its potential impact on each demonstration ferry vessel was discussed with the result that the ferry operators decided what technology would be tried. In many cases, such as with emulsified diesel fuel, the relative high cost and low availability in the NY region prevented its use in the demonstration. Some technologies, such as exhaust wet scrubbers, were simply too large or required significantly more auxiliary power than any of the vessels had and were thus listed as having fatal flaws. Other technologies, such as reducing vessel speeds or electric loads, were already in the process of being implemented by the ferry operators, and these vessels can only slow down so much without adversely impacting their schedules. The vessels were already operating close to their optimal speeds for the schedules they are trying to maintain. Table 3.7 presents the emissions control technologies that were deemed acceptable for the demonstration part of this project (Phase II).

Table 3.6. Emission Control Technologies (ECT) for Use in Phase II.

Rank	Emissions Control Technology	Score %	Fatal Flaw	Operator Acceptance
2	EGR (low-pressure) and DPF	82.2	No	Yes
7	LNC and DOC and FBC	68.6	No	Yes
11	Intake Air Fumigation	64.1	No	Yes
12	Fuel-borne Catalysts (FBCs)	63.9	No	Yes
16	Diesel Particulate Filters (DPF)	61.8	No	Yes
20	Diesel Oxidation Catalysts (DOC)	59.6	No	Yes
22	Engine Replacement: Tier 2 Engine	58.3	No	Yes
25	Lean NO_X Catalysts (LNC)	55.8	No	Yes

A request for quote was then issued to either the manufacturer or potential vendors for the product or combination of products. The quotes were then applied to the demonstration vessels. These were the MV PORT IMPERIAL MANHATTAN, MV FATHER MYCHAL JUDGE, MV ED ROGOWSKY, and MV SEASTREAK WALL STREET. Except for the MV PORT IMPERIAL MANHATTAN, sister vessels were also considered dependent upon the availability of the original vessel for fitting of the emissions control equipment. The main difference between the two selection methodologies is that the general ECT selection matrix spreadsheet focused on comparing the various individual and combined technologies, while the vessel specific spreadsheet focused on the actual cost benefit of installing the emissions control device on a particular ferry. The results of the vessel specific emissions control technologies spreadsheet are listed in Tables 3.7 through 3.10.

Table 3.7. M/V PORT IMPERIAL MANHATTAN ECT Selection Results.

Rank	Vendor/Technology	ECT Type	Operator Acceptance
1	Clean Diesel Technologies-DOC & FBC	DOC+FBC	Yes
2	Rypos-DPF	DPF	No
3	MA Turbo-Irenium	WIS+FBC	No
4	Johnson-Matthey SCR & DOC	SCR+DOC	No
5	Combustion Components Associates -SCR	SCR	No
6	Converter Tech-DPF/EGR	EGR+DPF	No
7	Tier 2 replacement engine/DOC	Tier 2+DOC	No

Table 3.8. M/V FATHER MYCHAL JUDGE ECT Selection Results.

Rank	Vendor/Technology	ECT Type	Operator Acceptance
1	Clean Diesel Technologies-DOC & FBC	DOC+FBC	Yes
2	Rypos-DPF	DPF	No
3	MA Turbo-Irenium	WIS+FBC	Yes
4	Johnson-Matthey SCR & DOC	SCR+DOC	No
5	Combustion Components Associates-SCR	SCR	No
6	Converter Tech-DPF/EGR	EGR+DPF	No
7	Tier 2 replacement engine/DOC	Tier 2+DOC	No
8	8. Munters SCR/DOC	SCR+DOC	No

Table 3.9. M/V ED ROGOWSKY ECT Selection Results.

Rank	Vendor/Technology	ECT Type	Operator Acceptance
1	Clean Diesel Technologies -DOC & FBC	DOC+FBC	Yes
2	Rypos-DPF	DPF	No
3	MA Turbo-Irenium	WIS+FBC	Yes
4	Johnson-Matthey SCR & DOC	SCR+DOC	No
5	Combustion Components Associates -SCR	SCR	No
6	Converter Tech-DPF/EGR	EGR+DPF	No
7	Tier 2 replacement engine/DOC	Tier 2+DOC	No

Table 3.10. M/V SEASTREAK WALL STREET ECT Selection Results.

Rank	Vendor/Technology	ECT Type	Operator Acceptance
1	Clean Diesel Technologies -DOC & FBC	DOC+FBC	Yes
2	Rypos-DPF	DPF	No
3	MA Turbo-Irenium	WIS+FBC	No
4	Johnson-Matthey SCR & DOC	SCR+DOC	No
5	Combustion Components Associates -SCR	SCR	Yes
6	Converter Tech-DPF/EGR	EGR+DPF	No
7	Tier 2 replacement engine/DOC	Tier 2+DOC	No

These selections were then resubmitted to the vessel operators to verify that the operators would be agreeable to installing the equipment on their vessels for the duration of the demonstration period. Another goal of the process was to combine as many emissions control devices together so that the effectiveness of any individual emissions control technology could be ascertained during the same demonstration period. It was deemed feasible to combine such emissions treatments as a WIS and a DOC since the WIS system could be turned on and off and its effectiveness could be measured simply by measuring the exhaust emissions prior to any subsequent emissions control device. Other devices, such as a DOC, would be end of the line devices and so their emissions effectiveness could be ascertained by turning the previous emissions control device on or off. Finally the technologies were set for the demonstration as shown in Table 3.11.

Table 3.11. Demonstration ECT Selection Results.

Vessel	Vendor/Technology	ECT Type
MV PORT IMPERIAL MANHATTAN	Clean Diesel Technologies	DOC+FBC
MV FATHER MYCHAL JUDGE	MA Turbo and Johnson Matthey	WIS+DOC
MV ED ROGOWSKY	Johnson-Matthey	DOC
MV SEASTREAK WALL STREET	Combustion Components Associates-SCR	SCR

ESTIMATE OF FLEETWIDE EMISSION REDUCTION POTENTIAL

The final reason to perform a technology demonstration on the ferry vessels is to quantify the potential emissions reductions that may be obtained by fitting selected emissions control devices to any or all of the ferry vessels that comprise the NY harbor private ferry vessel fleet. Tables 3.12 and 3.13 depict the annual reduction in emissions that may be obtained by fitting one or more of the emission control devices to any or all of the private ferry vessels. The actual emissions reduction may be more or less than the given values and will depend upon a host of factors including vessel operating cycle, engine maintenance, emissions control device maintenance, fuel type, weather, etc.

Table 3.12 presents an estimate of potential fleetwide emission reduction based on vessel route. Table 3.13 summarizes the potential reduction of harbor emissions assuming a fleetwide deployment of the selected ECT. Estimates of the emission reduction potential were made using the baseline ferry emissions data collected during the vessel characterization along with the ECT effectiveness reported by the manufacturers. The electronic worksheet lists the vessel, route, baseline emissions, and potential emissions device, and emissions reduction; it also calculates the annual emissions rate of the targeted pollutant. In the electronic version, the worksheet may be easily manipulated to depict the effect of emissions control devices fitted on one or more vessels upon harbor emissions of the targeted species.

In most cases the emissions were derived from the results of the baseline emissions test conducted during the Phase I emissions test. The generator engines are also included in the total vessel emissions. Where a specific engine was not tested, published emissions factors were used or, in the case of any engine built after 2000, the corresponding IMO emissions factor.

One of the results of the emissions selection matrices included repowering with Tier 2 engines. However, emissions values for engines with greater than 3 liters per cylinder displacement will not be published until the implementation date of 1 January 2007. Therefore the emissions rates for these engines were derived from the EPA Tier 2 regulation. A reduction of 25% for each emission constituent was estimated.

In creating the tables, it was assumed that each vessel not tested operated in the same manner as those tested, whether they be short-, medium-, or long-haul vessels. This means that the M/V YOGI BERRA, which has 3406E and waterjets for its propulsion, was assumed to have the same emissions rate per hour per engine as the M/V FATHER MYCHAL JUDGE since both vessels are classed as medium haul and have the same propulsion system. The same assumption was used for SeaStreak and NY Water Taxi because they operate fleets of identical vessels, and the vessels are totally interchangeable. The tables were also amended as the results of the Phase II emissions testing were made available.

Table 3.12. Emission Rate Reduction with ECT.

Route No.	Route Origin / Destination / End	Operator	Route Description	Route Distance	Propulsion Engine Type	NOx EMISSION RATE REDUCTIONS				PM2.5 EMISSION RATE REDUCTIONS				PM10 EMISSION RATE REDUCTIONS			
						Current Total Annual NOx, per route	Reduction Technology	% NOx Reduction	New Total Annual NOx, per route	Current Total Annual PM2.5, per route	Reduction Technology	% PM2.5 Reduction	New Total Annual PM2.5, per route	Current Total Annual PM10, per route	Reduction Technology	% PM10 Reduction	New Total Annual PM10, per route
				NM		(short tons/yr)		%	(short tons/yr)	(short tons/yr)		%	(short tons/yr)	(short tons/yr)		%	(short tons/yr)
1	Belford, NJ to Pier 11 to Belford, NJ	NY Waterway	Long Haul	45.8	Caterpillar 3412E	51.0	WIS	25%	38.2	0.12	WIS	17%	0.10	0.12	WIS	17%	0.10
2	Port Liberte to Pier 11 to Port Libete	NY Waterway	Medium Haul	9.4	Caterpillar 3406E	15.3	DOC+FBC	0%	15.3	0.14	DOC+FBC	40%	0.08	0.12	DOC+FBC	40%	0.07
3	Pier 11 to Port Liberte to Pier 11	NY Waterway	Medium Haul	9.4	Caterpillar 3406E	20.4	DOC+FBC	0%	20.4	0.18	DOC+FBC	40%	0.11	0.16	DOC+FBC	40%	0.10
4	Hoboken-South to (via WFC & Pier 11) WFC to Hoboken-South	NY Waterway	Medium Haul	7.7	Caterpillar 3412(2)	14.2	Repower + Doc	30%	9.9	1.77	Repower + Doc	50%	0.89	1.84	Repower + Doc	50%	0.92
5	38th Street to (via Newport & Harborside) Colgate to 38th Street	NY Waterway	Medium Haul	7.6	Caterpillar 3406E	36.7	DOC+FBC	0%	36.7	0.34	DOC+FBC	40%	0.20	0.29	DOC+FBC	40%	0.17
6	38th Street to (via Newport) Harborside to 38th Street	NY Waterway	Medium Haul	6.7	Caterpillar 3406E	20.8	DOC+FBC	0%	20.8	0.20	DOC+FBC	40%	0.12	0.17	DOC+FBC	40%	0.10
7	38th Street to (via Harborside) Newport to 38th Street	NY Waterway	Medium Haul	6.7	Caterpillar 3406E	7.3	DOC+FBC	40%	4.4	0.07	DOC+FBC	40%	0.04	0.06	DOC+FBC	40%	0.03
8	38th Street to Harborside to 38th Street	NY Waterway	Medium Haul	6.6	Caterpillar 3406E	5.6	DOC+FBC	0%	5.6	0.05	DOC+FBC	40%	0.03	0.04	DOC+FBC	40%	0.03
9	Liberty Harbor to Pier 11 to Liberty Harbor	NY Waterway	Medium Haul	5.8	Caterpillar 3406E	25.0	DOC+FBC	0%	25.0	0.23	DOC+FBC	40%	0.14	0.19	DOC+FBC	40%	0.12
10	38th Street to Newport to 38th Street	NY Waterway	Medium Haul	5.6	Caterpillar 3406E	13.9	DOC+FBC	0%	13.9	0.13	DOC+FBC	40%	0.08	0.11	DOC+FBC	40%	0.07
11	Hoboken-South to WFC to Hoboken-South	NY Waterway	Medium Haul	5	Caterpillar 3412(2)	40.9	Repower + Doc	30%	28.6	5.10	Repower + Doc	50%	2.55	5.31	Repower + Doc	50%	2.65
12	38th Street to (via Lincoln Harbor) Hoboken North to 38th Street	NY Waterway	Medium Haul	3.1	Caterpillar 3406E	25.7	DOC+FBC	0%	25.7	0.21	DOC+FBC	40%	0.12	0.19	DOC+FBC	40%	0.11
13	Hoboken-North to 38th Street to Hoboken-North	NY Waterway	Medium Haul	2.4	Caterpillar 3406E	21.4	DOC+FBC	0%	21.4	0.17	DOC+FBC	40%	0.10	0.15	DOC+FBC	40%	0.09
14	38th Street to Lincoln Harbor to 38th Street	NY Waterway	Medium Haul	2.4	Caterpillar 3412(2)	8.8	Repower + Doc	30%	6.1	1.08	Repower + Doc	50%	0.54	1.13	Repower + Doc	50%	0.56
15	Port Imperial to 38th Street to Port Imperial (weekdays)	NY Waterway	Short Haul	2	Caterpillar 3412E	34.9	WIS	25%	26.1	0.09	WIS	17%	0.08	0.10	WIS	17%	0.08
16	Port Imperial to 38th Street to Port Imperial (saturdays)	NY Waterway	Short Haul	2	Caterpillar 3412E	4.4	WIS	25%	3.3	0.01	WIS	17%	0.01	0.01	WIS	17%	0.01
17	Port Imperial to 38th Street to Port Imperial (sundays)	NY Waterway	Short Haul	2	Caterpillar 3412E	4.0	WIS	25%	3.0	0.01	WIS	17%	0.01	0.01	WIS	17%	0.01

Table 3.12. Emission Rate Reduction with ECT, cont'd.

Route No.	Route Origin / Destination / End	Operator	Route Description	Route Distance	Propulsion Engine Type	NOx EMISSION RATE REDUCTIONS				PM2.5 EMISSION RATE REDUCTIONS				PM10 EMISSION RATE REDUCTIONS			
						Current Total Annual NOx, per route	Reduction Technology	% NOx Reduction	New Total Annual NOx, per route	Current Total Annual PM2.5, per route	Reduction Technology	% PM2.5 Reduction	New Total Annual PM2.5, per route	Current Total Annual PM10, per route	Reduction Technology	% PM10 Reduction	New Total Annual PM10, per route
				NM		(short tons/yr)		%	(short tons/yr)	(short tons/yr)		%	(short tons/yr)	(short tons/yr)		%	(short tons/yr)
18	Colgate to WFC to Colgate	NY Waterway	Short Haul	1.6	Caterpillar 3412(2)	25.6	Repower + Doc	30%	17.9	3.18	Repower + Doc	50%	1.59	3.31	Repower + Doc	50%	1.65
Totals, NY Waterway						**375.6**		**14%**	**322.3**	**13.07**		**48%**	**6.78**	**13.31**		**48%**	**6.88**
19	Port Imperial to (via Hoboken-North, WFC) Pier 11 to (via WFC, Hoboken-North) Port Imperial	Billy Bey	Long Haul	13.1	Caterpillar 3406E	15.3	DOC+FBC	0%	15.3	0.14	DOC+FBC	40%	0.08	0.12	DOC+FBC	40%	0.07
20	Port Imperial to Pier 11 to Port Imperial	Billy Bey	Long Haul	12.8	Caterpillar 3406E	54.9	DOC+FBC	0%	54.9	0.53	DOC+FBC	40%	0.32	0.44	DOC+FBC	40%	0.26
21	Pier 11 to 38th Street to Pier 11	Billy Bey	Long Haul	11.8	Caterpillar 3406E	13.7	DOC+FBC	0%	13.7	0.13	DOC+FBC	40%	0.08	0.11	DOC+FBC	40%	0.06
22	Port Imperial to (via Hoboken-North) WFC to Port Imperial	Billy Bey	Medium Haul	8	Caterpillar 3406E	12.3	DOC+FBC	0%	12.3	0.11	DOC+FBC	40%	0.07	0.10	DOC+FBC	40%	0.06
23	WFC to (via Hoboken-North) Port Imperial to WFC	Billy Bey	Medium Haul	8	Caterpillar 3406E	12.7	DOC+FBC	0%	12.7	0.12	DOC+FBC	40%	0.07	0.10	DOC+FBC	40%	0.06
24	Hoboken-South to Pier 11 to Hoboken-South	Billy Bey	Medium Haul	7.4	Caterpillar 3406E	95.4	DOC+FBC	0%	95.4	0.86	DOC+FBC	40%	0.52	0.73	DOC+FBC	40%	0.44
25	38th Street to Colgate to 38th Street	Billy Bey	Medium Haul	7.4	Caterpillar 3406E	14.9	DOC+FBC	0%	14.9	0.13	DOC+FBC	40%	0.08	0.11	DOC+FBC	40%	0.07
26	38th St. to (via Newport Hoboken-South) Hoboken-North to 38th St.	Billy Bey	Medium Haul	6.2	Caterpillar 3412(2)	4.0	Repower + Doc	30%	2.8	0.50	Repower + Doc	50%	0.25	0.52	Repower + Doc	50%	0.26
27	38th St. to (via Hoboken North & Hoboken South) Newport to 38th St.	Billy Bey	Medium Haul	6.2	Caterpillar 3412(2)	7.5	Repower + Doc	30%	5.3	0.94	Repower + Doc	50%	0.47	0.98	Repower + Doc	50%	0.49
Totals, Billy Bey Ferry Company						**230.6**		**2%**	**227.2**	**3.46**		**44%**	**1.93**	**3.21**		**45%**	**1.78**
28	East 34th St. to Pier 11 to Highlands to Atlantic Highlands to Pier 11 to East 34th St.	Seastreak	Long Haul	50	Cummins KTA50-M2	187.6	SCR	80%	37.5	2.39	SCR	0%	2.39	2.37	SCR	0%	2.37
29	East 34th St. to Pier 11 to Highlands to Pier 11 to East 34th St.	Seastreak	Long Haul	48	Cummins KTA50-M2	18.9	SCR	80%	3.8	0.24	SCR	0%	0.24	0.24	SCR	0%	0.24
30	Pier 11 to South Amboy to Pier 11	Seastreak	Long Haul	45	Cummins KTA50-M2	92.5	SCR	80%	18.5	1.16	SCR	0%	1.16	1.15	SCR	0%	1.15
Totals, Seastreak						**298.9**		**80%**	**59.8**	**3.79**		**0%**	**3.79**	**3.75**		**0%**	**3.75**

Table 3.12. Emission Rate Reduction with ECT, cont'd.

Route No.	Route Origin / Destination / End	Operator	Route Description	Route Distance	Propulsion Engine Type	NOx EMISSION RATE REDUCTIONS				PM2.5 EMISSION RATE REDUCTIONS				PM10 E… RE…	
						Current Total Annual NOx, per route	Reduction Technology	% NOx Reduction	New Total Annual NOx, per route	Current Total Annual PM2.5, per route	Reduction Technology	% PM2.5 Reduction	New Total Annual PM2.5, per route	Current Total Annual PM10, per route	Rec Tecl
				NM		(short tons/yr)		%	(short tons/yr)	(short tons/yr)		%	(short tons/yr)	(short tons/yr)	
31	Various weekday routes [1]	NY Water Taxi	Medium Haul	-	DD Series 60	43.6	Act DPF	0%	43.6	0.73	Act DPF	80%	0.15	0.69	Ac
32	Various weekend routes [1]	NY Water Taxi	Medium Haul	-	DD Series 60	10.5	Act DPF	0%	10.5	0.18	Act DPF	80%	0.04	0.17	Ac
Totals, New York Water Taxi						**54.0**		**0%**	**54.0**	**0.91**		**80%**	**0.18**	**0.86**	
Grand Totals, New York City Harbor						**959.2**		**31%**	**663.3**	**21.23**		**40%**	**12.68**	**21.13**	

Notes: (1): Because NY Watertaxi vessels do not typically complete a closed circuit route the operating profile of the three modes of operation are presented as the total time in hours in each mode d hours of daily operation as determined du

(2): Emission data for mechanically controlled Caterpillar 3412 engines from PANY report dated April 2001

Table 3.13. Estimated Fleet Emissions Reductions with Selected ECTs.

Vessel Operator/Owner	No. of Vessels	Pre ECT NO_X, tons/year	Pre ECT NO_X, tons/year	% Nox Reduction	Pre ECT PM 2.5 tons/year	Post ECT PM 2.5 tons/year	% PM2.5 Reduction	Pre ECT PM 10 tons/year	Post ECT PM 10 tons/year	% PM10 Reduction	Pre ECT HC tons/year	Post ECT HC tons/year	% HC Reduction
NY Waterway, Inc	20	375.63	322.34	14.2%	13.07	6.78	48.1%	13.31	6.88	48.3%	59.62	36.41	38.9%
Billy Bey Ferry Co., Inc.	15	230.64	227.17	1.5%	3.46	1.93	44.2%	3.21	1.78	44.7%	38.91	19.45	50.0%
NY Water Taxi, Inc.	6	54.03	54.03	0.0%	0.67	0.18	80.0%	0.86	0.17	80.0%	5.79	4.63	20.0%
SeaStreak, Ltd.	4	334.02	66.80	80.0%	4.54	4.54	0.0%	4.47	4.47	0.0%	0.00	0.00	0.0%

Section 4

PHASE I: FUEL ECONOMY AND EMISSIONS EFFECTS OF ULSD AND LSD FUELS

INTRODUCTION

Exhaust emissions from diesel engines are influenced by three main factors: engine operating condition, engine design and maintenance, and fuel composition. This latter parameter influences the chemical composition of the exhaust hydrocarbons, as well as the quality of the combustion process, while the former two factors have a greater impact on the total mass of exhausted emissions. In order to reduce fuel consumption and emissions, engine manufacturers have introduced computer controlled fuel metering, turbocharging, after-cooling, exhaust gas recirculation, exhaust aftertreatment, and other in-cylinder design modifications to promote a more complete combustion process.

The Phase I field demonstration consisted of a fuel test field trial performed on representative NYC private ferry fleet vessels, as well as follow-up tests performed on a marine diesel test engine. For the operating ferries, the typical No. 2 low sulfur diesel (LSD) fuel was replaced with No. 1 ultra-low sulfur diesel (ULSD) fuel. Because of its low concentration of sulfur, ULSD has been recognized to reduce certain emissions from diesel engines, especially particulate matter (PM).

In addition to the fuel test trials on the operating ferry vessels, Phase I addressed this same issue by conducting quality controlled emission tests on a marine diesel test engine to minimize potential sources of error encountered during the shipboard trials. This quality control test was performed by an Environment Canada test program and was undertaken in conjunction with two separate projects. The first project, underwritten by NYSERDA, examined the emissions contributions from private passenger ferries, while the second project was a technology demonstration at the Environmental Technology Center located in Ottawa, Ontario, Canada, The purpose of these additional tests was to clarify any outstanding issues made apparent by the shipboard fuel tests. These controlled tests consisted of a full range of fuel test trials and operating mode simulations that maintained a high degree of quality and control on a secure shore-based marine diesel engine test.

PHASE I OUTLINE

The Phase I field demonstration was conducted on four NYC private passenger ferry vessels deemed representative of the majority of the NYC private ferry fleet. Phase I tests aimed at obtaining baseline emission rates for the operating ferries employing LSD fuel and ULSD fuel. The fuel trials for these ferries utilized the load profile and emissions test procedures and protocol developed in Section 2 of this report. These procedures included flushing and refilling the demonstration vessel fuel systems with ULSD, retesting the emissions of each vessel under the same load cycle, and reporting the recorded results. From these results, it was deemed necessary to complete additional tests in a more controlled setting.

In order to verify the fuel flow disparity noted during the initial fuel trials, engine dynamometer tests were conducted by the Emissions Research and Measurement Division (ERMD) laboratory of Environment Canada on a Caterpillar 3176 electronically controlled marine test bed engine.[2] This marine test bed engine was of similar displacement and configuration as the engine installed aboard MV FATHER MYCHAL JUDGE. These emissions tests were comprised of a five mode test cycle for variable speed engines. This test cycle was based on the ISO test cycle E5, which necessitates operating the engine at its rated and intermediate speeds with specified percentages of maximum torque applied at the respective speed. The ERMD test instrumentation and testing methods complied with the procedures outlined in the Canadian Environmental Protection Act (CEPA 99), Division 5 and are identical to those found in the U.S. EPA Code of Federal Regulation (CFR), volume 40, part 89. The five mode cycle used in these experiments is identical to the marine cycle listed in the U.S. CFR volume 40, part 94, §94.105. Two additional modes that represented the speed and torque encountered during the pushing and cruising modes of operating ferry vessels were also performed.

The controlled tests were conducted to compare fuel consumption rates, in addition to the emissions results, between three types of fuels: No. 2 LSD, No. 1 ULSD, and No. 2 ULSD fuels. Additionally, the accuracy of three different techniques for measuring fuel consumption was tested. These three methods for assessing the fuel flow and associated equipment included: a carbon balance method, a fuel flow meter system (FloScan 7500 Series meter, FloScan Instrument Company Inc.), and the indicated (calculated) fuel consumption output from the electronic control module (ECM). The fuel consumption and emission results from the controlled tests were compared with the previously obtained baseline emissions field test results to determine the change a No. 1 fuel imparts when used in place of a No. 2 fuel.

MATERIALS AND METHODS

Field Demonstrated Comparison of LSD and ULSD Fuels

As previously mentioned, the shipboard fuel test trials for the representative ferries utilized the same load profiles, equipment, and emissions sampling procedures and protocol developed in Section 2 of this report. Therefore, these baseline emissions tests were performed in close accordance with those procedures and protocol as outline by M.J. Bradley and the University of West Virginia (UWV). The measurements utilized specialized equipment for quantifying the particular emissions constituents in question. Such equipment included portable dilution tunnels, electrochemical gas sensors, and cyclone/gravimetric separators that measured and collected the gaseous and particulate emissions samples. The make and model of the vessel's propulsion engines and diesel generator sets are shown in Table 4.1.

[2] The Seaworthy Systems Inc. Project Team took advantage of the opportunity presented by Environment Canada to perform the alternate fuels testing on an engine already installed on Environment Canada's test bed undergoing similar testing on biodiesel B-20.

Table 4.1. Vessels and Engines in the Initial Fuel Test Emissions Baseline Experiments (18 Feb. to 7 Apr. 2004).

Operator	Vessel	Main Engine	Generator
NY Waterways	**MV PORT IMPERIAL MANHATTAN**	Cat 3412E	Northern Lights M673
Billy Bey	**MV FATHER MYCHAL JUDGE**	Cat 3406E	Northern Lights P844K
NY Water Taxi	**MV ED ROGOWSKI**	DDC Series 60	Northern Lights M20CR
SeaStreak	**MV SEASTREAK WALL STREET**	Cummins KTA50M2	Cummins/Onan 6BT 5.9

The Phase I baseline emissions tests were completed in such a way as to minimize any interference to the vessel's operations and normal revenue generation. Due to this non-interference policy, the tests were performed under various extenuating circumstances that detracted from the final results. One such uncontrollable factor was the passenger load. Other factors included time of day, tide, and weather. At the same time, each vessel was operated in a manner to simulate the push, cruise, and maneuver modes of operation outlined in earlier sections of this report. Additional modes of operation are presented as well for comparison purposes and were used in the final analysis. These operation modes consist of transit, idle, and diesel generator, and represent an entire one way voyage, no load, and just diesel generator emissions respectively. Testing each of the three modes of operation consisted of measuring the emissions over a recorded period of time, as displayed in Tables 4.2 and 4.3, while the vessel was in normal service. The duration for each test was determined by the amount of time required to collect a measurable emissions sample under near steady state conditions. The process was repeated at least three times for each load point for quality assurance purposes.

Following the baseline tests utilizing LSD, a source of ULSD was obtained, and each vessel was fueled at a common, central location via a tanker-truck. Fuel samples were taken before the first load of ULSD was delivered and at intermediate points in the refueling process to ensure that the associated fuel piping system had been thoroughly flushed to the point that the actual fuel being burned in the engines was less than 30 ppm sulfur. This processes helped to ensure a homogenous low sulfur fuel source when switching from LSD to ULSD fuels. The typical duration required to reach the upper limit for sulfur in the ULSD fuel tests was approximately equivalent to the length of time required to refuel the tanks five times. Additionally, fuel samples were taken at the time of the initial baseline emissions tests via the fuel return pipe from the engine. The samples were then submitted for analysis with the American Bureau of Shipping (ABS) Technical Services Group to quantify the differences between the LSD and ULSD fuels utilized aboard the test vessels. Fuel samples were also collected in the midst of the emissions tests in effort to obtain a running sample of the fuel the engine was actually consuming.

Table 4.2. Baseline Emissions Test's Operating Modes and Durations Utilizing LSD.

	MV PORT IMPERIAL MANHATTAN		MV FATHER MYCHAL JUDGE		MV ED ROGOWSKI		MV SEASTREAK WALL STREET	
1	Idle 1	10 min	Trans 1	10 min	Push 1	10 min	Push 1	10 min
2	Idle 2	5 min	Trans 2	10 min	Push 2	5 min	Push 2	5 min
3	Idle 3	5 min	Trans 3	10 min	Push 3	5 min	Push 3	5 min
4	Push 1	10 min	Push 1	10 min	Cruise 1	5 min	Cruise 1	10 min
5	Push 2	5 min	Push 2	5 min	Cruise 2	5 min	Cruise 2	10 min
6	Push 3	5 min	Push 3	5 min	Cruise 3	5 min	Cruise 3	10 min
7	Cruise 1	10 min	Idle 1	10 min	Cruise 4	5 min	Cruise 4	10 min
8	Cruise 2	5 min	Idle 2	5 min	Cruise 5	5 min	Cruise 5	10 min
9	Cruise 3	5 min	Idle 3	5 min	Cruise 6	5 min	Cruise 6	10 min
10	DG 1	10 min	Cruise 1	10 min	DG 1	10 min	DG 1	10 min
11	DG 2	5 min	Cruise 2	5 min	DG 2	5 min	DG 2	5 min
12	DG 3	5 min	Cruise 3	5 min	DG 3	5 min	DG 3	5 min
13	Trans 1	10 min	Trans 4	10 min				
14	Trans 2	10 min	Trans 5	10 min				
15	Trans 3	10 min	Trans 6	10 min				
16	Trans 4	10 min						
17	Trans 5	10 min						
18	Trans 6	10 min						

Table 4.3. Baseline Emissions Test's Operating Modes and Durations Utilizing ULSD.

	MV PORT IMPERIAL MANHATTAN		MV FATHER MYCHAL JUDGE		MV ED ROGOWSKI		MV SEASTREAK WALL STREET	
1	Idle 1	5 min	Trans 1	10 min	Push 1	10 min	Idle 1	5 min
2	Idle 2	5 min	Trans 2	10 min	Push 2	5 min	Idle 2	5 min
3	Idle 3	5 min	Trans 3	10 min	Push 3	5 min	Idle 3	5 min
4	Idle 4	5 min	Trans 4	10 min	Push 4	10min	Cruise 1	5 min
5	Push 1	5 min	Trans 5	10 min	Cruise 1	5 min	Cruise 2	5 min
6	Push 2	5 min	Trans 6	10 min	Cruise 2	5 min	Cruise 3	5 min
7	Push 3	5 min	Trans 7	10 min	Cruise 3	5 min	Cruise 4	5 min
8	Push 4	5 min	Trans 8	10 min	Cruise 4	5 min	Cruise 5	5 min
9	Cruise 1	5 min	Push 1	5 min	Cruise 5	5 min	Cruise 6	5 min
10	Cruise 2	5 min	Push 2	5 min	Cruise 6	5 min	Cruise 7	5 min
11	Cruise 3	5 min	Push 3	5 min	Cruise 7	5 min	DG 1	5 min
12	Cruise 4	5 min	Push 4	5 min	Cruise 8	5 min	DG 2	5 min
13	DG 1	5 min	Idle 1	5 min	DG 1	10 min	DG 3	5 min
14	DG 2	5 min	Idle 2	5 min	DG 2	5 min	DG 4	5 min
15	DG 3	5 min	Idle 3	5 min	DG 3	5 min		
16	Trans 1	8 min	Idle 4	5 min	DG 4	10 min		
17	Trans 2	8 min	Cruise 1	5 min	Idle 1	5 min		
18	Trans 3	8 min	Cruise 2	5 min	Idle 2	5 min		
19	Trans 4	8 min	Cruise 3	5 min	Idle 3	10 min		
20	Trans 5	8 min	Cruise 4	5 min				
21	Trans 6	8 min						

FUEL AND EMISSIONS COMPARISON ON MARINE DIESEL TEST ENGINE

Engine Description. The test engine used for the fuel and emissions comparisons was a 1994 Caterpillar Model 3176 600 hp 4-cycle marine engine located at Environment Canada's ERMD laboratory. Figure 4.1 shows the test engine mounted on the heavy-duty test cell. It is a compression ignition (CI) marine engine with greater than 37 kW of rated power and between 5 and 30 liters of displacement. This engine would have qualified as a category C2 marine diesel engine under Title 40 Part 94 ("Control of Emissions from Marine Compression-Ignition Engines") of the U.S. Code of Federal Regulations (CFR). From an emissions certification perspective, this engine may have been considered unregulated since no European Union, California Air Resources Board (CARB), or EPA emissions standards existed for this particular class of engine prior to 2000. This engine is primarily utilized in marine applications; this engine model and other Caterpillar engines of similar size were popular propulsion engines utilized during the time period of this report in small to midsize commuter ferries that carried approximately 30 to 100 people.

Figure 4.1. 1994 Caterpillar 3176 600hp Marine Engine.

Fuel and Lubrication Specifications. The engine was operated using three distinct test fuels. Samples of the fuels were sent to the ABS Group/Oiltest, Inc., in Roselle, NJ, for fuel properties analysis; the results are depicted in Table 4.4. The lubricating oil used during the controlled test bed experiments was commercially available oil recommended by the manufacturer, which met the requirements of the CFR.

Table 4.4. Fuel Properties.

FUEL PROPERTY	ANALYSIS METHOD	UNITS / CONDITIONS	NO. 2 LSD	NO. 1 ULSD	NO. 2 ULSD
Specific Gravity	D1298	60/60 Degree F	0.8519	0.8213	0.8368
Sulfur	D2622	PPM	396	22	21
Higher Heating Value	D4868	Btu/Lb	19,641	19,840	19,744
		Btu/Gal	139,314	135,666	137,556
Aromatic Content	D1319	% Volume	24.6	16.3	26.1
Cetane Index	D4737	Calculation	45.4	44.1	50.8
Cloud Point	D97	Degrees F	16	16	16
Carbon	D5291	% Weight	87.03	87.1	87.11
Hydrogen, %m	D5291	% Weight	12.9	12.79	12.81
Nitrogen, mg/L	D5291	% Weight	<0.1	<0.1	<0.1
Lubricity	D2266	1 hr @ 60ºC mm	0.62	0.77	0.79

Testing Protocol. Test bed engine emissions experiments, utilizing the three different fuels, were conducted at the ERMD's Heavy-Duty Engine Emissions Laboratory No. 2. It should be noted that all ERMD testing procedures and instrumentation complied with those applicable to this engine type and model as outlined in the 1999 Canadian Environmental Protection Act (CEPA 99), Division 5. These are identical to those found in the U.S. EPA's Code of Federal Regulation (CFR), Title 40, part 94, "Control of Emissions from Marine Compression-Ignition Engines" and the applicable provisions of CFR-40 part 89, "Control of Emissions from New and In-use Nonroad Compression-Ignition Engines," Subparts D and E.

Engine Pre-Conditioning. The engine was pre-conditioned prior to emission testing by operating it at idle for 2 to 3 minutes, intermediate speed for 5 to 7 minutes, and finally at maximum horsepower for 25 to 30 minutes. Following this warm-up period, engine and coolant temperatures were verified to ensure that they had stabilized at the normal engine operating temperatures (40 CFR Part §90.409(2)(i)).

Engine Mapping. The development of a maximum torque curve was conducted after the engine was pre-conditioned and prior to any initial emissions testing. This was performed to verify the operation and power output of the engine, as well as to determine the peak torque at the intermediate speed. The first engine speed recorded was with the engine operating at idle speed. At this point the electronically controlled engine throttle and load was increased to 100%. The load was then slowly released, which resulted in a predictable slow and controlled increase in the engine speed. Simultaneously, load observations and the concurrent engine speed were recorded at 300 points along this maximum torque curve. Power observations and the peak torque observed during the engine mapping process were plotted for verification and reference. The peak torque, measured only at the engine's intermediate and rated speeds, was then measured and recorded for 1 minute after the engine had stabilized. This value was used to generate the necessary modes for the emissions testing cycle. The engine was operated for approximately 15 minutes while completing the entire mapping procedure. Following the No. 1 ULSD fuel emissions test over the ISO E5 test cycle, the engine was subsequently operated over this same test cycle utilizing No. 2 LSD fuel to verify that the baseline emissions test results had not changed.

Exhaust Sampling. Acquisition of exhaust gas samples was performed in accordance with the "Gaseous Emissions Measurement and Analytical Techniques" as described in 40 CFR, Part 89, Subpart E. The exhaust gas sampling system in the Heavy-Duty Engine Emissions No. 2 Laboratory was designed to measure the true mass of both the gaseous and particulate emissions in the exhaust effluent of the diesel engine tested. A large single-dilution critical flow venturi (CFV) and constant volume sampler (CVS) were used to condition and sample the emissions. A schematic of this system is displayed in Figure 4.2.

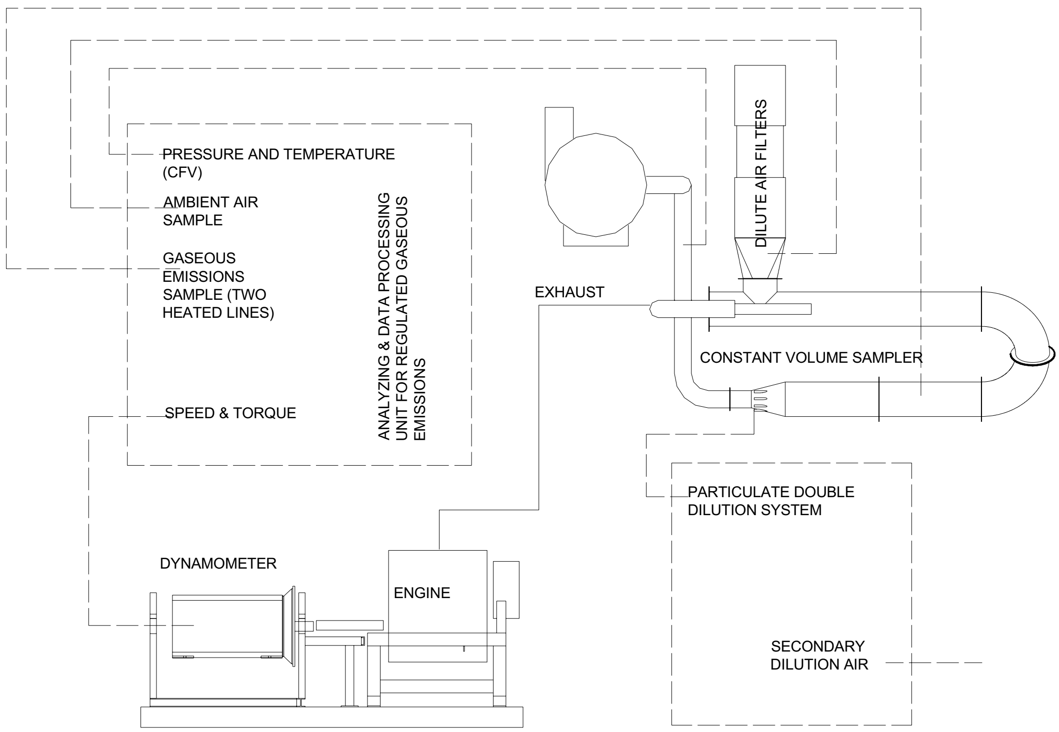


Figure 4.2. Exhaust Sampling System.

The operation of this system consisted of transferring the raw engine exhaust to a stainless steel dilution tunnel, 18" inches in diameter, where it was diluted with ambient air. For PM sampling, the CVS was coupled to a secondary dilution tunnel used to draw out a constant volume of diluted exhaust and dilute it again with ambient air. This process is termed double dilution. The process of conditioning the sample and enabling particulate collection was performed in accordance with the accepted test procedures. The main tunnel flow rate during emissions testing was a nominal 2700 standard cubic feet per minute (SCFM).

Gaseous exhaust samples were obtained using a large single dilution CVS according to the procedure described in the EPA's CFR. For determination of total hydrocarbons (THC) and oxides of nitrogen (NO_X), heated probes, filters, and sample lines were used to direct samples of the diluted exhaust from the dilution tunnel to a heated flame ionization detector (HFID) and a chemiluminescent (CLD) analyzer, respectively. The THC and NO_X emissions were continuously measured throughout the test and integrated to provide the emission rates for each test mode.

Similarly, the emission rates of carbon monoxide (CO) and carbon dioxide (CO_2) were determined by the continuously integrated method of analysis using a proportional sample of the dilute exhaust. Non-dispersive infrared (NDIR) analyzers were used for both CO and CO_2. The results of the real-time concentrations were then integrated over the entire test mode to obtain the emissions rate. Fuel consumption, in grams per kilowatt-hour, was determined via the carbon balance method (40 CFR, Part §600.113-93).

Dynamometer Specifications. Speed and power output for the test bed engine were measured through the use of a dynamometer. The specifications of the instrument were in accordance with those described in 40 CFR §90.305 to §90.321. The dynamometer was a computer controlled Clayton Industries 17-700-CE water brake dynamometer, serial number 2079. This dynamometer simulated the appropriate speeds and loads required for accurate and precise emissions testing. A calibrated torque cell mounted on a moment arm was employed to determine the engine torque. Engine speed was measured using a pulse pick-up installed on the dynamometer. The specifications for this system are contained in Table 4.5.

Table 4.5. Clayton Industries Heavy-Duty Engine Dynamometer Specifications.

	700 bhp
	Hydrokinetic
	Interface Type; Model No. SSMAJ-500; Serial No. D64516

Test Cycles. The Caterpillar 3176 engine was tested using the five-mode test cycle for variable speed engines, as defined in 40 CFR §94.105. This test cycle is based upon the ISO test cycle E5 and requires operating the engine at its rated and intermediate speeds, as well as at given percentages of maximum torque at that speed. Additionally, two modes representative of the speed and torque encountered during the pushing and cruising modes of the field sampling study were performed. A breakdown of the applicable speed, power, and weighting factors for each mode are presented in Table 4.6.

Table 4.6. Test Mode, Cycle E5 with Push and Cruise Modes.

Mode Number	1	2	3	4	5	PUSH	CRUISE
Speed (%)	100	91	80	63	Idle	55	66
Power (%)	100	75	50	25	0	28	30
Weighting Factor	0.08	0.13	0.17	0.32	0.3	-	-

The push and cruise mode test points were derived by applying the same percentage of rated speed that was used for the MV PORT IMPERIAL MANHATTAN emissions tests. The MV PORT IMPERIAL

MANHATTAN push emission test was conducted at an engine speed of approximately 1000 rpm, while the cruise emissions test was conducted at an engine speed of approximately 1200 rpm. The push and cruise speeds were approximately 55% and 67% percent, respectively, of the engine's rated rpm. Please refer to Section 2 of this report, "Vessel Characterization," for referenced material in this subsection.

The engine was operated at each mode for 5 minutes. After the engine temperatures had stabilized, recording of the continuous engine emissions and other necessary data commenced. Fuel consumption was calculated using the carbon balance method, measured with the FloScan fuel meter, and recorded from the indicated flow off the electronic control module (ECM).

Test Sequence. Table 4.7 lists the full sequence of tests for each fuel supplied to the engine. Three full tests were completed for No. 2 LSD fuel and almost fully completed for No. 1 ULSD fuel. Only one full test was performed with No. 2 ULSD fuel. This deficiency in quality control occurred due to the fuel arriving at the laboratory on the last day available for testing in the test cell, which resulted in insufficient time for additional tests.

Table 4.7. Full Test Sequence.

FUEL	DATE	TEST
No. 2 LSD	Oct. 12, 2004	Full 5 mode + Push and Cruise
	Oct. 12, 2004	Full 5 mode + Push and Cruise
	Oct. 14, 2004	Full 5 mode + Push and Cruise
No. 1 ULSD	Oct. 13, 2004	Full 5 mode + Push and Cruise
	Oct. 13, 2004	Full 5 mode + Push and Cruise
	Oct. 13, 2004	Modes 1,2,3 and Cruise
No. 2 ULSD	Oct. 14, 2004	Full 5 mode + Push and Cruise

Fuel Flow Measurement Methods. The fuel flow was determined using the three methods. These included a carbon balance, flow meter, and the Caterpillar ECM. It should be noted that these three methods yielded the actual volume of fuel consumed, which was not normalized or corrected to a standard fuel of known carbon content or heating value.

- **Carbon Balance.** The carbon balance method relates the concentration of carbon products in the exhaust to the amount of fuel burned. Using the measured concentrations of CO_2, CO, and THC in the known exhaust effluent volume, along with the carbon content and specific gravity of the fuel in question, it is possible to determine the amount of fuel consumed.
- **Flow Meter.** FloScan Series 7500 fuel flow meters, with display resolutions to 0.1 liters, were installed on the fuel inlet and return lines of the CAT 3176. Fuel usage for each test was determined from the displayed value.
- **Caterpillar ECM.** The manufacturer's Electronic Control Module (ECM) uses the engine speed and injector pulse width signal to calculate the fuel usage.

RESULTS

Field Demonstrated Comparison of LSD and ULSD Fuels

Fuels. Typical sulfur limits for LSD and ULSD are 500 ppm and 50 ppm respectively, and all fuels analyzed complied with these accepted limits. In addition to sulfur-in-fuel content, several other fuel properties differed significantly between the LSD and No. 1ULSD fuels, heating value being the most obvious. The LSD fuel had an approximate 3.5% to 4.0% higher heating value (based on BTUs per gallon) than the No. 1 ULSD. This difference is also observed in the specific gravities between the two fuels. Table 4.8 presents a summary of the fuel analysis.

Table 4.8. Summary of No. 2 LSD and No. 1 ULSD Fuel Properties as Analyzed by the American Bureau of Shipping Technical Services Group.

	MV PORT IMPERIAL MANHATTAN		MV FATHER MYCHAL JUDGE		MV ED ROGOWSKY		MV SEASTREAK WALL STREET	
	LSD	ULSD	LSD	ULSD	LSD	ULSD	LSD	ULSD
Specific Gravity	0.8641	0.8226	0.8648	0.8232	0.8684	0.8214	0.8638	0.8229
Sulfur, ppm	412	31	405	22	362	29	426	25
HHV, Btu/gal	140,676	135,740	140,741	137,791	141,181	135,557	140,681	135,836
Aromatic, % Vol	38.7	18.1	37.0	18.1	41.5	18.3	36.3	18.3
Cetane Index	43.3	42.5	42.8	42.3	42.0	42.8	44.4	42.7
Cloud Point, ^oF	10	-38	12	-44	10	-49	12	-37
Carbon, %wt	86.58	86.90	86.60	87.22	84.78	87.05	87.12	86.28
Hydrogen %w	13.33	13.10	13.31	12.74	12.71	12.80	11.78	13.61
Lubricity, MM 75^oC	0.63	0.76	0.64	0.75	0.69	0.89	0.65	0.82

Fuel Flow.

The fuel flows were derived from the flows measured during the LSD emissions test and were corrected for differences in engine RPM and volumetric fuel heating value. The fuel flows were derived because the installed fuel meters were unable to accurately measure the No. 1 ULSD flow to the same degree as the LSD. Moreover, the error spread of the meters became more acute as the engine load decreased. Fuel flow rates for the LSD and No. 1 ULSD fuels used in the calculation of the emissions rates for each vessel are presented in Table 4.9. The calculated emission rates are presented in terms of grams of pollutant versus gallon of fuel consumed (grams/gallon, or g/gal). Appendix W presents the emissions data in terms of grams of pollutant versus time (kg/hour).

Table 4.9. Comparison of LSD and ULSD Fuel Consumption Rates.

LSD/ULSD Summary							
MV PORT IMPERIAL MANHATTAN							
Mode	**LSD Test RPM**	**No. 1 ULSD Test RPM**	**LSD Fuel Flow, GPH**	**No. 1 ULSD Fuel Flow, GPH Gross**	**No. 1 LSD Fuel Flow Corr. for HV and RPM**	**% Diff., Gross Fuel Flow**	**% Diff., Corrected Fuel Flow**
Idle	700.1	699	4.6	3.7	4.7	18.9%	3.2%
Push	996.8	1013.1	12.1	16.0	13.2	32.0%	8.5%
Cruise	1189.6	1226.3	12.2	14.2	13.7	16.6%	12.8%
Transit	969.2	872.3	9.7	8.7	7.5	-10.2%	-22.8%
Generator	14.5 kW	15.0 kW	1.3	1.8	1.7	38.5%	29.2%
MV FATHER MYCHAL JUDGE							
Idle	652.5	728.1	1.1	1.9	1.50	71.3%	38.8%
Push	1191.5	1189.6	5.8	7.9	5.87	36.4%	1.7%
Cruise	1813.0	1792.8	18.8	22.3	18.6	18.6%	-1.0%
Transit	1404.0	1390.0	11.6	13.0	11.5	11.9%	-0.7%
Generator	NA	NA	NA	NA	NA	NA	NA
MV ED ROGOWSKY							
Push	1104.6	1100.3	9.7	13.3	10.0	36.2%	3.0%
Cruise 1500	1504.5	1502.8	13.3	16.0	13.8	20.2%	3.8%
Cruise 1800	1803.6	1797.2	20.1	22.3	20.7	11.0%	3.1%
Cruise 2000	1996.9	1981.0	26.6	29.2	27.1	9.6%	1.9%
Generator	5 kW	5 kW	0.14	0.15	0.14	7.1%	-3.5%
MV SEASTREAK WALL STREET							
Push	901.9	750.0	8.9	7.11	5.5	-19.7%	-38.2%
Cruise	1836.0	1861.5	71.9	82.45	77.5	14.6%	7.7%
Generator	47 kW	16 kW	3.7	2.3	1.2	-37.8%	76.2%
Notes:	1. 3.5% reduction in fuel heating value by volume of ULSD vs LSD.						
	2. Specific manufacturer propeller curve used to normalize No. 1 ULSD rpm to LSD rpm.						

For example, while testing the MV FATHER MYCHAL JUDGE in cruise mode, the LSD and ULSD fuel flows were measured at 18.81 and 22.30 GPH, respectively. Without taking engine speed and fuel analysis results into account, the increase in fuel consumption appears to be 18.6%. However, the average engine speeds over the cruise tests for the LSD and No. 1 ULSD fuels were 1813.0 and 1792.8 RPM, respectively. Thus, the direct comparison of the two values is of little practical value. While the actual 21 RPM difference may not appear to be significant, the engine load actually varies as a cubic function of the RPM so that the actual fuel flow and power change experienced is approximately 3.5%. Taking the manufacturer's fuel consumption curves into account as well as the fuel analysis results yields a corrected fuel flow of 18.62 GPH at 1792.8 RPM for No. 1 ULSD fuel in the cruise mode. A similar fuel flow correction calculation using RPM variance, volumetric heating value, and fuel meter values yielded differences of 2.7% to 34% over the test range. These values were deemed incorrect because this amount of excess fuel would have manifested itself in changing other engine parameter data and emissions fractions. Therefore, the differences in fuel flow are likely attributable to differences in fuel properties as shown in Table 4.4.

Demonstrated Vessel Emission Results. Tables 4.10 through 4.17 list the emissions results and the average recorded engine operating parameters gathered during testing. Emissions data are stated in mass of emission constituent per unit of fuel. Figures 4.3 through 4.23 display the average emissions per fuel for each mode of operation tested. Error bars are set at one standard deviation. All raw emissions and engine operating data for each test as well as calculated results in grams per unit fuel are presented in the Appendix W. Appendix I contains a sample calculation for the data reduction process. The grams per hour emissions are not intended to be compared to each other because different engine speeds affect the grams per hour emission value. Regardless of the actual fuel consumption, emissions on a gram per gallon basis of fuel remained constant. The No. 2 LSD fuel produces 10.4 kg of CO_2 per gallon combusted because the vast majority of carbon in the fuel is converted to CO_2. Likewise, the No. 1 ULSD fuel will produce a similar amount of CO_2 varying with the density and carbon fraction between the fuels. All other species vary in grams per gallon relative to the CO_2 value. As a result, the figures and tables in this section are all presented on a grams per gallon basis.

The engine operating parameters are significant in that they can delineate some of the issues that may occur when shifting from one type of fuel to another. The emissions, while stated on a mass per volume of fuel consumed basis, represent only part of the situation. Emissions, to be useful, are stated on a time basis so that their accumulation over time can be calculated. The engine parameter tables in Appendix W serve to qualify the fuel consumption rates that were used to state the emissions on a time basis.

MV PORT IMPERIAL MANHATTAN. It can be seen from Figure 4.3 that NO_X emissions decreased on a gram per gallon basis for the NO. 1 ULSD fuel relative to the LSD fuel over all four steady state operating modes, up to a maximum of 28.4% in the idle mode. Additionally, CO appears to increase for two of three modes for the main engine as well as the DG with the NO. 1 ULSD fuel. PM 2.5 and PM 10 generally decreased a small amount with the NO. 1 ULSD fuel, though usually not to a statistically significant level for the main engine. For the DG, an approximately 50% decrease in PM 2.5 and PM 10 emissions was seen for the NO. 1 ULSD fuel relative to the LSD on a grams per gallon of fuel basis.

Figure 4.5 shows an approximate 4% to 5% decrease in CO_2 emissions with the use of the NO. 1 ULSD fuel. This is likely attributable to the difference in specific gravity between the two fuels. In this case for a given volume of fuel the NO. 1 ULSD contains a smaller mass of carbon. This result should be common to all the vessels when comparing CO_2 emissions.

The transit mode (LSD) vs. transit mode (NO. 1 ULSD) emissions for all measured emissions are presented in Figure 4.8. It can be seen that in general the emissions were similar between the two fuels. At one standard deviation only PM 2.5 and PM 10 experienced a statistically significant reduction in emissions with the use of the NO. 1 ULSD.

Table 4.10. Summary of Exhaust Emission Rates for the MV PORT IMPERIAL MANHATTAN – LSD.

Test Description	NO_X [g/gal]	CO [g/gal]	CO_2 [kg/gal]	PM 2.5 [g/gal]	PM 10 [g/gal]	Comment
Cruise	222	7.6	10.4	0.59	0.61	RPM ~ 1200
Idle	324	6.1	10.4	0.53	0.58	RPM ~ 700
Push	248	8.6	10.4	0.31	0.35	RPM ~ 1000
DG	181	35.9	10.4	3.77	3.68	-
Transit	256	15.9	10.4	0.86	0.86	Manhattan to NJ
Transit	314	13.4	10.4	0.96	1.01	NJ to Manhattan

Table 4.11. Summary of Exhaust Emission Rates for the MV PORT IMPERIAL MANHATTAN – NO. 1 ULSD.

Test Description	NO_X [g/gal]	CO [g/gal]	CO_2 [kg/gal]	PM 2.5 [g/gal]	PM 10 [g/gal]	Comment
Cruise	180	6.1	10.0	0.59	0.53	RPM ~ 1200
Idle	232	9.1	10.0	0.45	0.45	RPM ~ 700
Push	206	11.4	10.0	0.32	0.30	RPM ~ 1000
DG	135	25.6	9.9	1.80	1.62	-
Transit	304	14.7	10.0	0.65	0.69	Manhattan to NJ
Transit	300	12.7	10.0	0.54	0.56	NJ to Manhattan

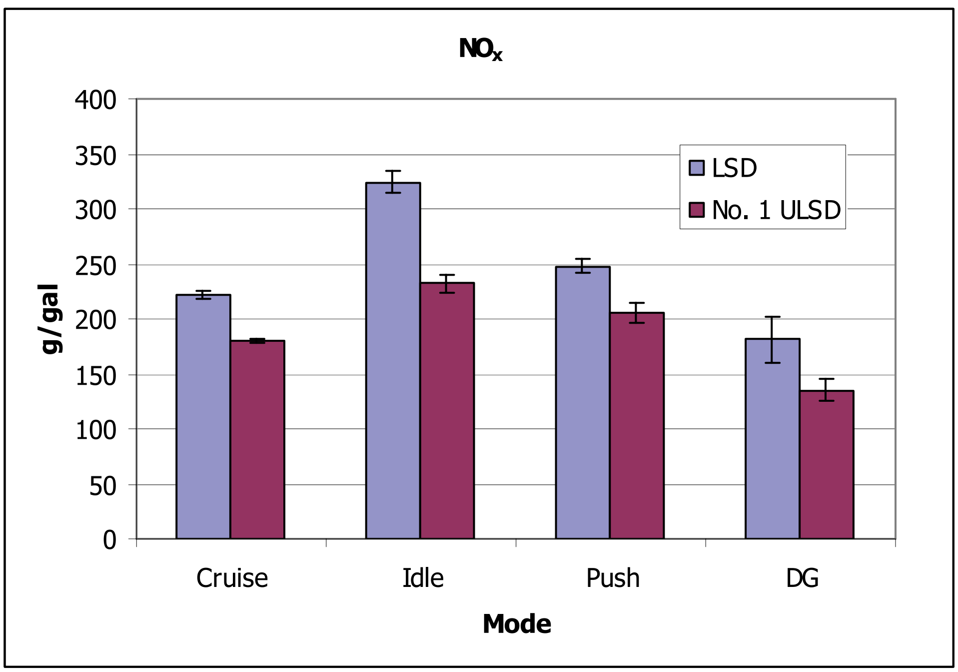


Figure 4.3. NO_X Comparison – MV PORT IMPERIAL MANHATTAN.

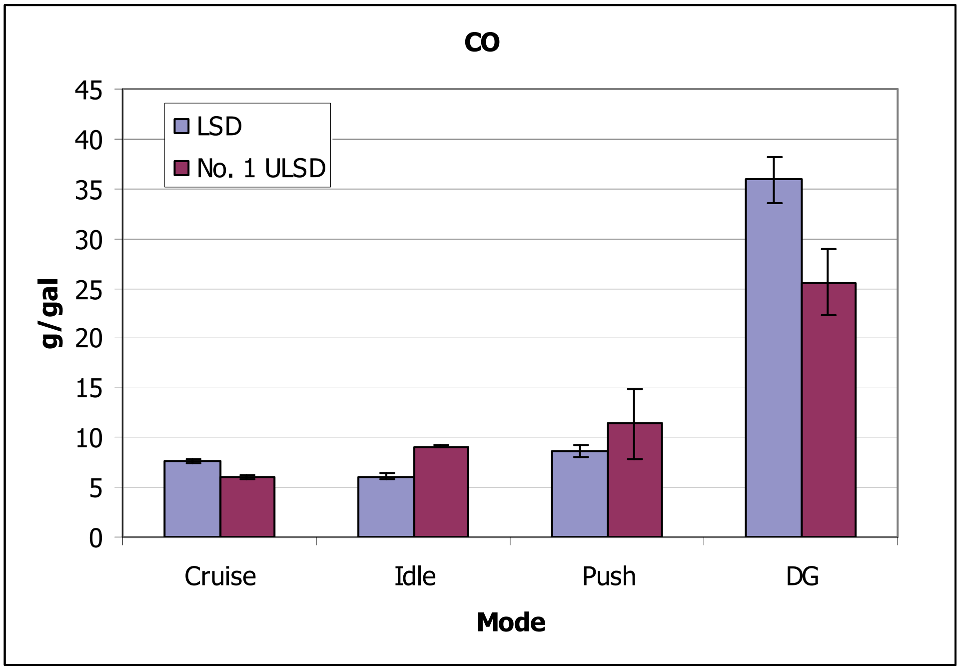


Figure 4.4. CO Comparison – MV PORT IMPERIAL MANHATTAN.

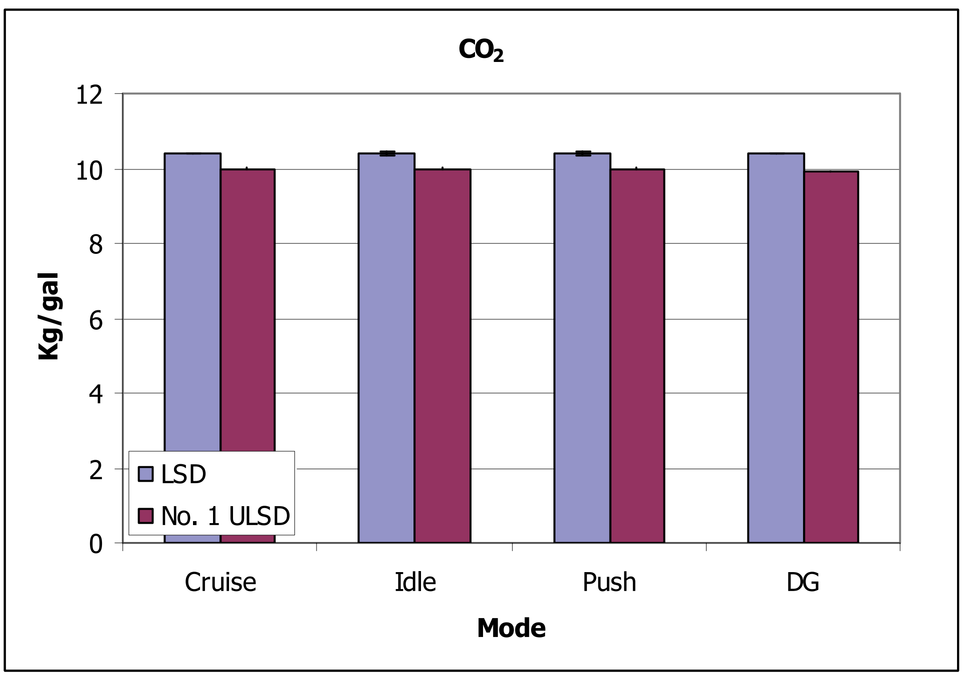


Figure 4.5. CO_2 Comparison – MV PORT IMPERIAL MANHATTAN.

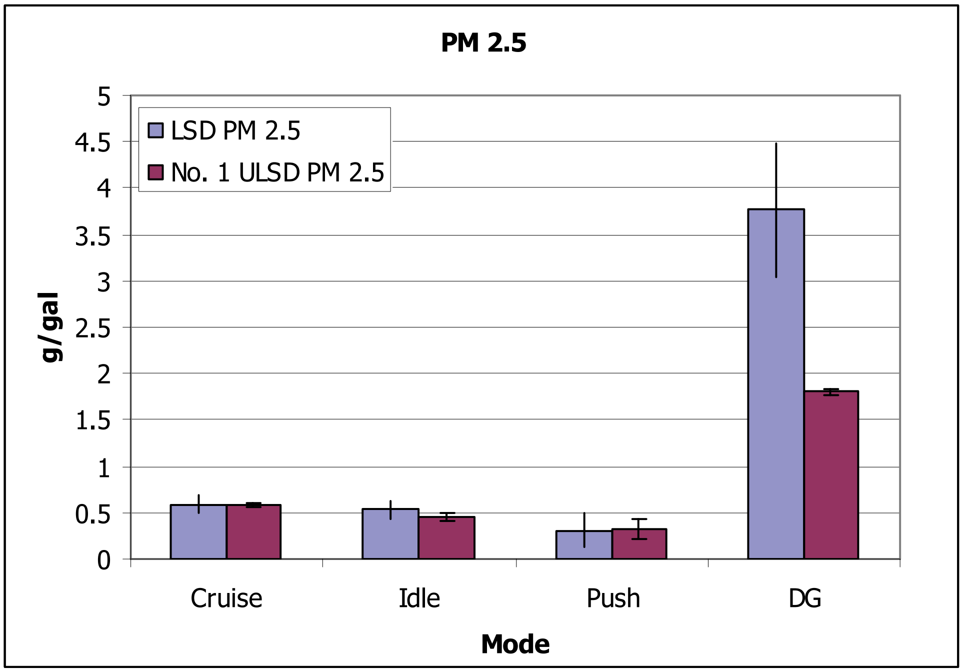


Figure 4.6. PM 2.5 Comparison – MV PORT IMPERIAL MANHATTAN.

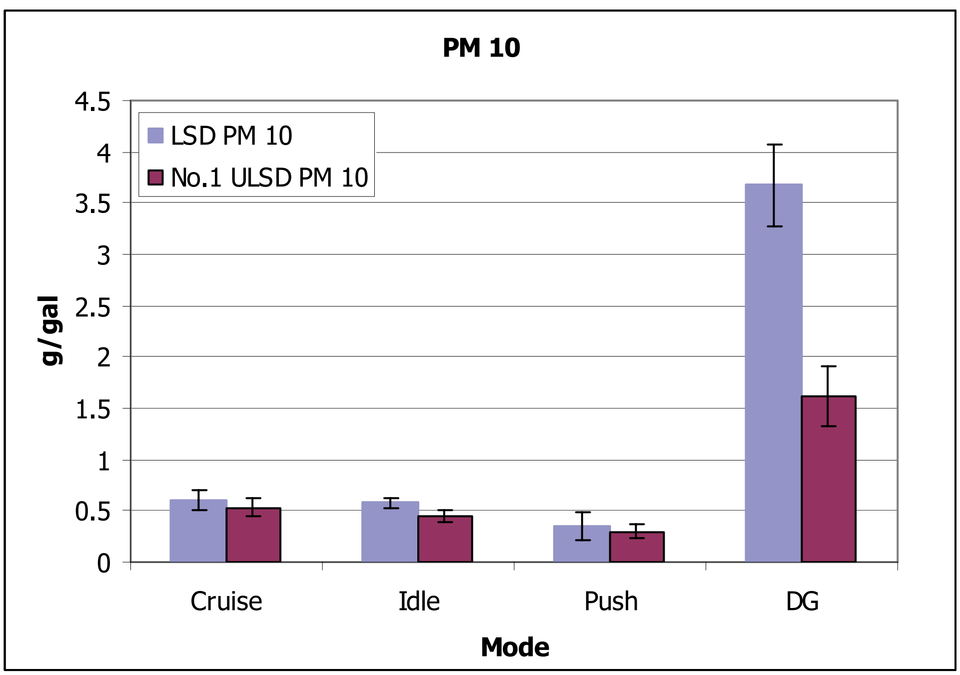


Figure 4.7. PM 10 Comparison – MV PORT IMPERIAL MANHATTAN.

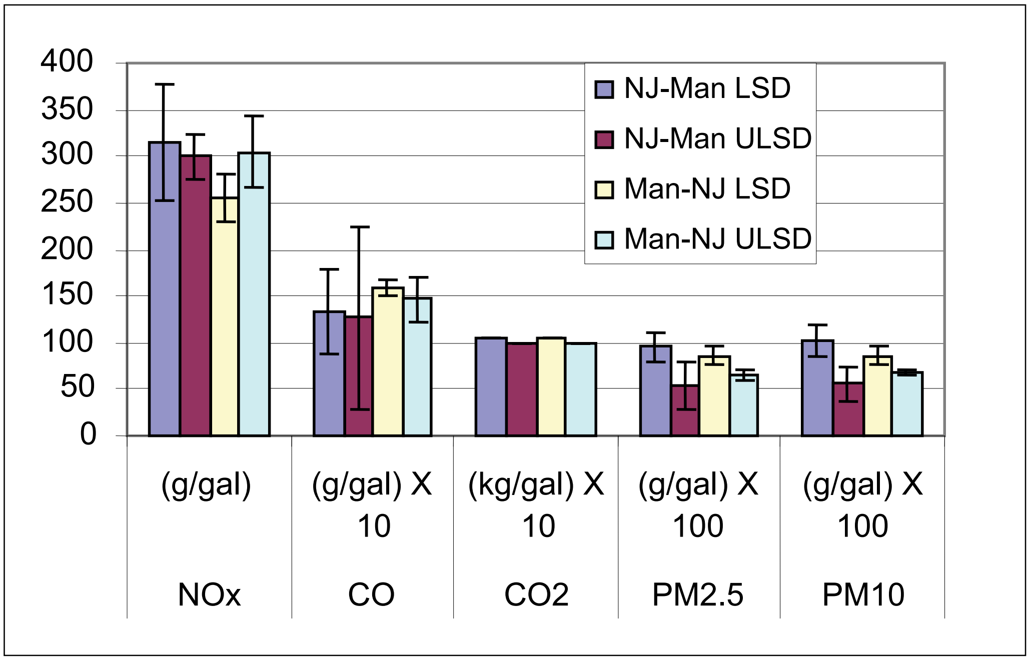


Figure 4.8. Transit Comparison – MV PORT IMPERIAL MANHATTAN.

MV FATHER MYCHAL JUDGE. It can be seen from Figure 4.9 that NO_X emissions decreased on a gram per gallon basis for the NO. 1 ULSD fuel relative to the LSD fuel. NO_X emissions decreased up to a maximum of 39% in the cruise mode. It can additionally be seen that CO and PM increased over the cruise mode and decreased over the idle mode with the NO. 1 ULSD fuel relative to the LSD.

Figure 4.11 shows an approximate 4% to 5% decrease in CO_2 emissions with the use of the NO. 1 ULSD fuel. This is attributable to the difference in specific gravity between the two fuels i.e., for a given volume of fuel the NO. 1 ULSD contains a smaller mass of carbon.

The transit mode (LSD) vs. transit mode (NO. 1 ULSD) for all measured emissions constituents are presented in Figure 4.13. It should be noted that the transit cycles for the LSD and NO. 1 ULSD fuels were not the same. Due to different operational requirements the MV FATHER MYCHAL JUDGE operated on a different route with each fuel. As a result there is limited value in comparing the results of the two transit cycles between fuels.

Table 4.12. Summary of Exhaust Emission Rates for the MV FATHER MYCHAL JUDGE – LSD.

Test Description	NO_X [g/gal]	CO [g/gal]	CO_2 [kg/gal]	PM 2.5 [g/gal]	PM 10 [g/gal]	Comment
Cruise	163	18.7	10.4	1.69	1.45	RPM ~ 1800
Idle	379	40.7	10.4	3.31	3.51	RPM ~ 650
Push	312	12.8	10.4	1.32	1.27	RPM ~ 1200
Transit	255	39	10.4	2.99	2.93	Start: Pier 11
Transit	207	23	10.4	1.55	1.41	Start: Harborside

Note: Trials 5,6,7 performed in PM rush hour, trials 2,3,4 performed in AM rush hour.

Table 4.13. Summary of Exhaust Emission Rates for the MV FATHER MYCHAL JUDGE – NO. 1 ULSD.

Test Description	NO_X [g/gal]	CO [g/gal]	CO_2 [kg/gal]	PM 2.5 [g/gal]	PM 10 [g/gal]	Comment
Cruise	100	67.5	9.9	4.19	4.08	RPM ~ 1800
Idle	369	22.2	10.0	0.97	0.87	RPM ~ 650
Push	244	16.5	10.0	0.93	1.66	RPM ~ 1200
Transit	150	53	9.9	3.17	3.14	Pier 76 to NJ
Transit	141	55	9.9	3.50	3.55	NJ to Pier 76

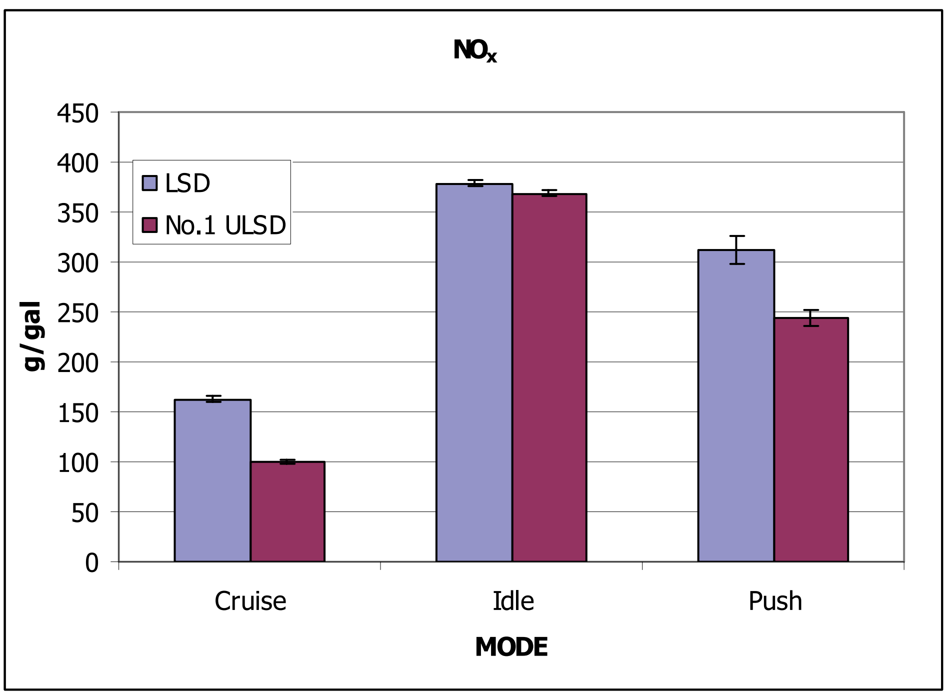


Figure 4.9. NO_X Comparison – MV FATHER MYCHAL JUDGE.

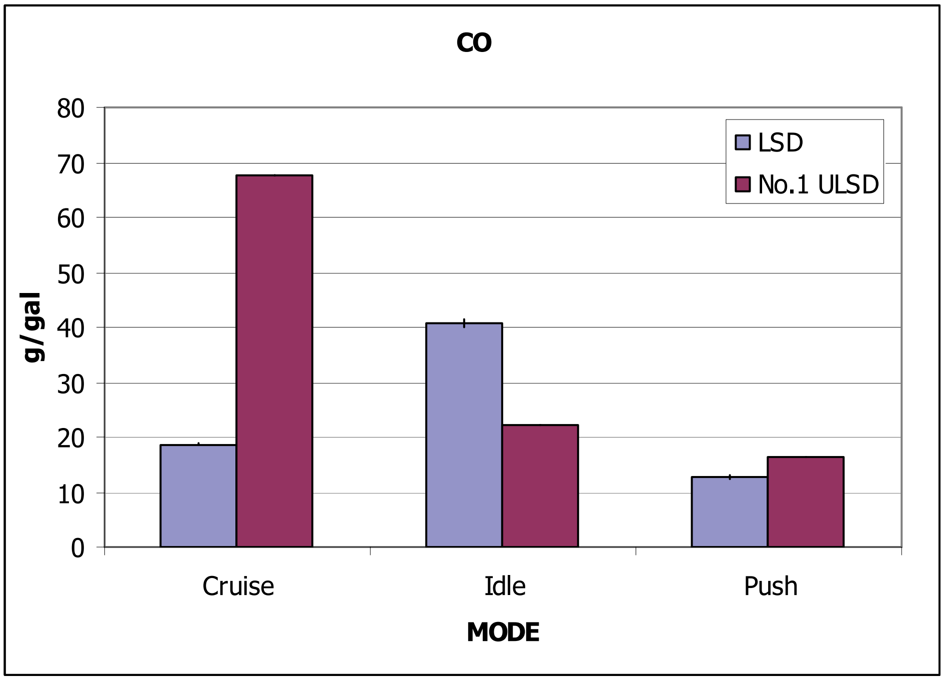


Figure 4.10. CO Comparison – MV FATHER MYCHAL JUDGE.

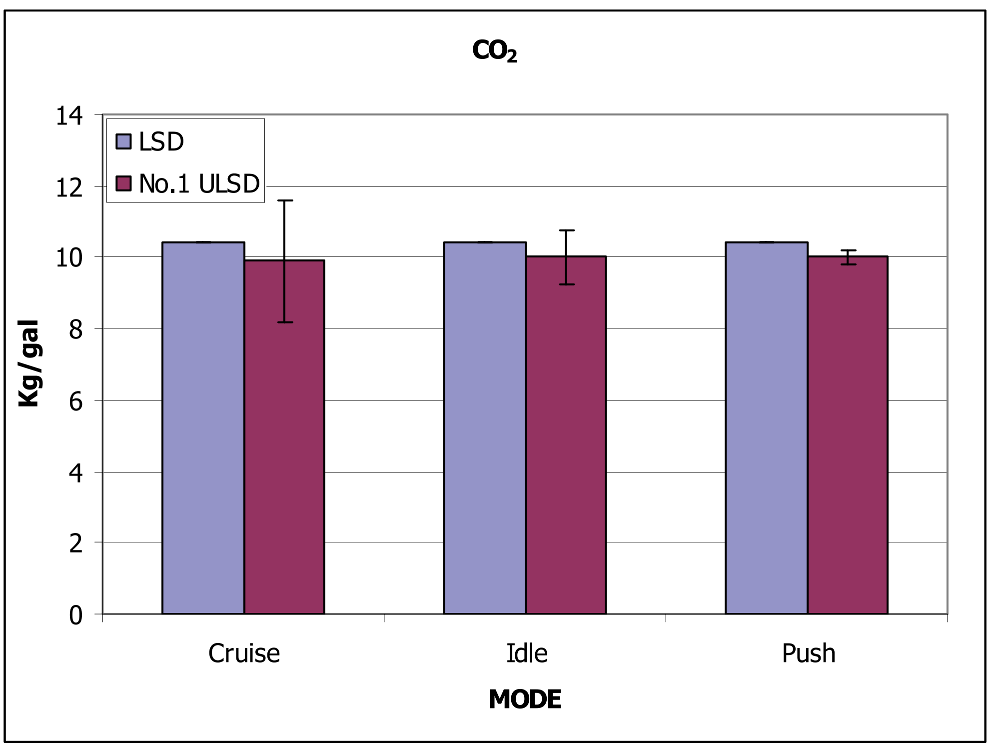


Figure 4.11. CO_2 Comparison – MV FATHER MYCHAL JUDGE.

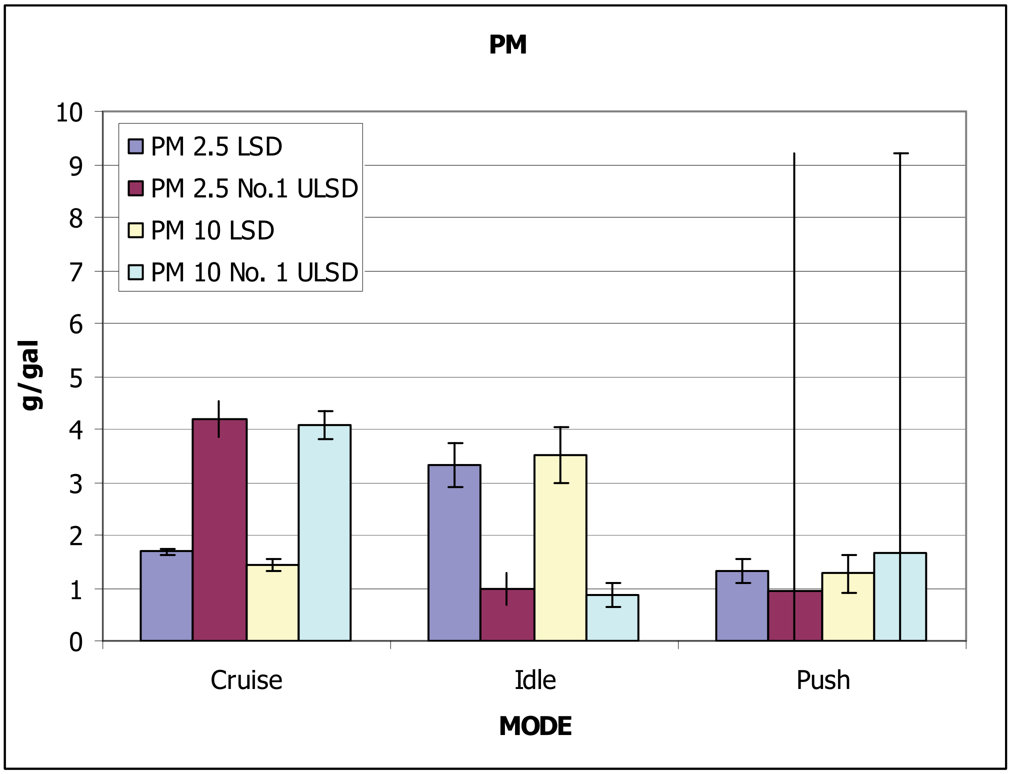


Figure 4.12. PM 2.5 and PM 10 Comparison – MV FATHER MYCHAL JUDGE.

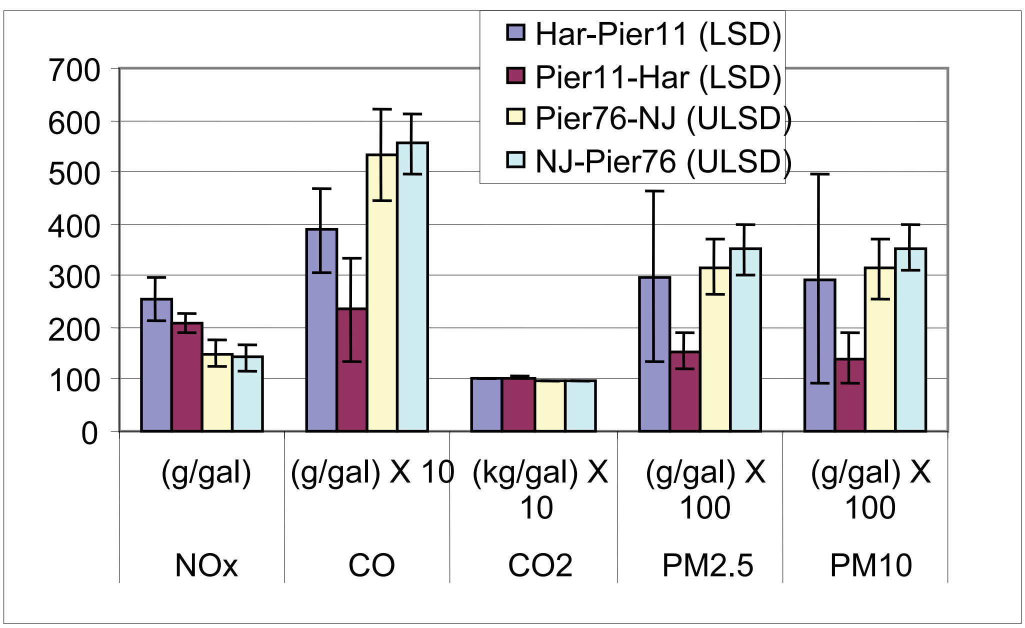


Figure 4.13. Transit Comparison – MV FATHER MYCHAL JUDGE.

MV SEASTREAK WALL STREET. Figure 4.14 shows a 20% decrease in NO_X emissions for the NO. 1 ULSD fuel relative to the LSD fuel in the cruise mode. The only other common testing to both fuels was for the DG, which saw a 70% decrease in NO_X emissions with the NO. 1 ULSD fuel.

It can additionally be seen that CO emissions saw a small statistically significant increase in the cruise mode with the NO. 1 ULSD and a large increase (≈400%) for the DG. The PM 2.5 and PM 10 results coincide closely with the CO emissions with a statistically insignificant decrease for the main engine in cruise mode and a large increase in PM emissions for the DG. As with the other vessels a 4% to 5% decrease in CO_2 emissions was seen with the use of the NO. 1 ULSD fuel relative to the LSD fuel.

Operational requirements during the NO. 1 ULSD round of testing did not allow for testing to be performed during the push mode of operation. However, enough time at idle was available to test with the NO. 1 ULSD fuel.

Table 4.14. Summary of Exhaust Emission Rates for the MV SEASTREAK WALL STREET – LSD.

Test Description	NO_X [g/gal]	CO [g/gal]	CO_2 [kg/gal]	PM 2.5 [g/gal]	PM 10 [g/gal]	Comment
Cruise	142	15	10.5	1.72	1.74	RPM ~ 1800
Push	131	13	10.5	3.31	3.03	RPM ~ 900
DG	129	13	10.5	4.01	3.99	-

Table 4.15. Summary of Exhaust Emission Rates for the MV SEASTREAK WALL STREET – NO. 1 ULSD.

Test Description	NO_X [g/gal]	CO [g/gal]	CO_2 [kg/gal]	PM 2.5 [g/gal]	PM 10 [g/gal]	Comment
Cruise	113	17	9.9	1.33	1.32	RPM ~ 1800
Idle	104	15	9.9	2.94	2.82	RPM ~ 700
DG	34	71	9.8	17.95	17.49	-

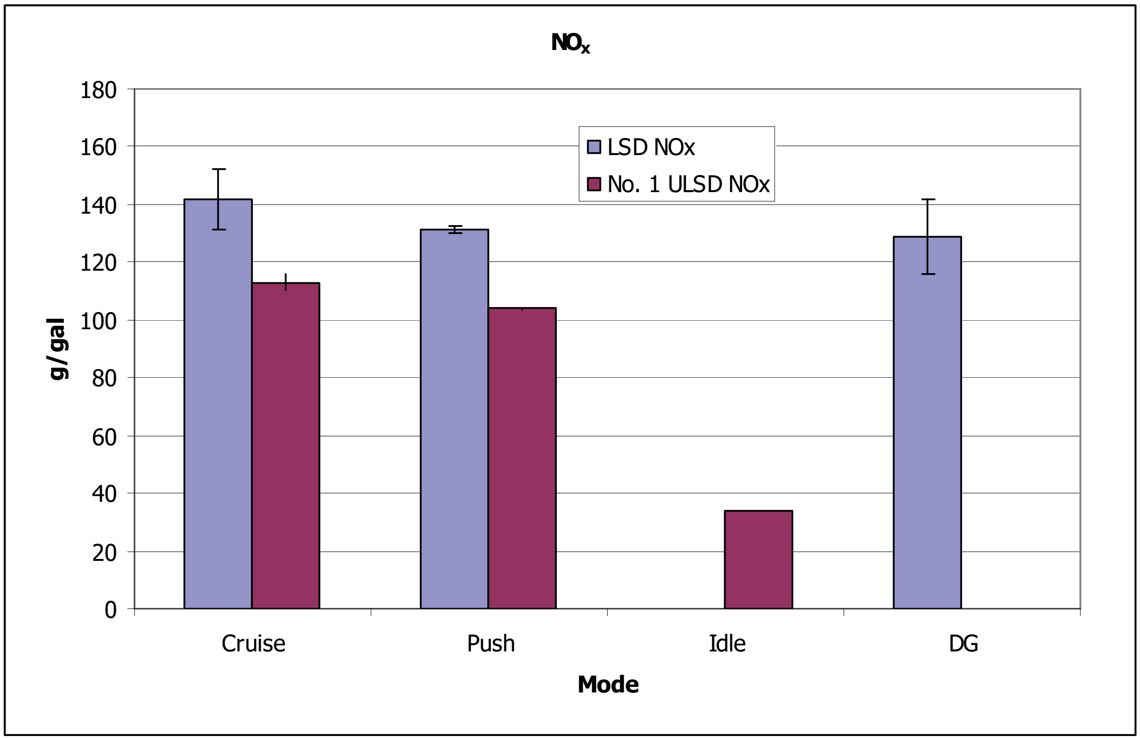


Figure 4.14. NO_X Comparison – MV SEASTREAK WALL STREET.

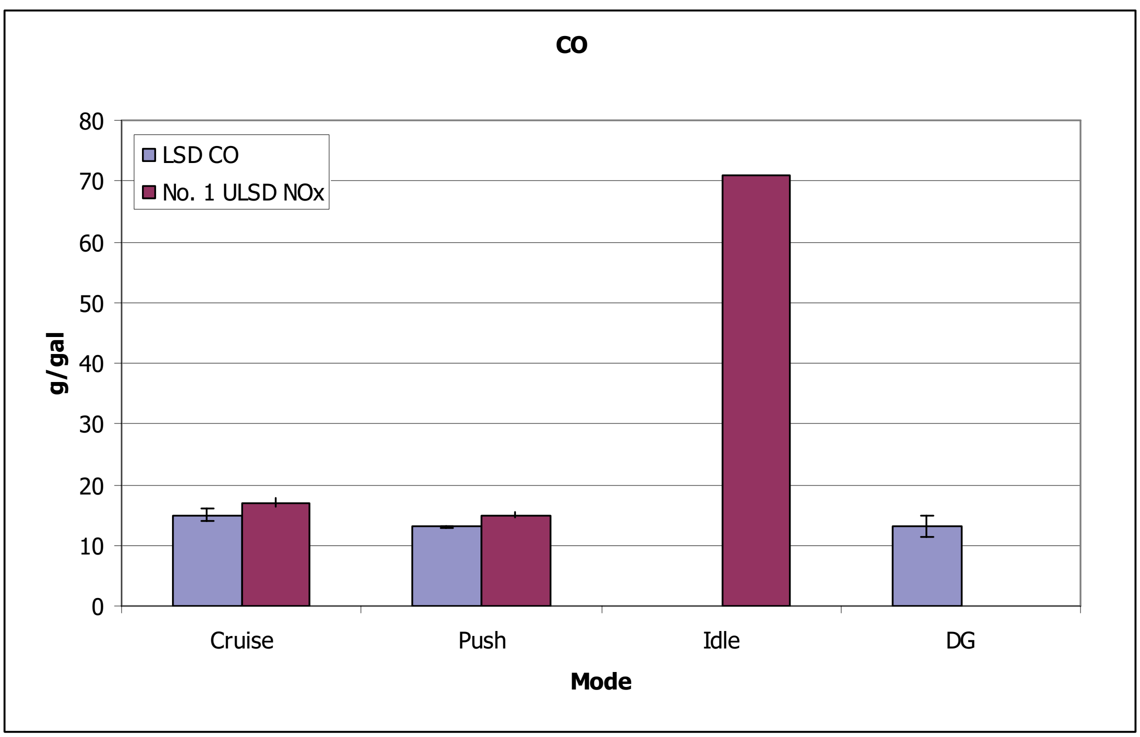


Figure 4.15. CO Comparison – MV SEASTREAK WALL STREET.

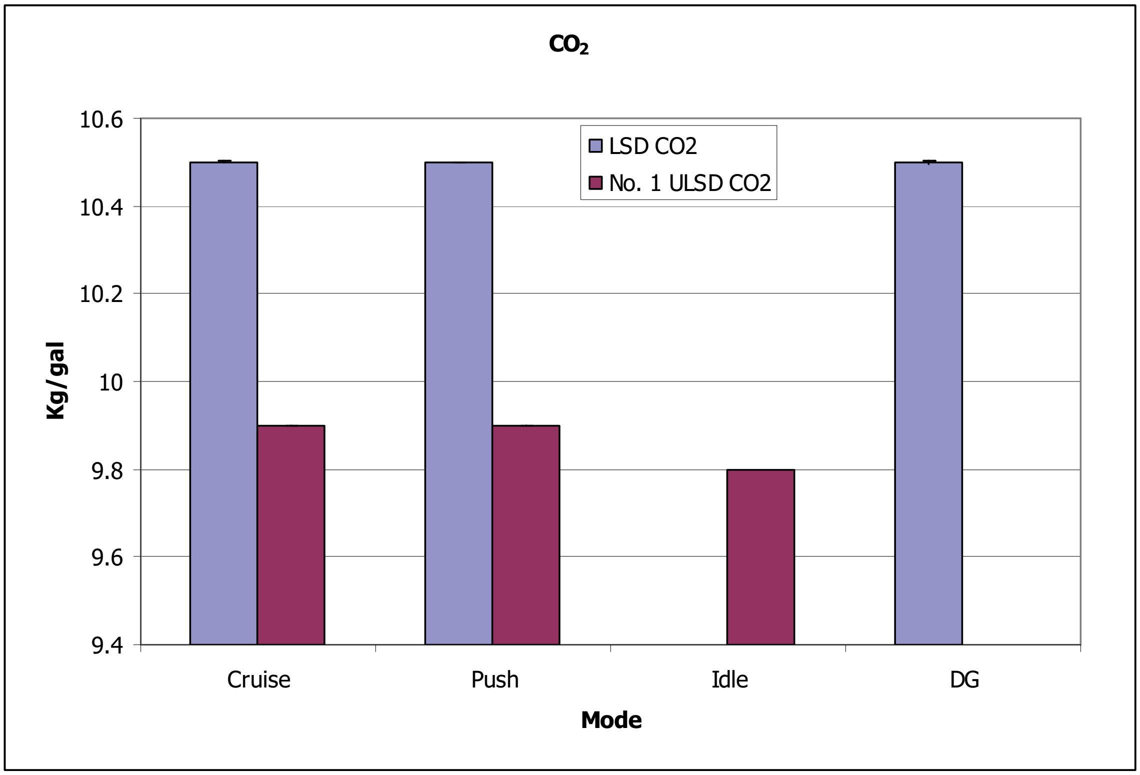


Figure 4.16. CO_2 Comparison – MV SEASTREAK WALL STREET.

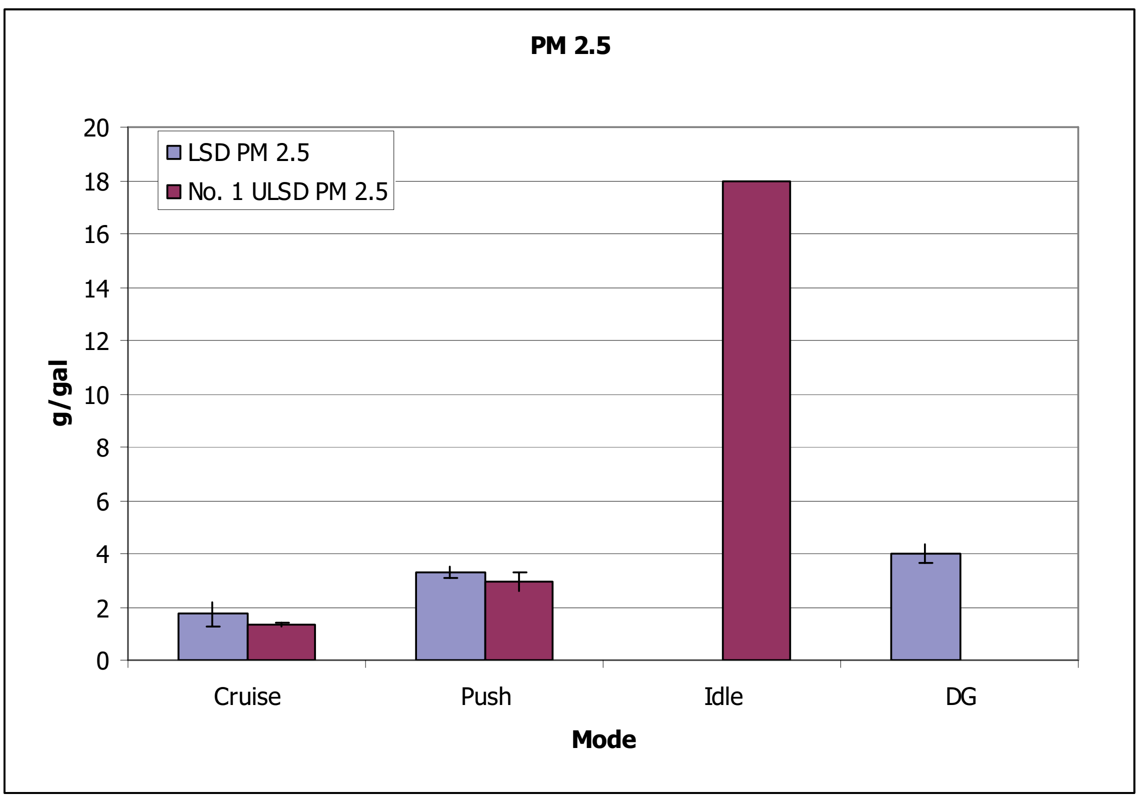


Figure 4.17. PM 2.5 Comparison – MV SEASTREAK WALL STREET.

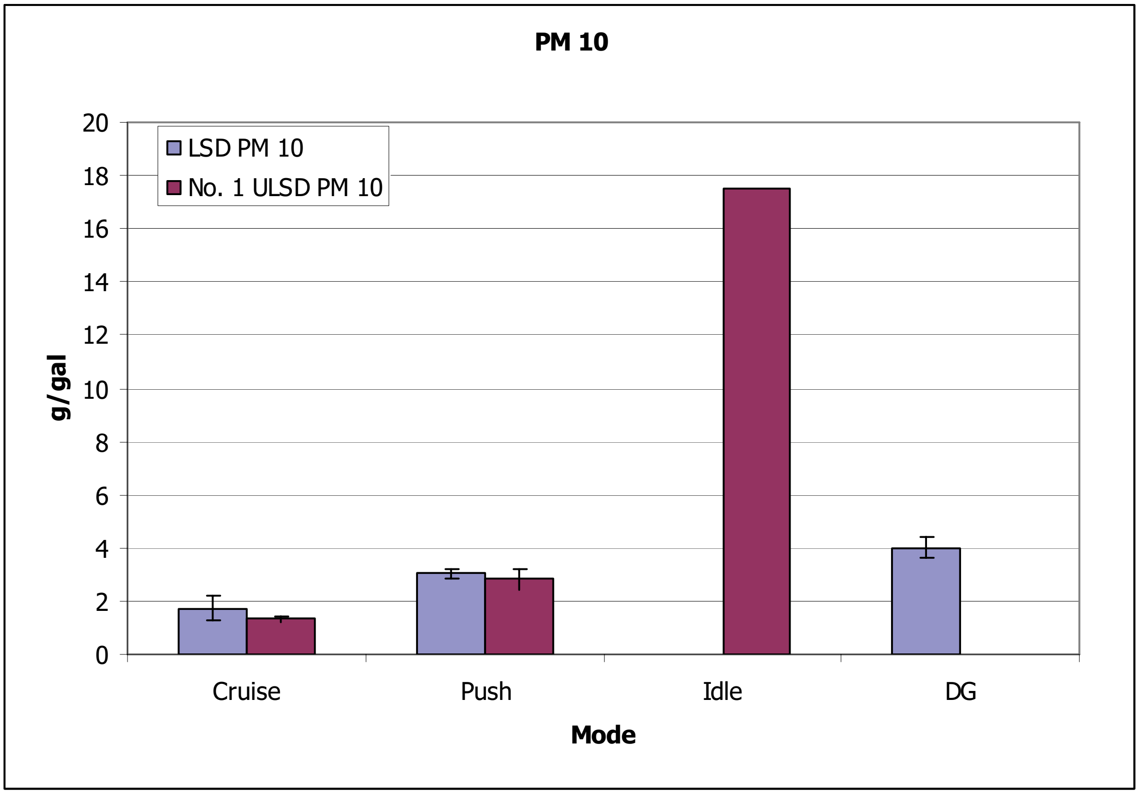


Figure 4.18. PM 10 Comparison - MV SEASTREAK WALL STREET.

MV ED ROGOWSKY. It can be seen from Figure 4.19 that NO_X experienced a decrease for all four test modes and the DG with the use of the NO. 1 ULSD fuel relative to the LSD fuel. The maximum decrease was approximately 28% when cruising at 2100 rpm.

For the MV ED ROGOWSKY the CO emissions experienced a 10% increase in the push mode with the NO. 1 ULSD fuel. Similar increases were seen in the cruise-1500 and cruise-1800 modes, though a decrease was seen in the cruise-2100 mode. It should be noted that the absolute value of the CO emissions in the push mode far exceeds that of the cruise modes regardless of fuel type. Thus, a statistically significant increase in the push mode outweighs a similar percentage decrease in one of the cruise modes.

It is readily observable from Figures 4.22 and 4.23 that PM 2.5 and PM 10 increased in the push mode but decreased in the cruise-1800 and cruise-2100 modes. Although the PM 2.5 and PM 10 emissions increased with NO. 1 ULSD fuel usage, the amount was not statistically significant at one standard deviation. As with the other vessels, a 4% to 5% decrease in CO_2 emissions was observed with the use of the NO. 1 ULSD fuel relative to the LSD fuel.

Table 4.16. Summary of Exhaust Emission Rates for the MV ED ROGOWSKY – LSD.

Test Description	NO_X [g/gal]	CO [g/gal]	CO_2 [kg/gal]	PM 2.5 [g/gal]	PM 10 [g/gal]	Comment
Push	158	97.1	10.1	1.36	1.25	RPM ~ 1100
Cruise	129	27.8	10.2	2.15	2.01	RPM ~ 1500
Cruise	141	10.2	10.3	2.96	3.06	RPM ~ 1800
Cruise	117	5.6	10.3	2.84	2.47	RPM ~ 2100
DG3	67	26.7	10.2	3.87	4.25	-

Table 4.17. Summary of Exhaust Emission Rates for the MV ED ROGOWSKY – NO. 1 ULSD.

Test Description	NO_X [g/gal]	CO [g/gal]	CO_2 [kg/gal]	PM 2.5 [g/gal]	PM 10 [g/gal]	Comment
Push	152	107.1	9.6	2.19	2.12	RPM ~ 1100
Cruise	106	30.2	9.7	2.51	2.40	RPM ~ 1500
Cruise	112	11.5	9.7	0.83	1.01	RPM ~ 1800
Cruise	84	4.5	9.7	0.44	0.52	RPM ~ 2100
DG3	50	26.5	9.7	4.22	4.40	-

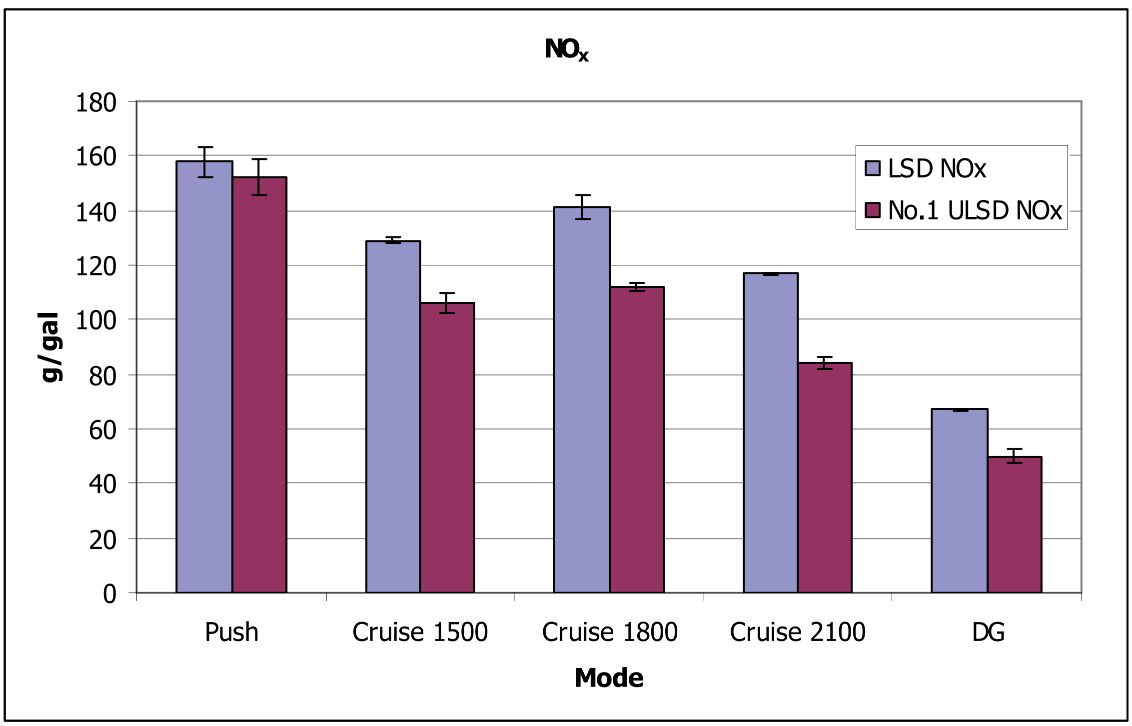


Figure 4.19. NO_X Comparison – MV ED ROGOWSKY.

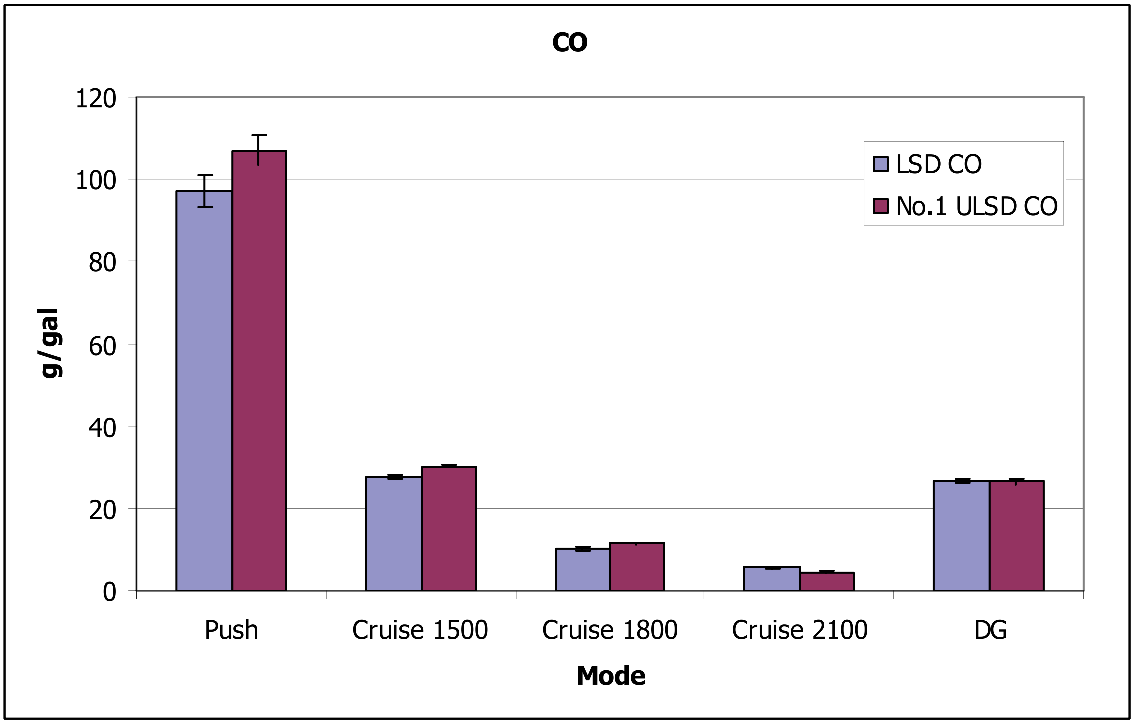


Figure 4.20. CO Comparison – MV ED ROGOWSKY.

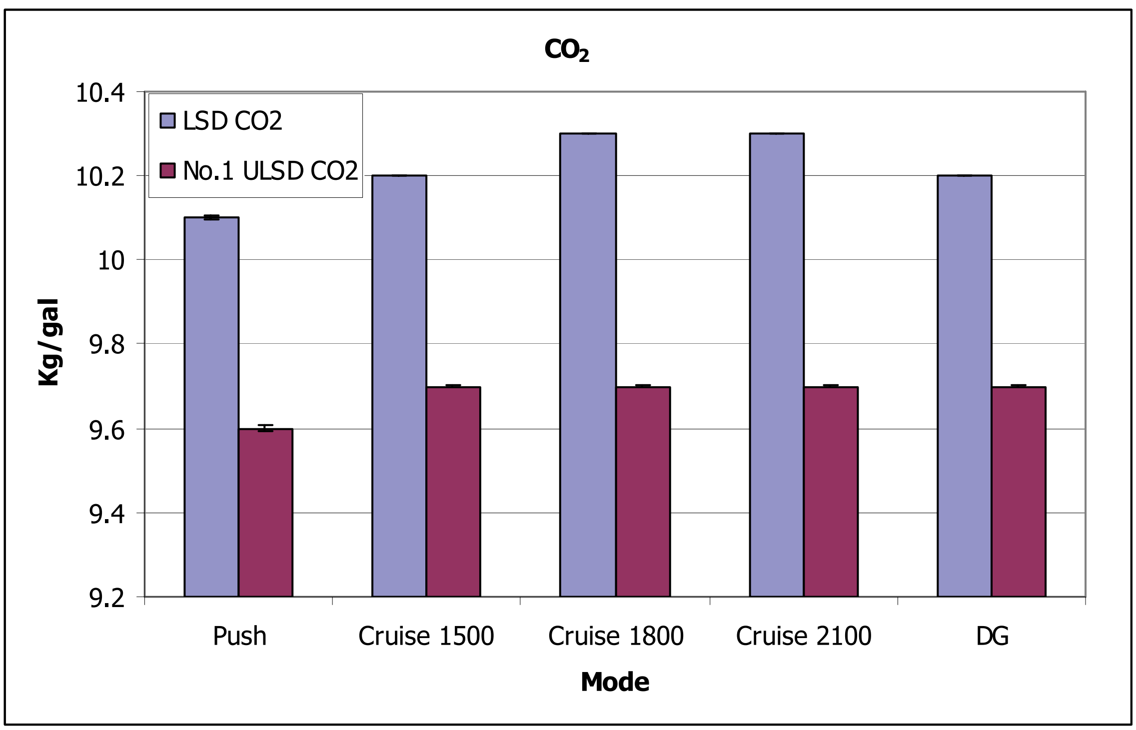


Figure 4.21. CO_2 Comparison – MV ED ROGOWSKY.

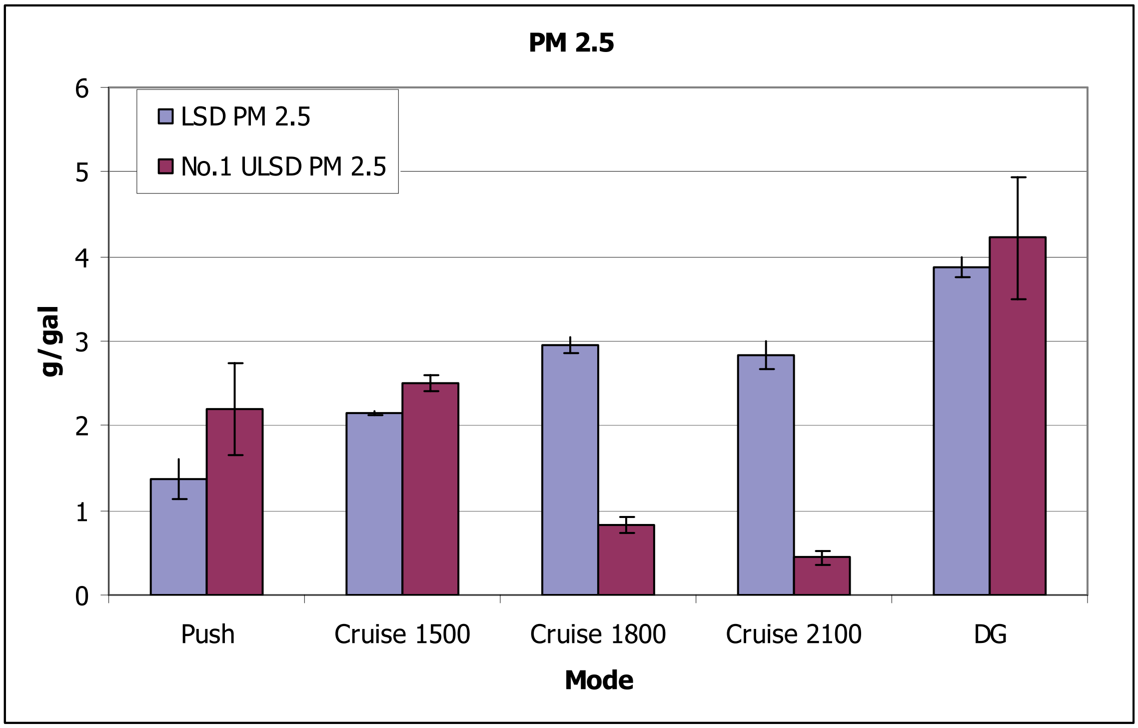


Figure 4.22. PM 2.5 Comparison – MV ED ROGOWSKY.

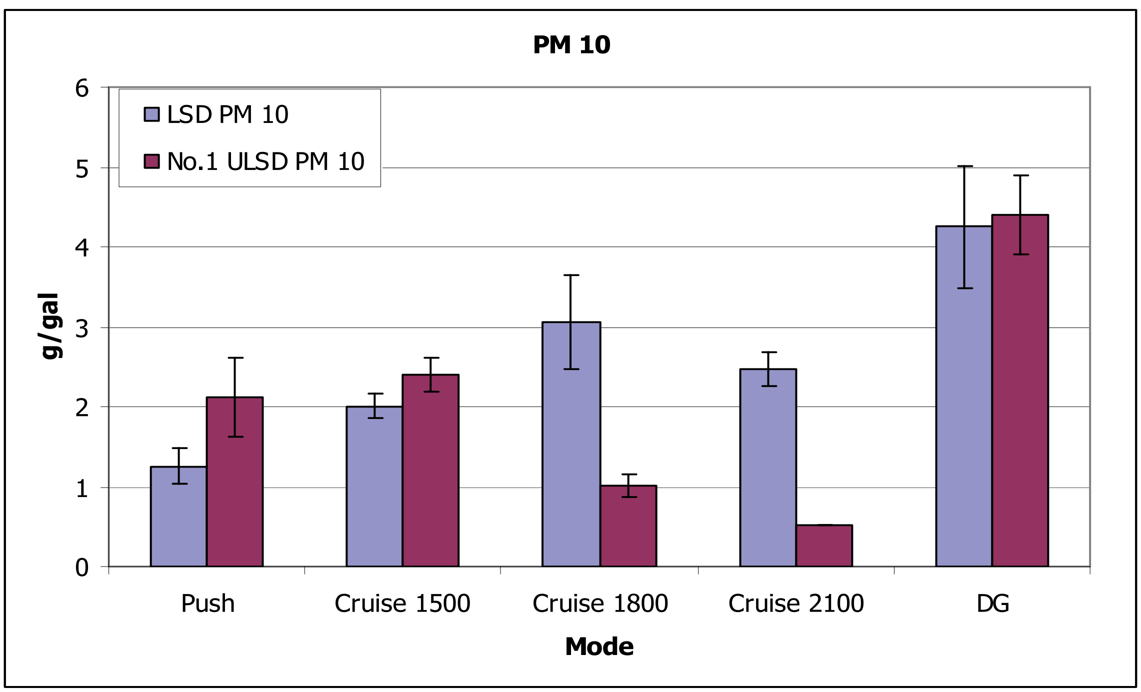


Figure 4.23. PM 10 Comparison – MV ED ROGOWSKY.

<u>Fuel Comparisons on Marine Diesel Test Engine.</u>

The results of the exhaust emissions measurements and fuel consumption measurements are presented in Tables 4.18 through 4.23. The data is presented in units of grams of pollutant per brake horsepower-hour (g/bhp-hr) of operation and literes per hour respectively. Due to time and manpower constraints, PM filters were not collected over the push and cruise modes. Also, in Mode 5 (idle), the fuel flow rate was not measurable with the FloScan meter. Additionally, it should be noted that in Mode 5 (idle), the torque was too low to be properly measured, resulting in an unreasonably low calculated horsepower value. It is known that the fuel consumption should be in the range of 150 to 200 g/bhp-hr in a properly operating four cycle diesel engine. It can be seen in the Conclusions of this report (Section 6) that the value for this particular engine is roughly 160 to 180 g/bhp-hr of fuel consumption. Thus, for Mode 5 only, a horsepower value resulting from this g/bhp-hr range of fuel consumption was used in order to calculate the exhaust emissions in g/bhp-hr.

Table 4.18. No. 2 LSD Emission Rates.

	EMISSION RATES, g/bhp-hr					
MODE	**CO**	**CO_2**	**NO_X**	**NO**	**THC**	**PM**
Mode 1	2.57	514	4.75	3.17	0.04	0.20
Mode 2	3.26	505	5.19	3.48	0.03	0.15
Mode 3	5.01	491	5.60	3.79	0.04	0.15
Mode 4	3.27	560	7.03	4.82	0.08	0.11
Mode 5	2.98	551	11.78	7.06	1.14	0.23
Cruise	4.38	554	6.56	4.44	0.08	-
Push	9.53	558	4.55	3.08	0.04	-

Table 4.19. No. 2 LSD Fuel Flow.

	FUEL FLOW RATES, liters/hr		
MODE	**CARBON BALANCE**	**FLOSCAN**	**CAT ECM**
Mode 1	99.7	104.5	96.0
Mode 2	84.5	88.1	85.2
Mode 3	55.5	59.1	57.2
Mode 4	30.8	28.5	28.1
Mode 5	10.1	-	9.5
Cruise	36.3	35.2	33.5
Push	35.0	34.1	34.0

Table 4.20. No. 1 ULSD Emission Rates.

	EMISSION RATES, g/bhp-hr					
MODE	**CO**	**CO_2**	**NO_X**	**NO**	**THC**	**PM**
Mode 1	2.67	514	4.10	2.72	0.05	0.23
Mode 2	3.25	498	4.59	3.16	0.04	0.15
Mode 3	5.09	486	5.13	3.55	0.05	0.16
Mode 4	4.52	539	6.39	4.39	0.10	0.12
Mode 5	2.57	545	11.57	7.47	0.89	0.19
Cruise	6.34	536	5.28	3.63	0.08	-
Push	9.18	549	4.11	2.82	0.04	-

Table 4.21. No. 1 ULSD Fuel Flow.

	FUEL FLOW RATES, liters/hr		
MODE	**CARBON BALANCE**	**FLOSCAN**	**CAT ECM**
Mode 1	103.4	112.8	101.8
Mode 2	86.2	93.9	89.7
Mode 3	56.8	63.6	60.7
Mode 4	31.4	31.3	30.3
Mode 5	9.9	-	9.5
Cruise	36.3	38.3	36.0
Push	35.7	36.7	36.0

Table 4.22. No. 2 ULSD Emission Rates.

	EMISSION RATES, g/bhp-hr					
MODE	**CO**	**CO_2**	**NO_X**	**NO**	**THC**	**PM**
Mode 1	2.65	508	4.25	2.97	0.04	0.18
Mode 2	3.24	497	4.67	3.29	0.03	0.13
Mode 3	5.05	487	4.98	3.53	0.04	0.14
Mode 4	4.00	447	5.20	3.43	0.06	0.09
Mode 5	2.06	546	10.700	6.91	0.92	0.21
Cruise	4.03	525	5.65	4.04	0.08	-
Push	9.06	541	3.88	2.78	0.04	-

Table 4.23. No. 2 ULSD Fuel Flow.

	FUEL FLOW RATES, liters/hr		
MODE	**CARBON BALANCE**	**FLOSCAN**	**CAT ECM**
Mode 1	100.3	103.2	97.3
Mode 2	84.5	86.4	85.5
Mode 3	55.9	57.6	58.2
Mode 4	30.1	26.4	27.9
Mode 5	10.0	-	9.5
Cruise	35.3	34.0	33.5
Push	34.6	32.4	34.6

Figures 4.24, 4.25, and 4.26 show the fuel flow rates as determined by the three methods for all three fuels.

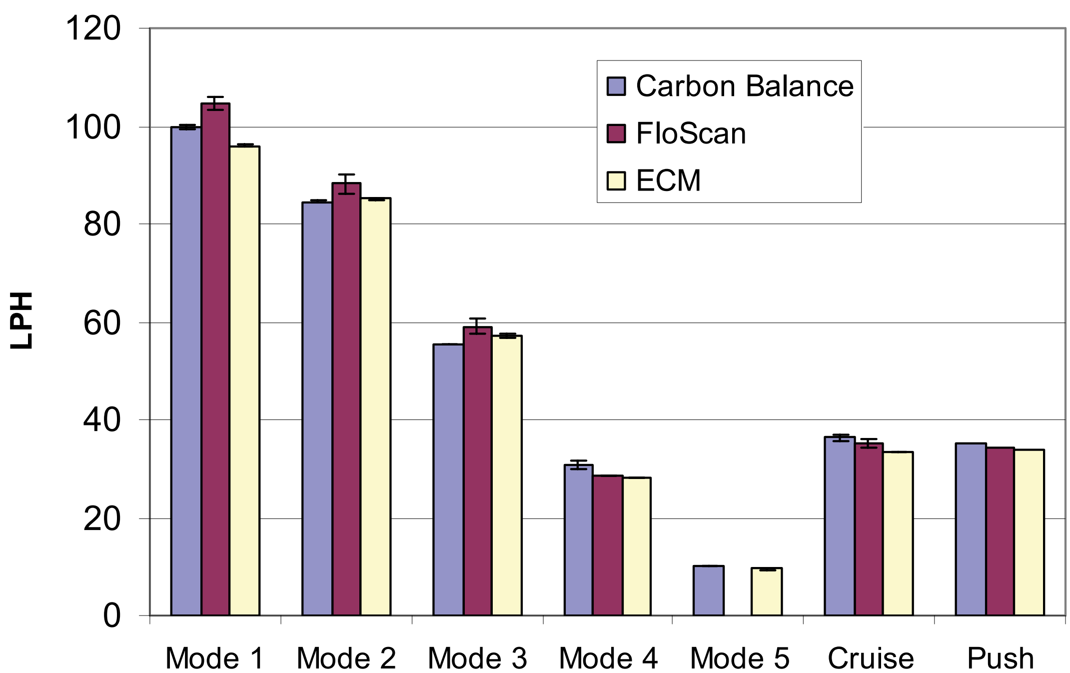


Figure 4.24. No. 2 LSD Flow Rate Measurement Comparison.

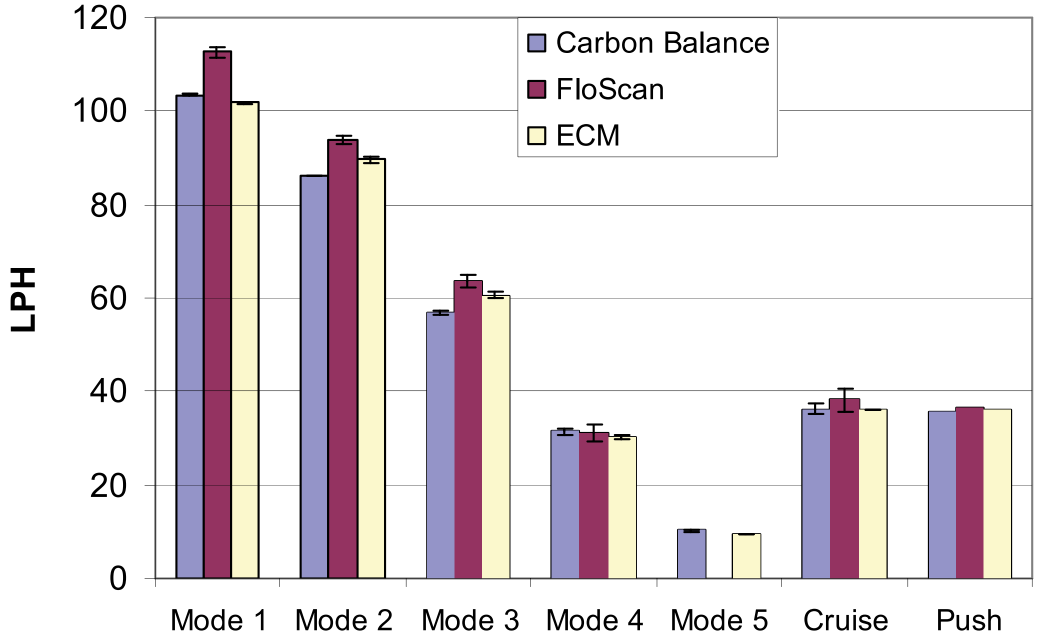


Figure 4.25. No. 1 ULSD Flow Rate Measurement Comparison.

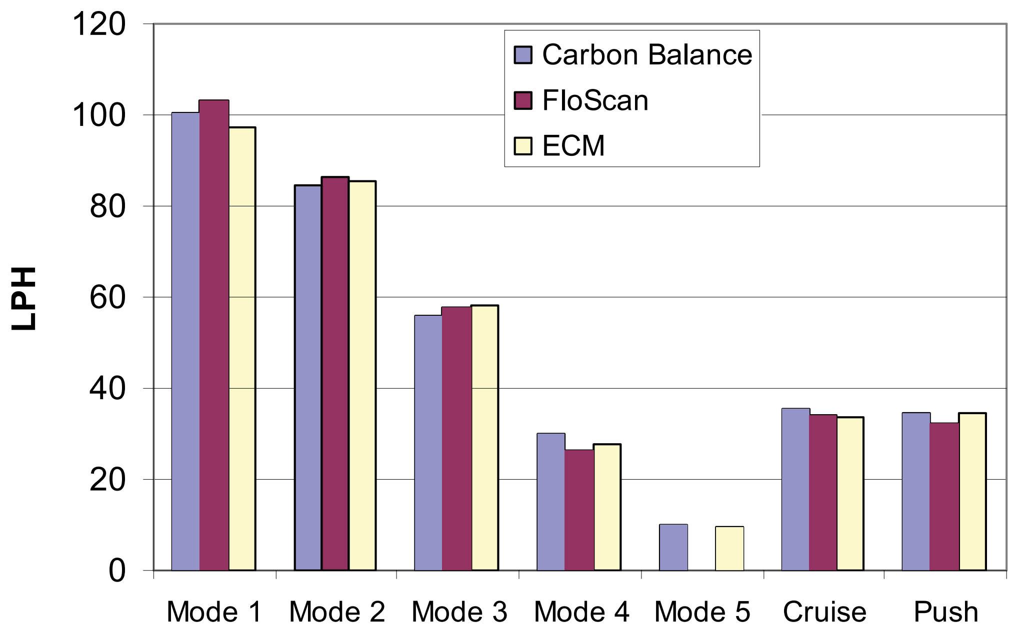


Figure 4.26. No. 2 ULSD Flow Rate Measurement Comparison.

It can be seen from the figures that similar flow rates were generally very similar between the three methods determined with each method in a given mode. However, differences were noted between methods. In all cases, the flow meter and ECM were within +/-10% of the carbon balance method. For all three fuels, the carbon balance method resulted in a lower fuel flow rate than the flow meter for Modes 1, 2, and 3 but a higher fuel flow rate for Mode 4. The ECM displayed the lowest flow rate in Mode 1, without exception, and then varied between modes but usually yielded a lower flow rate than the flow meter. In general, the three methods exhibited very similar flow results with good repeatability. The maximum relative deviation, for any of the tests that were performed in triplicate, was 2.4%. (No standard or relative deviations are available for the No.2 ULSD, as only one test was performed at each of the seven test points.)

Table 4.24 shows the percent change in flow rates between the No. 1 ULSD and the No. 2 LSD fuels. In all three methods, an increase in fuel use was noted when switching from No. 2 LSD to No.1 ULSD (denoted by positive values in the table). However the carbon balance method noted a maximum 3.7% increase (Mode 1), while the flow meter and ECM showed increases ranging from approximately 5% to 10%. It is unclear why this would be so. The latter two methods yield a volume that is unrelated to the fuel analysis, while the carbon balance takes the analysis into account (fuel fraction carbon, fuel fraction hydrogen, and density) to yield a volumetric flow rate. All three methods yield the flow rate for the actual fuel being used.

Table 4.24. No. 1 ULSD/ No. 2 LSD Flow Rate Deviation.

	Flow Rate Deviation Between No. 1 ULSD & No. 2 LSD		
MODE	**CARBON BALANCE**	**FLOSCAN**	**ECM**
Mode 1	3.7%	7.9%	6.1%
Mode 2	2.1%	6.6%	5.3%
Mode 3	2.4%	7.7%	6.1%
Mode 4	2.0%	9.8%	7.7%
Mode 5	1.2%	-	0.0%
Cruise	-0.1%	8.8%	7.6%
Push	2.2%	7.5%	6.0%

Table 4.25 shows the percent change in flow rates between the two No. 2 fuels using all three methods. The No. 2 ULSD vs. No. 2 LSD comparisons showed no identifiable trends. The carbon balance method showed no statistically significant change in fuel flow between the two fuels. The flow meter consistently seems to show a small decrease in fuel flow overall; however, the flow meter was +/- 1.4 to 2.4% at one standard deviation. Conversely, the ECM seems to show a slight increase in fuel flow across all modes, but again the statistical significance is questionable when comparing the percentage change to the standard deviation of flow seen with the No. 2 LSD fuel. Additionally, it is worth recalling that only one set of tests was completed with the No.2 ULSD, so any comparisons of flow rates between the two fuels are difficult to make with any level of certainty.

Table 4.25. No. 2 ULSD/ No. 2 LSD Flow Rate Deviation.

	Flow Rate Deviation Between No. 2 ULSD & No. 2 LSD		
MODE	**CARBON BALANCE**	**FLOSCAN**	**ECM**
Mode 1	0.6%	-1.2%	1.4%
Mode 2	0.0%	-2.0%	0.4%
Mode 3	0.7%	-2.5%	1.8%
Mode 4	-2.2%	-7.4%	-0.7%
Mode 5	-0.6%	-	0.0%
Cruise	-2.8%	-3.3%	0.1%
Push	-1.0%	-5.1%	1.9%

Emissions Comparison on Marine Diesel Test Engine

Figure 4.27 denotes the resultant NO_X emissions and shows that the values were always highest with the use of the No. 2 LSD fuel relative to the other fuels. Both ULSD fuels experienced lower average NO_X emissions across all modes relative to the No. 2 LSD fuel. On an integrated cycle basis (over the seven test modes), the No. 2 ULSD and No. 1 ULSD fuels experienced 14% and 11% lower NO_X emissions, respectively, when compared to the No. 2 LSD fuel. A comparison of the No. 2 ULSD results versus the No. 1 ULSD results shows that at one standard deviation the reduction is statistically significant for Modes 1-4 and the push mode. (No error bars are presented for the No. 2 ULSD fuel because only one full set of tests was performed on that fuel.)

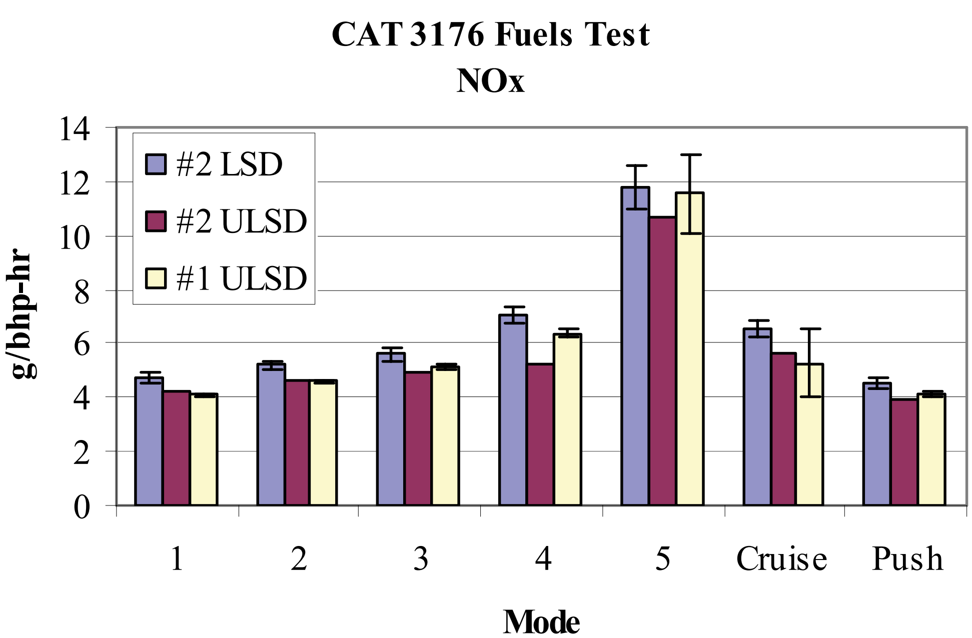


Figure 4.27. Comparison of NO_X Emissions.

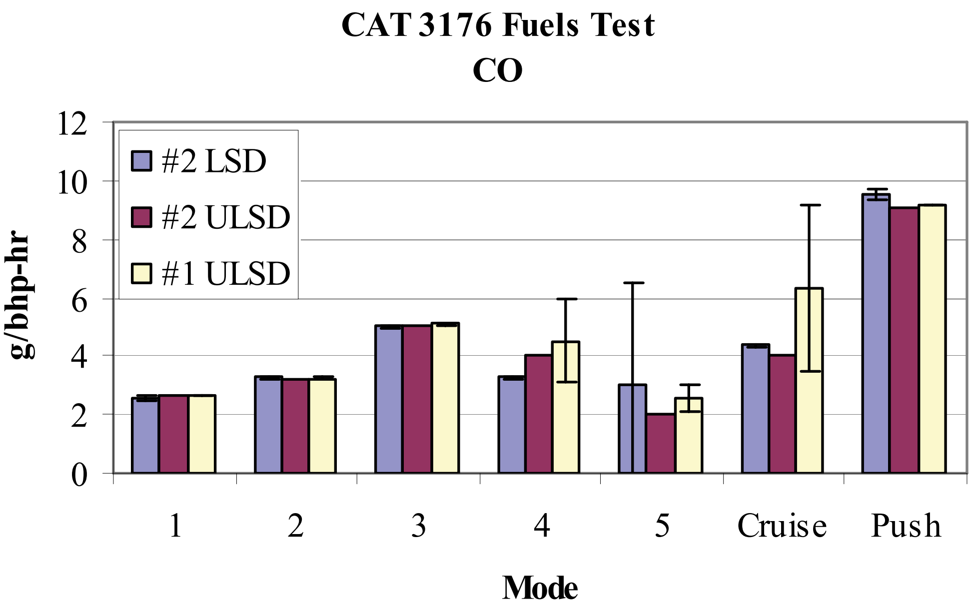


Figure 4.28. Comparison of CO Emissions.

Figure 4.28 displays the CO emissions for the three fuels. It can be seen that there is little statistically significant change in CO emissions at one standard deviation. The one exception is the push mode, which experienced a 4% decrease in CO emissions with the No. 1 ULSD fuel. Mode 4 and the cruise mode experienced higher average CO emissions with the ULSD fuels, but the results vary less than one standard deviation. The overall result is that no specific fuel-related trend was noted for the CO emissions when tested on the three fuels in question.

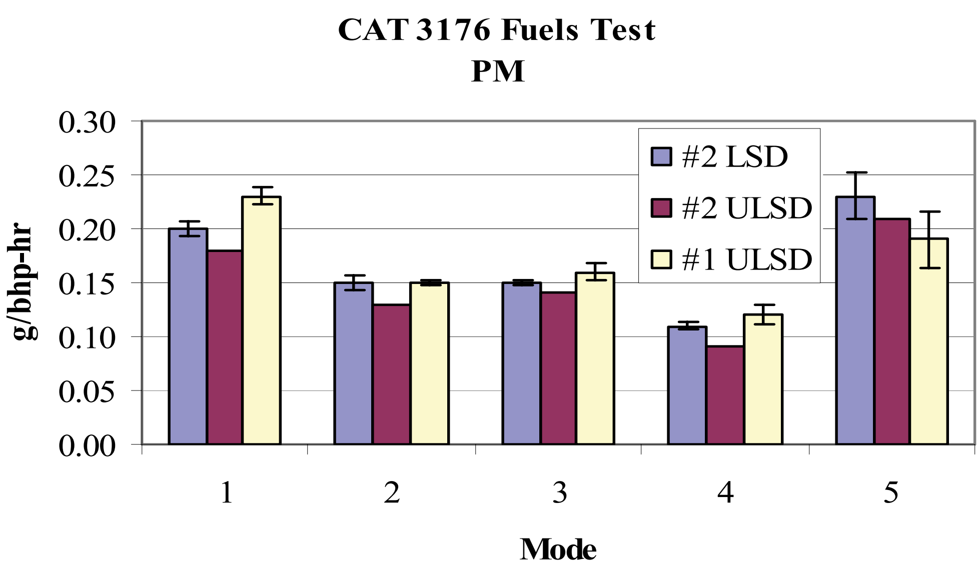


Figure 4.29. Comparison of PM Emissions.

Similar mixed results can be seen with regard to PM emissions. From Figure 4.29 it is apparent that three of the five modes experience greater emissions with the No. 1ULSD fuel compared to the No. 2 LSD fuel. Additionally, only in Mode 5 are the PM emissions lower with the No. 1 ULSD relative to the No. 2 LSD fuel. However, only the Mode 1 results are statistically significant. Overall, the average PM emissions for the five modes shows a 11% decrease for the No. 2 ULSD fuel and 8% increase for the No. 1 ULSD fuel relative to the No. 2 LSD fuel.

Please note, only TPM (total PM) filters were collected for each test. This is standard practice for all engine and chassis dynamometer testing. PM 2.5 and PM 10 collection, as it was done in the field, is not typical for in-lab testing and is not required by the CFR or other standards.

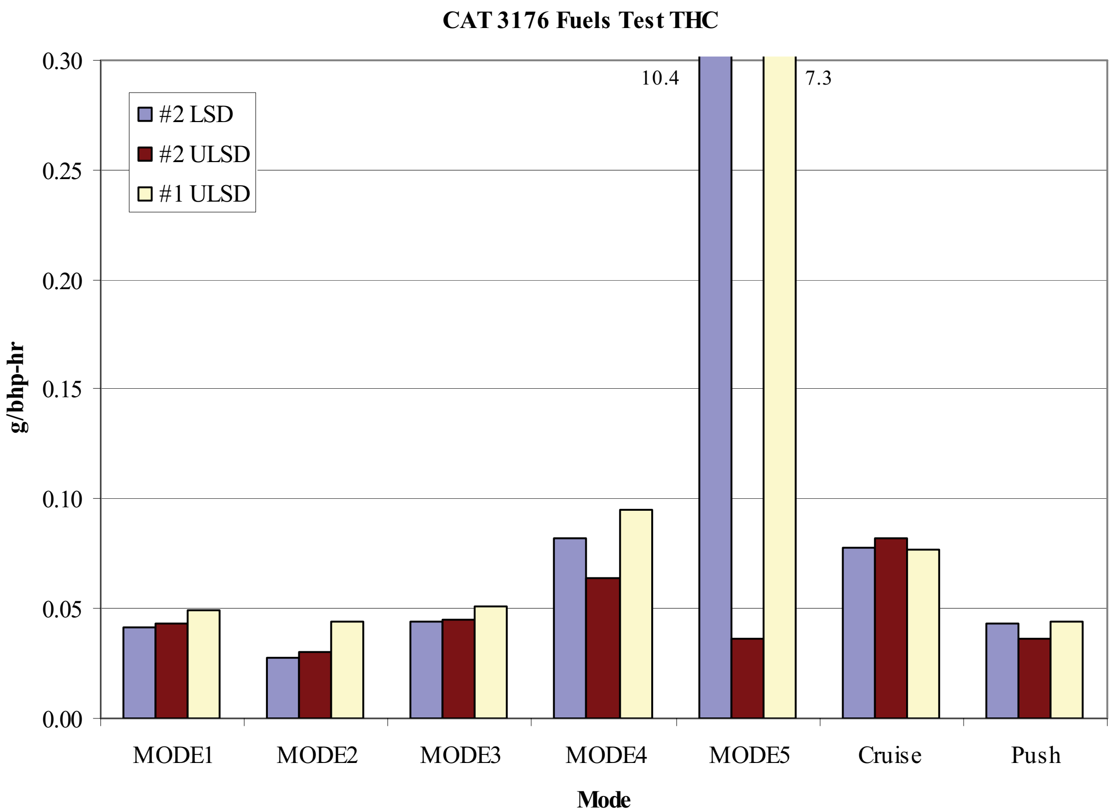


Figure 4.30. Comparison of THC Emissions.

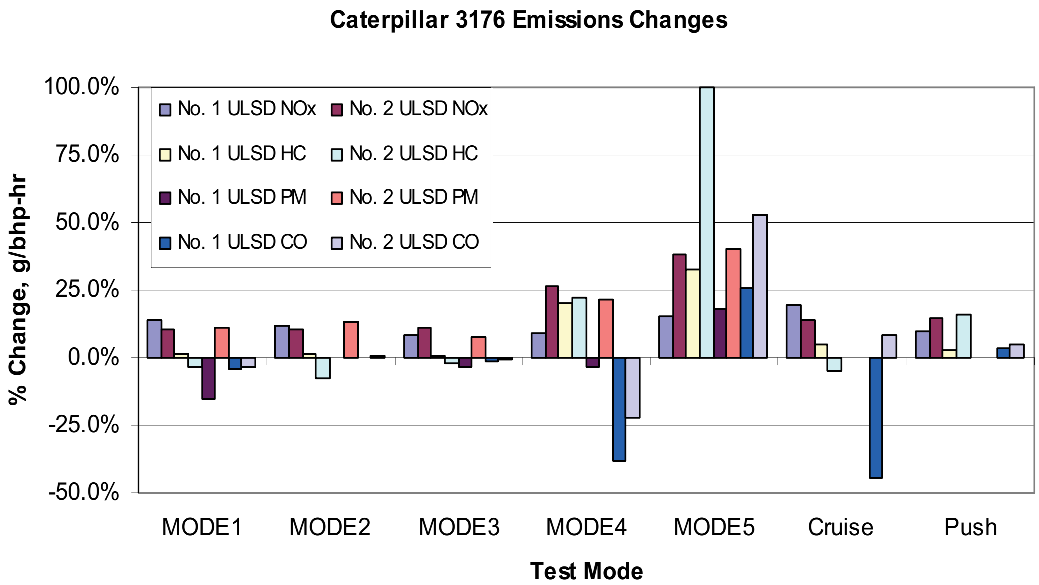


Figure 4.31. Specific Emissions Percent Change.

For the THC emissions shown in Figure 4.30, it appears as if the THC emissions are higher over Modes 1-4 for the No. 1 ULSD fuel relative to the two No. 2 fuels., Over the push and cruise modes the THC emissions were virtually identical. Over Modes 1-4, the increase in THC emissions for the No. 1 ULSD fuel compared to the No. 2 LSD fuel is statistically significant and averages 27%. The THC emissions for No. 2 ULSD fuel do not appear to trend in the same manner as the No. 1 ULSD fuel. In should be noted that for Mode 5, the emissions, reported in g/bhp-hr, are largely irrational because the power output at this mode is nearly zero. Please note, the CO_2 results are not presented due to direct relationship with all previously reported fuel consumption comparisons for the marine diesel test engine.

DISCUSSION

Field Demonstrated Comparison of LSD and ULSD Fuels

The only readily available ULSD fuel in the NYC area for these tests was refined No. 1 diesel fuel stock. The ULSD refined from No. 1 diesel fuel stock (No. 1 ULSD) had a decreased heating value on a volumetric basis, lowered viscosity, and a slightly lower cetane index when compared with No. 2 LSD. These different fuel properties had notable effects on the operation of the particular marine diesel engines tested. Due to No. 1 ULSD's decreased heating value and specific gravity compared with No. 2 LSD, a fuel penalty occurred for the experiments. On a BTU per mass of fuel basis the fuels are nearly identical, but on a BTU per volume basis a 3.5% to 4.0% difference exists due to the difference in the density of the two fuels. As a result of this lower heating value per volume of fuel, a greater volume of No. 1 ULSD must be used to provide the same energy contained in a unit of No. 2 LSD.

Additional fuel penalties beyond the degree previously listed may still exist and would be a topic for future research. The increased No. 1 ULSD consumption may have been related to the lower viscosity causing changes to the fuel injection quality, or the lower cetane index having been responsible for an increase in the ignition delay period.

The results of the fuel analysis, as provided in this section, had several implications that were taken into consideration for the later Phase II tests. In order to improve the No. 1 ULSD fuel's characteristics to make it more acceptable for use in marine engines, it was necessary to add a viscosity improver. Another potential obstacle to the continued use of No. 1 ULSD fuels in shipboard applications was the relatively low value of the No. 1 ULSD's flash point. The U.S. Coast Guard requires a flash point greater than 140 ^{o}F in subchapter K and H passenger vessels. The MV PORT IMPERIAL MANHATTAN and the MV SEASTREAK WALL STREET fell into this category. The U.S.Coast Guard granted permission for these tests as long as the engine room space was actively monitored.

Fuel and Emissions Comparison on Marine Diesel Test Engine

In the controlled laboratory settings of the test bed engine fuel tests, one of the several substantial outcomes was the direct comparison between the exhausted emissions and fuel consumption of the marine diesel engine for the three different fuels under the load cycle developed in Section 2. After analysis of these trials, it was assessed that changing from No. 2 LSD to No. 1 ULSD imparted a fuel penalty on a volumetric basis for the Caterpillar 3176 engine, as was seen in the shipboard tests discussed above. The flow meter and electronic control module were in agreement that the penalty was approximately 5% to 10% for the fuel test. The carbon balance displayed a fuel penalty of no more than 4%. This increased fuel use is the likely result of the minor difference in the heating values and specific gravities of the individual fuels. The heating values on a per pound basis are similar between the fuels; however, due to the lower specific gravity of No. 1 ULSD, there is a notable decrease (approximately 3%) in the heating value on a per volume basis. Therefore, a 3% increase by volume in fuel may be anticipated for the usage of No. 1 ULSD in order to supply the same amount of energy as No. 2 LSD. The additional fuel consumption of No. 1 ULSD, beyond 3%, is most likely due to unidentified fuel characteristics and properties affecting the engine's operation. These experiments and subsequent comparisons were instrumental in determining significant differences in each fuel's consumption rate on the experimental engine, as well as on equipment employed in the field demonstrations.

Potential Sources of Error

As with all field tests potential sources of error were unavoidable, and those identified were minimized to the greatest extent possible. Although all trials within both phases of this report were designed to minimize all controllable potential sources of error, uncontrollable factors must be recognized as potential vectors of error in the observed measurements and calculated values. Of these uncontrollable factors, the most noteworthy included environmental parameters such as weather, wind, current, and wave action. It was observed that these environmental parameters impacted the load on a vessel's engine from test to test (and even sample to sample) keeping the load in a nearly constant dynamic state. This made acquiring particular engine load data, used for emissions load calculations, difficult as a steady state condition was not always available. Moreover, during the transient sampling, it was observed that the actual load profile varied considerably depending upon which direction the vessel was travelling and which captain was operating the vessel.

External Review of Test Results

The data from the engine test program were provided to Mr. Robert Behr of the U.S. Department of Transportation Maritime Administration (MARAD). Mr. Behr had been involved in on-board emission test programs of larger vessels and was requested by NYSERDA to review the test results. Mr. Behr corrected the data for all three fuel rate measurement techniques (carbon balance, fuel meter, and electronic control module output) for specific gravity and heating value. Although the carbon balance technique takes into account the fuel composition, in particular the specific gravity as well as fuel hydrogen and fuel fraction carbon, the other two fuel measurement methods did not. The results of theanalysis are provided in Tables 4.26 and 4.27. Mr. Behr's comments are presented below.

During onboard ferry engine testing, significant differences in specific fuel consumption were observed between tests burning No. 2 LSD and No. 1 ULSD. The question became whether these differences were the result of inherent differences between No. 1 vs. No. 2 fuel or between LSD vs. ULSD fuel, or whether they represented undetected anomalies in testing.

This study investigated the differences in specific fuel consumption among No. 2 LSD, No. 1 ULSD, and No. 2 ULSD fuel under more controlled conditions, as a means of trying to better understand the results from the field testing. The values in Tables 4.10 through 4.17 for the fuel flows measured by the flow meter and indicated by the ECM were corrected for specific gravity and heating value. The measured higher heating value (HHV) was used in lieu of the more applicable lower heating value (LHV), but values are proportional on fuels of such similar carbon/hydrogen ratios. Carbon balance method had already taken specific gravity and heating values into account, so the calculations only returned the numbers to a mass basis.

As with the uncorrected results, the results of this analysis show fairly consistent changes in specific fuel rates between the three fuel types tested. The No. 2 ULSD fuel rate averaged 2.1% lower consumption and the No. 1 ULSD 2.5% higher consumption, when compared with the No. 2 LSD. The small values of these changes do not seem significant when compared to the accuracy of the instrumentation. Most critically, these results are not consistent with the much higher disparities observed during onboard testing.

Table 4.26. Modes 1, 2, 3 Summary of Test Results as Compiled by MARAD.

Caterpillar Engine Data and Emissions Measurements Fuel Flows Corrected for Heating Value and Specific Gravity									
Mode	1			2			3		
Fuel	#2 LSD	#1 ULSD	#2 ULSD	#2 LSD	#1 ULSD	#2 ULSD	#2 LSD	#1 ULSD	#2 ULSD
Power (BHP)	520.3	522.6	522.8	451.6	448.1	449.2	301.7	301.0	301.3
Power (KW)	388.0	389.7	389.9	336.7	334.1	335.0	225.0	224.5	224.7
Torque (ft-lbs)	1215.5	1219.5		1130.9	1125.1		859.7	859.4	
Engine Speed (rpm)	2251.0	2250.1		2090.0	2090.3		1842.0	1838.1	
Carbon Balance (liter/hr)	99.7	103.4	100.3	84.5	86.2	84.5	55.5	56.8	55.9
Flo-Scan (liter/hr)	104.5	112.8	103.2	88.1	93.9	86.4	59.1	63.6	57.6
									58.2
(Flo-Carb)/Carb(%)	4.8	9.0	2.8	4.3	8.9	2.3	6.5	12.0	3.1
Heating Value (btu/lb)	19641.	19840.	19744.	19641.	19840.	19744.	19641.	19840.	19744.
Specific Gravity	0.8519	0.8213	0.8368	0.8519	0.8213	0.8368	0.8519	0.8213	0.8368
Fuel (kg/hr) (Carb Bal)	84.9	85.8	84.4	72.0	71.6	71.1	47.2	47.1	47.0
Fuel (kg/hr) (Flo-Scan)	89.0	93.5	86.8	75.1	77.9	72.7	50.3	52.8	48.5
									49.0
									209.2
									215.7
									217.9
Fuel Rate Diff. (Carb Bal)	0.0%	0.6%	-1.1%	0.0%	0.2%	-0.8%	0.0%	-0.1%	-0.4%
									-3.6%
									0.7%
Fuel Rate Diff. (AVG)	0.0%	2.7%	-1.5%	0.0%	2.7%	-1.3%	0.0%	2.9%	-1.1%
Temp (ºC)			17.6			20.5			23.1
Exh. Temp (C)	472.6	467.0		487.1	462.2		484.9	468.9	
Eng. Coolant OUT (C)	48.0	51.1		49.4	52.7		40.4	44.2	
Manifold air temp (C)	47.6	45.4		53.8	54.2		51.9	52.8	
Engine Coolant IN (C)	38.3	40.7		40.1	42.4		33.7	36.7	
Engine oil temp (C)	121.8	116.5		124.5	123.7		116.1	117.7	
Exh. Back Press. (IWC)	23.8	24.7		16.9	16.5		7.8	6.3	
Interclr Press Drop (IWC)	4.7	5.0		3.8	3.9		2.6	2.7	
CO [g/bhp-hr]	2.57	2.67	2.65	3.26	3.25	3.24	5.01	5.09	5.05
CO_2 [g/bhp-hr]	514	514	508	505	498	497	491	486	487
NO_X [g/bhp-hr]	4.75	4.10	4.25	5.19	4.59	4.67	5.60	5.13	4.98
NO [g/bhp-hr]	3.17	2.72	2.97	3.48	3.16	3.29	3.79	3.55	3.53
THC [g/bhp-hr]	0.04	0.05	0.04	0.03	0.04	0.03	0.04	0.05	0.04
P.M. [g/bhp-hr]	0.20	0.23	0.18	0.15	0.15	0.13	0.15	0.16	0.14
CO [g/hr]	1336	1394	1387	1473	1457	1457	1511	1533	1523
CO_2 [g/hr]	267478	268767	265657	227881	223291	223202	148264	146308	146720
NO_X [g/hr]	2473	2140	2223	2344	2057	2096	1690	1544	1502
NO [g/hr]	1651	1423	1553	1573	1414	1479	1142	1068	1064
THC [g/hr]	21.6	26.0	22.4	12.6	19.9	13.5	13.2	15.5	13.5
P.M. [g/hr]	104.8	121.5	93.8	68.3	67.9	58.8	46.3	47.7	42.8

4.27. Modes 4, Push, Cruise Summary of Test Results as Compiled by MARAD.

Caterpillar Engine Data and Emissions Measurements Fuel Flows Corrected for Heating Value and Specific Gravity									
Mode	4			Push			Cruise		
Fuel	#2 LSD	#1 ULSD	#2 ULSD	#2 LSD	#1 ULSD	#2 ULSD	#2 LSD	#1 ULSD	#2 ULSD
Power (BHP)	150.1	150.7	151.2	177.8	177.4	177.2	166.5	166.5	166.5
Power (KW)	111.9	112.4	112.8	132.5	132.3	132.2	124.2	124.2	124.1
Torque (ft-lbs)	542.7	544.9		609.1	609.6		683.6	683.8	
Engine Speed (rpm)	1451.7	1451.2		1533.1	1531.5		1278.5	1276.3	
									34.6
									32.4
									34.6
(Flo-Carb)/Carb(%)	-7.5%	-0.3%	-12.4%	-3.2%	5.5%	-3.7%	-2.4%	2.7%	-6.4%
Heating Value (btu/lb)	19641.	19840.	19744.	19641.	19840.	19744.	19641.	19840.	19744.
Specific Gravity	0.8519	0.8213	0.8368	0.8519	0.8213	0.8368	0.8519	0.8213	0.8368
									29.1
									27.3
									29.1
									234.7
									219.5
									234.5
									-2.2%
									-6.2%
									0.6%
Fuel Rate Diff. (AVG)	0.0%	3.3%	-5.3%	0.0%	2.9%	-2.9%	0.0%	2.5%	-2.6%
Temp (ºC)			25.0			25.6			25.8
Exh. Temp (C)	389.4	389.0		427.4	417.0		491.2	482.5	
Engine Cool. OUT (C)	29.7	33.8		29.1	31.9		31.2	35.0	
Manifold air temp (C)	49.4	50.9		44.0	44.3		45.8	46.7	
Engine Coolant IN (C)	26.0	29.7		25.3	28.0		26.1	29.7	
Engine oil temp (C)	109.0	109.5		108.2	107.0		109.0	109.1	
Exh. Back Press. (IWC)	1.9	0.6		2.5	1.0		1.6	0.2	
Inter. Press Drop (IWC)	1.5	1.6		1.8	1.9		1.5	1.6	
CO [g/bhp-hr]	3.27	4.52	4.00	4.38	6.34	4.03	9.53	9.18	9.06
CO_2 [g/bhp-hr]	560	539	447	554	536	525	558	549	541
NO_X [g/bhp-hr]	7.03	6.39	5.20	6.56	5.28	5.65	4.55	4.11	3.88
NO [g/bhp-hr]	4.82	4.39	3.43	4.44	3.63	4.04	3.08	2.82	2.78
THC [g/bhp-hr]	0.08	0.10	0.06	0.08	0.08	0.08	0.04	0.04	0.04
P.M. [g/bhp-hr]	0.11	0.12	0.09						
CO [g/hr]	491	681	605	779	1125	714	1587	1529	1508
CO_2 [g/hr]	84001	81227	67651	98413	95037	93117	92991	91422	90065
NO_X [g/hr]	1055	964	786	1166	937	1001	757	684	647
NO [g/hr]	723	661	519	790	643	716	513	469	462
THC [g/hr]	12.3	14.3	9.6	13.9	13.7	14.5	7.2	7.3	6.1
P.M. [g/hr]	16.8	17.5	13.3	0.0	0.0	0.0	0.0	0.0	0.0

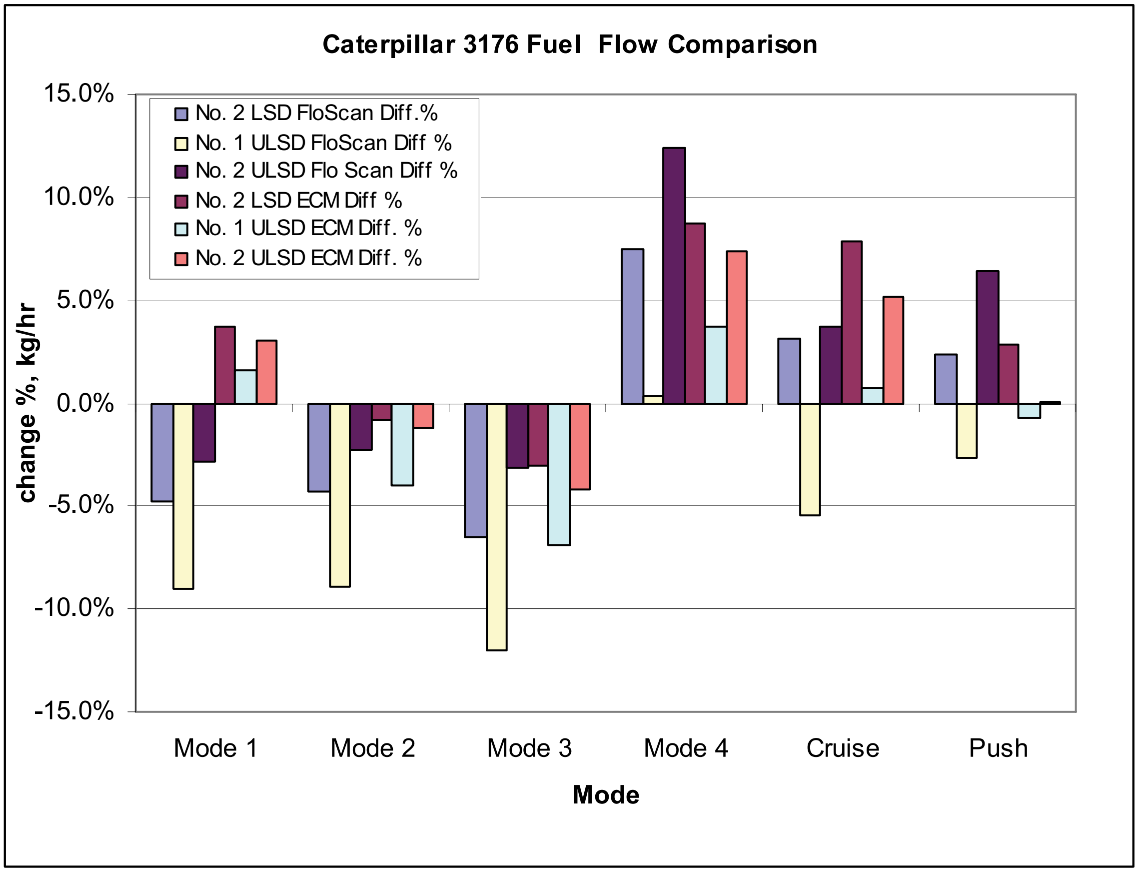


Figure 4.32. Comparison of Fuel Flows Between Carbon Balance, Flo Scan, and ECM for Different Fuels.

Section 5

PHASE II: FIELD DEMONSTRATIONS AND EVALUATION

INTRODUCTION

The content of this section builds on the results of the emissions control technology review and selection discussed in Section 3 and the Phase I fuel test discussed in Section 4. In Section 3, emissions control devices were selected that could be demonstrated on marine engines similar to those used in the NY harbor private ferry fleet. Seaworthy Systems, Inc., (SSI) in association with the Northeast States for Coordinated Air Use Management (NESCAUM), ESI International, Inc. (ESI), and Environment Canada (EC), and as tasked by the New York State Energy Research and Development Authority (NYSERDA) and NYCDOT, coordinated, planned, purchased, and demonstrated various emissions control devices applicable to these vessels.

This section reports on the experimental procedures, equipment, results, and analyses for the definitive shipboard emissions testing, and subsequent discussion of the Phase II demonstration and emissions testing. It discusses the performance of the actual emissions control devices installed on the selected vessels through a series of field trials. The tests were conducted to reestablish the baseline and evaluate the post-treatment emissions on the selected demonstration vessels and on a mechanically fuel injected vessel. From these field trials, it was possible to determine the emissions contributions of typical engines and vessels in the NYC private ferry fleet. Data obtained from these trials were further analyzed in an effort to approximate, to the highest degree of accuracy currently permissible, the total emissions load imposed by the fleet.

PHASE II OUTLINE

The vessels selected for pre- and post-treatment technology testing included: MV PORT IMPERIAL MANHATTAN, MV FATHER MYCHAL JUDGE, MV JOHN KEITH, and MV GEORGE WASHINGTON. Respective emissions control technologies were selected for MV PORT IMPERIAL MANHATTAN, MV FATHER MYCHAL JUDGE, and MV JOHN KEITH based on the vetting process used in Section 3 of this report. The MV SEASTREAK WALL STREET had been slated for a selective catalytic reduction (SCR) system installation but was withdrawn from the program, as explained under "Changes to Demonstration Participants" later in this section.

Although many emissions control technologies were reviewed, only those most adaptable to the marine industry as well as to the NYC private ferry fleet were selected. The emissions control technologies consisted of diesel oxidation catalysts (DOC) mounted in the exhaust systems of each vessel. The MV PORT IMPERIAL MANHATTAN also received a fuel-borne catalyst (FBC). Other emissions control technologies had been selected during the first part of this project, but upon final review of the processes they were deemed inappropriate due to extenuating circumstances. One prime example was the water injection system (WIS), which was rejected due to the device's unsuitable performance during cold weather. The MV GEORGE WASHINGTON was included in this trial because it was part of a group of vessels, including 18 mechanically fuel injected Caterpillar 3412Cs, that were subject to engine replacements with equivalent Tier 2 engines during the subsequent deployment phase based on the results of this project. By employing these various emissions control technologies on vessels representative of the fleet, a broad array of data was collected encompassing the majority of the NYC private ferry fleet.

The initial procedures used to evaluate engine emissions are described in Sections 2 and 4 of this report, and all subsequent changes are discussed within this Section. In addition, full details of the procedures, protocols, and equipment that were employed in Phase II are given in the Appendices of this report.

CHANGES TO TEST METHODOLOGY

The results from the initial emissions testing and Phase I fuel tests revealed a number of shortcomings with either the test points or the instrumentation. In order to provide emissions test results that were within the acceptable error rates of the instrumentation, it was deemed necessary to increase the number of load points for each of the steady state tests and to increase the number of samples for each emissions test.

For the purpose of recording more accurate and precise measurements than those collected during the Phase I testing described in Section 4, the emissions test load cycles for Phase II were extended over a greater number of steady state loads. The number of load points was also increased so that engine rating load points tested in Phase II were above and below those measured during Phase I. This made it possible to estimate the emissions at any load via linear, logarithmic, or semi-logarithmic least squares regression interpolation. Additionally, the increased number of samples taken at each load point gave a representative standard deviation in the reported values, as well as a means for calculating confidence intervals to a higher degree of accuracy.

The cycle loads included, where possible, each engine's 25%, 50%, 75%, and 100% rated load points. Every vessel's load cycle consisted of up to four steady state operating points where the vessel was in the push, cruise, or transit mode. A standardized transit mode protocol was developed so that the emissions could be measured for a nearly identical and repeatable load profile for the various vessels. Sampling of the exhaust emissions and the engine data collection was performed in accordance with the protocols set forth in Section 2 and the Appendices. The data from the increase in both load points and length in time will enable the estimated NYC harbor emissions rates to be modified with regard to individual vessel operating profiles.

Another significant change resulting from knowledge obtained from the Phase I emission testing was the switch to coriolis type fuel flow meters and the installation of a shaft torsion meter. During the initial emissions testing it was discovered that the fuel flow meters employed to develop the engine load profiles, and for calculating the fuel consumption, did not respond adequately to the change from No. 2 LSD to No. 1 ULSD fuel. This problem was confirmed during the engine test bed experiments, and a decision was made to relocate fuel flow measurement and use a more accurate method. For Phase II, a set of coriolis meters were initially borrowed to conduct the emissions tests in July of 2005. Then in November of 2005, a set of coriolis meters were purchased for the Phase II fuel flow measurements. These flow measurements were used to approximate the exhausted emissions to a high degree of accuracy. A shaft torsion meter was also fitted to each vessel test so that the actual developed power of the engine could be measured. This made it possible to calculate the emissions rates on a specific power basis, which made them more comparable to those provided by the engine manufacturers. These changes based on specific power allowed for improved emissions rate measurements and calculations to a greater degree of resolution without having to rely on engine manufacturers' test curves.

The test team attempted to control or limit as many experimental and environmental parameters as possible. When evaluating operating vessels at sea, however, laboratory controlled conditions must be recognized as unattainable. Phase I was influential in adopting a passenger restriction on the test ferries; they were deemed off-limits to any and all passengers during Phase II. This change minimized passenger number variations as a potential experimental error. During all Phase II trials, the vessels were considered off-limits to passengers and were scheduled as required for proper data acquisition.

A change to the data analysis was made. During the analysis of the Phase I emissions tests, the transit tests proved to be of little value. The original breakdown of the vessel operating modes was into cruise, push, and maneuvering (portion of the transit cycle where the vessel is not pushing or cruising). Unfortunately, the maneuvering mode is highly variable as the engines change load in an unpredictable and essentially unrepeatable fashion via the ferry operator's manner in which he/her docks and undocks the vessel. Thus, it was ascertained that simply measuring the transit emissions and calculating the maneuvering emissions rate as a time weighted percentage of the overall transit time was deemed to be too inaccurate. However, because the Phase II testing incorporated a shaft torsion meter and a coriolis fuel meter it was possible to break down each transit test into maneuvering, push, and cruise components. This made it possible to calculate the emissions rate of the maneuvering mode by using the amount of fuel used during the maneuvering portion of the transit test and estimating the emissions rates by fuel weighting of the transit push and cruise components. This method applied to the gaseous emissions. The manuevering PM 2.5 rate calculation proved to be difficult and similar methods were tried but with inconsistent results. Finally a straightforward method was adopted whereby the maneuvering PM 2.5 rate was equal to the overall transit rate.

Finally, it became apparent after the technology review and selection that the demonstrated ECTs would all be beneficial in significantly reducing hydrocarbons. Therefore, equipment for sampling this emissions constituent was added to the emissions test.

CHANGES TO EMISSIONS CONTROL TECHNOLOGIES

Following the selection of the acceptable emissions control devices as reported in Section 3, requests for quotations were issued to appropriate manufacturers or vendors for the vessel/emissions control technology selections as listed in Table 5.1. The goal of the request for quotations was to elicit a performance guarantee from the vendors. In many cases, this guarantee was easily confirmed because the respective technology was in a mature state or had been successfully tested on similar engines.

Table 5.1. Emissions Control Technologies Selected for the Demonstration Program.

Vessel	Vendor/Technology	ECT Type
MV PORT IMPERIAL MANHATTAN	Clean Diesel Technologies	DOC+FBC
MV FATHER MYCHAL JUDGE	MA Turbo and Johnson Matthey	WIS+DOC
MV ED ROGOWSKY	Johnson-Matthey	DOC
MV SEASTREAK WALL STREET	Combustion Components Associates	SCR

The water injection system (WIS) was the only one of the technologies initially selected in Phase II that was not considered a previously proven treatment option or in a mature state of development. The WIS technology had initially shown promise of being an effective method to reduce NO_X with the potential economic benefit of enhanced engine performance as an incentive for vessel operators. However, prior to installation the vender stated that the WIS technology would not be effective due to the cold weather during the experimental period. The vendor elaborated further by stating that the intercooling temperature for the engine was lower than anticipated, and the decreased temperature would cause problems with the water injection system. Based on the vendor's misgivings about installing the system on the selected vessel, it was decided to terminate the demonstration of the water injection system technology.

NO_X reduction technologies for the demonstration vessels were very difficult to find with the exception of a selective catalytic reduction (SCR) system. Upon further analysis, it was determined that SCR systems would be physically too large for the majority of the NYC private ferry fleet vessels. Moreover, for the deployment that was to follow this project, the NO_X reduction was slated to correspond with emissions control technologies fitted to the relatively larger vessels that account for the bulk of the NO_X emissions by the private ferry fleet. By consuming the most fuel on a per vessel basis, the large vessels emit more NO_x into the atmosphere.

CHANGES TO DEMONSTRATION PARTICIPANTS

During the time that this project was being executed, various changes occurred throughout the NYC private ferry fleet. Historically, there has been a fairly large turnover in vessels and routes. It is pertinent to note that the ferries carry passengers back and forth between the NYC boroughs, New Jersey, and Manhattan without any subsidies providing the ferry operators assurance during minimal passenger periods. NY Waterway, Inc., was at the end of an expansion phase, and most of the vessels in its fleet were of recent vintage.

The resumption of the PATH train service from New Jersey to lower Manhattan in 2005 had the effect of reducing ferry passenger numbers nearly overnight. As a consequence, the viability of NY Waterway was seriously in doubt, and bankruptcy was forestalled by transferring a portion of the fleet to the BillyBey Ferry Co. Fortunately for the project and demonstration, BillyBey chose to remain a participant.

SeaStreak withdrew from the program. During the course of the project the parent company of SeaStreak, Sea Containers, Ltd., deemed the ferry service untenable. The ferry service and the respective routes were placed up for sale. Consequently, there was doubt as to whether or not the SeaStreak vessels would even remain in the NYC private ferry fleet. One of the requirements of the subsequent deployment phase was that each vessel that received an emissions control device remained in NYC harbor waters. The withdrawal from the program was unfortunate, because the SeaStreak vessels showed significant potential for NO_X reductions while employing Combustion Components Associates'-SCR technology.

The SCR installation was the key NO_X solution treatment technology for the subsequent deployment phase. Although the SeaStreak fleet is relatively small, only four vessels, they account for nearly half of the NYC private ferry fleet NO_X emissions. The other emissions control devices selected for the demonstration typically had little or no effect upon NO_X emissions, with the exception of Tier-2 engine upgrades.

POTENTIAL SOURCES OF ERROR

It should be noted that these changes to the test protocol and equipment affected only the items over which the test team had control. With regard to factors deemed uncontrollable but within reasonable limits, the tests were performed as per the procedures outlined within this report. As explained at the end of Section 4, the most noteworthy of these uncontrollable factors included environmental parameters such as weather, wind, current, and wave action. The load on a vessel's engine was observed to be in a nearly constant dynamic state due to such uncontrollable factors. Although all field trials within Phase II were designed to minimize controllable potential sources of error, uncontrollable factors must be recognized as potential sources of error in the observed measurements and calculated values. Moreover, the error introduced by the instrumentation was approximately 5%. The only way to reduce the errors was to increase the number of samples. However, there was only a finite time period within which to collect the data so the number of samples was somewhat limited. The calculations used to derive the mode and overall harbour emissions rates may be found in Appendix I.

INSTALLATION, TEST AND DEMONSTRATION

The purpose of the Phase II emissions tests was to reestablish the baseline and quantify the post exhaust treatment emissions produced by demonstration vessels so that the cost-effectiveness of the proposed emissions control deployment could be ascertained. In addition, an emissions test was performed on an unregulated mechanically fuel injected powered vessel. It is anticipated that these unregulated engines will be replaced by similarly rated Tier 2 marine diesel engines in the spring of 2007. The information from the vessel characterization phase of this project was used to guide the development of the emissions test plan. The three operating modes from Phase I (maneuver, push, and cruise) were further divided to replicate the engine load/rpm curve of the engine. At least four load points were selected for each mode so that any curves developed from the data would be directionally accurate.

MV GEORGE WASHINGTON

The MV GEORGE WASHINGTON is a 95' aluminum monohull ferry vessel powered by two Caterpillar 3412C mechanically fuel-injected engines rated at 674 BHP at 2100 RPM that is representative of the nine vessels scheduled for a Tier 2 engine replacement. The engines drive propellers through a 2.03:1 ratio gearbox. The vessel was constructed in 1988, so the engines were not required to meet any emissions regulations. The power train and usage of this vessel is typical of the nine vessels that comprise part of NY Waterway's and BillyBey's ferry fleets. The load points and sample durations for this vessel are listed in Table 5.2.

Table 5.2. MV GEORGE WASHINGTON Test Operating Mode Load Points, Baseline (25-26 July 2005).

Test Mode	RPM / Load	Number of Samples	Sample Duration (min.)
Idle	700	4	10
Push	750	4	7
Push	900	4	7
Push	1000	4	7
Push	1200	4	7
Cruise	1000	4	7
Cruise	25%	4	7
Cruise	50%	4	7
Cruise	75%	0	N/A
Cruise	100%	0	N/A
Transit	Various	4	11

The transit load cycle consisted of operating the vessel on a simulated river transit similar to one that the vessel would normally be operated on. This simulated transit consisted of 3 minutes of operation pushing at 900 rpm followed by undocking, a normal river crossing, docking, and then another 3 minutes of pushing at 900 rpm. The time for the transit simulation averaged about 12 minutes. This would equate to a normal round-trip time of approximately 20 minutes. Not all of the load points were taken because the vessel failed to achieve more than 50% power output during the course of transit tests.

MV FATHER MYCHAL JUDGE

The MV FATHER MYCHAL JUDGE is an aluminum monohull vessel powered by three 600 bhp Caterpillar 3406E engines directly driving waterjets. Electric power is provided by a 20 kWe Northern Lights generator set.

Table 5.3 illustrates the load points that were used for baseline emissions testing the vessel during 27-28 July 2005. Table 5.4 illustrates the load points and durations used for the demonstration emissions testing on 29-30 March 2006. A significant number of load points were added to similar engine loads as were tested in 2004 to make this round of testing consistent with the ISO 8178 E3 test cycle. This was done so emissions at other load points could be estimated by interpolating between points. It also permits adjustments for operating a vessel at different loads. Where the vessel is operated at loads different from those stated in the Phase I emissions testing, the emissions can be predicted by adjusting the weighting of each particular mode. During the Phase II testing the vessel's engine emissions were sampled before and after the emissions control device installation in accordance with the load and test points listed in Table 5.4.

Table 5.3. MV FATHER MYCHAL JUDGE Test Operating Mode Load Points, Baseline (27-28 July 2005).

Test Mode	RPM / Load (nominal rpm)	Number of Samples	Sample Duration (min.)
Idle	650	4	7
Push	750	4	7
Push	900	4	7
Push	1000	4	7
Push	1200	4	7
Cruise	1000	4	7
Cruise	25% (1323)	4	7
Cruise	50% (1680)	4	7
Cruise	75% (1910)	4	7
Cruise	100%	0	N/A
Transit	Various	4	11.5

Table 5.4. MV FATHER MYCHAL JUDGE Test Operating Mode Load Points, Baseline/Post DOC (29-30 March 2006).

Test Mode	RPM / Load (nominal rpm)	Number of Samples	Sample Duration (min)
Idle	650	3	6
Push	750	3	6
Push	900	3	6
Push	1000	3	6
Push	1200	3	6
Cruise	1000	3	6
Cruise	25% (1323)	3	6
Cruise	50% (1680)	3	6
Cruise	75% (1910)	3	6
Cruise	100%	0	N/A
Transit	Various	3	13.5

The transit cycles are also different from the earlier tests. In 2004, the transit cycle emissions were measured with the vessel on an actual passenger run. In 2005 and 2006, the transit load cycle was modified to a simulation of a normal river transit. This simulated transit consisted of 3 minutes of operation pushing at 1000 rpm followed by undocking, a normal river crossing, docking, and then another 3 minutes of pushing at 1000 rpm. The time for the transit simulation averaged about 11.5 minutes. This would equate to a round-trip time of approximately 20 minutes. Not all of the load points for either of the tests were taken because the vessel's upper rpm limit was set lower than rated, so the maximum power output achieved during any particular transit was 75%.

The diesel oxidation catalyst (DOC), Johnson-Matthey BX-20D-6, was installed in the engine room on the centerline engine's exhaust. The DOC consists of an 18" cylindrical housing with a 6"-150 flanged inlet and outlet. Inside the main housing are two 17" diameter catalyst substrates. The DOC is pictured below in Figure 5.1. A specification sheet for this catalyst may be found in Appendix U.

The DOC was installed between the engine's turbocharger outlet and the existing water lift silencer and supported by brackets attached to the engine room's overhead. This location was chosen to limit the DOC's impact upon the engine room space. The advantage of this location is that it fit well and did not interfere with the normal servicing of the engine and engine room components. The disadvantage is that the location did not have optimal air circulation to reduce local temperatures around the DOC. Initially the vessel's engine room ventilation fan was inoperable, and the temperatures around the DOC and housing were high enough to melt the insulation on wiring running in the vicinity of the DOC. Moreover, the original catalyst band type access covers leaked, causing exhaust gases and heat to be released around the DOC. This problem was solved by modifying the catalyst access covers, modifying the support brackets to improve the ventilation flow, and improving the insulation surrounding the DOC body.

Figure 5.1. MV FATHER MYCHAL JUDGE DOC Installation in Engine Room.

The change in exhaust back pressure was a concern for the design. One of the features of the existing water lift silencer is that water is always being introduced to the silencer for cooling. The water lift silencer is constructed of fiberglass, and the overboard pipe from the silencer is also fiberglass. The water serves to cool both the silencer and the pipe. Because water is always being fed into a silencer, a certain amount of back pressure develops within the silencer. When the vessel's engine is exhausting through the original system, the back pressure is around 15-20 IWC. After the DOC was installed, the engine was run up to full rated speed and the back pressure measured with a manometer. The back pressure was at the manufacturer's rated limit, 27 IWC, at full rated power. This was due, in part, to the pressure drop across the DOC (about 6 IWC), and also to the addition of an extra pipe length and bends needed to connect the DOC to the existing water lift silencer. Had the engine been under warranty, the addition of the DOC system would have voided it.

Another issue with fitting a DOC to a vessel is the increased amount of heat generated within the compartment it is placed. This factor was brought to the surface during the installation and operation of this DOC. This particular DOC is placed within the engine compartment of the vessel. Its relatively large size and the associated piping increase the area of exhaust components that dissipate heat into the space. Normally, on this type of vessel, only the exhaust piping from the engine turbocharger outlet to the water lift silencer operates at the exhaust temperature. This section of exhaust piping is insulated, but the surface temperature still approaches 150ºC. The water lift silencer is cooled by a stream of water exiting from the engine, as is the overboard pipe from the silencer. The DOC adds about 12 ft^2 of additional surface area and the associated pipe about 8.5 ft^2. The DOC and its associated piping are insulated. Even so, the heat added to the space is approximately 5500 btu/hr. Moreover, the location of the DOC, in the overhead above the existing water lift silencer, creates a hot spot that causes the passenger deck located above the DOC to be warmer than the rest. Adequate attention to the ventilation and thermal insulation around the DOC would eliminate the potential for any safety or undue constraints to the vessel's operation, crew, or passengers.

The cost of the DOC system was approximately $23,000. The DOC itself cost $7,000, and the installation cost about $16,000. The installation cost was somewhat higher than expected because of some issues the shipyard had with routing the exhaust pipe from the DOC to the water lift silencer. It is anticipated that a more reasonable installation cost will be in the $8,000-$10,000 range.

MV PORT IMPERIAL MANHATTAN

The MV PORT IMPERIAL MANHATTAN is an aluminium monohull vessel powered by twin Caterpillar 3412E engines driving propellers through 2.03:1 reduction gears. The load points and sample durations are listed in Tables 5.5 and 5.6.

Table 5.5. MV PORT IMPERIAL MANHATTAN Test Operating Mode Load Points, Baseline and Post DOC (14-15 December 2005).

Test Mode	RPM / Load (nominal rpm)	Number of Samples	Sample Duration (min)
Idle	700	4	6
Push	750	4	6
Push	900	4	6
Push	1000	4	6
Push	1200	4	6
Cruise	1000	4	6
Cruise	25% (1125)	4	6
Cruise	50% (1434)	4	6
Cruise	75% (1640)	4	6
Cruise	100% (1830)	4	6
Transit	Various	4	13.5

Table 5.6. MV PORT IMPERIAL MANHATTAN Test Operating Mode Load Points, DOC + FBC (26-27 March 2006).

Test Mode	RPM / Load (nominal rpm)	Number of Samples	Sample Duration (min)
Idle	700	3	6
Push	750	3	6
Push	900	3	6
Push	1000	3	6
Push	1200	3	6
Cruise	1000	3	6
Cruise	25% (1125)	3	6
Cruise	50% (1434)	3	6
Cruise	75% (1640)	3	6
Cruise	100% (1830)	3	6
Transit	Various	3	12.5

The vessel was demonstrated with just the DOC in use and with the same DOC used in conjunction with a fuel-borne catalyst (FBC). The DOC was supplied by Clean Diesel Technologies and consisted of two 14" diameter substrates mounted in an oval enclosure and adapted for a 6"-150 flanged inlet and outlet. The DOC substrate was coated with a less active catalyst because it was selected for use with a FBC.

The DOC was installed in the vessel's lazarette (as shown in Figure 5.2), between the existing silencer outlet and the existing transom tailpipe, and supported by brackets attached to the engine room's overhead. This placement was chosen for its ease of installation (and removal) and so as not to interfere with the relatively cramped space that comprises the engine room. There were no major obstacles to fitting the DOC into this location, though the clearance between the DOC and the underside of the deck above was not optimal. The deck area above the DOC was warmer than the surrounding deck surface. No limitations to the vessel's service were noted due to the installation of the DOC.

The change in exhaust back pressure was a concern for the design; however, when the system was tested following installation, the change in back pressure proved to be minimal. There was no additional pipe installed. In fact, the existing exhaust pipe length was reduced because it was replaced with the DOC. The additional back pressure in the exhaust system due to the DOC was approximately 7 IWC. The total system back pressure was approximately 17 IWC.

Figure 5.2. MV PORT IMPERIAL MANHATTAN DOC in Lazarette.

The cost of the DOC system was around $12,000. The DOC itself cost $7,000, and the installation cost about $5,000. The installation cost was in line with what was expected. With the exception of having to cut a hole in the deck to pass the unit through, the installation consisted of straightforward pipe fitting. Depending upon the requirements of the vessel owner, the DOC could also have been furnished with silencing capability so that it would essentially replace the existing exhaust silencer. This would nearly triple the cost of the DOC, however the installation cost would remain about the same.

The FBC used in conjunction with the DOC was supplied by Clean Diesel Technologies and is sold under the name of Platinum Plus DFX. A specification sheet for this product has been provided in Appendix T. This was the only FBC listed by the EPA and certified to reduce emissions during the time period of the technology research study. It has been EPA verified alone and in conjunction with a DOC. Moreover, claims were made by the supplier that the FBC would also improve fuel economy. Following the initial DOC tests the vessel's fuel was treated with the FBC for a sufficient period so that any "seasoning" of the combustion surfaces and DOC with the FBC would be complete prior to the final emissions tests. The catalyst supplier stated that approximately two weeks of operation would be require while using the FBC for the results to be valid. No special equipment was required to use the FBC.

The FBC can be batch dispensed or metered into a fuel system. For larger fleets, a metering system can be used to deliver the correct amount of FBC into each vessel's fuel in proportion to the amount of fuel dispensed. For the MV PORT IMPERIAL MANHATTAN, the FBC was batch dispensed into the fuel system. A metering system was provided as part of the demonstration, but it was not possible to incorporate it into the existing fuel dispensing facility used by the vessel's operator. The FBC was metered according to the dosing chart provided with the FBC. While Clean Diesel Technologies checked the concentration of the FBC in the fuel during the time period before the emissions tests there is some uncertainty as to whether or not the concentration of the FBC was high enough.

The cost for the FBC is $75.00 per gallon, and each gallon can treat up to 1,500 gallons of fuel. The additional cost per gallon of fuel consumed is $0.05. No other costs are required to use this product. Precautions for handling the product are no stricter than those required for handling petroleum fuels.

MV JOHN KEITH

The MV JOHN KEITH is an aluminum catamaran vessel powered by two 600 bhp Detroit Diesel Series 60 engines driving conventional propellers through a 1.92:1 gearbox. Electric power is provided by a single 20 kWe Northern Lights diesel generator set. The MV JOHN KEITH was selected as the replacement demonstration vessel for the MV ED ROGOWSKY used in the initial 2004 emissions tests. These vessels in the New York Water Taxi fleet are sister ships, and the MV JOHN KEITH is mechanically identical to the MV ED ROGOWSKY. The load points and sample durations are listed in Table 5.7.

Table 5.7. MV JOHN KEITH Test Operating Modes Load Points, DOC (6-7 April 2006).

Test Mode	RPM / Load (nominal rpm)	Number of Samples	Sample Duration (min)
Idle	700	3	6
Push	820	3	6
Push	1000	3	6
Push	1200	3	6
Cruise	1000	3	6
Cruise	25% (1353)	3	6
Cruise	50% (1702)	3	6
Cruise	75% (1945)	3	6
Cruise	100% (2150)	3	6
Transit	Various	3	13

The DOC, Johnson-Matthey BS-OSS-30D-6, was installed in the engine room on the centerline engine's exhaust. The DOC consists of an 18" cylindrical housing with a 6"-150 flanged inlet and outlet. Inside the main housing are two 19.5" diameter catalyst substrates. This DOC is depicted in Figure 5.3. A specification sheet for this unit has been provided in Appendix V. These catalyst substrates were identical to those used on the MV FATHER MYCHAL JUDGE except for diameter. The other difference between the two DOCs is that the BS-OSS-30D-6 unit inlet and outlet were radial from the ends.

The DOC was installed between the engine's turbocharger outlet and the existing hull outlet pipe and supported by brackets attached to the engine room's overhead. This location was chosen to limit the DOC's impact upon the engine room space. The advantage is that it fit well, even though it was substantially larger than the silencer it replaced. The disadvantage is that the location did limit the access to maintenance points for the vessel. The unit was heavily insulated, and the catalyst access covers were modified from the initial band clamp type to bolt on. These installation modifications were largely a result of lessons learned on the MV FATHER MYCHAL JUDGE. The MV JOHN KEITH and its sister vessels have a marginal amount of air supplied to the engine room, so the additional insulation served to limit any additional heating of the space from the DOC. In fact, the extra insulation served to reduce the amount of heat added to the space in spite of the greater surface area.

Figure 5.3. MV JOHN KEITH Engine Room Looking Forward.

The change in exhaust back pressure was a concern for the design. When the vessel's engine is exhausting through the original system, the back pressure is around 5 IWC. After the DOC was installed, the engine was run up to full rated speed and the back pressure measured with a gage. The back pressure was well below the manufacturer's rated limit of 27 IWC at full rated power. In fact, during the demonstration, the back pressure was slightly below atmospheric pressure. This was possibly caused by a suction effect on the outlet pipe due to the vessel's speed and the pipe outlet location.

Another concern for this installation was the potential for noise increase within the vessel. The only way to fit a DOC into the limited space was to install it in place of the existing silencer. Silencers have resonance chambers to reduce the amount of sound. Some sound deadening would occur simply because the exhaust gas would have to pass through the catalyst and through the exhaust pipes. Following the installation, sound levels were taken and compared with measurements taken on a sister vessel in 2004. The interior sound levels were approximately 1.5 dBA higher at a location directly above the DOC. The exterior sound levels increased approximately 1.5 dBA from side to side. The low back pressures measured with this DOC means that subsequent designs could either be physically smaller or have a greater degree of sound attenuation built in.

The cost of the DOC system was approximately $16,000. The DOC itself cost $11,000, and the installation cost about $5,000. The cost of the DOC was significantly higher than anticipated due to expediting charges that were incurred to have the DOC fabricated to meet the schedule. The same DOC ordered with standard delivery times would cost about $8,000. The installation cost was about the same as was expected; however, because the vessel was already in the shipyard when the DOC was installed, there was no difficulty in getting the unit into the space. The unit, as configured, would not have fit down the access hatch to the space. It is anticipated that subsequent units could be constructed to fit down a vessel's access hatch.

FUEL

The fuel used for this round of testing was No. 2 LSD. Fuel samples were obtained at the time of testing and submitted to the American Bureau of Shipping (ABS) Technical Services Group for analysis. Representative fuel samples were obtained during the emissions tests from the fuel return pipe from each engine so as to collect a running sample of the fuel the engine was actually consuming. A summary of the analysis results for the fuels is provided in Table 5.8.

Table 5.8. Fuel Sample Test Results.

Fuel Parameter	MV GEORGE WASHINGTON	MV FATHER MYCHAL JUDGE	MV P. IMPERIAL MANHATTAN, Pre EBC	MV P. I. MANHATTAN, Post EBC	MV JOHN KEITH
Specific Gravity (-)	0.8553	0.8430	0.8452	0.8461	0.8544
Sulfur (ppm)	421	359	291	348	788
Higher Heating Value (btu/gal)	139,582	138,116	138,437	138,565	139,589
Aromatic Content (% vol.)	33.3	28.6	37.6	31.7	30.5
Cetane Index (-)	44.3	47.8	47.3	46.5	45.6
Cloud Point (^oF)	12	10	10	12	12
Carbon (% weight)	87.31	86.21	86.95	86.40	86.22
Hydrogen (% weight)	12.51	13.10	12.93	12.90	13.10
Viscosity (Cst @ 100 ^oF)	2.81	2.51	2.56	2.55	2.96
Flash Point (^oF)	148	140	143	142	149

RESULTS

This section provides a synopsis of measurements taken during the on-board emissions testing. Emission rates are presented in terms of grams (or kilograms) of pollutant per hour (g/hr or kg/hr). Appendix X also presents the emissions data in terms of grams of pollutant per brake horsepower-hour (g/bhp-hr) and grams of pollutant versus gallon of fuel consumed (grams/gallon). The suspected error in the emission rates is discussed and presented at the end of this section in terms of standard deviations, confidence intervals, and relative deviations.

MV GEORGE WASHINGTON Engine Operating Parameters and Emissions

The engine operating parameters and fuel flow rates used in the calculation of the emission rates for the MV GEORGE WASHINGTON are presented Tables 5.9 and 5.10. The volumetric fuel flows are based upon the specific gravity listed on the fuel analysis and derived from the fuel mass flows measured during the Phase I No. 1 LSD fuel test. In actual practice the volumetric fuel flows may be greater or less than those stated, depending upon the temperature and specific gravity of the fuel. Good correlation between the observed engine parameters and what was provided by the engine manufacturer was observed for the power levels and operating modes.

Table 5.9. MV GEORGE WASHINGTON Baseline Engine Operating Parameters and Fuel Consumption Rates (July 2005).

Mode	Exhaust Temp, C	RPM	Manifold Temp, C	Inlet Air Temp, C	Manifold Press, PSIG	Fuel Flow, lb/hr	Fuel Flow, gph	Torque, ft-lb	BHP	BSFC, lb/bhp-hr
Idle	N/A	555	N/A	N/A	N/A	9.0	1.25	N/A	N/A	N/A
Cruise 1000	238.4	973	69.3	37.7	0.28	36.0	5.00	914.9	87.7	0.409
Cruise 25%	324.3	1281	75.4	38.7	1.98	75.6	10.50	1588.7	200.5	0.377
Cruise 50%	387.6	1517	86.4	39.1	5.43	129.6	17.99	2161.4	322.9	0.400
Push 750	245.7	738	70.6	38.3	-0.28	39.0	5.42	1050.8	76.4	0.508
Push 900	311.0	900	72.7	40.4	0.60	59.4	8.25	1521.3	134.8	0.439
Push 1000	348.1	989	75.1	39.7	1.34	76.2	10.58	1831.9	175.3	0.435
Push 1200	430.4	1197	83.7	36.7	4.31	120.0	16.66	2553.9	301.0	0.399
Transit	297.7	980	74.1	41.9	0.76	62.4	8.80	1560.2	151.7	0.426

Table 5.10 lists the individual emission constituents' results on a mass per time basis. The emissions are expressed as a mass per time based rate since it is easier to resolve this rate into the annual contribution for this type of vessel operating in the modes listed. The vessel was unable to run at speeds higher than ~1500 rpm due to the adjustments made by the operator in an attempt to reduce smoke and improve fuel economy. According to the operator, the engine received a modified, smaller turbocharger and new fuel injectors prior to the emissions test.

Table 5.10. Summary of Hourly Exhaust Emission Rates for MV GEORGE WASHINGTON (July 2005).

MODE	**NO_X**, kg/hr	**CO**, kg/hr	**CO2**, kg/hr	**HC**, kg/hr	**PM2.5**, g/hr	**PM10**, g/hr
	(±95%C.I.)	(±95%C.I.)	(±95%C.I.)	(±95%C.I.)	(±95%C.I.)	(±95%C.I.)
Idle	0.241 (0.0141)	0.268 (0.0279)	12.6 (0.0434)	0.0360 (0.00158)	3.52 (0.922)	3.65 (0.623)
Cruise 1000	1.44 (0.0521)	0.268 (0.00247)	51.8 (0.0140)	0.205 (0.0278)	21.0 (0.764)	21.8 (0.370)
Cruise 25%	2.13 (0.0364)	0.258 (0.00648)	109 (0.0401)	0.417 (0.0899)	18.3 (2.20)	18.0 (1.98)
Cruise 50%	3.20 (0.0406)	0.362 (0.0124)	188 (0.0200)	0.301 (0.0502)	17.8 (1.67)	17.7 (0.451)
Push 750	1.69 (0.0102)	0.435 (0.0100)	56.0 (0.0702)	0.0429 (0.00457)	62.0 (23.2)	64.3 (9.37)
Push 900	1.95 (0.0305)	0.563 (0.0102)	85.4 (0.0200)	0.107 (0.0195)	28.7 (2.66)	29.4 (2.42)
Push 1000	2.22 (0.0787)	0.648 (0.0330)	110 (0.0702)	0.170 (0.0384)	65.9 (10.9)	64.8 (12.0)
Push 1200	2.71 (0.0185)	1.28 (0.0252)	172 (0.0501)	0.302 (0.0371)	36.7 (9.24)	36.8 (7.01)
Maneuver Out	1.91 (2.89)	0.709 (0.897)	97.6 (131)	0.301 (0.406)	N/A	N/A
Maneuver In	2.28 (2.65)	0.649 (0.761)	103 (115)	0.404 (0.493)	N/A	N/A
Transit	1.94 (0.833)	0.489 (0.0665)	89.9 (14.4)	0.107 (0.0160)	40.9 (8.80)	42.5 (5.44)

Since this is a baseline test, there are no emissions reductions to report. The collected emissions rates will be compared with a similarly rated Tier 2 compliant engine to determine the harbor emissions impact of replacing these mechanically fuel injected engines.

Figures 5.4 through 5.7 display the average emissions on a mass per hour basis for each mode of operation tested. Error bars are set at a 95 percent confidence interval about the mean observed value. All emission rate error bars presented in this section represent 95% confidence intervals (C.I.). Regardless of the actual fuel consumption, emissions on a gram per gallon basis of fuel remained constant. The No. 2 fuel produces approximately 10.4 kg of CO_2 per gallon combusted because the vast majority of carbon in the fuel is converted to CO_2. Other emissions constituents vary in grams per gallon do to their relatively lower concentration than the CO_2 values observed. As a result, the emissions are calculated first on a per mass (or volume) of fuel basis and then calculated on a specific power and rate basis. Additional discussion regarding this technology is presented later in the section with the final emission rates.

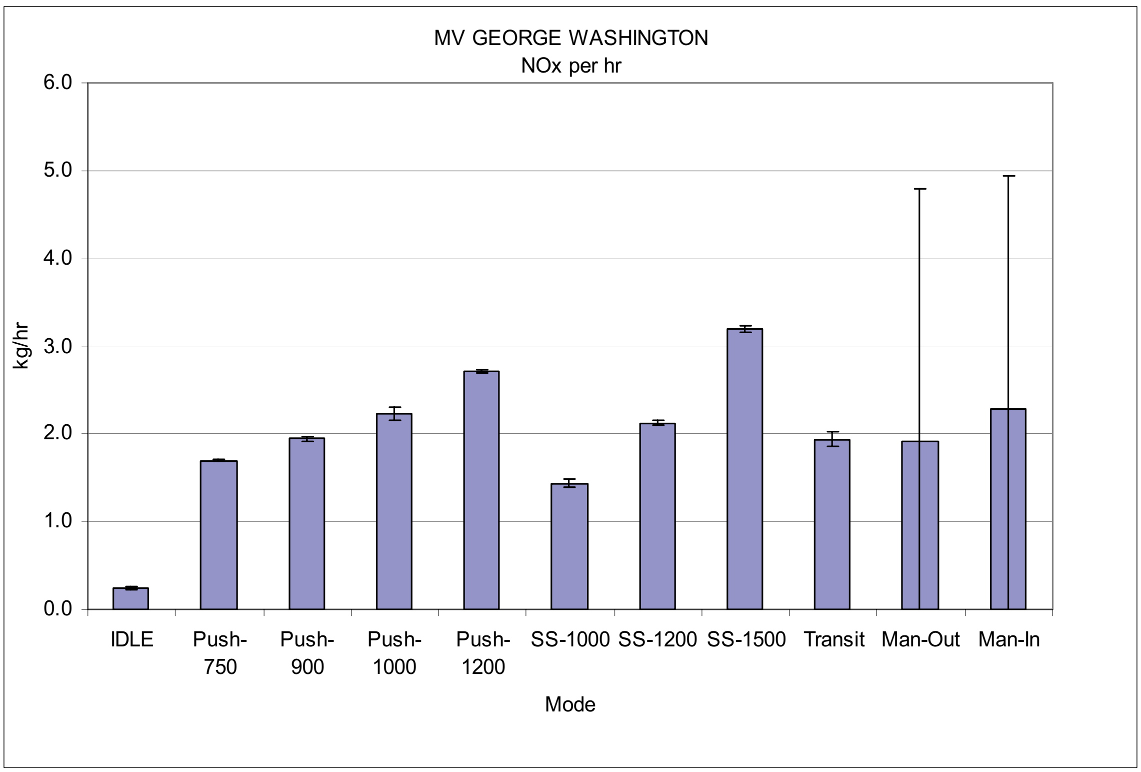


Figure 5.4. NO_X Emissions – MV GEORGE WASHINGTON (July 2005).

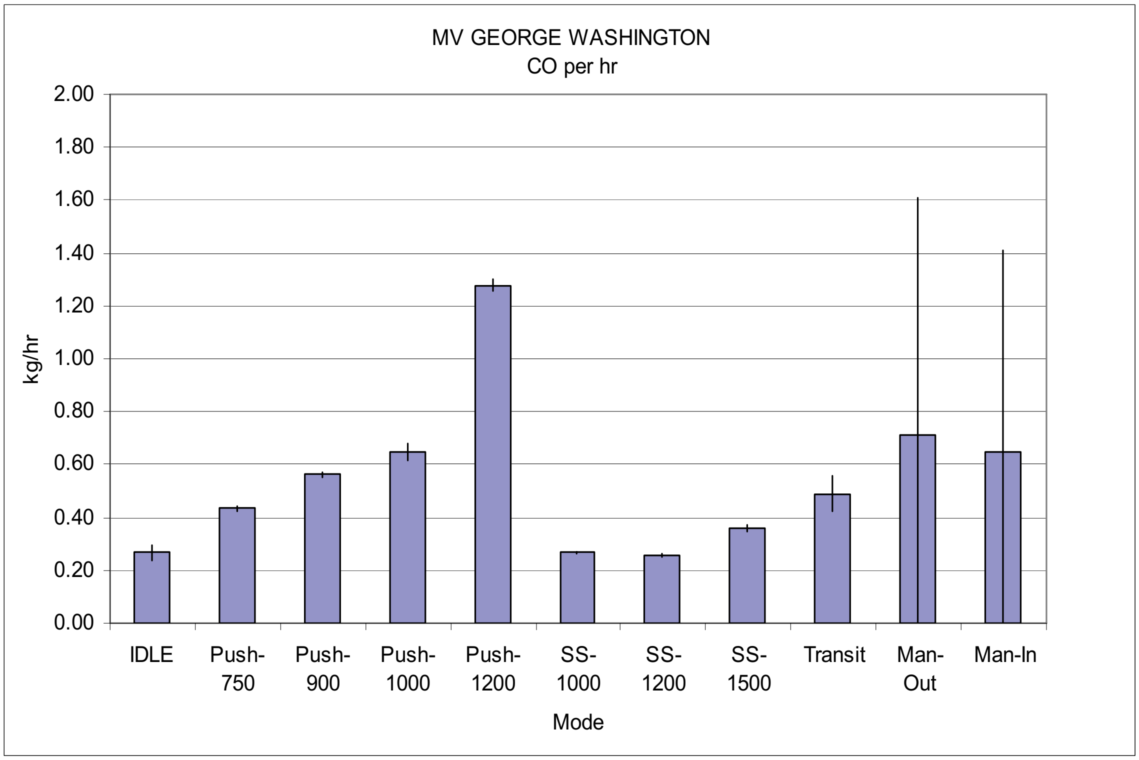


Figure 5.5. CO Emissions – MV GEORGE WASHINGTON (July 2005).

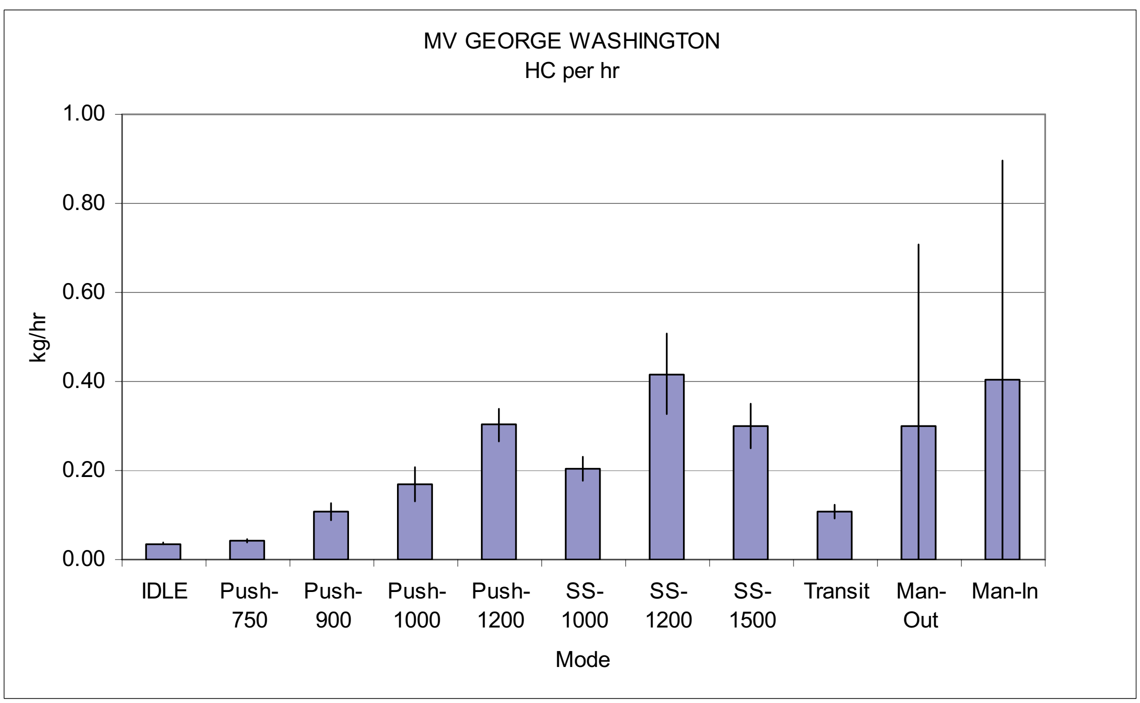


Figure 5.6. HC Emissions – MV GEORGE WASHINGTON (July 2005).

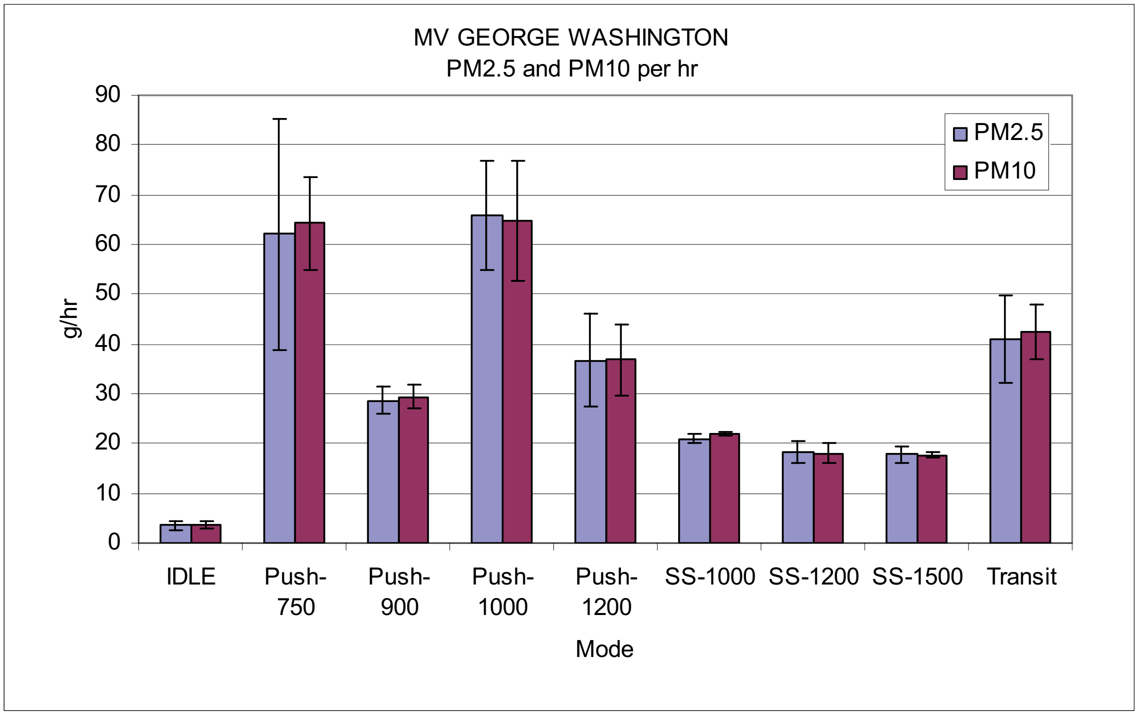


Figure 5.7. PM Emissions – MV GEORGE WASHINGTON.

MV FATHER MYCHAL JUDGE Engine Operating Parameters and Emissions

The engine operating parameters and fuel flow rates used in the calculation of the emissions rates for the MV FATHER MYCHAL JUDGE are presented Tables 5.11 through 5.13. The volumetric fuel flow is based upon the specific gravity listed on the fuel analysis and derived from the fuel mass flows measured during the emissions test. In actual practice the volumetric fuel flows may be greater or less than those stated, depending upon the temperature and specific gravity of the fuel. The MV FATHER MYCHAL JUDGE was tested a total of five times for emissions: two times as part of the LSD/ULSD fuel tests in Phase I, a second baseline test performed in July of 2005, and finally the two tests that measured the emissions before and after the demonstration DOC. The baseline emissions test in July of 2005 and the DOC demonstration emissions tests of March 2006 are presented here.

It should be noted that there is almost always some variance in engine load, especially in field testing, due to causes beyond the control of the operator. Thus, repeatability is often difficult to achieve in field tests involving marine engines.

The hourly emissions rates have been normalized for fuel flows. This was performed because the fuel flows varied between similar before and after treatment load points. The operating mode load points were kept as constant possible, but variations did occur because of the time span between the two like mode points, atmospheric conditions, and each particular vessel captain's setting for each vessel speed. Even so, the mode loads, especially the fuel flows and rpm, correlated very well and a high degree of confidence was placed on comparing these hourly emissions rates even though the loads were slightly different.

The power measured during the demonstration emissions test did not correlate as well as expected; however, the mass fuel flows, when plotted against engine rpm, indicate minimal error. From a practical standpoint, the engine power, while used in calculating an engine's emissions per bhp-hr, is of little significance. The vessel operators typically use only engine rpm to determine the correct speed to run in order to meet their schedules, and therefore they have little need for the vessel's power measurements.

The fuel flow measurements were also compared with the re-established baseline values measured in July of 2005. Fuel flow measurement is deemed more important for accurate emissions calculations than engine power, as it has direct correlation between the exhaust flows and the emissions constituent measured on a volume basis.

The torque, power, and bsfc values calculated for the data were consistent, though the values for post-DOC push modes, especially at 750 and 900 rpm, were significantly low. Subsequent tests were consistent and within the accuracy of the instrumentation. Directionally, the fuel flow was consistent with the change in torque and power. The difference between the pre- and post-DOC torque signals for 750 and 900 rpm was only 25MV, so it is possible there was some residual torque in the shaft when the meter was zeroed or another rotational force (current) was acting on the shaft when it was zeroed. These are potential sources of error in the torque measurement because the values converged at higher power levels.

The atmospheric conditions were significantly different between the tests in July 2005 and the tests in March of 2006. This change is reflected in the observed higher temperatures for the engine exhaust, charge air, and inlet air. There were also substantial changes in emissions from the July 2005 tests to the March 2006 pre-DOC emissions tests. Again, this change can be attributable to a host of vectors between the two tests including fuel properties, engine and vessel condition, and weather.

In addition to measuring the pre/post DOC emissions, the demonstration was also performed to determine whether or not DOCs can be successfully installed in this or similarly classed or powered vessels without reducing the vessel's capabilities. Back pressure was a particular concern. A change in back pressure can be expected anytime a device is placed within a vessel's exhaust stream. Back pressures higher than the manufacturer's limits will cause voiding of the warranty as well as reduced power output, reduced fuel economy, higher exhaust temperatures, and higher maintenance costs, especially for exhaust valves. The back pressure was measured at full rated speed after the installation of the unit. At that time it was nominally within the manufacturer's limits. A different instrument was used to measure the back pressure during the course of the demonstration. This instrument measured a back pressure moderately in excess of the manufacturer's limit. The DOC was integrated into the original water lift silencer system for ease of installation. The water lift silencer system has an inherent back pressure of approximately 20 IWC, and the DOC plus additional piping for the installation added another 8-10 IWC to the back pressure. After two months of operation, no additional back pressure increase was noted.

The results of the emissions testing were similar to those measured on the other DOC demonstrations in December 2005, March 2006, and April 2006. These results are shown in Table 5.14, and in Figures 5.8 through 5.11. Once again, significant reductions were noted for HC, CO, and PM. A slight decrease, 4.6% on average, was noted for NO_X. The DOC achieved the manufacturer's anticipated reductions of 80% CO, 80 % HC, and 15% PM, but those reductions are based on unspecified emissions inlets and as such are generic. During the testing, the actual CO, HC, and PM 2.5 reductions on a g/bhp-hr basis averaged 79.3%, 45.3%, and 57.6% respectively. The effectiveness of the DOC appeared to be highly dependent upon the engine load and exhaust temperature at lower loads.

The transit values remained difficult to correlate. Care was taken to duplicate the transit test to the greatest extent possible. The average duration of each pre-DOC test was 13' 05" and for each post-DOC test 12' 53", and the fuel rate was 75.8 lb/hr versus 77.8 lb/hr respectively. This would indicate that the post-DOC test had a greater portion of its time at higher power levels than the pre-DOC test. The transit mode is a special case since it is a composite made up of steady-state push and cruise modes along with a significant amount of time accelerating and decelerating during the maneuvering mode. Consequently, the gas flow, exhaust temperature, and gas constituent concentrations are always changing. However, this may be the best overall indication of the DOC's performance since it closely resembles the actual operating cycle the engine is used on. The DOC performed well in the transit test, again showing substantial reductions for CO, HC, and PM emissions.

Table 5.11. MV FATHER MYCHAL JUDGE Baseline Engine Operating Parameters and Fuel Consumption Rates (March 2006).

Mode	Exh. Temp, C	Air Temp, C	Mani. Temp, C	Exh. BP, IWC	Mani. Press, PSIG	RPM	Fuel flow, lb/hr	Fuel flow, gph	Torq, ft-lb	BHP	BSFC, lb/bhp-hr
Idle	N/A	N/A	N/A	N/A	N/A	700	10.0	1.4	190.9	26.7	0.374
SS-1000	223.8	21.9	N/A	11.8	1.0	1011.0	26.8	3.8	349.1	70.6	0.380
SS-1323	332.8	22.7	N/A	14.9	2.9	1334.9	57.3	8.2	584.2	155.9	0.368
SS-1680	418.8	27.6	N/A	23.0	8.3	1681.1	110.0	15.6	879.6	295.6	0.372
SS-1910	415.2	28.3	N/A	32.4	15.8	1914.9	161.1	22.9	1100.5	421.3	0.382
Push-750	150.3	54.1	N/A	1.7	12.0	753.5	11.7	1.7	158.8	23.9	0.490
Push-900	176.7	28.2	N/A	12.8	0.8	911.0	20.4	2.9	230.1	41.9	0.488
Push-1000	203.3	38.8	N/A	12.9	1.0	1015.2	26.8	3.8	286.7	58.2	0.461
Push-1200	268.0	45.2	N/A	13.5	1.7	1209.4	41.9	5.9	421.1	101.8	0.411
Transit	289.5	29.2	N/A	19.8	6.9	1289.9	75.8	10.8	593.2	153.1	0.495

Table 5.12. MV FATHER MYCHAL JUDGE Post DOC Engine Operating Parameters and Fuel Consumption Rates (March 2006).

Mode	Exh. Temp, C	Air Temp, C	Mani. Temp, C	Exh. BP, IWC	Mani. Press, PSIG	RPM	Fuel flow, lb/hr	Fuel flow, gph	Torq, ft-lb	BHP	BSFC, lb/bhp-hr
Idle	N/A	N/A	N/A	N/A	N/A	700.0	9.3	1.4	190.9	26.7	0.349
SS-1000	229.8	16.2	N/A	12.6	1.1	994.7	28.0	4.0	377.1	75.0	0.373
SS-1323	339.8	18.6	N/A	18.6	3.0	1344.0	57.5	8.2	567.6	152.5	0.377
SS-1680	424.4	21.0	N/A	23.7	7.9	1665.3	107.1	15.2	828.1	275.8	0.388
SS-1910	422.3	22.6	N/A	31.3	16.1	1918.0	162.2	23.1	1037.6	397.9	0.408
Push-750	155.9	16.3	N/A	10.5	0.5	753.7	12.5	1.8	219.2	33.0	0.380
Push-900	188.7	16.3	N/A	11.3	0.8	900.0	19.8	2.8	278.4	50.1	0.396
Push-1000	215.1	16.3	N/A	12.0	1.0	1002.7	25.9	3.7	295.9	59.3	0.436
Push-1200	281.6	16.6	N/A	15.1	1.9	1208.0	42.2	6.0	431.2	104.1	0.405
Transit	295.4	16.0	N/A	20.4	7.3	1302.4	77.8	11.1	586.6	152.7	0.510

Table 5.13. MV FATHER MYCHAL JUDGE Baseline/Post DOC Engine Operating Parameters and Fuel Consumption Rate Percent Changes (March 2006).

Mode	Exh. Temp	Air Temp	Mani. Temp	Exh. BP	Mani. Press	RPM	Fuel Flow, (lb/hr)	Fuel Flow, (gph)	Torque	BHP	BSFC
Idle	N/A	N/A	N/A	N/A	N/A	0.0%	6.7%	6.7%	0.0%	0.0%	6.7%
SS-1000	-1.2%	1.9%	N/A	0.0%	-0.6%	1.6%	-4.5%	-4.5%	-8.0%	-6.3%	1.7%
SS-1323	-1.2%	1.4%	N/A	-0.1%	-0.4%	-0.7%	-0.3%	-0.3%	2.8%	2.2%	-2.5%
SS-1680	-0.8%	2.2%	N/A	0.0%	1.9%	0.9%	2.6%	2.6%	5.9%	6.7%	-4.4%
SS-1910	-1.0%	1.9%	N/A	0.0%	-0.9%	-0.2%	-0.7%	-0.7%	5.7%	5.6%	-6.7%
Push-750	-1.3%	11.6%	N/A	-1.2%	43.0%	0.0%	-7.0%	-7.0%	-38.1%	-38.1%	22.5%
Push-900	-2.7%	3.9%	N/A	0.0%	0.0%	1.2%	3.0%	3.0%	-19.6%	-19.6%	18.8%
Push-1000	-2.5%	7.2%	N/A	0.0%	-0.4%	1.2%	3.4%	27.6%	-1.9%	-1.9%	5.3%
Push-1200	-2.5%	9.0%	N/A	0.0%	-1.2%	0.1%	-0.8%	-0.8%	-2.3%	-2.3%	1.4%
Transit	-1.0%	4.4%	N/A	0.0%	-2.0%	-1.0%	-2.7%	-2.7%	0.3%	0.3%	-3.0%

Table 5.14. MV FATHER MYCHAL JUDGE Baseline/Post DOC Emissions (March 2006).

Baseline DOC Emissions												
Mode	NO_X (kg/hr)		CO (kg/hr)		CO_2 (kg/hr)		HC (kg/hr)		PM2.5 (g/hr)		PM10 (g/hr)	
	Rate	95% C.I.	Rate	95% C.I.	Rate	95% C.I.	Rate	95% C.I.	Rate	95% C.I.	Rate	95% C.I.
Idle	0.441	0.0273	0.0285	0.00518	14.1	0.0274	0.105	0.00844	1.55	0.784	1.33	2.10
SS-1000	1.14	0.0389	0.0487	0.000554	38.2	0.0619	0.173	0.0195	3.44	0.555	3.49	3.79
SS-1323	1.33	0.0200	0.162	0.0306	82.2	0.0534	0.271	0.0136	11.0	3.63	10.2	4.21
SS-1680	1.92	0.0190	0.356	0.0532	157	0.0795	0.451	0.00186	27.3	2.68	27.5	6.09
SS-1910	2.48	0.0944	0.226	0.0272	231	0.290	0.744	0.0779	25.3	5.00	24.5	21.4
Transit	2.01	0.223	0.196	0.0605	108	17.3	0.500	0.153	10.3	5.65	10.0	18.2
Push-750	0.513	0.0243	0.0322	0.00637	16.5	0.0682	0.125	0.0190	4.23	1.68	3.87	7.80
Push-900	0.936	0.0178	0.0557	0.000921	28.8	0.189	0.228	0.0596	6.58	1.79	6.25	9.54
Push-1000	1.18	0.0236	0.0611	0.00332	37.8	0.0805	0.291	0.0238	8.69	1.46	8.34	3.72
Push-1200	1.36	0.0257	0.0980	0.000943	59.4	0.0232	0.358	0.00731	11.1	1.13	11.0	11.7
Man.-Out	1.12	0.880	0.292	0.236	75.5	59.5	0.282	0.102	N/A	N/A	N/A	N/A
Man.-In	0.553	0.732	0.0771	0.0413	36.9	19.6	0.0962	0.0193	N/A	N/A	N/A	N/A
Post DOC Emissions												
Mode	NO_X (kg/hr)		CO (kg/hr)		CO_2 (kg/hr)		HC (kg/hr)		PM2.5 (g/hr)		PM10 (g/hr)	
	Rate	95% C.I.	Rate	95% C.I.	Rate	95% C.I.	Rate	95% C.I.	Rate	95% C.I.	Rate	95% C.I.
Idle	0.404	0.0133	0.0134	0.0168	14.1	0.0202	0.0489	0.0114	0.289	0.264	0.366	0.5669
SS-1000	1.19	0.0386	0.0055	0.000828	41.9	0.0247	0.120	0.00745	1.16	0.335	1.10	0.9310
SS-1323	1.32	0.0276	0.0094	0.00188	82.4	0.0949	0.215	0.0307	8.52	2.39	8.01	12.7038
SS-1680	1.83	0.0958	0.0150	0.00788	149	0.122	0.375	0.0351	25.8	3.11	25.872	0.9417
SS-1910	2.52	0.0520	0.0174	0.00737	235	0.456	0.480	0.145	17.7	2.14	17.559	4.93
Transit	2.18	0.166	0.0323	0.0259	112	3.53	0.295	0.0590	3.54	0.975	3.64	2.69
Push-750	0.551	0.00277	0.0297	0.00506	19.2	0.0287	0.0613	0.00655	0.615	0.206	0.660	0.9322
Push-900	0.868	0.00779	0.0155	0.00242	27.5	0.0324	0.0914	0.0113	4.02	1.38	4.11	0.4828
Push-1000	1.10	0.0118	0.0112	0.0100	35.8	0.0149	0.0985	0.00186	0.796	0.572	0.619	1.56
Push-1200	1.34	0.0248	0.0085	0.00241	61.0	0.0261	0.131	0.00761	1.70	1.22	1.35	0.4790
Man.-Out	1.12	0.153	0.190	0.126	86.7	31.4	0.138	0.109	N/A	N/A	N/A	N/A
Man.-In	0.634	0.131	0.0677	0.00833	31.7	4.24	0.0601	0.0332	N/A	N/A	N/A	N/A

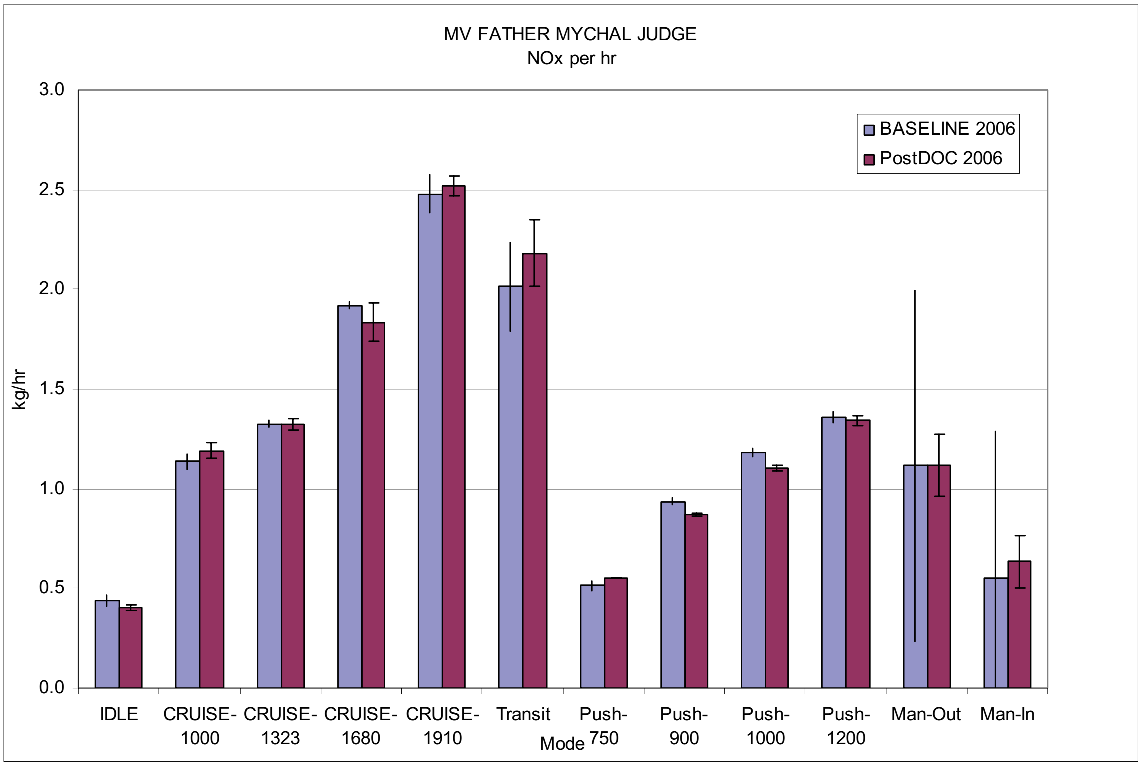


Figure 5.8. NO_X Emissions – MV FATHER MYCHAL JUDGE with DOC (March 2006).

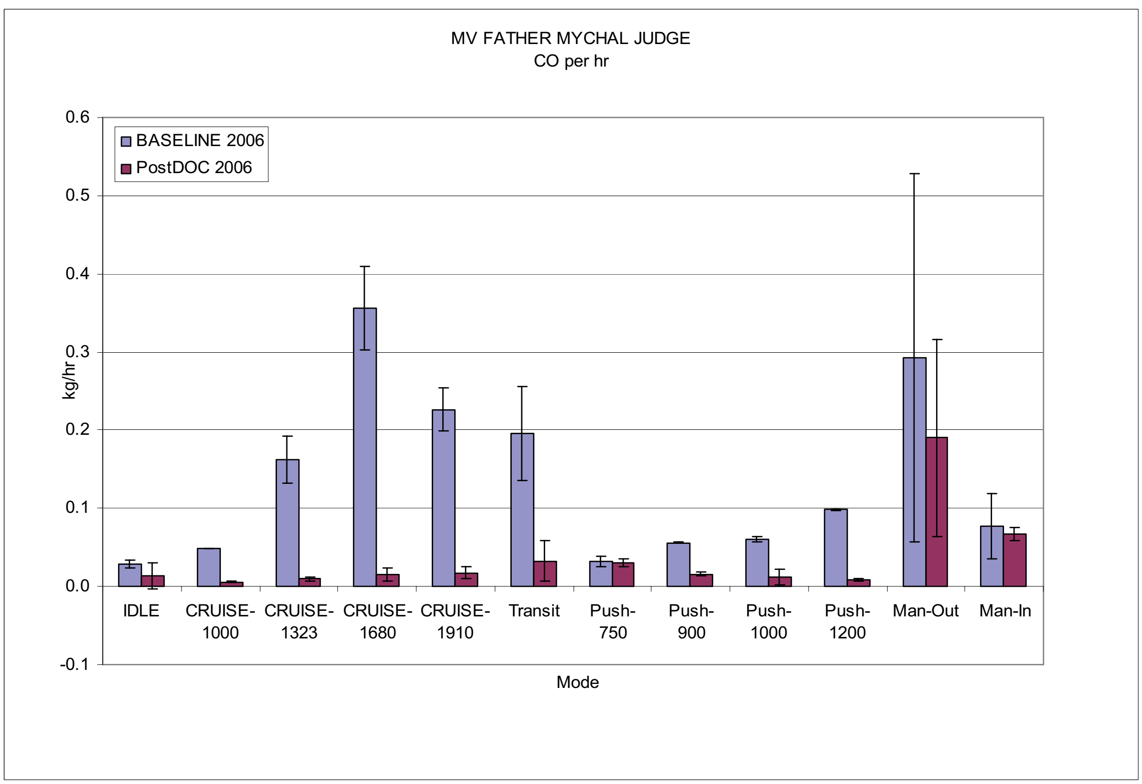


Figure 5.9. CO Emissions – MV FATHER MYCHAL JUDGE with DOC (March 2006).

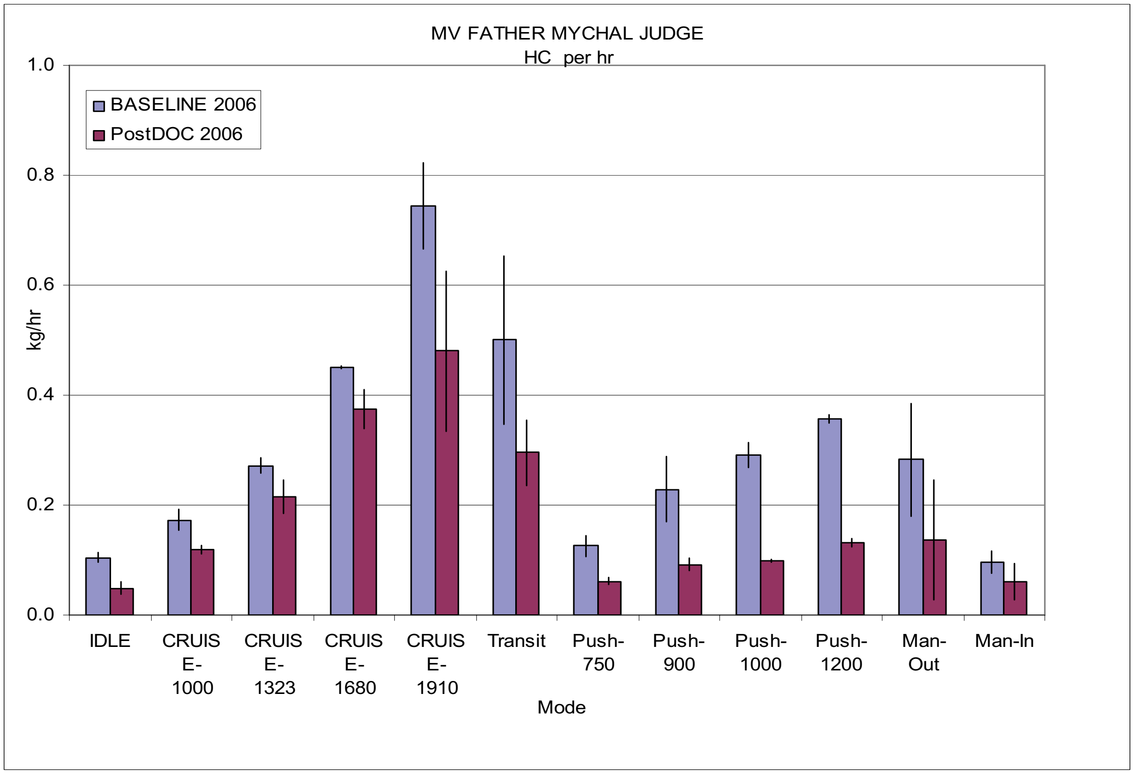


Figure 5.10. HC Emissions – MV FATHER MYCHAL JUDGE with DOC (March 2006).

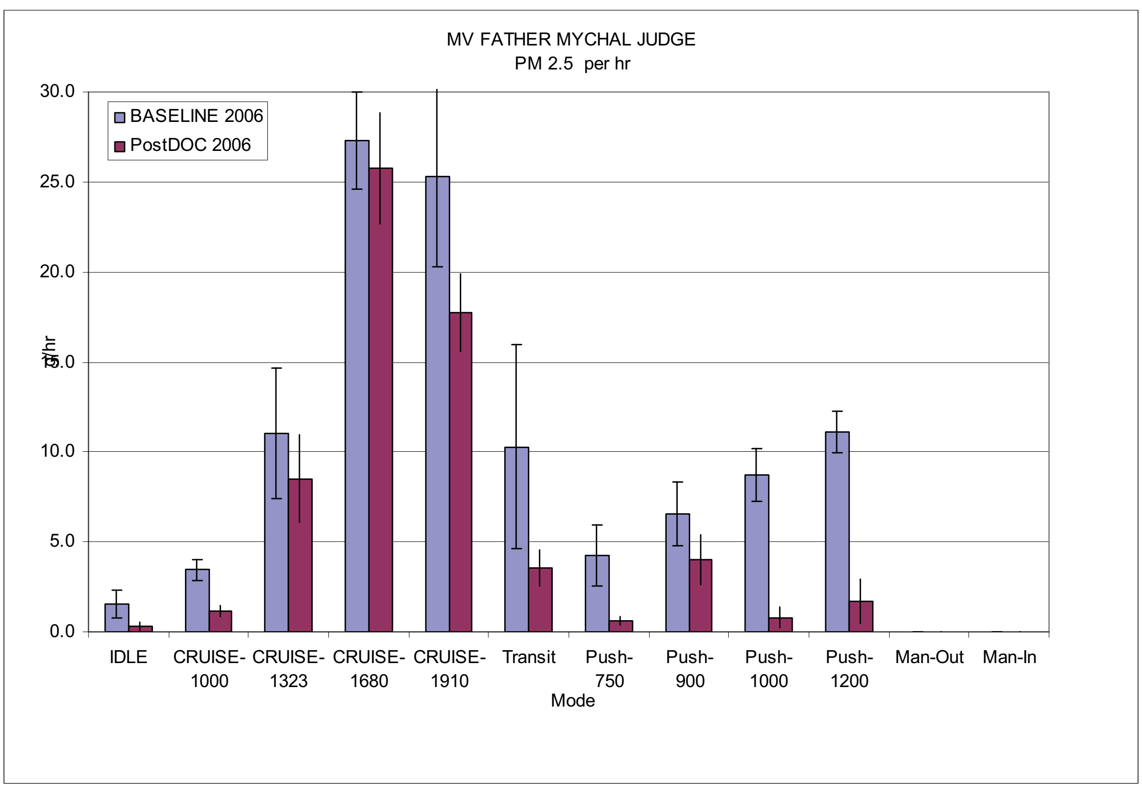


Figure 5.11. PM 2.5 Emissions – MV FATHER MYCHAL JUDGE (March 2006).

MV PORT IMPERIAL MANHATTAN Engine Operating Parameters and Emissions

The engine operating parameters and fuel flow rates used in the calculation of the emissions rates for the MV PORT IMPERIAL MANHATTAN are presented Tables 5.15 through 5.17. The volumetric fuel flow is based upon the specific gravity listed on the fuel analysis and derived from the fuel mass flows measured during the emissions test. In actual practice the volumetric fuel flows may be greater or less than those stated, depending upon the temperature and specific gravity of the fuel.

The MV PORT IMPERIAL MANHATTAN was tested a total of six times for emissions: two times as part of the LSD/ULSD fuel test in Phase I, a second baseline and a post-DOC test performed in December of 2005, and finally the two tests that measured the emissions before and after the demonstration DOC concurrent with a fuel-borne catalyst. The second baseline emissions test in December of 2005 was performed to establish the baseline emissions entering the demonstration DOC.

Ultrafine Particle Testing

In addition to the emissions tests performed by Environment Canada, NYDEC attempted to measure ultrafine particulate formation. Measurements of ultrafine particle emissions were performed during the baseline/DOC tests of December 2005 using an Electrical Low Pressure Impactor (ELPI, Dekati, Ltd.) which provides real-time measurement of particle size distributions for the size range from 13.2 nm to 6.12 microns.

Samples were taken from the same sample ports used for gravimetric PM measurements and diluted using a separate minidiluter. While ultrafine particle size distributions were successfully obtained using this method, the results were inconclusive due to the wide degree of variability in the data. Large differences were found in the particle size distributions before and after the catalyst which did not follow a consistent pattern and did not correlate with the testing mode or measured engine parameters such as RPM, torque, BHP, net fuel flow or exhaust temperature. Further, this behavior was not consistent with the results of previous dynamometer experiments on diesel engines with DOCs, which indicate that the use of a DOC will decrease the total emissions of ultrafine particulates without changing the mean particle size or the shape of the particle size distribution.

The most likely explanation for this result is that the variability inherent in this in-use testing is too great for reliable ultrafine particle measurements, which are much more sensitive than gravimetric PM measurements. In order to obtain reliable ultrafine particle measurements, this testing should first be performed under controlled conditions such as by using an engine dynamometer. This would allow the elimination of additional variables (e.g., water current, pilot, etc.) which could be perturbing the sensitive ultrafine particle measurements. It is also recommended that samples be taken at the end of the exhaust line, as is standard practice for such testing, rather than immediately before and after the catalyst. The influence of temperature, flowrate-induced shear, and mixing on ultrafine particle formation are poorly understood; sampling at the end of the exhaust line eliminates consideration of these issues and measures the actual ultrafine emissions to the environment. While sampling at the end of the exhaust line is problematic for this type of in-use testing, it is relatively straightforward when using an engine dynamometer. Once the effects on ultrafine particles of using a DOC for this particular application are evaluated in a controlled setting, such measurements can then potentially extended to in-use testing.

Table 5.15. MV PORT IMPERIAL MANHATTAN Baseline Engine Operating Parameters and Fuel Consumption Rates (December 2005).

Mode	Exh. Temp, C	Air Temp, C	Mani. Temp, C	Exh. BP, IWC	Mani. Press, PSI	RPM	Fuel Flow, lb/hr	Fuel Flow, gph	Torque, lb-ft	BHP	BSFC, lb/bhp-hr
Idle	105.07	25.73	69.66	0.60	-1.01	698.9	8.12	1.15	271.7	N/A	N/A
SS-1000	221.68	27.81	71.87	1.77	-0.32	1000.0	41.86	5.92	1067.5	105.1	0.398
SS-1200	259.83	28.95	72.56	2.44	0.24	1125.2	56.61	8.01	1367.9	151.6	0.373
SS-1500	348.01	29.65	77.77	5.67	3.83	1433.8	113.25	16.02	2298.9	324.6	0.349
SS-1600	384.91	30.62	85.25	10.19	8.10	1640.6	167.69	23.72	2998.5	484.5	0.346
SS-1800	405.37	31.08	97.22	17.82	14.62	1830.2	234.61	33.18	3729.8	672.3	0.349
Transit	305.43	33.97	74.71	2.54	0.65	1024.8	70.35	9.95	1942.0	196.1	0.359
Push-750	228.41	35.68	72.51	0.87	-0.84	757.0	36.15	5.11	1319.4	98.4	0.368
Push-900	289.24	37.01	74.24	1.74	-0.36	893.6	56.37	7.97	1839.8	161.9	0.348
Push-1000	333.81	34.72	75.56	2.55	0.87	1009.4	79.92	11.30	2355.6	234.2	0.341
Push-1200	410.62	34.32	79.95	5.10	4.41	1202.0	132.12	18.69	3324.0	393.5	0.336

The results of the emissions tests are shown in Table 5.18 and Figures 5.12 through 5.15. The change in the averaged engine operating parameters and emissions at each mode on a per hour basis can be seen. The DOC performed as expected. Significant reductions were noted for CO, HC, and PM (PM 2.5 and PM 10). A small of amount of NO_X reduction was noted over the whole operating range. A significant reduction was noted for the transit mode.

Table 5.16. MV PORT IMPERIAL MANHATTAN Post DOC Engine Operating Parameters and Fuel Consumption Rates (December 2005).

Mode	Exh. Temp, C	Air Temp, C	Mani. Temp, C	Exh. BP, IWC	Mani. Press, PSI	RPM	Fuel Flow, lb/hr	Fuel Flow, gph	Torque, lb-ft	BHP	BSFC, lb/bhp-hr
Idle	117.47	39.34	71.86	0.40	-1.42	700.3	8.19	1.16	N/A	N/A	N/A
SS-1000	223.92	23.23	71.33	1.70	0.07	995.7	42.21	5.97	1092.5	107.1	0.394
SS-1200	266.65	25.82	72.72	2.46	0.53	1135.7	59.10	8.36	1429.2	159.8	0.370
SS-1500	347.86	28.52	77.71	5.50	4.02	1433.2	113.15	16.00	2307.9	325.7	0.347
SS-1600	386.65	34.37	85.39	9.89	8.34	1635.1	167.84	23.74	3035.5	488.8	0.343
SS-1800	409.64	35.46	97.93	17.39	14.84	1829.9	236.78	33.49	3784.2	681.9	0.347
Transit	295.32	34.08	74.90	2.45	0.59	1013.1	65.55	9.27	1711.1	170.3	0.386
Push-750	235.49	35.36	72.61	1.02	-0.83	751.4	39.20	5.54	1390.7	102.9	0.381
Push-900	288.77	34.33	74.10	1.65	0.02	898.1	59.01	8.35	1936.8	171.3	0.344
Push-1000	336.09	34.11	75.95	2.43	0.84	1002.4	78.80	11.15	2367.1	233.7	0.337
Push-1200	419.39	35.68	80.71	5.02	4.30	1196.7	132.00	18.67	3338.1	393.4	0.336

Table 5.17. MV PORT IMPERIAL MANHATTAN Baseline/Post DOC Engine Operating Parameters and Fuel Consumption Percent Changes (December 2005).

Mode	Exh. Temp	Air Temp	Mani. Temp	Exh. BP	Mani. Press	RPM	Fuel Flow, (lb/hr)	Fuel Flow, (gph)	Torque	BHP	BSFC
Idle	-3.3%	-4.6%	-0.6%	0.0%	3.0%	-0.2%	-0.8%	-0.8%	N/A	N/A	N/A
SS-1000	-0.5%	1.5%	0.2%	0.0%	-2.7%	0.4%	-0.8%	-0.8%	-2.3%	-1.9%	1.0%
SS-1200	-1.3%	1.0%	0.0%	0.0%	-2.0%	-0.9%	-4.4%	-4.4%	-4.5%	-5.5%	1.0%
SS-1500	0.0%	0.4%	0.0%	0.0%	-1.0%	0.0%	0.1%	0.1%	-0.4%	-0.3%	0.4%
SS-1600	-0.3%	-1.2%	0.0%	0.1%	-1.1%	0.3%	-0.1%	-0.1%	-1.2%	-0.9%	0.8%
SS-1800	-0.6%	-1.4%	-0.2%	0.1%	-0.8%	0.0%	-0.9%	-0.9%	-15.3%	-1.4%	0.5%
Transit	1.7%	0.0%	-0.1%	0.0%	0.4%	1.1%	6.8%	6.8%	11.9%	13.2%	-7.7%
Push-750	-1.4%	0.1%	0.0%	0.0%	-0.1%	0.7%	-8.4%	-8.4%	-5.4%	-4.6%	-3.6%
Push-900	0.1%	0.9%	0.0%	0.0%	-2.7%	-0.5%	-4.7%	-4.7%	-5.3%	-5.8%	1.1%
Push-1000	-0.4%	0.2%	-0.1%	0.0%	0.2%	0.7%	1.4%	1.4%	-0.5%	0.2%	1.2%
Push-1200	-1.3%	-0.4%	-0.2%	0.0%	0.6%	0.4%	0.1%	0.1%	-0.4%	0.0%	0.1%

Table 5.18. MV PORT IMPERIAL MANHATTAN Baseline/Post DOC Emissions (December 2005).

Baseline DOC Emissions												
Mode	**NO_X (kg/hr)**		**CO (kg/hr)**		**CO_2 (kg/hr)**		**HC (kg/hr)**		**PM2.5 (g/hr)**		**PM10 (g/hr)**	
	Rate	95% C.I.	Rate	95% C.I.	Rate	95% C.I.	Rate	95% C.I.	Rate	95% C.I.	Rate	95% C.I.
Idle	0.318	0.00294	0.0431	0.00241	11.3	0.149	0.198	0.0475	1.79	0.545	1.92	0.542
SS-1000	1.57	0.00373	0.0796	0.00095	59.1	0.270	0.514	0.0846	5.78	1.11	5.47	2.11
SS-1200	1.97	0.0279	0.0924	0.000455	80.1	0.277	0.626	0.0875	6.20	0.276	5.88	0.529
SS-1500	2.97	0.0279	0.153	0.00285	161	0.735	1.07	0.231	11.8	2.17	12.5	2.015
SS-1600	4.14	0.0429	0.266	0.0110	238	1.01	1.67	0.314	16.2	1.59	16.5	2.41
SS-1800	5.13	0.0790	0.658	0.00931	336	0.738	1.26	0.228	21.9	3.89	20.6	3.25
Transit	2.67	0.173	0.138	0.0421	102	8.43	0.302	0.0657	4.32	1.72	4.53	2.07
Push-750	1.85	0.0284	0.0342	0.00328	52.2	0.146	0.0851	0.0478	2.32	0.308	2.47	0.353
Push-900	2.74	0.0653	0.0305	0.00610	81.3	0.0297	0.174	0.00801	2.90	1.36	3.07	1.28
Push-1000	3.21	0.0815	0.0530	0.00433	115	0.0306	0.303	0.00972	2.78	0.677	3.00	0.720
Push-1200	3.70	0.115	0.261	0.0156	191	0.190	0.317	0.0550	7.39	1.22	7.33	1.27
Man.-Out	2.75	0.632	0.367	0.223	120	29.0	0.442	0.133	N/A	N/A	N/A	N/A
Man.-In	1.34	0.503	0.227	0.230	62.8	30.1	0.230	0.136	N/A	N/A	N/A	N/A
Post DOC Emissions												
Mode	**NO_X (kg/hr)**		**CO (kg/hr)**		**CO_2 (kg/hr)**		**HC (kg/hr)**		**PM2.5 (g/hr)**		**PM10 (g/hr)**	
	Rate	95% C.I.	Rate	95% C.I.	Rate	95% C.I.	Rate	95% C.I.	Rate	95% C.I.	Rate	95% C.I.
Idle	0.311	0.00806	0.0594	0.00364	11.6	0.0424	0.0901	0.0116	1.10	0.387	1.16	0.233
SS-1000	1.57	0.00841	0.0880	0.00241	61.5	0.134	0.0800	0.0411	4.31	0.760	4.49	1.16
SS-1200	2.08	0.0205	0.0871	0.0212	88.9	0.103	0.180	0.0428	6.03	0.630	5.93	0.228
SS-1500	2.89	0.0199	0.0328	0.00959	163	0.101	0.337	0.0363	9.96	1.272	10.6	0.485
SS-1600	3.99	0.0908	0.0498	0.00782	242	0.0935	0.516	0.0313	13.3	1.054	13.6	2.30
SS-1800	5.04	0.0476	0.1153	0.00585	345	0.140	0.705	0.0465	18.1	1.69	19.7	1.37
Transit	2.22	0.165	0.0556	0.0469	94.6	6.63	0.178	0.0392	3.75	2.31	3.83	2.17
Push-750	2.02	0.0369	0.0263	0.0133	61.5	0.132	0.0774	0.0350	2.14	0.955	2.47	1.10
Push-900	2.84	0.215	0.0234	0.00777	89.4	0.0560	0.115	0.0215	2.04	1.35	2.19	0.348
Push-1000	2.94	0.0350	0.0149	0.00344	112	0.0296	0.154	0.00764	2.35	0.938	2.24	1.21
Push-1200	3.33	0.0563	0.0370	0.00873	191	0.0938	0.229	0.0316	6.62	1.48	6.62	1.94
Man.-Out	2.56	1.97	0.128	0.0814	116	97.5	0.227	0.160	N/A	N/A	N/A	N/A
Man.-In	1.19	0.703	0.134	0.0615	61.2	24.9	0.108	0.0659	N/A	N/A	N/A	N/A

The pre-DOC and post-DOC test engine parameters did not vary significantly, so that the emissions measured before and after the DOC can be correlated directly. The hourly emissions rates were corrected for fuel consumption. The calculated horsepower did vary significantly, but this was most likely caused by variations in tide and current. The significant values, fuel flow and engine rpm, did vary appreciably from test to test.

Significant differences were noted for the transit mode. The transit mode was a special case, subject to the way the vessel was operated by the vessel captains. For these tests, every effort was made to duplicate the operating profile of the transit mode so that the results could be compared to each other. One way to determine if the transit modes were similar was to measure the time and the fuel consumption. For the transit tests the pre-DOC fuel consumption rate was 70.35 lb/hr, while the rate for the post-DOC test was 65.55 lb/hr, or 6.8% less. Likewise, the time for the pre-DOC test average was 12.1 minutes versus 12.6 minutes, or 4.1% less, for the post-DOC test.

The results of the emissions testing were similar to those measured on the other demonstrations in March 2006 and April 2006. Significant reductions were noted for HC, CO, and PM. The NO_X appeared to have decreased slightly. The DOC exceeded the manufacturer's anticipated reductions of 40-50% CO, 40-50% HC, and 15% PM. Units for those reductions were not given by the manufacturer.

This catalyst was lightly plated and not as active as the one installed on the MV FATHER MYCHAL JUDGE because subsequent testing was with a fuel-borne catalyst. Higher than expected emissions reductions for NO_X were observed for the transit mode, while lower than expected reductions were noted for CO, HC and PM 2.5. The most probable reason for these results was the large variations in air to fuel ratios and cylinder temperatures as the vessel accelerates and decelerates.

In addition to measuring the pre/post DOC emissions, the demonstration was also performed to determine whether or not DOCs can be successfully installed in this or similarly classed or powered vessels without reducing the vessel's capabilities. Again, a particular concern was back pressures that exceeded the manufacturer's limits. The back pressure was measured at full rated speed after the installation of the unit. At that time it was well within the manufacturer's limits and was responsible for increasing the back pressure about 3-4 IWC at full load. After two months of operation, no additional back pressure increase was noted.

Heat generation was another concern. This particular DOC was placed within the lazarette of the vessel. It was fitted within a straight section of pipe between the existing silencer and the transom. Its relatively large size added about 15 ft^2 of additional surface area to the exhaust components that dissipate heat into the space. Normally, on this type of vessel, only the silencer and piping needed to duct the silencer exhaust through the transom operate at the exhaust temperature. The silencer and the exhaust piping were insulated, but their surface temperatures still approach 150ºC. The DOC and its associated piping were insulated. Even so, the heat they added to the space was approximately 3000 btu/hr. Normally, this space is not ventilated, so the heat must be dissipated through the hull and deck to the atmosphere. The location of the DOC, close to the overhead, created a hot spot that caused the passenger deck located above the DOC to be warmer than the rest. This warm location on deck did not impose any safety issues on the vessel's crew or passengers and did not impair its normal operation.

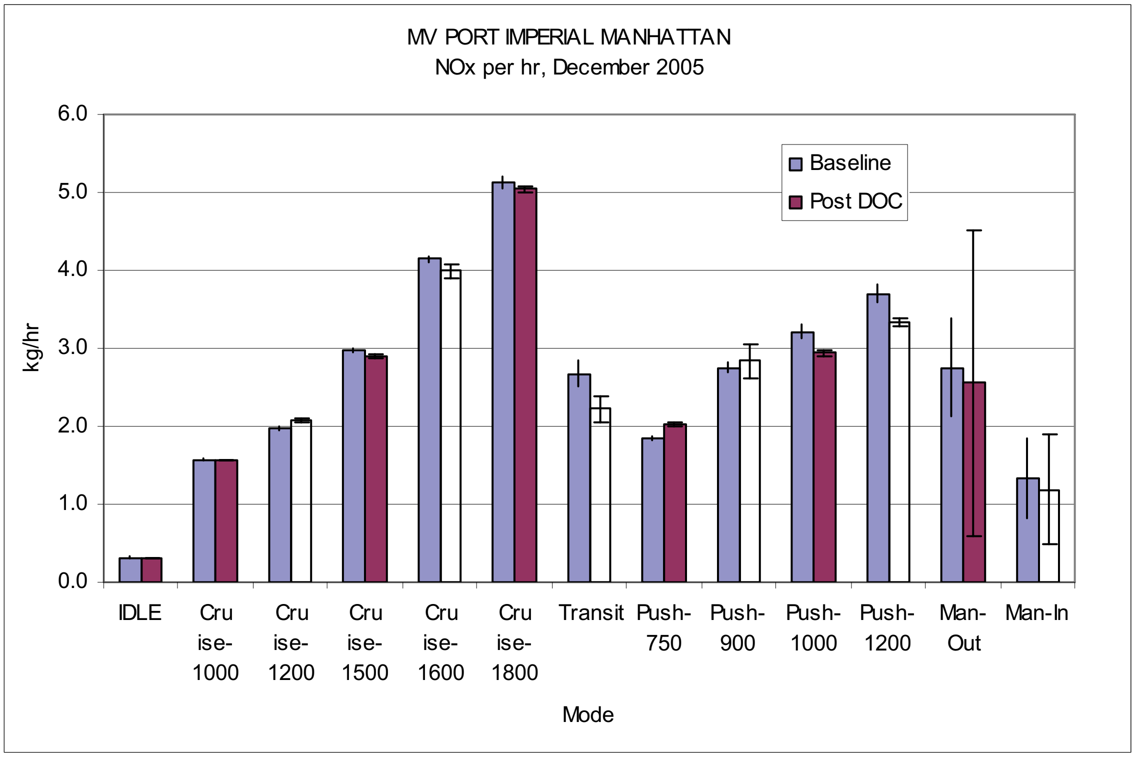


Figure 5.12. NO_X Emissions – MV PORT IMPERIAL MANHATTAN with DOC.

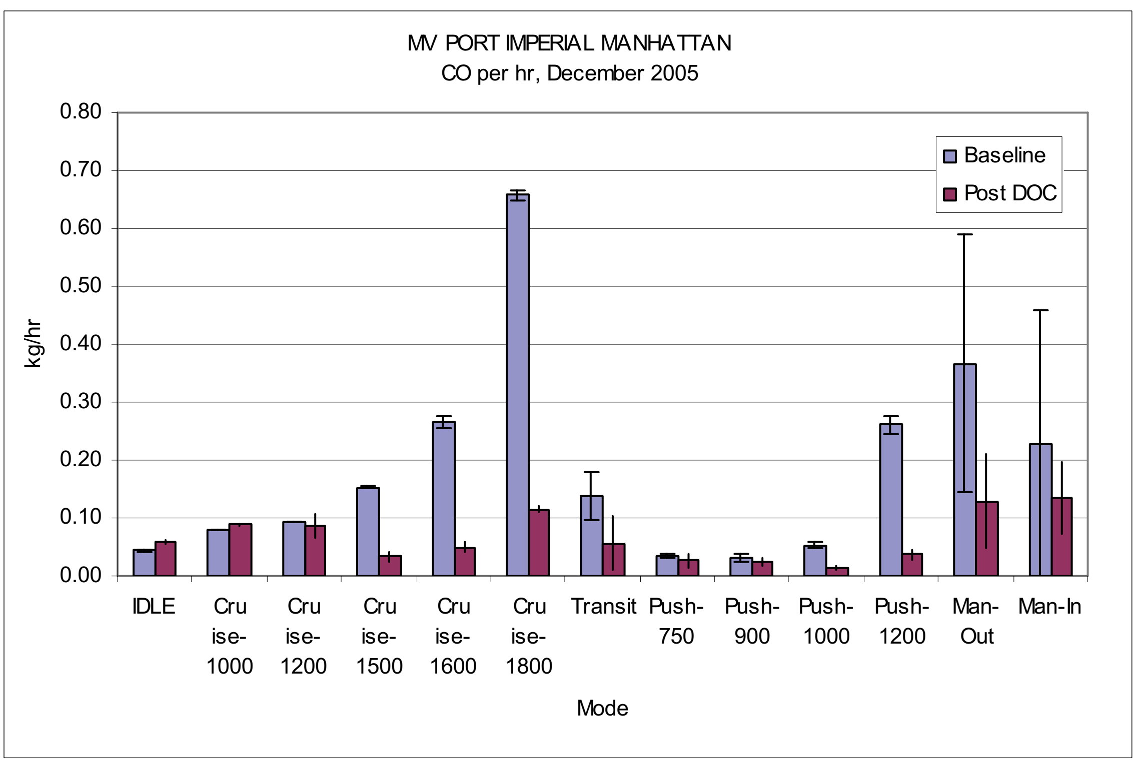


Figure 5.13. CO Emissions – MV PORT IMPERIAL MANHATTAN with DOC.

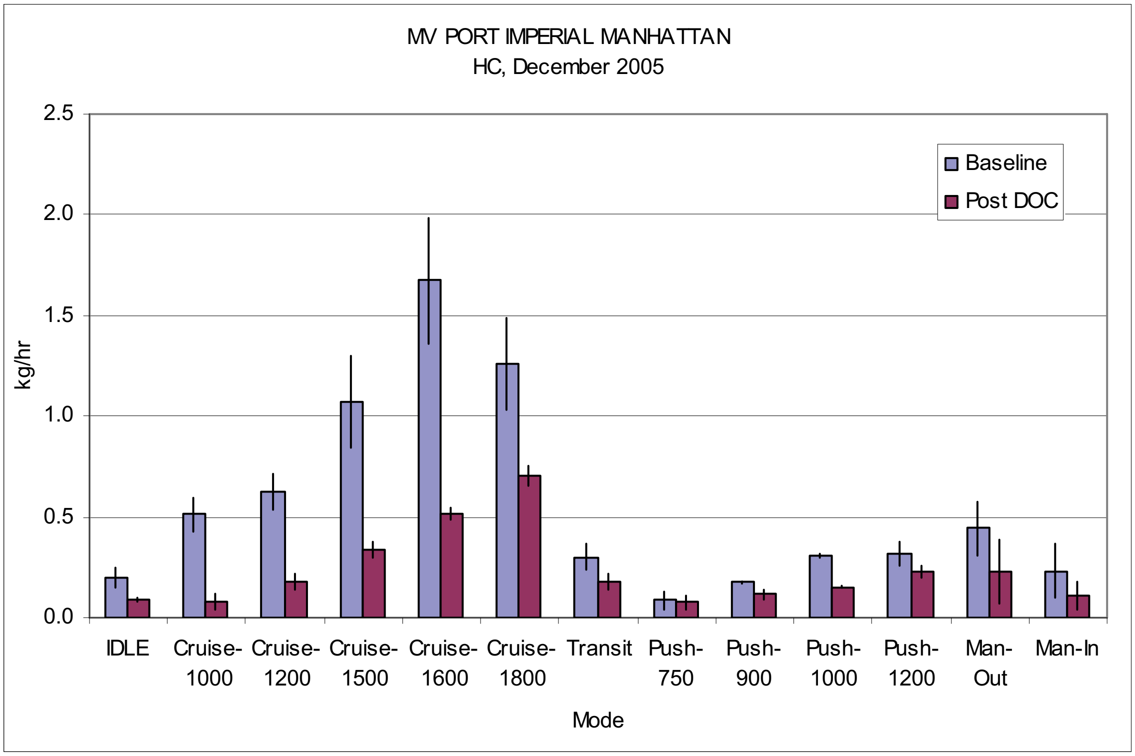


Figure 5.14. HC Emissions – MV PORT IMPERIAL MANHATTAN with DOC.

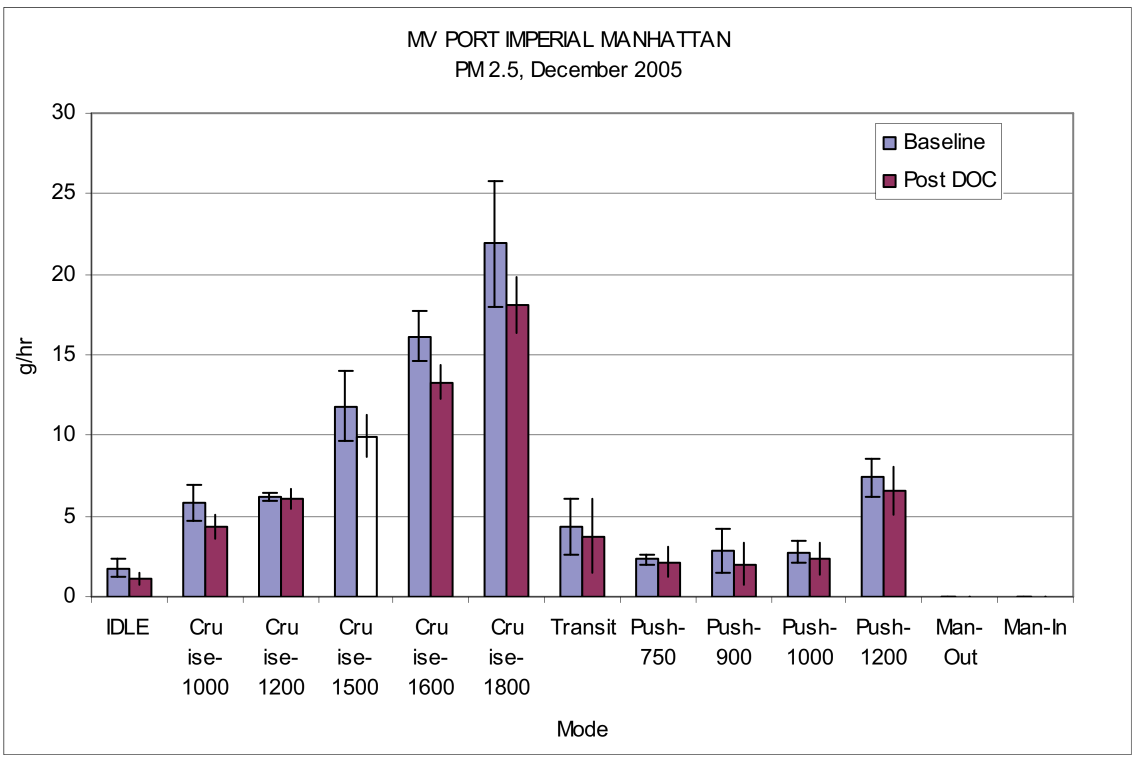


Figure 5.15. PM 2.5 Emissions – MV PORT IMPERIAL MANHATTAN with DOC.

MV PORT IMPERIAL MANHATTAN Engine Operating Parameters and Emissions with FBC

Following the emissions test with just the use of a DOC, another round of testing was done after a fuel-borne catalyst was added to the fuel. The purpose of the catalyst was to enhance the combustion properties of the fuel and, according to the manufacturer, offer some degree of emissions reduction even without a DOC. Tables 5.19 through 5.21 show the engine operating parameters and fuel consumption for these tests. Table 5.22 and Figures 5.16 through 5.19 depict the emissions of the vessel's engine on a per hour basis while using a the FBC. The hourly emissions rates have been corrected for fuel flow. Prior to the emissions test, the fuel tanks of the vessel were treated with the fuel-borne catalyst for a period of approximately eight weeks. According to the catalyst manufacturer, the engine should be treated with the catalyst in excess of two weeks in order to have verifiable emissions results. The catalyst is also supposed to enhance the performance of the installed DOC.

Table 5.19. MV PORT IMPERIAL MANHATTAN with FBC Pre DOC Engine Operating Parameters and Fuel Consumption Rates (March 2006).

Mode	Exh. Temp, C	Air Temp, C	Mani. Temp, C	Exh. BP, IWC	Mani. Press, PSIG	RPM	Fuel Flow, lb/hr	Fuel Flow, gph	Torque, ft-lb	BHP	BSFC, lb/bhp-hr
Idle	95.11	21.78	57.93	0.93	N/A	700.0	9.71	1.37	NMF	NMF	NMF
SS-1000	229.54	26.72	71.35	2.20	N/A	1012.0	42.67	6.04	1008.1	100.5	0.425
SS-1200	265.37	26.77	72.67	2.88	N/A	1142.0	58.46	8.27	1332.0	149.8	0.390
SS-1500	340.01	27.62	77.51	5.60	N/A	1417.0	107.27	15.17	2091.6	291.9	0.368
SS-1600	380.55	29.56	85.28	9.70	N/A	1631.7	162.62	22.83	2834.5	455.5	0.357
SS-1800	408.42	31.07	98.01	16.63	N/A	1830.6	235.79	33.20	3644.4	657.0	0.359
Transit	274.64	28.99	73.50	2.48	N/A	1016.4	53.60	7.58	1482.3	148.4	0.361
Push-750	217.42	21.93	70.83	1.40	N/A	754.0	36.44	5.15	1258.8	93.5	0.390
Push-900	281.92	25.40	72.65	2.27	N/A	901.3	58.08	8.22	1721.8	152.8	0.380
Push-1000	328.52	28.20	74.53	3.08	N/A	1001.7	77.77	11.00	2241.5	221.1	0.352
Push-1200	413.00	31.04	80.13	5.86	N/A	1205.7	134.43	19.01	3297.9	391.6	0.343

Table 5.20. MV PORT IMPERIAL MANHATTAN with FBC Post DOC Engine Operating Parameters and Fuel Consumption Rates (March 2006).

Mode	Exh. Temp, C	Air Temp, C	Mani. Temp, C	Exh. BP, IWC	Mani. Press, PSIG	RPM	Fuel flow, lb/hr	Fuel flow, gph	Torque, ft-lb	BHP	BSFC, lb/bhp-hr
Idle	96.96	22.37	60.35	0.88	0.64	700.0	8.27	1.17	NMF	NMF	NMF
SS-1000	229.42	25.72	71.16	2.19	1.60	1013.0	43.03	6.09	1069.9	106.7	0.403
SS-1200	259.78	26.35	72.14	2.76	2.29	1131.0	57.09	8.08	1339.4	149.2	0.383
SS-1500	339.26	27.56	76.99	5.64	6.08	1428.0	110.01	15.56	2201.0	309.5	0.355
SS-1600	379.51	29.04	85.07	9.93	10.75	1638.3	164.08	23.21	2916.9	470.6	0.349
SS-1800	404.80	29.51	97.69	16.86	17.60	1832.0	232.69	32.91	3663.1	660.9	0.352
Transit	252.57	25.34	71.97	2.15	1.91	975.6	49.38	6.98	1400.7	134.8	0.367
Push-750	222.05	26.11	71.38	1.41	1.03	747.7	35.97	5.09	1280.1	94.3	0.382
Push-900	286.88	28.72	73.14	2.21	1.90	901.3	59.20	8.37	1840.0	163.3	0.363
Push-1000	338.42	31.62	75.28	3.02	2.83	1001.0	79.92	11.30	2265.7	223.4	0.358
Push-1200	421.26	33.06	80.54	5.79	6.73	1205.0	136.08	19.25	3198.2	379.5	0.359

Table 5.21. MV PORT IMPERIAL MANHATTAN with FBC Pre/Post DOC Engine Operating Parameters and Fuel Consumption Changes % (March 2006).

Mode	Exh. Temp	Air Temp	Mani. Temp	Exh. BP	Mani. Press	RPM	Fuel Flow, (lb/hr)	Torque	BHP	BSFC
Idle	-0.5%	-0.2%	-0.7%	0.0%	N/A	0.0%	14.8%	N/A	N/A	N/A
SS-1000	0.0%	0.3%	0.1%	0.0%	N/A	-0.1%	-0.8%	-6.1%	-6.2%	5.1%
SS-1200	1.0%	0.1%	0.2%	0.0%	N/A	1.0%	2.3%	-0.6%	0.4%	1.9%
SS-1500	0.1%	0.0%	0.1%	0.0%	N/A	-0.8%	-2.6%	-5.2%	-6.0%	3.3%
SS-1600	0.2%	0.2%	0.1%	-0.1%	N/A	-0.4%	-0.9%	-2.9%	-3.3%	2.4%
SS-1800	0.5%	0.5%	0.1%	-0.1%	N/A	-0.1%	1.3%	-0.5%	-0.6%	1.9%
Transit	4.0%	1.2%	0.4%	0.1%	N/A	4.0%	7.9%	5.5%	9.1%	-1.5%
Push-750	-0.9%	-1.4%	-0.2%	0.0%	N/A	0.8%	1.3%	-1.7%	-0.8%	2.1%
Push-900	-0.9%	-1.1%	-0.1%	0.0%	N/A	0.0%	-1.9%	-6.9%	-6.9%	4.6%
Push-1000	-1.6%	-1.1%	-0.2%	0.0%	N/A	0.1%	-2.8%	-1.1%	-1.0%	-1.7%
Push-1200	-1.2%	-0.7%	-0.1%	0.0%	N/A	0.1%	-1.2%	3.0%	3.1%	-4.4%

Table 5.22. MV PORT IMPERIAL MANHATTAN with FBC Pre/Post DOC Emissions.

Baseline with FBC DOC Emissions												
Mode	NO_X (kg/hr)		CO (kg/hr)		CO_2 (kg/hr)		HC (kg/hr)		PM2.5 (g/hr)		PM10 (g/hr)	
	Rate	95% C.I.	Rate	95% C.I.	Rate	95% C.I.	Rate	95% C.I.	Rate	95% C.I.	Rate	95% C.I.
Idle	0.444	0.0100	0.0849	0.0185	16.3	0.0245	0.213	0.0105	1.85	2.33	2.40	2.53
SS-1000	1.61	0.0351	0.0992	0.0238	62.3	0.239	0.404	0.0955	6.10	5.14	7.24	4.75
SS-1200	2.08	0.0331	0.0952	0.000749	86.5	0.118	0.497	0.0561	6.56	0.462	5.82	0.888
SS-1500	2.63	0.0805	0.0943	0.0155	145	0.776	0.976	0.3781	9.56	0.430	9.47	1.40
SS-1600	3.64	0.0702	0.150	0.00708	222	0.537	1.73	0.249	14.5	2.78	14.0	3.93
SS-1800	4.44	1.56	0.411	0.0918	336	0.682	1.42	0.231	21.3	7.71	21.6	7.01
Transit	2.30	0.362	0.0611	0.0401	76.3	4.26	0.217	0.0159	3.81	0.714	3.74	0.832
Push-750	1.93	0.0425	0.0424	0.00100	52.6	0.378	0.101	0.0535	2.14	0.369	1.95	0.983
Push-900	2.81	0.661	0.0429	0.00876	85.7	0.0842	0.167	0.0101	3.33	4.55	3.21	1.82
Push-1000	3.20	0.0360	0.0502	0.000580	108	0.187	0.219	0.0267	2.76	1.69	2.79	0.0648
Push-1200	4.10	0.0598	0.182	0.00956	196	0.535	0.386	0.0740	6.52	6.44	6.65	2.70
Man.-Out	1.00	0.899	0.0343	0.0117	38.6	35.9	0.174	0.119	N/A	N/A	N/A	N/A
Man.-In	0.487	0.706	0.0270	0.0396	25.1	11.6	0.144	0.196	N/A	N/A	N/A	N/A
Post DOC Emissions with FBC												
Mode	NO_X (kg/hr)		CO (kg/hr)		CO_2 (kg/hr)		HC (kg/hr)		PM2.5 (g/hr)		PM10 (g/hr)	
	Rate	95% C.I.	Rate	95% C.I.	Rate	95% C.I.	Rate	95% C.I.	Rate	95% C.I.	Rate	95% C.I.
Idle	0.296	0.0228	0.0537	0.00957	12.1	0.066	0.0480	0.0502	1.21	1.52	1.17	1.80
SS-1000	1.54	0.00499	0.0745	0.00966	63.1	0.291	0.0824	0.0209	4.29	1.47	4.43	1.29
SS-1200	1.86	0.0444	0.0871	0.00120	82.1	0.224	0.161	0.0249	5.75	3.54	4.98	3.79
SS-1500	2.69	0.0978	0.0352	0.0551	153	0.253	0.278	0.0373	9.99	7.10	9.34	4.73
SS-1600	3.61	0.142	0.0339	0.00192	231	0.598	0.436	0.103	13.8	17.7	12.9	17.6
SS-1800	4.68	0.120	0.0895	0.0200	331	0.580	0.652	0.106	18.7	4.38	18.3	11.6
Transit	2.04	0.835	0.0459	0.00417	70.7	22.7	0.107	0.0607	2.70	0.808	2.56	0.942
Push-750	1.81	0.0531	0.0321	0.00353	51.3	0.462	0.0553	0.0396	1.73	0.734	1.65	0.179
Push-900	2.74	0.302	0.0337	0.00361	88.8	0.606	0.124	0.0520	2.03	1.26	2.12	0.880
Push-1000	2.83	0.0694	0.0109	0.00686	114	0.496	0.168	0.0431	2.08	1.39	2.24	0.981
Push-1200	3.88	0.167	0.0139	0.00494	200	1.02	0.278	0.0876	7.50	4.77	7.00	6.06
Man.-Out	0.704	1.37	0.0778	0.290	36.7	90.0	0.0760	0.144				
Man.-In	0.654	0.854	0.0365	0.0362	28.5	35.7	0.0834	0.0360				

As with the testing performed in December of 2005, the engine parameters were logged and averaged for each emissions test interval. The modal values between each pre- and post-DOC test corresponded very well.

The results of the emissions testing were similar to those measured on the other demonstrations in December 2005, March 2006, and April 2006. Significant reductions were noted for HC, CO, and PM. The NO_X appeared to have slightly decreased. The DOC alone exceeded the manufacturer's anticipated reductions of 40-50% CO, 40-50% HC, and 15% PM. With the addition of the FBC, the anticipated reductions were 5% NO_X, 40-50% CO, 40-50% HC, and 30-40% PM. Units for those reductions were not given by the manufacturer nor were the loads at which they were attained.

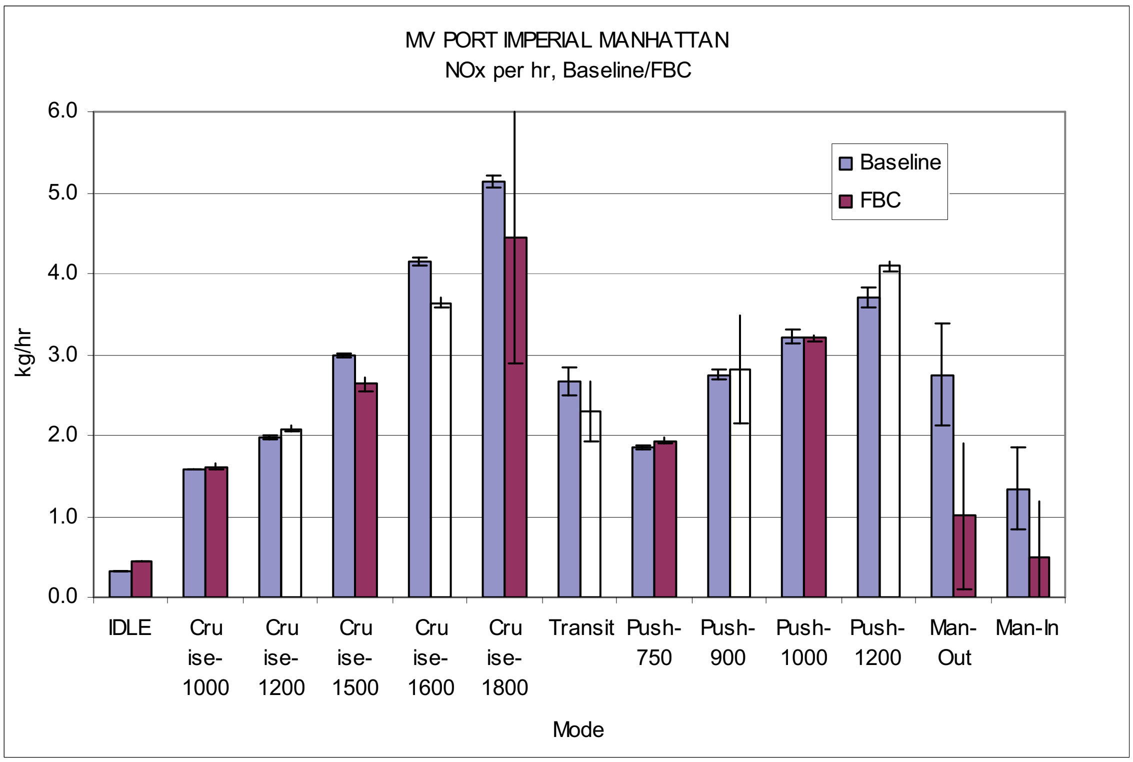


Figure 5.16. NO_X Emissions – MV PORT IMPERIAL MANHATTAN with FBC.

As can be seen by Figures 5.16 through 5.19, significant reductions of $NO_{x,}$ CO were noted while using just the FBC while the HC and PM 2.5 emissions stayed relatively constant throughout the engine's operating range. This result was not wholly expected since it was thought that the product would have reduced the PM emissions. The EPA verified this product when used in conjunction with a DOC.

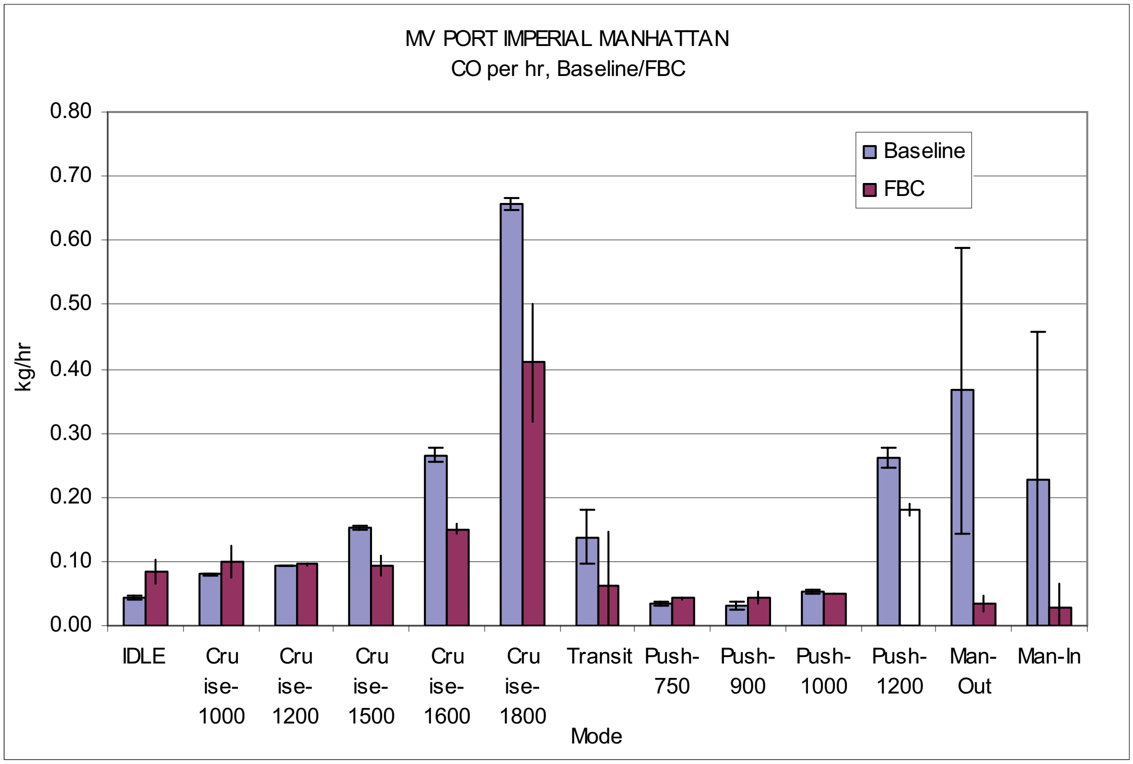


Figure 5.17. CO Emissions – MV PORT IMPERIAL MANHATTAN with FBC.

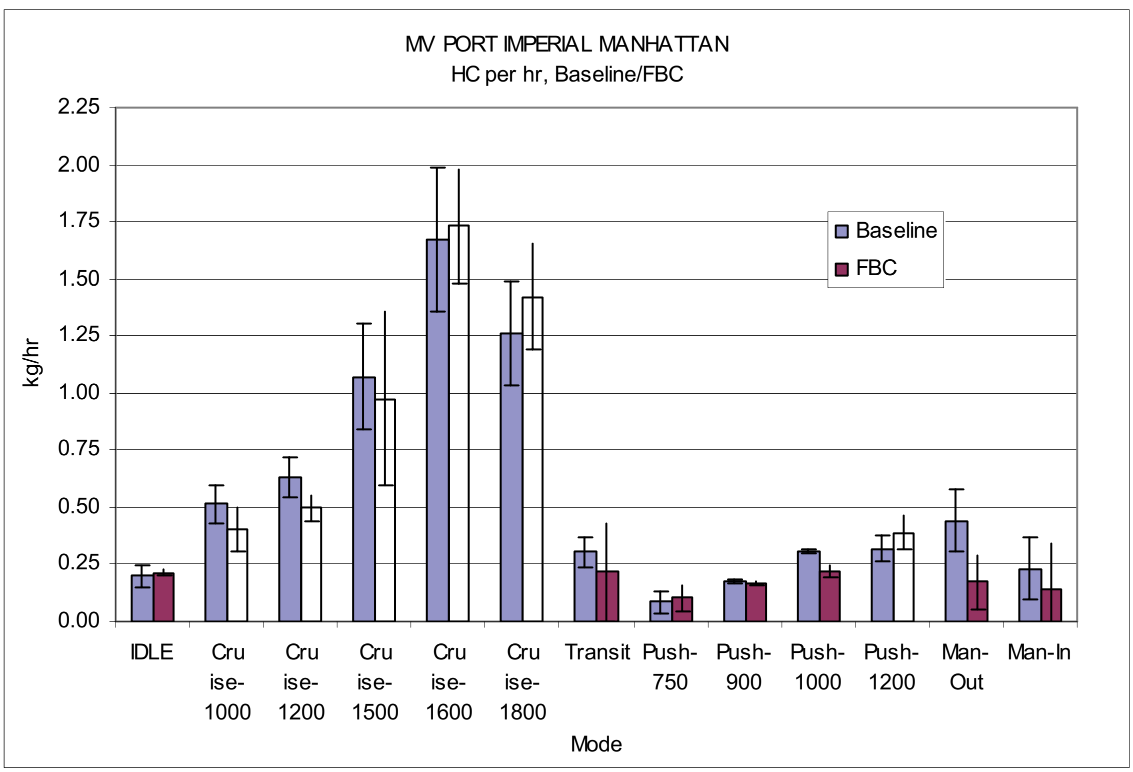


Figure 5.18. HC Emissions – MV PORT IMPERIAL MANHATTAN with FBC.

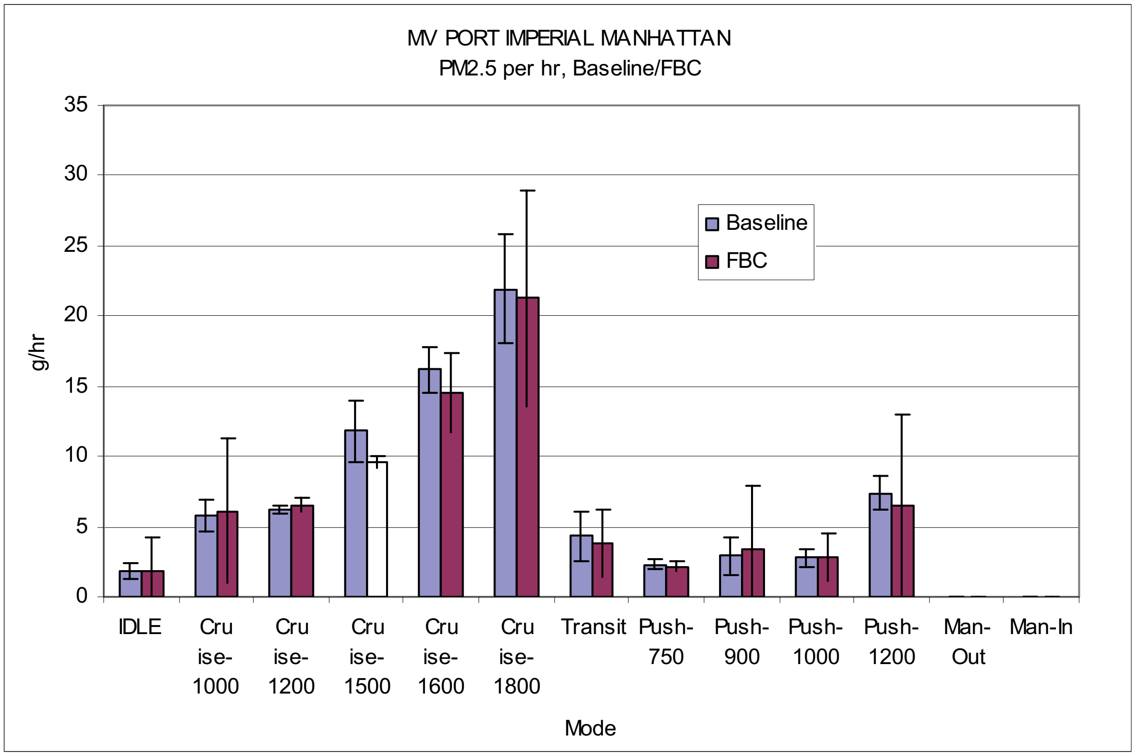


Figure 5.19. PM 2.5 Emissions – MV PORT IMPERIAL MANHATTAN with FBC.

MV PORT IMPERIAL MANHATTAN Engine Operating Parameters and Emissions with and without FBC

Finally, a comparison was made between the engine operating parameters and emissions tests of the December 2005 baseline test and the March 2006 post DOC with FBC test. The object of this comparison was to quantify, if possible, any additional emissions gains that might be achieved while using the FBC concurrent with a DOC. Table 5.23 and 5.24 and Figure 5.20 depict the change in emissions of the vessel's engine on a per hour basis while using a DOC in conjunction with an FBC as compared to the same vessel and engine without the FBC and the DOC.

Table 5.23. MV PORT IMPERIAL MANHATTAN Baseline/Post DOC with FBC Engine Parameter Comparison (December 2005/March 2006).

Mode	Exh. Temp	Air Temp	Mani. Temp	Exh. BP	Mani. Press	RPM	Fuel Flow, (lb/hr)	Fuel Flow, (gph)	Torque	BHP	BSFC
Idle	2.1%	1.1%	2.7%	-0.1%	-12.0%	-0.1%	-1.9%	-1.9%	N/A	N/A	N/A
SS-1000	-1.6%	0.7%	0.2%	-0.1%	-13.4%	-1.3%	-2.8%	-2.8%	-0.2%	-1.5%	-1.3%
SS-1200	0.0%	0.9%	0.1%	-0.1%	-13.7%	-0.5%	-0.9%	-0.9%	2.1%	1.6%	-2.5%
SS-1500	1.4%	0.7%	0.2%	0.0%	-12.1%	0.4%	2.9%	2.9%	4.3%	4.7%	-1.9%
SS-1600	0.8%	0.5%	0.1%	0.1%	-11.6%	0.1%	2.2%	2.2%	2.7%	2.9%	-0.7%
SS-1800	0.1%	0.5%	-0.1%	0.2%	-10.2%	-0.1%	0.8%	0.8%	-11.6%	1.7%	-0.9%
Transit	9.1%	2.8%	0.8%	0.1%	-8.2%	4.8%	29.8%	29.8%	27.9%	31.2%	-2.2%
Push-750	1.3%	3.1%	0.3%	-0.1%	-13.5%	1.2%	0.5%	0.5%	3.0%	4.2%	-3.8%
Push-900	0.4%	2.7%	0.3%	-0.1%	-15.8%	-0.9%	-5.0%	-5.0%	0.0%	-0.9%	-4.1%
Push-1000	-0.8%	1.0%	0.1%	-0.1%	-12.6%	0.8%	0.0%	0.0%	3.8%	4.6%	-4.9%
Push-1200	-1.6%	0.4%	-0.2%	-0.2%	-12.2%	-0.2%	-3.0%	-3.0%	3.8%	3.5%	-6.8%

Despite the relatively long, three-month period between the tests, the engine operating parameters were very similar. The ambient conditions were also similar. Significant reductions in PM 2.5, HC, and CO emissions were noted for most of the steady-state operations. Small gains were noted for NO_X. The emissions gains were also extended across the load range. The hourly emissions rates were normalized for fuel flows. The emissions reductions for the transit mode cannot be accurately ascertained due to the large fuel flow and power difference between the tests.

According to the manufacturer, the DOC required approximately 10 hours of seasoning before the emissions reductions would be verifiable. The DOC had accumulated about 24 hours of operation before being tested. Moreover, the full effect of the fuel-borne catalyst would not be realized until it had been in use for over two weeks.

One advertised benefit of using the FBC was its claimed positive effect upon fuel consumption. The compiled data and analysis did not reveal any statistically significant gain or loss in fuel economy. The tests were configured to collect emissions data and so were not structured to have any repeatability between weather, river currents, or any other external factors. However, a reduction in the amount of CO was noted when the baseline and Pre-DOC + FBC emissions tests were compared. A reduction in CO production usually means that the combustion process is more efficient. Moreover, the very nature of the FBC suggests that the engine condition, both at the time of the start of the treatment and during the tests, will have an effect upon the treatment's performance. No attempt was made to bring the engine to a "baseline" condition before or after the FBC treatment and any emissions tests.

Table 5.24. MV PORT IMPERIAL MANHATTAN Baseline/FBC/ post DOC with FBC (March 2006) Emissions Comparison.

	NOx			CO			HC			PM 2.5		
Mode	DOC	FBC	DOC + FBC	DOC	FBC	DOC + FBC	DOC	FBC	DOC + FBC	DOC	FBC	DOC + FBC
IDLE	2.3%	-39.6%	7.1%	-37.7%	-96.8%	-24.4%	54.5%	-7.5%	75.8%	38.6%	-3.2%	32.4%
Cruise-1000	0.6%	-2.0%	2.0%	-10.6%	-24.6%	6.4%	84.4%	21.4%	84.0%	25.5%	-5.6%	25.8%
Cruise-1200	-5.5%	-5.8%	5.6%	5.8%	-3.0%	5.8%	71.2%	20.6%	74.2%	2.8%	-5.7%	7.3%
Cruise-1500	2.8%	11.7%	9.6%	78.5%	38.4%	77.0%	68.5%	8.9%	74.0%	15.6%	19.0%	15.4%
Cruise-1600	3.7%	12.2%	13.0%	81.3%	43.4%	87.2%	69.2%	-3.4%	73.9%	17.7%	10.0%	14.7%
Cruise-1800	1.8%	13.5%	8.8%	82.5%	37.6%	86.4%	44.1%	-12.6%	48.4%	17.4%	2.9%	14.7%
Transit	16.9%	14.1%	23.7%	59.7%	55.7%	66.7%	41.0%	28.2%	64.8%	13.2%	11.8%	37.5%
Push-750	-9.1%	-4.2%	2.7%	23.1%	-23.9%	6.2%	9.1%	-18.9%	35.0%	7.7%	8.0%	25.5%
Push-900	-3.4%	-2.5%	0.3%	23.4%	-40.7%	-10.4%	33.7%	3.8%	28.5%	29.5%	-15.2%	30.0%
Push-1000	8.6%	0.4%	11.9%	71.8%	5.2%	79.5%	49.3%	27.8%	44.6%	15.4%	0.9%	25.2%
Push-1200	10.1%	-10.5%	-4.8%	85.8%	30.4%	94.7%	27.9%	-21.8%	12.3%	10.4%	11.7%	-1.6%

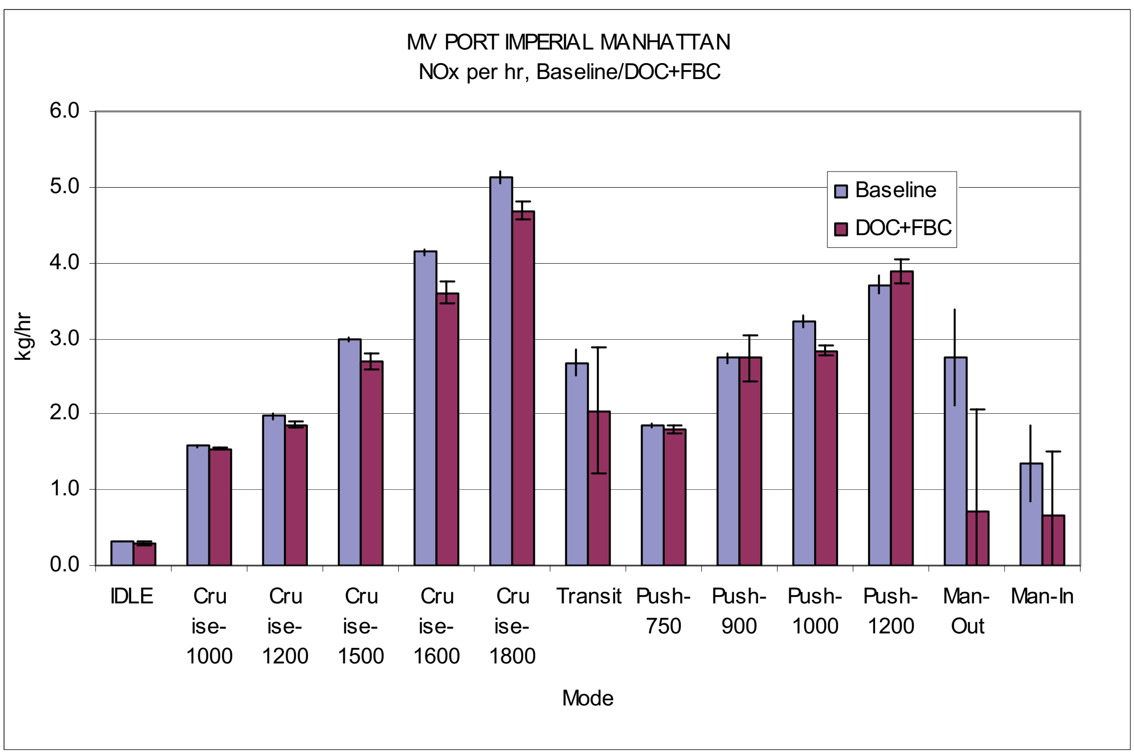


Figure 5.20. NO_x Emissions - MV PORT IMPERIAL MANHATTAN Baseline/Post DOC with FBC.

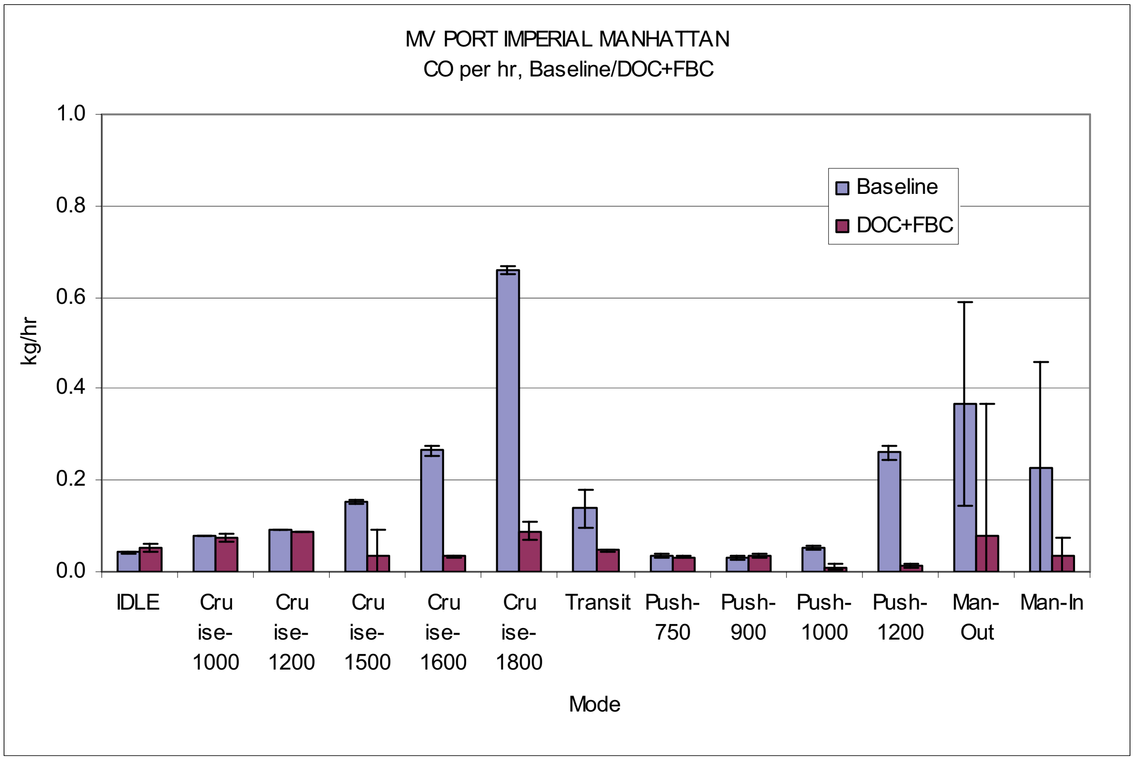


Figure 5.21. CO Emissions - MV PORT IMPERIAL MANHATTAN Baseline/Post DOC with FBC.

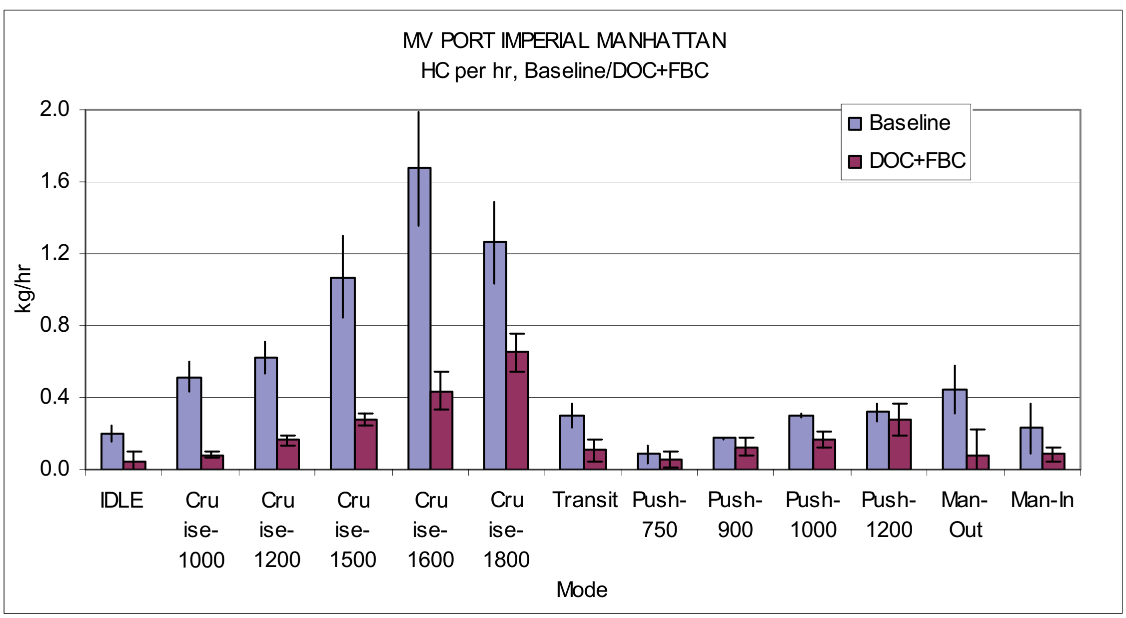


Figure 5.22. HC Emissions - MV PORT IMPERIAL MANHATTAN Baseline/Post DOC with FBC.

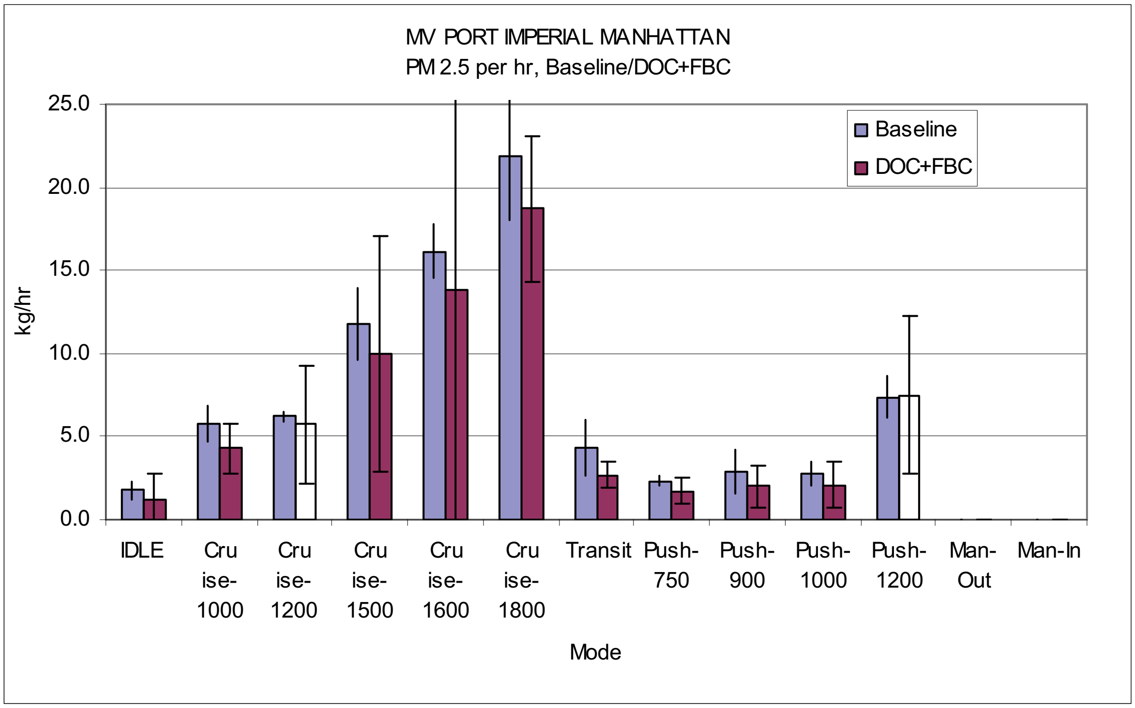


Figure 5.23. PM 2.5 Emissions - MV PORT IMPERIAL MANHATTAN Baseline/Post DOC with FBC.

Table 5.24 and Figures 5.24 through 5.27 depict the emissions rate change as compared to the baseline values for each of the 3 emissions control technologies or combinations that were demonstrated on the MV Port Imperial Manhattan. From the tables and figures it is it can be seen that alone the FBC was responsible for small but significant decreases in $NO_{X,}$ (1.4% average of steady state modes excluding idle) CO (7.0% average of steady state modes excluding idle),and HC (2.9% average of steady state modes excluding idle) was reduced in intermediate loads but increased for higher loads. PM 2.5 (2.9% average of steady state modes excluding idle) may have been reduced but the statistical error of the data sets makes it impossible to draw any conclusions. The FBC enhanced the performance of the DOC in removing NOx (5.5% vice 1.1% average of steady state modes excluding idle), and HC(52.8% vice 50.8% average of steady state modes excluding idle). PM 2.5 was also reduced (17.4% vice 15.8% average of steady state modes excluding idle) but the reduction was far less than the statistical error of the PM measurements so the reduction is not conclusive.

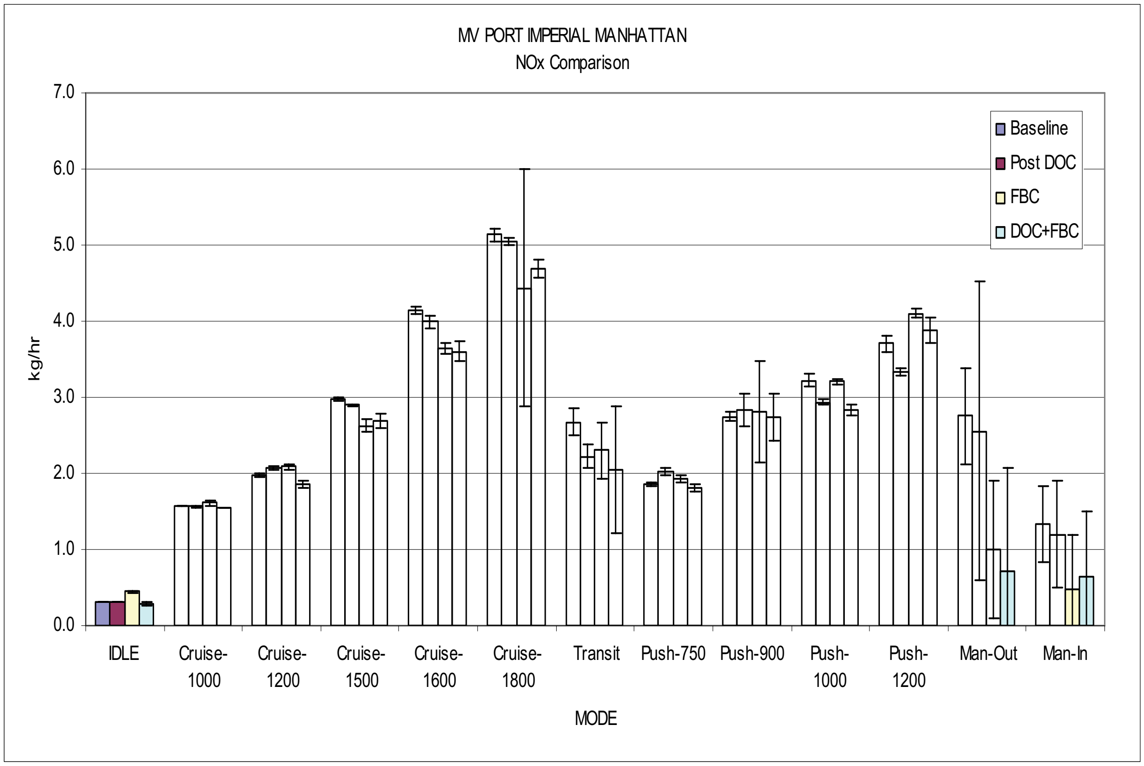


Figure 5.24. NO_x Emissions - MV PORT IMPERIAL MANHATTAN Baseline/DOC/FBC/ DOC + FBC.

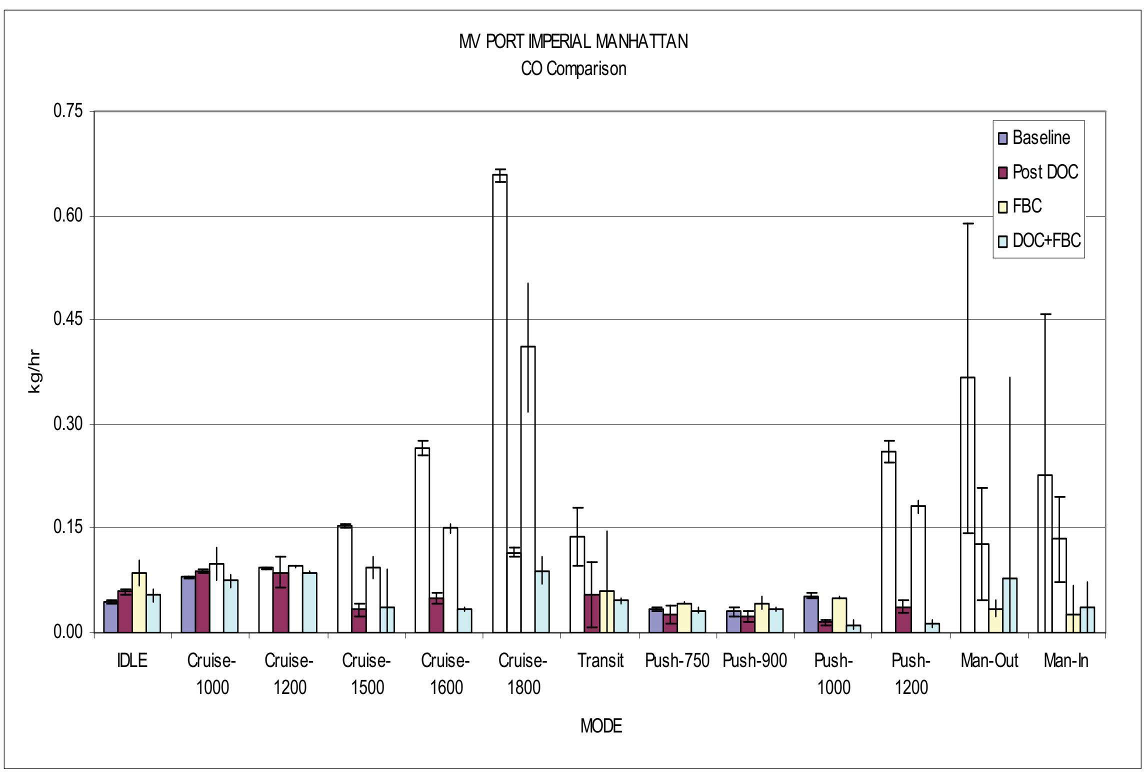


Figure 5.25. CO Emissions - MV PORT IMPERIAL MANHATTAN Baseline/DOC/FBC/ DOC + FBC.

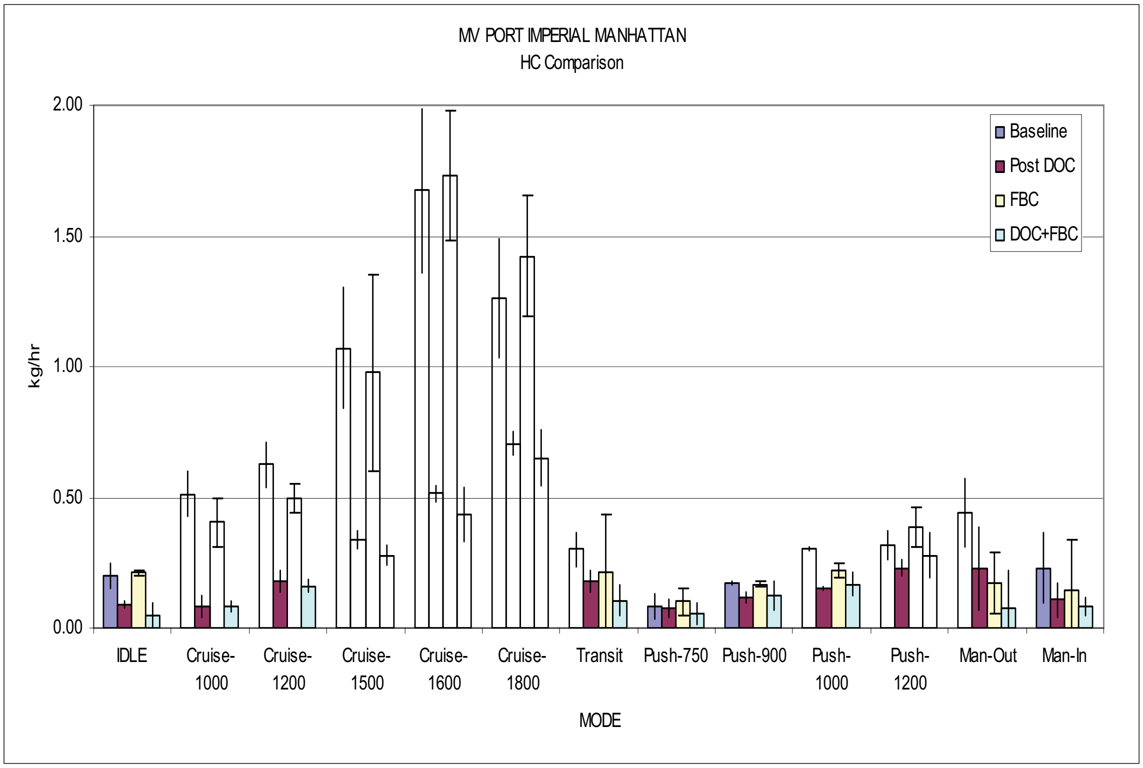


Figure 5.26. HC Emissions - MV PORT IMPERIAL MANHATTAN Baseline/DOC/FBC/ DOC + FBC.

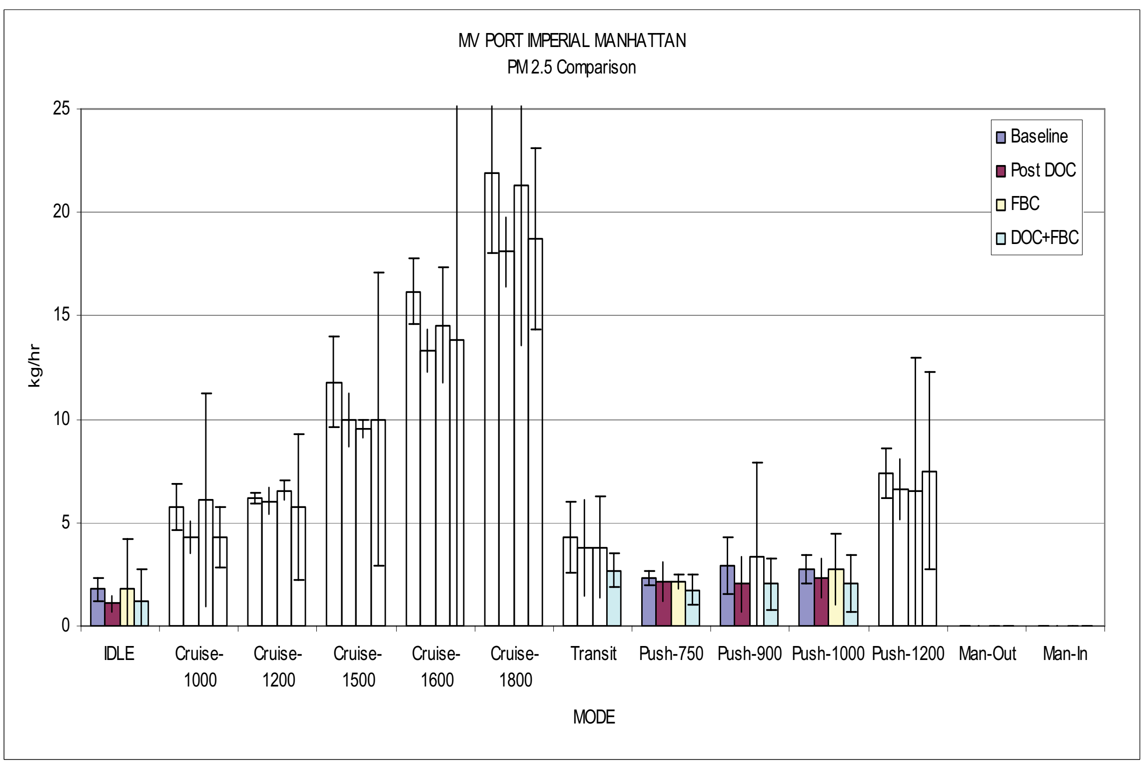


Figure 5.27. PM 2.5 Emissions - MV PORT IMPERIAL MANHATTAN Baseline/DOC/FBC/ DOC + FBC.

MV JOHN KEITH ENGINE Operating Parameters and Emissions

The engine operating parameters and fuel flow rates used to calculate the emissions rates for the MV JOHN KEITH are presented Tables 5.25 through 5.27. The volumetric fuel flow is based upon the specific gravity listed on the fuel analysis and derived from the fuel mass flows measured during the emissions test. In actual practice, the volumetric fuel flows may be greater or less than those stated, depending upon the temperature and specific gravity of the fuel. The MV JOHN KEITH was tested twice for emissions: two tests in April 2006 that measured the emissions before and after the demonstration DOC. The LSD/ULSD emissions tests were performed on a sister vessel, the MV ED ROGOWSKY. The results of the DOC demonstration emissions tests of April 2006 are presented here.

Table 5.25. MV JOHN KEITH Baseline Engine Operating Parameters (April 2006).

Mode	Exh. Temp, C	Air Temp, C	Exh BP, IWC	RPM	Fuel Rate, lb/hr	Torque, ft-lb	SHP	BHP	BSFC, lb/bhp-hr
IDLE 1	80.5	31.4	0.38	599.9	4.2	N/A			
SS- 1000	178.5	33.9	0.41	997.9	22.8	N/A	61.1	64.3	0.354
SS- 1350	259.9	31.9	0.88	1353.5	51.0	N/A	144.5	152.1	0.335
SS- 1700	265.8	42.0	-0.06	1702.5	91.6	N/A	312.2	328.3	0.287
SS- 1950	254.5	47.1	-3.58	1944.2	123.4	N/A	363.3	382.5	0.323
SS- 2150	265.8	49.7	-3.06	2148.6	163.3	N/A	431.7	454.4	0.360
Transit	260.6	46.9	-0.07	1303.0	63.2	N/A	177.1	186.5	0.339
Push- 820	201.5	45.2	0.51	839.7	22.7	N/A	57.4	60.4	0.376
Push- 1000	258.5	45.3	0.56	1006.9	36.4	N/A	108.6	114.4	0.318
Push- 1200	331.4	41.1	-0.07	1205.7	63.6	N/A	194.6	204.8	0.311

Table 5.26. MV JOHN KEITH Post DOC Engine Operating Parameters (April 2006).

Mode	Exh. Temp, C	Air Temp, C	Exh BP, IWC	RPM	Fuel Rate, lb/hr	Torque, ft-lb	SHP	BHP	BSFC, lb/bhp-hr
IDLE 1	78.0	24.3	0.16	642.3	4.57	N/A	N/A	N/A	N/A
SS-1000	179.8	31.1	0.58	1005.7	23.13	N/A	62.2	65.5	0.353
SS-1350	258.3	30.0	0.58	1354.3	51.10	N/A	144.8	152.4	0.335
SS-1700	264.5	37.5	0.57	1703.3	91.75	N/A	272.7	287.0	0.320
SS-1950	253.6	39.0	-3.49	1955.7	124.9	N/A	367.3	386.6	0.323
SS-2150	259.2	35.0	-3.45	2149.7	163.6	N/A	423.1	445.4	0.367
Transit	256.9	43.4	-0.02	1282.4	61.45	N/A	171.3	180.3	0.341
Push-820	200.2	39.5	0.42	822.3	22.69	N/A	55.2	58.1	0.391
Push-1000	273.8	40.0	0.67	1001.7	35.80	N/A	106.8	112.4	0.318
Push-1200	338.1	38.1	1.10	1205.0	63.63	N/A	194.6	204.8	0.311

Table 5.27. MV JOHN KEITH Baseline/Post DOC Engine Operating Parameters Change, % (April 2006).

Mode	Exhaust Temp	Air Inlet Temp	Exhaust Back Press.	RPM	Fuel Rate	Torque	SHP	BHP	BSFC
IDLE 1	0.7%	2.3%	0.1%	-7.1%	-8.8%	N/A	N/A	N/A	N/A
SS-1000	-0.3%	0.9%	0.0%	-0.8%	-1.6%	N/A	-1.8%	-1.8%	0.2%
SS-1350	0.3%	0.6%	0.1%	-0.1%	-0.2%	N/A	-0.2%	-0.2%	0.0%
SS-1700	0.2%	1.5%	-0.2%	-0.1%	-0.1%	N/A	12.7%	12.6%	-11.3%
SS-1950	0.2%	2.5%	0.0%	-0.6%	-1.2%	N/A	-1.1%	-1.1%	-0.1%
SS-2150	1.2%	4.6%	0.1%	-0.1%	-0.2%	N/A	2.0%	2.0%	-2.2%
Transit	0.7%	1.1%	0.0%	1.6%	2.8%	N/A	3.3%	3.3%	-0.4%
Push-820	0.3%	1.8%	0.0%	2.1%	0.0%	N/A	3.8%	3.8%	-4.0%
Push-1000	-2.9%	1.7%	0.0%	0.5%	1.5%	N/A	1.7%	1.7%	-0.2%
Push-1200	-1.1%	0.9%	-0.3%	0.1%	0.0%	N/A	0.0%	0.0%	0.0%

The engine operating parameters correlated well between tests. The torsion meter malfunctioned, so the values for shaft torque, engine power, and specific fuel consumption were derived from manufacturer's curves and curves from a sea trial conducted in 2004 on a sister vessel. Use of the derived engine power values should only impact the absolute emissions measurements. The change between the DOC inlet and outlet should remain the same.

Table 5.28. MV JOHN KEITH Baseline/Post DOC Emissions (April 2006).

Baseline with FBC DOC Emissions												
Mode	NO_X (kg/hr)		CO (kg/hr)		CO_2 (kg/hr)		HC (kg/hr)		PM2.5 (g/hr)		PM10 (g/hr)	
	Rate	95% C.I.	Rate	95% C.I.	Rate	95% C.I.	Rate	95% C.I.	Rate	95% C.I.	Rate	95% C.I.
Idle	0.112	0.00658	0.0612	0.00560	5.90	0.00823	0.0211	0.00349	1.22	0.735	1.30	0.111
SS-1000	0.702	0.0452	0.0843	0.00631	32.6	0.0383	0.0611	0.00942	5.64	1.10	5.43	0.978
SS-1350	0.844	0.0259	0.144	0.00796	73.1	0.0348	0.119	0.00816	15.3	6.89	15.6	1.83
SS-1700	0.962	0.0309	0.150	0.00815	131	0.0714	0.231	0.0231	38.2	2.17	37.5	2.07
SS-1950	1.30	0.0130	0.147	0.00795	177	0.0476	0.352	0.0150	38.0	5.53	38.5	38.3
SS-2150	2.05	0.112	0.162	0.00366	234	0.0830	0.383	0.0244	47.7	71.4	49.2	4.06
Transit	1.61	0.267	0.138	0.0406	90.7	8.55	0.140	0.0177	13.5	6.24	13.7	28.1
Push-820	0.778	0.0754	0.0465	0.00165	32.6	0.0340	0.0476	0.0101	2.37	0.427	2.50	2.24
Push-1000	0.817	0.0612	0.0515	0.00293	52.2	0.490	0.0737	0.00173	4.06	3.70	3.80	3.95
Push-1200	1.18	0.0822	0.0667	0.00905	91.4	0.0190	0.151	0.00833	13.3	14.4	13.1	13.9
Man.-Out	2.04	1.92	0.252	0.117	118	50.0	0.583	0.379	N/A	N/A	N/A	N/A
Man.-In	0.378	0.393	0.0403	0.0431	33.1	8.73	0.0892	0.0746	N/A	N/A	N/A	N/A
Post DOC Emissions with FBC												
Mode	NO_X (kg/hr)		CO (kg/hr)		CO_2 (kg/hr)		HC (kg/hr)		PM2.5 (g/hr)		PM10 (g/hr)	
	Rate	95% C.I.	Rate	95% C.I.	Rate	95% C.I.	Rate	95% C.I.	Rate	95% C.I.	Rate	95% C.I.
Idle	0.131	0.00861	0.0974	0.0227	6.98	0.0327	0.0127	0.0027	0.989	0.233	1.09	1.76
SS-1000	0.735	0.0399	0.0583	0.0134	33.7	0.0263	0.0277	0.00763	0.708	1.97	0.825	0.751
SS-1350	0.882	0.0321	0.00712	0.00198	73.6	0.0355	0.0595	0.0105	5.48	1.65	5.53	0.56
SS-1700	1.11	0.0658	0.0324	0.00674	132	0.227	0.0878	0.0727	28.6	13.2	28.4	9.67
SS-1950	1.61	0.0333	0.0868	0.00883	182	0.141	0.131	0.0417	30.7	1.02	29.5	0.613
SS-2150	2.20	0.0235	0.0939	0.00766	236	0.149	0.218	0.0507	29.8	46.5	30.6	44.3
Transit	1.65	0.0986	0.0523	0.0213	88.5	7.33	0.0585	0.00555	9.84	4.33	9.34	7.94
Push-820	0.789	0.0132	0.00962	0.00188	32.7	0.0298	0.0200	0.0101	1.41	0.687	1.42	0.802
Push-1000	0.901	0.0152	0.00148	0.000717	52.2	0.0181	0.0324	0.00569	2.85	0.264	2.79	0.179
Push-1200	1.31	0.0303	0.00337	0.00259	91.8	0.00879	0.0490	0.00336	11.7	5.15	11.4	3.07
Man.-Out	1.31	1.85	0.0647	0.0977	87.1	63.0	0.160	0.219	N/A	N/A	N/A	N/A
Man.-In	0.217	0.187	0.0234	0.0183	33.2	38.1	0.0183	0.0145	N/A	N/A	N/A	N/A

The results of the emissions testing were similar to those measured on the other demonstrations in December of 2005 and March 2006. Table 5.28 and Figures 5.21 though 5.25 display these results. Once again significant reductions were noted for HC, CO, and PM. However, the NO_X appeared to increase. According to the catalyst manufacturer, the DOC should have been NO_X neutral, so the increase was caused by something else. Two possible causes are a malfunctioning or faulty test cell or something in the fuel or exhaust that would increase the NO_X. The calibration of the test cell was checked and found to be adequate. The cause of the increased NO_X has yet to be determined.

The DOC did not achieve the manufacturer's anticipated reductions of 80% CO, 70 % HC, and 15% PM, but those reductions are based on a CO inlet of .20 g/bhp-hr, HC inlet of 0.068 g/bhp-hr, and PM inlet of 32.46 g/hr. During the actual emissions test, these values were somewhat different. The inlet CO ranged from 0.33 to 1.31 g/bhp-hr. The HC ranged from 0.64 to 0.95 g/bhp-hr and the PM from 1.22 to 47.74 g/hr. The average CO and HC reductions on a g/bhp-hr basis were 68.6% and 56.0%, respectively. The average PM reduction was 40.9% on a g/hr basis. While the anticipated and actual emissions reductions vary, it should be noted that the actual engine emissions varied from the rates the reductions were based on. The engine had been replaced just prior to the April 2006 emissions tests and had accumulated less than 10 hours of operation.

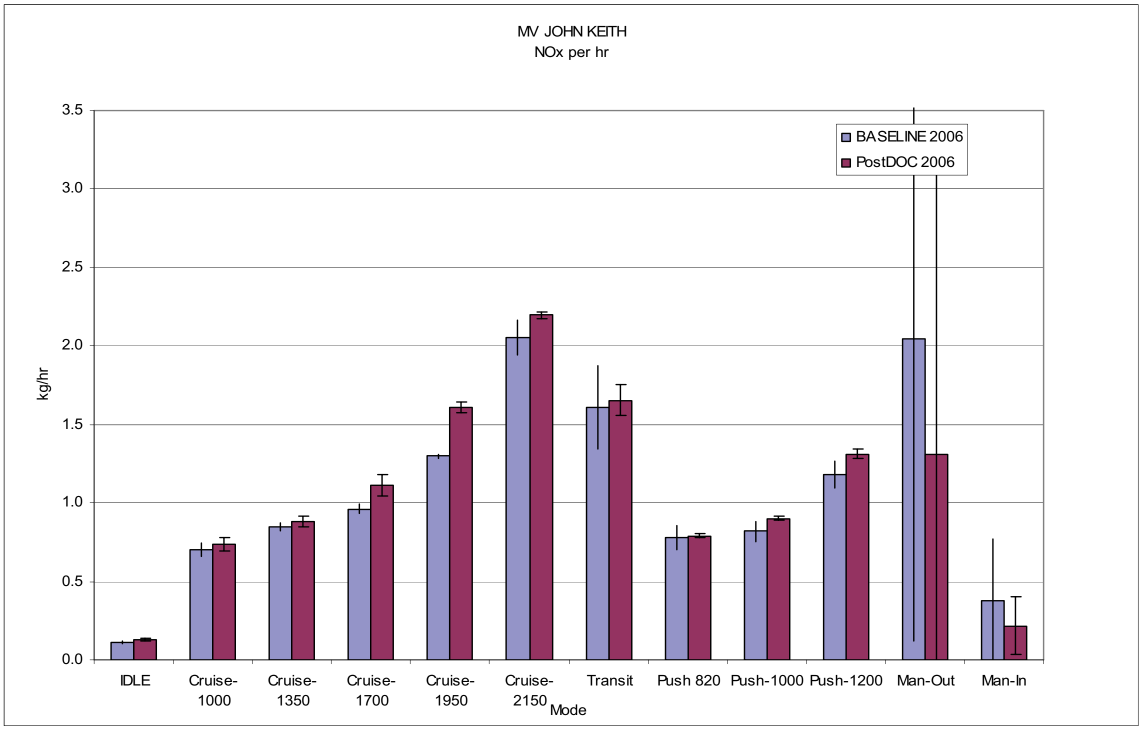


Figure 5.28. NOX Emissions – MV JOHN KEITH with DOC (April 2006).

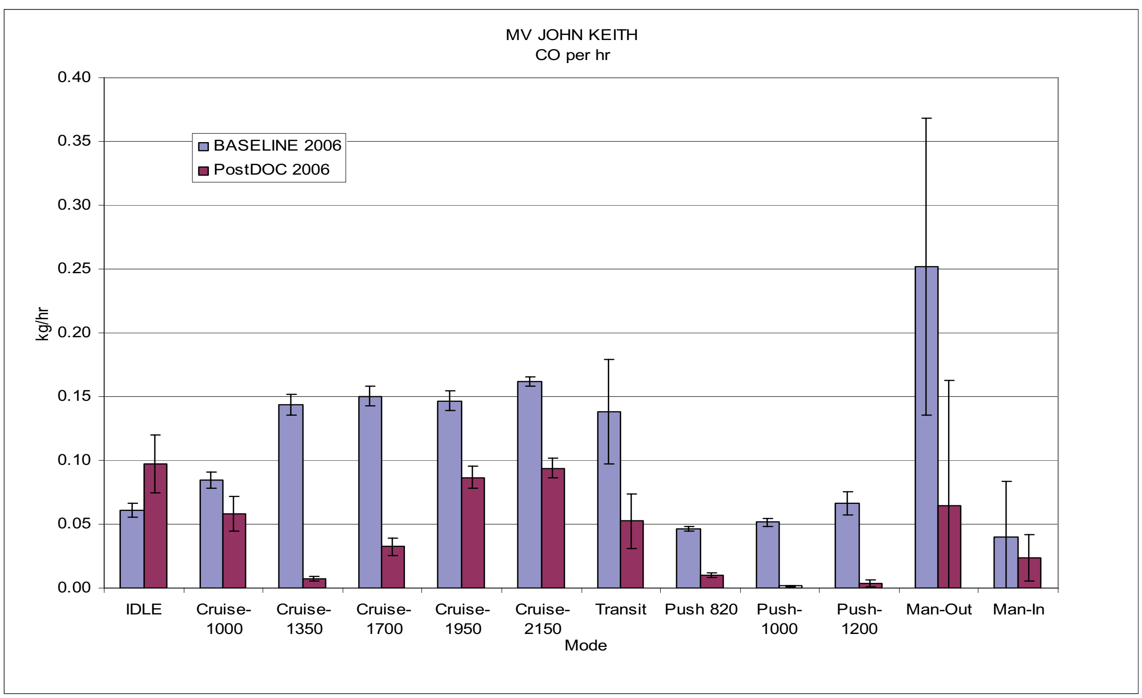


Figure 5.29. CO Emissions – MV JOHN KEITH with DOC (April 2006).

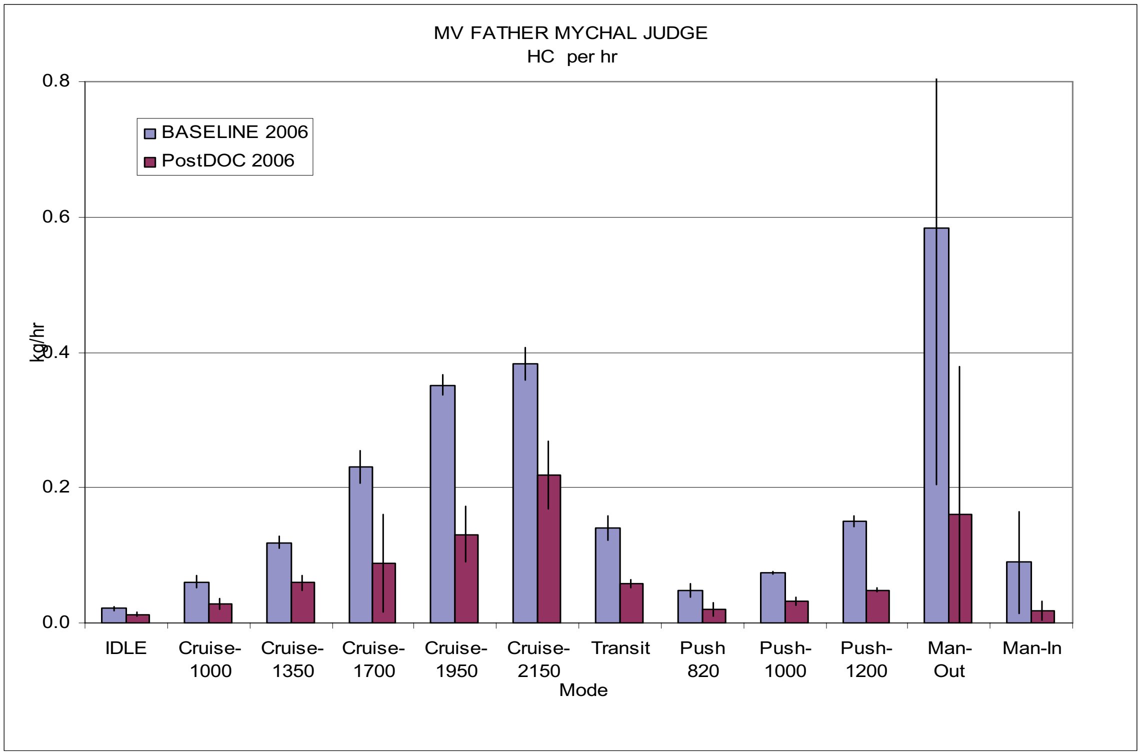


Figure 5.30. HC Emissions – MV JOHN KEITH with DOC (April 2006).

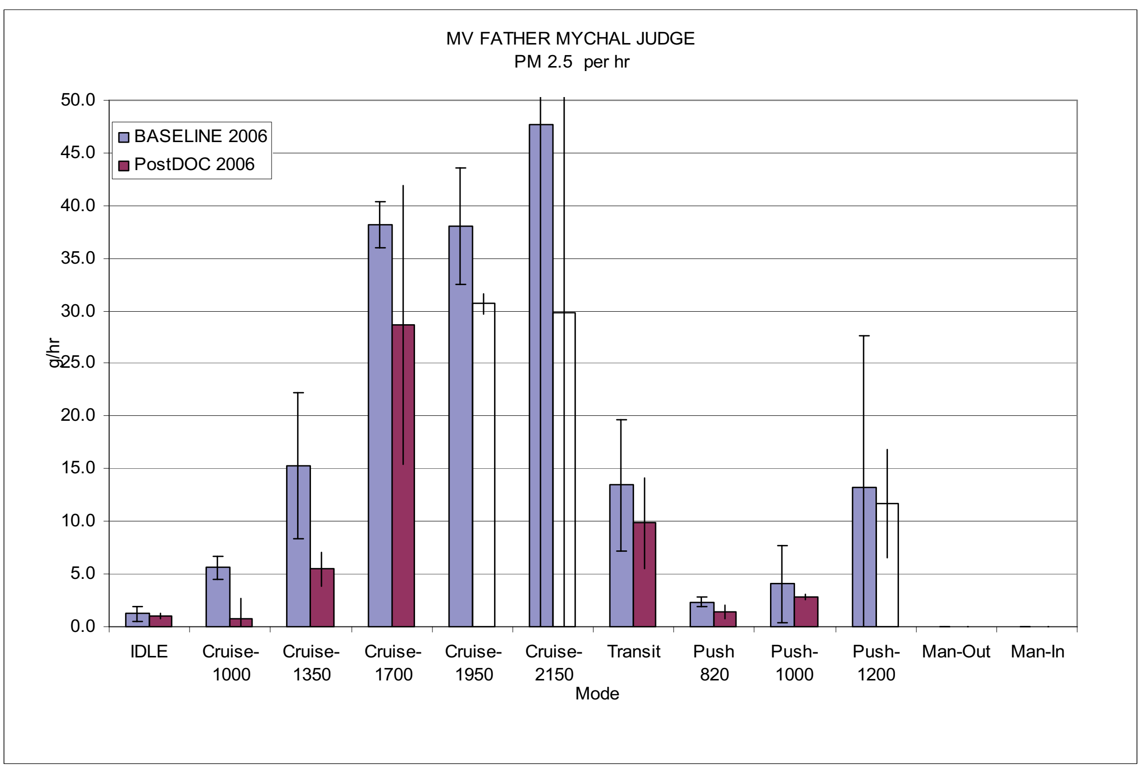


Figure 5.31. PM 2.5 Emissions – MV JOHN KEITH with DOC (April 2006).

VESSEL EMISSIONS RATES

Based on the emissions rates collected for the various modes during the Phase II demonstration, the vessel load profile emissions rates were recalculated. Where the test loads corresponded to the actual load determined from the vessel characterization, the hourly emissions rates were those of the measured load. Where the test load varied significantly from the operating load profile, the emissions were interpolated. This was possible because the revised tests used load points that bracketed the operating load point. The major difference between the original vessel emissions rates and the revised rates were those measured during the maneuvering modes.

The maneuvering mode was problematical. In the initial analysis, the maneuvering mode emissions rate was simply a time based proportion of the transit emissions rates. That is, if the maneuvering portion comprised 30% of the transit time, then the maneuvering mode emissions were assumed to be 30% of the measured emissions. Unfortunately this posed a significant problem because though the maneuvering portion of the vessel operating load cycle may have comprised 30% of the time, the actual load that the engine was operating at during that time varied considerably as the vessel accelerated and decelerated. It is conceivable that the actual maneuvering load could be just above the engine's idle.

In order to better depict what actually takes place during maneuvering, the modified transit tests were examined. Each transit test was broken down by graphing an engine load variable (rpm, fuel flow, or torque) versus time. Since this test always started and ended with 3 minutes of constant speed pushing and the duration of any test run was known, each transit run could be depicted as a timeline that broke out the time spent either pushing, maneuvering, or cruising. The average load variable for each portion of the timeline was broken out so each mode (push, cruise, or maneuver) had its own value for fuel consumption, rpm, torque, and bhp. Figure 5.26 depicts typical transit data graphed against time. Table 5.29 portrays an example of the raw data and calculated results for MV PORT IMPERIAL MANHATTAN using this time weighted approach to assess the emission rates for each mode. From this information it was it possible to calculate the emissions rate of the maneuvering mode by using the amount of fuel used during the maneuvering portion of the transit test and estimating the emissions rates by fuel weighting of the transit push and cruise components. This method was applied to the gaseous emissions. The manuevering PM 2.5 rate calculation proved to be difficult and similar methods were tried but with inconsistent results. Finally a straightforward method was adopted whereby the maneuvering PM 2.5 rate was equal to the overall transit rate.

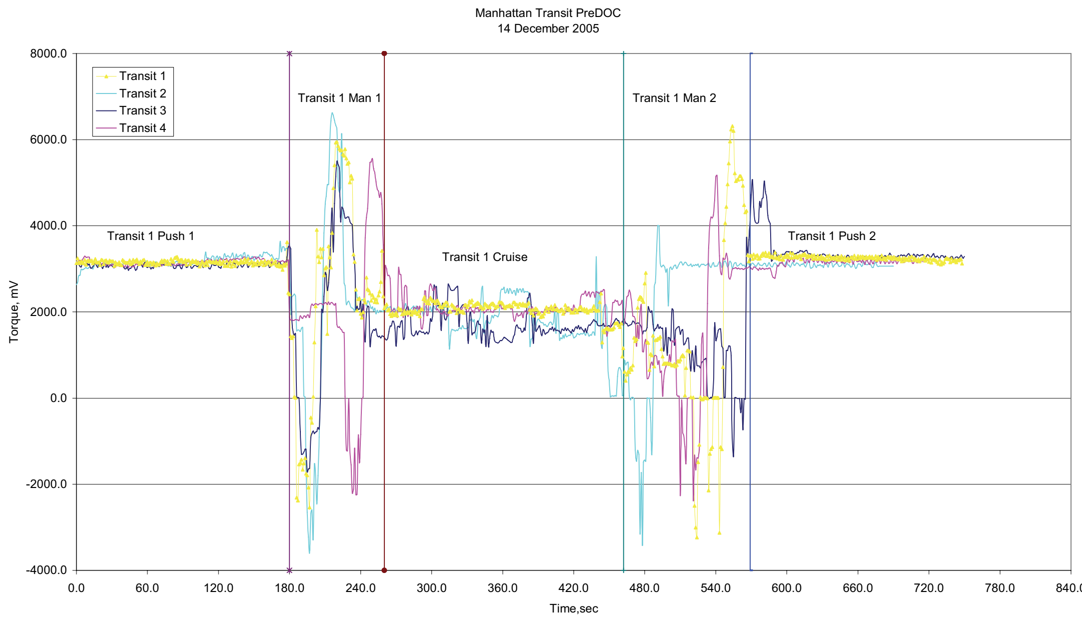


Figure 5.32 . Typical Transit Graph - MV PORT IMPERIAL MANHATTAN Baseline (December 2005).

Table 5.29. MV PORT IMPERIAL MANHATTAN Baseline Transit Test Averages (December 2005).

Mode	Time, sec	% of Time	RPM	Torque, ft-lb	BHP	Fuel Cons., lb	NO_X, kg/hr	PM 2.5, g/hr	HC, g/hr
Push	1441	49.5%	1006	2390	237	7.97	3.2	2.76	299
Maneuver	610	21.0%	941	1714	161	2.72	2.07	0.86	340
Cruise	859	29.5%	1133	1670	188	3.48	1.99	6.29	628
Total	2910	100.0%	N/A	N/A	N/A	14.17	N/A	N/A	N/A

The values calculated for the maneuvering portion of the transit tests and the steady state values for the push and cruise modes were then inserted into each vessel's operating load profile established during the vessel characterization. These new load profile emissions rates were then inserted into the harbor emissions matrix worksheet located in the appendix AB. The electronic version of this worksheet will be used to assess the potential overall harbor emissions reduction from the subsequent deployment utilizing the emissions control technologies from the Phase II demonstration.

It should be noted that one of the potential deployment technologies includes replacement Tier 2 engines. This deployment would be made on vessels whose engines did not meet the Tier 1 requirements. There was no demonstration data available for this particular technology, so the emissions rates had to be estimated. EPA's Tier 2 regulation provides emissions limits for NO_X, HC, and PM (g/bhp-hr) that the engine must meet and be able to achieve during its normal life span. These limits, particularly for PM, were found to be nearly achievable with even the older mechanically fuel injected engines. For the purposes of this comparison, the emissions for NO_X and HC was taken to be those of a Tier 1 engine operating at the modal bhp attained by the un-regulated engines and then reduced by the regulation difference in Tier 1 to Tier 2 emissions rates. Moreover, during the subsequent deployment phase of this program, a DOC or other exhaust aftertreament device may be fitted to the replacement engines to reduce particular emissions even further. Table 5.30 lists the pre- and post-emissions treatment operating load emission rates for the demonstrative field tests and 95% confidence intervals associated with each one. These rates are used in the NY harbor emissions matrix worksheet, attached in the appendix AB.

It should also be noted that while the fuel economy impacts of a Tier 2 versus Tier 0 engine have yet to be determined, they are expected to be positive. The manufacturer's published literature of the selected engine "will meet all current emissions requirements without compromising fuel efficiency." The more precise control of the fuel injection process by the engine electronic controls coupled to the higher injection pressures should enable the Tier 2 engines to be more fuel efficient in not only the steady state but transient modes.

EMISSIONS RATE ERRORS

Any errors in the results of the emissions tests could be considered reasonable in the face of the constraints imposed upon the field testing. Additionally, all errors as outlined in Section 4 of this report apply to the emissions testing in this phase. The major sources of the errors appeared to be the limited control of environmental factors and variable vessel operation under all operating modes, especially maneuvering. As seen in Table 5.31, the maneuvering mode standard deviations and subsequent confidence intervals are considerably larger than those for the push and cruise modes. Also, even though the vessels were tested off line, the time frame available for testing was very limited. Tests had to be completed without interfering with the maintenance schedules of the rest of the vessels in the fleet. Another area where more control would have been helpful was with the transit tests. The modified test was far and above the Phase I testing. A stringent protocol was followed, so more control was exercised over the modes the vessel operated under while transiting from one point to the next. However, when the data was reviewed, there was still enough discrepancy between each individual test to cause undue error.

As previously stated, the purpose of this test was to develop the capacity to calculate emissions as a sum of component parts. This was not entirely successful, and it was necessary to estimate the maneuvering portion of the emissions rate. The maneuvering emissions rates and subsequent errors for gaseous emissions were calculated using with the time dependent emission rates measured during the vessel transits. Due to the propagation of errors and the high variability in maneuvering, the errors associated with this mode are significantly higher than the other modes of operation.

Various methods were used to try and reconcile the maneuvering PM emission rates. The majority of the methods, time, power or fuel consumption weighting, produced results that were substantially lower than those measured not only for the entire transit period but also for either the push or cruise component. These results seemed counterintuitive. During the maneuvering portion of the transit the engine is accelerating and decelerating as the vessel approaches or leaves a dock. The loading on the engine is a mixture of both push and cruise and, even though the average load during the period is less than the cruise or push portions, the maximum loads seen are far greater. Therefore, it was decide to assign the PM emissions rate of the transit mode.

For all maneuvering calculations, the emission rates resulted in greater uncertainty and are only an estimated value. Additionally it should be noted that the engine load during the maneuvering away from passenger pick-up was significantly more than maneuvering in for passenger drop-off. This was most notably due to the heavy throttle required at the start of the maneuvering away portion, while the vessels tended to maneuver in under idle conditions.

In evaluating the PM 2.5 and PM 10 emission rates, particular sets of data depict the PM 2.5 emissions higher than the PM 10 emissions. This occurred in several locations throughout this report. This is not logical, as PM 2.5 is a constituent of PM 10, so PM 10 values should be greater than PM 2.5. It is unknown if this is an artifact of testing inaccuracy, if the PM 2.5 and PM 10 components were not totaled to provide the total PM 10 value, or if there are other errors. What is known is that the vast majority of diesel exhaust on a mass basis finds itself in the 0.1 to 1 micron range, very little diesel exhaust occurs in the 2.5 to 10 micron range. Thus, while sampling diesel emissions PM 2.5, PM 10, and total particulate matter (TPM), there is usually no statically significant difference between the three values based on the error associated with the test equipment. Also, it is often observed while collecting parallel samples in controlled laboratory conditions, the mass of particulate on a filter separated at 2.5 microns is slightly larger than the mass of particulate separated at 10 microns.

Additionally in these tests, the condition of the engine should be considered. The test program was fortunate in that the bulk of the tested engines were relatively new. Moreover, each vessel's engine was being maintained by manufacturer-trained technicians. It can be assumed that the engines, in general, were in very good condition. However, this condition cannot be assured, and it may be good practice to assess the condition of each tested engine prior to conducting the tests. This may be as simple as performing routine maintenance or as complex as overhauling and recalibrating the timing of the fuel injection system. In either case the object would be to bring the engine to a repeatable condition.

There are a number of improvements that can be made to improve the testing and reduce errors. Increasing the control over the vessels' operation will limit the source of the errors. For future emissions tests a possible solution is either to create a transient mode whereby the vessel is accelerated and decelerated at a predetermined rate for more precise measurements.   Another solution would be to perform more transit samples so that the results can be averaged with a greater set of data. Thus increasing the degrees of freedom associated with the data. These approaches would define more accurate emission rates, and both methods would significantly reduce the transit and maneuvering measurement error.

Table 5.30. Detailed Results of Emission Control Demonstrations (Per Engine)

MV GEORGE WASHINGTON Pre / Post Tier 2 Engine Harbor Load Cycle Emissions.									
							Reduction (%)		
									Cruise (±95% C.I.)
									29.4% (1.17%)
									50.8% (6.93%)
									65.6% (14.5%)
MV PORT IMPERIAL MANHATTAN Pre / Post FBC Harbor Load Cycle Emissions, Without DOC.									
							Reduction (%)		
									Cruise (±95% C.I.)
									-0.217% (1.69%)
									-1.56% (14.1%)
									27.1% (11.8%)
MV PORT IMPERIAL MANHATTAN Pre / Post DOC Harbor Load Cycle Emissions, Without FBC.									
							Reduction (%)		
									Cruise (±95% C.I.)
									0.233% (1.61%)
									9.50% (12.3%)
									74.1% (13.5%)
MV PORT IMPERIAL MANHATTAN Pre / Post DOC Harbor Load Cycle Emissions, With FBC.									
							Reduction (%)		
									Cruise (±95% C.I.)
									7.47% (1.55%)
									10.2% (3.88%)
									75.7% (15.2%)
MV FATHER MYCHAL JUDGE Pre / Post DOC Harbor Load Cycle Emissions.									
							Reduction (%)		
									Cruise (±95% C.I.)
									-1.73% (2.81%)
									14.5% (14.5%)
									35.8% (14.5%)
MV JOHN KEITH Pre / Post DOC Harbor Load Cycle Emissions.									
							Reduction (%)		
									Cruise (±95% C.I.)
									-19.7% (1.94%)
									33.2% (5.22%)
									65.7% (8.93%)

[+]Estimated value for Caterpillar C18 engine, derived from Caterpillar 3412E data.
[#]Maneuvering PM 2.5 values displayed in above Table are measurements from the transit operation mode.

Section 6
CONCLUSIONS

VESSEL CHARACTERIZATION

The compilation of the fleet characterization was challenging. There were numerous types of vessels to research, observe, and finally test. The fleet operators frequently did not have the required information readily available, and the engine manufacturers and their agents, in general, did not want to discuss any technical issues relating to their equipment. This meant that a significant portion of the time was used in the information gathering phase. The data logging and baseline emissions tests were performed on a "not to interfere" basis with the ferry vessel's operation to the greatest extent possible. The vessels were not only tested at the whim of the waves, schedules, and weather, but also to not impact the vessel's operation during passenger service. In one instance the emissions sampling equipment had to be installed in the passenger cabin, thereby making it impossible to test the vessel while it was in passenger service. Additionally, the operators' need to maintain the vessel schedules determined the speeds necessary to get the vessels from point to point. It was assumed that the vessels themselves were in satisfactory state of repair so that the results of the tests and data logging could be applied to similar vessels using similar propulsion systems.

The vessel characterization developed can be used as a tool to estimate future emission rates from the NY harbor private ferry vessels, and to accommodate any future additions or subtractions from the fleet. The characterization portrays the fleet operating in a mode unlike that expected by the current marine engine emissions test protocols. This is born out by the fuel flow and engine rpm histograms provided for each vessel. An E3 marine diesel test cycle is overlaid on each histogram, and it can be seen that the actual load cycling does not correspond with the test cycle. And while the emission rates do not necessarily act linearly between load points, they are continuous, so that for small intervals the emissions change should be very nearly linear. This is important because without actually testing each vessel over a large range of load points and time weighting the emissions, there would be no other way to estimate the emission rate of any vessel. The current emissions inventory calculations frequently use only the E3 test cycle emission rates and try to apply the estimated engine power to determine a time-based emission rate.

Shaft power was considered and then ruled out as a parameter on which to base the emissions. This is because the fuel flow versus engine rpm curve is equally good at depicting the engine load. Most of the operators do not record their vessel power levels, so this data is not common; however, they do record fuel consumption. By estimating the emissions on a fuel consumed basis, the emission rate is more easily calculated with the available information. Moreover, the portable shaft power instrumentation, being battery powered and wireless, would not be able to measure power for the time intervals that were being logged.

An effort was made to calculate the emission rate on a g/bhp-hr basis for the cruise or steady state mode of operation. The power was estimated using each manufacturer's fuel versus rpm propeller curve and applying that relationship to the manufacturer's power versus rpm curve. Surprisingly, the NO_X emission rates of each of the tested vessels were in line with the calculated E3 test cycle rate provided by the manufacturer. The manufacturers did not generally provide the PM emission rates; however, the PM g/bhp-hr rate was in line with what was published for the Detroit Diesel S 60 engine. Similar PM reductions as what would normally be expected from mechanically fuel injected engines should be expected for the electronically controlled engines. Typically, the PM emission factor for a mechanically injected engine would be ~1g/bhp-hr, and the tested propulsion engines had estimated PM emission rates of ~0.1 g/bhp-hr.

The subject vessels proved to be good fits for comparing the operating profiles from vessel to vessel. Especially within the NY Waterway and BillyBey fleets, the vessels utilizing the Caterpillar 3406E/waterjet propulsion system generally have similar vessel operating profiles. As a result, there is a high confidence in applying the emission rates from the test vessel, M/V FATHER MYCHAL JUDGE, to the others. There is a similarly high confidence in the emission values derived for the SeaStreak and NY Water Taxi vessels, as they all share nearly identical propulsion systems and routes.

What may not correlate so well are the emissions factors calculated for the unique vessels and vessels utilizing older mechanically injected engines. The emissions factors for these vessels were calculated using existing published emissions factors or the corresponding IMO number. There are still enough of these vessels in service to significantly impact the total NO_X, PM 2.5, and PM 10 contributions from the fleet.

The data logging produced operating curves and profiles matched expectations for the subject vessels. The exhaust temperature histograms were provided to be used by the potential emissions control device vendors to select the correct device for the application. This was critical for those devices that utilize engine exhaust heat for regeneration of captured particulate, such as diesel particulate filters (DPFs) or selective catalytic reduction (SCR) systems.

TECHNOLOGY SELECTION

The process used to select the emissions control technology for the ferry vessels was lengthy. Initially it was thought that a larger array of emissions control technologies could be applied to these vessels. All of the engines have land-based counterparts, and therefore land-based emissions control devices should have been readily available. Moreover, it was thought that the manufacturers of both the engines and the emissions control devices would have taken a more active role in selecting and/or providing a suitable emissions control device for the program.

The selection process finally arrived at the technologies listed in Table 6.1. A number of these technologies have found their way into wide spread use for on and off road applications. Unfortunately the manufacturers of these products did not feel that the economic benefit outweighed the cost of engineering equipment suitable for deployment in the marine market.

Table 6.1. Emission Control Technologies (ECT) for Use in Phase II.

Rank	Emissions Control Technology	Score %	Fatal Flaw	Operator Acceptance
2	EGR (low-pressure) and DPF	82.2	No	Yes
7	LNC and DOC and FBC	68.6	No	Yes
11	Intake Air Fumigation	64.1	No	Yes
12	Fuel Born Catalysts (FBCs)	63.9	No	Yes
16	Diesel Particulate Filters (DPF)	61.8	No	Yes
20	Diesel Oxidation Catalysts (DOC)	59.6	No	Yes
22	Engine Replacement: Tier 2 Engine	58.3	No	Yes
25	Lean NO_X Catalysts (LNC)	55.8	No	Yes

In one case, low pressure exhaust gas recirculation, the sales engineer was very anxious to provide equipment for the demonstration, but the company's standard product was not physically large enough for the air flow requirements of the marine engines. It was deemed economically infeasible to engineer a larger product specifically for this demonstration and the potential future market. In another case, the sales engineer was confident about the product being represented but backed out of the project, presumably because the company was being overwhelmed trying to bring their product to market in another geographical region.

In any event, it was difficult to find many emissions control devices other than the DOC and SCR that met the selection criteria and were deemed economically feasible by the vendor. Even for these two technologies, the custom nature of marine vessels made it difficult to select commercial off-the-shelf units, and a considerable amount of time was included in each proposal for design, installation, and commissioning.

A big restriction was also imposed by the vessel operators. The operators and owners of the NY harbor private ferry vessels are typically operating in a competitive financial environment so any changes or additional equipment to their vessels that do not contribute to the revenue stream are unwelcome. It was necessary to allow the operators and owners to have a considerable amount of influence as to which emissions control technologies would be demonstrated and then deployed. From all of the choices of emissions control technologies it stands to reason that the operators and owners would be driven to those that cause the least amount of financial impact. It should be noted that during the relatively short period of time encompassed this project one operator had to be divided to remain viable, and another is currently pulling out of the NY harbour ferry vessel business. To can be assured, ferry vessels will remain a means of transportation in and around NYC but the operators and the vessels will be in a dynamic state.

FUEL SUBSTITUTION TEST

The initial baseline testing conducted by the SSI team in February and March of 2004 was performed with the ferry vessels operating on their normally supplied fuel, characterized as No. 2 LSD. The typical No. 2 LSD fuel specification during the test included a specific gravity of 0.865, sulfur content of 400 ppm, higher heating value of 140,700 BTU/gallon, aromatic content of 38.4%, cetane index of 43.1, and fuel carbon content of 86.3%. The No. 1 ULSD fuel supplied for the Phase I emissions testing was in fact 55 grade kerosene, not No. 2 ULSD. Its average characteristics included a specific gravity of 0.822, sulfur content of 25 ppm, higher heating value of 135,700 BTU/gallon, aromatic content of 18.1%, cetane index of 42.6, and fuel carbon content of 86.9%.

To the maximum extent possible, given schedule and vessel availability constraints at the time of the No. 2 LSD and No. 1 ULSD emissions testing, the vessels were operated on the same routes and in the same modes for each test. The ambient conditions, even taking into account the 30-day lapse between testing cycles, were nearly identical. The condition of the engines and propulsion systems was assumed to be the same.

Engine emissions while operating on No. 2 LSD and No. 1 ULSD were measured using Environment Canada's apparatus and methodology, as described in earlier sections. Samples were collected for O_2, NO_X, CO, CO_2, PM 2.5, and PM 10 for each fuel type and operating mode. The results of the No. 2 LSD and No. 1 ULSD emissions tests compared well between the demonstrative vessels. Generally, for each vessel and operating mode, the engines' No. 2 LSD vs. No. 1 ULSD emissions levels for NO_X and CO_2 decreased, while the PM 2.5, PM 10, and CO values increased when computed on either an emissions mass rate or specific fuel consumption basis. Moreover, the measured fuel consumption for No. 1 ULSD operation was at least 5%-10% greater for all vessels compared to operation on No. 2 LSD, when corrected for volumetric heating value and engine load. These results were not expected. Conventional thinking, supported by the scientific literature, dictates that using ULSD fuel in place of LSD fuel should significantly reduce only PM emissions, as PM 2.5 and PM 10 production is directly proportional to the sulfur content of the fuel.

In order to determine the cause of this apparent discrepancy, the Seaworthy Systems team focused on fuel meter accuracy and/or fuel characteristics as the primary sources of the elevated No. 1 ULSD fuel flow measurements. The fuel meters selected for the project were stated to be ±2% accurate, with a repeatability of 0.25%. Based on the prior vessel performance testing during the initial logging effort, the fuel meters were deemed to be within the accuracy stated by the manufacturer. This confidence is largely the result of the good correlation of the measured fuel flow with the other logged engine parameters and with the corresponding design estimates and/or test bed measurements provided by the engine manufacturers. The No. 1 ULSD fuel (55 grade kerosene) utilized in the ferry vessel fuel test had a lower viscosity than the standard No. 2 LSD fuel. The No. 1 ULSD fuel viscosity used during the testing was 1.48 CST versus a viscosity in excess of 2 CST for No. 2 LSD fuel. Moreover, in subsequent engine parameter data collection on the M/V PORT IMPERIAL MANHATTAN in mid-July 2004, utilizing the same data logging equipment and No. 2 LSD, fuel flows very similar to those obtained during the February 2004 baseline testing were recorded while operating at the same engine speeds.

The increase in CO and the reduction in NO_X emissions were unexpected. It is believed that the engines did not combust the No. 1 ULSD as efficiently as No. 2 LSD, leading to a greater amount of CO production. The lower cylinder temperatures may have attributed to the decreased NO_X production.

The other recorded engine operating parameters were also examined as a result of the calculated emissions changes and the significantly different fuel flows. The changes in engine operating parameters did not correlate with the higher fuel flows recorded with the No. 1 ULSD when compared with No. 2 LSD. The only conclusion that could be reached is that the fuel flow measurements were incorrect. These discrepancies prompted the fuel tests performed in Canada in October of 2004.

MARINE DIESEL TEST ENGINE

As a result of the fuel substitution field trials, further tests were completed. These tests compared No. 1 ULSD, No. 2 LSD, and No. 2 ULSD fuels in a controlled environment on a shore-based marine diesel test engine for a more precise and verifiable change of emissions, fuel flow, and engine operating parameters. The conclusions drawn from these tests are described below.

It is evident that changing from No. 2 LSD to No. 1 ULSD caused an increase in fuel consumption for the Caterpillar 3176 engine. The flow meter and ECM were in agreement that the penalty was approximately 5% to 10%; the carbon balance set the penalty at no more than 4%. The associated error of the carbon balance fuel flow was 3%, so even though the calculated fuel rate discrepancy was 4% the actual fuel consumption increase could have ranged from 1% to 7 %. No statistically significant difference in fuel flows was noted between the No. 2 LSD fuel and No. 2 ULSD fuel. However, only one full round of tests was performed using the No. 2 ULSD. Although additional testing is required to verify this nonexistent difference in fuel flow between No. 2 LSD and ULSD, the results from this marine diesel test engine depicted the fuel test to be culprit for the increased fuel consumption and not the reduced sulfur concentration.

The heating values on a per pound basis are similar between the No. 1 ULSD and No. 2 LSD fuels; however, due to the lower specific gravity for the No. 1 ULSD, there is a notable decrease of approximately 3% in the heating value per volume of fuel relative to the No. 2 LSD. Therefore, one would expect a 3% increase in fuel usage by volume of the No. 1 ULSD to supply the same amount of energy as the No. 2 LSD. Any greater fuel requirement for the No. 1 ULSD is due to some other fuel characteristic and its effect on the engine's operation.

The NO_X and PM emission changes from the No. 2 LSD to the No. 1 ULSD on the engine test bed were directionally the same as those of the shipboard fuel test trials. The NO_X values, on a g/bhp-hr basis, decreased ~11%, for the No. 1 ULSD and ~14% for the No. 2 ULSD fuel for all test loads. The PM values, on a g/bhp-hr basis, increased 8% for the No. 1 ULSD and decreased 11% for the No. 2 ULSD when compared to the No. 2 LSD fuel. This runs counter to what had been expected. It was expected that the NO_X would remain relatively constant and the PM would decrease due to the reduced sulfur content. The sulfur is normally a source of PM. It is believed that the differences can be attributed to the way the electronic engine controls compensate for the different fuel properties.

The fuel flows as measured by the facility's flow bench, a set of FloScan meters and through the engine ECM revealed that the FloScan meters did measure fuel flow differently with the engine operating on No.1 fuel. The difference was not as severe but enough to conclude that the use of No 1 ULSD would not impact any of the vessel's fuel consumption significantly greater than the difference in volumetric heating value. The excessively large flow change as measured on the ferry vessels did not materialize and its cause is as yet to be determined. Future fuel flow measurements would be made with coriolis type mass flow meters. These meters are virtually impervious to the effects of fluid viscosity and temperature changes.

Looking ahead to the fleet wide deployment portion of the NYC private ferry fleet project, ULSD fuels will be either required or highly recommended for most emissions control technologies. Specifically, ULSD is required in order for most exhaust after treatments to effectively reduce PM emissions to proposed levels. The PM formed by burning LSD fuels contains respectively high concentrations of sulfur oxides. The sulfur compounds react adversely with the catalysts used within the exhaust after treatment devices, potentially causing catalyst fouling at a higher than normal rate. The compounds also hinder device regeneration, which is key to overall continued effectiveness when removing PM from diesel exhaust using diesel particulate filters (DPF). A DPF's ability to regenerate itself (to burn off the PM) is integral to its successful operation. Some DPFs are non-catalyzed and, as a result, require an external heat source (typically an electrical connection) to regenerate. These DPFs are less evolved than catalyzed DPFs, are less readily available, and have yet to be proven in a marine operating environment.

The fuel substitution field trials performed on operating ferries showed that No. 1 ULSD can be used without undue wear and additional maintenance of the subject vessels. Additionally, these trials identified that switching to No. 1 ULSD causes increases in fuel use that could exceed the difference in the volumetric heating value of the fuels. Until No. 2 ULSD in readily available in the NYC area marine market place (~2006/2007), the switch from No. 2 LSD to No. 1 ULSD could impose an additional cost burden for most ferry operators. It should be noted that the fuel used, No. 1 ULSD, may not be the actual fuel provided by the manufacturers when the fuel switch is finally mandated in 2006. Realistically, the fuel consumption of the vessels will increase at least in accordance with the difference in the volumetric heating value of the fuel if No. 1 ULSD is employed. However, the SSI team believes that the actual fuel consumption increase can be mitigated by controlling the vessel operating profiles. A 3% decrease in fuel consumption could be achieved by reducing the engine speed approximately 1%. It is recommended that further field trials utilizing the different fuels be conducted at a greater degree of quality assurance and control for more defined, repeatable, and practical measurements to evaluate the subsequent emissions, fuel consumption, and engine effects

EMISSIONS CONTROL DEVICE TESTING

The results from the Phase II demonstration prove that fitting an emissions control device to the small ferry vessels operating in the NY harbor is feasible. The installed devices worked well and significantly reduced the emissions of PM, HC, and CO from the vessels' engines. The use of a FBC enhanced the reduction of the same emissions constituents though not to the degree advertised. Based on the collected data and analysis, the report of any fuel economy gains through the use of the FBC proved to be inconclusive.

The results further proved that the devices employed on the demonstration vessels do not impose any limitations on the vessels to which they were fitted. There were some initial issues with heat generation and sound attenuation but those were overcome with relatively minor repairs or were not severe enough to cause any undue comfort or safety hazard to either the crew or the passengers. During the actual deployment these issues can be resolved by modifying the units and their installation.

The errors measured when calculating the mode emissions rates were very high. In many cases the single standard deviation statistical error bands of the pre and post treatment measurements overlapped. This is an indication that the potential for the emissions reduction, if any, could be statistically insignificant. This was exacerbated when each vessel's overall emissions rate was calculated. Determining statistically accurate maneuvering mode emissions rates proved to be difficult. These measurements drove the accuracies of the overall emissions rates. One solution would be to develop a better defined and repeatable emissions test and/or record a significantly greater amount of logged data sets to increase the tests degrees of freedom.

The results of the testing are presented on a time basis for reasons stated in Section 4. This method, though easier to use to determine fleet wide emissions rates and annual contributions, was somewhat unwieldy when compared to a specific fuel mass, volumetric, or bhp-hr based emissions rates. This is because the hourly emissions rates as tested can not be directly compared without equalizing the fuel flow basis. Time based emissions comparisons work sufficiently well provided the fuel flow differences and developed power between tests is minimal. It is important to realize that on these vessels a small change in engine rpm will lead to a large change in engine power output. This change may cause a significant change in air/fuel ratio which will significantly change the emissions output.

The actual reduction in emissions of any fleetwide deployment will depend upon a number of factors that will be beyond the control of the emissions control device manufacturer. These include wave action, current, differences in captains' vessel operation, vessel scheduling, routes, fleet makeup, etc. The demonstration provides a good amount of emissions data for those vessels during the brief amount of time they were tested.

MV GEORGE WASHINGTON

The MV GEORGE WASHINGTON was used as a basis of comparison for a Tier 2 engine retrofit, in order to estimate the benefits of replacing outdated mechanically fuel injected engines with modern ferry engines meeting Tier 2 specifications. The engine of the MV GEORGE WASHINGTON had been substantially modified in the owner's effort to reduce fuel consumption and visible smoke. In instances such as this, the actual emissions contribution from the engine may be quite different from that measured by the manufacturer or other published studies. Engines that must comply with emissions regulations in force at the time of their construction will at least have some degree of certainty regarding their respective emission rate(s).

Table 6.2. M/V GEORGE WASHINGTON Pre / Post Tier 2 Engine Harbor Load Cycle Emissions.

Pollutant	Current			Tier 2 Engine			Change, %		
	Push	Maneuver*	Cruise	Push	Maneuver*	Cruise	Push	Maneuver*	Cruise
NO_X, kg/hr	1.95	2.06	3.10	1.84	1.55	2.19	5.60%	24.6%	29.4%
NO_X, ± 95% C.I.	0.0305	1.51	0.0406	0.0490	0.233	0.0210	1.97%	68.0%	1.17%
PM 2.5, g/hr	50.4	40.9	17.6	2.20	3.55	8.66	95.6%	91.8%	50.8%
PM 2.5, ± 95% C.I.	2.66	8.80	1.67	1.02	1.29	0.207	4.89%	19.0%	6.93%
HC, g/hr	103	343	318	91.9	77.6	110	10.9%	77.4%	65.6%
HC, ± 95% C.I.	19.5	246	50.2	2.45	11.7	1.05	15.5%	80.7%	14.5%

*Estimated value as previously discussed in Section 5.

Looking ahead to the deployment phase of the NYC private ferry fleet project, replacing the mechanically fuel injected engines with similarly rated Tier 2 engines will prove to provide a substantial reduction of NO_X and PM emissions at a reasonable cost. Replacing each engine could result in a NO_X reduction of 19.9 tons/year (+/- 9.9 tons) at a cost of approximately $1.35 million for an annualized cost of $90.7 thousand, based on a useful life of 20 years and a 3% discount rate. This equates to a cost of $4.6 thousand per ton of NO_X removed. An additional reduction of nearly 0.76 tons/year (+/- 0.02 tons) of PM and 7.2 tons/year (+/- 1.6 tons) of HC would also be realized. Additional decreases in PM 2.5 and HC could be realized by fitting a DOC to the Tier 2 engines. Costs and percentage reductions would be similar to those described below for the M/V PORT IMPERIAL MANHATTAN.

M/V FATHER MYCHAL JUDGE

The DOC fitted to the M/V FATHER MYCHAL JUDGE reduced emissions as expected. When these measured values are correlated with the corrections for the load cycle developed in Section 2. The vessel's load cycle emission contribution becomes that given in Table 6.3.

Table 6.3. M/V FATHER MYCHAL JUDGE Pre / Post DOC Harbor Load Cycle Emissions.

Pollutant	Baseline			Post DOC			Change, %		
	Push	Maneuver*	Cruise	Push	Maneuver*	Cruise	Push	Maneuver*	Cruise
NO_X, kg/hr	1.35	0.906	2.48	1.36	0.984	2.52	-1.00%	-8.61%	-1.73%
NO_X, ± 95% C.I.	0.0257	0.369	0.0944	0.0248	0.0652	0.0520	1.71%	34.5%	2.81%
PM 2.5, g/hr	11.3	10.3	24.9	1.70	3.54	18.1	84.9%	65.6%	27.2%
PM 2.5, ± 95% C.I.	1.13	5.65	5.00	1.22	0.975	2.14	11.0%	42.8%	14.5%
HC, g/hr	359	231	743	130	116	477	63.7%	49.6%	35.8%
HC, ± 95% C.I.	7.31	33.4	77.9	7.61	36.7	145	2.08%	18.8%	14.5%

*Maneuvering PM 2.5 values displayed in above Table are measurements from the transit operation mode.

However, the real value in the demonstration on this vessel was to show that this particular emissions control device could be installed on this and similar NY harbor private ferry vessels without impacting the operation, safety, or performance of the vessels. There was a significant number of learning opportunities with the installation that underscore the need for flexibility given the "custom built" nature of marine vessels in general. These issues were overcome so that the installation, except for slightly higher than recommended back pressure, did not impact the vessel's operation. Only minor modifications such as improved thermal insulation and changes to the inlet/outlet pipe configurations would be necessary to the demonstration DOC to install this unit in similarly designed vessels. These modifications should not have a significant impact on cost given the potential number of units involved during any fleetwide deployment.

Based on the number of similarly powered vessels, the potential harbor PM 2.5 reduction would be 1.79 +/- 0.232 tons, and an HC reduction of 32.5 +/- tons 5.68annually. A zero NO_X benefit is anticipated. The anticipated cost to supply and install these DOCs is approximately $1.2 million for an annualized cost of $388 thousand per ton of PM 2.5 removed, based on a useful life of five years and a 3% discount rate.

M/V PORT IMPERIAL MANHATTAN

The PORT IMPERIAL MANHATTAN was used to evaluate the additional benefit of using a fuel-borne catalyst to a vessel outfitted with a DOC. Four rounds of emissions testing were used for this evaluation: initial baseline, pre-DOC baseline, post-DOC without FBC, and post-DOC with FBC. The DOC fitted to M/V PORT IMPERIAL MANHATTAN reduced emissions as expected. When these measured values are subject to the corrections for the load cycle developed in Section 2 the vessel's load cycle emission contribution becomes that given in Table 6.4.

Table 6.4. M/V PORT IMPERIAL MANHATTAN Baseline / Post DOC Harbor Load Cycle Emissions, Without FBC.

Pollutant	Baseline			Post DOC			Change, %		
	Push	Maneuver*	Cruise	Push	Maneuver*	Cruise	Push	Maneuver*	Cruise
NO_X, kg/hr	2.94	2.07	1.94	2.83	2.10	1.94	3.78%	-1.34%	0.233%
NO_X, ± 95% C.I.	0.0653	0.311	0.0279	0.0514	0.466	0.0295	1.82%	24.1%	1.61%
PM 2.5, g/hr	2.79	4.47	6.09	1.74	4.07	5.51	37.8%	8.84%	9.50%
PM 2.5, ± 95% C.I.	1.36	1.72	0.276	0.640	1.02	1.12	36.8%	28.9%	12.3%
HC, g/hr	222	339	622	126	190	161	43.3%	44.1%	74.1%
HC, ± 95% C.I.	8.01	72.9	87.5	2.57	23.3	1.47	2.65%	21.8%	13.5%

*Maneuvering PM 2.5 values displayed in above Table are measurements from the transit operation mode.

Use of the DOC produced significant reductions of CO (49.1% average of steady state modes excluding idle) and HC .(50.8% average of steady state modes excluding idle). Other reductions of NOx .(1.4% average of steady state modes excluding idle) and PM 2.5 .(15.8% average of steady state modes excluding idle) however, these reductions are statistically inconclusive. When the DOC was combined with the FBC, improvements were noted in NOx (5.5% vs. 1,.4%) HC (52.5% vs. 50.8%) and PM 2.5 (17.4% vs. 15.8%) however, only the reductions of the gaseous emissions are statistically conclusive. The PM reductions are not.

Table 6.5. M/V PORT IMPERIAL MANHATTAN Baseline / Post DOC Harbor Load Cycle Emissions, With FBC.

Pollutant	Baseline			Post DOC			Change, %		
	Push	Maneuver*	Cruise	Push	Maneuver*	Cruise	Push	Maneuver*	Cruise
NO_X, kg/hr	2.94	2.07	1.94	2.61	0.685	1.80	11.3%	66.9%	7.47%
NO_X, ± 95% C.I.	0.0653	0.311	0.0279	0.661	0.369	0.0331	14.6%	21.8%	1.55%
PM 2.5, g/hr	2.79	4.47	6.09	1.99	3.00	5.46	28.8%	32.9%	10.2%
PM 2.5, ± 95% C.I.	1.36	1.72	0.276	4.55	2.11	0.462	55.5%	32.2%	3.88%
HC, g/hr	222	339	622	125	88.5	151	43.5%	73.9%	75.7%
HC, ± 95% C.I.	8.01	72.9	87.5	10.1	74.0	56.1	3.88%	30.0%	15.2%

*Maneuvering PM 2.5 values displayed in above Table are measurements from the transit operation mode.

By itself, the FBC appeared to improve the emission rates of NO_x,(1.4% average of steady state modes excluding idle) CO (7.0% average of steady state modes excluding idle), HC .(2.9% average of steady state modes excluding idle), and PM 2.5 .(2.9% average of steady state modes excluding idle) on a mass per hour basis. The reductions for NOx, CO and HC are statistically significant. The statistical error of the PM measurements makes the reductions inconclusive. Similar reductions were noted for emissions on a mass per bhp-hr basis. These reductions are statistically inconclusive.

The effect of the FBC on a specific fuel consumption basis was inconclusive, though an increase was noted in CO_2 emissions. The specific fuel consumption values were within the limits of the experimental error between the tests, however, a reduction of CO emissions coupled to a similar increase in CO_2 is usually an indication that the combustion efficiency has improved. So, there is a potential for fuel economy improvement while using the FBC. There is also reason to suspect that, if a significant fuel economy improvement is realized during future testing, similar reductions in fuel economy could be achieved with any and all of the similarly powered vessels currently operating in the NY harbor fleet.

As with the MV FATHER MYCHAL JUDGE, this demonstration showed that a DOC could be installed on this and similar types of NY harbor private ferry vessels without impacting the operation, safety, or performance of the vessels. This particular installation was straightforward. These ferry vessels have a significant amount of unused space within which a DOC can be easily placed. The exhaust piping within the space requires minimal modification and, if necessary, the DOC itself could be modified so as to incorporate sound baffling, thereby making it a replacement for the existing exhaust silencer.

Currently, there are only two vessels on which a similar DOC system may be placed, not including the nine vessels slated for engine replacement during the deployment phase. Based on these vessels the potential harbor PM 2.5 reduction would be 0.028 +/1 0.019 tons, annually. The potential HC reduction would be 13.80 +/- 1.81 tons annually.. A zero NO_X benefit is anticipated. The anticipated cost to supply and install these DOCs is approximately $61 thousand for an annualized cost of $13.4 thousand based on a useful life of five years and a 3% discount rate. On a cost per ton of removed PM 2.5 basis, this works out to $508 thousand per ton.

However, the real value in this demonstration was to show that a further benefit could be gained by using the FBC in conjunction with the DOC. The additional PM 2.5 emissions reduction would be approximately 0.003 tons annually (about a 10% reduction). The cost would be negligible assuming that the potential fuel economy gains equal or outweigh the cost of the FBC. Currently the cost of FBC to treat 1,500 gallons of fuel is $75.00, or $0.05 per gallon. In order to offset the cost of using FBC, a real fuel economy benefit of 1.5% to 2% would need to be realized, assuming that the fuel costs $3.00 per gallon.

It should be noted that concewrns remain in the envionemental community relative to the possible health effects of potential small particle emissions of meteals used in some fuel-borne catalysts, and additional investigations are required in this area.

M/V JOHN KEITH

The DOC fitted to the M/V JOHN KEITH reduced emissions as expected. When these measured values are subject to the corrections for the load cycle developed in Phase I the vessel's load cycle emission contribution becomes that given in Table 6.6.

Table 6.6. M/V JOHN KEITH Baseline / Post DOC Harbor Load Cycle Emissions.

Pollutant	Baseline			Post DOC			Change, %		
	Push	Maneuver*	Cruise	Push	Maneuver*	Cruise	Push	Maneuver*	Cruise
NO_X, kg/hr	0.771	1.23	1.19	0.793	0.949	1.42	-2.85%	22.7%	-19.7%
NO_X, ± 95% C.I.	0.0754	0.633	0.0130	0.0132	0.600	0.0333	6.40%	59.8%	1.94%
PM 2.5, g/hr	2.33	13.5	38.4	1.55	9.84	25.6	33.4%	26.9%	33.2%
PM 2.5, ± 95% C.I.	0.427	6.24	5.53	0.687	4.33	1.02	11.9%	19.6%	5.22%
HC, g/hr	48.6	341	328	22.2	113	113	54.2%	66.7%	65.7%
HC, ± 95% C.I.	10.1	125	15.0	10.1	70.9	41.7	20.3%	40.4%	8.93%

*Maneuvering PM 2.5 values displayed in above Table are measurements from the transit operation mode.

As with the previous two vessels, this demonstration showed that a DOC could be installed on this and similar types of NY harbor private ferry vessels without impacting the operation, safety, or performance of the vessels. There were not many problems with this installation. With the exception of modifying the DOC case so that it would fit down the existing access hatch, no other major changes would be needed to either the vessel or the DOC. Initially there was some concern that the larger size of the unit as compared to the original silencer would impair the servicing of the vessel. This proved not to be the case. While the access to the engine has been compromised by the DOC, it should be noted that these particular vessels have very cramped engine rooms to begin with. The normal service points for the machinery are still accessible.

There was some concern about the higher noise levels in and outside of the vessel. However, it may be possible to change to configuration of the DOC case so that sound baffling can be installed. Modifications to the DOC case for size or sound baffling should not have a significant impact on cost given the potential number of units involved in any fleetwide deployment.

Based on the number of similarly powered vessels, the potential harbor PM 2.5 reduction would be 0.192 +/- .013 tons, annually. The anticipated HC reduction would be 4.23 +/- 0.494 tons annually. A zero NO_X benefit is anticipated. The anticipated cost to supply and install these DOCs is approximately $190 thousand for an annualized cost of $41.5 thousand, based on a useful life of five years and a 3% discount rate. This works out to $316 thousand per ton of PM 2.5 removed.

SUMMARY

The following tables summarize the potential emissions reductions on an annualized basis. The reductions are based on the load and operating profiles generated by the harbor emissions reduction tables. The overall harbor emissions are driven by the effectiveness of any emissions control strategy and by vessel use. It is clear that vessels with high usage rates will have the greatest impact on the absolute reduction of emissions even if their emissions control technology does not have the highest reduction when stated on a percentage reduction basis.

Table 6.7. ECT Installation Costs and Annual Emission Reduction for Demonstration Vessels.

Vessel	ECT Desc.	Vendor	Annual Cost				Annual Reductions		
			Hard-ware	Install	Cons	Total	Nox ton/yr	PM 2.5 lb/yr	HC ton/yr
MV PORT IMPERIAL MANHATTAN	DOC	Clean Diesel Tech.	$6642	$10727	$0.00	$17369	0.69	39.1	5.24
MV PORT IMPERIAL MANHATTAN	DOC+ FBC	Clean Diesel Tech.	$6642	$10727	$5900	$23269	11.1	54.7	5.86
MV FATHER MYCHAL JUDGE	DOC	Johnson Matthey	$7065	$17719	$0.00	$24784	-0.09	50.02	2.40
MV JOHN KEITH	DOC	Johnson Matthey	$11625	$10627	$0.00	$22252	-0.81	45.83	0.86

Table 6.8 illustrates the potential harborwide emissions reductions utilizing the technologies and the vessel load cycles and usage identified in this study. On an absolute basis, the emissions reductions can be quite large. It is unfortunate that SeaStreak was unable to participate fully in this study. SeaStreak's potential for harbor wide NO_x reduction is substantial, but not included in Table 6.8 due to their withdrawal from the NYC private ferry fleet emissions reduction program.

Table 6.8. NYC Harbor Potential Emissions Reduction via Owner.

Owner/Operator[1]	ANNUAL NOx EMISSION RATE REDUCTIONS				ANNUAL PM2.5 EMISSION RATE REDUCTIONS				ANNUAL HC EMISSION RATE REDUCTIONS			
	Curr Total	Proj. Total	NOx Reduc-tion	% NOx Reduc-tion	Curr. Total	Proj. Total	PM2.5 Reduc-tion	% PM2.5 Reduction	Curr. Total	Proj. Total	HC Reduc-tion	% HC Reduc-tion
	(short tons/yr)	(short tons/yr)	(short tons/yr)	%	(short tons/yr)	(short tons/yr)	(short tons/yr)	%	(short tons/yr)	(short tons/yr)	(short tons/yr)	%
NY Waterway, Inc.	293	277	15.3	5.22%	2.44	0.989	1.45	59.5%	62.6	28.9	33.8	53.9%
± 95% C.I.	3.95	4.26	6.46	2.21%	0.0391	0.0161	0.0408	1.91%	1.41	0.953	1.66	2.91%
Billy Bey Ferry Co., Inc.	154	155	-1.05	-0.682%	2.23	0.853	1.37	61.7%	42.6	24.4	18.2	42.7%
± 95% C.I.	2.95	0.735	2.95	1.92%	0.0602	0.0244	0.0615	3.18%	0.855	1.52	1.68	4.04%
New York Water Taxi, Inc.	32.2	34.2	-2.02	-6.28%	0.591	0.399	0.192	32.5%	6.53	2.30	4.23	64.7%
± 95% C.I.	2.11	1.95	2.64	8.21%	0.0161	0.00544	0.0130	2.31%	0.417	0.338	0.494	8.46%
Total Harbor[2]	479	466	12.2	2.55%	5.26	2.24	3.02	57.4%	112	55.6	56.2	50.3%
± 95% C.I.	6.24	4.33	7.48	1.56%	0.0700	0.0284	0.0734	1.58%	1.66	1.77	2.39	2.26%

Note 1: Based on fleet make up as of 31 December 2004
Note 2: No ECT projected reductions included for SeaStreak vessels included in calculations due to withdrawal from program.

Accomplishments

The accomplishments of the program include the following:

- Successfully completed what is the largest and most extensive onboard emission test program ever performed on a fleet of operating ferries.
- Identified and demonstrated technologies applicable to a majority of ferries operating in New York Harbor with the potential with full deployment of reducing emission of NO_X by 12.2 (± 7.48) tons/year, PM 2.5 by 3.02 (± 0.0734) tons/year, and HC by 56.2 (± 2.39) tons/year.
- Conducted the first onboard demonstration of a DOC on a ferry nationwide.
- Conducted the first onboard demonstration of a fuel-borne catalyst on a ferry nationwide.
- Conducted the first onboard demonstration of ULSD on a ferry nationwide.
- Made significant progress in the development of successful methods of testing emissions on board ferry vessels including a number of lessons that will be of use in future testing.

Lessons Learned

This program is the largest and most extensive onboard emission test program ever performed on a fleet of operating ferries. In many areas, the learning curve was steep and significant effort was required to complete the project successfully. A number of lessons were learned that may be of benefit to those who undertake similar programs in the future.

- Well-developed and proven on-road emission control technologies can not just be seamlessly applied to a marine environment. Operational and space considerations can change the effectiveness of control devices and can present installation challenges. The program did however prove that most of these challenges can be overcome and emissions can be effectively reduced.
- DOC's generally resulted in somewhat higher back pressures, though when properly sized these pressures could be kept within limits. No measurable increase in fuel consumption was noted.
- Onboard testing proved to be quite challenging requiring many replications to obtain meaningful results. Factors such as current, wind, sea state and operator idiosyncrasies made duplication of results difficult to correlate, particularly for tests separated by significant periods of time.
- Whenever possible the vessel should be taken out of service so that conditions can be controlled purely on the basis of testing needs.
- Proper instrumentation is essential. The use of coriolis effect mass flow meters and strain gauge torsion measurement on the later tests provided means to clearly establish and crosscheck operating conditions.
- Obtaining reliable data during the dynamic maneuvering phase of vessel operation is particularly challenging. Meaningful data during these periods of rapidly changing power and propeller operating conditions was proven very difficult to measure, quantify, calculate, and produce qualitative results. Although in many cases the contribution of these periods is small when compared to the overall operational cycle, in ferry operation with shorter runs and frequent docking the proportion of maneuvering can become significant. This topic warrants further investigation and tests.

Recommendations

Based on the successful results of the technology evaluations and demonstrations, the project staff recommends that the program proceed to the next phase, which consists of funding the deployment of the successful technologies throughout the NY Harbor private ferry fleets.

This planned deployment phase is expected to consist of providing funds to repower that portion of the fleet having unregulated (Tier 0) engines with the newest, cleanest, EPA Tier 2 marine diesel engines, and to retrofit all participating vessels with diesel oxidation catalysts.

If, as a result of this or any other report, fuel-borne catalysts are still considered economically viable, that is their projected fuel savings are equal to or greater than their cost, then it is recommended that a more controlled test be made either on a test bed or in actual service. This test will not only have to simulate the operating profile of the vessels but will also have to incorporate a significant number of corrections for ambient conditions and control for sea state and currents. Moreover, the tested engine(s) should start from the same mechanical condition.

Ferry vessels constructed in the future for service in NY harbor should have provisions for fitting exhaust aftertreatment devices built into the design. The existing designs are very compact and are not optimized for current emissions reduction strategies.

APPENDICES

APPENDIX A

GLOSSARY OF ACRONYMS, AND TERMS

APPENDIX A

Glossary of Acronyms, and Terms

ASTM American Society for Testing Materials Organization that sets standards for fuels and and other materials.

Bhp Brake horsepower. Power the engine is providing as measured by the dynamometer. US units.

B(XX) Biodiesel fuel. Diesel fuel made from vegetable oil stocks and blended with No. 2 diesel fuel.

Bollard Pull Propeller load condition where the propeller is rotating but the vessel is held stationary either by pushing against a dock or pulling on a line fastened to a dock or bit.

Carbon Balance Method to calculate mass emission rates from exhaust CO2 and CO volumetric concentrations, fuel flow and fuel carbon content.

CO Emissions specie, carbon monoxide

CO2 Emissions specie, carbon dioxide

Cruise Cruise is the mode where the vessel is operating in the forward direction with a steady engine load.

CCV Closed Crankcase Ventilation. Crankcase ventilation system where the crankcase vapors are conveyed to the intake air.

CR Common Rail. Fuel injection system utilizing a common high pressure reservoir of fuel connected to individual cylinder nozzles.

DPF Diesel Particulate Filter

DOC Diesel Oxidation Catalyst

Dynamometer Measuring device used to measure the torque output of an engine. Used with rpm to calculate bhp.

E3 Marine Commercial Engine test cycle used to quantify overall marine engine emissions based on percentage of time at load.

E5 Marine Pleasure Craft Engine test cycle used to quantify overall marine engine emissions based on percentage of time at load.

ECD Emissions control device. Equipment added to an engine to reduce the exhaust emissions of one or more emission specie.

ECM Electronic control module. Electronic control system to control the engine’s fuel/air system and monitor operating parameters.

ECU Electronic control unit. Electronic control system used to control the engine’s fuel/air system and monitor operating parameters.

EDF Emulsified Diesel Fuel. Diesel fuel/water emulsion.

EUI Electronic Unit Injector. Fuel injection system utilizing a integral pump/nozzle/control valve for each cylinder.

FBC Fuel Born Catalyst. Catalyst metal dissolved or suspended within fuel. Used to promote fuel combustion.

FIE Fuel Injection Equipment. Equipment used to meter and inject the fuel into the diesel engine.

FT Fischer-Tropsh diesel fuel. Synthetic fuel made from natural gas or coal.

Free Running Propeller load condition where the vessel is moving forward at a speed close to the rate of advance of the propeller.

Front Load Vessel configuration where the normal ferry vessel access is through doors located in the front.

g/bhp-hr Mass flow rate per bhp output. Used for specific representation of exhaust emission or fuel consumption.

GHG Green House Gas. Gas produced by combustion that contributes to the greenhouse effect of the atmosphere, such as CO_2.

GPH Rate of fuel usage, gallons per hour.

GPS Global Positioning System; A system of satellites in geostationary position around the earth that is used, by triangulation, to establish a location on earth using a GPS receiver.

HAM Humid Air Motor

HC Emissions specie, hydro carbons

Heating Value Amount of heat released when a fuel is burned. May be expressed as high heating value or low heating value. The difference between the two values is the heat recovered when the water vapor in the exhaust is condensed.

IMO International Maritime Organization. International organization formed to set standards for the design and construction of ships.

ISO International Standards Organization. International organization formed to set design, construction and test standards for nearly everything man made.

IWC Unit of pressure, inches water column.

Knot Unit of vessel speed, one knot equals one nautical mile per hour.

Lazarette Storage space found at either end of a vessel usually used to store lines.

LSD Low sulfur diesel fuel, diesel fuel containing less than 500 PPM sulfur.

Maneuver Maneuvering is the mode that the vessel is in when it is not cruising or pushing, and typically incorporates accelerating, decelerating and turning to and from the dock.. Overall, the percentage of time that each ferry vessel spent operating in each mode was similar despite length of route.

MARAD U.S. Maritime Administration. U.S. government organization providing guidance on the operation and construction of vessels.

MARPOL	Marine Pollution. The MARPOL Conventi on is the main international convention covering prevention of pollution of the marine environment by ships from operational or accidental causes. It is a combination of two treaties adopted in 1973 and 1978 respectively and updated by amendments through the years
NO_X	Emissions specie, oxides of nitrogen
O2D	Oxygenated Diesel Fuel. No. 2 Diesel Fuel blended with ethanol.
P-L-N	Pump-Line-Nozzle. Old style of fuel injecti on system using a relatively long injection pipe between the pump and the nozzle.
PM 2.5	Emissions particle size, 2.5 microns
PM 10	Emissions particle size, 10 micron
PSIG	Unit of pressure, pounds per square inch
Push	Push is the mode where the vessel is using engine power to hold the bow of the vessel to the dock for passenger disembarkation and loading
RPM	Rate of speed of a rota ting device, revolutions per minute
SCR	Selective Catalytic Reduction
Soft Patch	Easily removable section of a vessel's deck or bulkhead that can be used to install and remove equipment.
ULSD	Ultra low sulfur diesel fuel, diesel fuel cont aining less than 30 PPM sulfur.

Appendix B

DATA LOGGING PROTOCOL

PROTOCOLS FOR ON-BOARD MARINE VESSEL DATA LOGGING FOR IMPLEMENTING EMISSIONS REDUCTION STRATEGIES

Staten Island Ferry Emissions Reduction Program Data Logging Protocol/Plan

Submitted to:

Port Authority of New York and New Jersey

October 15, 2003

West Virginia University
Where Greatness is Learned

Prepared By: M. J. Bradley & Associates

Overview

The objective of the Data Logging Protocol Development and Logging of Vessel and Engine Parameters task is to record engine performance metrics including engine exhaust temperature to facilitate the design and cost estimation of exhaust aftertreatment systems. This is a standalone protocol that can be used in conjunction with additional protocols for emissions testing and vessel information gathering. It is understood that the engines on the Staten Island Ferry demonstration vessel, the Austen Alice, are mechanically controlled as opposed to electronically controlled and that data logging is not as convenient as it would be on an electronically controlled engine. The protocol is intended to be a general guideline document. Summary information on the data logging equipment and specific sensors used for the Staten Island Ferry Demonstration are contained at the end of this document.

Most exhaust aftertreatment designs require the collection of information on two critical parameters, exhaust temperature and exhaust backpressure. Exhaust temperatures are logged to determine the average and range of temperatures that occur during specific operations. It should be noted that high temperature excursions are also important because catalyst sintering is the single most notable cause of catalyst deterioration. Also, SCR systems require exhaust temperatures to be above a certain minimum value to operate effectively. Backpressure directly affects engine performance and excessive backpressure raises particulate matter emissions.

In-use vessel data logging will require continuous 1 Hz storage rate of all data channels in order to sufficiently capture transient engine activity. The individual sensor accuracy targets are set at ±10% with 95% confidence over the full range of steady state and transient engine operations. The proposed protocol and recommended sensors have been selected to obtain accurate, meaningful data for this and future marine emissions reduction programs.

Procedures have been developed for in-use emissions testing. On-road procedures have been developed for the Consent Decree work for the settling heavy-duty diesel engine manufacturers (Gautam et al, 2000) and a draft set of procedures have been developed for in-use marine emissions for the San Francisco Bay Water Transit Authority (Weaver, 2002). However, there are no known published standards or guidelines for the process of data logging engine and exhaust parameters to be used in the sizing of the emissions reduction technology as much of this information is considered competition sensitive information by the control system vendors. This document proposes a set of procedures for the collection of engine and vessel data for the design and cost estimation of emissions reduction equipment. Data gathered under this protocol can also be used for the development of a representative in-use test cycle to evaluate the emissions reduction technology once it is implemented however, the development of test cycles from logged data is beyond the scope of this protocol.

Background

Emission control efforts and the implementation of emission control systems require knowledge of the engine duty cycle and engine operating parameters for optimization of the system design. Emissions reductions may be effected through the use of "clean" fuels, by improving the in-cylinder combustion, or by adding aftertreatment devices to the engine. Aftertreatment devices may include but are not limited to oxidation catalysts, selective catalytic reduction (SCR) systems, exhaust gas recirculation (EGR) and particulate filters.

For a specific engine, the operating condition is usually defined by engine speed and engine torque. Since engine power is determined from the product of torque and speed, one may alternately use speed and power or torque and power, and convey similar information about engine load. By recording a time sequence of torques and speeds in actual use, it is possible to determine how repeatable the engine behavior is from trip to trip, and to prepare test modes in an emissions test procedure that reasonably mimic in-use emissions. For marine in-use evaluations repeatability is one of the single largest operational variables and as a result it is not anticipated that a standard test cycle will be determined, but instead that the data will be used to verify operational repeatability.

For mechanically controlled engines, engine torque may not be readily available and, perhaps more importantly, the control system manufacturer cannot as a result be expected to utilize engine torque as an emission control parameter (i.e. as an input parameter for an SCR system). Under these circumstances an alternative indicator for engine load must be determined. It is possible for instance to establish engine operating condition with fair accuracy (i.e. 25%) by knowing other pairs of variables, such as engine speed and exhaust temperature, engine speed and fueling rate, or engine speed and boost pressure. While these parameters may not yield engine load data suitable for mathematical calculations during emission testing for instance, they will typically provide the necessary level of accuracy for operation of the emission control system.

Additional operational information is required to satisfy the need for aftertreatment selection or design. Aftertreatment devices must be sized to match the flowrate of exhaust gas from the engine. Although the exhaust flowrate is determined by the speed and torque on a specific engine, it does not provide a direct measure of the flow. Flowrate may be inferred by one of the following methods:

1) The intake air mass flow is substantially the same as the exhaust mass flow and may be measured directly, using one of a variety of devices.
2) The exhaust mass flow may be measured directly.

3) The flow may be inferred using the engine speed, engine displacement, and measures of the pressure and temperature in the intake manifold along with an assumed volumetric efficiency.

Aftertreatment devices catalyze chemical reactions, and operate within designated temperature windows. Measurement of exhaust gas temperature must be logged to allow selection of the most appropriate catalytic formulation.

In special cases where the engine drives a generator for an electric propulsion drive system, it is also possible to measure the engine power by measuring the current and potential (volts) to yield the power from the generator. The generator efficiency may be known or estimated quite reliably, and the generator power will provide an excellent reflection of the engine power.

In the case of more modern engines, where electronic controls are implemented, information is often available directly from the controller. This information invariably includes engine speed and a measure of engine load or fueling rate, which can be used to infer torque or power. In many cases, other variables, such as temperatures and pressures, are also available from the controller.

A strong relationship also exists for diesel engines between fuel consumed and power output. It is possible to estimate fuel consumption, particularly at high power outputs, from the engine output power, and conversely, to estimate power output if fuel consumption is known. Fuel consumption can be measured, but the difference in flow between the supply and return lines must be considered.

Recorded Parameters

The primary engine parameters of interest in this study are engine speed, exhaust (or intake) flowrate, exhaust temperature, and exhaust backpressure. These parameters may be measured directly, calculated or estimated. Table 1 illustrates the proposed parameters to measure and the prioritization assigned to each parameter. Engine speed, exhaust temperature, and exhaust backpressure are relatively simple parameters to measure directly. However, intake or exhaust flowrate measurement is a more difficult parameter to measure accurately and precisely and may be more easily determined from other operational factors such as intake manifold pressure and intake temperature. Engine speed, exhaust flowrate, exhaust temperature, and exhaust backpressure are all somewhat inter-related to the required load on the vessel. Exhaust flowrate and exhaust temperature are the primary variables that the aftertreatment manufacturer will use in design the system.

Secondary parameters that may have future application include vessel speed, water current speed and direction, engine load, ambient temperature, intake humidity, and barometric pressure. These parameters provide information on the operating characteristics of the vessel and would provide useful information for the emissions testing verification of the aftertreatment system but are not necessarily useful as parameters for standalone data logging. Vessel speed and water current information give an indication of how the vessel is loaded throughout the day and will indicate the duty cycle of the vessel on a per trip basis and on a per day basis. GPS is recommended as a mandatory parameter to determine vessel route repeatability even though this parameter cannot be used to determine vessel speed (i.e. through the water) or vessel load directly. Engine load would supplement the vessel speed data and may provide information on engine-to-engine variability or duty usage between engines. Humidity, temperature, and barometric pressure will give the range of ambient conditions that the engine intake is expected to operate in.

Table 1 Parameter prioritization for initial engine and vessel data logging.

Parameter	Prioritization	Use
Date and Time	Required	Data Integrity, archive
Exhaust Temperature	Required	Aftertreatment Design
Global Positioning Data	High	Vessel Repeatability
Engine Speed	High	Intake/Exhaust Flow Calculation
Exhaust Flow	High	Aftertreatment Design
Exhaust Backpressure	High	Aftertreatment Design
Engine Load	Medium	Future Emissions Testing
Ambient Conditions	Low	Range of Intake Conditions
Vessel Speed	Low	Vessel Load

Parameters prioritized as "Required" are absolutely essential and are the primary target variables without which the suitability of the emission control after treatment cannot be determined. Parameters prioritized as "High" are variables that can typically be measured and/or calculated on both mechanical and electronically controlled engines and should be collected if the logging equipment capability and project budget allows. Parameters prioritized as "Medium" may not be easily measured on mechanically controlled engines but if available (i.e. electronically controlled engine or electric drive) should be recorded. Parameters prioritized as "Low" are parameters that could potentially be recorded but the measured data is expected to be either inaccurate (i.e. vessel speed) or more easily gathered from other sources (ambient conditions).

Data Logging System and Sensors

The data collection system must be able to record data accurately and reliably for extended periods of time. The data logger should have some level of battery backup and should be programmed to periodically restart to minimize data loss should the unit lose external power. The data logger and sensors must faithfully operate unattended and should be field serviceable if a component fails.

Data Acquisition System

The data collection device should be capable of concurrently measuring the necessary parameters from all of the engines on the vessel. By concurrently measuring the parameters, engine-to-engine variability can be identified and redundant data can be collected to minimize lost data.

The data logging system should be compact and modular so that it can be installed and serviced with minimal disruption to the crew of the vessel. It should be small enough to be placed on a wall or ceiling away from any areas that may need to be serviced on the vessel. The data logger should be able to operate under its own power for a few hours and have the ability to be powered from AC or DC sources. It may be advisable to have an isolated power conditioning system to avoid any line spikes.

The data logger should be able to capture data at 1 Hz for a suitable period (i.e. greater than one week) before downloading. Wireless communication is an advantage but is most likely too slow for the amount of data to be collected. Wireless communication may provide for a means to check the data logger activity as a quality assurance, quality control check to minimize lost data. The data logger and associated sensors must not interfere with the vessel's communications.

The data logger should be able to take a wide range of sensor output that include voltage, current, frequency, digital, and serial. It should allow sensors to be easily changed out when one fails or to accept a new signal input if a sensor type has changed. The electrical connections and the data logger should be watertight and be able to withstand the marine environment. The data logger and sensors must be able to withstand on-board shock and vibrations found during normal vessel operation. The logger and sensors should be tamperproof but still allow for the normal maintenance of the vessel. The data logger should be able to power down in a "sleep mode" while the engines are turned off to conserve power. Likewise the loggers should be able to "wake up" when the engines are started. Therefore, a time and date stamp is essential.

Sensors

From the parameters identified above, sensors should be selected based upon prior in-use testing. Prior experience should be used to identify specific sensors that can be used in the marine environment and are not influenced by the medium being measured or the vibration from the engine or from the movement of the vessel.

Temperature

On-board temperature measurements should be made using type K thermocouples. Type K thermocouples provide for a wide range of temperatures, are robust (will not corrode), and are readily available. Braided thermocouple wire is recommended between the thermocouple and the data logger. Thermocouples should have an accuracy of ±3°C and a response time of no more than a few seconds. Temperature parameters include:

1. 1. Two exhaust temperatures per engine (post turbocharger outlet and expected location of aftertreatment system)
2. 2. One intake manifold air temperature per engine
3. 3. One ambient temperature per vessel

Pressure

Pressures (absolute and/or differential) may be measured on the vessel with capacitive or strain-gage transducers. Pressure parameters include:

1. 1. One exhaust backpressure per engine
2. 2. One intake manifold air pressure per engine
3. 3. One Barometric Pressure per vessel

Ambient or barometric pressure can be measured if the data logger has sufficient capacity. In the absence of barometric pressure being measured directly, it is recommended that weather data be used from the local reporting station. Pressure measurements should be made to within 2% of the actual pressure. Thermal effects should be less than 2% between 0 to 60 °C. The sensor(s) must be compatible with the fluid media being measured (i.e. stainless steel for exhaust measurements). Pressure sensor exposure to heat (intake manifold or exhaust backpressure) will require that the sensor be remotely mounted from the port location to minimize thermal effects and avoid thermal damage. This can be accomplished by using a short section (~12") of SS tubing. Response times should be less than one second to capture transient events.

Fuel Flow

Fuel flow may be measured by fuel flow meters installed in both the supply and return lines to the engine and may give an alternative method of determining engine load although this method is considered suitable only for short-term emission measurement efforts and not for long-term data logging or emission control system operation. The accuracy of the sensors will be additive and as a result the use of such measurements in subsequent mathematical calculations should be minimized.

Engine Speed

Engine speed can be easily measured by tapping into the existing engine speed signal or by placing a second speed sensor into the engine bell housing, if a port is available. Engine speed is measured by counting the number of teeth on the starter ring gear teeth passing the sensor. Engine speed can be accurately measured to within two rpm. Alternate methods are available and include optical and magnetic from the engine pulleys or electrically from the alternator. All methods require knowledge of the engine component geometry. Engine speed is necessary if exhaust flowrate is to be inferred from manifold air pressure and manifold air temperature. Engine speed will also be necessary to infer engine power.

Intake Air Flowrate or Exhaust Flowrate

Intake or exhaust flow rate may be difficult to measure directly for the purposes of data logging. Methods employed in engine testing include averaging Pitot tubes, constant temperature anemometers (hot-wire anemometers), subsonic and critical flow venturis, laminar flow elements, ultrasonic flow meters and vortex shedding flow meters. Because of non-ideal geometrical layouts of the intake or exhaust system, most flow devices cannot be installed according to manufacturers recommendations (required upstream and downstream straight pipe lengths) due to space limitations in the engine compartment. If these flow measurement devices are placed in a non-ideal flow stream, then these devices should be calibrated for the specific geometric layout.

To avoid the problems with direct flow measurement for data logging (as opposed to emission testing), a good estimate of the intake or exhaust flow rate through the engine can be obtained from the manifold air pressure, manifold air temperature, engine speed, and knowledge of the volumetric efficiency of the engine. A good estimation of the volumetric efficiency can be made that would be on the same order of error as installing a flow meter in a non-ideal flow geometry.

Ambient Conditions

Ambient conditions (barometric pressure, temperature, and humidity) data is not recommended for continuous capture during on-board data logging. It is recommended that weather data be used from the local reporting station if this information is required.

Vessel Speed and Route

Given the variable characteristics of water currents and vessel orientation in the region that the vessels operate it is effectively impossible to determine vessel speed over the water with any degree of accuracy. It is essential however that vessel location, speed and direction be determined using a global positioning system (GPS) to verify route repeatability and overall vessel activity (e.g. cruise, maneuvering and idle). A commercial GPS unit will be used to measure the speed and direction of the vessel. Data should be recorded at the nominal 1 Hz broadcast rate.

Engine Load

Engine load is not easily measured on mechanically controlled engines and not required for the sizing of the aftertreatment system, however, many vendors utilize an engine torque speed map to operate and optimize their control system. Direct measurement of engine torque is possible however the methods used for direct measurement are generally not suitable for long term operation of an emission control system and some other method of inferring engine load (e.g. power or torque) is recommended. If an electronically-controlled engine is used and or if a generator is connected to the output shaft of the engine, the engine load can be inferred. For the electronically controlled engine, the method of obtaining the load is discussed below. For a generator set, the load can be inferred by measuring the generator potential and current and applying generator efficiency. This method will provide an engine load within 10% accuracy.

ECU Interface

For electronically controlled engines, a wide range of engine data may be available. Specifically, intake manifold temperature, intake manifold pressure, engine speed, and engine load may be broadcast at a 10 Hz rate. A close examination of the engine(s) to be tested with ECUs will have to be made before deciding if this data can be collected. The procedure to infer torque and power from an ECU-controlled engine can be found in Thompson et al. (2002) and the associated SAE J standards.

Measurement Procedure

The data logging system integrity and operation will need to be verified and qualified prior to installing it onto the vessel. The following procedure is proposed to insure a high degree of accuracy in the data:

Qualify the Sensors in a Laboratory Setting

All sensors will be qualified in a laboratory before being placed into service. All sensors will be calibrated against known standards.

Qualify the Data Logger in a Laboratory Setting

The data loggers will be qualified in a laboratory before being placed into service. Each analog input, digital line, counter timer line, etc. of the data logger will be verified against known standards.

Qualify the System in a Laboratory Setting

The complete data collection system, sensors, cables, data logger, memory cards, etc., will be verified prior to the installation on the vessel. All power sources, signal conditioning, etc. will be verified that they work.

Verify the System Integrity on Road

The intent of verifying the system integrity is to determine if there are any vibration influences or responses of the sensors and data logging equipment. The qualified system from the laboratory will be installed into an on-road or off-road vehicle for example and driven over normal roads to see if there are inertial or vibration influences on the data logging system. These vibration influences are considered greater than those on board a vessel.

Install the System on Board the Vessel

The verified system will be installed on the vessel with the help from the vessel's operator.

Check or Verify the Sensors' Response

The sensors will be checked while the engine(s) is (are) off to insure that ambient or zero values are being recorded. This will verify that the sensors are "zeroed."

Take Preliminary Data While the Engine Idles

With the engine(s) at idle, the values recorded from the sensors will be recorded. The preliminary data will be examined to identify any errors or faults in the data logging system. If the data appears complete, data collection can commence. If there is any error, the sources of the error will be identified and repaired.

Download the Data

The data will be downloaded per the project requirements. Initial data will be downloaded within a short time frame during the first several days and then allowing for a slightly longer duration thereafter. After the data has been download, or memory cards swapped, the data logger will be restarted for the next collection period.

Post Data for Review

The downloaded data will be reviewed (QA/QC). Any errors will be identified and the source of error rectified by the next download session. The data will be posted for the sponsors review.

Remove Data Logger

At the completion of the data logging, the system will be removed from the vessel.

References

Gautam, M., Clark, N., Thompson, G. J., Carder, D. K., and Lyons, D. W., "Development of In-Use Testing Procedures for Heavy-duty Diesel-Powered Vehicle Emissions," Phase II Report, Submitted to the Settling Heavy-Duty Diesel Engine Manufacturer, Morgantown, WV, West Virginia University, 2000.

SAE Standard J1587, "Joint SAE/TMC Electronic Data Interchange Between Microcomputer Systems in Heavy-Duty Vehicle Applications," Warrendale, PA: Society of Automotive Engineers, 1996.

SAE Standard J1922, "Powertrain Control Interface for Electronic Controls Used in Medium and Heavy Duty Diesel On-Highway Vehicle Applications," Warrendale, PA: Society of Automotive Engineers, 1989.

SAE Standard J1939/71, "Vehicle Application Layer," Warrendale, PA: Society of Automotive Engineers, 1996.

Thompson, G. J., Clark, N. N., Gautam, M., Carder, D. K., and Lyons, D. W., "Inference of Torque and Power from Heavy-Duty Diesel Engines for On-road Emissions Monitoring." Warrendale, PA: SAE Paper No. 2002-01-0614, 2002.

Weaver, C. S., "Protocol for Measurement of Air Pollutant Emissions from Ferry Boats," Draft Document to the San Francisco Bay Water Transit Authority Dated August 19, 2002, San Francisco, CA, 2002.

Parameters Specific to the Staten Island Ferry

Demonstration

Table 2 illustrates parameters that will be measured on board the Austen Alice Staten Island Ferry Vessel as well as the sensor used to measure each parameter. Data will be collected at a frequency of 1 Hz for a minimum period of approximately 15 days up to an expected maximum of 60-days to determine operational repeatability. Note that there are two primary drive engines (Cat 3516) and two auxiliary engines (Cat 3406) that will be logged as part of this demonstration.

Table 2 Parameters for Austen Alice vessel data logging.

Parameter	Sensor	Application
Date and Time	Internal to Data Logger	One for the vessel
Exhaust Temperature	Thermocouple Omega CASS-18U-12	Two for each drive engine, One for each auxiliary engine
Global Positioning Data	GPS Module	One for the vessel
Engine Speed	Magnetic Sensor	One for each drive engine, Essentially fixed for the aux engines
Exhaust Flow	Calculated	Calculated each drive engine, Manufacturers data for aux engines
Intake Temperature	Thermocouple Omega CASS-18U-12	One for each drive engine located after the intake air intercooler
Intake Pressure	Remote Pressure sensor Omega PX215-030GI	One for each drive engine located after the intake air intercooler
Exhaust Backpressure	Remote Pressure sensor Omega PX215-015GI	One for each drive engine measured at the turbocharger
Engine NOx ppm	Chemical Cell	One for each drive engine, Slipstream taken at the turbocharger

The data logger utilized for the data logging will be a DataTaker DT800 (www.datataker.com). This unit is capable of recording up to 42 analog channels of data and GPS a 1 Hz for six weeks between downloads. Data is downloaded by removing the memory card and inserting a blank card into the data logger. Data is continuously recorded while the memory card is exchanged so no data is lost in the exchange.

This demonstration project is targeting the control of NOx and PM emissions from the primary drive engines only at this time and as a result the majority of the data logging parameters being recorded are to facilitate the design of SCR for the main engines only. The project is considering available PM control options for the auxiliary engines and as a result only exhaust temperature is necessary and is being recorded on these engines. A suitable estimate of exhaust flow for the auxiliary engines can be determined from engine manufacturers data which will be included in the vessel information report.

APPENDIX C

Ferry Operator Questionnaire

NYSERDA / NYCDOT: NYC PRIVATE FERRY EMISSION REDUCTION TECNOLOGY STUDY

FLEET/VESSEL CHARACTERIZATION SURVEYS

Background
The New York State Energy Research and Development Authority (NYSERDA) and the New York City Department of Transportation (NYCDOT) have tasked Seaworthy Systems, Inc. to characterize the fleets and vessels of NYC private ferry operators, in support of the above agencies Emission Reduction Program. Specific objectives of this tasking are to identify the inventory of applicable private ferry boats, and perform a characterization of the engine types, operating profiles, space constraints, and other factors impacting the possible applicability of various emissions control options.

Completion of Surveys
Attached with this cover sheet are two surveys with fleet specific and vessel specific questions, in support of this tasking. In order to obtain a clear characterization and categorization of all applicable vessels, Seaworthy requests your assistance in completing these forms. It is Seaworthy's intention to visit your facilities and/or vessels to collect applicable data, as well as communicate with appropriate personnel to complete the surveys. Any assistance in filling out the attached forms is greatly appreciated. Please mail or fax, copies of these surveys to the address below.

Frederick Pardi
Senior Marine Engineer
Seaworthy Systems, Inc.
22 Main Street
Centerbrook, CT 06409
Fax: (860) 767-1263

Contact Fred Pardi at (860) 767-9061, extension 121 or Don Ricciuti (x 103) if you have technical questions on the program or the characterization surveys.

Seaworthy Systems, Inc.

FLEET SURVEY

Send completed survey to:
Fred Pardi at fpardi@seaworthysys.com
Fax: (860) 767-1263
Tel: (860) 767-9061

These questions apply to all vessels in fleet (currently operating, under construction, and anticipated)

Organization Name:
NYSERDA Emissions Program Point of Contact: **Phone Number:** **Email:** **Fax:**
What is the total number of operating vessels in fleet?
Are there any new vessels under construction or anticipated? If so, how many?
If there are vessels under construction, list the vessel names, vessel type and/or class, and delivery dates. *(For each new vessel complete a Vessel Survey form as well.)*
Are there identical vessels (*same hull, engine(s), and builder)* **in fleet? If yes, identify the class name and the amount of vessels in class.** *(on the Vessel Survey form there is a line entry for vessel class, identify class name on that form as well, maintaining uniformity with what is indicated here.)*
Does each vessel have a dedicated route? If no, are vessels replaced on route by similar sized/class vessel, or is it happenstance?
Fleet Survey Form completed by: **Date:**

Seaworthy Systems, Inc.

VESSEL SURVEY

Send completed survey to:
Fred Pardi at fpardi@seaworthysys.com
Fax: (860) 767-1263
Tel: (860) 767-9061

These questions apply to all vessels in your fleet (currently operating, under construction, and anticipated)

Organization Name:	**Vessel Name:**	**Vessel Class:** *(if applicable)*

Estimated remaining service life of vessel:

Is vessel available for an exclusive one (1) day of emission testing operations:

Operating Profile

Longest Run:

Time:______minutes
Maximum Engine Load: _______% **Time @ Max Load: _______ min.**
Minimum Engine Load: _______% **Time @ Min Load: _______ min.**

Shortest Run:

Time:______minutes
Maximum Engine Load: _______% **Time @ Max Load: _______ min.**
Minimum Engine Load: _______% **Time @ Min Load: _______ min.**

Standard Run:

Time:______minutes
Maximum Engine Load: _______% **Time @ Max Load: _______ min.**
Minimum Engine Load: _______% **Time @ Min Load: _______ min.**

Run Allocation: *(% of vessel operating time on long, short, or standard runs)*

Longest Run:_______% **Shortest Run:_______%** **Standard Run:_______%**

Main Engines

Quantity: _______
Manufacturer: _________________
Model: ________________________
Rated horsepower: _____________

Seaworthy Systems, Inc.

Are any main engines scheduled for replacement? If yes, which ones, what will they be replaced with, and when?

Engine 1: ________________________ Engine 2: ________________________

Engine 3: ________________________ Engine 4: ________________________

What vendor is supplying engines? Who is POC? Telephone Number?

<u>Main Engine History</u>

Installation Date: *(mm/yy)* Engine 1: __________ Engine 2: __________

Engine 3: __________ Engine 4: __________

Current Engine Hours: *(as of mm/dd/yy)*__________

Engine 1: __________ Engine 2: __________

Engine 3: __________ Engine 4: __________

Last Overhaul:

Engine 1: _______________ *(hrs/mm/yy)* Engine 2: _______________ *(hrs/mm/yy)*

Engine 3: _______________ *(hrs/mm/yy)* Engine 4: _______________ *(hrs/mm/yy)*

Next Scheduled Overhaul:

Engine 1: _______________ *(hrs/mm/yy)* Engine 2: _______________ *(hrs/mm/yy)*

Engine 3: _______________ *(hrs/mm/yy)* Engine 4: _______________ *(hrs/mm/yy)*

Noteworthy main engine maintenance items or general comments:

Seaworthy Systems, Inc.

<u>Alternate Fuel Capability</u> *{Ultra Low Sulfur Diesel(ULSD) or BioDiesel}*

Is the operator acceptable of using alternate fuels in engines?

Is the engine manufacturer acceptable of using alternate fuels in engines?

Is current fuel supplier capable of supplying alternate fuels to vessel?

<u>Main Engine Exhaust</u>

What type of exhaust system(s) is/are installed? WET or DRY

What is length of exhaust piping in feet?

Engine 1: __________ft. Engine 2: __________ft.

Engine 3: __________ft. Engine 4: __________ft.

Is there a current means to measure exhaust temperature?

If not, is there suitable existing means to install temperature measuring equipment?

If not, what equipment modification(s) is/are necessary to install temperature measuring equipment?

Is there adequate space in the exhaust stream for installation of emission testing equipment?

If yes, what modification to piping is required to install equipment?

<u>Main Engine Exhaust Emissions</u>

Are the engines IMO Compliant with regards to exhaust emissions?

If yes, what are the as-built emission certification values for:

Nitrogen Oxide (NO_x + HC): _____________ (g/kW-hr)
Particulate Matter: _____________ (g/kW-hr)
Carbon Monoxide: _____________ (g/kW-hr)

Seaworthy Systems, Inc.

Generator Engines

Quantity: _______

Manufacturer 1: ____________ Model: ____________ Rated Load:___________

Manufacturer 2: ____________ Model: ____________ Rated Load:___________

Manufacturer 2: ____________ Model: ____________ Rated Load:___________

Generator Loads

What is average generator load during transits?

Engine 1: ________________________ Engine 2: ________________________

Engine 3: ________________________ Engine 4: ________________________

Are any generator engines scheduled for replacement? If yes, which ones, what will they be replaced with, and when?

Engine 1: ________________________ Engine 2: ________________________

Engine 3: ________________________ Engine 4: ________________________

What vendor is supplying engines? Who is POC? Telephone Number?

Generator Engine History

Installation Date: *(mm/yy)* Engine 1: __________ Engine 2: __________

Engine 3: __________ Engine 4: __________

Current Engine Hours: *(as of mm/dd/yy)*__________

Engine 1: __________ Engine 2: __________

Engine 3: __________ Engine 4: __________

Last Overhaul:

Engine 1: _______________ *(hrs/mm/yy)* Engine 2: _______________ *(hrs/mm/yy)*

Engine 3: _______________ *(hrs/mm/yy)* Engine 4: _______________ *(hrs/mm/yy)*

Seaworthy Systems, Inc.

<u>Generator Engine History</u> (cont.)

Next Scheduled Overhaul:

Engine 1: _______________ *(hrs/mm/yy)* Engine 2: _______________ *(hrs/mm/yy)*

Engine 3: _______________ *(hrs/mm/yy)* Engine 4: _______________ *(hrs/mm/yy)*

Noteworthy generator engine maintenance items or general comments:

<u>Alternate fuel capability:</u> *{Ultra Low Sulfur Diesel(ULSD) or BioDiesel}*

Is the operator acceptable of using alternate fuels in generator engines?

Is the engine manufacturer acceptable of using alternate fuels in generator engines?

Is current fuel supplier capable of supplying alternate fuels to vessel?

<u>Generator Engine Exhaust</u>

What type of exhaust system(s) is/are installed? WET or DRY

What is length of exhaust piping in feet?

Engine 1: __________ft. Engine 2: __________ft.

Engine 3: __________ft. Engine 4: __________ft.

Is there a current means to measure exhaust temperature?

If not, is there suitable existing means to install temperature measuring equipment?

If not, what equipment modification(s) is/are necessary to install temperature measuring equipment?

Seaworthy Systems, Inc.

<u>Generator Engine Exhaust</u> (cont.)

Is there adequate space in the exhaust stream for installation of emission testing equipment?

If yes, what modification to piping is required to install equipment?

<u>Generator Engine Exhaust Emissions</u>

Are the engines IMO Compliant with regards to exhaust emissions?

If yes, what are the as-built emission certification values for:

Nitrogen Oxide (NO_x + HC): _____________ (g/kW-hr)
Particulate Matter: _____________ (g/kW-hr)
Carbon Monoxide: _____________ (g/kW-hr)

<u>General Comments / Additional Notes:</u>

Fleet Survey Form completed by: **Date:**

Seaworthy Systems, Inc.

APPENDIX D

Specification Sheets of Installed Data Logging Equipment

PRODUCT REPORT 09:26 19/06/03

DT800 : 12-42 Channels, Ethernet, USB, 100kHz

SN 81064

Assemblies :	1137-103 AS1156B1	DT800 Kernel Board
	1138-009 AS1157A3	DT800 Analog Board
	1139-032 AS1158A3	DT800 PC Card Board
	1140-123 AS1159A3	DT800 Charger Board
	1141-034 AS1160A3	DT800 Terminal Board

ROM 6:14

Datataker Product Warranty

Data Electronics (Aust.) Pty. Ltd. warrants its instruments against defects in materials or workmanship for a period of 3 years from the date of delivery to the original customer. This warranty is limited to the repair or replacement of such defect, without charge, when the instrument is returned to Data Electronics (Aust.) Pty. Ltd. or one of its authorised dealers.

This warranty excludes all other warranties, either express or implied, and is limited to a value not exceeding the purchase price of the instrument.

Data Electronics (Aust.) Pty. Ltd. shall not be liable for any incidental or consequential loss or damages resulting from the use of the instrument, or for damage to the instrument, resulting from accident, abuse, improper implementation, lack of reasonable care, or loss of parts.

This warranty expressly excludes batteries supplied with products, including loggers, card readers and memory cards.

Third Party Products

Third party products supplied by Data Electronics (Aust.) Pty. Ltd. carry the original warranty defined by the manufacturer. Unless expressly stated, Data Electronics (Aust.) Pty. Ltd. does not extend or otherwise modify the terms and conditions of such warranties.

The Test Report

The attached report details the results of tests performed on your DT800 before shipping, to ensure the highest possible standards of quality, precision and accuracy.

These tests are performed using equipment whose calibration is traceable to instruments certified by the National Association of Testing Authorities, Australia (NATA).

dataTaker Pty Ltd Melbourne & Sydney Australia Tel: +613 9764 8600
dataTaker Ltd Letchworth United Kingdom Tel: +441 462 481291
dataTaker, Inc Los Angeles United States of America Tel: 1-800-9-LOGGER

PRODUCT REPORT 09:26 19/06/03

T800	:	12-42 Channels, Ethernet, USB, 100kHz	
Assemblies	:	1137-103 AS1156B1	DT800 Kernel Board
		1138-009 AS1157A3	DT800 Analog Board
		1139-032 AS1158A3	DT800 PC Card Board
		1140-123 AS1159A3	DT800 Charger Board
		1141-034 AS1160A3	DT800 Terminal Board

SN 81084

ROM 6:14

www.dataTaker.com

TEST REPORT GENERATED ON 06/19/2003 AT 9:25:05

SERIAL NUMBER 081084

ASSEMBLY		Prodn #		
Kernel	AS1156B1	1137-103	RAM Size	4096 kB
Analog	AS1157A3	1138-009	RAM Speed	100 nS
PCMCIA	AS1158A3	1139-032	Flash Size	2048 kB
Charger	AS1159A3	1140-123	Flash Speed	120 nS
Terminal	AS1160A3	1141-034		

dataTaker 800 Version 3.16.0001 Flash 2003/02/07 15:46:14

External Supply	13.527 V	N/A	VddhISense	3.329 V	PASS
System Voltage	13.015 V	PASS	Vddh1 Rail	3.306 V	PASS
ttery Voltage	13.547 V	PASS	Vddh2 Rail	3.305 V	PASS
thium Battery	3.607 V	PASS	Vddh3 Rail	3.305 V	PASS
Host RS-232 Supply	-7.697 V	PASS	VccISense	3.341 V	PASS
Analog +Mux Supply	18.668 V	PASS	Vcc1 Rail	3.338 V	PASS
Analog -Mux Supply	-18.899 V	PASS	Vcc2 Rail	3.339 V	PASS
Analog +5 V Supply	5.319 V	PASS	3V3 Rail	3.344 V	PASS
Analog -5 V Supply	-5.340 V	PASS	Vbackup	3.129 V	PASS
PCMCIA +3 V Supply	3.332 V	PASS			
PCMCIA +5 V Supply	5.028 V	PASS	Sensor Power @ 5V	5.007 V	PASS
PCMCIA 12 V Supply	12.045 V	PASS	Sensor Power @ 10V	10.185 V	PASS
Kernel 1.182 V Ref	1182.0 mV	PASS	Analog 2.5 V Ref	2.500 V	PASS
Kernel Zero V Ref	-0.000 V	PASS	Analog Zero V Ref	0.013 V	PASS
CMR Ratio	102 dB	PASS			

Ethernet Address 00-90-2E-00-08-82

ADC Gain 0 Zero	-2.042267e+04	mV
ADC Gain 1 Zero	-1.134276e+04	mV
ADC Gain 2 Zero	-5.639370e+03	mV
ADC Gain 3 Zero	-2.268670e+03	mV
ADC Gain 4 Zero	-1.009035e+03	mV
ADC Gain 5 Zero	-5.045569e+02	mV
ADC Gain 6 Zero	-2.018172e+02	mV
ADC Gain 7 Zero	-1.009563e+02	mV
ADC Gain 8 Zero	-5.669434e+01	mV
C Gain 9 Zero	-2.060516e+01	mV
ADC Gain 10 Zero	-1.004367e+01	mV

dataTaker
...keeping an eye on reality

dataTaker Pty Ltd
Melbourne & Sydney
Australia
Tel: +613 9764 8600

dataTaker Ltd
Letchworth
United Kingdom
Tel: +441 462 481291

dataTaker, Inc
Los Angeles
United States of America
Tel: 1-800-9-LOGGER

PRODUCT REPORT 09:26 19/06/03

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*****************
*      SN       *
*               *
*         81084 *
*****************
```

DT800 : 12-42 Channels, Ethernet, USB, 100kHz

Assemblies :	1137-103 AS1156B1	DT800 Kernel Board
	1138-009 AS1157A3	DT800 Analog Board
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	1140-123 AS1159A3	DT800 Charger Board
	1141-034 AS1160A3	DT800 Terminal Board

ROM 6:14

www.dataTaker.com

DAC Excite Zero	0.000000e+00	mV	DAC Trigger Zero	0.000000e+00	mV
DAC Excite Slope	4.028320e+00	mV/b	DAC Trigger Slope	4.028320e+00	mV/b
DAC Excite Full	1.650000e+04	mV	DAC Trigger Full	1.650000e+04	mV

ADC Gain 0 Slope	6.231239e-01	mV/b
ADC Gain 1 Slope	3.460885e-01	mV/b
ADC Gain 2 Slope	1.725334e-01	mV/b
ADC Gain 3 Slope	6.922128e-02	mV/b
ADC Gain 4 Slope	3.078895e-02	mV/b
ADC Gain 5 Slope	1.539744e-02	mV/b
ADC Gain 6 Slope	6.157578e-03	mV/b
ADC Gain 7 Slope	3.078081e-03	mV/b
ADC Gain 8 Slope	1.727307e-03	mV/b
ADC Gain 9 Slope	6.257035e-04	mV/b
ADC Gain 10 Slope	3.035490e-04	mV/b

Excite Path Resistance	1.000171e+02	Ohm
Return Path Resistance	1.000171e+02	Ohm

Temperature Offset	0.96	degC
Charact'd at Temperature	21.43	degC

Power Supply	PASS	PCMCIA Card Test	PASS	AS1156 Assembly	PASS
Supply Rails	PASS	LED Display Test	PASS	AS1157 Assembly	PASS
Ref Voltages	PASS	Digital I/O Test	PASS	AS1158 Assembly	PASS
Communications	PASS	Analog Channels	PASS	AS1159 Assembly	PASS
Baud Rates	PASS	Characterisation	PASS	AS1160 Assembly	PASS

END OF TEST REPORT

```
****************************************************************************
*                                                                          *
* Passed by   OC   09:26 19/06/03                                          *
*          OC.                                                             *
****************************************************************************
```

GREATER RANGE LESS FUEL
DON'T LEAVE THE DOCK WITHOUT IT

NEW Series K Diesel Fuel Flow Monitoring Systems

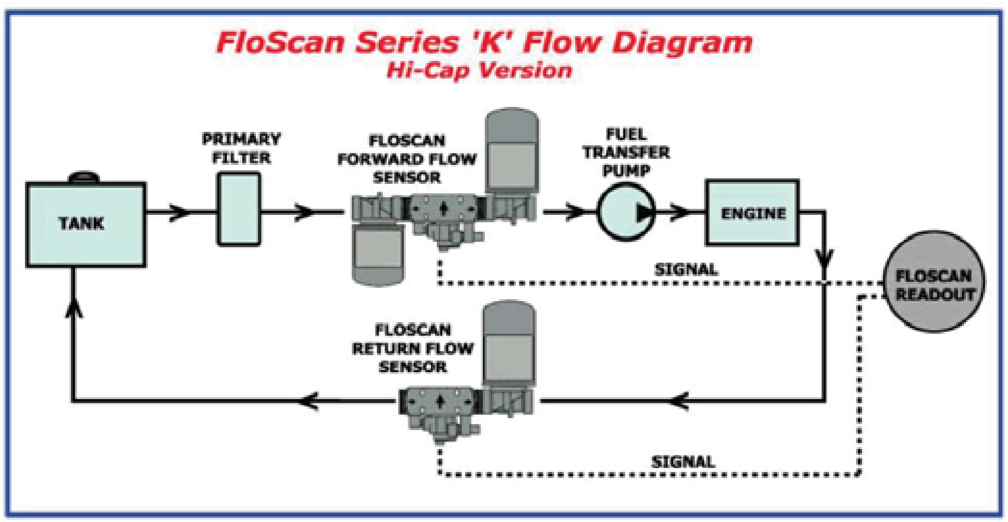
FloScan's new Series K Diesel Fuel Flow Monitoring System represents a major technical breakthrough in diesel fuel management. The easier-to-install Series K model cuts the installation time and cost in half over previous diesel models. IMPORTANT NOTE: **Separately mounted fuel pulsation dampers are no longer required.** New fuel flow sensor design also enhances system performance and accuracy. Simplified procedures allow for do-it-yourself installation. Fits diesel engines from 25 to 4300 hp.

FloScan Fuel Flow Monitoring Systems are the industry standard for determining the instantaneous fuel burn rate and total fuel consumed. A list of the uses include:

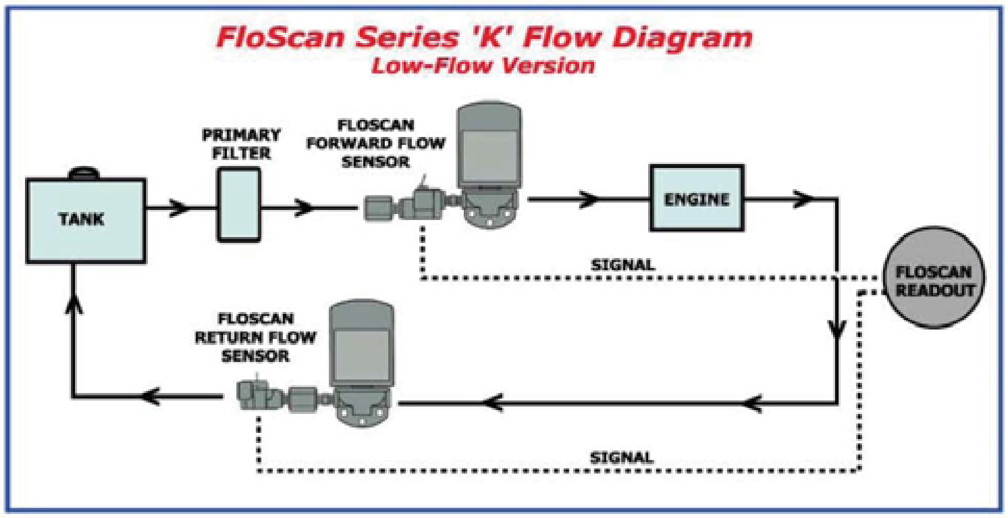
Marine Applications
- Provides most efficient engine running speed under any load or operating condition
- Keeps track of total fuel consumed on every trip

Generator and Prime Power Applications
- Provides accurate fuel usage data for determining NOx emission output
- Provides accurate fuel usage data for billing purposes
- Provides method for determining engine service intervals

Click here to access our Series K Model Selection Guide



Hi-Capacity Sensors:



Low-Capacity Sensor:

Model 209

Pressure Transducer

Setra Systems 209 pressure transducers have been designed specifically for industrial applications with demanding price and performance requirements. The 209 offers exceptional reliability in typical industrial grade environments. Standard features tailor the Model 209 for applications with more extreme environmental conditions or more stringent performance needs. The Model 209 offers unparalleled performance in a configurable transducer designed specifically for the budget conscious OEM.

Setra's proven center mount electrode configuration is the heart of this simple, yet industrialized, design. A 17-4 PH stainless steel sensor and a rigid stainless steel electrode form the variable capacitor.

Setra 209 transducers are packaged in rugged stainless steel/Valox housings, which are small and lightweight for optimum compatibility with system designs. As a totally self - contained electronic package, the 209 stainless steel capacitance sensing element, coupled with a high level output IC-based circuit, assures excellent accuracy and long term stability.

When it comes to a product to rely on - choose the Model 209. When it comes to a company to trust - choose Setra

Model 209 Specifications

Performance Data

AccuracyRSS* (at constant temperature)	±0.25% FS
Non-Linearity (BFSL)	±0.22% FS
Hysteresis	0.10% FS
Non-Repeatability	0.05% FS
Thermal Effects	
Compensated Range °F (°C)	-4 to +176 (-20 to +80)
Zero Shift %FS/100°F (%FS/50°C)	±2.0 (±1.8)
Span Shift %FS/100°F (%FS/50°C)	±1.5 (±1.3)
Warm-up Shift	±0.1% FS total
Response Time	5 milliseconds
Stability	0.5% FS/Year

*RSS of Non-Linearity, Non-Repeatability and Hysteresis.

Environmental Data

Temperature	
Operating °F (°C)	-40 to +185 (-40 to +85)
Storage °F (°C)	-40 to +185 (-40 to +85)
Vibration*	20g
Shock**	200g
Environmental Protection	Weather Resistant

*MIL-STD 202, Method 204, Cond. C

**MIL-STD 202, Method 213B, Cond. C

Physical Description

Case	Stainless Steel & Valox
Sensor	17-4 PH Stainless Steel
Electrical Connection	2 ft. multiconductor cable
Pressure Fitting*	1/4" -18 NPT external, 17-4 PH Stainless Steel
Vent	Through cable
Weight (approx.)	2.3 ounces (65 grams)

*See ordering information for other fittings available (minimum quantities apply)

Electrical Data (Voltage)

Circuit	3-Wire (Com, Out, Exc)
Excitation	9 to 30 VDC
Output*	0.5 to 5.5 VDC**
Output Impedance	10 ohms

*Calibrated into a 50K ohm load, operable into a 5000 ohm load or greater.

**Zero output factory set to within ±50mV.

**Span (Full Scale) output factory set to within ±50mV.

Note: Other outputs are available with 9 to 30 VDC excitation.
An output of 0.5 to 4.5 VDC output is available with 5 VDC excitation.

Electrical Data (Current)

Circuit	2-Wire
Output*	4 to 20 mA**
External Load	0 to 800 ohms

Minimum supply voltage (VDC) = 9 + 0.02 x (Resistance of receiver plus line).

Maximum supply voltage (VDC) = 30 + 0.004 x (Resistance of receiver plus line).

*Calibrated at factory with a 24 VDC loop supply voltage and a 250 ohm load.

**Zero output factory set to within ±0.16mA.

**Span (Full Scale) output factory set to within ±0.16mA.

Pressure Media

Liquids or gases compatible with 17-4 PH Stainless Steel*.

*Note: Hydrogen not recommended for use with 17-4 PH Stainless Steel.

Specifications are subject to change without notice.

NOTE: Setra quality standards are based on ANSI-Z540-1.
The calibration of this product is NIST traceable.
U.S. Patent Nos. 409315, and other Patents Pending.

Gauge, Compound, and Vacuum Pressure Ranges*

(Sealed ranges available on 200 PSI and above)

	STANDARD		OPTION	
Full Scale Range (PSI)	Proof Pressure (PSI)	Burst Pressure (PSI)	High Proof Pressure (PSI)	High Burst Pressure (PSI)
1	2	250	N/A	N/A
2	4	250	N/A	N/A
5	10	250	N/A	N/A
10	20	500	N/A	N/A
25	50	500	N/A	N/A
50	100	750	800	5000
100	200	1000	1000	5000
200	400	2000	1500	5000
250	500	2000	2000	8000
500	1000	3000	2500	10,000
1000	2000	5000	4000	10,000
1500	2500	6000	5000	12,000
2000	3000	6500	N/A	N/A
3000	4500	7500	N/A	N/A
5000	7500	10,000	N/A	N/A
10,000	12,500	20,000	N/A	N/A
-14.7 (Vacuum)	10	15	N/A	N/A

*Also available in Bar ranges. Consult Factory.

Gauge Pressure: Pressure measured relative to ambient atmospheric pressure. Referred to as pounds per square inch (gauge) or psig.
Proof Pressure: The maximum pressure that may be applied without changing performance beyond specifications (±0.5% FS zero shift).
Burst Pressure: The maximum pressure that may be applied to the positive pressure port without rupturing the sensing element.

Applications

- Industrial OEM Equipment
- Hydraulic Systems
- Compressor Control
- HVAC/R Equipment
- Industrial Engines
- Process and Containerized Refrigeration Systems

Benefits

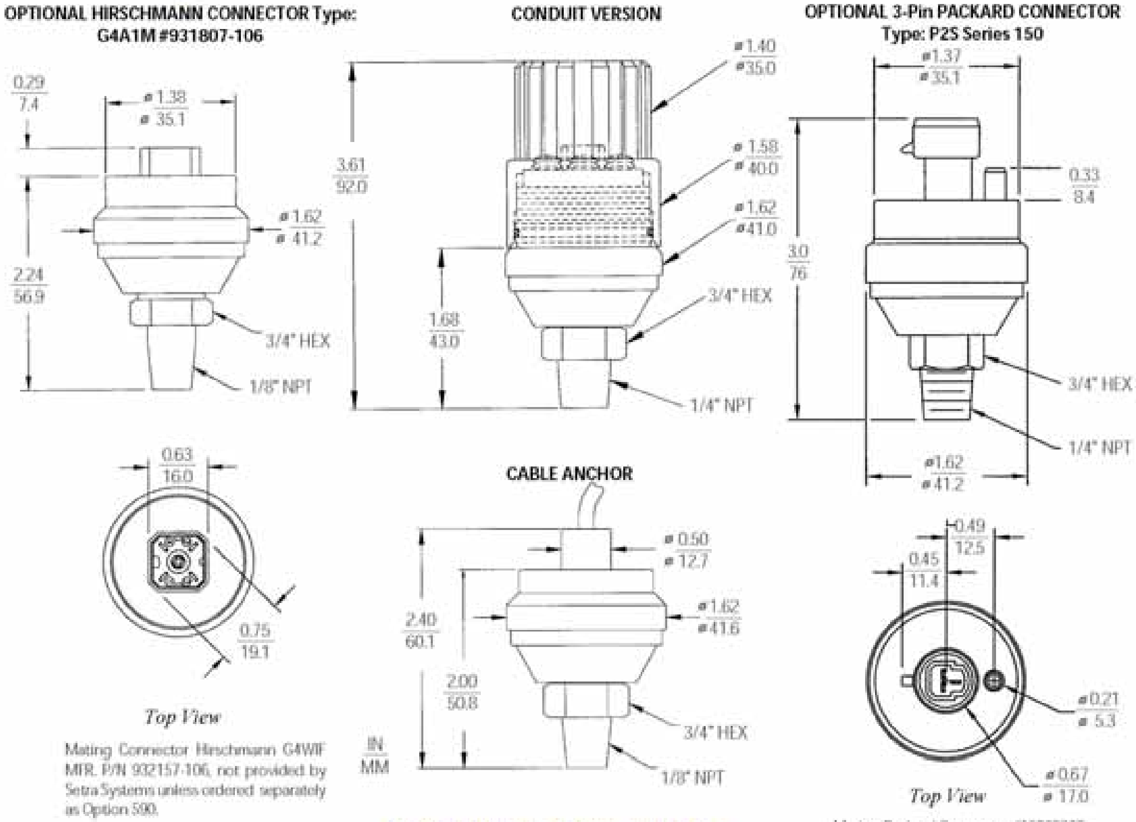
- High Over Pressure Option Available on Selected Ranges NEW
- Rugged Design Survives Harsh Environments
- Operates Over a Wide Temperature Band
- Compatible with Wide Range of Gases and Liquids
- Operates on Low Cost Unregulated DC Power
- Suitable for High Shock and Vibration Applications
- No Seals or "O" Rings to Cause Leakage
- No Brazed Joints Susceptible to Corrosion Problems
- 3 to 5 Day Shipment for Small Quantities, Standard Configurations

ISO 9001 Certified

Visit Setra Online:
http://www.setra.com

setra
800-257-3872

Outline Drawings



Mating Connector Hirschmann G4WIF MFR. P/N 932157-106, not provided by Setra Systems unless ordered separately as Option 590.

Mating Packard Connector #12065287, 3 terminals #12103881, not provided by Setra Systems unless ordered separately as Option 854.

ORDERING INFORMATION

Model 209 Pressure Transducer

Code all blocks in table.

Example: Part No. 2091050PG2M1102 for a 209 Transducer 0 to 50 PSIG Range, 1/4" NPT Male Pressure Fitting, 4 to 20 mA Output, and 2 Feet of Cable.

2 0 9 1 — ☐☐☐☐ — ☐ — ☐☐ — ☐☐ — ☐☐ — ☐

Model

2091 = 209

Pressure Ranges

PSI

- **001P** = 0 to 1 PSI
- **002P** = 0 to 2 PSI
- **005P** = 0 to 5 PSI
- **010P** = 0 to 10 PSI
- **025P** = 0 to 25 PSI
- **050P** = 0 to 50 PS
- **100P** = 0 to 100 PSI
- **200P** = 0 to 200 PSI
- **250P** = 0 to 250 PSI
- **500P** = 0 to 500 PSI
- **10CP** = 0 to 1000 PSI
- **15CP** = 0 to 1500 PSI
- **20CP** = 0 to 2000 PSI
- **30CP** = 0 to 3000 PSI
- **50CP** = 0 to 5000 PSI
- **10KP** = 0 to 10000 PSI
- **Z01** = 0 to -14.7 PSI

Type

- **G** = Gauge
- **C** = Compound
- **S** = Sealed (Sealed Version Available on 200 PSI Range & Above.)
- **V** = Vacuum (Z01 Range Code Only)

Pressure Fitting

- **2M** = 1/4" NPT Male
- **J7** = 7/16" SAE Male
- **1M** = 1/8" NPT Male
- **P1** = 1/8" NPT Female Bulkhead (Available on Ranges >50 PSI)

Output

- **11** = 4 to 20 mA
- **24** = 0.5 to 5.5 VDC
- **28** = 1 to 6 VDC
- **45** = 0.5 to 4.5 VDC (5 VDC Excitation)

Electrical Termination

- **XX** = Cable length in feet (i.e., 2 feet = 02)
- **P1** = Packard (3-Pin)
- **P3** = Packard (4-Pin)
- **H2** = Hirschmann, ("Mini")
- **A1** = Terminal Block w/Conduit Cover

Options

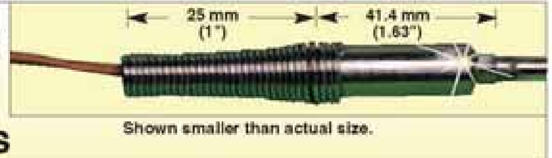
- **H** = High Overpressure Capability (Only Available on 50 PSI up to 1500 PSI Pressure Ranges)

NOTE: Standard configuration consists of: PSI Range, 1/4" NPT Fitting and 2 feet of cable. Minimum quantities apply for all other configurations. Consult a Setra Applications Engineer for assistance.

159 Swanson Road, Boxborough, Massachusetts 01719/Tel: 800-257-3872; Fax: 978-264-0292; Email: sales@setra.com; Web: www.setra.com

setra

Rugged Transition Joint Probes
With Standard Dimensions



Shown smaller than actual size.

Note: See page A-87 for probe terminations. Please see page A-131 for compression fittings.

- **304 SS, 310 SS, 316 SS, 321 SS, Inconel or Super OMEGACLAD® XL Sheath**
- **Diameters from 1/16 to 1/4"**
- **40" Teflon® Coated Stranded Lead Wire: 20 AWG for 3/16 and 1/4" O.D., 24 AWG for 1/16 and 1/8" O.D. Probes**
- **Cal-5 Available**

OMEGA® Heavy Duty Transition Joint Probes offer convenient termination to Teflon® coated lead wire. The transition joint is 1.63" long, with a 1" spring for strain relief. The joint diameter is 1/4" for 1/16 and 1/8" dia. probes, 3/8" for 3/16 and 1/4" dia. probes.

Dual Element TJ Probes
To Order, add suffix "**-DUAL**" to model no. Add to base probe price any options (extra probe length, overbraiding, armored cable), then multiply this price x 1.75.
Ordering Example: TJ36-CASS-14G-12-DUAL, $35 x 1.75 = **$61.25**.

For additional Teflon® lead wire length, add **$1.00** per 12" over 40" and change "**36**" in part no. to desired length in inches.
Ordering Example: TJ120-ICSS-14G-12, type J transition joint probe with 120" of Teflon® lead wire, 1/4 O.D. stainless steel sheath, 12" length, $35 + 7 = **$42**.

Available as Super OMEGACLAD® XL

See Pages A-45 to A-48

SLE

ANSI color code shown

To order IEC color code see pg. A-9

310 Stainless Steel Sheaths
To Order, replace "**SS**" in Model no. with 310SS, no add'l charge. **Ordering Example: TJ36-CA310SS-18G-12**, type K transition joint probe with 310 stainless steel sheath, **$28**.

Discount Schedule

1-10 units	Net
11-24 units	10%
25-49 units	20%
50 and up	Consult Sales

ALL MODELS AVAILABLE FOR FAST DELIVERY!

To Order *(Specify Model Number)*

Alloy/ANSI Color Code	Sheath Dia. (")	Model No. 12" Length	Price G*/E	Price U*	Model No. 18" Length	Price G*/E*	Price U*	Model No. 24" Length	Price G*/E*	Price U*	Price/ Add'l 12"
IRON-CONSTANTAN Inconel Sheath J	1/16	TJ36-ICIN-116(*)-12	$28.00	$30.00	TJ36-ICIN-116(*)-18	$28.80	$30.80	TJ36-ICIN-116(*)-24	$29.55	$31.55	$1.55
	1/8	TJ36-ICIN-18(*)-12	28.00	30.00	TJ36-ICIN-18(*)-18	29.60	31.60	TJ36-ICIN-18(*)-24	31.15	33.15	3.15
	3/16	TJ36-ICIN-316(*)-12	29.00	31.00	TJ36-ICIN-316(*)-18	31.20	33.20	TJ36-ICIN-316(*)-24	33.35	35.35	4.35
	1/4	TJ36-ICIN-14(*)-12	35.00	37.00	TJ36-ICIN-14(*)-18	38.80	40.80	TJ36-ICIN-14(*)-24	42.50	44.50	7.50
IRON-CONSTANTAN 304 SS Sheath J	1/16	TJ36-ICSS-116(*)-12	28.00	30.00	TJ36-ICSS-116(*)-18	28.80	30.80	TJ36-ICSS-116(*)-24	29.55	31.55	1.55
	1/8	TJ36-ICSS-18(*)-12	28.00	30.00	TJ36-ICSS-18(*)-18	28.90	32.90	TJ36-ICSS-18(*)-24	29.85	31.85	1.85
	3/16	TJ36-ICSS-316(*)-12	29.00	31.00	TJ36-ICSS-316(*)-18	30.60	32.60	TJ36-ICSS-316(*)-24	32.15	34.15	3.15
	1/4	TJ36-ICSS-14(*)-12	35.00	37.00	TJ36-ICSS-14(*)-18	37.50	39.50	TJ36-ICSS-14(*)-24	40.00	42.00	5.00
CHROMEGA®-ALOMEGA® ** Inconel Sheath K	1/16	TJ36-CAIN-116(*)-12	28.00	30.00	TJ36-CAIN-116(*)-18	28.80	30.80	TJ36-CAIN-116(*)-24	29.55	31.55	1.55
	1/8	TJ36-CAIN-18(*)-12	28.00	30.00	TJ36-CAIN-18(*)-18	29.60	31.60	TJ36-CAIN-18(*)-24	31.15	33.15	3.15
	3/16	TJ36-CAIN-316(*)-12	29.00	31.00	TJ36-CAIN-316(*)-18	31.20	33.20	TJ36-CAIN-316(*)-24	33.35	35.35	4.35
	1/4	TJ36-CAIN-14(*)-12	35.00	37.00	TJ36-CAIN-14(*)-18	38.80	40.80	TJ36-CAIN-14(*)-24	42.50	44.50	7.50
CHROMEGA®-ALOMEGA® 304 SS Sheath K	1/16	TJ36-CASS-116(*)-12	28.00	30.00	TJ36-CASS-116(*)-18	28.80	30.80	TJ36-CASS116(*)-24	29.55	31.55	1.55
	1/8	TJ36-CASS-18(*)-12	28.00	30.00	TJ36-CASS-18(*)-18	28.90	30.90	TJ36-CASS-18(*)-24	29.85	31.85	1.85
	3/16	TJ36-CASS-316(*)-12	29.00	31.00	TJ36-CASS-316(*)-18	30.60	32.60	TJ36-CASS-316(*)-24	32.15	34.15	3.15
	1/4	TJ36-CASS-14(*)-12	35.00	37.00	TJ36-CASS-14(*)-18	37.50	39.50	TJ36-CASS-14(*)-24	40.00	42.00	5.00
CHROMEGA®-CONSTANTAN Inconel Sheath E	1/16	TJ36-CXIN-116(*)-12	28.00	30.00	TJ36-CXIN-116(*)-18	28.90	30.90	TJ36-CXIN-116(*)-24	29.85	31.85	1.85
	1/8	TJ36-CXIN-18(*)-12	28.00	30.00	TJ36-CXIN-18(*)-18	29.90	31.90	TJ36-CXIN-18(*)-24	31.15	33.15	3.75
	3/16	TJ36-CXIN-316(*)-12	29.00	31.00	TJ36-CXIN-316(*)-18	31.50	33.50	TJ36-CXIN-316(*)-24	33.35	35.35	5.00
	1/4	TJ36-CXIN-14(*)-12	35.00	38.00	TJ36-CXIN-14(*)-18	39.80	41.80	TJ36-CXIN-14(*)-24	43.50	45.50	7.50
CHROMEGA®-CONSTANTAN 304 SS Sheath E	1/16	TJ36-CXSS-116(*)-12	28.00	30.00	TJ36-CXSS-116(*)-18	28.90	30.80	TJ36-CXSS-116(*)-24	29.55	31.55	1.55
	1/8	TJ36-CXSS-18(*)-12	28.00	30.00	TJ36-CXSS-18(*)-18	29.90	31.30	TJ36-CXSS-18(*)-24	30.50	32.50	2.50
	3/16	TJ36-CXSS-316(*)-12	29.00	31.00	TJ36-CXSS-316(*)-18	31.50	32.60	TJ36-CXSS-316(*)-24	32.15	34.15	3.15
	1/4	TJ36-CXSS-14(*)-12	35.00	37.00	TJ36-CXSS-14(*)-18	39.80	39.50	TJ36-CXSS-14(*)-24	40.00	42.00	5.00
COPPER-CONSTANTAN Inconel Sheath T	1/16	TJ36-CPIN-116(*)-12	28.00	30.00	TJ36-CPIN-116(*)-18	28.90	30.90	TJ36-CPIN-116(*)-24	29.55	31.55	1.85
	1/8	TJ36-CPIN-18(*)-12	28.00	30.00	TJ36-CPIN-18(*)-18	29.90	31.90	TJ36-CPIN-18(*)-24	31.75	33.75	3.75
	3/16	TJ36-CPIN-316(*)-12	29.00	31.00	TJ36-CPIN-316(*)-18	31.50	33.50	TJ36-CPIN-316(*)-24	33.35	35.35	5.00
	1/4	TJ36-CPIN-14(*)-12	35.00	38.00	TJ36-CPIN-14(*)-18	39.80	41.80	TJ36-CPIN-14(*)-24	43.50	45.50	7.50
COPPER-CONSTANTAN 304 SS Sheath T	1/16	TJ36-CPSS-116(*)-12	28.00	30.00	TJ36-CPSS-116(*)-18	28.80	30.80	TJ36-CPSS-116(*)-24	29.55	31.55	1.55
	1/8	TJ36-CPSS-18(*)-12	28.00	30.00	TJ36-CPSS-18(*)-18	29.30	31.30	TJ36-CPSS-18(*)-24	30.50	32.50	2.50
	3/16	TJ36-CPSS-316(*)-12	29.00	31.00	TJ36-CPSS-316(*)-18	30.60	32.60	TJ36-CPSS-316(*)-24	32.15	34.15	3.15
	1/4	TJ36-CPSS-14(*)-12	35.00	37.00	TJ36-CPSS-14(*)-18	37.50	39.50	TJ36-CPSS-14(*)-24	40.00	42.00	5.00
OMEGALLOY®-NICROSIL-NISIL ** Inconel Sheath N	1/16	TJ36-NNIN-116(*)-12	28.00	30.00	TJ36-NNIN-116(*)-18	28.80	30.80	TJ36-NNIN-116(*)-24	29.55	31.55	1.55
	1/8	TJ36-NNIN-18(*)-12	28.00	30.00	TJ36-NNIN-18(*)-18	29.60	31.60	TJ36-NNIN-18(*)-24	31.15	33.15	3.15
	3/16	TJ36-NNIN-316(*)-12	29.00	31.00	TJ36-NNIN-316(*)-18	31.20	33.20	TJ36-NNIN-316(*)-24	33.35	35.35	4.35
	1/4	TJ36-NNIN-14(*)-12	35.00	37.00	TJ36-NNIN-14(*)-18	38.80	40.75	TJ36-NNIN-14(*)-24	42.50	44.50	7.50

Note: *Other lengths are available, consult Sales. 6" probes also available, change* ***"-12"*** *to* ***"-6"*** *to order. No additional charge. To order optional sheaths, change* ***"SS"*** *in Model no. to* ***"IN"*** *for Inconel,* ***"304SS"*** *for 304 SS,* ***"310SS"*** *for 310 SS,* ***"316SS"*** *for 316 SS or "321SS" for 321 SS. No additional charge.*

Specify junction type:* ***E* *(Exposed),* ***G*** *(Grounded) or* ***U*** *(Ungrounded). For lengths from 2" to 12", please consult Sales.*

For* ***Super OMEGACLAD® XL*, change "IN" to "XL" and add* ***$3*** *to price.*

Ordering Examples: TJ36-CASS-18U-12*, heavy duty transition joint probe, Type K (CHROMEGA®-ALOMEGA®), 304 SS sheath, 1/8" O.D., ungrounded junction, 12" length,* ***$30. TJ36-NNXL-14G-12****, Type N transition joint probe with Super OMEGACLAD®, 1/4 O.D. stainless steel sheath, 12" length, $35 + 3 =* ***$38****.*

Rugged Transition Joint Probes
With Metric Dimensions

Shown smaller than actual size.

Note: See page A-87 for probe terminations. Please see page A-131 for compression fittings.

- 304 SS, 310 SS, 316 SS, 321 SS, Inconel or Super OMEGACLAD® XL Sheath
- Diameters from 1.5 to 6 mm
- 1 m Teflon® Coated Stranded Lead Wire: 20 AWG for 4.5 and 6 mm O.D., 24 AWG for 1.5 and 3 mm O.D. Probes
- Cal-5 Available

OMEGA® Heavy Duty Transition Joint Probes offer convenient termination to Teflon® coated lead wire. The transition joint is 41.4 mm long, with a 25.4 mm spring for strain relief. The joint diameter is 6.4 mm for 1.5 and 3 mm dia. probes, 9.7 mm for 4.5 and 6 mm dia. probes.

Dual Element TJ Probes
To Order, add suffix **"-DUAL"** to model no. Add to base probe price plus any options (extra probe length, overbraiding, armored cable), then multiply this price x 1.75.
Ordering Example: TJ1-CASS-M600G-300-DUAL, $35 x 1.75 = **$61.25**.

For additional Teflon® lead wire length, add **$3.00** per meter over 1 m and change **"1"** in part no. to desired total length in meters. **Ordering Example: TJ3-ICSS-M600G-300**, type J transition joint probe with 3 m of Teflon® lead wire, 6mm O.D. stainless steel sheath, 300mm probe length, $35 + 6 = **$41**.

Available as Super OMEGACLAD® XL

See Pages A-45 to A-48

ANSI color code shown

To order IEC color code see pg. A-9

310 Stainless Steel Sheath
To Order, replace **"SS"** in Model no. with 310SS, no add'l charge. **Ordering Example: TJ1-CA310SS-M600G-300**, type K transition joint probe with 310 stainless steel sheath, **$28**.

Discount Schedule

1-10 units .... Net
11-24 units 10%
25-49 units 20%
50 and up .... Consult Sales

ALL MODELS AVAILABLE FOR FAST DELIVERY!

To Order *(Specify Model Number)*

Alloy/ANSI Color Code	Sheath Dia. mm	Model No. 300mm Length	Price G*/E	Price U*	Model No. 450 mm Length	Price G*/E*	Price U*	Model No. 600 mm Length	Price G*/E*	Price U*	Price/Add'l 300mm
IRON-CONSTANTAN Inconel Sheath J	1.5	TJ1-ICIN-M15(*)-300	$28.00	$30.00	TJ1-ICIN-M15(*)-450	$28.80	$30.80	TJ1-ICIN-M15(*)-600	$29.55	$31.55	$1.55
	3.0	TJ1-ICIN-M30(*)-300	28.00	30.00	TJ1-ICIN-M30(*)-450	29.60	31.60	TJ1-ICIN-M30(*)-600	31.15	33.15	3.15
	4.5	TJ1-ICIN-M45(*)-300	29.00	31.00	TJ1-ICIN-M45(*)-450	31.20	33.20	TJ1-ICIN-M45(*)-600	33.35	35.35	4.35
	6.0	TJ1-ICIN-M60(*)-300	35.00	37.00	TJ1-ICIN-M60(*)-450	38.80	40.80	TJ1-ICIN-M60(*)-600	42.50	44.50	7.50
IRON-CONSTANTAN 304 SS Sheath J	1.5	TJ1-ICSS-M15(*)-300	28.00	30.00	TJ1-ICSS-M15(*)-450	28.80	30.80	TJ1-ICSS-M15(*)-600	29.55	31.55	1.55
	3.0	TJ1-ICSS-M30(*)-300	28.00	30.00	TJ1-ICSS-M30(*)-450	28.90	30.90	TJ1-ICSS-M30(*)-600	29.85	31.85	1.85
	4.5	TJ1-ICSS-M45(*)-300	29.00	31.00	TJ1-ICSS-M45(*)-450	30.60	32.60	TJ1-ICSS-M45(*)-600	32.15	34.15	3.15
	6.0	TJ1-ICSS-M60(*)-300	35.00	37.00	TJ1-ICSS-M60(*)-450	37.50	39.50	TJ1-ICSS-M60(*)-600	40.00	42.00	5.00
CHROMEGA®-ALOMEGA® ** Inconel Sheath K	1.5	TJ1-CAIN-M15(*)-300	28.00	30.00	TJ1-CAIN-M15(*)-450	28.80	30.80	TJ1-CAIN-M15(*)-600	29.55	31.55	1.55
	3.0	TJ1-CAIN-M30(*)-300	28.00	30.00	TJ1-CAIN-M30(*)-450	29.60	31.60	TJ1-CAIN-M30(*)-600	31.15	33.15	3.15
	4.5	TJ1-CAIN-M45(*)-300	29.00	31.00	TJ1-CAIN-M45(*)-450	31.20	33.20	TJ1-CAIN-M45(*)-600	33.35	35.35	4.35
	6.0	TJ1-CAIN-M60(*)-300	35.00	37.00	TJ1-CAIN-M60(*)-450	38.80	40.80	TJ1-CAIN-M60(*)-600	42.50	44.50	7.50
CHROMEGA®-ALOMEGA® 304 SS Sheath K	1.5	TJ1-CASS-M15(*)-300	28.00	30.00	TJ1-CASS-M15(*)-450	28.80	30.80	TJ1-CASS-M15(*)-600	29.55	31.55	1.55
	3.0	TJ1-CASS-M30(*)-300	28.00	30.00	TJ1-CASS-M30(*)-450	28.90	30.90	TJ1-CASS-M30(*)-600	29.85	31.85	1.85
	4.5	TJ1-CASS-M45(*)-300	29.00	31.00	TJ1-CASS-M45(*)-450	30.60	32.60	TJ1-CASS-M45(*)-600	32.15	34.15	3.15
	6.0	TJ1-CASS-M60(*)-300	35.00	37.00	TJ1-CASS-M60(*)-450	37.50	39.50	TJ1-CASS-M60(*)-600	40.00	42.00	5.00
CHROMEGA®-CONSTANTAN Inconel Sheath E	1.5	TJ1-CXIN-M15(*)-300	28.00	30.00	TJ1-CXIN-M15(*)-450	28.90	30.90	TJ1-CXIN-M15(*)-600	29.85	31.85	1.85
	3.0	TJ1-CXIN-M30(*)-300	28.00	30.00	TJ1-CXIN-M30(*)-450	29.90	31.90	TJ1-CXIN-M30(*)-600	31.15	33.15	3.75
	4.5	TJ1-CXIN-M45(*)-300	29.00	31.00	TJ1-CXIN-M45(*)-450	31.50	33.50	TJ1-CXIN-M45(*)-600	33.35	35.35	5.00
	6.0	TJ1-CXIN-M60(*)-300	36.00	38.00	TJ1-CXIN-M60(*)-600	39.80	41.80	TJ1-CXIN-M60(*)-600	43.50	45.50	7.50
CHROMEGA®-CONSTANTAN 304 SS Sheath E	1.5	TJ1-CXSS-M15(*)-300	28.00	30.00	TJ1-CXSS-M15(*)-450	28.80	30.80	TJ1-CXSS-M15(*)-600	29.55	31.55	1.55
	3.0	TJ1-CXSS-M30(*)-300	28.00	30.00	TJ1-CXSS-M30(*)-450	29.30	31.30	TJ1-CXSS-M30(*)-600	30.50	32.50	2.50
	4.5	TJ1-CXSS-M45(*)-300	29.00	31.00	TJ1-CXSS-M45(*)-450	30.60	32.60	TJ1-CXSS-M45(*)-600	32.15	34.15	3.15
	6.0	TJ1-CXSS-M60(*)-300	35.00	37.00	TJ1-CXSS-M60(*)-450	37.50	39.50	TJ1-CXSS-M60(*)-600	40.00	42.00	5.00
COPPER-CONSTANTAN Inconel Sheath T	1.5	TJ1-CPIN-M15(*)-300	28.00	30.00	TJ1-CPIN-M15(*)-450	28.90	30.90	TJ1-CPIN-M15(*)-600	29.55	31.55	1.85
	3.0	TJ1-CPIN-M30(*)-300	28.00	30.00	TJ1-CPIN-M30(*)-450	29.90	31.90	TJ1-CPIN-M30(*)-600	31.75	33.75	3.75
	4.5	TJ1-CPIN-M45(*)-300	29.00	31.00	TJ1-CPIN-M45(*)-450	31.50	33.50	TJ1-CPIN-M45(*)-600	33.35	35.35	5.00
	6.0	TJ1-CPIN-M60(*)-300	36.00	38.00	TJ1-CPIN-M60(*)-450	39.80	41.80	TJ1-CPIN-M60(*)-600	43.50	45.50	7.50
COPPER-CONSTANTAN 304 SS Sheath T	1.5	TJ1-CPSS-M15(*)-300	28.00	30.00	TJ1-CPSS-M15(*)-450	28.80	30.80	TJ1-CPSS-M15(*)-600	29.55	31.55	1.55
	3.0	TJ1-CPSS-M30(*)-300	28.00	30.00	TJ1-CPSS-M30(*)-450	29.30	31.30	TJ1-CPSS-M30(*)-600	30.50	32.50	2.50
	4.5	TJ1-CPSS-M45(*)-300	29.00	31.00	TJ1-CPSS-M45(*)-450	30.60	32.60	TJ1-CPSS-M45(*)-600	32.15	34.15	3.15
	6.0	TJ1-CPSS-M60(*)-300	35.00	37.00	TJ1-CPSS-M60(*)-450	37.50	39.50	TJ1-CPSS-M60(*)-600	40.00	42.00	5.00
OMEGALLOY®-NICROSIL-NISIL ** Inconel Sheath N	1.5	TJ1-NNIN-M15(*)-300	28.00	30.00	TJ1-NNIN-M15(*)-450	28.80	30.80	TJ1-NNIN-M15(*)-600	29.55	31.55	1.55
	3.0	TJ1-NNIN-M30(*)-300	28.00	30.00	TJ1-NNIN-M30(*)-450	29.60	31.60	TJ1-NNIN-M30(*)-600	31.15	33.15	3.15
	4.5	TJ1-NNIN-M45(*)-300	29.00	31.00	TJ1-NNIN-M45(*)-450	31.20	33.20	TJ1-NNIN-M45(*)-600	33.35	35.35	4.35
	6.0	TJ1-NNIN-M60(*)-300	35.00	37.00	TJ1-NNIN-M60(*)-450	38.80	40.75	TJ1-NNIN-M60(*)-600	42.50	44.50	7.50

***Note:** Other lengths are available, consult Sales. 6" probes also available, change **"-12"** to **"-6"** to order. No additional charge. To order optional sheaths, change **"SS"** in Model no. to **"IN"** for Inconel, **"304SS"** for 304 SS, **"310SS"** for 310 SS, **"316SS"** for 316 SS or **"321SS"** for 321 SS. No additional charge.*

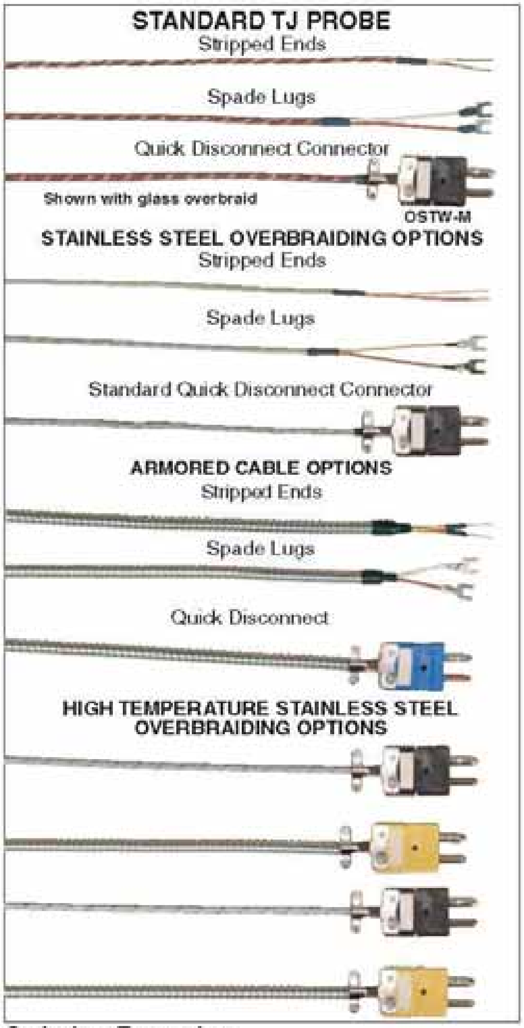
Specify junction type: **E (Exposed), **G** (Grounded) or **U** (Ungrounded). For lengths from 50 to 300 mm, please consult Sales Department.*

***For **Super OMEGACLAD® XL**, change "IN" to "XL" and add **$3** to price.*

***Ordering Example: TJ1-CASS-M30U-300**, heavy duty transition joint probe, Type K (CHROMEGA®-ALOMEGA®), 304 SS sheath, 3 mm O.D., grounded junction, 300 mm length, **$30**.*

Transition Joint Probe
Lead Configurations

ANSI color code shown | To order IEC color code see omega.com



All products shown smaller than actual size.

Standard TJ probe construction is Teflon® insulation. For glass braid insulation, use "-**CC**" suffix show below.

Standard TJ probe construction with thermocouple alloy compensated spade lugs attached. Add suffix "**-LUG**" and **$3** to the standard price.

For OSTW male connector, add "**-OSTW-M**" suffix and **$5** to the standard price, or add "**-OSTW-F**" and **$5** to the standard price for female.

For molded version of male round pin connector, add "**-LRTC**" suffix and **$3** to the standard price.

For miniature SMPW male connector, add "**-SMPW-M**" suffix and **$5** to the standard price, or add "**-SMPW-F**" and **$5** to the standard price for female.

For molded version of male flat pin connector, add "**-SRTC**" suffix and **$3** to the standard price.

Stainless Steel Overbraiding

Standard TJ probe construction with stainless steel overbraided lead wire. Add suffix "**-SB**" and **$3** to standard price. For lead wire lengths over 900 mm (36") add **$2.25** per 300 mm (12").

Standard TJ probe construction with stainless steel overbraided lead wire thermocouple alloy compensated spade lugs. Add suffix "**-SB-LUG**" and **$6.00** to the standard price.

Standard TJ probe with stainless steel overbraided lead wire and OST or SMP male connector. Add suffix "**-SB-OSTW-M**" or "**-SB-SMPW-M**" and **$8.00** to the standard price.

Armored Cable TJ Probes

Standard TJ probe construction with spiral armor cable. Add suffix "**-BX**" and **$5** to standard price. For lead wire lengths over 900 mm (36") add **$2.25** per 300 mm (12").

Standard TJ probe construction with spiral armor cable and thermocouple alloy compensated spade lugs. Add suffix "**-BX-LUG**" and **$8.00** to the standard price.

Standard TJ probe with spiral armor cable and OST male connector. Add suffix "**-BX-OST-WM**" and **$10.00** to the standard price.

High Temperature TJ Probes 480°C (900°F)

Available in the same terminations shown above but with high temperature construction. Entire probe will withstand 480°C (900°F). Add suffix "**-CC**" to suffixes used above and **$10** additional to price of probe.

Ultra-High Temperature TJ Probes 815°C (1500°F)

Available in the same terminations shown above but with special high temperature construction with Nextel® ceramic fiber insulation and Inconel overbraiding or SS armor for a temperature rating of 815°C (1500°F). Add suffix "**-CC-XCIB**" or "**-CC-XCBX**" to above numbers and **$17** additional to price of probe. For lead wire lengths over 900 mm (36"), add **$3.60** per 300 mm (12").

Ordering Examples

ALL MODELS AVAILABLE FOR FAST DELIVERY!

Model Number-ANSI Color Code	Price	Description
TJ36-ICSS-316G-24-LUG	$35.15	600 mm (24") Type J probe with 900 mm (36") lead wire. Spade lug termination
TJ48-CASS-14G-12-SB-OST-M	45.25	300 mm (12") Type K probe with 1.2 m (48") stainless steel overbraid and OSTW standard size connector termination
TJ36-CASS-14G-12-CC-BX-OST-M	55.00	300 mm (12") High temperature type K probe with 900 mm (36") armor cable and OSTW standard size connector termination
TJ60-CXSS-116G-12-CC-XCIB-LUG	55.20	300 mm (12") Type E probe with 1.5 m (5') of ultra-high temperature lead wire and Inconel overbraid. Spade lug termination

Accessory

Model No.	Price	Description
CO-1045	$135	Reference Book: IEEE Standard Dictionary, 7th Edition

Fast Response Thermocouples
With Self-Adhesive Backing

ANSI color code shown	To order IEC color code see pg. A-9

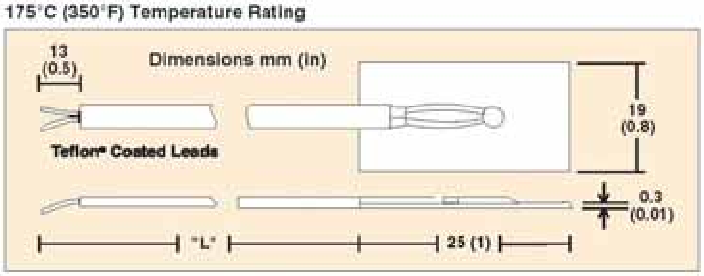
- Self Adhesive Backing for Easy Installation
- Better Than 0.3 Second Response Time
- 1 m (40") or 2 m (80") Color-Coded PFA Teflon® Insulated Leads
- Rated to 175°C (350°F) Long Term
- Available in J, K, T, and E Calibrations

OMEGA's self-adhesive thermocouples are designed for fast surface temperature measurements. These sensors are manufactured from 30 AWG Teflon® coated thermocouple wire, with a flattened bead secured between a high temperature polymer and a high temperature, fiber-reinforced polymer, for good thermal conductivity and fast response. For easy installation, the probes have a self-adhesive backing; no epoxy or cement is required.

175°C (350°F) Temperature Rating

Specifications

Thermocouple Calibrations:
J (Iron-Constantan)
K (CHROMEGA®-ALOMEGA®)
T (Copper Constantan)
E (CHROMEGA®-Constantan)
Adhesive: Silicon based cement
Maximum Temperature:
175°C (350°F) continuous
Minimum Temperature:
-60°C (-75°F) continuous
Laminates:
High temperature polymer, and fiberglass reinforced polymer layers
Wire: 30 AWG PFA Teflon® coated



ALL MODELS AVAILABLE FOR FAST DELIVERY!

To Order *(Specify Model Number)*

Model No. ANSI Color Code	Price (pkg of 5)	Description, "L" Dimension, Termination
SA1-(*)	$60	Thermocouple, 1 m (40") long, stripped ends
SA1-(*)-72	80	Thermocouple, 2 m (80") long, stripped ends
SA1-(*)-120	100	Thermocouple, 3 m (120") long, stripped ends
SA1-(*)-SRTC	75	SA1-(*) with molded strain relief & SMP male connector

**Specify J, K, T or E thermocouple type.*

Ordering Example: ***SA1-K-SRTC****, package of 5 Self-Adhesive Type K thermocouples, 30 AWG Teflon® insulation, 1 m (40") long with molded strain relief and SMP male connector,* ***$75.***

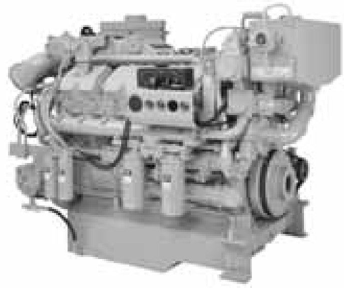
APPENDIX E

Propulsion Engine and Generator Specification Sheets

CATERPILLAR®

Marine Propulsion Engine 3412E

537 bkW (720 bhp) 730 mhp @ 1800 rpm



Keel Cooled Arrangement
Shown with Accessory Equipment

STANDARD EQUIPMENT

Air Inlet System
Corrosion resistant aftercooler core, regular duty panel type air cleaner, air cleaner inlet adapter 178 mm (7 in.)

Cooling System
Gear driven, non-self-priming auxiliary sea water pump with bronze impeller (heat exchanger engines); gear driven, centrifugal jacket water pump, expansion tank (keel engines only); heat exchanger and coolant recovery system (heat exchanger engines); transmission oil cooler; engine oil cooler; thermostats and housing with 92°C (198°F) full open temperature

Exhaust System
Watercooled manifold and turbocharger; dry elbow and flange, 203 mm (8 in.)

Flywheel and Flywheel Housing
SAE No. 0 (136 teeth)

Fuel System
Fuel priming pump; fuel transfer pump; fuel filter — RH service on port, LH service on starboard; Hydraulically actuated Electronically Controlled Unit Injector (HEUI) fuel system; flexible fuel lines

Instruments
Instrument panel with start/stop switch; emergency stop button; maintenance lamp; diagnostic lamp; electric service meter; warning lamp; 15A breakers; starter motor magnetic switch; 5-hole panel with oil pressure, water temperature, and fuel pressure gauges

Lube System
Oil level gauge and oil filter — RH service on port, LH service on starboard; crankcase breather; oil filler in valve cover; deep sump oil pan; manual sump pump

Mounting System
Front support

Protection System
Electronic — 24 volt only

General
Vibration damper and guard, Caterpillar yellow paint, lifting eyes, customer wiring connector, service tool connector

SPECIFICATIONS

V-12, 4-Stroke-Cycle-Diesel

Emissions .... IMO compliant
Displacement .... 27 L (1649 cu in.)
Bore............................. 137.2 mm (5.4 in.)
Stroke........................... 152.4 mm (6.0 in.)
Aspiration................ Turbocharged-Aftercooled
Governor .... Electronic
Engine Weight, Net Dry (approx)
  Heat Exchanger Cooled .... 2840.7 kg (6257 lb)
  Keel Cooled .... 2769 kg (6105 lb)
Capacity for Liquids
  Cooling System (engine and
    expansion tank)............ 72.5 L (19.1 U.S. gal)
  Lube Oil System (refill)...... 138.1 L (36.5 U.S. gal)
Oil Change Interval .... 400 hr
  Caterpillar DEO 10W30 or 15W40
Rotation (from flywheel end)....... Counterclockwise

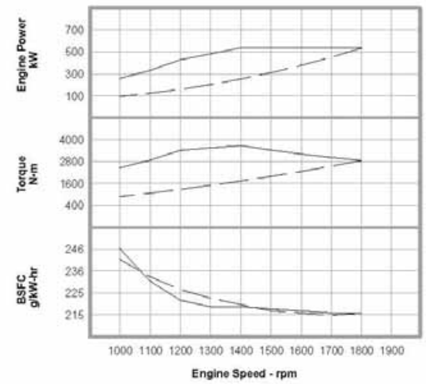
ACCESSORY EQUIPMENT

Air Starting Motor
24V 35 Amp, 24V 60 Amp Alternator
Auxiliary Drive Pulley
Auxiliary Sea Water Pump
Coolant Level Switch (Keel Cooled Engines)
Double Wall Oil Line
Dry Charge Coolant Conditioner
Duplex Fuel Lines
Duplex Oil Filters
24V Electric Starting Motor
Engine Monitoring System
Engine-to-Engine Wiring Harness
Engine Vision Display System
Exhaust Elbow, Pipe, Flexible Fittings
Front Enclosed Clutch
GPS Interface Module
Hydraulic Pump Drive
8-Hole Instrument Panel
Marine Power Display
OEM Wiring Harness
Pilot House Instrument Panel
Primary Fuel Filter/Water Separator
Remote Positive Locking Governor Control
SAE No. 0 Flywheel
Sea Water Inlet Connection
Spare Parts Kit
Throttle Position Sensor
Vibration Isolation Mounting

PERFORMANCE CURVES

B Rating — DM6396-00

IMO Compliant

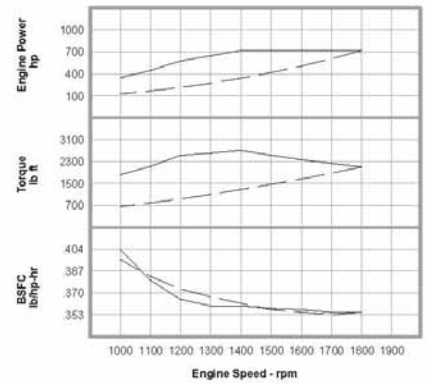


Metric | Maximum Power ——— / Prop Demand — — | **537 kW**

Performance Data

	Engine Speed rpm	Engine Power kW	Engine Torque N•m	BSFC g/kW-hr	Fuel Rate L/hr
Maximum Power Data	1800	537	2849	216.0	138.4
	1700	537	3017	216.0	138.3
	1600	537	3205	217.0	138.9
	1500	537	3419	218.0	139.6
	1400	537	3663	219.0	139.9
	1300	482	3538	219.0	125.7
	1200	428	3409	222.0	113.2
	1100	330	2866	231.0	90.9
	1000	257	2456	246.0	75.5
Prop Demand Data	1800	537	2849	216.0	138.4
	1700	452	2541	215.0	116.0
	1600	377	2251	216.0	96.9
	1500	311	1978	217.0	80.4
	1400	253	1723	220.0	66.2
	1300	202	1486	223.0	53.8
	1200	159	1266	227.0	43.1
	1100	123	1064	233.0	34.0
	1000	92	879	241.0	26.4

Cubic prop demand curve with 3.0 exponent for displacement hulls only.

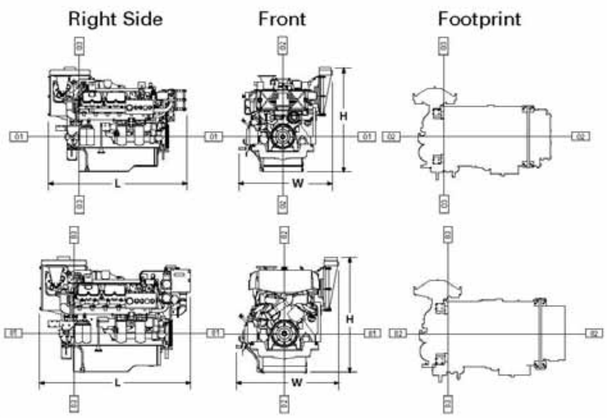


English | Maximum Power ——— / Prop Demand — — | **720 hp**

Performance Data

	Engine Speed rpm	Engine Power hp	Engine Torque lb ft	BSFC lb/hp-hr	Fuel Rate gph
Maximum Power Data	1800	720	2101	.355	36.6
	1700	720	2225	.355	36.5
	1600	720	2364	.357	36.7
	1500	720	2522	.358	36.9
	1400	720	2702	.360	37.0
	1300	646	2609	.360	33.2
	1200	574	2514	.365	29.9
	1100	443	2114	.380	24.0
	1000	345	1811	.404	19.9
Prop Demand Data	1800	720	2101	.355	36.6
	1700	607	1874	.353	30.6
	1600	506	1660	.355	25.6
	1500	417	1459	.357	21.2
	1400	339	1271	.362	17.5
	1300	271	1096	.367	14.2
	1200	213	934	.373	11.4
	1100	164	785	.383	9.0
	1000	124	648	.396	7.0

Power produced at the flywheel will be within standard tolerances up to 50°C (122°F) combustion air temperature measured at the air cleaner inlet, and fuel temperature up to 52°C (125°F) measured at the fuel filter base. Power rated in accordance with NMMA procedure as crankshaft power. Reduce crankshaft power by 3% for propeller shaft power.



DIMENSIONS*

	Heat Exchanger Cooled		Keel Cooled	
	mm	in.	mm	in.
Overall Length	2137.2	84.1	2119.7	83.5
Length from front to rear face of block	1660.7	65.4	1643.2	64.7
Overall Height	1621.4	63.8	1621.4	63.8
Height from crankshaft centerline to top of engine	1072.9	42.2	1072.9	42.2
Height from crankshaft centerline to bottom of oil pan	548.5	21.6	548.5	21.6
Overall Width	1444.3	56.9	1444.3	56.9
Width from crankshaft centerline to port side (left side)	764.0	30.1	764.0	30.1
Width from crankshaft centerline to starboard side (right side)	680.3	26.8	680.3	26.8

(Heat Exchanger and Keel Cooled arrangements)	Front		Rear	
	mm	in.	mm	in.
Customer mounting hole diameter	20.5	0.8		5/8
Width from crankshaft centerline to side	431.8	17.0	352.7	13.9
	457.2	18.0	413.0	16.3
Length from rear face of block to front	1242.5	48.9	78.3	3.1
	1261.5	49.7	154.6	6.1
	1350.5	53.2		
	1369.5	53.9		

*Illustrations and dimensions from drawings: 183-1405 Heat Exchanger Cooled, 183-2012 Keel Cooled.

RATING DEFINITIONS AND CONDITIONS

B Rating –

Typical Application . . . Vessels such as midwater trawlers, purse seiners, crew and supply boats, ferries, and towboats where locks, sandbars, and curves dictate frequent slowing, and engine load and speed are constant with some cycling.

Typical Hours Per Year . . . . 3000 to 5000

Time at Rated Speed . . . . Up to 80%

Load Factor . . . . 40 to 80%

Typical Time at Full Load . . . . 10 out of 12 hours

Rated Speed . . . . 1800 rpm

Maximum Cruise Speed. . . . . 1750 rpm

Maximum Continuous Cruise Speed. . . . 1700 rpm

Engine Performance Parameters

Power. . . . . ±3%

Specific Fuel Consumption . . . . ±3%

Fuel Rate . . . . ±5%

Ratings are based on SAE J1228/ISO8665 standard conditions of 100 kPa (29.61 in. Hg), 25°C (77°F), and 30% relative humidity. These ratings also apply at ISO3046/1, DIN6271/3, and BS5514 conditions of 100 kPa (29.61 in. Hg), 27°C (81°F), and 60% relative humidity.

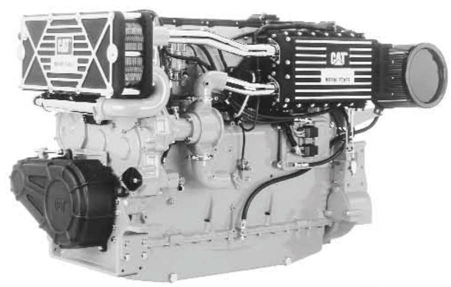
Fuel rates are based on fuel oil of 35° API [16°C (60°F)] gravity having an LHV of 42 780 kJ/kg (18,390 Btu/lb) when used at 29°C (85°F) and weighing 838.9 g/L (7.001 lb/U.S. gal).

Additional ratings may be available for specific customer requirements. Consult your Caterpillar representative for additional information.

CATERPILLAR®

Marine Propulsion Engine 3406E

448 bkW (600 bhp) 608 mhp @ 2100 rpm



Shown with Accessory Equipment

SPECIFICATIONS

I-6, 4-Stroke-Cycle-Diesel

Emissions .... IMO compliant
Displacement .... 14.6 L (893 cu. in.)
Bore............................ 137.2 mm (5.4 in.)
Stroke........................... 165.1 mm (6.5 in.)
Aspiration .... Turbocharged-Aftercooled
Governor .... Electronic
Engine Weight, Net Dry (approx) ... 1586 kg (3497 lb)
Capacity for Liquids
  Cooling System.............. 43.7 L (11.4 U.S. gal)
  Lube Oil System (refill)........... 49 L (13 U.S. gal)
Oil Change Interval.......................... 250 hr
  Caterpillar DEO 10W30 or 15W40
Rotation (from flywheel end) .... Counterclockwise

STANDARD EQUIPMENT

Air Inlet System
Corrosion resistant sea water aftercooler; light-duty air cleaner, open system

Cooling System
Self-priming sea water pump with rubber impeller, gear driven jacket water pump, titanium plate heat exchanger with expansion tank, coolant recovery system, thermostat and housing

Exhaust System
Watercooled manifold and turbocharger; round flanged outlet, 152 mm (6 in.)

Flywheel and Flywheel Housing
SAE No. 1 (113 teeth)

Fuel System
Fuel priming pump; fuel transfer pump; fuel filter — RH service on port, LH service on starboard; flexible fuel lines

Instruments
24-volt instrument panel with start/stop switch, emergency stop button, maintenance light, diagnostic light, warning light, 15-amp and 3-amp breakers, starter motor magnetic switch, electric service meter

Lube System
Crankcase breather; engine oil cooler; oil level gauge and oil filter — RH service on port, LH service on starboard; shallow oil pan; gear driven oil pump

Mounting System
Adjustable front support

General
Vibration damper and guard, Caterpillar yellow paint, lifting eyes

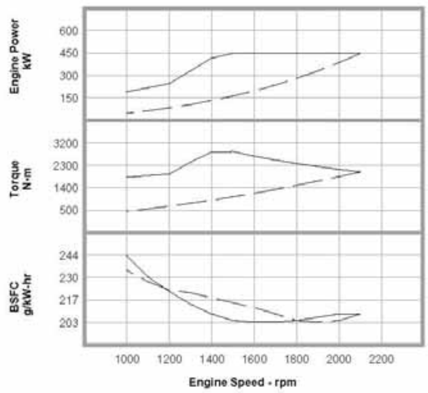
ACCESSORY EQUIPMENT

Aftercooler Condensate Drain
Air Starting Motor
12V 51 Amp, 12V 105 Amp Alternator
Cruise Kits
12V/24V DC Converter
Digital Tachometer
Double Wall Fuel Lines and Drain
Dress-Up Kit
Duplex Fuel Filters
Electric Starting Motor
Engine Monitoring System
Engine-to-Engine Wiring Harness
Engine Vision Display System
Exhaust Elbow, Dry or Watercooled
Exhaust Pipe, Flange, Flexible Fittings
Front Enclosed Clutch
Front Stub Shaft
Fuel Cooler
GPS Interface Module
Heavy-Duty Front Support
Hydraulic Pump Drive
12V Instrument Panel
Jacket Water Heater
Marine Power Display
OEM Wiring Harness
Primary Fuel Filter/Water Separator
Pulley and Damper
Spare Parts Kit
Throttle Position Sensor
Transmission Oil Cooler
Vibration Isolation Mounting

PERFORMANCE CURVES

C Rating — DM6120-00

IMO Compliant

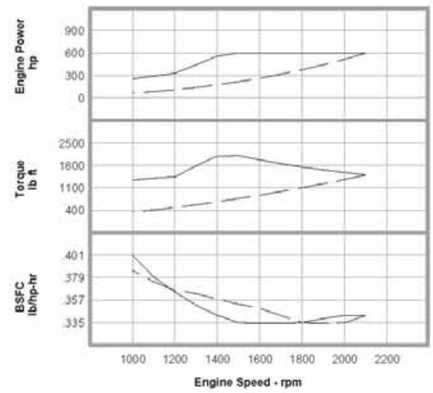


Metric | Maximum Power ——— Prop Demand — — | 448 kW

Performance Data

	Engine Speed rpm	Engine Power kW	Engine Torque N•m	BSFC g/kW-hr	Fuel Rate L/hr
Maximum Power Data	2100	448	2035	208.0	111.1
	2000	448	2136	208.0	110.9
	1900	448	2249	206.0	109.8
	1800	448	2374	204.0	108.6
	1700	448	2513	203.0	108.3
	1600	448	2671	203.0	108.3
	1500	447	2848	204.0	108.7
	1400	415	2832	208.0	103.0
	1300	330	2425	214.0	84.3
	1200	245	1951	222.0	64.7
	1100	218	1894	231.0	60.1
	1000	190	1815	244.0	55.3
Prop Demand Data	2100	448	2035	208.0	111.1
	2000	387	1846	204.0	94.1
	1900	331	1666	203.0	80.1
	1800	282	1495	204.0	68.6
	1700	237	1333	208.0	58.7
	1600	198	1181	212.0	49.9
	1500	163	1038	215.0	41.9
	1400	133	904	218.0	34.5
	1300	106	780	221.0	27.9
	1200	84	664	223.0	22.2
	1100	64	558	228.0	17.5
	1000	48	461	235.0	13.5

Cubic prop demand curve with 3.0 exponent for displacement hulls only.



English | Maximum Power ——— Prop Demand — — | 600 hp

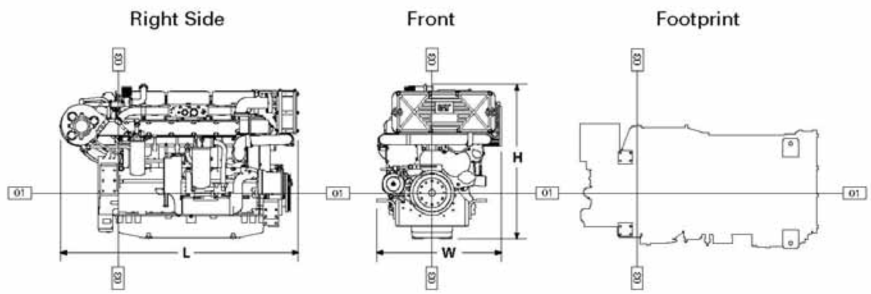
Performance Data

	Engine Speed rpm	Engine Power hp	Engine Torque lb ft	BSFC lb/hp-hr	Fuel Rate gph
Maximum Power Data	2100	600	1501	.342	29.3
	2000	600	1575	.342	29.3
	1900	600	1659	.339	29.0
	1800	600	1751	.335	28.7
	1700	600	1853	.334	28.6
	1600	600	1970	.334	28.6
	1500	600	2100	.335	28.7
	1400	557	2089	.342	27.2
	1300	443	1788	.352	22.3
	1200	329	1439	.365	17.1
	1100	292	1397	.380	15.9
	1000	255	1339	.401	14.6
Prop Demand Data	2100	600	1501	.342	29.3
	2000	518	1361	.335	24.9
	1900	444	1229	.334	21.2
	1800	378	1103	.335	18.1
	1700	318	983	.342	15.5
	1600	265	871	.349	13.2
	1500	219	766	.353	11.1
	1400	178	667	.358	9.1
	1300	142	575	.363	7.4
	1200	112	490	.367	5.9
	1100	86	412	.375	4.6
	1000	65	340	.386	3.6

Power produced at the flywheel will be within standard tolerances up to 50°C (122°F) combustion air temperature measured at the air cleaner inlet, and fuel temperature up to 52°C (125°F) measured at the fuel filter base. Power rated in accordance with NMMA procedure as crankshaft power. Reduce crankshaft power by 3% for propeller shaft power.

3406E MARINE PROPULSION — 448 bkW (600 bhp)

CATERPILLAR®



DIMENSIONS*

	mm	in.		
Overall Length	1822.7	71.8		
Length from front to rear face of block	1379.4	54.3		
Length from rear face of block to back of flywheel housing	155.1	6.1		
Overall Height	1177.8	46.4		
Height from crankshaft centerline to top of engine	829.8	32.7		
Height from crankshaft centerline to bottom of oil pan	348.0	13.7		
Overall Width	953.6	37.5		
Width from crankshaft centerline to port side (left side)	520.1	20.5		
Width from crankshaft centerline to starboard side (right side)	421.0	16.6		

	Front		Rear	
	mm	in.	mm	in.
Customer mounting hole diameter	27.5	1.1		5/8
Width from crankshaft centerline to mounting holes	380.0	15.0	252.4	9.9
			312.8	12.3
Length from rear face of block to mounting holes	1168.5	46.0	57.9	2.3
			134.1	5.3

*Illustrations and dimensions from drawing: 137-6875 Heat Exchanger Cooled.

RATING DEFINITIONS AND CONDITIONS

C Rating –

Typical Application . . . Vessels such as ferries, harbor tugs, fishing boats moving at higher speeds out and back (e.g. lobster, crayfish, and tuna), offshore service boats, and also displacement hull yachts and short trip coastal freighters where engine load and speed are cyclical.

Typical Hours Per Year . . . . 2000 to 4000
Time at Rated Speed. . . . . Up to 50%
Load Factor . . . . 20 to 80%
Typical Time at Full Load . . . . . 6 out of 12 hours

Rated Speed . . . . 2100 rpm
Maximum Cruise Speed. . . . . 2000 rpm
Maximum Continuous Cruise Speed. . . . 1900 rpm

Engine Performance Parameters

Power. . . . . ±3%
Specific Fuel Consumption . . . . ±3%
Fuel Rate. . . . . ±5%

Ratings are based on SAE J1228/ISO8665 standard conditions of 100 kPa (29.61 in. Hg), 25°C (77°F), and 30% relative humidity. These ratings also apply at ISO3046/1, DIN6271/3, and BS5514 conditions of 100 kPa (29.61 in. Hg), 27°C (81°F), and 60% relative humidity.

Fuel rates are based on fuel oil of 35° API [16°C (60°F)] gravity having an LHV of 42 780 kJ/kg (18,390 Btu/lb) when used at 29°C (85°F) and weighing 838.9 g/L (7.001 lb/U.S. gal).

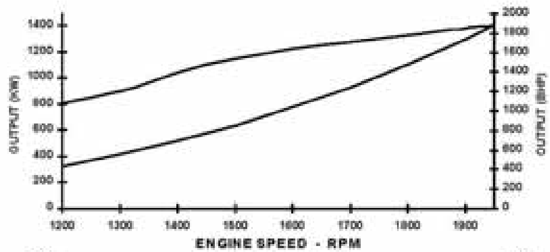
Additional ratings may be available for specific customer requirements. Consult your Caterpillar representative for additional information.

CUMMINS ENGINE COMPANY, INC Columbus, Indiana 47201 **Marine Performance Curve**	Basic Engine Model: **KTA50-M2**		Curve Number: **M-6277**	*Marine Pg. No.* **K50** **199**
Marine	Engine Configuration: **D283033MX02**	CPL Code: **2589**	Date: **26Nov02**	

Displacement:	**50 litre**	**[3067 in.^{3}]**
Bore:	**159 mm**	**[6.25 in.]**
Stroke:	**159 mm**	**[6.25 in.]**
Fuel System:	**PT (CENTRY and V.S.)**	
Cylinders:	**16**	

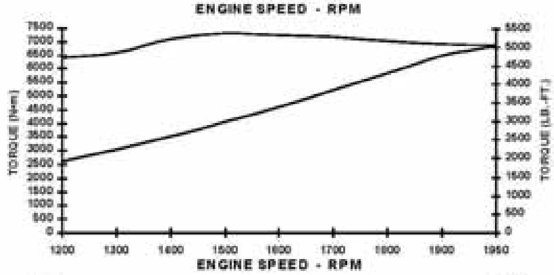
	kW [HP] @ RPM
Advertised Power:	**1398 [1875] @ 1950**
Aspiration:	**Turbocharged/Aftercooled**
Rating Type:	**Medium Continuous**

CERTIFIED: This marine diesel engine conforms with the NOx requirements of the International Maritime Organization (IMO), MARPOL 73/78 Annex VI, Regulation 13 as applicable.



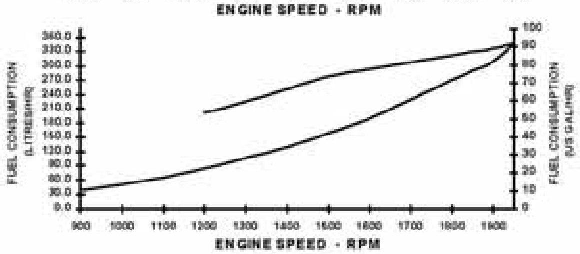
RATED POWER OUTPUT CURVE

RPM	kW	BHP
1950	1398	(1875)
1900	1378	(1847)
1800	1327	(1779)
1700	1275	(1709)
1600	1217	(1631)
1500	1148	(1539)
1400	1041	(1396)
1300	899	(1206)
1200	805	(1079)



FULL LOAD TORQUE CURVE

RPM	N•m	lb.-ft.
1950	6847	(5050)
1900	6922	(5105)
1800	7038	(5190)
1700	7161	(5281)
1600	7259	(5353)
1500	7334	(5409)
1400	7101	(5237)
1300	6605	(4871)
1200	6404	(4723)



FUEL CONSUMPTION - PROP CURVE

RPM	Litres/hr	Gal/hr
1950	348.0	(91.9)
1900	310.3	(82.0)
1800	270.1	(71.4)
1700	229.0	(60.5)
1600	190.9	(50.4)
1500	160.1	(42.3)
1400	130.9	(34.6)
1300	107.5	(28.4)
1200	83.8	(22.1)
1100	**67.1**	**(17.7)**
1000	**52.6**	**(13.9)**
900	**40.2**	**(10.6)**

Rating Conditions: Ratings are based upon ISO 8665 and SAE J1228 reference conditions; air pressure of 100 kPa [29.612 in. Hg], air temperature 25°C [77°F], and 30% relative humidity. Power is rated in accordance with IMCI procedures. Member NMMA.

Rated Curves (upper) represent rated power at the crankshaft for mature gross engine performance capabilities obtained and corrected in accordance with ISO 3046. Propeller Curve (lower) is based on a typical fixed propeller demand curve using a 3.0 exponent. Propeller Shaft Power is approximately 3% less than rated crankshaft power after typical reverse/reduction gear losses and may vary depending on the type of gear or propulsion system used.

Fuel Consumption is based on fuel of 35° API gravity at 16°C [60°F] having LHV of 42,780 kj/kg [18390 Btu/lb] and weighing 838.9 g/liter [7.001 lb/U.S. gal].

Medium Continuous Rating: This power rating is intended for continuous use in variable load applications where full power is limited to six (6) hours out of every twelve (12) hours of operation. Also, reduced power operations must be at or below 200 RPM of the maximum rated RPM. This is an ISO 3046 Fuel Stop Power Rating and is for applications that operate 3,000 hours per year or less.

CHIEF ENGINEER

Marine Engine Performance Data

Curve No. M-6277
DS-4998
CPL: 2589
DATE: 26Nov02

General Engine Data

Engine Model	KTA50-M2
Rating Type	Medium Continuous
Rated Engine Power ... kW [HP]	1398 [1875]
Rated Engine Speed ... RPM	1950
Rated HP Production Tolerance ... %	**±3**
Rated Engine Torque ... N•m [ft/lb]	**6847 [5050]**
Peak Engine Torque ... N•m [ft/lb]	**7334 [5409]**
Minimum Idle Speed Setting ... RPM	**650**
Normal Idle Speed Variation ... RPM	**±25**
High Idle Speed Range - **Minimum** ... RPM	**1965**
High Idle Speed Range - **Maximum** ... RPM	**2184**
Maximum Allowable Engine Speed ... RPM	**2375**
Brake Mean Effective Pressure ... kPa [PSI]	**1712 [248]**
Compression Ratio	13.9:1
Piston Speed ... m/sec [ft/min.]	10 [2031]
Maximum Torque Capacity from Front of Crank[2] ... **N•m [ft/lb]**	**4341 [3202]**
Firing Order	1R-1L-3R-3L-2R-2L-5R-4L-8R-8L-6R-6L-7R-7L-4R-5L
Weight (Dry) Engine Only - **Average** ... kg [lb]	**5431 [11,973]**
Weight (Dry) Engine With Heat Exchanger System - **Average** ... **kg [lb]**	**5751 [12,678]**
Weight Tolerance (Dry) Engine Only ... %	**±10**

Noise and Vibration

Average Noise Level - Top	**(Idle) ... dBA @ 1m**	**100**
	(Rated) ... dBA @ 1m	**110**
Average Noise Level - Right Side	**(Idle) ... dBA @ 1m**	**98**
	(Rated) ... dBA @ 1m	**109**
Average Noise Level - Left Side	**(Idle) ... dBA @ 1m**	**99**
	(Rated) ... dBA @ 1m	**108**
Average Noise Level - Front	**(Idle) ... dBA @ 1m**	**98**
	(Rated) ... dBA @ 1m	**108**

Fuel System[1]

Fuel Consumption **@ rated speed** ... litre/hr [GPH]	**348 [92]**
Approximate Fuel Flow to Pump ... litre/hr [GPH]	**632 [167]**
Maximum Allowable Fuel Supply to Pump Temperature ... °C [°F]	**60 [140]**
Approximate Fuel Flow Return to Tank ... l/hr [gal/hr]	**284 [75]**
Approximate Fuel Return to Tank Temperature ... °C [°F]	**68 [155]**
Maximum Heat Rejection to Drain Fuel ... kW [BTU/min]	**4 [235]**
Fuel Rail Pressure - Gauge ... kPaG [PSIG]	**1034 [150]**
Fuel Rail Pressure - INSITE ... kPaA [PSIA]	**1062 [154]**

Air System[1]

Intake Manifold Pressure ... mm Hg [in. Hg]	**1473 [58]**
Intake Air Flow ... litre/sec [CFM]	**2068 [4381]**
Heat Rejection to Ambient ... kW [BTU/min.]	**82 [4681]**

Exhaust System[1]

Exhaust Gas Flow ... litre/sec [CFM]	**4445 [9418]**
Exhaust Gas Temperature **(Turbine Out)** ... °C [°F]	**502 [935]**
Exhaust Gas Temperature (Manifold) ... °C [°F]	**N.A.**

Emissions (in accordance with ISO8178 Cycle E3)

NOx **(Oxides of Nitrogen)** ... g/kw-hr [g/bhp-hr]	**8.63 [6.44]**
HC (Hydrocarbons) ... g/kw-hr [g/bhp-hr]	**0.19 [0.14]**
CO (Carbon Monoxide) ... g/kw-hr [g/bhp-hr]	**2.22 [1.66]**

TBD = To Be Decided N/A = Not Applicable N.A. = Not Available

[1]All Data at Rated Conditions

[2]Consult Installation Direction Booklet for Limitations

[3]Heat rejection values are based on 50% water/ 50% ethylene glycol mix and do NOT include fouling factors. If sourcing your own cooler, a service fouling factor should be applied according to the cooler manufacturer's recommendation.

[4]Consult option notes for flow specifications of optional Cummins seawater pumps, if applicable.

CUMMINS ENGINE COMPANY, INC.
COLUMBUS, INDIANA

All Data is Subject to Change Without Notice - consult the following Cummins internet site for most recent data: http://www.cummins.com

Cooling System[1]

Minimum Sea-Water Flow **(With Heat Exchanger Option)**[4]	litre/min. [GPM]	**613 [162]**
Pressure Cap Rating **(With Heat Exchanger Option)**	kPa [PSI]	**103 [15]**
Engines with Standard Aftercooling		
Coolant Flow to Engine Heat Exchanger/Keel Cooler	litre/min. [GPM]	N/A
Standard Thermostat Operating Range **(Start to Open)**	°C [°F]	N/A
Standard Thermostat Operating Range **(Full Open)**	°C [°F]	N/A
Heat Rejection to Engine Coolant[3]	kW [BTU/min.]	N/A
Engines with Low Temperature Aftercooling (if applicable)		
Main Cooler		
Coolant Flow to Engine Heat Exchanger/Keel Cooler	litre/min. [GPM]	**1211 [320]**
Standard Thermostat Operating Range (Start to Open)	**°C [°F]**	**82 [180]**
Standard Thermostat Operating Range (Full Open)	**°C [°F]**	**94 [202]**
Heat Rejection to Engine Coolant[3]	kW [BTU/min.]	**538 [30,631]**
LTA Cooler		
Coolant Flow to LTA Heat Exchanger/Keel Cooler	litre/min. [GPM]	**310 [82]**
LTA Thermostat Operating Range (Start to Open)	**°C [°F]**	**66 [150]**
LTA Thermostat Operating Range (Full Open)	**°C [°F]**	**80 [175]**
Heat Rejection to LTA Coolant[3]	kW [BTU/min.]	**276 [15,729]**

INSTALLATION DRAWINGS

KTA50-M2 Subsytem	3170560

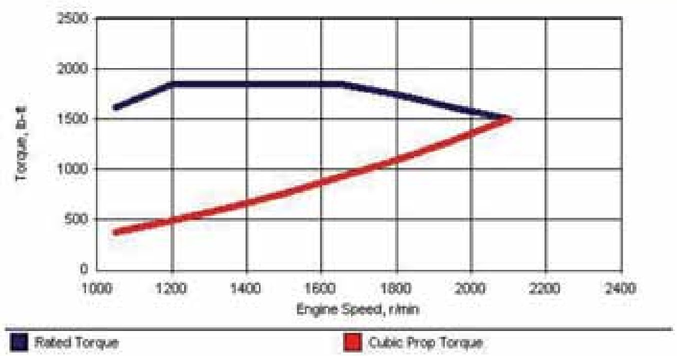
TBD = To Be Decided   N/A = Not Applicable   N.A. = Not Available

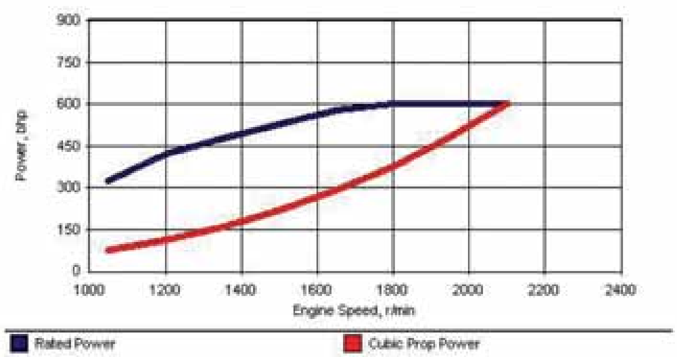
[1]All Data at Rated Conditions
[2]Consult Installation Direction Booklet for Limitations
[3]Heat rejection values are based on 50% water/ 50% ethylene glycol mix and do NOT include fouling factors. If sourcing your own cooler, a service fouling factor should be applied according to the cooler manufacturer's recommendation.
[4]Consult option notes for flow specifications of optional Cummins seawater pumps, if applicable.

PowerEvolution Network

Commercial Marine: Maximum-Continuous — Power & Torque Data

Series 60 (14L) - 6062HK12/13 — 06N04M7849





Rated Power: 600 bhp @ 2100 r/min

IMO MARPOL 73/78 Annex VI Compliant.

Engine Speed r/min	Power bhp (kW)	Prop Power bhp (kW)	Torque lb-ft (N-m)	Prop Torque lb-ft (N-m)
600	96 (72)	14 (10)	840 (1139)	123 (166)
750	151 (113)	27 (20)	1057 (1434)	189 (256)
900	219 (163)	47 (35)	1278 (1733)	274 (372)
1050	324 (242)	75 (56)	1621 (2198)	375 (509)
1200	423 (316)	112 (84)	1851 (2510)	490 (665)
1350	476 (355)	159 (119)	1852 (2511)	619 (839)
1500	528 (394)	219 (163)	1849 (2507)	767 (1040)
1650	581 (433)	291 (217)	1849 (2508)	926 (1256)
1800	600 (448)	378 (282)	1751 (2374)	1103 (1496)
1950	600 (448)	480 (358)	1616 (2191)	1293 (1753)
2100	600 (448)	600 (448)	1501 (2035)	1501 (2035)

Power output guaranteed within +2/-0% at SAE J1228 conditions:

77°F (25°C) air inlet temperature
100°F (38°C) fuel inlet temperature
.838 specific fuel gravity at 100°F (38°C)
77°F (25°C) raw water temperature
29.31 in. Hg (99 kPa) dry barometer

Performance shown includes:

Air intake restriction: 10 in. H_2O (2.5kPa)
Exhaust back pressure: 15 in. H_2O (3.7kPa)

Propeller load is the theoretical horsepower absorbed by a typical fixed pitch propeller, which has been designed to absorb the engines full power output at rated speed. For reference purpose, DDC uses a propeller load curve that is a function of the cube of the rpm.

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Date Last Updated: 5/21/2001

Printed on: 12/9/2003

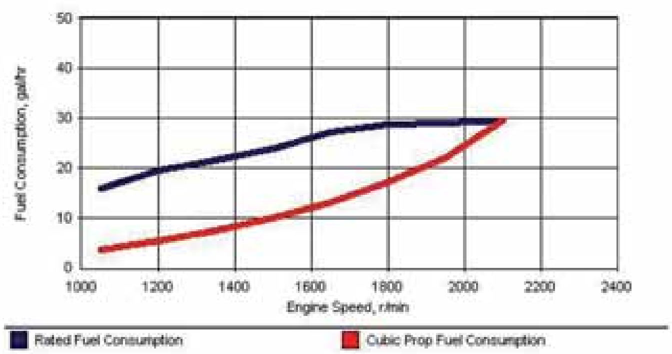
The user is advised to check the PowerEvolution Network for latest information.

PowerEvolution Network

Commercial Marine: Maximum-Continuous — Fuel Data

Series 60 (14L) - 6062HK12/13 — 06N04M7849

Rated Power: 600 bhp @ 2100 r/min



IMO MARPOL 73/78 Annex VI Compliant.

Engine Speed r/min	Rated Fuel Consumption gal/hr	Rated Fuel Consumption lb/bhp-hr	Prop Fuel Consumption gal/hr	Prop Fuel Consumption lb/bhp-hr
600				
750				
900	11.4	0.363	2.6	0.379
1050	15.9	0.343	3.8	0.350
1200	19.6	0.324	5.5	0.346
1350	21.6	0.317	7.6	0.335
1500	24.0	0.318	10.2	0.325
1650	27.3	0.329	13.3	0.320
1800	28.9	0.337	17.3	0.320
1950	29.0	0.338	22.2	0.323
2100	29.6	0.345	29.6	0.345

Fuel density: 6.99 lb/gal
.838 kg/L

Propeller load is the theoretical horsepower absorbed by a typical fixed pitch propeller, which has been designed to absorb the engines full power output at rated speed. For reference purpose, DDC uses a propeller load curve that is a function of the cube of the rpm.

Power output guaranteed within +2/-0% at SAE J1228 conditions:
77°F (25°C) air inlet temperature
100°F (38°C) fuel inlet temperature
.838 specific fuel gravity at 100°F (38°C)
77°F (25°C) raw water temperature
29.31 in. Hg (99 kPa) dry barometer

Performance shown includes:
Air intake restriction: 10 in. H_2O (2.5kPa)
Exhaust back pressure: 15 in. H_2O (3.7kPa)

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Date Last Updated: 5/21/2001

Printed on:
12/9/2003

The user is advised to check the PowerEvolution Network for latest information.

Calibration Details

Rated Power	600 bhp
Rated Power Speed	2100 r/min
High Idle Speed	2150 r/min
Low Idle Speed	600 r/min

Cooling System

Engine Heat Rejection to Coolant in the Engine Circuit	13,550 Btu/min
Engine Radiated Heat Rejection	850 Btu/min
Total Engine Coolant Capacity	60 qt
Raw Water Circuit Flow	128 gal/min
Minimum Raw Water Circuit Flow	115 gal/min
Engine Circuit Coolant Flow	119 gal/min
Minimum Engine Circuit Coolant Flow	107 gal/min
Maximum Raw Water Pump Inlet Restriction	2.5 lb/in.²

All values shown are at rated engine speed, rated power, and SAE J1228 conditions, unless otherwise noted.

Rated Power: 600 bhp @ 2100 r/min

Exhaust System

Exhaust Temperature	633 °F
Exhaust Flow	2,953 ft³/min

Fuel System

Fuel Injector / Pump	EUI
Injection Timing Height	81 mm
Fuel Consumption, Mass	207.0 lb/hr
Fuel Consumption, Volume	29.6 gal/hr
Fuel Spill Mass	507.1 lb/hr
Fuel Spill, Volume	72.5 gal/hr
Total Fuel Flow, Mass	714.1 lb/hr
Total Fuel Flow, Volume	102.2 gal/hr
Heat Rejection to Fuel	

Intake System

Engine Air Flow	1,398 ft³/min
Turbocharger Compressor Out Temperature	
Intake Manifold Pressure	67.9 in. Hg

Lubrication System

Oil Consumption, Mass	0.21 lb/hr
Oil Consumption, Volume	0.11 qt/hr
Oil Flow	37 gal/min
Oil Pressure	50.0 lb/in.²
Oil Pressure at Low Idle Engine Speed	25 lb/in.²

Other Information

Compression Ratio	16 : 1
Mean Piston Speed	2,315 ft/min
Brake Mean Effective Pressure (BMEP)	265 lb/in.²
Turbocharger	UTW7801 (1.03 A/R)
Friction Power	101 hp

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Date Last Updated: 10/8/2001

Rated Power: 600 bhp @ 2100 r/min

Cooling System

Maximum Raw Water Pressure at Raw Water Pump Outlet	
Maximum Raw Water Pressure at Heat Exchanger Outlet	7.0 lb/in.²
Maximum Charge Air Circuit Water Pump Inlet Temperature Rise from Raw Water	
Minimum Top Tank Coolant Temperature	180 °F
Maximum Engine Coolant Out Temperature	198 °F
Maximum System Pressure (Exclusive of Pressure Cap)	27.6 lb/in.²
Minimum Pressure Cap	7.0 lb/in.²
Recommended Raw Water Pipe Inlet Diameter	3.0 in.
Recommended Raw Water Pipe Outlet Diameter	2.5 in.
Recommended Simplex Sea Strainer Size (Maximum Screen Opening 3.0mm)	4 in.
Recommended Duplex Sea Strainer Size (Maximum Screen Opening 3.0mm)	

Electrical System

Maximum Resistance of Starting Circuit for a 12 Volt System	0.0012 ohms
Maximum Resistance of Starting Circuit for a 24 Volt System	0.0020 ohms
Recommended Battery Capacity for a 12 Volt System	1,875 CCA
Recommended Battery Capacity for a 24 Volt System	950 CCA

Exhaust System

Maximum Back Pressure	2.5 in. Hg
Recommended Single Dry Exhaust Pipe Diameter	6 in.
Recommended Dual Dry Exhaust Pipe Diameter	
Recommended Single Wet Exhaust Pipe Diameter	8 in.
Recommended Dual Wet Exhaust Pipe Diameter	

Fuel System

Secondary Fuel Filter Size	8 microns
Maximum Fuel Inlet Temperature	156 °F
Maximum Fuel Pump Suction for Clean System	6.0 in. Hg
Maximum Fuel Pump Suction for Dirty System	12.1 in. Hg
Recommended Primary Fuel Filter Size	30 microns

Intake System

Maximum Ambient to Turbocharger Compressor Inlet Temperature Rise	25 °F
Maximum Air Intake Restriction for a Clean Air Cleaner	10 in. H_2O
Maximum Air Intake Restriction for a Dirty Air Cleaner	20 in. H_2O
Maximum Intake Manifold Pressure	
Maximum Charge Air Cooler System Total Pressure Drop	
Maximum Intake Manifold Temperature	
Maximum Ambient to Intake Manifold Temperature Differential	
Maximum Crankcase Pressure	3 in. H_2O
Recommended Single Intake Pipe Diameter	
Recommended Dual Intake Pipe Diameter	

Lubrication System

Remote Mounted Filters: Maximum Change in Oil Pressure from Engine Out to Oil Cooler Inlet

UNCONTROLLED COPY
Date Last Updated: 5/21/2001

The user is advised to check the PowerEvolution Network for latest information.

Summary

Rated Engine Speed, r/min	2100
Certification Code (CWC)	6026
US Nonroad Certification	No
EURO Nonroad (Stage 1) Certification	No
IMO MARPOL 73/78 Annex VI Compliance	Yes
US EPA IMO statement of compliance approval number	DDX-IMO-01-01
Comments	

Rated Power: 600 bhp @ 2100 r/min

Steady-state Emission Summary, g/hr

NO_x	4.9
CO	0.155
HC	0.055
SO_2 - with .5% sulfur content fuel	469
SO_2 - with .05% sulfur content fuel	46.9
Particulates	0.06

E3 Cycle, g/bhp-hr

NO_x	5.73
CO	0.20
HC	0.068
Particulates	0.079

Smoke Summary, Bosch No.

Smoke	0.4

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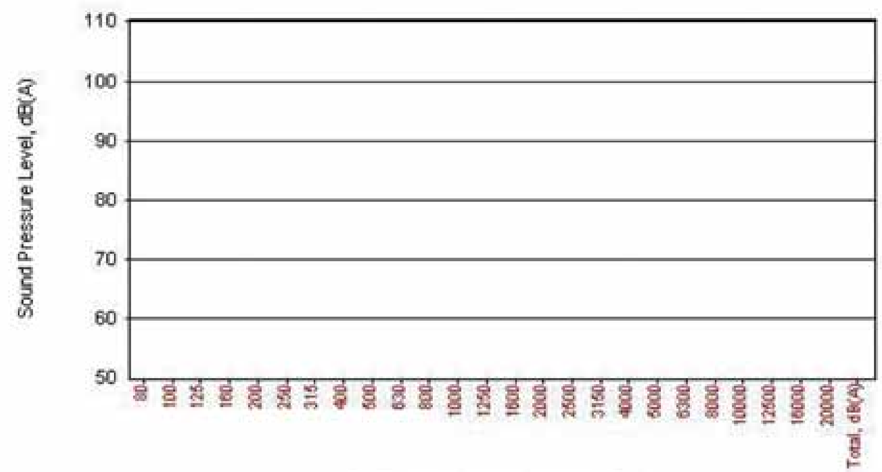
Date Last Updated: 5/21/2001

Commercial Marine: Maximum-Continuous | Noise Data

Series 60 (14L) - 6062HK12/13 | 06N04M7849

Rated Power: 600 bhp @ 2100 r/min



Noise conditions are not known.

Cylinder Head

Type	Slab, 4-Valve
Material	Cast Iron
Arrangement	

Exhaust Valve

Type	Poppet
Number (per cylinder)	2
Arrangement	Positive Rotation Overhead Valve
Material	
Location	In Cylinder Head
Operating Mechanism	Mechanical Rocker Arm
Type of Lifter	Roller Follower
Number of Valve Springs (per valve)	1

Exhaust Valve Insert

Type	
Material	Iron-based

Intake Valve

Type	Poppet
Number (per cylinder)	2
Arrangement	Positive Rotation Overhead Valve
Material	
Location	In Cylinder Head
Operating Mechanism	Mechanical Rocker Arm
Type of Lifter	Roller Follower
Number of Valve Springs (per valve)	1

Intake Valve Insert

Type	
Material	Nickel-based

Liner

Type	Wet
Material	Cast Iron (Bainitic)

Piston

Type	Articulated
Crown Material	Steel
Skirt Material	Aluminum
Cooling	Oil-Cocktail Shaker/p-tube

Piston Pin

Type	Polished and Hardened
Material	Steel- SAE 8622
Wrist Pin Keepers	Circlips

Piston Pin Bearing

Type	Bushing
Material	Cu-Zn Brass

Piston Ring Compression

Top Ring Type	Keystone - CKS Barrel Faced
Second Ring Type	Chrome Barrel Tapered Faced
Number (per piston)	

Piston Ring Oil

Type	Conformable Double Rail with Expander
Number (per piston)	1
Location	Bottom Piston Dome

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Date Last Updated: 10/8/2001

The user is advised to check the PowerEvolution Network for latest information.

Description

Number of Cylinders	6
Bore	5.24 in.
Stroke	6.61 in.
Displacement	855 in.³
Description	Starboard Engine with DDEC Electronics. This model has Marine Intermittent Ratings.
Certification	Emission levels comply with IMO MARPOL 73/78 Annex VI NOx Limits.
Comments	This model has heat exchanger cooling.
Combustion System	Direct Injection
Charge Air Cooling System	Air-to-raw water
Engine Type	Inline, 4-cycle
Aspiration Type	Turbocharged
Vent System	Closed Engine Crankcase
Status	Available
Availability Date	3/8/2001
Discontinued Date	12/31/2003

Size

Overall Length	83.39 in.
Overall Width	39.17 in.
Overall Height	45.75 in.
Length from Front of Engine to the Output Flange of the Marine Gear	80.44 in.
Length from Front of Engine to the Marine Gear Mounting Surface on the Flywheel Housing	61.44 in.
Overall Width excluding the Marine Gear	39.17 in.
Overall Height excluding the Marine Gear	45.45 in.

Weight

Approximate Dry Weight	4232 lb
Approximate Wet Weight	4466 lb
Approximate Dry Weight excluding the Marine Gear	3600 lb
Approximate Wet Weight excluding the Marine Gear	3808 lb

Center of Gravity Location for a Dry Engine

Distance from Rear Face of Block: x-axis	17.96 in.
Distance above Crankshaft: y-axis	5.10 in.
Distance to the Right of the Crankshaft: z-axis	0.41 in.
Distance from Rear Face of Block excluding the the Marine Gear: x-axis	22.10 in.
Distance above Crankshaft excluding the the Marine Gear: y-axis	6.80 in.
Distance to the Right of the Crankshaft excluding the Marine Gear : z-axis	0.70 in.

The user is advised to check the PowerEvolution Network for latest information.

RUN HARD. DREAM BIG.™

Cummins Marine

6BT5.9-D(M)

MARINE AUXILIARY

ENGINE SPECIFICATIONS

Configuration	In-line 6 cylinder, 4 stroke diesel
Bore & Stroke	102 mm x 120 mm (4.02 in x 4.72 in)
Displacement	5.9 L (359 in³)
Compression Ratio	16.5:1
Rotation	Counterclockwise facing flywheel
Installation Drawing	3170397

ENGINE DIMENSIONS

Length		Width		Height		Weight (Dry)	
mm	in	mm	in	mm	in	kg	lb
1062	42	678	27	1201	47	447	988

PRIME POWER RATINGS

Engine Speed	1500 RPM (50 HZ)		1800 RPM (60 HZ)	
Aspiration	Turbocharged		Turbocharged	
Rated kWe*	72	84	84	103
kWm	78	91	91	112
(BHP)	104	122	122	150
Fuel Consumption @ rated				
L/hr	19.8	22.4	23.4	27.1
gal/hr	5.2	5.9	6.2	7.2

*kWe represents the approximate amount of power available when used in a genset configuration.

DESIGN FEATURES

Cast Iron Skirted Block: With main bearing supports between each cylinder, for maximum strength and rigidity, low weight, and optimum crankshaft support.

Compact Size: For ease of installation and easy access for routine maintenance.

Direct Fuel Injection System: With high swirl intake ports for thorough mixing of air and fuel to provide low fuel consumption.

Exhaust Manifold: Water cooled with either top out or rear out exhaust outlet.

Fewer Parts: For less inventory and faster maintenance and repair. Parts simplicity also enables engines to be serviced and repaired with ordinary hand tools.

Forged Steel Crankshaft: With integral counterweights, allowing high power output from a compact size.

Forged Steel, I-Beam Cross Section Connecting Rods: With angle split cap-to-rod interface and capscrew attachment for maximum structural strength and ease of service.

Single Piece Cross Flow Cylinder Head: For short length and maximum structural stiffness of the block/head assembly.

Turbocharger: Holset water cooled turbocharger mounted at top of engine provides increased power, improved fuel economy, altitude compensation, and lower smoke and noise levels.

AVAILABLE EQUIPMENT

Drive Pulley: 8 groove pulley.
Alternator: 12 or 24-volt.
Front Engine Support: Available as optional equipment.
Governor: Mechanical and electronic available.
Oil Pan: Rear sump type
Starter: 12 or 24-volt.
FPTO Clutches: Electronic up to 100 bhp, 12 or 24-volt.
Certifications/Classification Society Approvals: Consult your nearest Cummins representative for current listing.
For other available equipment consult your local Cummins representative.

Cummins Marine

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E-mail: wavemaster@cummins.com

Bulletin 4000145 Printed in U.S.A. Rev. 6/01

CUMMINS MARINE Columbus, Indiana 47201 **Marine Performance Curve**	Basic Engine Model: **6BT5.9-D(M)**		Curve Number: **D(M)-90438**	*Marine Pg. No.* **6B 305**
	Engine Configuration: **D402051MX02**	CPL Code: **1523**	Date: **25Mar03**	

Displacement: **5.88 litre [359 in.^{3}]**
Bore: **102 mm [4.02 in.]**
Stroke: **120 mm [4.72]**
Fuel System: **Stanadyne DB4**
Cylinders: **6**

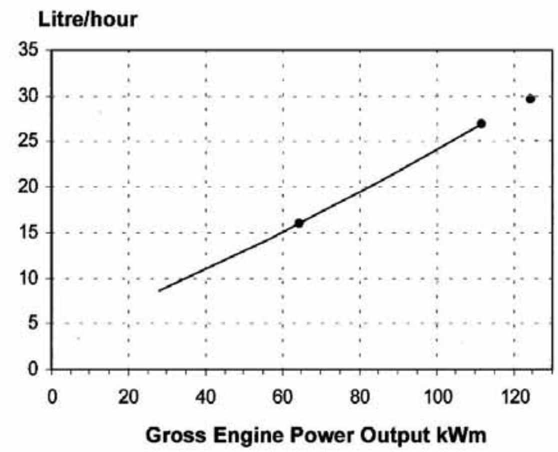
Aspiration: **Turbocharged**
Exhaust Type: **Wet**

Prime Power Rating: kW [HP] @ RPM **112 [150] @ 1800**

Engine Speed	Overload Capacity		Prime Power		Continuous Power	
RPM	kWm	BHP	kWm	BHP	kWm	BHP
1800	124	166	112	150	65	87

Engine Performance Data @ 1800 RPM

OUTPUT POWER			FUEL CONSUMPTION			
%	kWm	BHP	kg/ kWm·h	lb/ BHP·h	litre/ hour	U.S. Gal/ hour
10% OVERLOAD CAPACITY						
110%	124	166	0.205	0.337	29.9	7.89
PRIME POWER						
100	112	150	0.206	0.339	27.1	7.16
75	84	113	0.207	0.341	20.4	5.40
50	56	75	0.216	0.356	14.2	3.76
25	28	38	0.262	0.432	8.63	2.28
CONTINUOUS POWER						
100	65	87	0.213	0.350	16.2	4.29



Rating Conditions: Ratings are in accordance with ISO 3046 reference conditions; air pressure at 100 kPa (29.61 in. Hg.), air temperature 25°C (77°F), and 30% relative humidity. The fuel consumption data is based on No. 2 diesel fuel weight at 0.85 kg/litre (7.1 lb/U.S. gal).

Power output curves are based on the engine operating with fuel system, water pump and lubricating oil pump; not included are battery charging alternator, fan, optional equipment and driven components.

Operation at elevated temperatures for sustained operation above 40°C (104°F), derate 2% per 11°C (1% per 10°F).

Prime Power Rating is applicable for supplying continual electrical power at varied load. The following are the Prime Rating parameters:

* Prime Power is available for an unlimited number of hours per year in a variable load application. Variable load should not exceed a 70% average of the Prime Power rating during any operating period of 250 hours.
* The total operating time at 100% Prime Power shall not exceed 500 hours per year.
* There is a 10% overload capability for a period of 1 hour within a 12 hour period of operation. Total operating time at 10% overload shall not exceed 25 hours per year.

Continuous Power Rating is applicable for supplying continual power at a constant 100% load for an unlimited number of hours per year. There is no overload capability for this rating.

TECHNICAL DATA DEPT.

CHIEF ENGINEER

Auxiliary Marine Engine Performance Data

General Engine Data[1]

Engine Model	6BT5.9-D(M)	
Rating Type	Prime Power	Overload
Rated Engine Power ... kW [HP]	112 [150]	124 [166]
Governed Engine Speed ... RPM	1800	1800
Rated HP Production Tolerance ... %	±5	
Rated Engine Torque ... Nm [ft./lb]	593 [438]	657 [484]
Idle Speed Range ... RPM	950-1150	
Brake Mean Effective Pressure ... kPa [PSI]	1268 [184]	1403 [203]
Compression Ratio	16.5:1	
Piston Speed ... m/sec [ft./min]	7.2 [1416]	
Firing Order	1-5-3-6-2-4	
Friction Power ... kW [HP]	16 [22]	
Steady State Stability Band at any Constant Load ... %	± 0.5	

Fuel System[1]

Approximate Fuel Flow to Pump ... litre/hr [GPH]	127 [34]	127 [34]
Max. Allowable Fuel Supply to Pump Temperature ... °C [°F]	60 [140]	60 [140]
Approximate Fuel Flow Return to Tank ... litre/hr [GPH]	100 [26]	100 [26]

Weight[1]

Dry - Engine Only ... kg [lb]	426 [940]	
Dry - Engine With Heat Exchanger ... kg [lb]	508 [1120]	

Air System[1]

Intake Manifold Pressure ... mm Hg [in Hg]	TBD	TBD
Intake Air Flow ... litre/sec [CFM]	132 [280]	146 [310]
Heat Rejection to Ambient ... kW [BTU/min]	16 [915]	18 [1015]

Exhaust System[1]

Exhaust Gas Flow ... litre/sec [CFM]	326 [690]	361 [765]
Exhaust Gas Temperature (Turbine Out) ... °C [°F]	388 [730]	433 [810]
Exhaust Gas Temperature (Manifold) ... °C [°F]	TBD	TBD
Heat Rejection to Exhaust ... kWm [BTU/min]	58 [3275]	62 [3545]

Cooling System[1]

Coolant Flow to Engine Heat Exchanger/Keel Cooler		
At 1 psi Friction Head External to Engine ... litre/min [GPM]	144 [38]	
At 5 psi Friction Head External to Engine ... litre/min [GPM]	114 [30]	
Standard Thermostat Operating Range (Min.) ... °C [°F]	82 [180]	
Standard Thermostat Operating Range (Max.) ... °C [°F]	95 [203]	
Heat Rejection to Engine Coolant[3] ... kWm [BTU/min]	87 [4950]	TBD
Sea Water Flow @ 10 psi Pump Discharge Pressure ... litre/min [GPM]	42 [11]	
Pressure Cap Rating (With Heat Exchanger Option) ... kPa [PSI]	69 [10]	

Installation drawings ... 3170397

Engine General Data Sheet ... **DS-4020**

TBD = To Be Decided **N/A = Not Applicable** **N.A. = Not Available**

[1]All Data at Rated Conditions

[2]Consult Installation Direction Booklet for Limitations

[3]Heat rejection to coolant values are based on 50% water/ 50% ethylene glycol mix and do NOT include fouling factors. If sourcing your own cooler, a service fouling factor should be applied according to the cooler manufacturer's recommendation.

[4]Consult option notes for flow specifications of optional Cummins seawater pumps, if applicable.

APPENDIX F

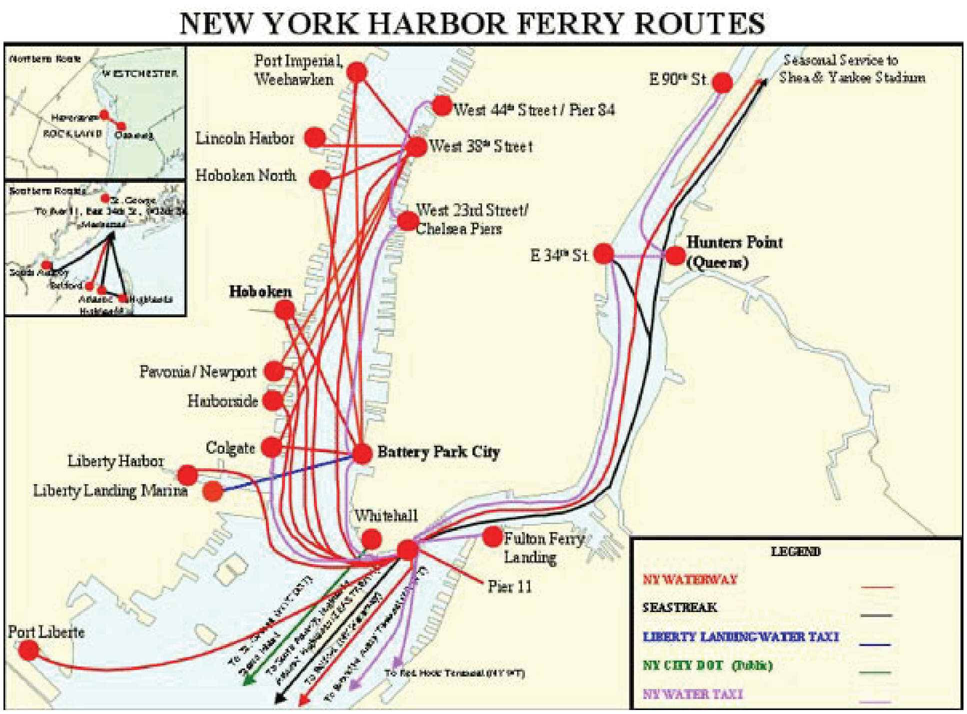
PANYNJ Ferry Vessel Routes

FERRY SERVICES

*W*elcome to the Port Authority's menu of waterborne transportation travel options. We hope you leave your auto at home and enjoy the scenery along the region's waterways. You can take the ferry to work, enjoy a ballgame or visit the tourist attractions of the New York/New Jersey region.

a. The Port Authority is sponsor of the ferry service program between Hoboken, NJ and the World Financial Center, NY, and diligently works with local municipalities throughout the New York/New Jersey region in developing new ferry services. We provide information on all available ferry services as a way of encouraging you to use the rich transit resources of our region. The Port Authority's role in developing regional ferry transportation dramatically expanded after September 11, 2001. With the destruction of the PATH's lower Manhattan link, ferries have played an important role in efficiently moving commuters. Please note all schedules, fares, etc. are subject to change by the ferry operators.

b. The Port Authority serves as a ferry transportation clearinghouse for the NY-NJ metropolitan area. We are here to help you "navigate" the region. Please feel free to contact us via the Feedback Form on the navigation bar. You can contact the ferry operators directly by calling them at the telephone numbers shown at the bottom of this page or by clicking on the links to their web pages.



NY Waterway

1. Weehawken (Port Imperial) to Pier 11, Wall Street
2. Hoboken to Pier 11, Wall Street
3. Harborside to Pier 11, Wall Street
4. Port Liberte to Pier 11, Wall Street
5. Liberty Harbor to Pier 11, Wall Street
6. Newport to Pier 11, Wall Street
7. Belford (Monmouth County, NJ) to Pier 11, Wall Street and West 38th St.
8. Hoboken to World Financial Center (WFC) at Battery Park City
9. Colgate (Exchange Place, Jersey City) to Battery Park City

10. Weehawken to Hoboken North and World Financial Center (WFC) at Battery Park City
11. Hoboken North to W 38th Street
12. Lincoln Harbor to W. 38th Street
13. Colgate to W. 38th Street
14. Newport to Harborside and W. 38th Street
15. Weehawken to W. 38th Streeet
16. Haverstraw (Rockland County, NY) to Ossining (Westchester County, NY)

SEASTREAK

17. Highlands & Atlantic Highlands to Pier 11,Wall Street and E. 34th St.
18. Atlantic Highlands to Pier 11, E. 34th St.
19. South Amboy to Pier 11, E. 34th St

LIBERTY PARK WATER TAXI

20. Liberty Landing, Liberty State Park to World Financial Center

NEW YORK WATER TAXI

21. Fulton Ferry Landing, Pier 11, Red Hook, WFC, Chelsea Piers W. 44th St.
22. East River Hunters Point - E. 90th st., HuntersPoint, E. 34th St. , Pier 11, Wall St.
23. Brooklyn Army Terminal to Red Hook Terminal and Pier 11, Wall St.
24. Colgate to Pier 11, Wall Street

NEW YORK CITY DOT

25. St. George, Staten Island to South Ferry

SEASONAL SERVICE

NY WATERWAY

1. Weehawken to Yankee Stadium via Hoboken, South Street Seaport, E. 34th St., E. 90th St.
2. Weehawken to Shea Stadium via Hoboken, South Street Seaport, E. 34th St., E. 90th St.

SEASTREAK

3. Atlantic Highlands to Yankee Stadium via Pier 11, E. 34th St., E. 90th St.
4. Atlantic Highlands to Shea Stadium via Pier 11, E. 34th St., E. 90th St.

For Further Directions, Information and Schedules Click on the Links Below:

NY Waterway	1-800-53-FERRY
Seastreak	1-800-BOATRIDE
New York Water Taxi	1-212-742-1969
Liberty Park Water Taxi	1-201-985-8000
NYC DOT	1-718-815-BOAT

APPENDIX G

Emission Test Procedure

System Set-up:

1. Install sampling probe.
2. Locate sampling system in secure location.
3. Locate analyzers in secure location.
4. Turn on analyzers and bring to temperature.
5. Verify analyzer calibration with reference gases.
6. Install dummy filters into all filter holders.
7. Turn on pumps and verify flow rates.

Selecting Dilution Rate:

1. Request vessel operator to start engine and allow the engine to warm up as recommended by operator.
2. Request vessel operator to apply load to engine up to selected setting.
3. Install dummy filters in bypass, PM10, PM2,.5, filter holders.
4. When the engine is sufficiently warmed up begin drawing sample through tunnel in bypass mode with zero dilution.
5. Record raw (ECOM) CO and NOx, and SMART CO and NOx
6. Verify dilution rate is 15% to 25% of total flow
7. Check that exhaust concentrations agree with desired dilution rate.
8. Switch to PM10 and PM2.5 filter flow path.

Prepare to sample and sample

1. Disconnect from sample probe.
2. Remove dummy filters and inspect for moisture.
3. Install test filters.
4. Reconnect to exhaust in bypass mode.
5. Record raw (ECOM) CO and NOx, and SMART CO and NOx.
6. Verify dilution rate is 15% to 25% of total flow.
7. Confirm fuel flow rate with Seaworthy Systems.
8. Switch to PM10/PM2.5 filters and initiate gaseous exhaust data logging.
9. Conduct test run.
10. Repeat as needed to collect three valid samples

APPENDIX H

Error Resolution

Sample Error Propagation Calculation

Sample Calculation: John Keith - PreDOC – Push820 #1

Values from analyzers are on a volume to volume basis. In order to convert these values into a mass the volume of exhaust must be known.

Fuel flow rate and fuel analysis results in conjunction with the following equations yield the rate of exhaust. By performing a mass balance on the carbon the following equations yield the rate of exhaust volume.

The method below is essentially identical to Method 2 of Annex A of ISO 8178-1 *Calculation of the exhaust gas mass flow rate and/or of the combustion air consumption.*

Kg of carbon per hour of fuel (Cfuel) = Kg of carbon per hour in exhaust (Cex)

Calculation of Cfuel in kg/hr:

Cfuel = Fuel flow rate * Percent weight of carbon
= (3.19 GPH * 0.8544 kg/L * 3.7854 L/gallon) * 0.8731
= 9.008 kg/hr

$$\Delta C_{fuel} = \sqrt{\left(\frac{\Delta Fuelflowrate}{Fuelflowrate}\right)^2 + \left(\frac{\Delta \%weightcarbon}{\%weightcarbon}\right)^2} \times C_{fuel}$$

$$\Delta C_{fuel} = \sqrt{\left(\frac{.06}{3.19}\right)^2 + \left(\frac{0.01}{0.8731}\right)^2} \times 9.008$$

$$\Delta C_{fuel} = 0.20 \text{ kg/hr}$$

Calculation of carbon mass per unit volume of exhaust (Cvol) in kg/m^3:

Cvol = kg of carbon per meter cubed from (CO2 + CO + HC)
= $C_{CO2} + C_{CO} + C_{HC}$

C_{CO2} = % volume ÷ 100 * density of CO2 * % C in CO2 by mass
= 4.80 ÷ 100 * 1.830862 kg/m^3 * 0.273
= 0.02400 kg/m^3

$$\Delta C_{CO2} = \sqrt{\left(\frac{\Delta\%vol}{\%vol}\right)^2} \times C_{CO2} == \sqrt{\left(\frac{0.1\%}{4.80\%}\right)^2} \times 0.0240 = 0.0005$$

Cvol = 0.02400 + 0.00005302 + 0.000101
= **0.02415 kg/m^3**

CO2 is responsible for 0.0240 ÷ 0.02415 = 99.3 % of total mass of C
Therefore ΔC_{CO2} is approximately equal to ΔCvol.

Therefore:

Cvol +/- ΔCvol = **0.02415 kg/m^3 +/- 0.0005 kg/m^3**

Calculation of total exhaust volume per hour (TEXvol) in m^3/hr:

TEXvol = Cfuel ÷ Cvol
= 9.008 kg/hr ÷ 0.02415 kg/ m^3
= **373.0 m^3/hr**

$$\Delta TEX_{VOL} = \sqrt{\left(\frac{\Delta C_{FUEL}}{C_{FUEL}}\right)^2 + \left(\frac{\Delta C_{VOL}}{C_{VOL}}\right)^2} \times TEX_{VOL} = \sqrt{\left(\frac{0.0005}{0.02415}\right)^2 + \left(\frac{0.20}{9.008}\right)^2} \times 373$$

$\Delta TEX_{VOL} =$ **11 m^3/hr**

NOx Calculation

Push 1000 #1: Raw NOx: 1127 ppm

NOx correction for humidity and temperature:

Dry bulb temp: 16 ºC Wet bulb: 10 ºC yields ~40 grains of water per lb of dry air.

For Diesel engines this yields a correction factor of 0.95

Therefore: adjusted raw NOx = 1127 * 0.95 = 1071

Calculation of NOx in kg/hr:

NOx (kg/hr) = (NOxad ÷ 1,000,000) * ρ_{NOX} * TEXm3/hr

Where:

NOxad is the adjusted raw NOx in ppm = 1071 ppm
ρ_{NOX} is the density of NOx at STP; = 1.912429 kg/m^3
TEXm3/hr is the total exhaust volume per hour in m^3/hr = 373.0 m^3/hr

NOx (kg/hr) = (1071 ppm ÷ 1,000,000) * 1.912429 kg/m^3 * 373.0 m^3/hr

= 0.764 kg/hr of NOx

$$\Delta NOx_{(KG/HR)} = \sqrt{\left(\frac{\Delta NOx_{AD}}{NOx_{AD}}\right)^2 + \left(\frac{\Delta TEX_{VOL}}{TEX_{VOL}}\right)^2} \times TEX_{VOL} = \sqrt{\left(\frac{21}{1071}\right)^2 + \left(\frac{11}{373}\right)^2} \times 0.764$$

$\Delta NOx_{(KG/HR)} = 0.022$ **kg/hr**

Calculation of NOx in g/gal:

NOx (g/gal) = NOx (kg/hr) ÷ GPH * 1000 g/kg
= 0.764 kg/hr ÷ 3.19 GPH * 1000 g/kg

= 239 g/gal of NOx

The mass of NOx per hour of operation and mass of NOx per gallon of fuel for the John Keith during run #1 of the Push-820 mode were **0.764 kg/hr +/- 0.022 kg/hr** and **239 g/gal +/- 7 g/gal** respectively.

Harbor Composite Emissions Rate

The equation used to determine the error of the composite vessel emissions rate is a simple weighted standard deviation calculation.

$$STDEVcomp = STDEV_{PUSH} \times WtPush + STDEV_{CRUISE} \times WtCruise + STDEV_{MAN} \times WtMan$$

MV JOHN KEITH Post DOC Harbor Load Cycle Emissions. April 2006												
										Composite Values		
												Rel. Dev. (%)
												10.97%
												9.36%
												25.53%

In the case on the John Keith as presented in the above table, the values entered into the formula for the composite NO_x calculation are:

Composite Rate **= 0.79 * 0.260 + 1.01 * .318 + 1.42 * 0.412 = 1.11 kg/hr of NOx**

Composite error **= 0.01 * 0.260 + .748 * .318 + 0.19 * 0.412 = +/- 0 .122 kg/hr of NOx**

The composite rate is then **1.11 +/- 0.122 kg/hr of NOx**

NYC PRIVATE FERRY FLEET EMISSIONS REDUCTION TECHNOLOGY STUDY AND DEMONSTRATION

Error Propagation and Analysis Report

Prepared for

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Introduction

The statistical analysis and propagation of errors reported in the data was completed for the validating the final values presented in this report. In order to complete this analysis, two major assumptions were made. First, it was assumed that all emissions rates may be represented by a normal distribution. Second, the composite standard deviation of the standard deviations at specific load points for each operating mode and vessel may be applied to the mean emissions rate. The mean emissions rate was determine via a best fit curve at the mean load (measured in RPM) for each operating mode and vessel. From these assumptions the standard deviations were propagated throughout the fleet. Confidence intervals were determined from all propagated standard deviations via multiplying the standard deviation of the mean value by a t-distribution coefficient.

In order to complete a more thorough analysis with the data at hand additional data was removed from the analysis and additional assumptions were made. The emissions from generators were ignored, as well as SeaStreak vessels due to their withdrawal from the program. Additionally, the PM 2.5 value for maneuvering was assumed to be the same as the PM 2.5 rate for the vessel's transit. The following sections depict all formulas and calculations used in the statistical analysis.

Emissions Rate Standard Deviations

In probability and statistics, the standard deviation of a sample set is defined as the square root of the variance. The units of the standard deviation are the same as the values in the sample set. Therefore, for a sample set of emission rates in short tons per year the units for the standard deviation are in short tons per year as well and the variance is in units of (short tons per year)^2. Standard deviations were computed for this data as it is the most common measurement of statistical dispersion. Dispersion may be defined as how spread out the individual values in a data set is. Additionally, since no universal variance or standard deviation (σ) has been defined for the emission rates used, it is estimated by a modified standard deviation (s).

The emissions rate standard deviations were calculated as the composite standard deviation from samples taken at various loads for each mode of operation and vessel. These standard deviations were calculated via the following equation:

$$V_x = s_x^2$$

$$s_x^2 = \frac{\sum (x - \bar{x})^2}{n - 1}$$

$$s_x = \sqrt{\frac{\sum (x - \bar{x})^2}{n - 1}}$$

$$s_x^2 = \frac{\left(\sum x^2\right) - n\bar{x}^2}{n - 1}$$

$$s_x = \sqrt{\frac{\left(\sum x^2\right) - n\bar{x}^2}{n - 1}}$$

$$s_x^2 = \frac{\sum x^2 - \frac{\left(\sum x\right)^2}{n}}{n - 1}$$

$$s_x = \sqrt{\frac{\sum x^2 - \frac{\left(\sum x\right)^2}{n}}{n - 1}}$$

V_x = sample variance of x

s_x = sample standard deviation of x

x = individual value

$\bar{x}$ = mean of "n" observation

n = number of observations

After the sample standard deviations were calculated for all single load values, the specific sample mode standard deviation of the mean was calculated using the following equations. Additionally, the standard deviation of the mean for any calculated value or dependent sample data set was computed by employing the fundamental equations used for the addition/subtraction and multiplication/division of standard deviations. These equations are presented in the following subsection "Propagation of Errors."

$$V_{x_1} = V_{x_2} = V_{x_3} = V_{x_n} \equiv V_{\bar{x}}$$

$$V_{\bar{x}} = n\left(\frac{1}{n}\right)^2 V_x = \frac{V_x}{n}$$

$$s_{\bar{x}} = \frac{s_x}{\sqrt{n}}$$

After the standard deviation of the mean was calculated for all specific sample modes, a composite sample standard deviation was calculated via the general equations listed below:

$$\bar{x}_C = f(\bar{x}_1, \bar{x}_2, \bar{x}_3, \ldots \bar{x}_n) = \frac{1}{n}(\bar{x}_1 + \bar{x}_2 + \bar{x}_3 + \cdots \bar{x}_n)$$

$$\frac{\partial \bar{x}_C}{\partial \bar{x}_1} = \frac{\partial \bar{x}_C}{\partial \bar{x}_2} = \frac{\partial \bar{x}_C}{\partial \bar{x}_3} = \frac{\partial \bar{x}_C}{\partial \bar{x}_n} = \frac{1}{n}$$

$$V_{\bar{x}_C} = \left(\frac{1}{n}\right)^2 V_{\bar{x}_1} + \left(\frac{1}{n}\right)^2 V_{\bar{x}_2} + \left(\frac{1}{n}\right)^2 V_{\bar{x}_3} + \cdots + \left(\frac{1}{n}\right)^2 V_{\bar{x}_n}$$

$$V_{\bar{x}_C} = \left(\frac{1}{n}\right)^2 \left(V_{\bar{x}_1} + V_{\bar{x}_2} + V_{\bar{x}_3} + \cdots + V_{\bar{x}_n}\right)$$

$$s_{\bar{x}_C} = \sqrt{\left(\frac{1}{n}\right)^2 \left(V_{\bar{x}_1} + V_{\bar{x}_2} + V_{\bar{x}_3} + \cdots + V_{\bar{x}_n}\right)}$$

$$s_{\bar{x}_C} = \sqrt{\left(\frac{1}{n}\right)^2 \left(s_{\bar{x}_1}^2 + s_{\bar{x}_2}^2 + s_{\bar{x}_3}^2 + \cdots + s_{\bar{x}_n}^2\right)}$$

Propagation of Errors

In order to propagate the standard deviations from single emissions rates or values throughout the fleet, the emissions rate standard deviations of the mean were added, subtracted, multiplied, and divided in the proper fashion to obtain the presented values. When adding and subtracting standard deviations or standard deviations of the mean, the following procedure was used.

$$w = f(x, y, z) = x + y + z$$

$$V_w = \left(\frac{\partial w}{\partial x}\right)^2 V_x + \left(\frac{\partial w}{\partial y}\right)^2 V_y + \left(\frac{\partial w}{\partial z}\right)^2 V_z$$

$$\frac{\partial w}{\partial x} = \frac{\partial w}{\partial y} = \frac{\partial w}{\partial z} = 1$$

$$V_w = (1)^2 V_x + (1)^2 V_y + (1)^2 V_z$$

$$s_w^2 = s_w^2 + s_y^2 + s_z^2$$

$$s_w = \sqrt{s_w^2 + s_y^2 + s_z^2}$$

$$w = ax + by + cz$$

$$\frac{\partial w}{\partial x} = a; \quad \frac{\partial w}{\partial y} = b; \quad \frac{\partial w}{\partial z} = c$$

$$V_w = a^2 V_x + b^2 V_y + c^2 V_z$$

$$s_w^2 = a^2 s_x^2 + b^2 s_y^2 + c^2 s_z^2$$

$$s_w^2 = (as_x)^2 + (bs_y)^2 + (cs_z)^2$$

$$s_w = \sqrt{(as_x)^2 + (bs_y)^2 + (cs_z)^2}$$

When multiplying and dividing standard deviations the following procedure was used. The specific case where this was applied was to obtain percent reduction value standard deviations. The following outlines the equation used to obtain these values.

$$\mathrm{w} = f(\mathrm{x}, \mathrm{y}) = \frac{(ax)}{(by)}$$

$$\frac{\partial \mathrm{w}}{\partial \mathrm{x}} = \frac{a}{by} = \frac{w}{x}$$

$$\frac{\partial \mathrm{w}}{\partial \mathrm{y}} = -\frac{ax}{b} = -\frac{w}{y}$$

$$\mathrm{V_w} = \left(\frac{w}{x}\right)^2 \mathrm{V_x} + \left(-\frac{w}{y}\right)^2 \mathrm{V_y}$$

$$\mathrm{s_w} = \sqrt{\left(\frac{w}{x}\right)^2 \mathrm{s_x^2} + \left(-\frac{w}{y}\right)^2 \mathrm{s_y^2}}$$

Confidence Intervals

Confidence Intervals are used to take the uncertainty of the standard deviation into account. When computing confidence intervals the number of degrees of freedom, φ, becomes imperative. When calculating confidence intervals the Student's t-Distribution coefficients were used to take into account the uncertainty in the standard deviation. The following equation was used to compute all reported confidence intervals.

$$x \pm t_{\alpha,\varphi} s_{\bar{x}}$$

φ = degrees of freedom (independent deviation calculations) possible within the sample after $\bar{\mathrm{x}}$ has been calculated

α = area under one tail of Student's t-Distribution curve

Degrees of freedom represent the number of independent deviation calculations possible within a sample after the mean has been calculated. This number is a function of the number of points used to define a specific data set, and is independent of the number of observations of a known input. When calculating the standard deviation about a single set of data, the degrees of freedom is equal to the number of individual data points minus one. As noted in the definition of degrees of freedom above, since the mean value of x from a sample data set was used in calculating the standard deviation of that data set, a calculated value from the data set was used to calculate the standard deviation of that set. Thus, the total number of degrees of freedom for a sample data set is the number of individual data points minus one (n-1). For values that are a composite of multiple unique data sets, the same rule applies. For example, if a composite standard deviation is calculated from 10 unique data sets all composed of 3 individual data points, the degrees of freedom is equal to [$(n_1$-1)+(n_2-2)+…+(n_{10}-1)] which equals 20.

EXAMPLE

The following example calculation follows the procedures used to create reported values.

Single Emissions Rate Standard Deviation (MV JOHN KEITH, Cruise 1000, NO_X)

Universal Data	n	x (kg/hr)	x^2 (kg/hr)^2
SS-1000-1	1	0.68252	0.46584
SS-1000-2	1	0.70658	0.49926
SS-1000-3	1	0.71819	0.51579
Total	3	2.1073	1.4809

$$s_x = \sqrt{\frac{\sum x^2 - \frac{\left(\sum x\right)^2}{n}}{n-1}} = \sqrt{\frac{1.4809 - \frac{2.1073^2}{3}}{2}} = 0.018190 \left({}^{kg}\!/_{hr} \right)$$

$$s_{\bar{x}} = \frac{s_x}{\sqrt{n}} = \frac{0.018190}{\sqrt{3}} = 0.0105 \left({}^{kg}\!/_{hr} \right)$$

Total Emissions Rate Standard Deviation of the Mean (MV JOHN KEITH, Cruise, NO_X)

MODE	n	$\bar{x}$ (kg/hr)	$S\bar{x}$ (kg/hr)	$S\bar{x}^2$ (kg/hr)^2
SS-1000	1	0.70243	0.010502	0.0001102 9
SS-1350	1	0.84351	0.006016	0.0000362 0
SS-1700	1	0.96218	0.007180	0.0000515 5
SS-1950	1	1.3004	0.003011	0.0000090 6
SS-2150	1	2.0542	0.025925	0.0006721 2
Total	5	5.8627	0.051358	0.0026377

$$s_{\bar{x}_C} = \sqrt{\left(\frac{1}{5}\right)^2 \left(s^2_{\bar{x}_1} + s^2_{\bar{x}_2} + s^2_{\bar{x}_3} + s^2_{\bar{x}_4} + s^2_{\bar{x}_5}\right)}$$

$$s_{\bar{x}} = 0.005930 \left({}^{kg}\!/_{hr} \right)$$

Total Emissions Rate Standard Deviation of the Mean Summed Values (Representative Values)

Distance (NM)	Engine Type	NO_X at Push, per Engine (kg/hr)	NO_X at Push STD Deviation (kg/hr)
13.1	Caterpillar 3406E	1.35	0.00464
12.8	Caterpillar 3406E	1.35	0.00464
11.8	Caterpillar 3406E	1.35	0.00464
8.00	Caterpillar 3406E	1.35	0.00464
8.00	Caterpillar 3406E	1.35	0.00464
7.40	Caterpillar 3406E	1.35	0.00464
7.40	Caterpillar 3406E	1.35	0.00464
6.20	Caterpillar 3412(2)	2.02	0.0137
6.20	Caterpillar 3412(2)	2.02	0.0137

$$w = f(x, y, z) = x + y + z$$

$$V_w = a^2 V_x + b^2 V_y + c^2 V_z$$

$$a = 1$$

$$b = 1$$

$$c = 1$$

$$V_w = V_x + V_y + V_z$$

$$s_{\overline{w}} = \sqrt{(s_{\overline{x}})^2 + (s_{\overline{y}})^2 + (s_{\overline{z}})^2}$$

$$s_{\overline{w}} = \sqrt{7(0.00464^2) + 2(0.137)^2} = 0.0229\left(kg/hr\right)$$

Percent Reduction Standard Deviation of the Mean (Representative Vales)

Current Total Annual NOx, per route	Current NOx STD Deviation	NOx Reduction	NOx Reduction STD Deviation	% NOx Reduction	% NOx Reduction STD Deviation
(short tons/yr)	(short tons/yr)	(short tons/yr)	(short tons/yr)	(%)	(%)
46.8	0.818	0.267	2.21	0.570%	4.72%

$$\mathrm{w} = f(\mathrm{x},\mathrm{y}) = \frac{(ax)}{(by)}$$

$$\mathrm{s}_{\overline{\mathrm{w}}} = \sqrt{\left(\frac{w}{x}\right)^2 \mathrm{s}_{\overline{\mathrm{x}}}^2 + \left(-\frac{w}{y}\right)^2 \mathrm{s}_{\overline{\mathrm{y}}}^2}$$

$$\mathrm{s}_{\overline{\mathrm{w}}} = \sqrt{\left(\frac{0.00570}{0.267}\right)^2 2.21^2 + \left(-\frac{0.00570}{46.8}\right)^2 0.818^2}$$

$$\mathrm{s}_{\overline{\mathrm{w}}} = 4.72\%$$

95% Confidence Interval (Representative Values)

NOx at Push, per Engine	NOx at Push STD Deviation	NOx at Push ± 95.0% C.I.
(kg/hr)	**(kg/hr)**	**(± kg/hr)**
2.94	0.0159	0.0507

$$x \pm t_{\alpha,\varphi} s_{\bar{x}} = 2.94 \pm 3.18 * 0.0159 = 2.94 \pm 0.0507 \left({}^{kg}\!/_{hr} \; 95\% \; C.I. \right)$$

Source: Peters, D.G., et al., 1974, "Treatment of Analytical Data," Chapter 2 in Chemical Separations and Measurements: Theory and Practice of Analytical Chemistry, W.B. Saunders, Philadelphia.

APPENDIX I

Sample Calculation

Sample Calculation: PORT IMPERIAL MANHATTAN Idle #1 LSD

Values from analyzers are on a volume to volume basis. In order to convert these values into a mass the volume of exhaust must be known.

Fuel flow rate and fuel analysis results in conjunction with the following equations yield the rate of exhaust. By performing a mass balance on the carbon the following equations yield the rate of exhaust volume.

The method below is essentially identical to Method 2 of Annex A of ISO 8178-1 *Calculation of the exhaust gas mass flow rate and/or of the consumption air consumption*.

Kg of carbon per hour of fuel (Cfuel) = Kg of carbon per hour in exhaust (Cex)

Calculation of Cfuel in kg/hr:

Cfuel = Fuel flow rate * Percent weight of carbon
= (4.59 GPH * 0.8641 kg/L * 3.7854 L/gallon) * 0.8658
= 12.998 kg/hr

Calculation of carbon concentration per unit volume of exhaust (Cvol) in kg/m³:

Cvol = kg of carbon per meter cubed from (CO2 + CO + HC)
= $C_{CO2} + C_{CO} + C_{HC}$

C_{CO2} = % volume ÷ 100 * density of CO2 * % C in CO2 by mass
= 6.15 ÷ 100 * 1.830862 kg/m^3 * 0.273
= 0.03073 kg/m^3

Cvol = 0.03073 + 0.00002949 + negligible
= **0.03076 kg/m^3**

Calculation of total exhaust volume per hour (TEXvol) in m^3/hr:

TEXvol = Cfuel ÷ Cvol
= 12.998 kg/hr ÷ 0.03076 kg/ m^3
= **422.7 m^3/hr**

<u>NO_X Calculation</u>

Idle #1: Raw NO_X: 1916 ppm

NO_X correction for humidity and temperature:

Dry bulb temp: 19 ºC   Wet bulb: 12 ºC yields ~42 grains of water per lb of dry air.

For Diesel engines this yields a correction factor of 0.92

Therefore: adjusted raw NO_X = 1916 * 0.92 = 1762.7

Calculation of NO_X in kg/hr:

NO_X (kg/hr) = (NO_{Xad} ÷ 1,000,000) * ρ_{NOX} * TEXm3/hr

Where:

NO_{Xad} is the adjusted raw NO_X in ppm = 1762.7 ppm
ρ_{NOX} is the density of NO_X at STP; = 1.912429 kg/m^3
TEXm3/hr is the total exhaust volume per hour in m^3/hr = 422.7 m^3/hr

NO_X (kg/hr) = (1762.7 ppm ÷ 1,000,000) * 1.912429 kg/m^3 * 422.7. m^3/hr

= 1.425 kg/hr of NO_X

Calculation of NO_X in g/gal:

NO_X (g/gal) = NO_X (kg/hr) ÷ GPH * 1000 g/kg
= 1.425 kg/hr ÷ 4.59 GPH * 1000 g/kg

= 310 g/gal of NO_X

The mass of NO_X per hour of operation and mass of NO_X per gallon of fuel for the PORT IMPERIAL MANHATTAN during run #1 of the Idle mode with LSD were **1.425 kg/hr** and **310 g/gal respectively.**

<u>CO Calculation</u>

Idle #1: Raw CO: 59 ppm

Calculation of CO in kg/hr:

CO (kg/hr) = (COppm ÷ 1,000,000) * ρ_{CO} * TEXm3/hr

Where:

COppm is the raw CO in ppm = 59 ppm
ρ_{co} is the density of CO at STP; = 1.164195 kg/m^3
TEXm3/hr is the total exhaust volume per hour in m^3/hr = 422.7 m^3/hr

CO (kg/hr) = (59 ppm ÷ 1,000,000) * 1.164195 kg/m^3 * 422.7. m^3/hr

= 0.029 kg/hr of CO

Calculation of CO in g/gal:

CO (g/gal) = CO (kg/hr) ÷ GPH * 1000 g/kg
= 0.029 kg/hr ÷ 4.59 GPH * 1000 g/kg

= 6.33 g/gal of CO

The mass of CO per hour of operation and mass of CO per gallon of fuel for the PORT IMPERIAL MANHATTAN during run #1 of the Idle mode with LSD were **0.029 kg/hr** and **6.33 g/gal respectively.**

CO_2 Calculation

Idle #1: Raw CO_2: 6.15 %

Calculation of $_{CO2}$ in kg/hr:

CO_2 (kg/hr) = (CO_2 % ÷ 100) * ρ_{CO2} * TEXm3/hr

Where:

CO_2 ppm is the raw CO_2 in % = 6.15 %
ρ_{CO2} is the density of CO_2 at STP; = 1.830862 kg/m^3
TEXm3/hr is the total exhaust volume per hour in m^3/hr = 422.7 m^3/hr

CO_2 (kg/hr) = (6.15 % ÷ 100) * 1.830862 kg/m^3 * 422.7. m^3/hr

= 47.8 kg/hr of CO2

Calculation of CO_2 in g/gal:

CO_2 (g/gal) = CO2 (kg/hr) ÷ GPH * 1000 g/kg
= 47.80 kg/hr ÷ 4.59 GPH * 1000 g/kg

= 10.4 kg/gal of CO_2

The mass of CO_2 per hour of operation and mass of CO_2 per gallon of fuel for the PORT IMPERIAL MANHATTAN during run #1 of the Idle mode with LSD were **47.8 kg/hr** and **10.4 kg/gal respectively.**

Sample Calculation: Corrected Fuel Consumption Rates – ULSD FloScan meter correction

Example: Manhattan, Cruise @ ~ 1200 RPM

<u>LSD</u>

Value from Flow-meter: 11.86, 12.27 and 12.38 GPH @ 1189, 1190 and 1190 RPM.
Average: 12.17 GPH @ 1190 RPM.

<u>ULSD</u>

Value from Flow-meter: 14.58, 13.64, 14.06, 14.47 GPH @ 1227, 1227, 1227, 1226 RPM.
Average: 14.19 GPH at 1227 RPM.

From manufacturer's fuel consumption curves:

Consumption @ 1190 rpm is 11.07 GPH
Consumption @ 1227 rpm is 12.08 GPH

Therefore 9.1% of the increase with ULSD is directly attributable to the RPM being higher between the LSD and ULSD testing events.

In addition the BTU/gallon for the 2 fuels were:

140,676 BTU per gallon #2 LSD
135,740 BTU per gallon #1ULSD

Thus, correcting for BTUs yields:

12.08 * (140,676/135,740) = 12.51 GPH

(12.51/11.07) -1 = 13%

Now, approximately 13% of the increase is attributable to engine speed and energy density differences between the two sets of tests.

So, the original 14.19 GPH fron the flow-meter must be corrected downwards:

Original value * (BTU + Speed Correction) = Corrected value

14.19 * (1/(1.00 + 0.13)) = **12.56 GPH**

Thus, this corresponds to an increase of ~ 3%. Performing the same calculation for the other load points and vessels yielded fuel consumption differences in excess of 20%.

***: Due to similar fuel temperatures between test events temperature corrections are deemed to be insignificant relative to the other sources of error.**

Sample Calculation: Corrected Fuel Consumption Rates, LSD FloScan meter correction

Example: Manhattan, Cruise @ ~ 1200 RPM

LSD

Value from Flow-meter: 11.86, 12.27 and 12.38 GPH @ 1189, 1190 and 1190 RPM.
Average: 12.17 GPH @ 1190 RPM.

ULSD

Value from Flow-meter: 14.58, 13.64, 14.06, 14.47 GPH @ 1227, 1227, 1227, 1226 RPM.
Average: 14.19 GPH at 1227 RPM.

From manufacturer's fuel consumption curves:

Consumption @ 1190 rpm is 11.07 GPH
Consumption @ 1227 rpm is 12.08 GPH

Therefore 9.1% of the increase with ULSD is directly attributable to the RPM being higher between the LSD and ULSD testing events.

Now the original baseline LSD value is increased by 9.1 percent:

12.17 * 1.091 = 13.28 GPH

Now the difference in BTU per lb between the two fuels is added to this value.

13.28 * (140,676/135,740) = 13.7 GPH

This is the corrected fuel consumption rate utilized in the report tables.

In essence the first sample calculation on fuel flow corrects the ULSD for engine speed and BTU towards a comparable volume for LSD fuel working with the ULSD flow meter value as the starting point. Manufacture's curves and energy per unit volume differences are used to make the correction.

The second calculation uses the LSD meter value as the start point. Manufacturers' curves are then used to correct for engine speed. Energy per unit volume differences are then applied to obtain a fuel flow value.

This is the value used to calculate the grams per hour emissions as it is more likely representative of the true fuel flow than using the values obtained from the first calculation.

APPENDIX J

Emission Test Protocol

EMISSION MEASUREMENT PROTOCOLS FOR ON-BOARD MARINE VESSELS FOR IMPLEMENTING EMISSIONS REDUCTION STRATEGIES

Staten Island Ferry Emissions Reduction Program Emission Measurement Protocol

Submitted to:

Port Authority of New York and New Jersey

October 15, 2003

Prepared By:

West Virginia University
Where Greatness is Learned

M. J. Bradley & Associates

Scope of Emission Test Protocol

The primary scope of this emission test protocol is for the determination of actual in-use emissions both with and without emission control devices for a vessel in a defined service. The measurement criteria contained within this protocol could also be used for the determination of modal emissions during steady state vessel testing, however, this protocol does not contain information regarding the types of modes, how modes would be determined and how modes would be replicated during actual testing. This emission testing protocol relies on prior in-use vessel activity data.

A separate data logging protocol was developed that discusses the vessel and engine parameters that are suitable for aftertreatment-sizing data logging. The test mode(s), cycle(s), or route(s) that are identified as predominate vessel activities in the data logging exercise should be used to develop the emissions test mode(s), cycle(s), or route(s). From the data logging exercise, the run-to-run variability can be compared a priori to the emissions testing to obtain an indication of the emissions run-to-run variability due to different engine loading history. Data that result from the emission testing may be used directly to calculate the reduction of a pollutant species from a vessel in units of tons/year subject to the testing accuracy limitations. This protocol provides for the primary determination of emission factors in units of grams per gallon and grams per second, although grams per brake horsepower-hour can be determined either directly or with subsequent calculations for certain vessel operating modes. This protocol recommends continuous measurement as the primary data collection method with the subsequent determination of modal emission factors from the continuous emission monitoring data. Modal emission factors could then facilitate the calculation of emissions if the vessel in question were operated in a different service or activity level, where the proportion of modes may change (i.e. a longer route with more vessel cruise).

The recommended method is to measure the emissions of CO, CO2 and NOx from the vessel in a continuous manner from either raw or dilute exhaust. The use of continuous monitors further allows for a check of consistency between fuel consumption and the pollutant emissions. It is also recommended that PM sampling be collected via gravimetric methods and as a result PM sampling is essentially modal in nature. The use of integrated bag sampling is not preferred but can be used where marine regulatory restrictions (i.e. HC measurement by FID) may prevent the use of certain continuous measurement equipment. It is not recommended to perform bag sample testing for certain pollutants for reasons such as the potential for secondary reactions to occur between the sample gases, creating inaccurate emissions testing data but these would need to be addressed on a pollutant by pollutant basis. This protocol does not preclude the use of bag samples as a QA/QC for certain compounds.

Pollutant Species from Diesel Engines

Oxides of Nitrogen (NOx)

Diesel engines are recognized as a major contributor to the inventory of oxides of nitrogen in most urban regions. NOx not only contributes to low-level ozone formation, but also forms secondary particulate matter in the atmosphere. The bulk of the NOx is formed by the combination of nitrogen (predominately from air but fuel bound nitrogen can contribute) and oxygen (again dominated by oxygen in air but oxygenated fuels provide oxygen as well) during the high temperature combustion process in the cylinder. For diesel engines with no aftertreatment, the NOx consists primarily of nitric oxide (NO) with a few percent of nitrogen dioxide (NO2), although the NO2 can exceed ten percent at high engine speeds and light loads. Some exhaust gas aftertreatment technology may raise the proportion of NO2 substantially by oxidizing additional NO in the exhaust stream.

Particulate Matter (PM)

Particulate matter emissions from diesel engines are also of substantial concern because they contribute to poor visibility and negatively impact human health. The particles themselves are a complex mixture of elemental carbon (EC), unburned or partly combusted fuel (organic carbon [OC]), sulfate from fuel sulfur, lubricant products (i.e. ash and additives) and wear products (i.e. metals) from the engine. Diesel engines are very efficient combustors, so the total carbon emitted as PM from a modern engine will typically account for less than 0.1% of the carbon originally in the fuel. Not all of the PM mass is present as an aerosol in the exhaust, and the PM continues to develop through nucleation and condensation processes after the exhaust contacts the atmosphere. Therefore, to some extent, the PM mass is defined by the measurement method. For both engine emissions certification and for atmospheric sampling, filtration of PM (gravimetric sampling) is usually preferred and prescribed, in part because the composition of PM is not consistent on a mass per unit volume basis. It is noted that TPM is used for certification, but PM10 and now PM2.5 are used for ambient air quality standards and hence SIPs. However, TPM, PM10, and PM2.5 are generally similar in value because most PM is less than 1 micron (<PM1.0) in size. Optical measurement of PM is not recommended for the calculation of mass or mass apportionment at this time.

Carbon Monoxide (CO)

Diesel engines are not particularly targeted as significant producers of carbon monoxide, but they do contribute to the CO inventory, and CO non-attainment remains a concern in some urban areas. The CO is produced by imperfect combustion of the fuel, particularly at high loads or during transient operation, where zones that are locally rich in fuel can exist in the cylinder.

Hydrocarbon (HC)/Volatile Organic Compound (VOC)

The high combustion efficiency of diesel engines is reflected in their exceptionally low hydrocarbon emissions. Most of the hydrocarbons consist of unburned fuel, although some products of combustion as well as some oxygenated combustion products (VOC but no HC) may also be present. Heavy hydrocarbons generally partition to the PM fraction, and are accounted for in the PM mass rather than as VOC.

Carbon Dioxide (CO_2)

While only NOx, CO, HC and PM are regulated in the US as diesel engine emissions, it is customary to measure carbon dioxide (CO2), as it facilitates the use of carbon balance to calculate emissions on a grams per gallon basis by providing information on fuel combusted by the engine. CO2 can also be used as an acceptable method to determine the dilution ratio in a PM sampling system. PANYNJ3s We will reference 40CFR86 requirements: max percent difference for calibration in the forward sections and we will list the actual sensitivity specifications for the proposed equipment in the back of the document.

Ammonia (NH_3)

When diesel engines are equipped with selective catalytic reduction (SCR) systems, operating with urea injection, there is concern that adding too much reductant can cause ammonia emissions referred to as ammonia slip. Ammonia emissions from an uncontrolled diesel engine are generally considered to be near zero but this can be verified during subsequent emission testing.

Toxics

There is increasing interest in air toxic species emitted by diesel engines. Collection of air toxic species is done via bag, cartridge, and or filter-based methods. All of the hydrocarbon species in the exhaust cannot be quantified, because the individual species number in the thousands. However, volatile compounds, such as 1,3-butadiene, and "BTEX" compounds (Benzene, Toluene, Ethylbenzene, and Xylene) are often quantified to get an indication of what constitutes a majority of the toxic subcomponents within both HC and PM emissions. Additionally, species can be measured from the existing filters used to capture the PM (TPM, PM10, or PM2.5) and include the soluble organic fraction (SOF) and elemental and organic carbon (EC/OC).

Parameters and Instrument Methods

Emission Units of Measure (Gram per Gallon)

This protocol is predicated on the need to quantify the amount of emission reduction of diesel exhaust components of NOx, CO, HC, CO2 and PM in units of tons/year. The simplest way to determine this emission reduction is to determine the emissions rates in fuel-specific units of g/gallon and to multiply by the number of gallons of fuel consumed per year, and then convert mass to tons. In any moderately steady-state operating mode of a vessel (e.g. idle, cruise or full power) the fuel specific emissions of a gaseous component may be found directly from the ratio of the gas in question to the concentration of CO2, by using a carbon balance and knowing the carbon content (grams of carbon per gallon) of the fuel. PM may be quantified on a g/gallon basis by taking the ratio of the mass of PM on a filter to the equivalent CO2 mass in the exhaust passed through the filter. PANYNJ1s We will reference 40CFR86 requirements. PM filters will be stored in a temperature and humidity controlled environment both pre- and post-testing, with the preference to not weigh them on-site. Both WVU and Environment Canada have sealed the filters in the field (in petri dishes) and shipped to the laboratory to equilibrate and to obtain a post-test mass. WVU has carried out specific experiments to see if shipping the filters introduces any error and has found laboratory-acceptable deviations. Both field and method blanks will be analyzed as additional quality control measures.

For the purposes of determining emission on a fuel specific (grams per gallon) basis, neither the flow rate of exhaust from the engine nor the power output of the engine must be known to complete the calculations. The resulting grams per gallon emission factor is generally a more accurate determination of emissions related to the fewer number of variables, and the associated errors of each measurement used, to calculate the result.

Oxides of Nitrogen Measurement

In the laboratory NO is customarily measured using a chemiluminescent analyzer but the analyzer does not respond to NO2 in the same fashion as NO and may be susceptible to vibration on board a marine vessel. The measurement of total NOx including NO2 with a chemiluminescent analyzer is typically measured by using an upstream converter to convert any NO2 in the exhaust stream to NO (with a high conversion efficiency) ahead of the analyzer. The analyzer itself then measures the oxidation of NO to NO2 to determine the total NOx emissions. For regulatory purposes of reporting NOx tons, the NO measured is reported as NO2 (molecular weight 46). NO and NOx may be determined separately by employing or bypassing the NO2 to NO converter described above. However, when NO2 is a small percentage of the total NOx, it cannot be quantified reliably by subtracting NO from NOx.

Recent research into on-board truck emissions measurement has demonstrated that NO may also be measured with a high level of accuracy using a Zirconia sensor. This sensor has a built in conversion technology so that it measures all of the NOx including both NO and NO2 if NO2 levels are relatively low. For higher NO2 concentration levels, a converter can be used to convert NO2 to NO as is done in a chemiluminescent analyzer. Given the vibration sensitivity concerns this measurement method is recommended however, if there is a need to determine the NO/NO2 relative concentrations in additional to total mass emission, some other technology must be utilized.

NO may also be measured with electrochemical cells or non-dispersive ultra-violet (NDUV) however, reliability and accuracy requirements would need to be evaluated to assess their suitability. Regardless of the analyzer used, calibration gases with a known NO concentration are required for initial calibration of the analyzer and subsequent zero and span checks.

Particulate Matter Measurement

When PM is measured from an engine, the exhaust must first be diluted with air to provide a cooler stream that mimics more closely the final atmospheric contribution. Dilution is well established for the certification of truck engines, where the whole exhaust is diluted in a constant volume flow tunnel, but for larger engines this approach is impractical. For large engines, a slipstream of the exhaust is mixed with air at a known dilution ratio, usually in a “mini-tunnel,” and the diluted stream is passed through a filter that captures the PM. Since the PM mass that is captured depends on the filter face temperature and on the velocity of the flow through the filter, these values must be bounded.

The PM mass is small relative to the filter mass and to avoid weighing errors, the filters must be conditioned at a set temperature and humidity before weighing (50% RH –5% and 70°F –10°F), both before and after they are loaded with PM. A microbalance with accuracy of 1 microgram or less is needed to properly weigh filters. While measurement of the filters both before and after use could be accommodated on site for logistical reasons, the accuracy of a portable microbalance may not meet the current regulatory requirements and my impose a financial burden for smaller emission testing efforts. Filters must however be normalized for temperature and humidity as this can have a significant effect. Filters may be pre-weighed and delivered to the site, used and then returned for subsequent analysis. Ambient background filters, field blanks (unused filters) and method blanks (installed in the filter holder but still unutilized filters) should also be collected so that laboratory accuracy and method accuracy can be determined in the QA/QC process.

Generally speaking, about 98% of diesel PM is less than ten microns in size, and 90 to 95% of the PM is less than 2.5 microns in size. This distribution will certainly vary by engine type (e.g. two-stroke vs. four-stroke) and will also vary to some extent over a given engine's operation (e.g. idle vs. full power). Present US air quality standards are based on suspended PM less than ten microns in size (PM-10), and PM-2.5 is the emerging metric. Although certification procedures have typically measured total PM, for a program that seeks to ameliorate the environment, it is appropriate to measure PM10 and PM-2.5. This is achieved by placing size-selective cyclones in the sampling stream ahead of the filter to remove oversized PM. When two separate filters draw from a single dilution tunnel, it is essential that there is a high degree of mixing of raw exhaust and dilution air in the tunnel, so that a similar dilute mixture is fed to both filters.

An acceptable alternative may be to only measure PM2.5, estimating PM10 and total PM from that value. The engine exhaust must be equipped with a sampling port to provide an exhaust slipstream. It is not necessary that any sampling probe used should be isokinetic; because PM particles are sufficiently small that sample biasing will not occur. There is an additional assumption that the engines will be operating in sufficiently steady state modes that the sampling flow rate will not need to vary given a relatively steady exhaust flow rate. For engines that are operated in highly transient modes or where maneuvering is a large portion of the duty cycle, isokinetic sampling would need to be performed using mass flow controllers to vary sampling flow rate and a suitable engine flow rate measurement device to determine engine flow for feed forward control of the sampling rate. The use of isokinetic sampling for PM is not typically necessary for marine vessels however, where integrated bag sampling will be used for the other gaseous species, integrated PM sampling is easily accommodated. Note however that the use of isokinetic sampling for PM will also potentially require active control of dilution air to maintain filter face flow and temperature requirements and may also effectively prevent the use of size-selective cyclones as these devices require flows within a narrow range.

The point of analysis of the exhaust composition should be as close to the sampling point as practical. The exhaust slipstream should be transported to the point of analysis using a heated line to prevent water condensation in the sampling line. The exhaust slipstream must then be diluted with air using a mini-dilution tunnel or a mixing system, and passed through a filter to measure PM. In keeping with EPA (40CFR86) protocols, the PM filter face temperature must be kept below 125 degrees Fahrenheit, and sufficient dilution air must be used to meet this requirement. Dilution ratio is customarily maintained by controlling the tunnel exit flowrate and the dilution air flowrate. At high dilution ratios, the control of these two flows becomes critical to assure that the quantity of raw exhaust that is sampled is known. The flows should be controlled using pumps and mass flow controllers, and the system should be verified by examining concentrations of a species in the raw exhaust, dilution air, and diluted exhaust. Suitable species for verifying the dilution ratio may be NO or CO2 and would require that two of these analyzers are present. Note that while background NO is essentially zero, background CO2 may vary and a background value will need to be determined and accounted for.

Where PM10 and PM2.5 must be measured, the exit flow from the dilution tunnel should be split, and drawn through two parallel sampling systems, one consisting of a cyclone with a 2.5 micron cutpoint, followed by a filter, and one consisting of a 10 micron cyclone, followed by a filter. Two mass flow controllers will be needed, one to manage each filter flow. PANYNJ4s We propose to add that flow meters should be calibrated or verified once per year against a primary standard. Most flow meters have correction factors for humidity effects and measurement should be corrected following the manufacturer's methods.

Carbon Monoxide and Carbon Dioxide Measurement

CO and CO2 are usually measured using infrared analyzers that are suitable for use on board a vessel. Because water vapor present in the exhaust can mask some of the infrared spectrum the analyzer will be preceded by a chiller or similar device to remove water from the exhaust sample stream. Because CO emission levels are generally very low for a diesel engine the question of calibration range can be an issue. For a majority of engine operation the CO levels will be very low, which would dictate the use of a narrow calibration range for the analyzer to maintain accuracy. During transient events the CO emission levels may momentarily spike to levels well above this narrow calibration range, which would appear to dictate the use of a wider calibration range. One solution would be to utilize two separate CO analyzers, one calibrated for each range, however, this solution is not cost effective given the very low overall CO levels. A second solution would be to utilize the wider calibration range for continuous measurements, sacrificing some accuracy in exchange for being able to see the extent of the transient spikes and utilizing a secondary bag sample to verify the total CO emission measurement.

Hydrocarbon/Volatile Organic Compound Measurement

In the laboratory, hydrocarbons are measured using a flame ionization detector (FID) that counts the carbon atoms in a filtered exhaust stream. The use of hydrogen fuel for the FID flame is generally considered impractical for marine applications. Portable analyzers employ infrared analysis for hydrocarbons, but these analyzers are geared to detection of gasoline, and are calibrated on hexane, which is not a significant constituent of diesel fuel or diesel exhaust. Portable analyzers (even portable FIDs), generally fail to capture diesel HC emissions in a defensible fashion. Noting the low level of hydrocarbons in the exhaust, and the difficulty of quantifying the hydrocarbons in a safe manner, it is suggested in this protocol that hydrocarbons are not to be quantified and that for the purposes of carbon balance calculation that the HC contribution be ignored. An alternative would be to collect a bag sample for subsequent analysis with an FID off-board the vessel. The resulting accuracy may be poor but the value itself is expected to be very low and the actual emission variance should be acceptable for inventory purposes.

Ammonia Measurement

To verify that an emission control system such as SCR is operating appropriately, the concentration of ammonia in the exhaust must be verified at some level. This can accomplished using a photoacoustic analyzer. The analyzer also measures CO2 directly, allowing the determination of a direct NH3/CO2 ratio as well as a gram per gallon emission factor. Note also that NDUV could also potentially be used to determine NO, NO2 and NH3 as a continuous data stream rather than the batch sampling response of the photoacoustic analyzer however the use of NDUV on board a marine vessel has not been verified and as a result photoacoustic is recommended at this time.

The issue with the use of a photoacoustic analyzer for ammonia is that the device conducts the analysis on a batch basis so that appropriate sample conditioning can take place. Rather than take 200-sec batch samples and miss everything in between the samples it is recommended to collect a bag sample and then sample the bags via the photoacoustic analyzer. Bags identified with more than a predetermined concentration level (2-ppm or 10-ppm) of ammonia would warrant further exhaust analysis to determine the extent of a possible ammonia spike. In many cases the SCR system control logic can be modified to eliminate the excess ammonia emissions even if the absolute extent of the spike cannot be determined.

Toxics Measurement

Volatile compounds, such as 1,3-butadiene, and "BTEX" compounds (Benzene, Toluene, Ethylbenzene, and Xylene) are often quantified using a gas chromatograph to analyze bag samples gathered from diluted exhaust. Aldehydes may be measured in the laboratory from DNPH cartridges used to adsorb from a dilute exhaust slipstream. The PM filters may also be extracted to determine the soluble organic fraction (SOF) in the PM. The SOF is usually the largest PM component after the elemental carbon, and may be associated with PM toxicity. Although there is interest in determining the content of Polyaromatic Hydrocarbons (PAH) or Nitro-PAH compounds in diesel exhaust, these compounds are large in number and work in this area is still at a research level.

Continuous Measurement vs. Integrated Samples

NOx, HC, CO2 and CO may be measured either from raw exhaust gas or from the dilute gas stream used for the PM formation and filtration. It is advisable to sample NOx on a continuous basis rather than from a sample bag because continuing reactions in the bag may alter the NOx concentration. Measurement of CO and CO2 continuously offers the advantage of establishing stability of engine operation in real time. It is recommended, therefore, that gases be sampled continuously over the entire engine-operating regime and that individual modes be picked out of the continuous data set.

On-road engine emissions are evaluated using constant volume sampling (CVS) systems that essentially fix the flow rate of the measurement system. This type of sampling system can be adapted for small marine vessels but is unsuitable for larger vessels from both available space and power perspective. The alternative is to evaluate engine emissions using either raw continuous sampling or integrated bag sampling techniques and both are acceptable for determining total mass emissions and emission levels on a gram per gallon basis. The difference lies in that with continuous data you can essentially pick out modal data after the fact, where with integrated bag samples you only get the end result. While bag samples can be broken into modes, which can be an entire trip or a discrete mode, transient diversions can not be determined and in many cases the regulatory agency is concerned with the both the total as well as the transient behavior.

Equipment Qualification and Background

The emission measurement equipment package should be assembled and verified against a laboratory grade system prior to installation on the vessel. The measurement system should use calibration gases that are NIST traceable with a specified accuracy. The gas analyzers must be calibrated after installation on board and must be set for zero and span quantities between modes or groups of modes. This requires either the storage of nonflammable gases on board, or an ability to check calibration from shore-based gases at regular intervals. PANYNJ5s We agree and will state that emission equipment must be calibrated on board but will state that other transducers (temperature, pressure, humidity, etc.) can be verified with a two-point check. There are still some potential issues with bringing calibration gases on board the vessel (even non-flammable) that may prevent calibration more often than daily.

The vessel activity may be viewed in terms of a number of modes. For each mode, PM filters must be loaded into filter holders, connected to the dilution system. The start and stop times of filter flow must be recorded, and must be synchronized with the continuous data gathered from the analyzers by time signature. It is recommended that continuous engine data should be collected at a frequency of one sample per second although it is advisable to collect emission information at 5 to 10 Hz.

To process data accurately, it is necessary to compensate for emissions species in the background (ambient) air. This is most easily achieved by providing the facility to change the sampling line from the exhaust probe to an ambient air port. Data should be recorded in the same manner, as they would be for an operating mode. Background data should be acquired at least at the beginning and end of the day of testing. PANYNJ6s We will expand upon this. For raw gaseous sampling, background is not needed in the existing regulations. However, gaseous background data should be collected for raw sampling to identify potential problems with the data at least once a day. For dilute gaseous (from the PM mini tunnel), backgrounds should be collected for each mode or test and used similar to 40CFR86. Typically for PM, one or two maybe three backgrounds a day are used, most likely one at each dock and one during vessel cruise.

A fuel sample must be collected, and a fuel analysis must be performed using the appropriate ASTM methods. For each mode of operation, the exhaust emissions data, background data and fuel carbon content should be processed to yield emissions levels in g/gallon. In order to project the emissions for a vessel over an operating period or round trip, it is necessary to determine the fuel quantity used in each mode, and to combine the modal emissions, weighted by fuel quantity. In cases where the modes are dominated by idle operation and high power operation, the modal contributions can be estimated closely using manufacturer's fuel consumption and efficiency data and data on the fuel used by the vessel. If the vessel operates in a wide variety of modes, this approach becomes more difficult. PANYNJ7s We will reference 40CFR86 requirements. The ASTM for carbon analysis is D-5291. In the project specific section we will carry though the analysis methods outlined in the contract.

Emission Units of Measure (Gram per Second/Hour)

In cases where it is necessary to express emissions in units of g/second or g/hour, or when the modal activity of a vessel is complex, a measure of exhaust gas mass flow is needed in addition to all of the previous parameters needed to compute the g/gallon fuel specific rate. The mass rate emissions may be found in several ways as follows:

1) The actual mass flow of the exhaust may be measured.
2) The actual mass flow of the intake air may be measured: the intake mass flow reflects the exhaust mass flow with a reasonable degree of accuracy.
3) The fuel consumption may be measured, and through knowledge of the carbon concentration (primarily due to CO2) in the exhaust, the exhaust flowrate may be computed.
4) The engine speed, intake manifold pressure and intake manifold temperature may be used along with an assumed engine efficiency to calculate intake flow. While this method is the least accurate it is an acceptable metric for QA/QC purposes and may allow for preliminary emission testing or pre-screening during data logging procedures.

Although the third option, to measure the fuel flowrate, may seem less direct than an exhaust or intake flow measurement, there are substantial difficulties in accurate measurement of the pulsating flows typical in engine exhaust and intake systems that make the fuel method preferable in many cases. Also note that access to the exhaust system may be limited and modification to the exhaust system of the vessel may not be considered an available option.

Exhaust flow is best measured with a pressure difference device, such as an Annubar, along with a total pressure transducer, a differential pressure transducer and a temperature sensor. Calibration is required, and it is difficult to configure the system to measure flow accurately from idle to full power.

Intake air flow can be measured using a variety of systems, with a laminar flow element as the preferred device. Absolute pressure, differential pressure and temperature sensors are required. This method may become preferred as these devices are further developed for use on diesel engines.

Fuel flow to the engine is reported by many electronically measured engines and can be queried from the engine controller. In the case of mechanical engines, the fuel flow in the delivery and return lines must be measured separately, and the difference determined, which can lead to inaccuracy at low power output. Coriolis effect flow meters have been used successfully in this application.

Emission Units of Measure (Gram per bhp-hr)

Units of brake-specific emissions (g/bhp-hr) are used in certification to insure that engines that produce similar work output are limited by a similar emissions mass production. However, when the engines are installed in a vessel, the metric of vessel activity is not typically work done, but rather either (a) the quantity of fuel consumed, (b) the distance traveled, or (c) the number of "trips" completed. In this way, if emissions are quantified in units such as "g/gallon," "g/hour," or "g/trip," the emissions factor is readily multiplied by the measure of activity to determine the mass of emissions produced. These units are therefore far more suited to assessing regional air quality impact or inventory, whereas the brake-specific certification units are not. Gram per bhp-hr emission factors cannot be determined for idle activities as a result of zero net engine power. There is usually a desire to present emissions in brake specific (or energy specific) units primarily for comparison to engine certification standards, because the standards are promulgated in brake specific units to account for engine efficiency. When brake specific data are required, it is necessary to estimate the power output of the engine in each mode of operation. This can be achieved in one of the following ways:

1) If the engine is electronically controlled, a direct "broadcast" torque and engine speed may be available from the engine controller. Power is the product of torque and speed. An electronic interface is needed to acquire the data. The broadcast torque is computed by the manufacturer from the fuel injection rate and known engine characteristics. In some cases the broadcast torque is not available, but a torque figure can be calculated from a broadcast "percent load" signal or even from broadcast fueling information, provided that additional engine performance data, such as a full torque curve, are available.

2) If a fuel flowrate is known, the engine output power can be determined by using published values for the engine fuel efficiency. However, the efficiency figures may be unreliable at low power settings. For cruise or full power calculations the published tables should prove sufficiently accurate.

3) The engine power output may be determined directly by measuring engine speed and shaft output torque. In some cases, engines may be instrumented while in regular service. Otherwise, instrumentation must be added specifically for the emissions measurement program. Engine speed can be measured with relative ease, usually at the flywheel, but torque can be determined only by instrumenting the engine output shaft. This requires the installation of a strain gage on the shaft, and calibration of the shaft twist using torque arms. It is also possible to calibrate the strain gage, perhaps less accurately, during high power operation by using a known engine efficiency and fuel flow rate.

4) If the vessel has electric drive, it is possible to measure the electrical output of the generator attached to the engine, and to estimate engine output power using generator electrical efficiency.

It is recommended that the second method be used to estimate brake specific emission factors where they are deemed necessary.

Proposed Measurement Plan (SI Austen Class Vessel)

Pollutants to be measured

The measurement plan will depend on the features and available space on each vessel. The regulated gases that will be measured continuously on the Austen Alice are CO, CO2 and NOx. NH3 will be measured via batch sampling of an integrated bag as well as HC on a spot basis as the bags can be exported from the vessel. Both PM2.5 and PM10 will be measured gravimetrically via integrated min-dilution tunnel filtration.

Based on a data set gained during preliminary data logging using the approved data logging protocol, vessel operation will be divided into a number of modes for PM sampling purposes. Examples may include idling, maneuvering, operating under power upstream, and operating under power downstream. With the exception of maneuvering, these are all steady state modes. PM emissions measurements will be conducted for each mode with the remaining criteria pollutants measured on a continuous basis. At least three repeat modal measurements will be made for PM. Separate filters will be used for maneuvering modes, however, the PM data is expected to have a large degree of uncertainly both due to the highly transient nature of the activity as well as the large trip-to-trip variation.

Measurements will be made during actual revenue operation of the vessel and as a result variations due to wind or draft (passenger load etc.) cannot be controlled. However, the researchers must exercise good engineering judgment and avoid conducting measurements in conditions that are deemed "outliers." Actual ambient conditions will be recorded during emission testing as well as ambient conditions and passenger load.

Each modal measurement period for PM need not be as long as the whole mode during vessel operation, but the mode must be of sufficient length to capture accurate emissions data.

An area will be selected on the vessel to house the emissions measurement and data acquisition system. The area will be as close as is practical to the exhaust system. Necessary electrical power must also be available to this area.

Measurement System Configuration Description

Emissions will be measured from each engine separately. The exhaust of the engine, downstream of the turbocharger, but ahead of any aftertreatment system, will be fitted with a sampling port. A second sampling port will be fitted downstream of the aftertreatment device. A probe will be fitted into one of the sampling ports and a heated sampling line will convey exhaust gas from the probe to the equipment in the measurement area. The heated line will be connected to the raw exhaust input of a mini-dilution system. The mini-dilution system will include of a supply of dilution air regulated by a mass flow controller and a dilution volume, or mini-tunnel, where the raw exhaust and dilution air will mix. Dilute exhaust leaving the tunnel will be split into two paths, one to a first filter holder through a PM2.5 cyclone, and one to a second filter holder through a PM10 cyclone. Flow is drawn through each filter with a mass flow controller and pump. These mass flow controllers and the dilution air mass flow controller will receive setpoint signals from the control and data logging system that will be located in the measurement area. These three flowrates will be used to compute mini-tunnel dilution ratio.

The PM filters used in this testing will be pre-weighed at a set temperature and humidity in a laboratory setting, and weighed at the same temperature and pressure after they are loaded with PM. Careful filter container labeling will be used for quality assurance and filters will be shipped in glass containers. Filter shipments will include field blanks and method blanks, as well as daily background filters. With the exception of shipping the filters to a laboratory location, the remaining regulatory procedures for filter preconditioning and normalization will be followed.

Both CO and CO2 will be measured in the dilute flow using infrared analyzers. Water will be removed from the sample stream prior to entering the analyzers. CO and CO2 data will be available on a continuous basis. The analyzers will be calibrated using known gases and correct function of analyzers will be verified using both zero concentration gas and span concentration gas at intervals during the testing.

NOx will be measured using a zirconia sensor with a NO2 to NO converter. NOx sensors will also be used to verify the dilution ratio of the dilution system in addition to CO2, which may also be used for QA/QC purposes. The zirconia sensors must be calibrated in the same fashion as the infrared sensors.

Ammonia will be measured using a photoacoustic analyzer. The analyzer is capable of batchwise measurements, at approximately 200-second intervals, and will extract and analyze batches from an integrated bag sample throughout each mode of testing. Bag samples for entire trips may also be analyzed off board the vessel for QA/QC purposes.

Exhaust flow rate will be determined via fuel flow rate to the engine, which will be measured using two Coriolis meters. A mass balance on carbon will be used to compute the exhaust flowrate. This is possible because CO and CO2 concentrations in the exhaust will be known. Estimated engine flow utilizing engine intake conditions and engine speed from the data logging system will also be collected however, this data is only considered viable for QA/QC purposes.

For the purposes of estimating brake specific emission factors, the efficiency of the engine supplied by the engine manufacturer shall be used to determine estimated power and torque during each mode.

Analyzer Specifications

Company	Use	Description	Part #	Range	Accuracy
Computer Aided Solutions	Data Logging	DataTaker Stand-alone data logger	DT800	12 to 42 Channels	0.02%
Omega	Manifold Air Pressure (MAP)	0-30 psig pressure sensor	PX215-030GI	0 - 30 psig	.25% FS
	Exhaust Backpressure	0-15 psig pressure sensor	PX215-015GI	0 - 15 psig	.25% FS
	Misc. Temperature	K Type thermocouple	CASS-18U-12		
	Ambient Relative humidity and Temperature	Engine Intake Air relative Humidity and T	emperatureHX93A	3 - 95%, -4 - 167 F	2.5% Absolute RH, 1 F
	Ambient Pressure	Engine Intake Air Absolute Pressure	PX 176-025A5V	0 - 25 pgia	1%
Automatic Controls Co.	Engine Speed	5/8-18 treaded TTL output Hall effect	H1512-006		
Horiba	CO2 Emissions	NDIR CO2 Analyzer	BE-140	0 - 16%	3% Reading or 0.3% Absolute
	NOx Emissions	Zirconium Oxide NOx Analyzer	MEXA-120	0 - 5000 ppm	30 ppm, 3% Reading
	Gas Analyzer Calibration	Gas Divider	SGD-710C	0 - 100%, 10% increments	0.50%
	THC Emission	Flame Ionization Detector	FIA-236	0-10, 30, 100, 300, 1000, 300	0, 10,000, 30,000 ppm1% FS
California Analytical	CO2-Based Dilution Ratio Control	Dual Range CO2 Analyzer with CO	Model 300	0-5%, 0-15%, 0-5000 ppm	<2%
Sierra Instruments	Mini-Tunnel Flow Controller	PM Dilution Air and Total Flow Mass Con	trol740-N3-3	7 scfm	2.00%
Scott Specialty Gas	CO2 Calibration Gas	CO2, Balance N2 ****		12% CO2	2%
	CO2 Calibration Gas	CO2, Balance N2 ****		15% CO2	2%
	CO2 Calibration Gas	CO2, Balance N2 ****		3% CO2	2%
	CO Calibration Gas	CO, Balance N2 ****		500 ppm CO	2%
	CO Calibration Gas	CO, Balance N2 ****		5000 ppm CO	2%
	NOx Calibration Gas	NO, Balance N2 ****		1500 ppm NO	2%
	NOx Calibration Gas	NO, Balance N2 ****		3000 ppm NO	2%
	NOx Calibration Gas	NO, Balance N2 ****		500 ppm NO	2%
	Zero point	N2		99.999%	<10 ppm Other Constituents
	**** We may purchase a mix bottles to reduce the number of bottles required.				
1302	Ammonia Emissions	Photoacquistic	Bruel & Kjaer 1302	analyzer:Ammonia: 0-110ppm	2.50%

APPENDIX K

EPA VERIFIED RETROFIT EMISSIONS CONTROL TECHNOLOGIES

U.S. Environmental Protection Agency
Diesel Retrofit Program

Voluntary Diesel Retrofit Program

GO

Recent Additions | Contact Us | Print Version Search:

EPA Home > Transportation and Air Quality > Voluntary Diesel Retrofit > Technology > Verified Products

Verified Products

National Clean Diesel Campaign: EPA creates new campaign to reduce pollution from diesel engines

Verified Technology List **Key Topics:**

Technology

Verification Process This table summarizes all the diesel retrofit technologies that the U.S. Environmental Protection Agency (EPA) has approved for use in engine retrofit programs. Select the Testing Protocols manufacturer link to learn more about the retrofit technology and its operating criteria. The In-use Testing table shows the percent reduction (of verified or tested levels) that EPA will recognize for Technical Summary emission reductions for each technology. See the retrofit manufacturers contact page for more information on these manufacturers. Verified Products Cost Survey

Verified Retrofit Technologies						
Manuf.	Technology	Applicability	Reductions (%)			
			PM	CO	NOx	HC
Caterpillar, Inc.	Catalyzed Converter/Muffler (CCM)	Highway, heavy-heavy and medium-heavy duty, 4 cycle, non-EGR, model year 1998 - 2003, turbocharged or naturally aspirated engines	20	20	na	40
Caterpillar, Inc.	Diesel Particulate Filter	Nonroad, 4 cycle, non-EGR equipped, model year 1996-2005, turbocharged engines with power ratings 130 ⩽ KiloWatts < 225 (174.2 ⩽ Horsepower < 301.5)	89	90	na	93
Clean Diesel Technologies, Inc.	Platinum Plus Purifier System (fuel borne catalyst plus DOC)	Highway, medium heavy- and heavy heavy-duty, 4 cycle, model year 1988 - 2003, turbocharged or naturally aspirated engines	25 to 50	16 to 50	0 to 5	40 to 5
Clean Diesel Technologies, Inc.	Platinum Plus Fuel Borne Catalyst/Catalyzed Wire Mesh Filter (FBC/CWMF) System	Highway, medium heavy-duty, 4 cycle, model year 1991 - 2003, non-EGR, turbocharged or naturally aspirated engines	55 to 76*	50 to 66*	0 to 9*	75 to 89
Donaldson	Series 6000 DOC & Spiracle (closed	Highway, heavy heavy- and medium heavy-duty, 4 cycle, non-EGR, model year 1991 -	25 to 33[a]	13 to 23	n/a	50 to 5

	crankcase filtration system)	2003, turbocharged or naturally aspirated engines				
Donaldson	Series 6100 DOC	Highway, heavy heavy- and medium heavy-duty, 4 cycle, non-EGR, model year 1991 - 2003, turbocharged or naturally aspirated engines	20 to 26	38 to 41	n/a	49 to 6
Donaldson	Series 6100 DOC & Spiracle (closed crankcase filtration system)	Highway, heavy heavy- and medium heavy-duty, 4 cycle, non-EGR, model year 1991 - 2003, turbocharged or naturally aspirated engines	28 to 32[a]	31 to 34	n/a	42
Engelhard	DPX Catalyzed Diesel Particulate Filter	Highway, heavy-duty, 4 cycle, model year 1994 - 2002, turbocharged or naturally aspirated engines	60	60	n/a	60
Engelhard	CMX Catalyst Muffler	Highway, heavy-duty, 2 cycle engines	20	40	n/a	50
Engelhard	CMX Catalyst Muffler	Highway, heavy-duty, 4 cycle engines	20	40	n/a	50
Engine Control Systems	Purifilter - Diesel Particulate Filter	Highway, heavy and medium heavy-duty; Urban Bus; 4 cycle; model years 1994 - 2003; turbocharged or naturally aspirated; non-EGR engines	90	75	n/a	85
Engine Control Systems	AZ Purimuffler or AZ Purifier Diesel Oxidation Catalyst with ECS closed crankcase ventilation (CCV) system with Low Sulfur Diesel Fuel (30 ppm S max)	Highway, heavy-duty, 4 cycle, mechanically or electronically injected, turbocharged or naturally aspirated, originally manufactured from 1991 through 2004 model years which meet a 5 or 4 g/bhp-hr NOx standard with open crankcase ventilation and no aftertreatment engines	40	60	n/a	75
Engine Control Systems	AZ Purimuffler or AZ Purifier Diesel Oxidation Catalyst with Low Sulfur Diesel Fuel (30 ppm S max)	Highway, medium heavy-duty, 4 cycle, model years 1991 - 2003 Cummins and Navistar/International engines originally manufactured with no aftertreatment, turbocharged or naturally aspirated, non-EGR engines	40	40	n/a	70
Engine Control Systems	AZ Purimuffler or AZ Purifier Diesel Oxidation Catalyst with Low Sulfur Diesel Fuel (30 ppm S max)	Highway, heavy heavy-duty, 4 cycle, model years 1991 - 1993 Cummins engines originally manufactured without exhaust aftertreatment, turbocharged or naturally aspirated, non-EGR engines	35	40	n/a	70
Engine Control	AZ Purimuffler	Highway, heavy duty, 2 cycle	20	40	n/a	50

Systems	AZ Purifier	engines				
Engine Control Systems	AZ Purimuffler AZ Purifier	Highway, heavy duty, 4 cycle engines	20	40	n/a	50
International Truck & Engine Corp.	Green Diesel Technology-Low NOx Calibration plus Diesel Oxidation Catalyst with Ultra Low Sulfur Diesel (ULSD)	Highway, light heavy-duty, 4 cycle, Navistar/International engines, model years 1999 - 2003 in the following families: XNVXH0444ANA, YNVXH0444ANB, 1NVXH0444ANB, 2NVXH0444ANB, 3NVXH0444ANB	0 to 10	10 to 20	25	50
Johnson Matthey	Catalyzed Continuously Regenerating Technology (CCRT) Particulate Filter	Highway, heavy-duty, urban bus, 4 cycle, non-EGR model year 1994 - 2003, turbocharged or naturally aspirated engines.	60	60	n/a	60
Johnson Matthey	Continuously Regenerating Technology (CRT) Particulate Filter	Highway, heavy-duty, 2 & 4 cycle, model year 1994 - 2002, turbocharged or naturally aspirated engines	60	60	n/a	60
Johnson Matthey	CEM™ Catalytic Exhaust Muffler and/or DCC™ Catalytic Converter	Highway, heavy-duty, non-urban bus, 4 cycle, non-EGR model year 1991 - 2003, turbocharged or naturally aspirated engines	20	40	n/a	50
Johnson Matthey	CEM Catalyst Muffler	Highway, heavy-duty, 2 cycle engines	20	40	n/a	50
Lubrizol	PuriNOx Water emulsion fuel	Highway & Non-road, heavy-duty, 2 & 4 cycle	16 to 58	-35 to 33	9 to 20	-30 to -1
Paceco Corporation	MES diesel particulate filter (MES-DPF)	Pre-1996 nonroad, 4-cycle, heavy-duty diesel engines in the 225 - 450 kW (NR7) power range in electrical generation applications	39	90	N/A	95
Various	Biodiesel (1 to 100%)	Highway, heavy-duty, 2 & 4 cycle	0 to 47	0 to 47	0 to -10	0 to 67
Various	Cetane Enhancers	Highway, heavy-duty, 4 cycle, non-EGR-equipped engines	n/a	n/a	0 to 5	n/a

[a]- Total PM reduction figures reflect reductions from both tailpipe and crankcase emissions.
* - These effectiveness figures are provisional values subject to change pending final review of the test data.
Note: For after-treatment devices the reductions are based on the installation of retrofits to engines that were
originally produced without diesel oxidation catalysts or diesel particulate filters.

Memorandum of Agreement (MOA) with California Air Resources Board (ARB)

The Environmental Protection Agency's (EPA's) Voluntary Diesel Retrofit Program signed a Memorandum of Agreement (MOA) [200KB PDF] with the State of California Air Resources

Board (ARB) for the Coordination and Reciprocity in Diesel Retrofit Device Verification. The MOA establishes reciprocity in verifications of hardware or device-based retrofits, and further reinforces EPA's and ARB's commitment to cooperate on the evaluation of retr technologies. This agreement commits EPA and ARB to work toward accepting particulate matter (PM) and oxide of nitrogen (NOx) verification levels assigned by the other's verification programs. Additionally, as retrofit manufacturers initiate and conduct in-use testing, EPA and ARB agreed to coordinate this testing so data generat may satisfy the requirements of each program. This MOA is intended to expedite the verification and introduction innovative emission reduction technologies. Additionally, this MOA should reduce the effort needed for retrofit technology manufacturers to complete verification.

In addition to the above list of EPA verified retrofit technologies, EPA recognizes and accepts those retrofit hardware strategies or device-based systems that have been verified by the California Air Resources Board (CARB). Information about CARB's Verification Program and links to their list of ver EXIT Disclaimer ified technologies can be foun at www.arb.ca.gov/diesel/verdev/home/home.htm.

APPENDIX L

CARB VERIFIED RETROFIT EMISSIONS CONTROL TECHNOLOGIES

Updated: 8/14/06

Currently Verified Technologies

The following information is provided as a summary of verified diesel emission control strategies. Additional requirements specific to engine compatibility are provided in the Executive Order. The factors outlined in the Executive Order are legal requirements of each verification; therefore, these conditions must be met before determining if a particular device is applicable to the end-user's type of engine. The Air Resources Board recommends that you contact the manufacturer, or their authorized distributor, prior to making any purchasing decision. Please click on the manufacturer link for additional information.

PM Level	Product Name	Technology Type	PM Reduction	NOx Reduction	Applicability
Level 3	Cleaire Flash and Catch CRT	DPF	85%	25%	1994+ on-road (limited - Cummins off-cycle NOx engines); 15 ppm sulfur diesel.
	Cleaire Flash and Catch DPX	DPF	85%	25%	1994+ on-road (limited - Cummins off-cycle NOx engines); 15 ppm sulfur diesel.
	Cleaire Horizon	DPF	85%	N/A	1994-2005 on-road; 15 ppm sulfur diesel; CARB diesel
	Cleaire Longview	Lean NOx Catalyst and DPF	85%	25%	1993-2003 model year on-road; 15 ppm sulfur diesel.
	Clean Air Power	CPF	85%	N/A	Specific 1994-2002 Power System Associates and Caterpillar bifuel engines on-road; 15 ppm sulfur diesel.
	CleanAIR Systems PERMIT	DPF	85%	N/A	Stationary emergency generators; 15 ppm sulfur diesel.
	Donaldson DPM	DPF	85%	N/A.	1993-2004 on-road; 15 ppm sulfur diesel.
	International Truck and Engine Corporation DPX	DPF	85%	N/A.	1994-2003 on-road Navistar (International); 15 ppm sulfur diesel.
	Johnson Matthey CRT	DPF	85%	N/A.	1994-2006 on-road; 2002-2006 Cummins ISM and ISB with EGR;15 ppm sulfur diesel; B20. Stationary emergency and prime generators. Conditionally verified for stationary pumps.
	Johnson Matthey CCRT	DPF	85%	N/A.	1994-2006 on-road; 2002-2006 Cummins ISM and ISB with EGR;15 ppm sulfur diesel.

	Johnson Matthey EGRT	EGR/DPF	85%	40%	2000 International DT-466, 2000 Cummins ISM 2001 Cummins ISB, 1998-2002 Cummins ISC, 2001 Cummins ISL, 2001 MY DDC - 50, and 2001 DDC - 60. on-road; 15 ppm sulfur diesel.
	Engine Control System Purifilter	DPF	85%	N/A	1994-2003 on-road; 15 ppm sulfur diesel.
	Engine Control System Combifilter	DPF	85%		1996-2004 off-road; 15 ppm sulfur diesel; CARB diesel.
	Miratech Corporation combiKat	DPF	85%	N/A	Stationary emergency and prime generators with a PM emission rate of 0.2 g/bhp-hr or less.
Level 2	Donaldson	Flow Through Filter	50%	N/A	1991-2002 on-road; 15 ppm sulfur diesel.
	Environmental Solutions Worldwide Particulate Reactor	Flow Through Filter	50%	N/A	1991-1997 on-road, CARB diesel.
	Lubrizol PuriNOx	Alternative Fuel	50%	15%	1988-2003 on-road.
	Engine Control System AZ Purimuffler/Purifier	DOC + Alt Fuel	50%	20%	1996-2002 off-road; PuriNOx
	Johnson Matthey PCRT	DOC + FTF	50%	N/A	1991-1993 on-road; 15 ppm sulfur diesel.
	Rypos ADPF	DPF	50%	N/A	1996-2002 stationary engines; CARB diesel.
Level 1	Cleaire Flash and Match	DOC	25%	25%	1993+ on-road (limited - Cummins off-cycle NOx engines); 15 ppm sulfur diesel; CARB diesel.
	Donaldson DCM 6000	DOC	25%	N/A	1988-1990 on-road; 15 ppm sulfur diesel; CARB diesel.
	Donaldson 6000 + Spiracle	DOC + crankcase filter	25%	N/A	1988-2002 on-road; 15 ppm sulfur diesel; CARB diesel.
	Donaldson DCM 6100 + Spiracle	DOC + crankcase filter	25%	N/A	1991-2002; CARB diesel.
	Donaldson DCM 6100	DOC	25%	N/A	1994-2002; 15 ppm sulfur diesel.
	Donaldson 6000 +	DOC +			Off-road port equipment; 15

	Spiracle (off-road)	crankcase filter	25%	N/A	ppm sulfur diesel; CARB diesel.
	Extengine	DOC + SCR	25%	80%	1991-1995 Cummins 5.9 liter off-road; 15 ppm sulfur diesel or CARB diesel.
	Engine Control System AZ Purifier & Purifmuffler	DOC	25%	N/A	1991-2003 Cummins and Navistar on-road; 15 ppm sulfur diesel. 1973-1993 DDC 2 stroke; CARB diesel.1991-2002 HHD certain model Cummins and DDC; 15 ppm sulfur.
	Engine Control System AZ Purifier & Purifmuffler	DOC	25%	N/A	1996-2002 off-road; 15 ppm sulfur diesel.

APPENDIX M

EMISSIONS CONTROL TECHNOLOGY EVALUATION MATRIX

EMISSIONS CONTROL TECHNOLOGY EVALUATION AND SELECTION SCORING MATRIX

TECHNOLOGIES	CATEGORIES, CRITERION, SCORES, AND WEIGHTS															NORMALIZED SCORE 1-100%: (RAW SCORE/14.7)	FATAL FLAW:	COMMENTS
	EXPERIENCE AND PERFORMANCE (40%): **(NOx + PM + O +E) (.40)**					**ANNUALIZED COSTS (30%):** **(P+O)(0.30)** **(CRF=0.0802 @ 5%, 20yrs) (notes 1, 2, 3 and 4)**			**DESIGN AND OPERATION (15%):** **(S+A)(.15)**			**SAFETY AND FIELD SUPPORT (15%):** **(S+C+F)(.15)**						
	NOx Reduction (note 5)	**PM Reduction (note 5)**	**Other Pollutants: (HC, CO, CO_2 NH_3, SOx, Smoke, etc.) (note 5)**	**Prior Application Experience**	**Category Score**	**Amortized Purchase and Installation ($/yr)**	**Operating/Renewal ($/year)**	**Category Score**	**Space; Weight; Utility**	**Additional Operational Burden**	**Category Score**	**Safety**	**Crew Training**	**Field Service Support (includes availability for fuels & technologies)**	**Category Score**			
	-1 = ≥ +10% 0 = none 1 = < 10% 2 = 10-20% 3 = 20-35% 4 = 35-50% 5 = > 55%	-1 = ≥ +10% 0 = none 1 = < 10% 2 = 10-30% 3 = 30-50% 4 = 50-70% 5 = > 70%	-2 = major neg. benefit -1 = minimal neg. benefit 0 = no benefit 1 = minimal pos. benefit 2 = major pos. benefit	0 = None 1 = Some Related 2 = Extensive Related 3 = Some Marine and Extensive Related 4 = Extensive Marine and Related 5 = Extensive Marine and Extensive Related	Category Score = sum of criterion weighted score x category weight	1 = > $20K, 2 = $16K-$20K, 3 = $12K - $16K 4 = $8K - $12K 5 = < $8K	1 = > $150K 2 = $100K-$150K 3 = $50K-$100K 4 = $25K-$50K 5 = < $25K	Category Score = sum of criterion weighted score x category weight	1 = Extensive 2 = Challenging 3 = Moderate 4 = Minimal 5 = None	1 = Extensive 2 = Challenging 3 = Moderate 4 = Minimal 5 = None	Category Score = sum of criterion weighted score x category weight	1 = Extensive 2 = Challenging 3 = Moderate 4 = Minimal 5 = None	1 = Extensive 2 = Challenging 3 = Moderate 4 = Minimal 5 = None	1 = Extensive 2 = Challenging 3 = Moderate 4 = Minimal 5 = None	Category Score = sum of criterion weighted score x category weight			
	(score x 2)	(score x 1)	(score x 0.3)	(score x 0.5)	(score sum x 0.4)	(score x 1)	(score x 1)	(score sum x 0.3)	(score x 1)	(score x 1)	(score sum x 0.15)	(score x 1)	(score x 0.5)	(score x 0.5)	(score sum x 0.15)			
	criterion weight	criterion weight	criterion weight	criterion weight	category weight	criterion weight	criterion weight	category weight	criterion weight	criterion weight	category weight	criterion weight	criterion weight	criterion weight	category weight			
	2	1	0.3	0.5	0.4	1	2	0.3	1	1	0.15	1	0.5	0.5	0.15			
EXHAUST AFTERTREATMENT DEVICES:																		
1. Diesel Particulate Filters (DPF)	0	5	2	2	*2.64*	5	5	*4.50*	3	3	*0.90*	4	3	3	*1.05*	**61.8%**		Superior PM, HC, CO reduction; moderate operational requirements; mandatory ULSF use; periodic filter cleaning.
2. Selective Catalytic Reduction (SCR)	5	0	1	3	*4.72*	2	4	*3.00*	1	2	*0.45*	4	2	2	*0.90*	**61.7%**		Superior NO_X reduction; challenging operational & field service requirements; high cost.
3. Wet Scrubbers	1	5	1	3	*3.52*	3	5	*3.90*	1	1	*0.30*	5	3	3	*1.20*	**60.7%**	**X**	PM transfer from air to water; extensive space, weight, and/or utility issues for some vessels.

4. Diesel Oxidation Catalysts (DOC)	0	2	2	3	*1.64*	5	5	*4.50*	4	4	*1.20*	5	4	5	*1.43*	**59.6%**		Moderate PM reduction; minimal operational requirements; fuel flexibility; direct mulffler replacement.
5. Lean NOx Catalysts (LNC)	2	0	-1	1	*1.68*	5	5	*4.50*	3	3	*0.90*	4	3	4	*1.13*	**55.8%**		Moderate NOX reduction; uses fuel as reductant with 5 to 7 % fuel penalty.
1. Exhaust Gas Recirculation (EGR): high pressure	4	-1	-1	2	*3.08*	4	4	*3.60*	5	5	*1.50*	5	4	3	*1.28*	**64.3%**		Purchase cost includes engine dynamometer calbration, retrofit of new engine & high pressure EGR system; costs reduced if enigine change is part of routine overhaul; few applications to date; 3 - 5% potential fuel consumption increase.
2. Intake Air Fumigation	2	1	0	3	*2.60*	5	5	*4.50*	3	4	*1.05*	5	3	4	*1.28*	**64.1%**		Detrimental effects if water not completely vaporized; must have provision for water removal after air cooler.
3. Engine Replacement: Tier 2 Engine	2	1	1	3	*2.72*	2	5	*3.60*	4	3	*1.05*	5	3	3	*1.20*	**58.3%**		Category 1 Tier 2 engine availability is very limited; NOx reductions based upon EPA/IMO Tier 1 to Tier 2; all other pollutants based upon unregulated to Tier 2.
4. Ceramic Coating of Engine Components	-1	2	1	3	*0.72*	5	5	*4.50*	5	5	*1.50*	5	4	5	*1.43*	**55.4%**		Prior experience indicates a fuel savings benefit of 1 to 3% with coatings.
5. FIE Optimization for NO_x	2	-1	-1	0	*1.08*	5	4	*3.90*	5	4	*1.35*	5	4	5	*1.43*	**52.8%**		Increased fuel consumption; power decrease; assumes electronically-controlled engine; requires engine mfg recal and recert. Only one recalibration required for each group of like engines.
ALTERNATIVE FUELS:																		**Based on annual per vessel fuel consumption of 150,000 gallons/year.**
1. Fuel Born Catalysts (FBCs)	1	2	2	4	*2.64*	5	5	*4.50*	4	3	*1.05*	5	3	3	*1.20*	**63.9%**		Fuel treatment a recurring annual cost; wide variety of products availible; may decrease fuel consumption ~3-5%.
2. Oxygenated Diesel Fuel	1	2	1	1	*1.92*	5	5	*4.50*	5	5	*1.50*	5	5	2	*1.28*	**62.6%**		CARB verified; very limited supply and availability.
3. Emulsified Diesel	2	3	-1	3	*3.28*	5	3	*3.30*	5	2	*1.05*	5	3	4	*1.28*	**60.6%**		Significant cost penalty due to emulsion cost & fuel consumption increase; possible significant power loss w/o recalibration; cold weather operation and emulsion stability

																		issues; one engine manufacturer discourages use.
4. ULSD	0	1	0	3	*1.00*	5	5	*4.50*	5	5	*1.50*	5	5	5	*1.50*	**57.8%**		Currently only available as No. 1D (kerosene); primarily an enabler for aftertreatment technologies.
5. Fischer Tropsch Fuels (Synthetic Diesel Fuels)	2	3	2	1	*3.24*	5	1	*2.10*	5	5	*1.50*	5	5	2	*1.28*	**55.2%**		Very significant per gallon cost penalty (approximately $2/gallon); very limited availability.
6. Biodiesel (assumes B20 blend)	-1	2	2	5	*1.24*	5	3	*3.30*	5	4	*1.35*	5	5	5	*1.50*	**50.3%**		Potential NOx increase (testing inconclusive); heating value penalty.
COMBINATIONS:																		**All combinations assume engine operating on ULSD (No. 1D).**
1. EGR (low-pressure) and DPF	4	5	2	1	*5.64*	5	5	*4.50*	3	3	*0.90*	4	3	3	*1.05*	**82.2%**		Low pressure EGR can only be used in combination with DPF; purchase cost includes required one-time engine calibration. Commercially available as a packaged system.
2. Intake Air Fumigation, FIE, and DPF	4	5	2	3	*6.04*	4	4	*3.60*	3	3	*0.90*	4	3	3	*1.05*	**78.8%**		
3. EGR (high-pressure) and DOC	4	2	2	1	*4.44*	4	4	*3.60*	4	4	*1.20*	5	4	3	*1.28*	**71.5%**	**X**	High Pressure EGR not currently offered on any marine engines or off-road counterparts. Will require engine calibration and input from manufacturer.
4. SCR and DPF	5	5	2	1	*6.44*	1	4	*2.70*	1	2	*0.45*	4	2	2	*0.90*	**71.4%**		
5. LNC and DPF	2	5	2	1	*4.04*	5	5	*4.50*	3	3	*0.90*	4	3	3	*1.05*	**71.4%**		LNC is temperature sensitive; lube oil compatibilty with LNC is a concern as certain lube oil properties can poison catalyst.
		2	2	1	*3.64*	5	5	*4.50*	3	3	*0.90*	4	3	3	*1.05*	**68.6%**		Possible net fuel savings benefit of ~1%, Advertised tolerance to 500 PPM sulfur fuels.
7. Ceramic coatings and FIE optimization	2	2	0	1	*2.60*	5	4	*3.90*	5	4	*1.35*	5	4	5	*1.43*	**63.1%**		Coatings last ≈ 28, 000 hours; fuel savings benefit 1 to 3%.
8. Emulsified fuel and DPF	2	5	2	1	*4.04*	5	3	*3.30*	3	2	*0.75*	4	3	3	*1.05*	**62.2%**		one engine manufacturer discourages use.

9. Emulsified fuel and DOC	2	3	2	1	*3.24*	5	3	*3.30*	4	2	*0.90*	5	3	4	*1.28*	**59.3%**		some related non-road experience. one engine manufacturer discourages use of emulsified fuel.
OPERATING STRATEGIES:																		**NOX, PM and other criteria pollutant concentrations assumed to change directly with change in fuel consumption associated with each operating strategy. All operating stratagies will produce an annual fuel consumption reduction and inherent cost savings. While attractive, emissions reducing operating stratagies will be difficult to incorporate in present time constrained ferry schedules.**
1. Operate Minimum Number of Engines	7	4	4	5	*8.68*	5	5	*4.50*	5	5	*1.50*	5	3	5	*1.35*	**109.0%**		A 29% reduction in vessel speed will produce a 65% reduction in required engine power and fuel consumption, e.g., operation with two rather than four MEs in MV Seastreak Wall Street.
2. Reduce Transit Speeds	1	1	1	5	*2.32*	5	5	*4.50*	5	5	*1.50*	5	3	5	*1.35*	**65.8%**		A 5% transit speed, 15% power reduction will produce a 7-8%, overall fuel consumption reduction
3. Reduce Pushing Mode Engine Loads	1	1	1	5	*2.32*	5	5	*4.50*	5	5	*1.50*	5	3	5	*1.35*	**65.8%**		A 5% engine RPM reduction will reduce fuel consumption up to 7-8% when pushing at dock.
4. Reduce Electric Loads	0	0	0	5	*1.00*	5	5	*4.50*	5	5	*1.50*	5	5	5	*1.50*	**57.8%**		Every ≈ 1 kWe decrease in electric load will reduce vessel overall fuel consumption by ≈ 1%.

NOTES:

1. VESSEL LIFESPAN IS 20 YEARS
2. COST OF MONEY IS 5% FOR ANNUAL AMORTIZATION CALCULATIONS
3. TECHNOLOGY REPLACEMENT COST IS 50% OF CURRENT ACQUISITION AND INSTALLATION COST.
4. EACH TECHNOLOGY WILL REQUIRE RENEWAL AT YEAR 10.
5. EMISSIONS REDUCTION EFFECTIVENESS ARE AVERAGE VALUES EXPECTED OVER ENTIRE OPERATING PROFILE AS PER ECT MANUFACTURERS.

Appendix N

MV PORT IMPERIAL MANHATTAN EMISSIONS CONTROL TECHNOLOGY EVALUATION MATRIX

VESSEL SPECIFIC EMISSIONS CONTROL TECHNOLOGY EVALUATION AND SELECTION MATRIX

CATEGORIES AND CRITERION

SSEL: MV PORT IMPERIAL MANHATTAN
AIN ENGINE: 2X CATERPILLAR 3412E, 720 BHP @ 1800
M GENSET: 2X
RTHERN LIGHTS M673, 40 KWe

TECHNOLOGY	PERFORMANCE: Uncontrolled Annual Emissions Output – Nox, tons/yr/vessel (note 6)	PERFORMANCE: Uncontrolled Annual Emissions Output – PM, lb/yr/vessel (note 6)	PERFORMANCE: Assumed ECT Reduction – Nox, % (note 5)	PERFORMANCE: Assumed ECT Reduction – PM, % (note 5)	PERFORMANCE: Projected Annual ECT Treatment Emissions Reduction – Nox, tons/yr/vessel	PERFORMANCE: Projected Annual ECT Treatment Emissions Reduction – PM, lb/yr/vessel	PERFORMANCE: Post ECT Treatment Emissions Output – Nox, tons/yr/vessel	PERFORMANCE: Post ECT Treatment Emissions Output – PM, lb/yr/vessel	ANNUALIZED INSTALLATION AND OPERATING COSTS: Purchase and Installation, $/year CRF=0.0802 (5%/20 years) (notes 1, 2, 3 and 4) – Nox Reduction Technology	ANNUALIZED INSTALLATION AND OPERATING COSTS: Purchase and Installation – PM Reduction Technology	ANNUALIZED INSTALLATION AND OPERATING COSTS: Operating and Renewal Costs, $/yr (notes 1, 2, 3, 4 and 8) – Nox Reduction Technology	ANNUALIZED INSTALLATION AND OPERATING COSTS: Operating and Renewal Costs – PM Reduction Technology	ANNUALIZED INSTALLATION AND OPERATING COSTS: Total Costs, $/yr (=P+I+O) – Total Nox Cost, $/yr/vessel	ANNUALIZED INSTALLATION AND OPERATING COSTS: Total Costs – Total PM Cost, $/yr/vessel	ANNUALIZED INSTALLATION AND OPERATING COSTS: Total Costs – Total Cost, Nox + PM, $/yr/vessel	ANNUALIZED EMISSIONS REDUCTION COST (note 7): Specific Emissions Reduction Costs – Nox, $/ton-yr	ANNUALIZED EMISSIONS REDUCTION COST (note 7): Specific Emissions Reduction Costs – PM, $/lb-yr	COMMENTS
CDT-DOC & FBC	15.5	57.7	0%	40%	0.0	23.1	15.5	34.6	$0	$1,948	$0	$3,594	$0	$5,542	$5,542	#DIV/0!	$240	DECREASE IN FUEL CONSUMPTION OF 2%. $0. FUEL SURCHARGE PER GAL.
Rypos-DPF	15.5	57.7	0%	70%	0.0	40.4	15.5	17.3	$0	$4,547	$0	$400	$0	$4,947	$4,947	#DIV/0!	$122	
MA Turbo-Irenium	15.5	57.7	19%	50%	2.9	28.9	12.6	28.9	$1,231	$1,231	$720	$720	$1,951	$1,951	$3,902	$662	$68	
ohnson-Matthey SCR & DOC	15.5	57.7	50%	15%	7.8	8.7	7.8	49.1	$4,116	$1,839	$1,121	$400	$5,238	$2,239	$7,477	$675	$259	UREA COST OF $2.34/GAL AND DOSING RATE (3% OF FUEL
CA-SCR	15.5	57.7	60%	0%	9.3	0.0	6.2	57.7	$7,490	$0	$4,205	$0	$11,695	$0	$11,695	$1,257	#DIV/0!	UREA COST OF $2.34/GAL AND DOSING RATE (0.8% OF FUEL
Converter Tech-DPF/EGR	15.5	57.7	50%	85%	7.8	49.1	7.8	8.7	$1,518	$5,870	$2,246	$400	$3,764	$6,270	$10,035	$485	$128	
Tier 2 replacement engine/DOC	15.5	57.7	30%	50%	4.7	28.9	10.9	28.9	$8,020	$931	$1,497	$0	$9,517	$931	$10,449	$2,045	$32	

TES:

VESSEL USEFUL LIFESPAN IS 20 YEARS

COST OF MONEY IS 5% FOR ANNUAL AMORTIZATION CALCULATIONS
ECHNOLOGY REPLACEMENT COST IS 50% OF CURRENT ACQUISITION AND
STALLATION COST.

ACH TECHNOLOGY WILL REQUIRE RENEWAL AT YEAR 10.
MISSIONS REDUCTION EFFECTIVENESS ARE AVERAGE VALUES EXPECTED OVER ENTIRE OPERATING PROFILE AS PER ECT
NUFACTURERS.
VESSEL A OPERATING PROFILE IS 13.24 HRS/DAY, 5 DAYS PER WEEK, 52 WEEKS PER
AR.
ANNUALIZED EMISSIONS COST BASED ON INCORPORATION OF ECT COMBINATIONS ON ALL MAIN
GINES ONLY.
OPERATING COSTS INCLUDE ULSD, CONSUMABLES, TECHNICAL SUPPORT,
INTENANCE, ETC.

APPENDIX O

MV FATHER MYCHAL JUDGE EMISSIONS CONTROL TECHNOLOGY EVALUATION MATRIX

VESSEL SPECIFIC EMISSIONS CONTROL TECHNOLOGY EVALUATION AND SELECTION MATRIX

CATEGORIES AND CRITERION

.: MV FATHER MYCHAL JUDGE **MAIN ENGINE:**
ERPILLAR 3406E, 600 BHP @ 2100 RPM
T: NORTHERN LIGHTS P844K, 20 KWe

TECHNOLOGY	PERFORMANCE								ANNUALIZED INSTALLATION AND OPERATING COSTS							ANNUALIZED EMISSIONS REDUCTION COST (note 7)		COMM
	Uncontrolled Annual Emissions Output		Assumed ECT Reduction		Projected Annual ECT Treatment Emissions Reduction		Post ECT Treatment Emissions Output		Purchase and Installation, $/year CRF=0.0802 (5%/20 years) (notes 1, 2, 3 and 4)		Operating and Renewal Costs, $/yr (notes 1, 2, 3, 4 and 8)		Total Costs, $/yr (=P+I+O)			Specific Emissions Reduction Costs		
	Nox, tons/yr/vessel (note 6)	PM, lb/yr/vessel (note 6)	Nox, % (note 5)	PM, % (note 5)	Nox, tons/yr/vessel	PM, lb/yr/vessel	Nox Reduction, tonss/yr/vessel	PM Reduction, lbs/yr/vessel	Nox Reduction Technology	PM Reduction Technology	Nox Reduction Technology	PM Reduction Technology	Total Nox Cost, $/yr/vessel	Total PM Cost, $/yr/vessel	Total Cost, Nox + PM, $/yr/vessel	Nox , $/ton-yr	PM, $/lb-yr	
DOC & FBC	27.2	459.6	0%	40%	0.0	183.8	27.2	275.8		$1,851		$1,851	$0	$3,702	$3,702	#DIV/0!	$20	
s-DPF	27.2	459.6	0%	70%	0.0	321.7	27.2	137.9		$4,547	$0	$1,557	$0	$6,103	$6,103	#DIV/0!	$19	
'urbo-Irenium	27.2	459.6	19%	50%	5.2	229.8	22.1	229.8	$1,355	$1,107	$720	$720	$2,075	$1,827	$3,902	$401	$8	
n-Matthey SCR & DOC	27.2	459.6	50%	15%	13.6	68.9	13.6	390.7	$4,116	$1,839	$577	$0	$4,694	$1,839	$6,533	$345	$27	
SCR	27.2	459.6	60%	0%	16.3	0.0	10.9	459.6	$8,790		$2,166	$0	$10,956	$0	$10,956	$670	#DIV/0!	
erter Tech-DPF/EGR	27.2	459.6	50%	85%	13.6	390.7	13.6	68.9	$2,769	$4,186	$1,157	$400	$3,926	$4,586	$8,512	$288	$12	
replacement engine	27.2	459.6	30%	50%	8.2	229.8	19.1	229.8	$8,878	$1,324	$771	$0	$9,649	$1,324	$10,973	$1,181	$6	
rs SCR/DOC	27.2	459.6	70%	15%	19.1	68.9	8.2	390.7	$6,665	$2,110	$2,551	$0	$9,216	$2,110	$11,326	$483	$31	

:
EL USEFUL LIFESPAN IS 20 YEARS
' OF MONEY IS 5% FOR ANNUAL AMORTIZATION CALCULATIONS
NOLOGY REPLACEMENT COST IS 50% OF CURRENT ACQUISITION AND INSTALLATION COST.
I TECHNOLOGY WILL REQUIRE RENEWAL AT YEAR 10.
SIONS REDUCTION EFFECTIVENESS ARE AVERAGE VALUES EXPECTED OVER ENTIRE OPERATING PROFILE AS PER ECT MANUFACTURERS.
EL B OPERATING PROFILE IS 12.2 HRS/DAY, 5 DAYS PER WEEK, 52 WEEKS PER YEAR.
UALIZED EMISSIONS REDUCTION COSTS BASED ON INCORPORATION OF ECT COMBINATIONS ON MAIN ENGINES ONLY.
RATING COSTS INCLUDE ULSD, CONSUMABLES, TECHNICAL SUPPORT, MAINTENANCE, ETC.

APPENDIX P

MV ED ROGOWSKY
EMISSIONS CONTROL TECHNOLOGY EVALUATION MATRIX

VESSEL SPECIFIC EMISSIONS CONTROL TECHNOLOGY EVALUATION AND SELECTION MATRIX

CATEGORIES AND CRITERION

PM 20KWe MAIN ENGINE: 2X	PERFORMANCE								ANNUALIZED INSTALLATION AND OPERATING COSTS							ANNUALIZED EMISSIONS REDUCTION COST (note 7)		COMM
	Uncontrolled Annual Emissions Output		Assumed ECT Reduction		Projected Annual ECT Treatment Emissions Reduction		Post ECT Treatment Emissions Output		Purchase and Installation, $/year CRF=0.0802 (5%/20 years) (notes 1, 2, 3 and 4)		Operating and Renewal Costs, $/yr (notes 1, 2, 3, 4 and 8)		Total Costs, $/yr (=P+I+O)			Specific Emissions Reduction Costs		
ECHNOLOGY	Nox, tons/yr/vessel (note 6)	PM, lb/yr/vessel (note 6)	Nox, % (note 5)	PM, % (note 5)	Nox, tons/yr/vessel	PM, lb/yr/vessel	Nox Reduction, tonss/yr/vessel	PM Reduction, lbs/yr/vessel	Nox Reduction Technology	PM Reduction Technology	Nox Reduction Technology	PM Reduction Technology	Total Nox Cost, $/yr/vessel	Total PM Cost, $/yr/vessel	Total Cost, Nox + PM, $/yr/vessel	Nox , $/ton-yr	PM, $/lb-yr	
	10.2	355.5	0%	40%	0.0	142.2	10.2	213.3	$693	$1,062	$0	$2,053	$693	$3,115	$3,808	#DIV/0!	$22	FUEL CONS. DECREASE OF 2% AND $0.06
	10.2	355.5	0%	70%	0.0	248.8	10.2	106.6	$0	$3,811	$0	$400	$0	$4,211	$4,211	#DIV/0!	$17	
	10.2	355.5	19%	50%	1.9	177.7	8.3	177.7	$1,355	$1,107	$720	$720	$2,075	$1,827	$3,902	$1,070	$10	
	10.2	355.5	50%	15%	5.1	53.3	5.1	302.2	$4,116	$1,839	$641	$0	$4,757	$1,839	$6,596	$932	$34	UREA COST OF $2.34 AND INJECTION RA
	10.2	355.5	60%	0%	6.1	0.0	4.1	355.5	$10,345		$2,402	$0	$12,747	$0	$12,747	$2,081	#DIV/0!	UREA COST OF $2.34 AND INJECTION RA
	10.2	355.5	50%	85%	5.1	302.2	5.1	53.3	$2,769	$3,577	$1,283	$400	$4,053	$3,977	$8,029	$794	$13	
	10.2	355.5	30%	50%	3.1	177.7	7.1	177.7	$8,878	$1,259	$855	$0	$9,734	$1,259	$10,993	$3,178	$7	

ARS
. AMORTIZATION CALCULATIONS
IS 50% OF CURRENT ACQUISITION AND INSTALLATION COST.
RENEWAL AT YEAR 10.
IESS ARE AVERAGE VALUES EXPECTED OVER ENTIRE OPERATING PROFILE AS PER ECT MANUFACTURERS.
.7 HRS/DAY, 5 DAYS PER WEEK, 52 WEEKS PER YEAR.
ED ON INCORPORATION OF ECT COMBINATIONS ON ALL MAIN ENGINES ONLY.
CONSUMABLES, TECHNICAL SUPPORT, MAINTENANCE, ETC.

APPENDIX Q

MV SEASTREAK WALL STREET EMISSIONS CONTROL TECHNOLOGY EVALUATION MATRIX

VESSEL SPECIFIC EMISSIONS CONTROL TECHNOLOGY EVALUATION AND SELECTION MATRIX

CATEGORIES AND CRITERION

VESSEL: MV SEA STREAK WALL STREET MAIN ENGINES: 4X CUMMINS KTA50M2, 1875 BHP @ 1950 RPM GENSET: 2X CUMMINS/ONAN 6BT5.9, 95 KWe	PERFORMANCE								ANNUALIZED INSTALLATION AND OPERATING COSTS							ANNUALIZED EMISSIONS REDUCTION COST (note 7)		COMMENTS
TECHNOLOGY	Uncontrolled Annual Emissions Output		Assumed ECT Reduction		Projected Annual ECT Treatment Emissions Reduction		Post ECT Treatment Emissions Output		Purchase and Installation, $/year CRF=0.0802 (5%/20 years) (notes 1, 2, 3 and 4)		Operating and Renewal Costs, $/yr (notes 1, 2, 3, 4 and 8)		Total Costs, $/yr (=P+I+O)			Specific Emissions Reduction Costs		
	Nox, tons/yr/vessel (note 6)	PM, lb/yr/vessel (note 6)	Nox, % (note 5)	PM, % (note 5)	Nox, tons/yr/vessel	PM, lb/yr/vessel	Nox, tons/yr/vessel	PM, lb/yr/vessel	Nox Reduction Technology	PM Reduction Technology	Nox Reduction Technology	PM Reduction Technology	Total Nox Cost, $/yr/vessel	Total PM Cost, $/yr/vessel	Total Cost, Nox + PM, $/yr/vessel	Nox , $/ton-yr	PM, $/lb-yr	
1. CDT-DOC & FBC	58.2	1626.5	0%	40%	0.0	650.6	58.2	975.9	$457	$2,009	$0	$40,063	$457	$42,072	$42,529	#DIV/0!	$65	FUEL CONS. DECREASE OF 2% AND $0.06 PER MIXED GALLON SURCHARGE
2. Rypos-DPF	58.2	1626.5	0%	70%	0.0	1138.6	58.2	488.0	$0	$0	$0	$0	$0	$0	$0	#DIV/0!	$0	
3. MA Turbo-Irenium	58.2	1626.5	19%	50%	11.1	813.3	47.1	813.3	$1,484	$1,179	$720	$720	$2,204	$1,899	$4,103	$199	$2	
4. Johnson-Matthey SCR & DOC	58.2	1626.5	50%	15%	29.1	244.0	29.1	1382.6	$6,209	$3,385	$8,823	$0	$15,032	$3,385	$18,417	$517	$14	UREA COST OF $2.34 AND INJECTION RATE OF 0.8% OF FUEL USE.
5. CCA-SCR	58.2	1626.5	60%	0%	34.9	0.0	23.3	1626.5	$13,271		$33,087	$0	$46,358	$0	$46,358	$1,328	#DIV/0!	UREA COST OF $2.34 AND INJECTION RATE OF 3% OF FUEL USE.
6. Converter Tech-DPF/EGR	58.2	1626.5	50%	85%	29.1	1382.6	29.1	244.0	$5,357	$16,034	$17,675	$400	$23,032	$16,434	$39,466	$792	$12	
7. Tier 2 replacement engine	58.2	1626.5	30%	50%	17.5	813.3	40.7	813.3	$27,226	$3,672	$11,783	$0	$39,009	$3,672	$42,682	$2,235	$5	

NOTES:

1. VESSEL USEFUL LIFESPAN IS 20 YEARS
2. COST OF MONEY IS 5% FOR ANNUAL AMORTIZATION CALCULATIONS
3. TECHNOLOGY REPLACEMENT COST IS 50% OF CURRENT ACQUISITION AND INSTALLATION COST.
4. EACH TECHNOLOGY WILL REQUIRE RENEWAL AT YEAR 10.
5. EMISSIONS REDUCTION EFFECTIVENESS ARE AVERAGE VALUES EXPECTED OVER ENTIRE OPERATING PROFILE AS PER ECT MANUFACTURERS.
6. VESSEL C OPERATING PROFILE IS 10.3 HRS/DAY, 5 DAYS PER WEEK, 52 WEEKS PER YEAR.
7. ANNUALIZED EMISSIONS COST BASED ON INCORPORATION OF ECT COMBINATIONS ON ALL MAIN ENGINES ONLY.
8. OPERATING COSTS INCLUDE ULSD, CONSUMABLES, TECHNICAL SUPPORT, MAINTENANCE, ETC.

APPENDIX R

Caterpillar 3176 Engine Data

CATERPILLAR®

Marine Engine 3176B

450 bhp, 525 bhp, 600 bhp
2300 rpm

Shown with Accessory Equipment

CATERPILLAR® ENGINE SPECIFICATIONS

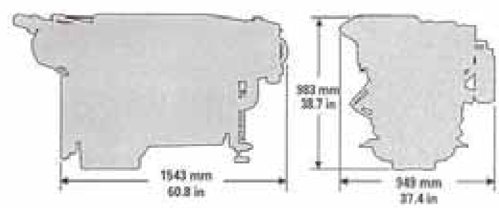
I-6, 4-Stroke-Cycle-Diesel

Bore—mm (in)	125 (4.9)
Stroke—mm (in)	140 (5.5)
Displacement—L (cu in)	10.3 (629)
Rotation (from flywheel end)	Counterclockwise
Compression Ratio	16:1
Capacity for Liquids — L (U.S. gal)	
Cooling System (engine only)	45 (12)
Lube Oil System (refill)	28 (7.5)
Oil Change Interval—L (gal)	9475 (2500)/fuel
Engine Weight, Net Dry (approx)— kg (lb)	1104 (2430)
Governor	Electronic

STANDARD EQUIPMENT

Air intake
single-stage, fumes disposal (closed system)
Cooling
low profile expansion tank, jacket water and sea water pumps, outlet regulated thermostats lube oil cooler
Exhaust
watercooled exhaust manifold and turbo
Flywheel and flywheel housing
SAE No. 1
Fuel system
priming and transfer pumps, filter, flexible lines
General
left hand and right hand service options, electronic installation kit
Governor
electronic
Instrumentation
electronic service meter
Lubricating system
oil pump, oil filters, dipstick

DIMENSIONS



ISO 9001 CERTIFIED — CATERPILLAR ENGINE FACILITIES

Power produced at the flywheel will be within standard tolerances up to 50° C (122° F) combustion air temperature measured at the air cleaner inlet, and fuel temperature up to 70° C (158° F) measured at the fuel filter base. Power rated in accordance with NMMA procedure as crankshaft power. Reduce crankshaft power by 3% for propeller shaft power.

RATING CONDITIONS

Ratings are in compliance with SAE J1228/ISO8665 standard conditions of 100 kPa (29.61 in Hg) and 25° C (77° F). These ratings also apply at ISO3046/1, DIN6271, and BS5514 conditions of 100 kPa (29.61 in Hg), 27° C (81° F) and 60% relative humidity.

Fuel rates are in compliance with fuel oil of 35° API [16° C (60° F)] gravity having an LHV of 42 780 kJ/kg (18 390 Btu/lb) when used at 29° C (85° F) and weighing 838.9 g/liter (7.001 lbs/U.S. gal).

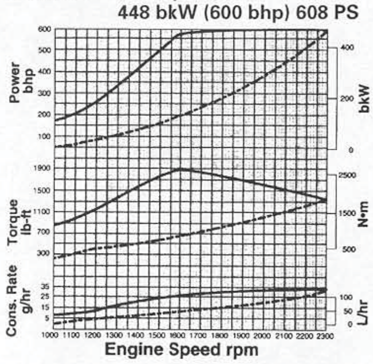
Consult your Caterpillar representative for additional information.

CATERPILLAR®

3176B MARINE ENGINE – 450, 525, 600 bhp

PERFORMANCE CURVES

E RATING – 2300 rpm
448 bkW (600 bhp) 608 PS

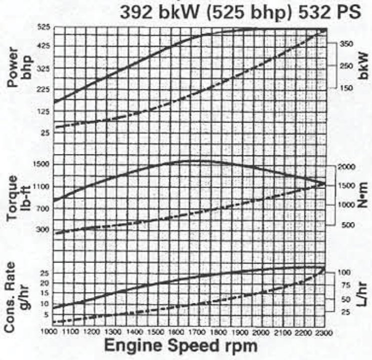


	Max Power Curve Data				Prop Demand Curve Data			
Speed rpm	Power bkW	Torque N•m	Fuel Cons g/bkW-hr	Fuel Rate L/hr	Power bkW	Torque N•m	Fuel Cons g/bkW-hr	Fuel Rate L/hr
2300	448	1860	227	121.4	448	1860	227	121.4
2200	448	1945	228	121.8	392	1702	214	100.0
2000	448	2140	221	118.0	295	1407	204	71.6
1800	448	2377	213	113.7	215	1139	206	52.8
1600	429	2561	213	108.9	151	900	212	38.1
1400	313	2136	216	80.5	101	689	220	26.5
1200	194	1545	211	48.9	64	506	246	18.6
1000	124	1184	202	29.8	37	352	277	12.2

Speed rpm	Power bhp	Torque lb-ft	Fuel Cons lb/bhp-hr	Fuel Rate g/hr	Power bhp	Torque lb-ft	Fuel Cons lb/bhp-hr	Fuel Rate g/hr
2300	600	1372	.373	32.1	600	1372	.373	32.1
2200	600	1435	.375	32.2	526	1255	.352	26.4
2000	600	1578	.363	31.2	395	1038	.335	18.9
1800	600	1753	.350	30.0	288	840	.339	13.9
1600	575	1889	.350	28.8	202	664	.349	10.1
1400	420	1575	.355	21.3	136	508	.362	7.0
1200	260	1140	.347	12.9	85	373	.404	4.9
1000	166	873	.332	7.9	49	260	.455	3.2

E RATING – Planing hull vessels such as pleasure craft, harbor patrol, harbor master, and some fishing and pilot boats.

D RATING – 2300 rpm
392 bkW (525 bhp) 532 PS

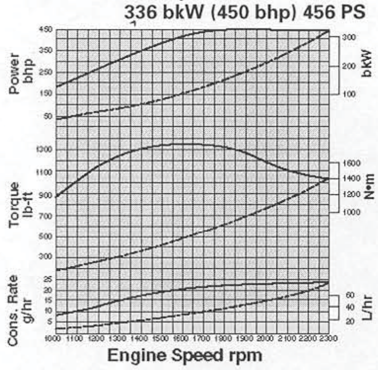


Speed rpm	Power bkW	Torque N•m	Fuel Cons g/bkW-hr	Fuel Rate L/hr	Power bkW	Torque N•m	Fuel Cons g/bkW-hr	Fuel Rate L/hr
2300	392	1628	222	103.6	392	1628	222	103.6
2200	392	1702	219	102.4	343	1489	211	86.3
2000	392	1872	213	99.7	258	1231	207	63.7
1800	385	2040	208	95.3	188	997	211	47.4
1600	347	2068	210	86.7	132	788	216	33.9
1400	273	1860	215	69.8	88	603	222	23.4
1200	194	1545	211	48.9	56	443	254	16.9
1000	124	1184	202	29.9	32	308	294	11.3

Speed rpm	Power bhp	Torque lb-ft	Fuel Cons lb/bhp-hr	Fuel Rate g/hr	Power bhp	Torque lb-ft	Fuel Cons lb/bhp-hr	Fuel Rate g/hr
2300	525	1201	.365	27.4	525	1201	.365	27.4
2200	525	1255	.360	27.1	460	1098	.347	22.8
2000	525	1381	.350	26.3	346	908	.340	16.8
1800	516	1505	.342	25.2	252	735	.347	12.5
1600	465	1525	.345	22.9	177	581	.355	9.0
1400	366	1372	.353	18.4	119	445	.365	6.2
1200	260	1140	.347	12.9	75	327	.418	4.5
1000	166	873	.332	7.9	43	227	.483	3.0

D RATING – Planing hull vessels such as off-shore patrol boats, customs, police, and some fire and fishing boats. Also used for bow and stern thrusters.

C RATING – 2300 rpm
336 bkW (450 bhp) 456 PS



Speed rpm	Power bkW	Torque N•m	Fuel Cons g/bkW-hr	Fuel Rate L/hr	Power bkW	Torque N•m	Fuel Cons g/bkW-hr	Fuel Rate L/hr
2300	336	1395	221	88.4	336	1395	221	88.4
2200	336	1459	217	87.0	294	1277	214	75.0
2000	336	1605	211	84.5	221	1055	210	55.3
1800	336	1783	208	83.3	161	855	212	40.7
1600	303	1811	211	76.4	113	675	217	29.3
1400	259	1767	215	66.4	76	517	228	20.6
1200	194	1545	211	48.9	48	380	271	15.4
1000	124	1184	202	29.9	28	264	322	10.5

Speed rpm	Power bhp	Torque lb-ft	Fuel Cons lb/bhp-hr	Fuel Rate G/hr	Power bhp	Torque lb-ft	Fuel Cons lb/bhp-hr	Fuel Rate G/hr
2300	450	1029	.363	23.4	450	1029	.363	23.4
2200	450	1076	.357	23.0	394	942	.352	19.8
2000	450	1184	.347	22.3	296	778	.345	14.6
1800	450	1315	.342	22.0	216	631	.349	10.8
1600	407	1336	.347	20.2	152	498	.357	7.7
1400	347	1303	.353	17.5	102	381	.375	5.4
1200	260	1140	.347	12.9	64	280	.446	4.1
1000	166	873	.332	7.9	37	195	.524	2.8

C RATING – Planing hull vessels such as ferries, fishing boats moving at higher speeds out and back (i.e. lobster, crayfish, and tuna), off-shore service boats, and also displacement hull yachts and short trip coastal freighters where engine load and speed are cyclical.

- Prop Demand -------- 3.0 Exponent
- Engine Performance Parameters: Power +/- 3%; Specific Fuel Consumption +/- 3%; Fuel Rate +/- 5%.

Materials and specifications are subject to change without notice.

The International System of Units (SI) is used in this publication.

LEHM6388 (5-96)
Supersedes LEHM5326

908 EXHAUST BACK PRESSURE	MAX KPA	6.7 IN.H2O	27
912 EXHAUST STACK TEMPERATURE	MAX DEG C	DEG F	
909 CRANKSHAFT ENDPLAY	MM	IN	
DIFFERENTIAL TEMP BETWEEN CYL	MAX DEG C	82 DEG F	148
DIFFERENTIAL TEMP BETWEEN MANF. SECT.	MAX DEG C	100 DEG F	180
CRANKCASE PRESSURE	MAX KPA	.5 IN.H2O	2
CRANKCASE BLOWBY RATE	M3/H	CU FT/H	

Heat Rejection

TOTAL COOLING SYSTEM	KW	269 BTU/MIN	15298

Engine Coolant Pump Flow Rate

```
MAX L/MIN  360  4.6 M  H2O EXT RESIST|MIN L/MIN  204 12.8 M  H2O EXT RESIST
MAX   GPM   95 15.1 FT H2O EXT RESIST|MIN   GPM   54 42.0 FT H2O EXT RESIST
```

Auxiliary Water System

```
MAX L/MIN  326  3.1 M  H2O EXT RESIST|MIN L/MIN  284 10.4 M  H2O EXT RESIST
MAX   GPM   86 10.2 FT H2O EXT RESIST|MIN   GPM   75 34.1 FT H2O EXT RESIST
```

Fuel Rate Specifications

ENGINE RATED FUEL RATE: RPM	MAX LPH	MIN LPH	MAX GPH	MIN GPH
2300	93.8	84.7	24.8	22.4
2100	90.4	82.1	23.9	21.7
1900	87.0	78.7	23.0	20.8

NORMAL OPERATION						BOLLARD OPERATION					
TOP CURVE			BOTTOM CURVE			TOP CURVE			BOTTOM CURVE		
LPH	GPH	RPM	RPM	GPH	LPH	LPH	GPH	RPM	RPM	GPH	LPH
93.9	24.8	2300	2375	18.3	69.3	85.6	22.6	2070	2231	23.3	88.2
82.1	21.7	2200	2300	16.7	63.2	77.2	20.4	2000	2100	19.5	73.8
71.5	18.9	2100	2200	14.6	55.3	66.2	17.5	1900	2000	16.8	63.6
61.7	16.3	2000	2100	12.7	48.1	56.4	14.9	1800	1900	14.4	54.5
53.0	14.0	1900	2000	10.9	41.3	47.3	12.5	1700	1800	12.3	46.6
45.0	11.9	1800	1900	9.4	35.6	43.5	11.5	1650	1700	10.3	39.0

Additional Data

RATED BSFC	G/KW-HR	225.5	LB/HP-HR	.3710
TORQUE CHECK TORQUE	N.M	1689	FT/LB	1246
TORQUE CHECK SPEED	RPM	1900		
TORQUE CHECK FUEL RATE	LPH	82.9	GPH	21.9
CORRECTION FACTOR - BP		0.909		
CORRECTION FACTOR - BP1		1.135		

Emissions Certification

Serial Number	9WK00057
Arrgmt Number	1006450
Spec Number	2T6187
Certification - 1	NONROAD - EUROPEAN UNION EXEMPT
Certification - 2	NONROAD - EPA, CARB, EXEMPT
Has Engine Been Rerated?	Yes
Interlock Code Actual Progression	10 6 10 6
As - Shipped Interlock Code	No Interlock Code
As - Shipped Flash File	No Flash File Found
As - Shipped Flash File CRB	Re-rated
As - Shipped CORR FL Power	455 HP (339.0 KW)
Build Date	1993-11-08

CATERPILLAR

Caterpillar Confidential: Green
Content Owner: Alan Scott
Current Date: Fri Oct 08 11:14:32 2004
Web Master: e-business Solutions

ENGINE TEST [9WK00057] — *OCTOBER 08, 2004*

Sales Model: 3176
Built Date: 08Nov1993 **Tested Date:** 19Nov1993 **Shipped Date:** 08Dec1993
Tested: DD **Plant:** Mossville **Test Number:** 01 **Cell Number:** 42

Test Element	Test Value	Spec Value	Label
Spec Number	2T6187	2T6187	
Arrangement Number	1006450	1006450	
CORR FL PWR	459 **R**	455	HP
Speed	2,299	2,300	RPM
CORR FL FUEL RATE	1,218.6 **R**	1,204.7	BTU/MIN
CSFC	159	159	BTU/HP-H
Jacket Water Temp			F
IN SCAC H2O			F
Compressor Out Pressure			PSIA
Inlet Manifold Pressure			PSIA
Excess Oxygen			%
Nox Level			PPM
FL Oil Press	52	51	PSI
High Speed	2,407	2,410	RPM
Diff Fuel Pressure High			PSI
Low Idle Speed	698	700	RPM
Low Idle Oil Pressure	22	20	PSI
Fuel Pressure	81	80	PSIA
Timing BTDC			DEG

SEA TRIAL DATA [9WK00057] OCTOBER 08, 2004

MARINE PROPULSION
3176 DITA SCAC ENG AR TEST SPEC 2T-6187 EFF S/N 9WK00056
ADV PWR 451 BHP (336.3 BKW) @ 2300 RPM PERF REF -00 EFF S/N

Air Systems

930 INLET AIR TEMP @ AIR CLEANER	MAX DEG C	48	DEG F	118
907 INLET AIR RESTRICTION (CLN FILTER)	MAX KPA		IN.H2O	
906 INLET AIR MANIFOLD AIR TEMP	MAX DEG C		DEG F	
911 INLET MANIFOLD PRESSURE (BOOST) @ RATED	MIN KPA		PSI	
911 INLET MANIFOLD PRESSURE (BOOST) @ RATED	MAX KPA		PSI	
960 TURBO COMPRESSOR OUTLET PRESSURE	NOMINAL KPA		PSI	
931 TURBO COMPRESSOR OUTLET TEMPERATURE	MAX DEG C		DEG F	

Jacket Water Systems

922 JW INLET TEMP (FROM COOLER)	MAX DEG C		DEG F	
921 JW PRESSURE FROM COOLING SYSTEM	NOMINAL KPA		PSI	
901 JW OUTLET TEMP (BEFORE REG)	MAX DEG C	99	DEG F	210
918 JW OUTLET PRESS (BEFORE REG)	NOMINAL KPA		PSI	
902 JW TEMP (AFTER WATER PUMP)	MAX DEG C		DEG F	
DELTA T JACKET WATER (OUT - IN)	MAX DEG C	99.0	DEG F	10.0
919 JW PUMP OUTLET PRESSURE	MIN KPA		PSI	
920 JW PUMP INLET PRESSURE	MAX KPA		PSI	
903 AFTERCOOLER WATER INLET TEMP	MAX DEG C	33	DEG F	91
923 AFTERCOOLER WATER INLET PRESS	MIN KPA		PSI	
903A AFTERCOOLER OUTLET WATER TEMP	MAX DEG C	52	DEG F	125
924 AFTERCOOLER WATER OUTLET PRESS	MAX KPA		PSI	
905 RAW WATER PUMP OUTLET PRESS	MIN KPA		PSI	
904 RAW WATER PUMP INLET PRESS	MAX KPA		PSI	

Engine Lubrication Systems

913 OIL TEMP TO BEARINGS	MAX DEG C	110	DEG F	230
914 OIL PRESSURE LOW IDLE	NOM KPA		PSI	
914 OIL PRESSURE FULL LOAD	NOM KPA		PSI	
938 OIL COOLER WATER OUTLET TEMP	MAX DEG C	99	DEG F	210
939 OIL COOLER WATER OUTLET PRESS	MIN KPA		PSI	
927 OIL FILTER INLET PRESSURE	MIN KPA		PSI	
928 OIL FILTER OUTLET PRESSURE	MIN KPA		PSI	

Engine Fuel Systems

917 FUEL PRESSURE	MIN KPA	379	PSI	55
961 FUEL PUMP INLET RESTRICTION	MAX KPA		PSI	
935 FUEL INLET TEMP	MAX DEG C	37	DEG F	99
962 FUEL OUTLET TEMP	MAX DEG C	60	DEG F	140
FUEL DENSITY	API MAX	36.0	MIN	34.00
FULL LOAD STATIC FUEL SETTING (NOMINAL)	MM		IN	
STATIC TIMING DEGREES	BTDC		ADVANCE	

Engine Idle Speeds

HIGH IDLE	RPM MAX	2450	MIN	2410
LOW IDLE	RPM MAX	720	MIN	700
MIN ENGINE SPEED DURING REVERSAL	RPM MIN	600		

Engine Exhause System

APPENDIX S

Environment Canada QA/QC Procedures

2.5 Test Preparation:

The test engine was operated on the initial (baseline) test fuel in order to ensure the proper operation of the engine and test instrumentation. The dynamometer and sampling system were subjected to the procedure described in the US Code of Federal Regulations § 86.1334-84 Pre-test engine and dynamometer preparation. All emission measurements and testing were conducted in accordance with the respective sections of the CFR.

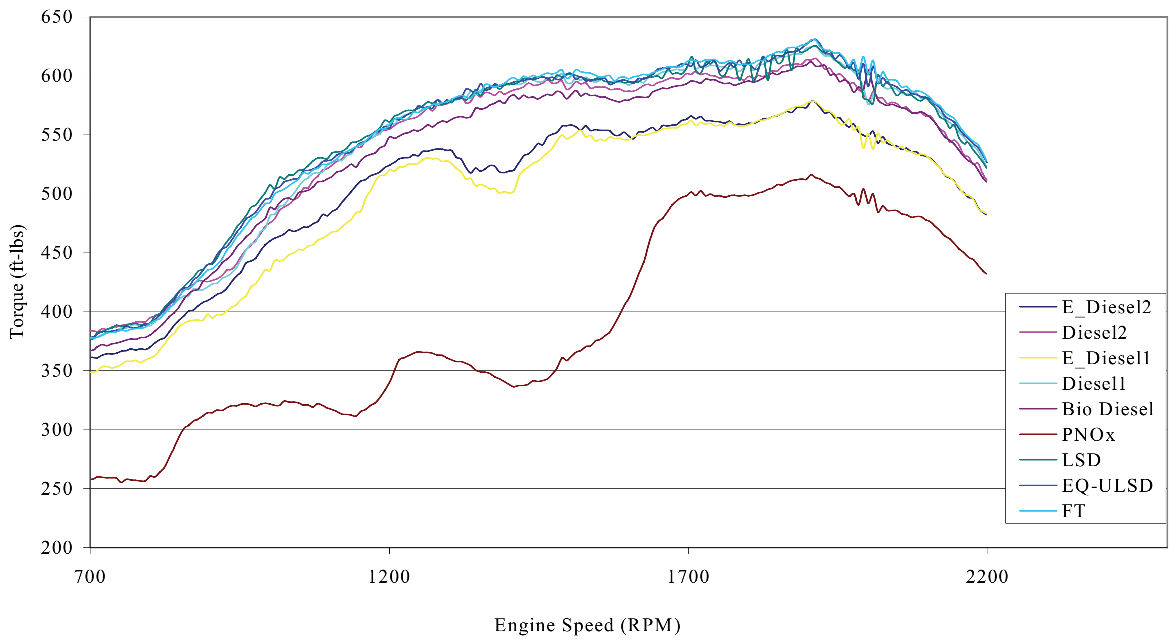
Final calibration of the dynamometer and throttle control systems was performed. The calibrations were verified during practice runs. The sampling system was preconditioned by operating the engine at a condition of rated-speed, 100 percent torque for a period of 20 minutes. The CVS and secondary dilution system temperatures were verified in order to establish conformance with § 86.1310-2007. The flow rate on the secondary tunnel was preset at this point in time. The engine was cooled as per § 86.1335-90.

At the conclusion of this period, with the approval of the quality control/ quality assurance team, the engine was mapped according to § 86.1332-90.

Mapping Procedure:

The purpose of this procedure was to generate a maximum torque curve for the test engine from curb idle through the manufacturer's rated speed. The maximum torque curve was then used to generate data for the transient test cycle for the test engine. The procedures for the transient test cycle generation for heavy-duty engine testing are described in CFR Title 40 Part 86.1333-90 regulations. The following Figures are a typical map and a Heavy Duty Engine Transient Test Cycle for the selected test engine.

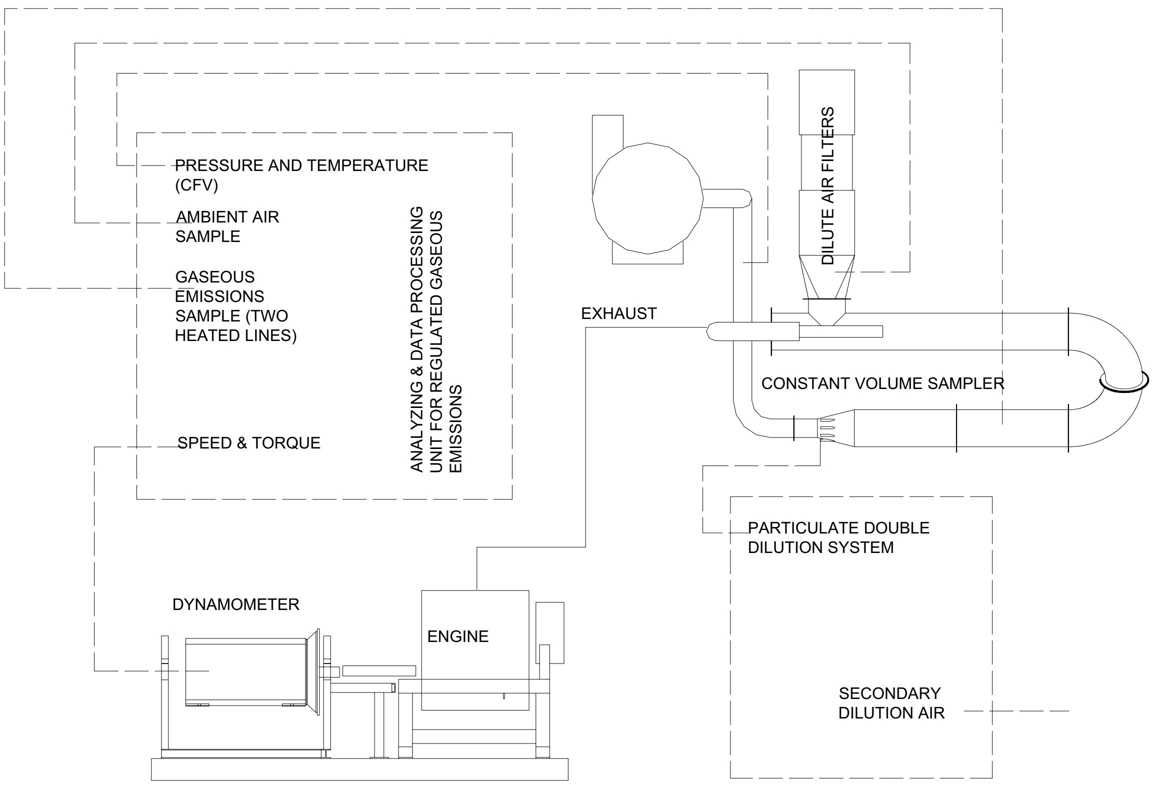
Figure 1 Engine Map for Navistar DT466



Emission Collection Apparatus:

The emission collection apparatus in the program utilized a constant volume sampling (CVS) system that diluted the engine exhaust during the test with filtered ambient air from the test cell. A schematic of Test Cell #5 is shown in **Figure 4**. This system allows measurement of the true mass of the gaseous and particulate matter emissions from the engine during operation. The design of this sampling and analytical system for engine emissions follows the protocol of the CFR Title 40 Part 86.1310-90.

Figure 2 HD Test Cell Schematic



The total volume of raw exhaust was transferred from the engine's exhaust manifold to the CVS through a 13 cm diameter steel exhaust pipe. The raw exhaust was then diluted with hepa filtered laboratory ambient air within the dilution tunnel, which is 46 cm (18 inches) in diameter and 12 meters (~40 feet) in length. The dilute exhaust was passed through a critical flow venturi, which maintained the flow at 84.96 cubic meters per minute (3000 standard cubic feet per minute). Data obtained from temperature and pressure sensors located upstream of the venturi and downstream of the sampling zone allow for correction of the volumetric flow rate to ASME standard conditions (i.e., 273 K, 101.325 kPa). Dilution air was filtered through a set of filters (bag, activated carbon and HEPA) to increase particulate measurement accuracy.

During emissions testing, a continuous flow of the diluted exhaust was collected through in-line sampling probes and directed to the particulate matter sampling system and gas analyzers.

Particulate filters were handled according to procedure described in § 86.1339-90 Particulate filter handling and weighing. Exhaust samples were analyzed according to § 86.1340-90 Exhaust sample analysis. The entire test underwent a validation process as per § 86.1341-90 Test cycle validation criteria. Calculation of emission rates were conducted according to procedure § 86.1342-90 Calculations; exhaust emissions, particulate emissions were assessed according to § 86.1343-88 Calculations; particulate exhaust emissions.

3. Analytical Methods

3.1 Regulated Emission Measurements

Table 4 lists the instrumentation used for the emissions analysis. Further details on the complete emissions characterization is provided in a subsequent section of the report.

Table 1 Regulated Emission Measurements

COMPOUND	Analysis Method	Instrument	Sample Collection
Carbon Monoxide	Non-Dispersive Infrared Detection (NDIR)	HORIBA Model AIA-210 LE	Continuous Collection
Carbon Dioxide	Non-Dispersive Infrared Detection (NDIR)	HORIBA Model OPE-115	Continuous Collection
Oxides of Nitrogen	Heated Chemiluminescence Detection	California Analytical Instruments Model 400-HCLD	Continuous Collection
Nitric Oxide	Heated Chemiluminescence Detection	California Analytical Instruments Model 400-HCLD	Continuous Collection
Total Hydrocarbons	Heated Flame Ionization Detection (FID)	California Analytical Instruments Model 300M-HFID	Continuous Collection
Particulate Matter	Gravimetric Procedure	Mettler AE 240	70mm Pallflex T60A20 Filters

The continuous sampling and analysis systems for CO, CO_2, NO_X and THC conform to the specifications of CFR Title 40 Part 86.1310-90 and Part 86.1339-90 (3). All sample lines, pumps, probes, and filters were heated and insulated over their entire length in order to prevent water condensation.

Particulate matter emission rates were obtained by directing the exhaust through the double dilution diesel particulate sampling system (DPS) allowing the particles to be deposited on pre-weighed 70 mm Pallflex™ T60A20 Teflon coated glass fiber filters. The samples were collected using methods described in CFR

Title 40 Part 86.1339-90 Particulate filter handling and weighing. This procedure and associated standard operating procedures are further described in later sections of the report.

Prior to the test, all filters were stored in a desiccator where the conditions were maintained at 40±10% relative humidity and 24°C. After this stabilization period, the filters were weighed on a Mettler AE240 balance readable to 0.01 mg. The filters were then stored in covered Petri dishes and remained in the desiccator until needed for testing. The filters were removed from the desiccator just prior to commencing the testing and placed in a sealed stainless steel filter holder assembly located downstream of the double dilution tunnel. After the test, the filters were re-stabilized in the desiccator for 12-24 hours and re-weighed to determine the net mass of diesel particulate emissions. This mass, together with other emissions data, was then used to calculate the PM emission rate in g/bhp-hr or g/kWh.

Special Note:
Atmospheric conditions are known to affect engine exhaust emissions and cause variability in measured NO_X data. During each heavy-duty transient test, the wet and dry bulb temperatures were recorded using a Bendix Psychometer, along with the barometric pressure. Based on these three parameters, a humidity value was calculated and a KH factor derived. This applied factor was used to correct the NO_X data to standard conditions of 75 grains H_2O/lb dry air and 85°F as per CFR Title 40 Part 86.341-79 (3).

3.2 Emission Characterization Measurements

Table 5 provides a general overview of the unregulated emissions that were characterized during the project. The emissions characterization consisted of per cycle sampling during the HDTC tests (with the exception of PAH/NPAH which had one sample collected overt three cycles).

Table 2. Emission Characterization Analysis and Sample Collection

Compound	Analysis Method	Sample Collection
Organic & Elemental Carbon	NIOSH 5040 – thermal optical transmittance	47 mm quartz filters
Ammonia	Ion Chromatography	Citric acid coated filter
Particle phase SO_4	Ion Chromatography	Teflon membrane filters
SO_2	Ion Chromatography	Potassium Carbonate Coated Filters
Carbonyl Compounds (incl. Form & Acetaldehyde	High Performance Liquid Chromatography	2,4-DNPH coated- Silica Gel Cartridges
Volatile Organic Compounds (incl. benzene, 1,3 butadiene)	Gas Chromatography-Flame Ionization Detection	Tedlar ™ Bag
Methane and Light HC	Gas Chromatography	Tedlar ™ Bag

PAH and Nitro-PAH	High resolution gas chromatography/mass spectrometry	Pallflex T60A20 Filter and Polyurethane Foam

Table 3. Direct Particulate Emission Characterization Analysis and Sample Collection

Compound	Analysis Method	Sample Collection
Particle Size Distribution	Scanning Mobility Particle Sizer	Continuous (mini-dilution)
Particulate Count	Electrical Low Pressure Impactor	Continuous
Particulate Mass	Tapered Element Oscillating Microbalance	Continuous

3.3 Quality Assurance and Quality Control

The Emissions Research and Measurement Division has played a leading role in characterizing the emissions from mobile and stationary sources in Canada and in other countries for over seventeen years. A key focus of the Mobile Source Section has been directed toward supporting research and development of new technologies for the reduction of the pollution contribution from these sources. The majority of this work has been with other government departments and industry.

The Division's laboratory specializes in the testing and analysis of gaseous and particle bound emissions from a variety of sources. One of the benchmark programs that has been undertaken by the laboratory is the vehicle/engine emissions compliance program that is under the authority of the Canadian Environmental Protection Act.

In order to support the development of new regulations, emissions inventory studies, and technology development, the Division has established sampling and analytical techniques for methane and non-methane hydrocarbons (both volatile and semi-volatile), oxygenated hydrocarbons, carbonyl compounds, and other gaseous components of the exhaust. More recently the Division has developed techniques for particulate sampling and analysis to examine metals, organic and elemental carbon content, and other solid phase emissions.

3.3.1 QUALITY ASSURANCE OVERVIEW

A critical part of the mission statement of the Environmental Technology Centre is to provide "specialized sampling and analytical expertise and services to the highest standards". Therefore quality management has always been a fundamental element of the ETC's many and varied programs.

The ETC is accredited through the Standards Council of Canada / Canadian Association for Environmental Laboratories for 21 test methods which include 33 appendices. This provides the Centre with a systematic, internationally recognized, quality system. As a Federal government science and technology institute it has been a tenet of the operating principles that the Centre should set an example by adopting the most stringent standards available and applicable to the work in the centre.

The scope of the accreditation encompasses the Centre's Quality Management System and the analytical testing procedures of the Ambient Air Quality Division, the Environmental Sciences Technology Division, and the Emissions Research and Measurement Division. The Quality Manual is identified as CAN-P-4D, ISO/IEC 17025 "General Requirements for the Competence of Testing and Calibration Laboratories".

The Methods that have been submitted for the accreditation process have been categorized as either Vehicle Testing Methods or Chemistry Methods. It should be noted that in most instances the appropriate sections of the USEPA Federal Register, Schedule 40, is a guiding document for these procedures and for testing conducted by the ERMD.

3.3.2 QUALITY ASSURANCE SYSTEMS

Calibrations and Frequency

Instrument calibrations conducted in the heavy-duty diesel test cell are based on the CFR Title 40 Part 86.1316-84 (3) for processes and acceptance criteria. The following five calibration procedures are routinely performed:

1. Three-Gas Mix Check,
2. Propane Injections,
3. NO_X Efficiency Check,
4. Instrumentation Response Test, and
5. Load Cell and Throttle Calibrations.

3.3.2.1 THREE-GAS MIX CHECK

This test verifies that the NDIR and FID instruments are reading within acceptable limits. A Tedlar™ bag is filled with a calibration gas mixture of CO, CO_2, and THC. The mixture analysis is traceable to within one percent of National Institute Standards and Technology (NIST) or National Bureau of Standards (NBS) gas standards. This gas sample is then analyzed by the NDIR and FID instruments in the test cell. The measured concentrations are compared to the theoretical concentrations. A measured acceptable tolerance on the procedure is within ± 5%.

3.3.2.2 PROPANE INJECTIONS

These calibration checks ensure proper flow through the CVS tunnel (CFR Title 40 Part 86.1319-84) (3). This check involves the injection of propane (at a known gas concentration) at 70 psi through a critical flow orifice into the CVS tunnel. The known injected propane concentration (100 ppm) is compared to the concentration indicated by the Flame Ionization Detector. A measured acceptable tolerance on the procedure is within ± 2%. Prior to performing this calibration, the critical venturi may be removed from the tunnel and cleaned.

3.3.2.3 NO_X EFFICIENCY CHECK

Once a week the NO_X converter efficiency is checked as per the CFR 86.1323-84 (3). The converter efficiency check is used to determine the conversion efficiency of NO_2 to NO. The acceptable range of tolerance for conversion efficiency is to be within ± 5%. In the NOx mode of operation the analyzer first converts the NO_2 in the sample to NO. This is done by means of a thermo-catalytic converter. This converted NO plus the NO present in the original sample is oxidized with ozone. The analyzer measures the concentration of NO_X by monitoring the chemiluminescent reaction of ozone and NO which produces NO_2.

3.3.2.4 INSTRUMENTATION RESPONSE TEST

Once a month, CO, CO_2, NO_X, and THC instrument drift responses are determined. This involves the use of a gas divider, span gases and zero calibration gases for each component. The gas divider mixes span gas with zero gas. A gas concentration versus meter reading curve is generated using the gas divider starting at 100% span gas and decreasing in increments of 10% concentration. This new calibration concentration curve coefficient is then compared to the current accepted curve coefficients programmed in the analyzer computer. A ± 2% tolerance is necessary between the new calibration curve coefficients and the current programmed computer coefficients. For CO the 300 ppm range is used in the heavy-duty engine cell. Five other CO ranges are available to be used in the heavy-duty engine cell. One theoretical concentration versus meter reading curve is generated for each of these CO ranges (CFR Title 40 Part 86.320-79) (3). The following Table shows the concentration ranges used to sample the diesel engine exhaust emissions.

Table 4. Gas Concentration Ranges used in the Heavy Duty Engine Test Cell

GAS	Range	Concentration
CO	R3	300 ppm
CO_2	R4	2 %
THC	R4	30 ppm
NO_X	R4	300 ppm

3.3.2.5 LOAD CELL AND THROTTLE CALIBRATIONS

The engine dynamometer must be capable of controlling both engine torque and speed simultaneously over the heavy-duty transient cycle. Once a month, the load cell in the test cell is calibrated as per CFR Title 40 Part 86.1308-84 (3). The setup for this procedure involves two calibration arms installed on both sides of the 500 hp DC electric dynamometer and calibration weights (8 x 35 lb). Also required for this calibration is the PC DOS based engine dynamometer controller. The purpose of this procedure is to ensure that the engine output torque values measured for the transient cycle evaluation are accurate.

Throttle calibrations involved the use of the 500 hp DC electric dynamometer (2200 rpm maximum recommended speed), PC DOS based engine dynamometer controller, and the engine control unit with MPSI PROLINK 9000 scanner. This procedure verifies the speed measurement system, made by comparing readings from the speed signal and data acquisition system to a frequency counter used as a reference (CFR Title 40 Part 86.1308-86).

3.3.2.6 ANALYTICAL GASSES

All gas cylinders used by the ERMD are analyzed every 8 weeks and are traceable to standard gases obtained from NIST.

3.3.2.7 ANALYTICAL INSTRUMENT CALIBRATION METHOD AND FREQUENCY

The bench integrity is checked weekly by analyzing mixture of 'known' (CO, CO2 and HC) gases. The Table below describes analytical instruments used for detection of particular compounds as well methods and frequencies of their calibrations.

Table 5. Calibration System and Schedule

Compound	Analysis Method	Sample Collection	Calibration Method	Calibration Frequency
Carbon Monoxide	Non-Dispersive Infrared Detection (NDIR)	Continuous Collection – online analyzer	Curve generated and compared with the existing one. Changed only if off by more than 2%	every 4 weeks, zero and span checks before each test.
Carbon Dioxide	Non-Dispersive Infrared Detection (NDIR)	Continuous Collection – online analyzer	Curve generated and compared with the existing one. Changed only if off by more than 0.5%	every 4 weeks, zero and span checks before each test.
Oxides of Nitrogen (NO_X)	Heated Chemiluminescence Detection	Continuous Collection – online analyzer	Curve generated and compared with the existing one. Changed only if off by more than 0.5%	every 4 weeks, zero and span checks before each test.

			NOx Converter Efficiency Check	weekly
Nitric Oxide (NO)	Heated Chemiluminescence Detection	Continuous Collection – online analyzer	Curve generated and compared with the existing one. Changed only if off by more than 0.5%	every 4 weeks, zero and span checks before each test.
			NOx Converter Efficiency Check	weekly
Nitrogen Dioxide (NO_2)	Calculated difference between NO_X and NO as determined by Heated Chemiluminescense method. The result can have large uncertainty if NO_2 concentration is less than 10% of NO_X concentration.			
Nitrogen Dioxide (NO_2)	High Performance Liquid Chromatography	2,4-DNPH coated-Silica Gel Cartridges	Check Std, Duplicate, Extraction Std, Reagent Std Low Concentration Std Calibration	Every run Monthly When required
Total Hydrocarbons	Heated Flame Ionization Detection (FID)	Continuous Collection – online analyzer	Curve generated and compared with the existing one. Changed only if off by more than 0.5%	Every 4 weeks, zero and span checks before each test.
Particulate Matter	Gravimetric Procedure	70mm Emfab Filters	Sample system flows verified by bubble meter. Filters contained in temperature and humidity controlled balance room. Balance calibrated by control weights.	Weekly Daily
Particulate Matter Organic & Elemental Carbon	NIOSH 5040 – thermal optical transmittance (Sudbury-NRCAN)	47 mm Tissuquartz filters-fired @ 900°C to remove contamination	Replicate 3 Spikes, 1 Blank Standards	Every 9 samples Every run Every 3 months
Organic Acids (particle phase and gas phase)	Capillary Electrophoresis And Ion Chromatography (AAQD)	Teflon membrane filters for particle phase samples. Fired Tissuquartz filters coated with potassium hydroxide for gas phase samples	Screening Std, Verification Std, 2 Control Stds, Reagent and Method Blanks, Spikes Calibration	Every run Weekly or as required
Ammonia	Ion Chromatography (AAQD)	Whatman 41 cellulose filters coated with citric acid	Calibration, Check Stds Verification Std, Method Blank, Reagent Blank	Weekly or as required Every run
Particle phase inorganic ions including SO_4	Ion Chromatography (AAQD)	Teflon membrane filters	Calibration, Check Stds Verification Std, Method Blank, Reagent Blank	Weekly or as required Every run
SO_2	Ion Chromatography (AAQD)	Whatman 41 cellulose filters coated with potassium carbonate	Calibration, Check Stds Verification Std, Method Blank, Reagent Blank	Weekly or as required Every run
Carbonyl Compounds (incl. Form & Acetaldehyde	High Performance Liquid Chromatography	2,4-DNPH coated-Silica Gel Cartridges	Check Std, Duplicate, Extraction Std, Reagent Std Low Concentration Std Calibration	Every run Monthly When required
Non-methane hydrocarbons (incl. benzene, 1,3 butadiene)	Cryogenic preconcentration followed by GC-FID or GC-MS	Tedlar ™ Bag	Check Std, Duplicate Proficiency Testing Calibration	Every run Monthly When required
Methane and Light HC	GC-FID	Tedlar ™ Bag	Check Std, Duplicate Low Concentration Std,	Every run Monthly

			Proficiency Testing Calibration	When required
PAH and Nitro-PAH	GC-MS	Emfab Filter and Polyurethane Foam (PUF)	Check Std Calibration Surrogate and Internal Std	Every run When required Calibrated at least every second run

3.3.2.8 DATA ACQUISITION AND DATA MANAGEMENT PROCEDURES

The data acquisition for both the engine and dynamometer operations as well as the regulated emissions sampling is controlled and automated through proprietary software developed by Environment Canada.

Data collection is conducted through the National Instrument cards in both dynamometer controlling and test controlling computers. Data comes in the form of frequencies (i.e. dynamometer speed) or voltages (analyzer outputs, load cell output, thermocouples outputs etc.) Data is stored as CSV files and linked with the appropriate calibration files using C++ software. The raw results represent data in the appropriate units (torque, speed, pollutant concentrations, temperatures, humidity etc.) This data undergo primary quality control and is further processed using series of the excel spreadsheets based on § 86.1342-90 Calculations; exhaust emissions to obtain final test results. The final results are transferred to the project manager and scrutinized for test-to-test repeatability.

APPENDIX T

CLEAN DIESEL TECHNOLOGIES PLATINUM PLUS DFX FUEL ADDITIVE AND DIESEL OXIDATION CATALYST

REDUCED FUEL CONSUMPTION ■ INCREASED POWER ■ REDUCED SMOKE AND EMISSIONS ■ EXTENDED LIFE AND IMPROVED DOC AND DPF PERFORMANCE ■ CUMMINS L-10 DETERGENCY ■ ENHANCED LUBRICITY ■ IMPROVED STABILITY ■ WATER SHEDDING

Platinum Plus® DFX

Technical Data Sheet – Premium Diesel Additive

Platinum Plus® DFX is a technologically advanced multifunctional diesel additive containing a bimetallic combustion catalyst. Formulated to increase the rate and completeness of fuel combustion and to clean up fuel systems and injectors, Platinum Plus® DFX upgrades typical No. 2 diesel to an "ultra" premium diesel. Platinum Plus® DFX delivers an effective dosage of a patented bimetallic combustion catalyst that increases power and lowers fuel consumption with reduced soot, smoke and gaseous emissions. Platinum Plus® DFX also contains an L-10 superior detergent package that cleans up deposits and keeps injectors clean with regular use. Platinum Plus® DFX improves the performance of diesel oxidation catalysts (DOC) and catalyzed diesel particulate filters (DPF). Meets NCWM premium diesel specifications.

Benefits

- Improves fuel combustion
- Helps improve fuel economy up to 10%
- Increases horsepower up to 5%
- Reduces smoke and opacity up to 40%
- Reduces particulate and gaseous emissions up to 30%
- Improves performance and durability of Diesel Oxidation Catalyst (DOC)
- Improves particulate filter regeneration and minimizes back pressure
- Helps recover fuel economy lost with "low emission" engines
- Provides detergency demonstrated by the "Cummins L-10" test
- Enhances water shedding, lubricity, and stability

Application

Platinum Plus® DFX with detergent is designed for use in bulk fuel treatment or for blending and packaging as a dose for individual vehicles. The product is generally compatible with other additives, diluents, and fuels but compatibility tests are recommended. For emission reduction and fuel economy improvement, the minimum recommended dosage is 1 gallon per 1500 gallons of fuel.

Storage and Handling

Platinum Plus® DFX contains active catalysts in a combustible hydrocarbon base. To maintain peak catalytic activity, it should not be contaminated with foreign matter or exposed to temperatures in excess of 40°C (104°F) or light for prolonged periods. Normal precautions should be taken as when handling any industrial chemical. Please refer to the MSDS for further information.

Typical Properties

- Appearance: Thin dark amber liquid with solvent odor
- Specific Gravity (23-24°C): 0.9
- Flash Point: 126°F
- Pour Point: -40°F
- Active Catalyst @ 1:1500: 7.5 PPM

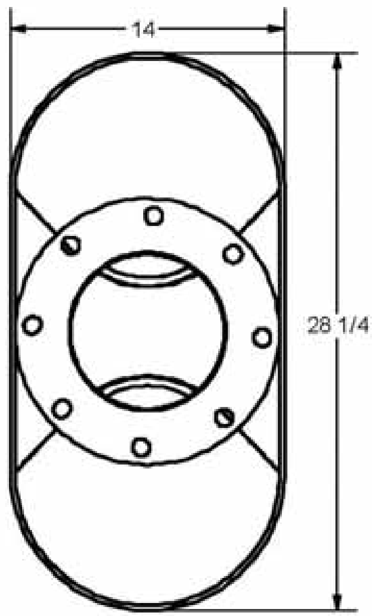
Availability

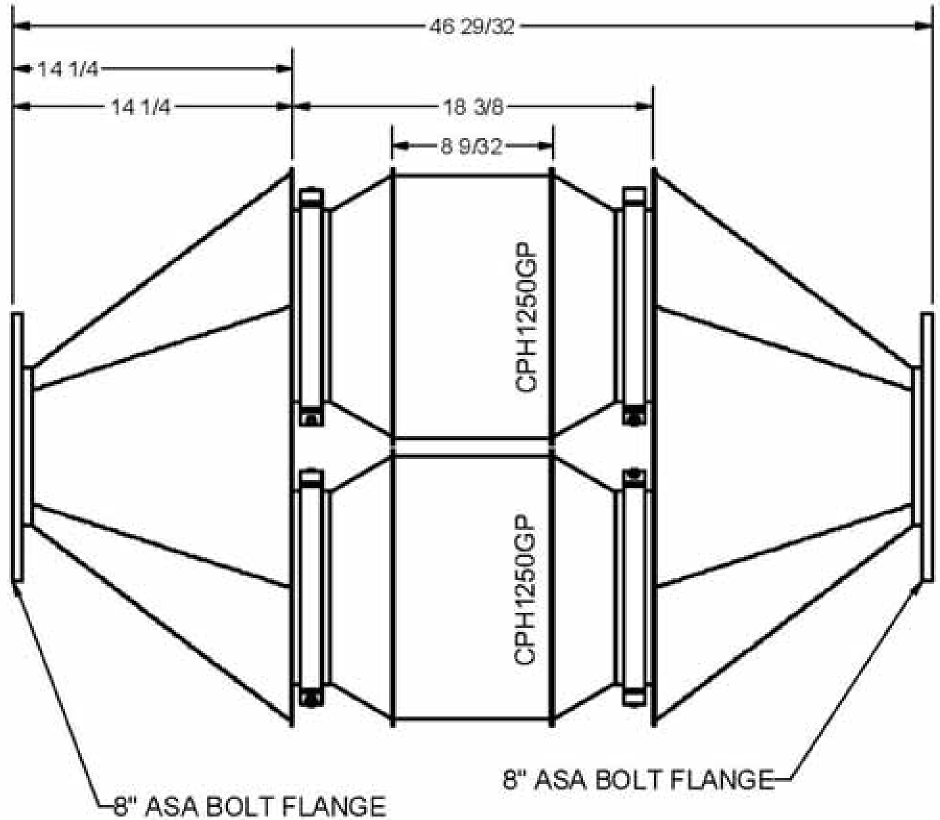
Platinum Plus® DFX is available in 30 oz bottles, 1-gallon jugs, 5-gallon pails, and 55 gallon, non-returnable steel drums.

Platinum Plus® is a registered trademark of Clean Diesel Technologies, Inc.

Clean Diesel Technologies, Inc.

300 Atlantic Street, Suite 702, Stamford, CT 06901-3522, Tel: (203) 327-7050, Fax: (203) 323-0461 www.cdti.com





NOTE:
ESTIMATED PRESSURE DROP
GIVEN A FLOW RATE OF
4260 ACFM @
1120 DEG. F = 15.7" W.C.

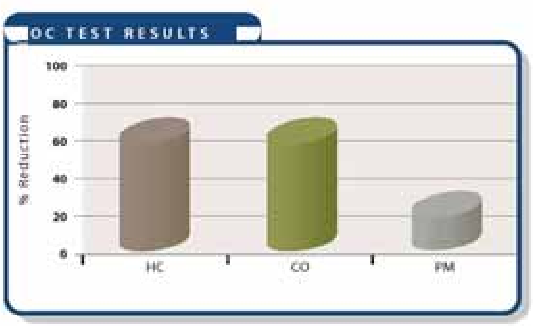
TITLE: 05083102AD		CleanAIR Systems, Inc. Santa Fe New Mexico U.S.A.			
SCALE	MATERIAL: 304L S/S		FIXTURE NUMBER		GENERAL TOLERANCES
DRAWN BY: DBS	DATE: 9/1/05	TOTAL PAGES	PAGE#	DRAWN IN: INVENTOR	THIS DRAWING IS THE EXCLUSIVE PROPERTY OF CLEANAIR SYSTEMS, INC. ANY DUPLICATION OR REPRODUCTION WITHOUT THE CONSENT OF CLEANAIR SYSTEMS, INC. IS PROHIBITED.
DWG #: 05083102AD		3RD ANGLE PROJECTION		SIZE: A	

Appendix U

MV FATHER MYCHAL JUDGE
JOHNSON-MATTHEY
DIESEL OXIDATION CATALYST

DOC
(Diesel Oxidation Catalyst)

Reduces PM, CO & HC emissions on all diesel engines



Johnson Matthey's **DOC** converter is a basic PM emissions control device designed to remove up to 25% of the particulate matter. Depending on operating temperature, PM reductions can be achieved without using Ultra-low Sulfur Diesel (ULSD) fuel. The **DOC** oxidizes the soluble organic fraction (SOF) of the soot, while also converting up to 70% of the HC and CO emissions.

Technology Driven

Johnson Matthey utilizes a highly active platinum-based catalyst and proprietary materials to minimize sulfate formation during operation. The **DOC** converter is fully adaptable and effective on all 1991 and newer diesel engines and on some older models.

Featuring

- EPA verified technology
- Reduces PM by 25% and HC & CO over 70%.
- Reduces odors and runs cleaner.
- No ULSD required.
- Fit & Forget technology, no maintenance required.

Proven Success

For 40 years, Johnson Matthey has been the global leader in the emissions control industry. Johnson Matthey SSEC designs and supplies catalytic systems to control emissions of NOx, CO, NMHCs, VOCs, HAPs and PM.

JM
Johnson Matthey
Stationary Source Emissions Control
380 Lapp Road, Malvern, PA 19355, USA
TEL: (610) 971-3100, FAX: (610) 971-3116
www.jmssec.com info@jmssec.com

APPENDIX V

MV JOHN KEITH
JOHNSON-MATTHEY
DIESEL OXIDATION CATALYST

Johnson Matthey

DOC
(Diesel Oxidation Catalyst)

Reduces PM, CO & HC emissions on all diesel engines

Johnson Matthey's **DOC** converter is a basic PM emissions control device designed to remove up to 25% of the particulate matter. Depending on operating temperature, PM reductions can be achieved without using Ultra-low Sulfur Diesel (ULSD) fuel. The **DOC** oxidizes the soluble organic fraction (SOF) of the soot, while also converting up to 70% of the HC and CO emissions.

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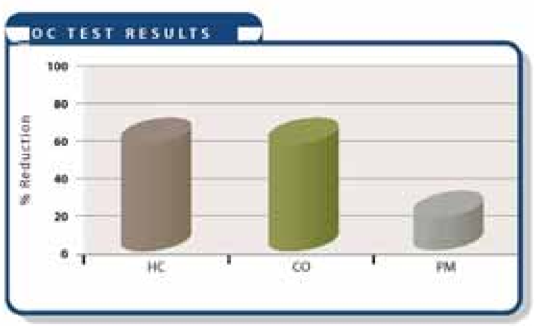


Johnson Matthey
Stationary Source Emissions Control
380 Lapp Road, Malvern, PA 19355, USA
TEL: (610) 971-3100, FAX: (610) 971-3116
www.jmssec.com info@jmssec.com

APPENDIX W

Phase I Emissions Testing Data and Graphs

Table W.1. Raw Data, MV PORT IMPERIAL MANHATTAN – LSD

						PM10 (mg/filter)
Idle1	12.7	59	6.1	1916	0.203	0.207
Idle2	12.7	57	6.2	1978	0.084	0.088
Idle3	12.5	55	6.3	2071	0.072	0.089
Cruise1	10.3	93	7.9	1715	0.285	0.298
Cruise2	10.0	90	8.1	1787	0.130	0.127
Cruise3	10.0	90	8.1	1811	0.104	0.110
Push1	8.0	124	9.6	2329	0.220	0.222
Push2	7.9	134	9.7	2375	0.105	0.106
Push3	8.1	113	9.5	2406	0.025	0.047
Trial1	10.6	315	7.7	1826	0.479	0.451
Trial2	11.0	106	7.5	2094	0.221	0.251
Trial3	9.2	146	8.8	2170	0.357	0.348
Trial4	10.8	205	7.6	1867	0.325	0.343
Trial5	13.7	105	5.1	1719	0.292	0.314
Trial6	14.2	67	5.0	1815	0.289	0.304
DG1	14.3	254	4.9	817	1.117	1.032
DG3	14.7	260	4.6	898	0.393	0.412

Table W.2. Raw Data, MV PORT IMPERIAL MANHATTAN – ULSD

						PM10 (mg/filter)
Idle1	15.9	54	3.8	873	0.048	0.042
Idle2	15.8	54	3.8	915	0.043	0.037
Idle3	15.9	54	3.7	916	0.043	0.049
Idle4	15.7	55	3.9	978	0.050	0.038
Cruise1	10.5	71	7.5	1413	0.041	0.049
Cruise2	10.9	74	7.5	1398	-	0.043
Cruise3	10.8	75	7.5	1419	0.115	0.111
Cruise4	10.5	73	7.8	1435	0.121	0.120
Push1	7.1	224	9.9	2103	0.113	0.105
Push2	7.8	121	9.8	2240	-	0.082
Push3	7.4	142	10.0	2141	0.108	0.102
Push4	6.9	243	10.5	2177	0.086	0.082
Trial1	13.2	99	5.1	1445	0.057	0.067
Trial2	13.5	180	5.5	1457	-	0.068
Trial3	13.7	103	5.3	1660	0.156	0.150
Trial4	12.4	71	6.3	2256	0.181	0.212
Trial5	13.5	119	5.6	1896	0.119	0.148
Trial6	12.8	156	6.1	2015	0.145	0.146
DG1	13.6	199	5.4	740	0.125	0.118
DG2	14.5	221	4.7	726	0.221	0.216
DG3	13.6	208	5.4	731	0.260	0.255

Table W.3. Calculated Average Emissions, MV PORT IMPERIAL MANHATTAN – LSD

Transit	2.76	0.14	0.10	8.78	9.04	9.7	285.1	14.6	10.4	0.91	0.94
Push	2.98	0.10	0.13	3.59	4.03	12.1	246.1	8.5	10.4	0.30	0.33
Cruise	2.69	0.09	0.13	6.95	7.16	12.2	220.8	7.5	10.4	0.57	0.59
Idle	1.52	0.03	0.05	2.40	2.61	4.6	321.4	6.1	10.4	0.51	0.55
Generator	0.23	0.05	0.01	4.69	4.95	1.3	180.2	35.7	10.4	3.61	3.81

Table W.4. Calculated Emissions, MV PORT IMPERIAL MANHATTAN – ULSD

											PM 10 g/gal
Transit	2.26	0.10	75.0	4.46	4.66	7.5	301.8	13.7	10.0	0.60	0.62
Push	2.72	0.15	131.7	4.30	3.98	13.2	206.3	11.4	10.0	0.33	0.30
Cruise	2.47	0.08	137.3	8.15	7.31	13.7	179.5	6.2	10.0	0.59	0.53
Idle	1.13	0.04	48.79	2.22	2.20	4.9	231.8	9.1	10.0	0.45	0.45
Generator	0.23	0.04	16.94	3.05	2.74	1.7	135.0	25.6	10.0	1.80	1.61

Table W.5. Engine Parameters, MV PORT IMPERIAL MANHATTAN – LSD

								EXHAUST TEMP, F
Transit	969.2	9.7	140,676	9.7	68.6	1.2	165.3	NA
Push	996.8	12.1	140,676	12.1	78.4	2.6	164.8	NA
Cruise	1189.6	12.2	140,676	12.2	79.5	3.0	165.5	NA
Idle	700.1	4.6	140,676	4.6	77.2	0.1	161.2	NA
	Load, kWe							
Generator	14.5	1.3	140,676	1.3	75.4			

Table W.6. Engine Parameters, MV PORT IMPERIAL MANHATTAN – ULSD

								EXHAUST TEMP, F
Transit	872.3	8.7	135,740	7.5	88.9	0.5	163.3	NA
Push	1013.1	16.0	135,740	13.2	82.5	2.7	166.3	NA
Cruise	1226.3	14.2	135,740	13.7	83.2	2.2	166.1	NA
Idle	699.0	3.7	135,740	4.9	81.8	-0.4	161.5	NA
	Load kWe							
Generator	15.0	1.8	135,740	1.70	86.8			

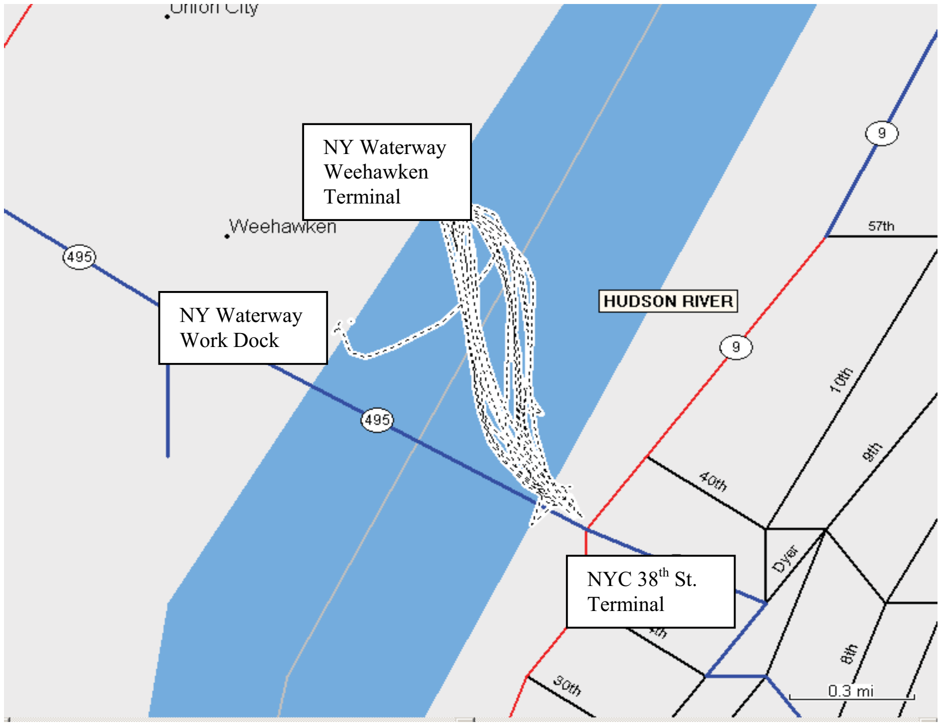


Figure W.1. MV PORT IMPERIAL MANHATTAN Transit LSD and ULSD Emission Routes

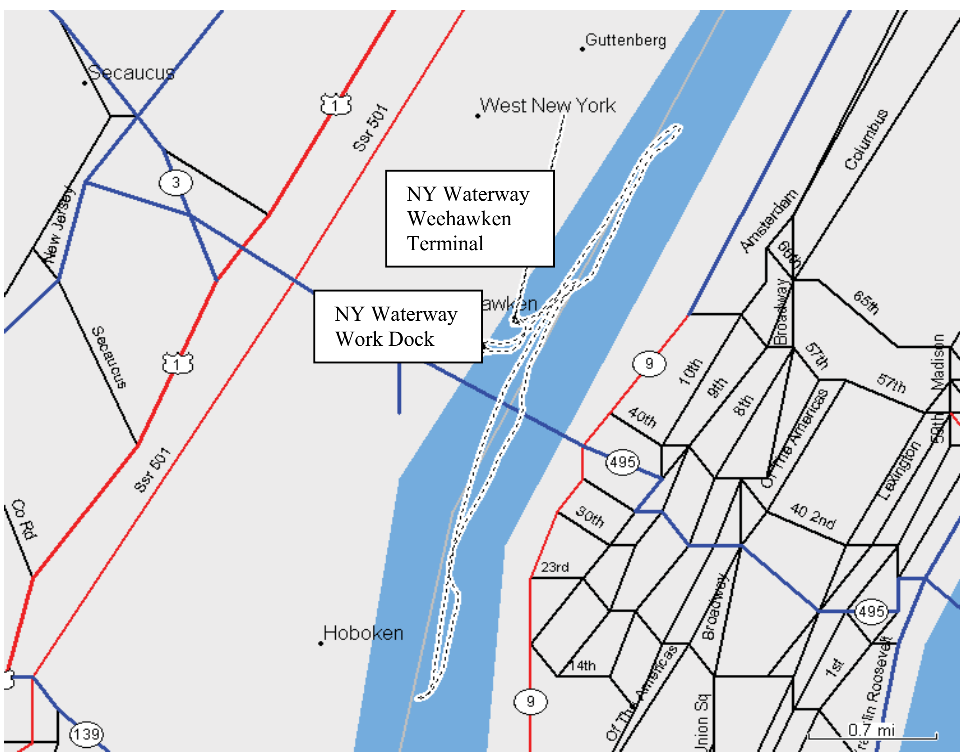


Figure W.2. MV PORT IMPERIAL MANHATTAN Cruise and Push ULSD Emission Routes

Table W.7. Raw Data, MV FATHER MYCHAL JUDGE – LSD

						PM10 (mg/filter)
Idle 1	16.50	198	3.28	1259	0.285	0.269
Idle 2	16.50	203	3.28	1243	0.305	0.286
Idle 3	16.50	205	3.28	1236	0.476	0.422
Push1	11.41	140	7.08	2092	0.393	0.310
Push2	11.50	135	7.02	2229	0.279	0.257
Push3	11.50	132	7.02	2249	0.225	0.176
Cr1	8.80	255	9.03	1478	0.789	0.590
Cr2	8.73	254	9.08	1463	0.379	0.265
Trial2	12.35	457	6.38	1716	1.163	1.093
Trial3	11.17	381	7.26	1631	0.534	0.474
Trial4	12.33	367	6.39	1842	0.611	0.486
Trial5	10.42	191	7.82	1458	0.402	0.290
Trial6	10.64	358	7.66	1591	0.469	0.326
Trial7	10.80	221	7.54	1584	0.380	0.276

Table W.8. Raw Data, MV FATHER MYCHAL JUDGE – ULSD

						PM10 (mg/filter)
Idle 1	15.9	136	3.7	1443	0.078	0.125
Idle 2	15.9	127	3.7	1417	0.068	0.077
Idle 3	15.9	129	3.7	1440	0.122	0.102
Idle 4	15.8	130	3.8	1457	-	0.055
Push1	11.2	186	7.2	1752	3.032	3.263
Push2	11.2	187	7.3	1854	0.122	0.174
Push3	11.2	190	7.2	1909	0.247	0.764
Push4	11.2	186	7.2	1825	-	0.055
Cr1	6.4	1195	10.8	1113	1.215	1.178
Cr2	6.5	1151	10.7	1115	1.037	1.038
Cr3	6.5	1140	10.8	1115	1.088	1.100
Cr4	6.5	1121	10.8	1152	-	1.014
Trial2	8.6	798	9.1	1416	1.618	1.651
Trial3	8.3	844	9.4	1275	1.570	1.592
Trial4	8.8	711	9.0	1492	1.262	1.263
Trial5	9.4	660	8.6	1563	1.320	1.327
Trial6	9.7	572	8.4	1616	1.077	1.021
Trial7	7.6	991	10.0	1287	2.025	2.029
Trial8	7.7	995	9.9	1325	1.850	1.830
Trial9	7.7	856	9.9	1237	1.525	1.558

Table W.9. Calculated Average Emissions, MV FATHER MYCHAL JUDGE – LSD

Transit	2.69	0.36	120.9	26.34	25.28	11.6	231.2	31.1	10.4	2.27	2.18
Push	2.67	0.11	88.9	11.29	10.86	8.6	312.3	12.8	10.4	1.32	1.27
Cruise	3.06	0.35	195.7	31.70	27.28	18.8	162.5	18.7	10.4	1.69	1.45
Idle	0.41	0.04	11.3	3.58	3.81	1.1	379.0	40.7	10.4	3.31	3.51
Generator	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table W.10. Calculated Average Emissions, MV FATHER MYCHAL JUDGE – ULSD

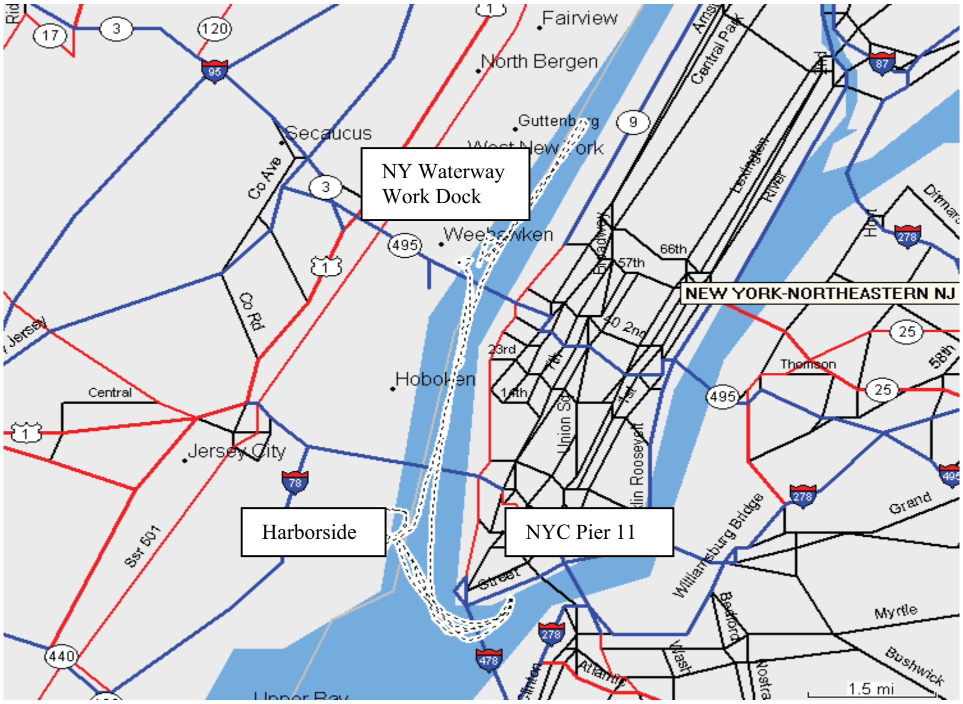
											PM 10
											g/gal
Transit	1.68	0.63	114.3	38.37	38.41	11.50	145.8	54.40	9.94	3.34	3.34
Push	1.44	0.10	59.0	33.61	31.55	5.9	243.8	16.5	10	5.70	5.35
Cruise	1.85	1.26	184.1	78.00	75.89	18.6	99.5	67.5	9.9	4.19	4.08
Idle	0.55	0.03	15	1.46	1.48	1.5	369.3	22.3	10	0.97	0.98
Generator	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA	NA

Table W.11. Engine Parameters, MV FATHER MYCHAL JUDGE – LSD

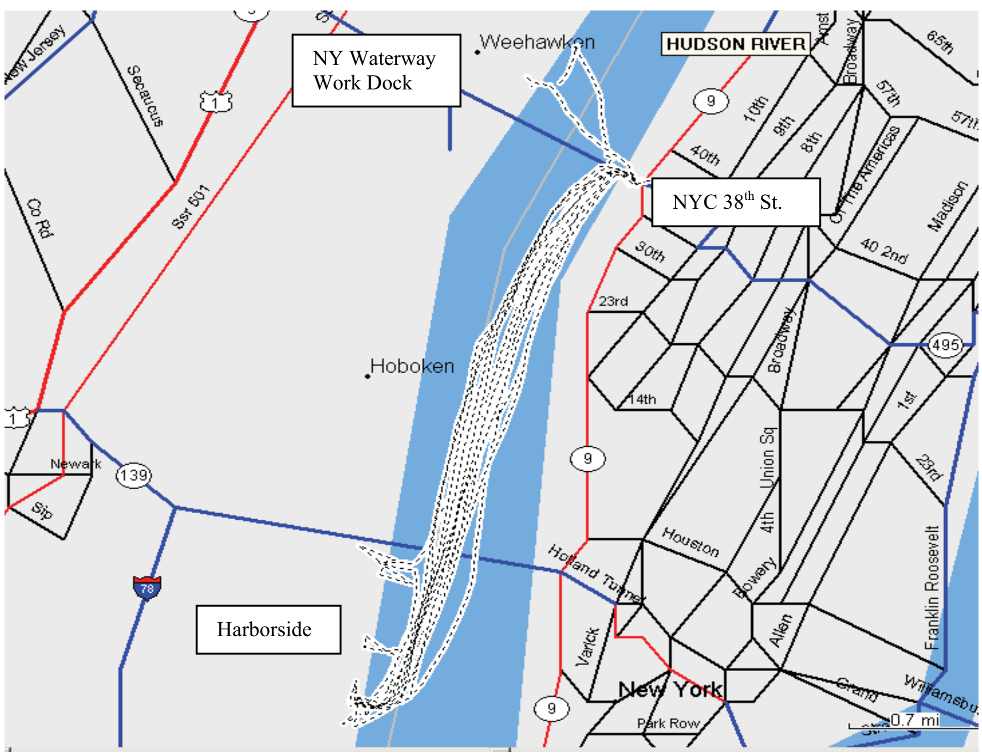
								EXHAUST TEMP, F
Transit	1404.0	11.6	140,741	11.6	61.7	7.1	57.9	NA
Push	1191.5	5.8	140,741	5.8	68.6	1.4	48.2	NA
Cruise	1813.0	18.8	140,741	18.8	70.1	11.2	63.7	NA
Idle	652.5	1.1	140,741	1.1	68.8	0.1	49.3	NA

ENGINE PARAMETERS: MV FATHER MYCHAL JUDGE – ULSD

								EXHAUST TEMP, F
Transit	1390.0	13.0	137,791	11.5	63.5	4.8	61.1	NA
Push	1189.6	7.9	137,791	5.9	72.5	0.9	56.0	NA
Cruise	1792.8	22.3	137,791	18.6	73.0	8.5	69.1	NA
Idle	728.1	1.9	137,791	1.5	73.0	0.0	56.3	NA



MV FATHER MYCHAL JUDGE Transit, Cruise and Push LSD Emission Route



MV FATHER MYCHAL JUDGE Transit, Cruise and Push ULSD Emission Route

RAW DATA MV ED ROGOWSKI – LSD

						PM10 (mg/filter)
Push1	7.4	1509	10.1	1568	0.335	0.304
Push2	7.5	1452	10.0	1633	0.218	0.203
Push3	7.3	1587	10.1	1689	0.235	0.215
Cr1500-1	10.6	334	7.7	1006	0.263	0.263
Cr1500-2	10.6	323	7.7	1015	0.247	0.216
Cr1800-1	12.8	99	6.1	889	0.301	0.345
Cr1800-2	11.0	111	7.4	1032	0.484	0.442
Cr2100-1	12.0	56	6.7	790	0.170	0.133
Cr2100-2	12.0	58	6.6	786	0.158	0.151
DG1	15.3	174	4.2	284	0.729	0.709
DG2	15.3	168	4.2	285	0.348	0.478
DG3	15.3	170	4.2	286	0.368	0.353

RAW DATA: MV ED ROGOWSKI – ULSD

						PM10 (mg/filter)
Idle1	15.3	80	4.2	1035	0.123	0.103
Idle2	15.2	78	4.2	1143	0.126	0.106
Idle3	15.1	78	4.3	1189	-	0.314
Push1	8.3	1612	9.4	1465	1.105	1.097
Push2	7.9	1677	9.7	1602	0.444	0.398
Push3	7.7	1731	9.8	1681	0.407	0.398
Push4	7.7	1816	9.8	1670	-	0.909
Cr1500-1	10.8	370	7.5	834	0.421	0.416
Cr1500-2	11.0	361	7.4	863	0.465	0.434
Cr1800-1	11.1	141	7.3	878	0.102	0.149
Cr1800-2	11.2	135	7.2	854	-	0.215
Cr1800-3	11.2	130	7.2	871	0.169	0.172
Cr2100-1	10.5	54	7.8	680	0.098	0.149
Cr2100-2	10.5	55	7.8	706	0.087	0.098
Cr2100-3	10.6	60	7.7	708	0.079	0.101
Gen 1	16.3	148	3.4	175	0.773	0.850
Gen 2	16.2	144	3.5	186	0.316	0.336
Gen 3	16.4	146	3.4	185	0.328	0.314
Gen4	16.4	148	3.4	190	-	0.626

CALCULATED EMISSIONS: MV ED ROGOWSKI – LSD

											PM 10 g/gal
Push	1.54	0.95	98.4	13.28	12.21	9.7	158.0	97.1	10.1	1.36	1.25
Cr1500	1.72	0.37	135.9	28.64	26.71	13.3	129.0	27.8	10.2	2.15	2.01
Cr1800	2.92	0.21	213.2	61.38	63.24	20.7	141.0	10.2	10.3	2.97	3.06
Cr2000	3.10	0.15	272.5	75.15	65.49	26.5	117.0	5.6	10.3	2.84	2.48
	g/hr	**g/hr**									
Generator	9.43	3.74	1.43	0.54	0.59	0.1	67.3	26.7	10.2	3.87	4.24

CALCULATED EMISSIONS: MV ED ROGOWSKI – ULSD

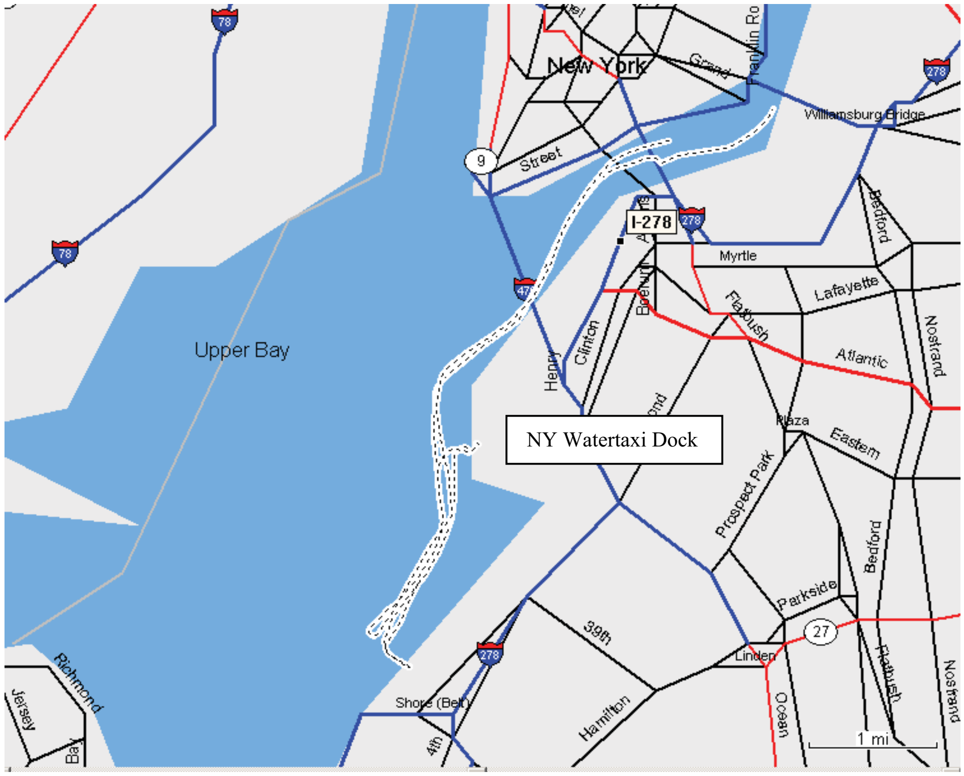
											PM 10 g/gal
Push	2.08	1.46	132.7	27.32	26.17	13.8	150.3	105.5	9.6	1.98	1.89
Cruise 1500	1.30	0.71	96.5	26.00	25.65	10.0	129.5	71.3	9.65	2.60	2.57
Cruise 1800	2.12	0.40	187.1	32.59	34.13	19.3	110.0	21.0	9.7	1.69	1.77
Cruise 2000	3.01	0.31	262.9	24.93	25.47	27.1	111.0	11.3	9.7	0.92	0.94
	g/hr	**g/hr**									
Generator	12.53	0.65	1.46	0.07	0.08	0.2	83.5	4.4	9.7	0.44	0.56

ENGINE PARAMETERS: MV ED ROGOWSKY – LSD

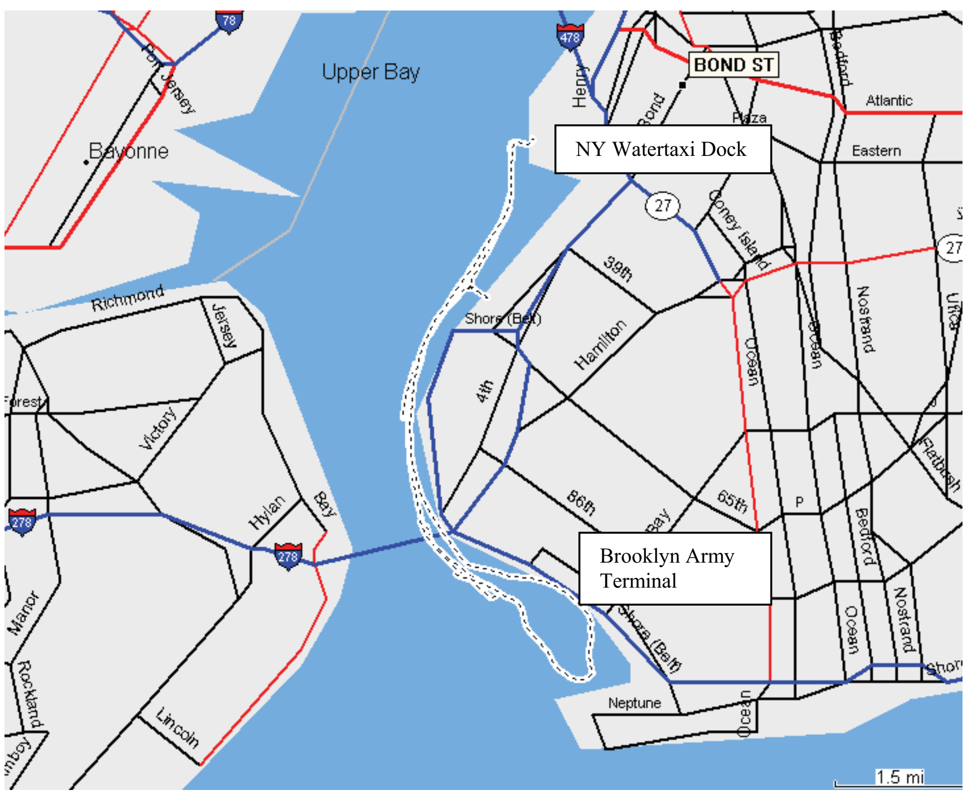
								EXHAUST TEMP, F
Push	1104.6	9.7	141,181	9.7	46.6	6.5	41.9	NA
Cruise 1500	1504.5	13.3	141,181	13.3	48.6	12.2	43.2	NA
Cruise 1800	1803.6	20.1	141,181	20.1	48.5	21.0	45.5	NA
Cruise 2000	1996.9	26.6	141,181	26.6	47.3	28.1	51.5	NA
	Load, kWe							
Generator	5.00	0.14	141,181	0.14	46.7			

ENGINE PARAMETERS: MV ED ROGOWSKY – ULSD

								EXHAUST TEMP, F
Push	1100.3	13.3	135,557	10.03	53.8	6.1	47.0	NA
Cruise 1500	1502.8	16.0	135,557	13.82	54.1	12.2	51.6	NA
Cruise 1800	1797.2	22.3	135,557	20.71	51.5	20.7	53.4	NA
Cruise 2000	1981.0	29.2	135,557	27.12	51.1	27.9	58.1	NA
	Load, kWe							
Generator	5.00	0.15	135,557		50.0			



MV ED ROGOWSKY Cruise and Push LSD Emission Route



MV ED ROGOWSKY Cruise and Push ULSD Emission Route

RAW DATA: MV SEA STREAK WALL STREET – LSD

						PM10
						(mg/filter)
Push1	13.7	108	5.4	697	0.768	0.717
Push2	13.7	105	5.4	691	0.421	0.346
Push3	13.8	104	5.3	697	0.377	0.377
Cr1	10.4	185	7.8	1097	0.575	0.566
Cr2	10.7	186	7.6	968	0.573	0.599
Cr3	10.3	186	7.9	1148	0.426	0.437
Cr4	10.5	162	7.8	1174	0.341	0.334
DG1	13.2	120	5.7	636	1.054	1.051
DG2	12.6	106	6.2	789	0.502	0.491
DG3	13.6	121	5.5	558	0.519	0.524

RAW DATA: MV SEA STREAK WALL STREET – ULSD

						PM10
						(mg/filter)
Idle1	15.8	95	3.8	419	0.288	0.280
Idle2	15.8	92	3.8	414	0.279	0.257
Idle3	15.3	97	4.2	463	0.381	0.374
Cr1	10.1	234	8.1	930	0.444	0.441
Cr2	10.1	225	8.1	955	0.433	0.444
Cr3	10.1	218	8.0	955	0.383	0.418
Cr4	10.1	220	8.1	955	0.407	0.416
Cr5	10.3	199	7.9	918	0.381	0.374
Cr6	10.3	205	7.9	957	0.423	0.390
Cr7	10.2	220	8.0	990	-	0.376
DG1	16.1	392	3.6	127	1.627	1.533
DG2	16.1	396	3.6	131	1.629	1.782
DG3	16.3	402	3.5	129	1.504	1.178
DG4	16.3	403	3.5	122	-	1.654

CALCULATED AVERAGE EMISSIONS: MV SEA STREAK WALL STREET – LSD

											PM 10 g/gal
Push (900)	1.17	0.12	93.5	29.5	27.0	8.9	131.3	13.2	10.5	3.31	3.03
Cruise	10.24	1.11	756.0	123.5	125.1	72.0	142.3	15.4	10.5	1.72	1.74
	g/hr	**g/hr**									
Generator	836.2	135.3	38.9	14.8	14.8	3.7	226.0	36.6	10.5	4.01	3.99

CALCULATED AVERAGE EMISSIONS: MV SEA STREAK WALL STREET – ULSD

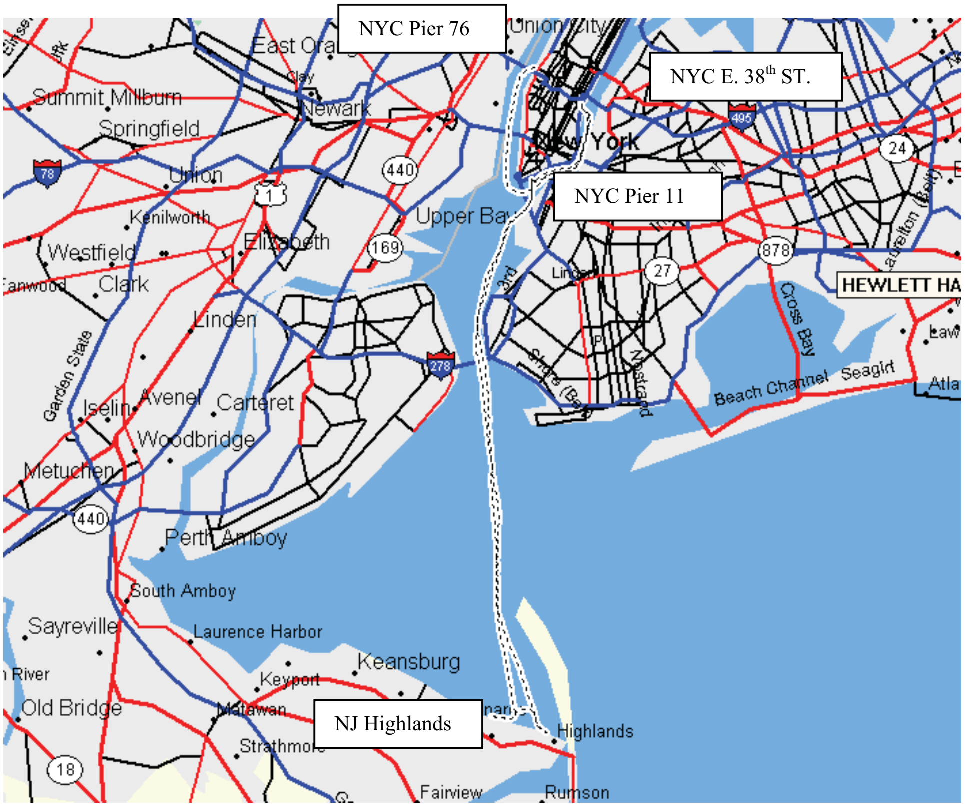
											PM 10 g/gal
Push (750)	0.57	0.08	54.5	16.2	15.5	5.5	104.3	15.1	9.9	2.94	2.82
Cruise	8.76	1.32	767.3	103.1	102.1	77.5	113.0	17.1	9.9	1.33	1.32
	g/hr	**g/hr**									
Generator	41.5	86.1	12.0	21.9	21.3	1.22	34.0	70.6	9.8	17.95	17.49

ENGINE PARAMETERS: MV SEA STREAK WALL STREET – LSD

								EXHAUST TEMP, F
Push (900)	901.9	8.9	140681	8.9	76.5	1.5	142.5	NA
Cruise	1836.0	72.0	140681	72.0	73.3	24.0	155.6	NA
	Load, kWe							
Generator	47.00	3.70	140681	3.70	78.52	5.96		

ENGINE PARAMETERS: MV SEA STREAK WALL STREET – ULSD

								EXHAUST TEMP, F
Push (750)	750.0	7.1	135836	5.5	90.2	0.6	142.9	NA
Cruise	1861.5	82.5	135836	77.5	70.8	25.2	161.5	NA
	Load, kWe							
Generator	16.00	2.33	135836	1.22	72.11	3.86		



MV SEA STREAK WALL STREET Cruise and Push LSD and ULSD Emission Rout

APPENDIX X

PHASE II DATA, CALCULATED EMISSION VALUES AND GRAPHS

MV GEORGE WASHINGTON

CALCULATED EMISSIONS DATA: M/V GEORGE WASHINGTON July 2005											
											PM10 [g/gal]
Idle 2	0.23	0.29	12.60	NA	3.72	1.25	183	235	10.1	-	2.98
Idle 3	0.24	0.26	12.64	3.11	4.09	1.25	196	212	10.1	2.49	3.27
Idle 4	0.25	0.26	12.65	3.60	3.14	1.25	197	207	10.1	2.89	2.51
Idle 5	0.25	0.26	12.66	3.84	3.65	1.25	197	204	10.1	3.07	2.92
Push-750-1	1.70	0.43	55.98	56.22	58.63	5.42	313	80	10.3	10.38	10.83
Push-750-2	1.69	0.43	55.99	57.04	59.99	5.42	312	79	10.3	10.53	11.08
Push-750-3	1.68	0.44	55.96	72.83	67.79	5.42	311	82	10.3	13.45	12.52
Push-750-4	1.70	0.44	55.97	NA	70.71	5.42	314	80	10.3	-	13.06
Push-900-1	1.96	0.56	85.38	NA	29.19	8.25	238	68	10.4	-	3.54
Push-900-2	1.96	0.56	85.38	29.92	29.20	8.25	238	68	10.4	3.63	3.54
Push-900-3	1.94	0.55	85.39	28.05	27.78	8.25	236	67	10.4	3.40	3.37
Push-900-4	1.92	0.57	85.36	28.08	31.45	8.25	233	69	10.4	3.40	3.81
Push-1000-1	2.19	0.62	109.68	70.97	74.22	10.58	207	59	10.4	6.71	7.02
Push-1000-2	2.19	0.65	109.62	63.57	56.63	10.58	207	61	10.4	6.01	5.35
Push-1000-3	2.22	0.64	109.62	63.12	61.36	10.58	209	61	10.4	5.97	5.80
Push-1000-4	2.30	0.67	109.57	NA	66.84	10.58	217	64	10.4	-	-
Push-1200-1	2.70	1.27	172.25	40.17	42.90	16.66	162	76	10.3	2.41	2.58
Push-1200-2	2.70	1.26	172.22	32.77	32.81	16.66	162	76	10.3	1.97	1.97
Push-1200-3	2.72	1.29	172.20	37.11	34.57	16.66	163	77	10.3	2.23	2.08
Push-1200-4	2.71	1.30	172.17	NA	36.82	16.66	163	78	10.3	-	-
SS-1000-1	1.48	0.27	51.79	20.67	21.61	5.00	297	54	10.4	4.14	4.32
SS-1000-2	1.43	0.27	51.78	21.22	22.08	5.00	286	54	10.4	4.25	4.42
SS-1000-3	1.41	0.27	51.78	21.18	21.84	5.00	281	54	10.4	4.24	4.37
SS-1000-4	1.43	0.27	51.77	NA	21.59	5.00	286	53	10.4	-	-
SS-63%rpm-1	2.13	0.26	109.26	19.09	19.17	10.50	203	25	10.4	1.82	1.83
SS-63%rpm-2	2.16	0.26	109.24	18.57	18.52	10.50	205	24	10.4	1.77	1.76
SS-63%rpm-3	2.10	0.26	109.22	17.37	18.07	10.50	200	25	10.4	1.65	1.72
SS-63%rpm-4	2.12	0.25	109.20	NA	16.27	10.50	202	24	10.4	-	-
SS-80%rpm-1	3.21	0.36	187.75	17.34	17.51	17.99	179	20	10.4	0.96	0.97
SS-80%rpm-2	3.23	0.36	187.73	17.46	18.14	17.99	179	20	10.4	0.97	1.01
SS-80%rpm-3	3.17	0.36	187.72	18.56	17.63	17.99	176	20	10.4	1.03	0.98
SS-80%rpm-4	3.19	0.37	187.70	NA	17.63	17.99	177	21	10.4	-	-
Transit-1	1.88	0.43	77.79	36.81	38.76	7.50	251	58	10.4	4.91	5.17
Transit-2	1.91	0.49	88.16	43.15	45.66	8.50	224	57	10.4	5.08	5.37
Transit-3	1.96	0.52	95.95	42.72	45.17	9.25	212	56	10.4	4.62	4.89
Transit-4	2.00	0.52	97.69	NA	40.50	9.41	213	55	10.4	-	-

CALCULATED EMISSIONS DATA: MV GEORGE WASHINGTON, Baseline, July 2005						
						PM10
						g/bhp-hr
	-	-	-	-	-	-
	-	-	-	-	-	-
	-	-	-	-	-	-
	-	-	-	-	-	-
						0.768
						0.785
						0.888
					-	0.926
					-	0.215
						0.217
						0.207
						0.233
						0.416
						0.319
						0.339
					-	0.376
						0.143
						0.109
						0.115
					-	0.122
						0.246
						0.262
						0.258
					-	0.229
						0.096
						0.094
						0.091
					-	0.084
						0.054
						0.056
						0.054
					-	0.055
						0.382
						0.245
						0.288
					-	0.250

CALCULATED AVERAGE EMISSIONS, SPECIFIC POWER BASIS: M/V GEORGE WASHINGTON

Mode	NOx, g/bhp-hr	CO, g/bhp-hr	CO_2, g/bhp-hr	PM2.5, g/bhp-hr	PM10, g/bhp-hr
Push 750	22.11	5.69	732.9	0.812	0.842
Push 900	14.40	4.17	633.1	0.213	0.218
Push 1000	13.73	3.70	625.3	0.376	0.369
Push 1200	13.09	4.25	572.1	0.122	0.122
Idle					
Cruise 1000	16.39	3.06	160.4	0.240	0.248
Cruise 25%	10.61	1.29	544.8	0.091	0.090
Cruise 50%	9.91	1.12	581.3	0.055	0.055
Transit Average	12.77	3.22	592.6	0.270	0.280

CALCULATED AVERAGE EMISSIONS, TIME BASIS: M/V GEORGE WASHINGTON

Mode	NOx, kg/hr	CO, kg/hr	CO_2, kg/hr	PM2.5, g/hr	PM10, g/hr
Push 750	1.69	0.43	56.0	62.0	64.3
Push 900	1.95	0.56	85.4	28.7	29.4
Push 1000	2.22	0.65	109.6	65.9	64.8
Push 1200	2.71	1.28	172.2	36.7	36.8
Idle	0.24	0.27	12.6	3.5	3.7
Cruise 1000	1.44	0.27	51.8	21.0	21.8
Cruise 25%	2.13	0.26	109.2	18.3	18.0
Cruise 50%	3.20	0.36	187.7	17.8	17.7
Transit Average	1.94	0.49	89.9	40.9	42.5

CALCULATED AVERAGE EMISSIONS, FUEL VOLUME BASIS: M/V GEORGE WASHINGTON

Mode	NOx, g/gal	CO, g/gal	CO_2, g/gal	PM2.5, g/gal	PM10, g/gal
Push 750	312.4	80.3	10.3	11.5	11.9
Push 900	236.0	68.2	10.4	3.5	3.6
Push 1000	210.3	61.2	10.4	6.2	6.1
Push 1200	162.5	76.7	10.3	2.2	2.2
Idle	193.1	214.7	10.1	2.8	2.9
Cruise 1000	287.4	53.6	10.4	4.2	4.4
Cruise 25%	202.6	24.6	10.4	1.7	1.8
Cruise 50%	177.8	20.1	10.4	1.0	1.0
Transit Average	225.0	56.5	10.4	4.9	5.1

ENGINE PARAMETERS: M/V GEORGE WASHINGTON

Mode	ME Exh. Temp, F	RPM	Int. Mani. Temp, F	Inlet Air Temp, F	Int. Mani. Press., PSIG	Fuel flow, lb/min	Fuel flow, gph	Torq., ft-lb	BHP	BSFC
Push 750	474.3	738	159.1	100.9	-0.28	0.65	5.42	1050.8	76.4	0.508
Push 900	591.8	900	162.8	104.7	0.60	0.99	8.25	1521.3	134.8	0.439
Push 1000	658.6	989	167.2	103.5	1.34	1.27	10.58	1831.9	175.3	0.435
Push 1200	806.7	1196.7	182.6	98.1	4.31	2.00	16.66	2553.9	301.0	0.399
Idle	-	555	-	-	-	0.15	1.25	-	-	-
Cruise 1000	461.2	973	156.7	99.9	0.28	0.60	5.00	914.9	87.7	0.409
Cruise 25%	615.7	1281	167.7	101.6	1.98	1.26	10.50	1588.7	200.5	0.377
Cruise 50%	729.6	1517	187.5	102.4	5.43	2.16	17.99	2161.4	322.9	0.400
Transit Average	567.9	980.3	165.4	107.5	0.76	1.04	8.80	1560.2	151.7	0.426

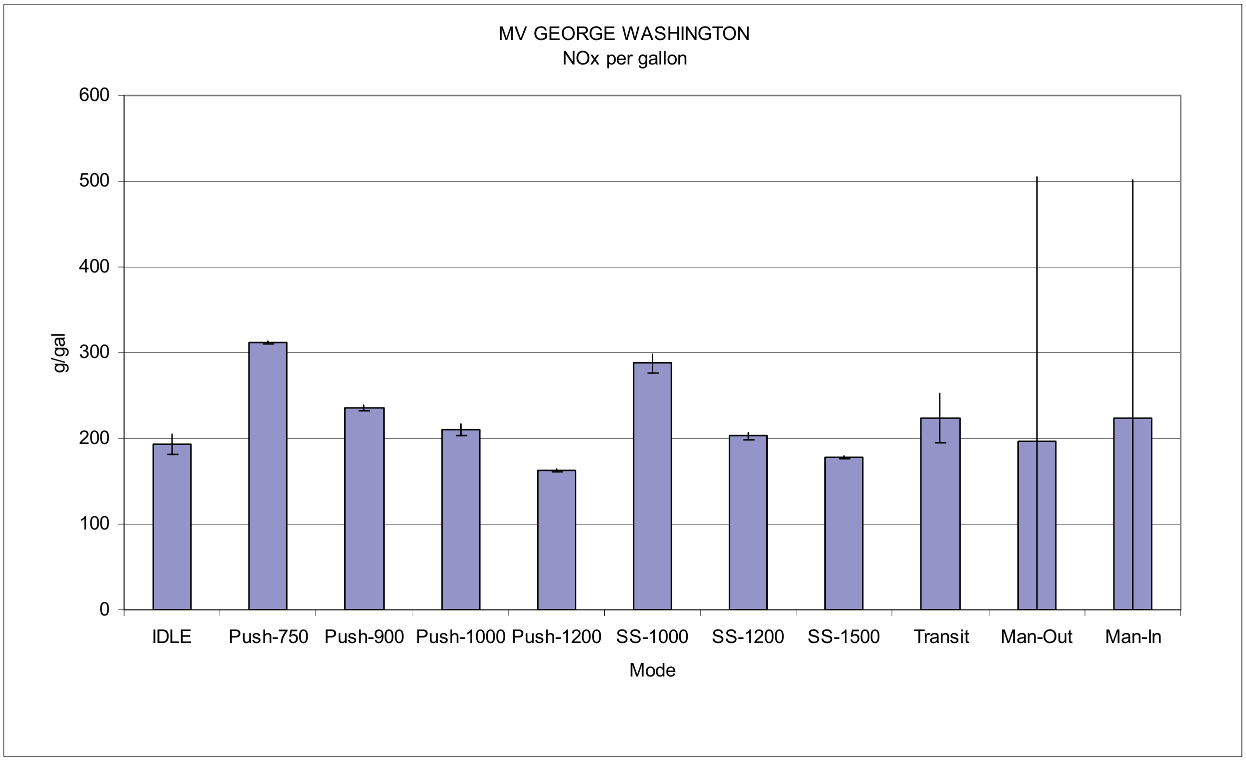
MV GEORGE WASHINGTON Baseline July 2005 Transit Test

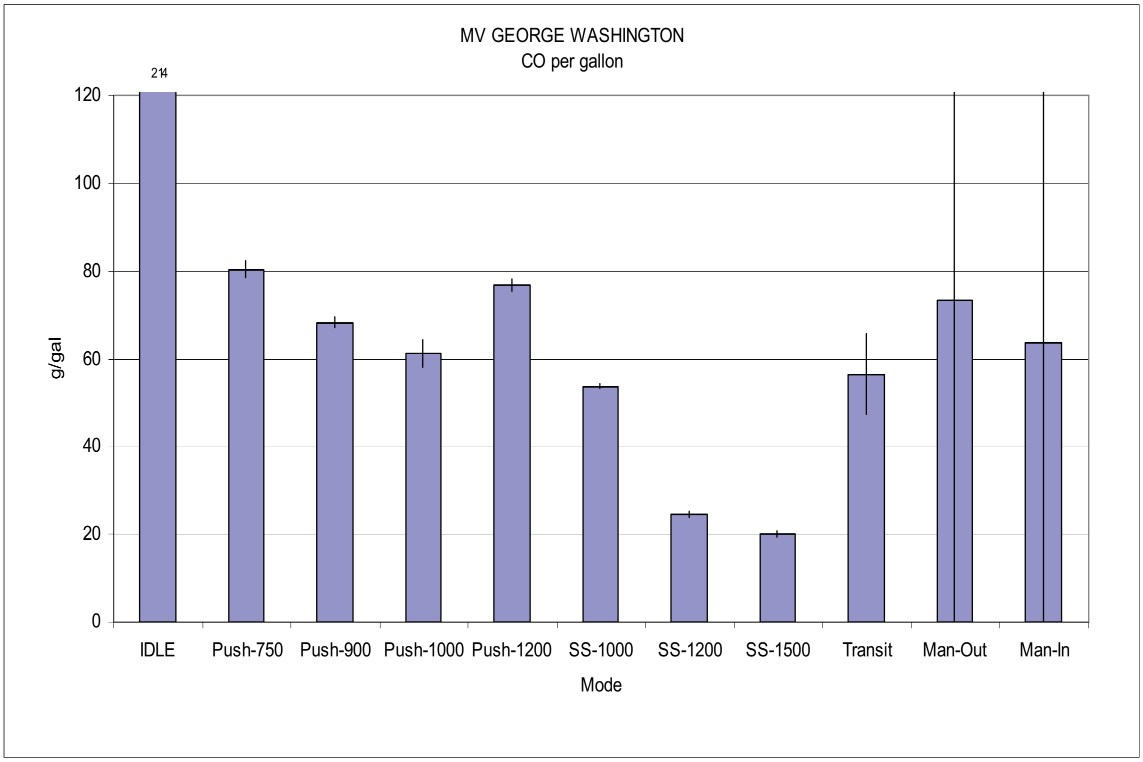
Mode	Transit 1				Transit 2				Transit 3				Transit 4			
	Start , sec	Stop, sec	Duration, sec	% of Time	Start , sec	Stop, sec	Duration, sec	% of Time	Start , sec	Stop, sec	Duration, sec	% of Time	Start , sec	Stop, sec	Duration, sec	% of Time
Push	0	180	180	21.5	0	162	162	22.8	0	180	180	25.0	0	180	180	26.3
Maneuver, Out	181	227	46	5.5	163	263	100	14.1	181	243	62	8.6	181	245	64	9.4
Cruise	228	562	334	39.8	264	390	126	17.8	244	441	197	27.3	246	447	201	29.4
Maneuver, In	563	660	97	11.6	391	533	142	20.0	442	545	103	14.3	448	508	60	8.8
Push	661	843	182	21.7	534	713	179	25.2	546	725	179	24.8	509	688	179	26.2

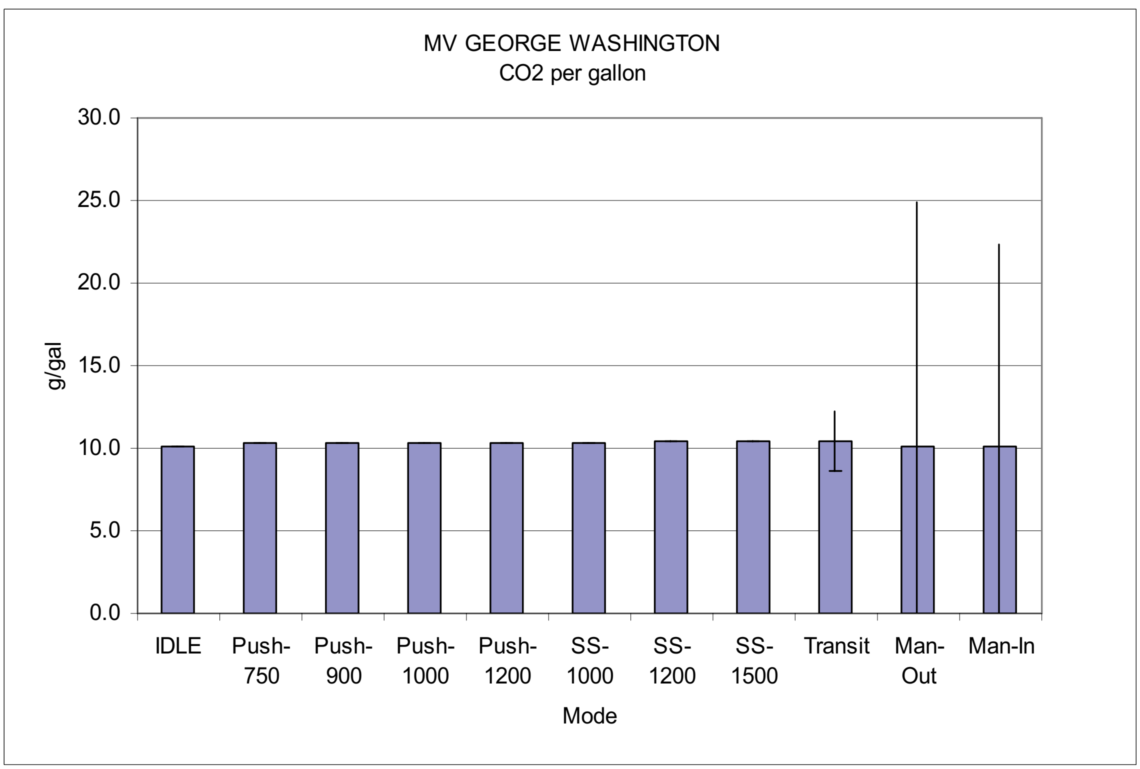
Mode	Transit 1				Transit 2				Transit 3				Transit 4			
	RPM	Torque	rpm	Fuel Consumed, lb	RPM	Torque	rpm	Fuel Consumed, lb	RPM	Torque	rpm	Fuel Consumed, lb	RPM	Torque	rpm	Fuel Consumed, lb
Push	963	1728	164	3.57	964	1747	166	3.22	861	1314	111	2.74	961	1861	176	3.55
Maneuver, Out	873	1244	107	1.87	1194	1465	172	2.09	963	1103	105	2.32	1027	1684	170	1.43
Cruise	960	870	82	3.16	1077	1139	121	1.66	1219	857	103	3.70	1248	1488	183	4.04
Maneuver, In	629	523	32	0.31	815	1189	95	1.64	1045	894	92	1.85	627	369	23	0.17
Push	964	1793	170	3.62	944	1659	154	3.38	853	1248	105	2.67	974	1863	179	3.65

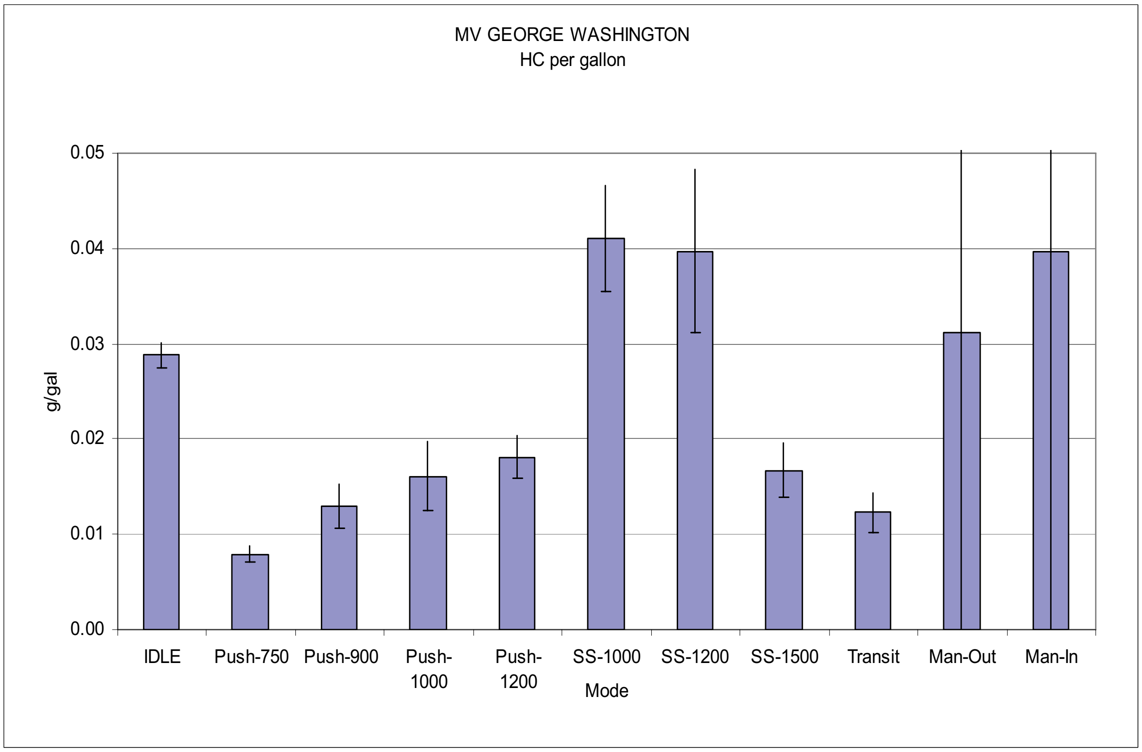
MV GEORGE WASHINGTON Transit Test Averages (July 2006).

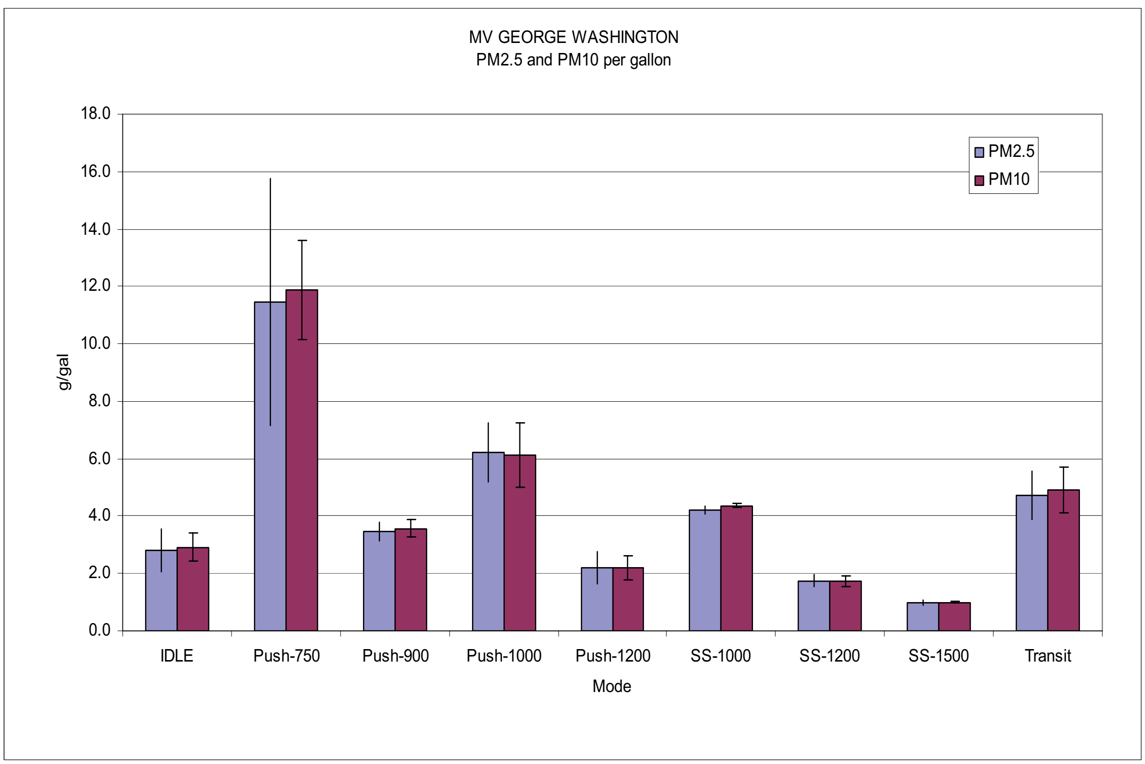
Mode	Time, sec	% of Time	RPM	Torque	BHP	Fuel Cons., lb	NOx, kg/hr	PM 2.5, g/hr	HC, g/hr
Push	1421	48.10%	936	1652	153	6.6	2.10	49.07	120
Maneuver	674	22.80%	897	1059	100	2.92	2.06	8.68	340
Cruise	858	29.10%	1126	1089	122	3.14	1.81	19.85	260
Total	2953	100.00%				12.66			

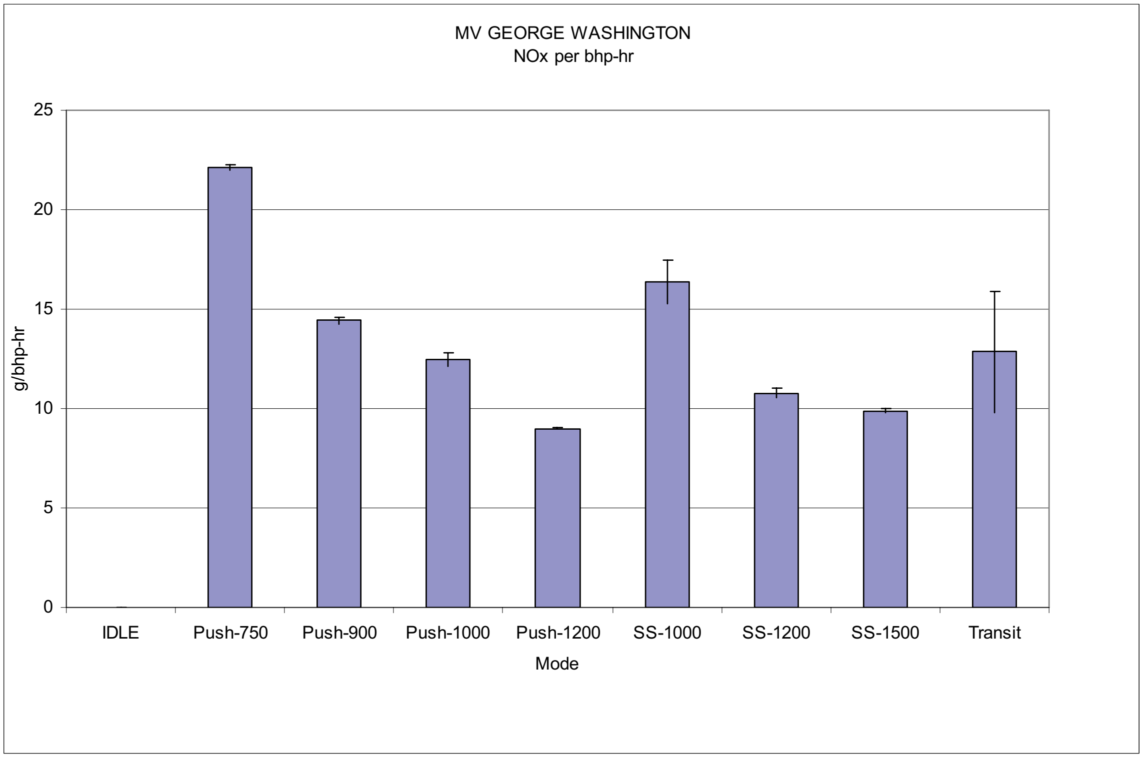


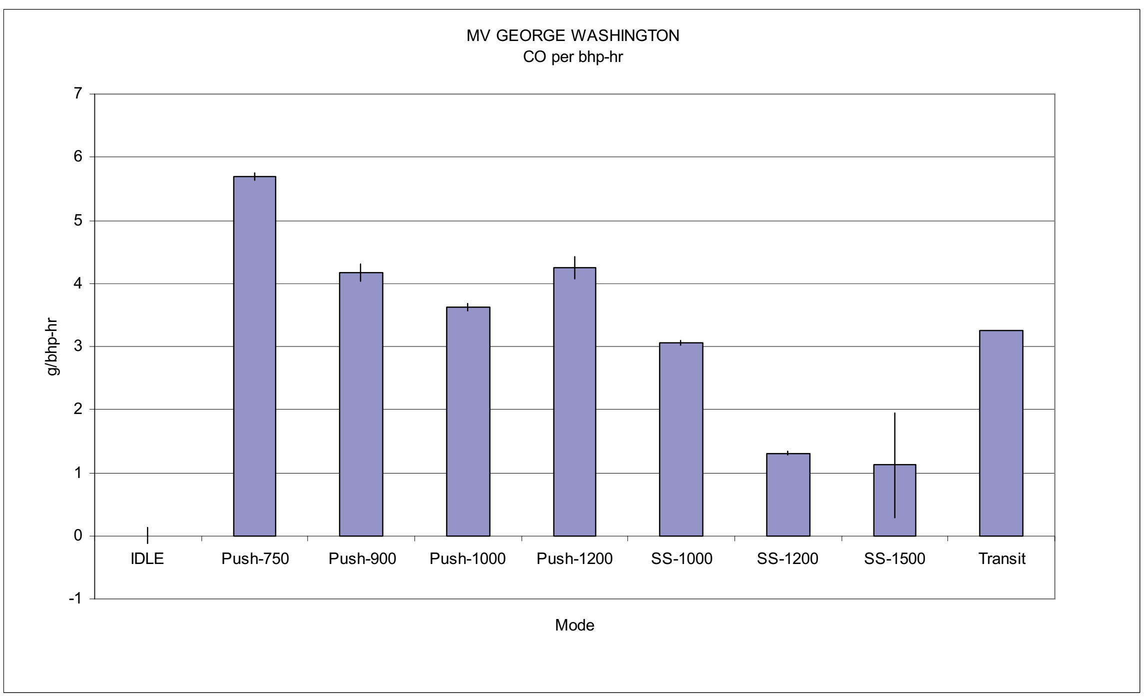

MV GEORGE WASHINGTON
CO per gallon
214
120
100
80
60
40
20
0
g/gal
IDLE
Push-750
Push-900
Push-1000
Push-1200
SS-1000
SS-1200
SS-1500
Transit
Man-Out
Man-In
Mode

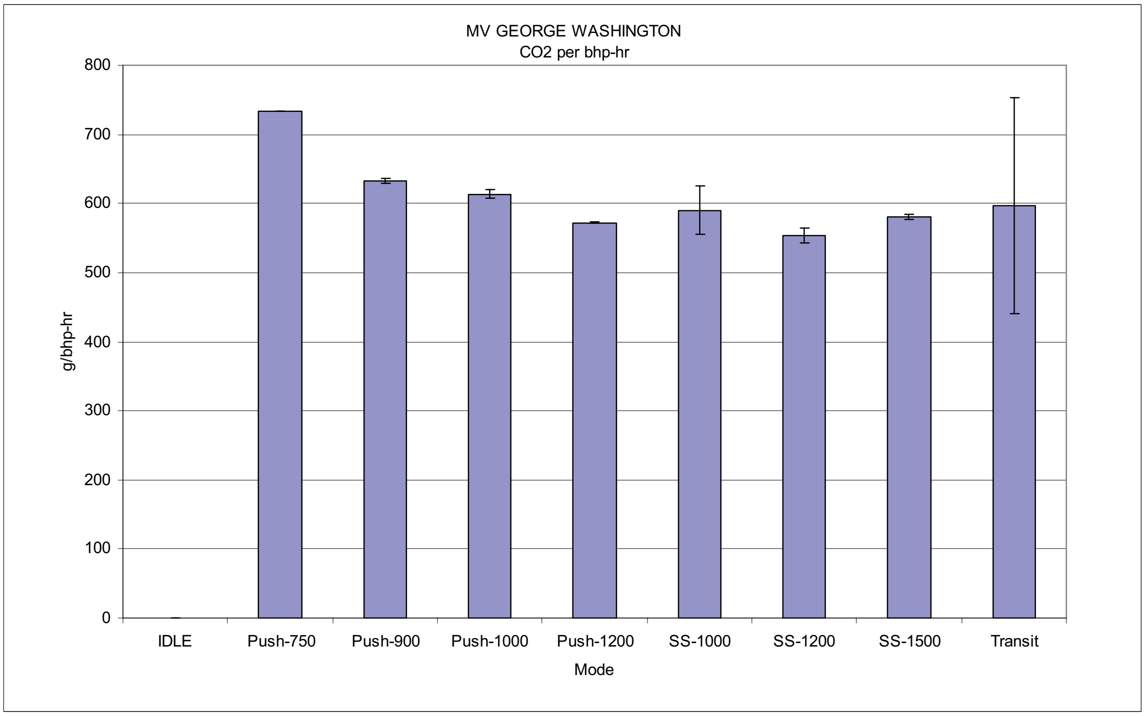

MV GEORGE WASHINGTON
CO2 per gallon
30.0
25.0
20.0
15.0
10.0
5.0
0.0
g/gal
IDLE
Push-750
Push-900
Push-1000
Push-1200
SS-1000
SS-1200
SS-1500
Transit
Man-Out
Man-In
Mode

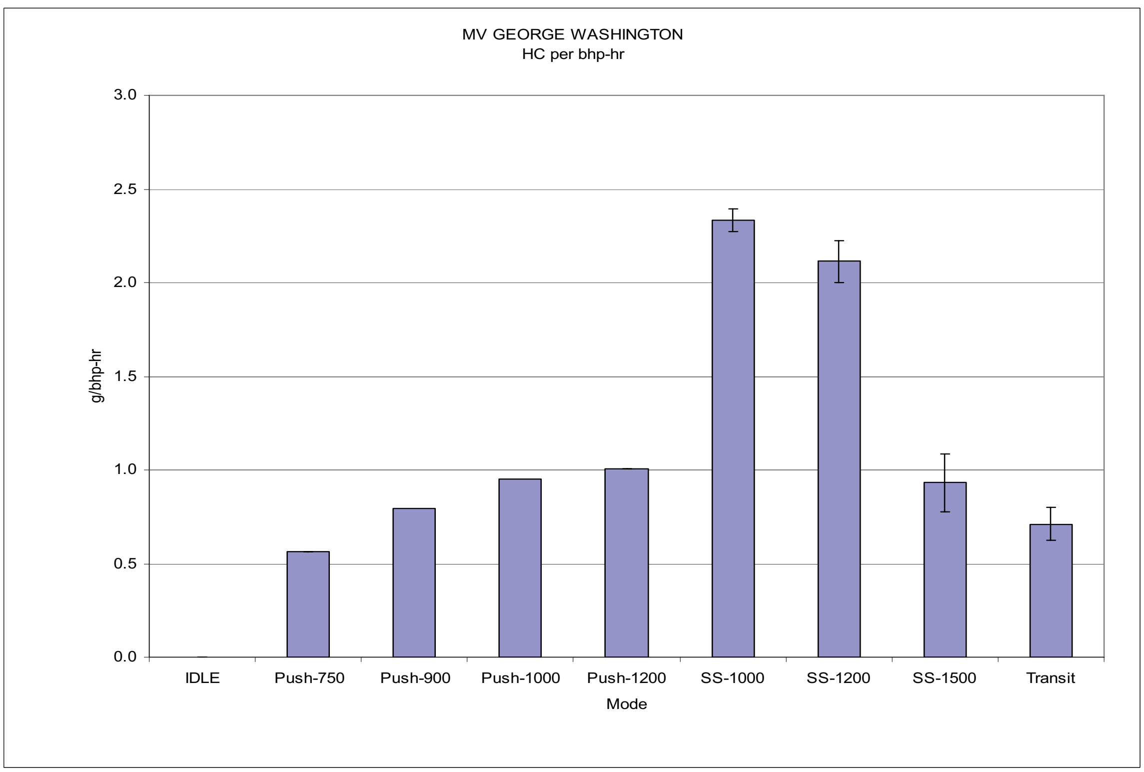

MV GEORGE WASHINGTON
HC per gallon
0.05
0.04
0.03
0.02
0.01
0.00
g/gal
IDLE
Push-750
Push-900
Push-1000
Push-1200
SS-1000
SS-1200
SS-1500
Transit
Man-Out
Man-In
Mode

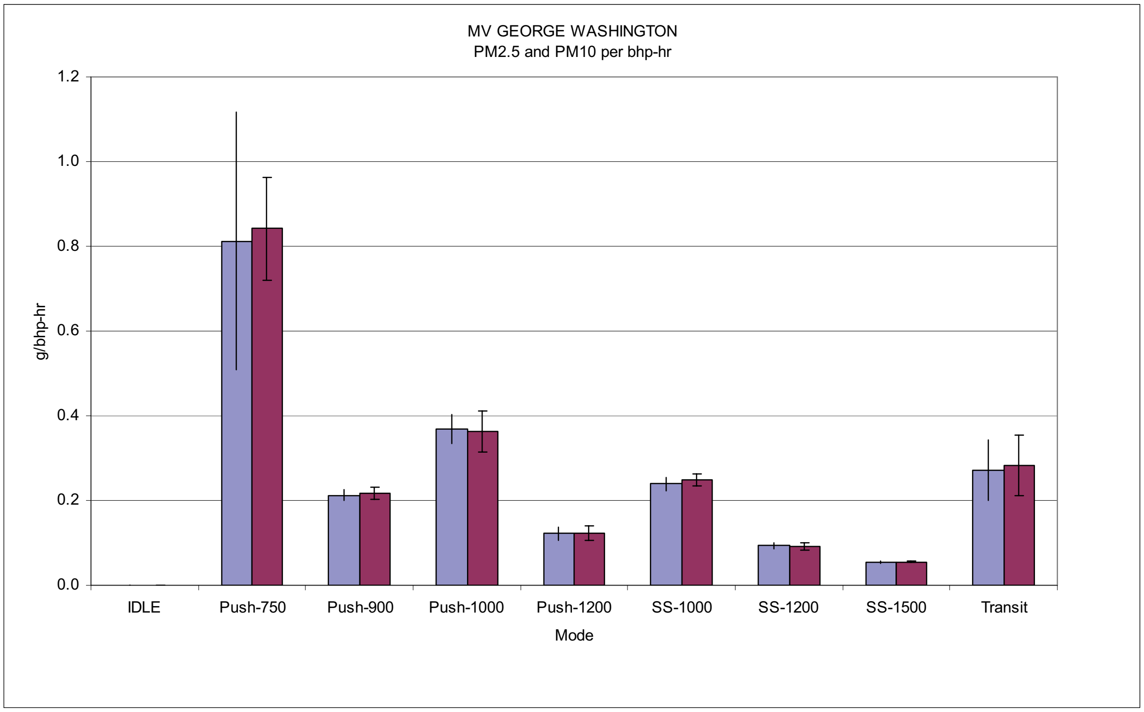

MV GEORGE WASHINGTON
PM2.5 and PM10 per gallon
18.0
16.0
14.0
12.0
10.0
8.0
6.0
4.0
2.0
0.0
g/gal
PM2.5
PM10
IDLE
Push-750
Push-900
Push-1000
Push-1200
SS-1000
SS-1200
SS-1500
Transit
Mode


MV GEORGE WASHINGTON
NOx per bhp-hr
g/bhp-hr
25
20
15
10
5
0
IDLE
Push-750
Push-900
Push-1000
Push-1200
SS-1000
SS-1200
SS-1500
Transit
Mode


MV GEORGE WASHINGTON
CO per bhp-hr
g/bhp-hr
7
6
5
4
3
2
1
0
-1
IDLE
Push-750
Push-900
Push-1000
Push-1200
SS-1000
SS-1200
SS-1500
Transit
Mode


MV GEORGE WASHINGTON
CO2 per bhp-hr
g/bhp-hr
800
700
600
500
400
300
200
100
0
IDLE
Push-750
Push-900
Push-1000
Push-1200
SS-1000
SS-1200
SS-1500
Transit
Mode


MV GEORGE WASHINGTON
HC per bhp-hr
g/bhp-hr
3.0
2.5
2.0
1.5
1.0
0.5
0.0
IDLE
Push-750
Push-900
Push-1000
Push-1200
SS-1000
SS-1200
SS-1500
Transit
Mode



MV GEORGE WASHINGTON
PM2.5 and PM10 per bhp-hr
1.2
1.0
0.8
0.6
0.4
0.2
0.0
g/bhp-hr
IDLE
Push-750
Push-900
Push-1000
Push-1200
SS-1000
SS-1200
SS-1500
Transit
Mode

MV FATHER MYCHAL JUDGE

CALCULATED EMISSIONS DATA: M/V FATHER MYCHAL JUDGE, July 2005													
													PM10
													[g/gal]
													3.60
													2.97
													3.32
					-	-						-	-
													1.42
													1.22
													1.00
					-	-						-	-
													3.26
													2.83
													2.71
					-	-						-	-
													1.48
													1.30
													1.29
					-	-						-	-
													1.31
													1.59
													1.57
					-	-						-	-
													1.67
													1.44
													1.20
					-	-						-	-
													1.80
													1.83
													1.51
					-	-						-	-
													2.83
													1.98
													1.75
					-	-						-	-
													2.83
													2.65
													2.68
					-	-						-	-
													0.92
													0.90

CALCULATED EMISSIONS DATA: M/V FATHER MYCHAL JUDGE, July 2005													
													PM10
													[g/gal]
													0.87
					-	-						-	-

CALCULATED EMISSIONS DATA: M/V FATHER MYCHAL JUDGE, Baseline, March 2005													
													PM10
													[g/gal]
													0.83
													1.06
						-							-
													0.84
													1.00
						-							-
													1.21
													1.29
						-							-
													1.81
													1.74
						-							-
													1.15
													1.00
						-							-
													1.11
													0.84
						-							-
													1.97
													2.71
						-							-
													1.91
													2.43
						-							-
													2.28
													2.13
						-							-
													2.01
													1.70
						-							-

CALCULATED EMISSIONS DATA: MV FATHER MYCHAL JUDGE, Baseline, March 2006						
						PM10
						g/bhp-hr
						0.044
						0.056
						-
						0.045
						0.054
						-
						0.063
						0.068
						-
						0.094
						0.092
						-
						0.062
						0.054
						-
						0.078
						0.059
						-
						0.135
						0.187
						-
						0.130
						0.167
						-
						0.148
						0.139
						-
						0.117
						0.098
						-

													PM10
													[g/gal]
													0.23
													0.30
						-							-
													0.28
													0.25
						-							-
													1.11
													0.87
						-							-
													1.76
													1.77
						-							-
													0.75
													0.78
						-							-
													0.32
													0.35
						-							-
													0.31
													0.39
						-							-
													1.53
													1.50
						-							-
													0.21
													0.14
						-							-
													0.23
													0.22
						-							-

CALCULATED EMISSIONS DATA: MV FATHER MYCHAL JUDGE, Post DOC, March 2006						
						PM10
						g/bhp-hr
						0.012
						0.015
						-
						0.016
						0.014
						-
						0.060
						0.046
						-
						0.090
						0.093
						-
						0.042
						0.045
						-
						0.023
						0.028
						-
						0.018
						0.022
						-
						0.083
						0.081
	-	-	-	-	-	-
						0.013
						0.008
						-
						0.013
						0.013
						-

MV FATHER MYCHAL JUDGE Baseline/Post DOC Average Emissions

	Baseline Emissions g/gal						Post DOC Emissions g/gal					
	NOx	CO	CO2	HC	PM2.5	PM10	NOx	CO	CO2	HC	PM2.5	PM10
Mode	[g/gal]	[g/gal]	[g/gal]	[g/gal]	[g/gal]	[g/gal]	[g/gal]	[g/gal]	[g/gal]	[g/gal]	[g/gal]	[g/gal]
Idle	312.6	20.2	10.0	74.33	0.96	0.94	290.6	9.65	10.15	35.18	0.17	0.26
SS-1000	301.4	12.9	10.1	45.81	0.88	0.92	289.0	1.34	10.18	29.13	0.27	0.27
SS-1323	163.6	19.9	10.1	33.47	1.28	1.25	163.4	1.17	10.19	26.63	1.02	0.99
SS-1680	123.8	22.9	10.1	29.07	1.80	1.78	125.1	1.02	10.19	25.57	1.73	1.76
SS-1910	109.1	9.97	10.2	32.76	1.10	1.08	109.6	0.76	10.21	20.90	0.79	0.76
Push-750	310.7	19.5	10.1	75.94	2.46	2.34	292.1	15.7	10.15	32.50	0.30	0.35
Push-900	324.6	19.2	10.1	79.18	2.24	2.17	320.6	5.71	10.16	33.76	1.40	1.52
Push-1000	312.7	16.7	10.1	77.10	2.21	2.21	274.8	3.19	10.19	28.02	0.21	0.18
Push-1200	230.1	16.6	10.2	60.58	1.86	1.86	224.3	1.43	10.20	21.92	0.28	0.23
Transit	188.5	18.3	10.1	46.67	1.02	0.97	199.1	2.95	10.18	26.91	0.31	0.33

MV FATHER MYCHAL JUDGE July 2005 Transit Test

Mode	Transit 1				Transit 2				Transit 3				Transit 4			
	Start , sec	Stop, sec	Duration, sec	% of Time	Start , sec	Stop, sec	Duration, sec	% of Time	Start , sec	Stop, sec	Duration, sec	% of Time	Start , sec	Stop, sec	Duration, sec	% of Time
Push	0	179	179	26.3 %	0	180	180	26.2 %	0	180	180	25.9 %	0	180	180	26.2 %
Maneuver, Out	179	212	33	4.8%	180	210	30	4.4%	180	221	41	5.9%	180	208	28	4.1%
Cruise	212	435	223	32.7 %	210	429	219	31.9 %	221	443	222	31.9 %	208	427	219	31.9 %
Maneuver, In	435	505	70	10.3 %	429	519	90	13.1 %	443	511	68	9.8%	427	505	78	11.4 %
Push	505	681	176	25.8 %	519	686	167	24.3 %	511	696	185	26.6 %	505	686	181	26.4 %

Mode	Transit 1				Transit 2				Transit 3				Transit 4			
	RPM	Torque	bhp	Fuel Consumed, lb	RPM	Torque	bhp	Fuel Consumed, lb	RPM	Torque	bhp	Fuel Consumed, lb	RPM	Torque	bhp	Fuel Consumed, lb
Push	999	281	54	1.21	1013	291	56	1.26	997	283	54	1.22	1015	290	56	1.27
Maneuver, Out	1380	558	147	0.08	1289	580	142	0.38	1140	429	93	0.72	1265	564	136	0.53
Cruise	1976	1120	421	11.1	1957	1124	419	10.6	1957	1124	419	10.8	1958	1121	418	10.6
Maneuver, In	899	211	36	0.01	922	247	43	0.09	881	217	36	0.23	973	266	49	0.16
Push	1009	290	56	1.22	991	279	53	1.11	1015	291	56	1.30	992	300	57	1.21

MV FATHER MYCHAL JUDGE Baseline Transit Test Averages (March 2006).

Mode	Time, sec	% of Time	RPM	Torque	BHP	Fuel Cons., lb	NOx, kg/hr	PM 2.5, g/hr	HC, g/hr
Push	1012	44.10%	916	340	59	1.9	0.95	0.26	231
Maneuver	471	20.50%	1127	475	105	1.9	0.91	2.25	230
Cruise	810	35.30%	1959	1146	427	12.5	2.59	24.33	823
Total	2293	100.00%				16.3			

MV FATHER MYCHAL JUDGE Baseline March 2006 Transit Test

Mode	Transit 1				Transit 2				Transit 3			
	Start , sec	Stop, sec	Duration, sec	% of Time	Start , sec	Stop, sec	Duration, sec	% of Time	Start , sec	Stop, sec	Duration, sec	% of Time
Push	0	180	180	24.5	0	180	180	23.7	0	180	180	22.6
Maneuver, Out	181	268	87	11.8	181	228	47	6.2	181	223	42	5.3
Cruise	269	514	245	33.3	229	486	257	33.8	224	532	308	38.7
Maneuver, In	515	626	111	15.1	487	584	97	12.7	533	620	87	10.9
Push	627	740	113	15.4	585	765	180	23.7	621	800	179	22.5

Mode	Transit 1				Transit 2				Transit 3			
	RPM	Torque	bhp	Fuel Consumed, lb	RPM	Torque	bhp	Fuel Consumed, lb	RPM	Torque	bhp	Fuel Consumed, lb
Push	912.2	245.3	42.6	1.0	913.2	298.0	51.8	1.0	908.6	299.8	51.9	1.0
Maneuver, Out	1236.0	511.7	120.4	1.61	1346.7	612.2	157.0	1.27	1215.7	681.0	157.6	1.61
Cruise	1959.0	1156.7	431.5	11.3	1958.3	1149.4	428.6	11.9	1959.7	1132.1	422.4	14.3
Maneuver, In	1008.9	356.4	68.5	0.42	974.2	347.1	64.4	0.36	982.2	341.0	63.8	0.38
Push	941.1	285.7	51.2	0.7	926.3	621.3	109.6	1.1	892.4	290.3	49.3	1.0

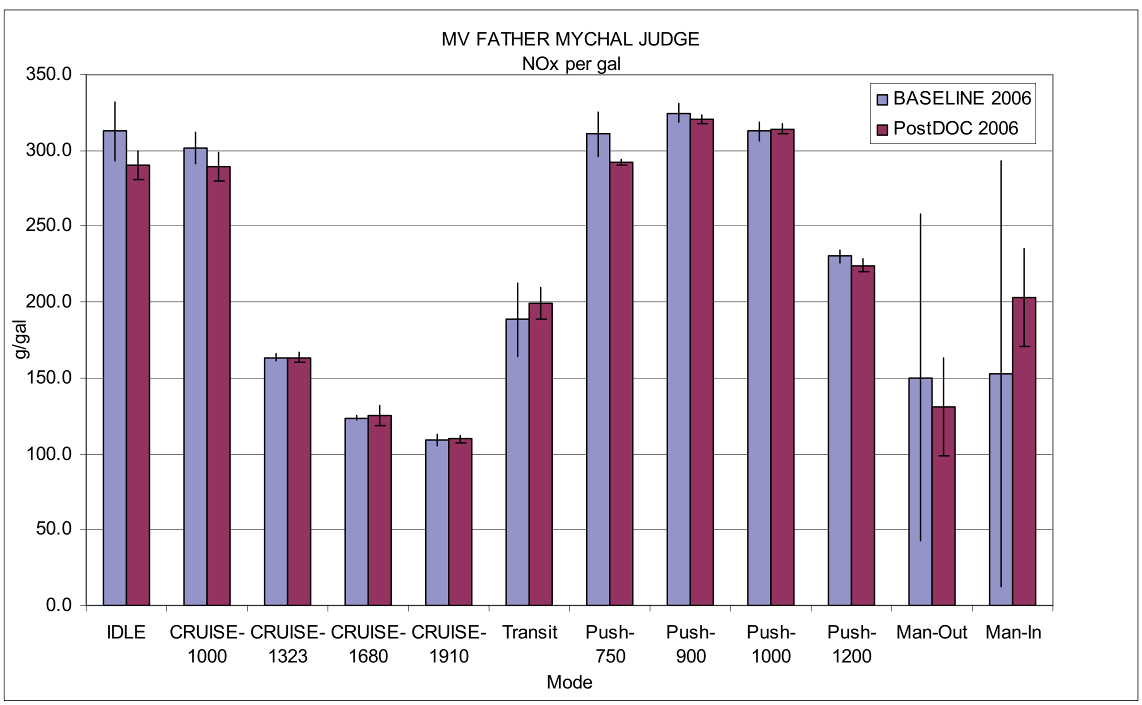
MV FATHER MYCHAL JUDGE Post DOC Transit Test Averages (March 2006).

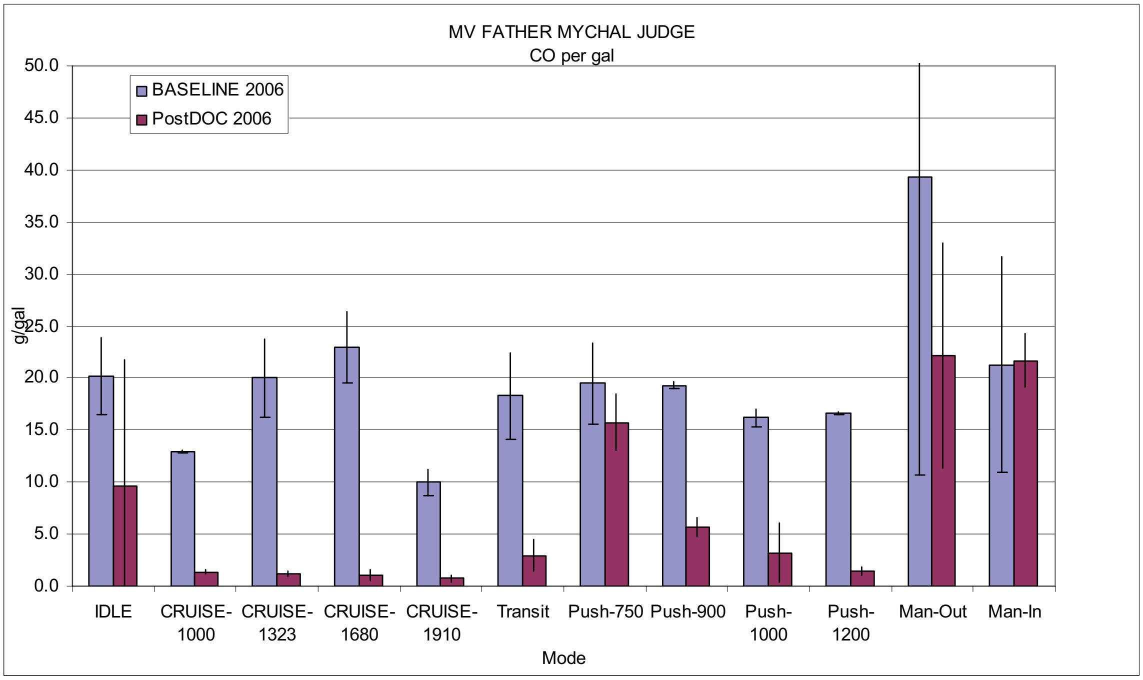
Mode	Time, sec	% of Time	RPM	Torque	BHP	Fuel Cons., lb	NOx, kg/hr	PM 2.5, g/hr	HC, g/hr
Push	1078	46.70%	904	347	60	2	0.90	0.19	124
Maneuver	395	17.10%	1139	499	114	1.92	0.98	1.26	120
Cruise	835	36.20%	1959	1142	426	12.87	2.59	16.67	483
Total	2308	100.00%				16.79			

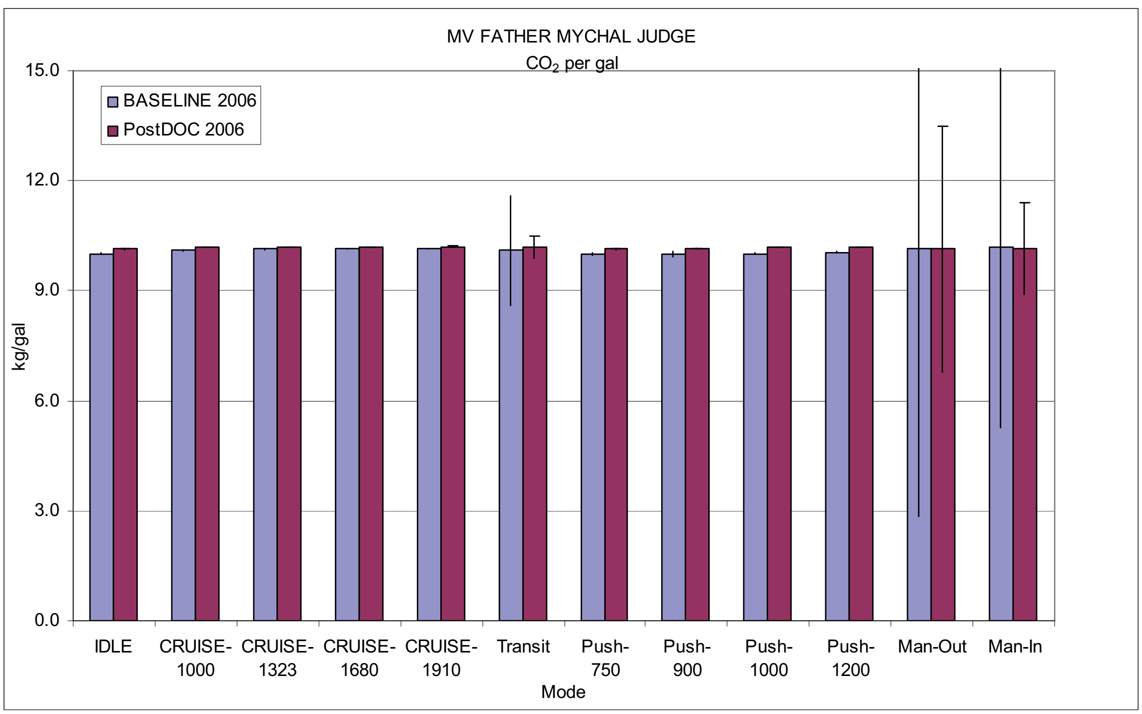
MV FATHER MYCHAL JUDGE Post DOC March 2006 Transit Test

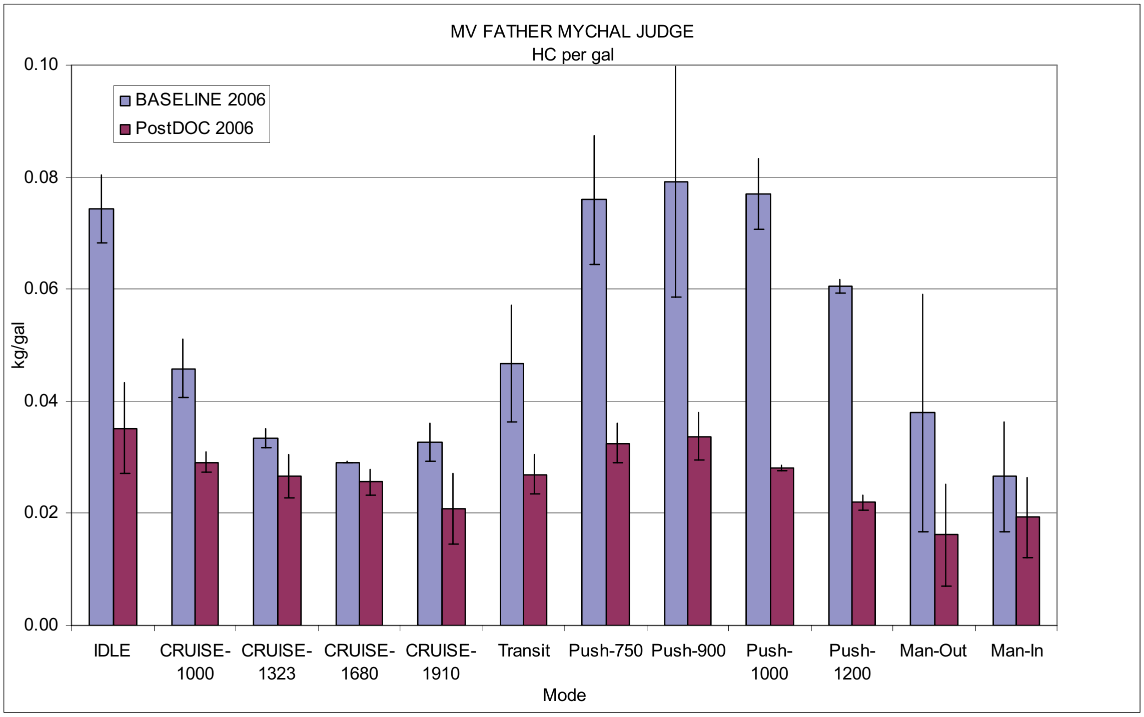
Mode	Transit 1				Transit 2				Transit 3			
	Start , sec	Stop, sec	Duration, sec	% of Time	Start , sec	Stop, sec	Duration, sec	% of Time	Start , sec	Stop, sec	Duration, sec	% of Time
Push	0	180	180	23.8	0	180	180	23.2	0	180	180	23.2
Maneuver, Out	181	217	36	4.8	181	215	34	4.4	181	220	39	5.0
Cruise	218	492	274	36.2	216	490	274	35.3	221	508	287	37.0
Maneuver, In	493	580	87	11.5	491	600	109	14.0	509	599	90	11.6
Push	581	760	179	23.7	601	780	179	23.1	600	780	180	23.2

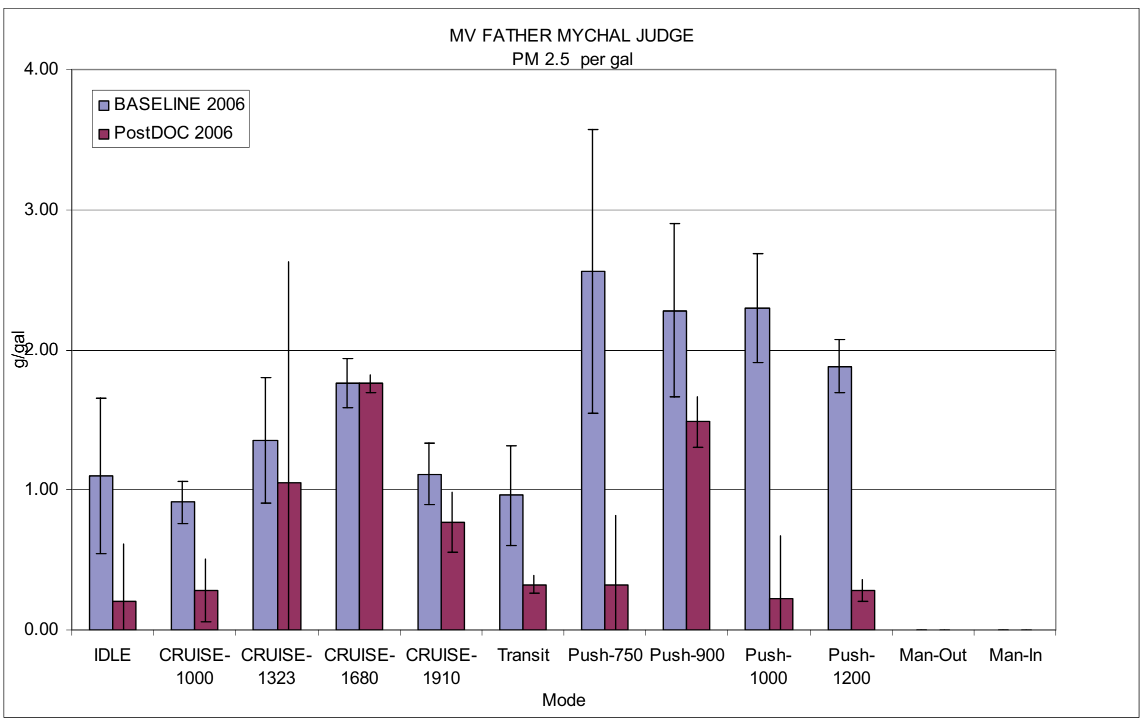
Mode	Transit 1				Transit 2				Transit 3			
	RPM	Torque	bhp	Fuel Consumed, lb	RPM	Torque	bhp	Fuel Consumed, lb	RPM	Torque	bhp	Fuel Consumed, lb
Push	890.8	280.5	47.6	1.0	913.2	298.0	51.8	1.0	908.6	299.8	51.9	1.0
Maneuver, Out	1393.2	692.1	183.6	1.39	1346.7	612.2	157.0	1.78	1215.7	681.0	157.6	1.47
Cruise	1957.8	1144.7	426.7	12.7	1958.3	1149.4	428.6	12.7	1959.7	1132.1	422.4	13.3
Maneuver, In	924.7	317.5	55.9	0.28	974.2	347.1	64.4	0.48	982.2	341.0	63.8	0.37
Push	895.3	290.1	49.4	1.0	926.3	621.3	109.6	1.1	892.4	290.3	49.3	1.0

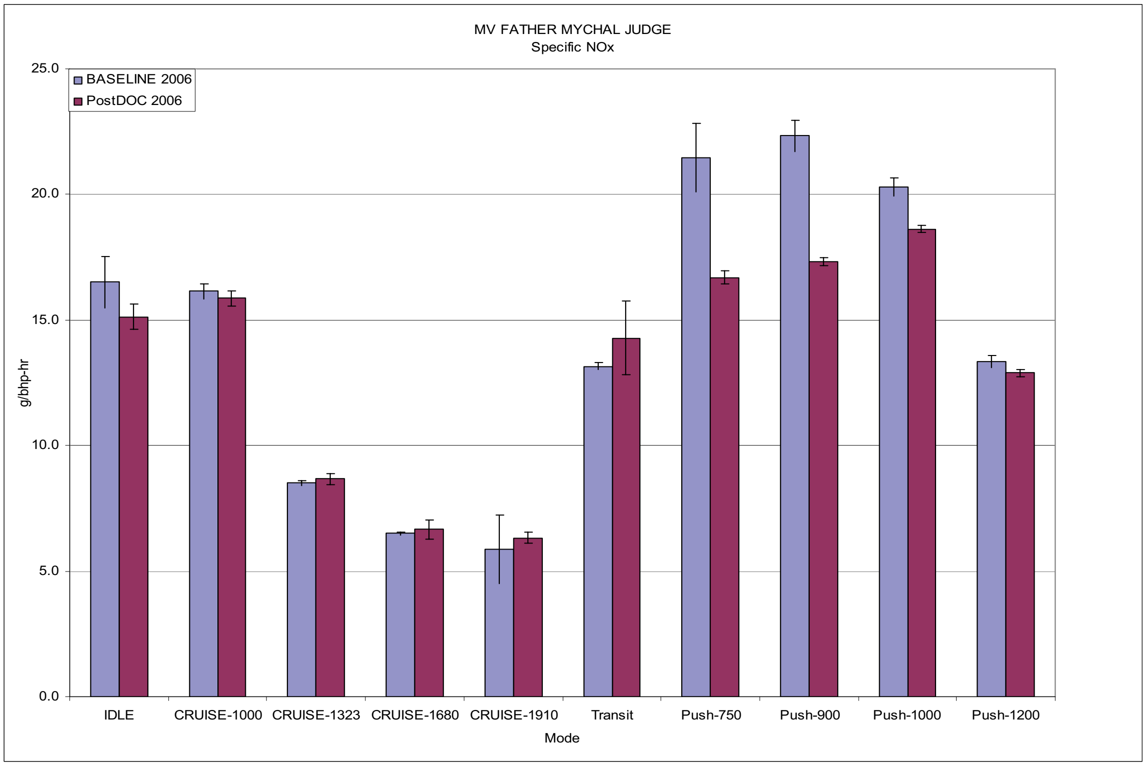


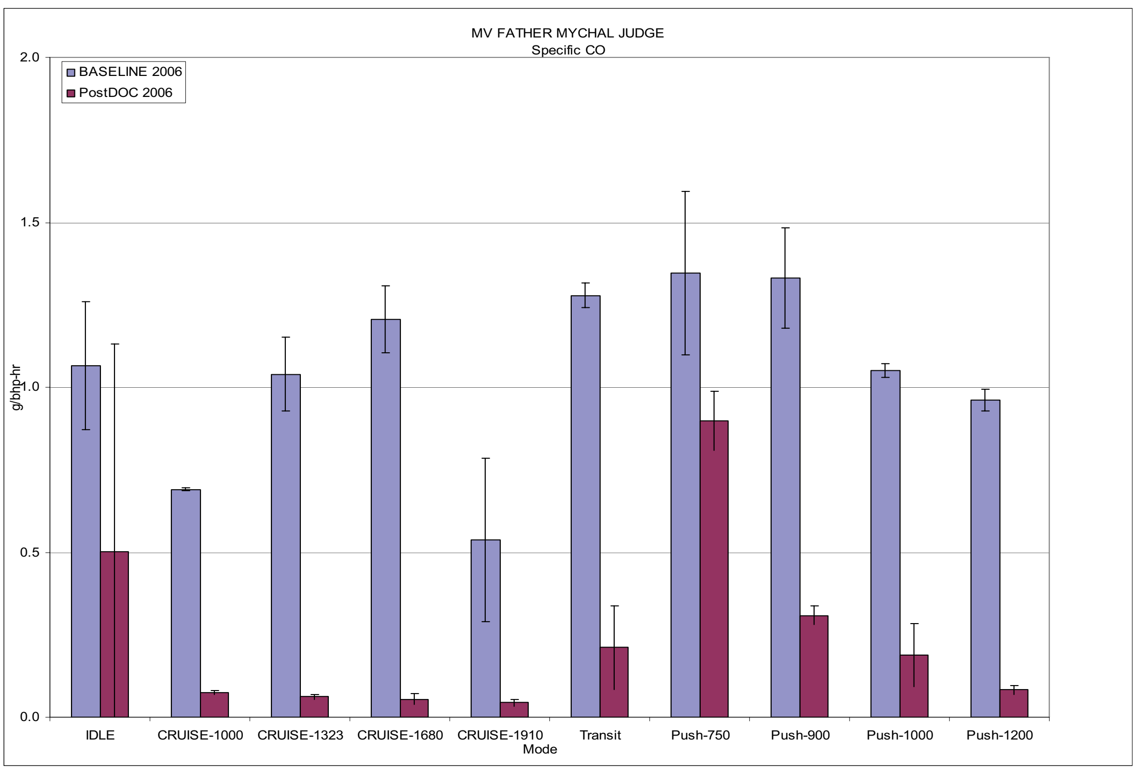

MV FATHER MYCHAL JUDGE
CO per gal
BASELINE 2006
PostDOC 2006
g/gal
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
IDLE
CRUISE-1000
CRUISE-1323
CRUISE-1680
CRUISE-1910
Transit
Push-750
Push-900
Push-1000
Push-1200
Man-Out
Man-In
Mode

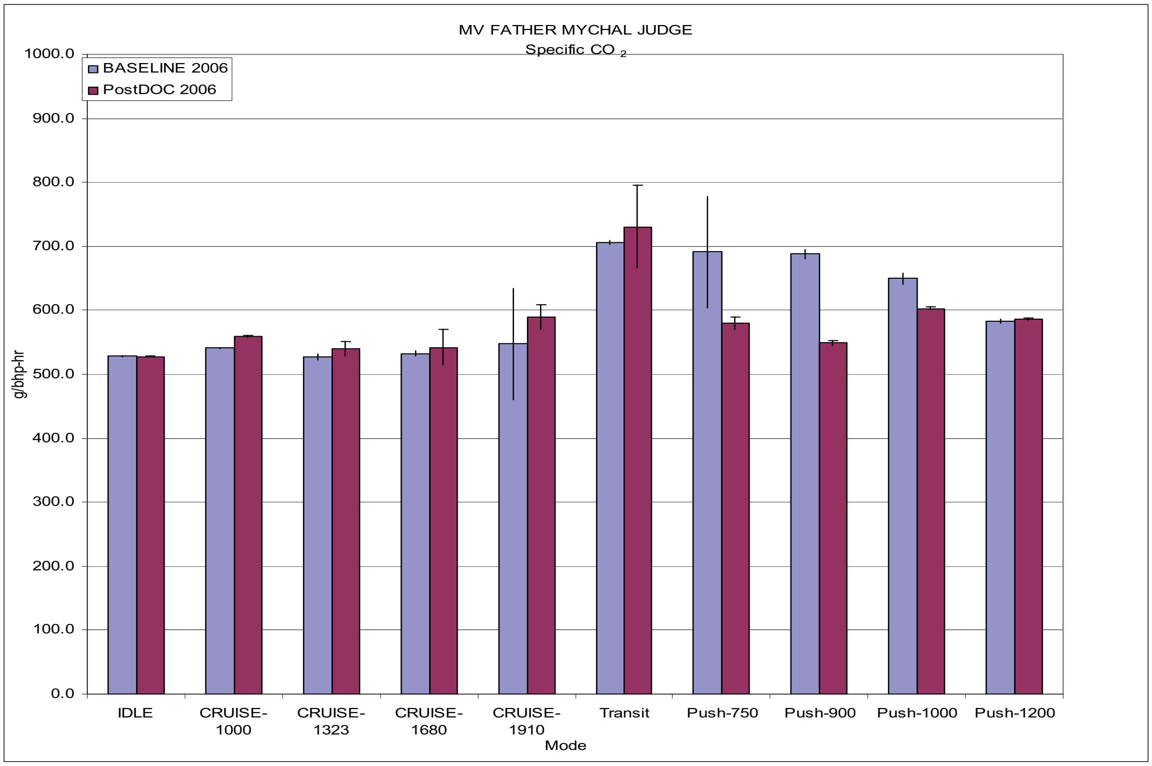

MV FATHER MYCHAL JUDGE
CO2 per gal
BASELINE 2006
PostDOC 2006
kg/gal
15.0
12.0
9.0
6.0
3.0
0.0
IDLE
CRUISE-1000
CRUISE-1323
CRUISE-1680
CRUISE-1910
Transit
Push-750
Push-900
Push-1000
Push-1200
Man-Out
Man-In
Mode

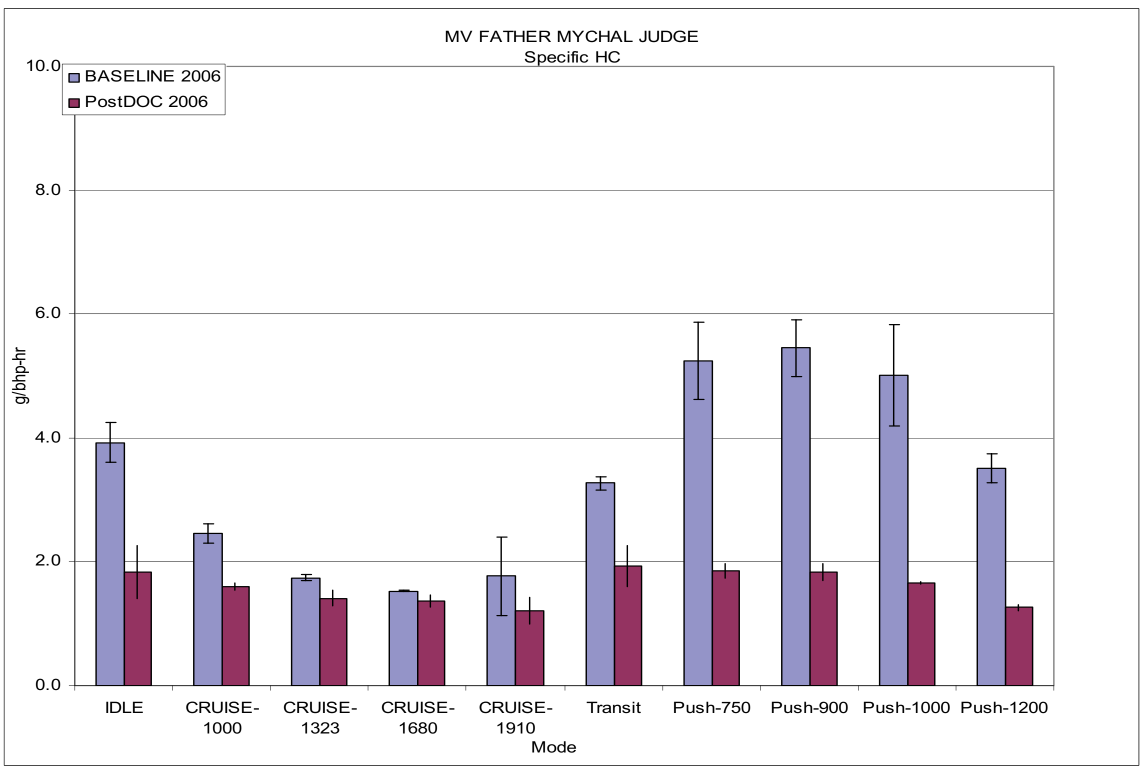

MV FATHER MYCHAL JUDGE
HC per gal
BASELINE 2006
PostDOC 2006
kg/gal
0.10
0.08
0.06
0.04
0.02
0.00
IDLE
CRUISE-1000
CRUISE-1323
CRUISE-1680
CRUISE-1910
Transit
Push-750
Push-900
Push-1000
Push-1200
Man-Out
Man-In
Mode

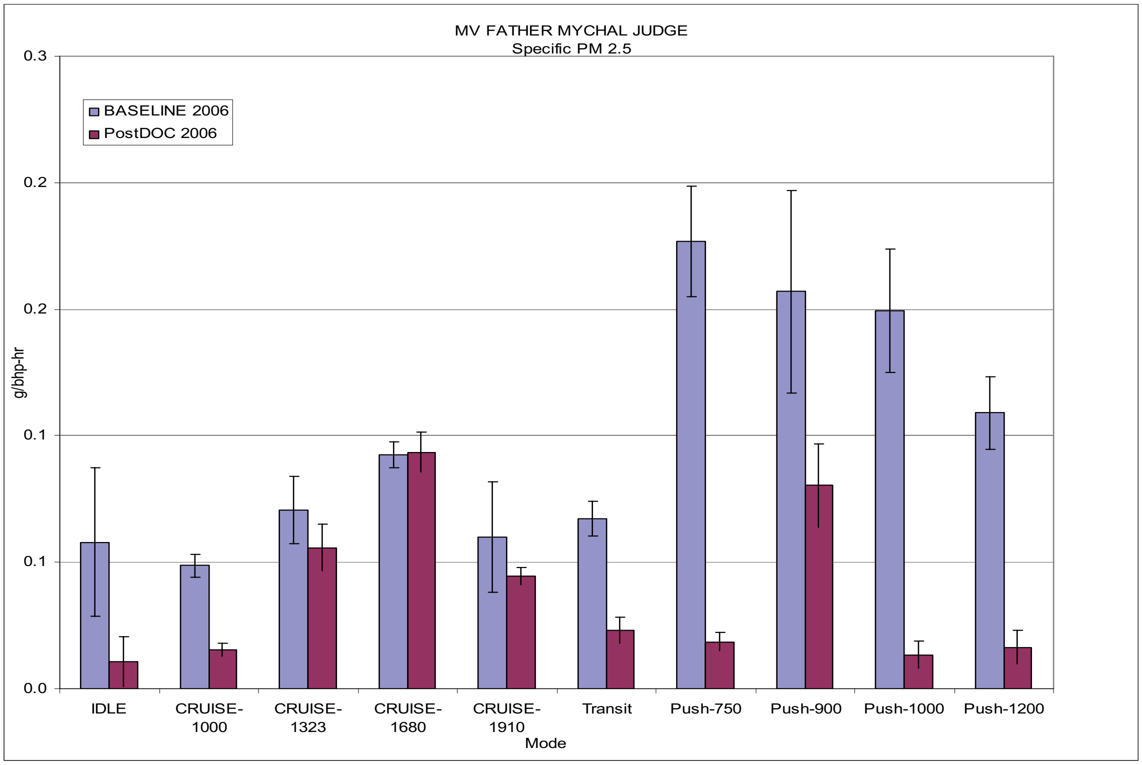

MV FATHER MYCHAL JUDGE
PM 2.5 per gal
BASELINE 2006
PostDOC 2006
g/gal
4.00
3.00
2.00
1.00
0.00
IDLE
CRUISE-1000
CRUISE-1323
CRUISE-1680
CRUISE-1910
Transit
Push-750
Push-900
Push-1000
Push-1200
Man-Out
Man-In
Mode


MV FATHER MYCHAL JUDGE
Specific NOx
BASELINE 2006
PostDOC 2006
g/bhp-hr
25.0
20.0
15.0
10.0
5.0
0.0
IDLE
CRUISE-1000
CRUISE-1323
CRUISE-1680
CRUISE-1910
Transit
Push-750
Push-900
Push-1000
Push-1200
Mode


MV FATHER MYCHAL JUDGE
Specific CO
BASELINE 2006
PostDOC 2006
g/bhp-hr
2.0
1.5
1.0
0.5
0.0
IDLE
CRUISE-1000
CRUISE-1323
CRUISE-1680
CRUISE-1910
Transit
Push-750
Push-900
Push-1000
Push-1200
Mode


MV FATHER MYCHAL JUDGE
Specific CO_2
BASELINE 2006
PostDOC 2006
g/bhp-hr
1000.0
900.0
800.0
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
IDLE
CRUISE-1000
CRUISE-1323
CRUISE-1680
CRUISE-1910
Transit
Push-750
Push-900
Push-1000
Push-1200
Mode


MV FATHER MYCHAL JUDGE
Specific HC
BASELINE 2006
PostDOC 2006
g/bhp-hr
10.0
8.0
6.0
4.0
2.0
0.0
IDLE
CRUISE-1000
CRUISE-1323
CRUISE-1680
CRUISE-1910
Transit
Push-750
Push-900
Push-1000
Push-1200
Mode


MV FATHER MYCHAL JUDGE
Specific PM 2.5
BASELINE 2006
PostDOC 2006
g/bhp-hr
0.3
0.2
0.2
0.1
0.1
0.0
IDLE
CRUISE-1000
CRUISE-1323
CRUISE-1680
CRUISE-1910
Transit
Push-750
Push-900
Push-1000
Push-1200
Mode

MV PORT IMPERIAL MANHATTAN

CALCULATED EMISSIONS DATA: MV PORT IMPERIAL MANHATTAN, Baseline, December 2005													
													PM10
													[g/gal]
													1.64
													1.49
													1.87
					-	-						-	-
													1.06
													0.77
													0.95
					-	-						-	-
													0.75
													0.75
													0.70
					-	-						-	-
													0.74
													0.76
													0.84
					-	-						-	-
													0.66
													0.74
													0.68
					-	-						-	-
													0.62
													0.66
													0.58
					-	-						-	-
													0.51
													0.45
													0.40
					-	-						-	-
													0.45
													0.49
													0.51
													0.42
													0.31
													0.43
													0.26
													0.24
													0.29
													0.39
													0.37
													0.42

CALCULATED EMISSIONS DATA: MV PORT IMPERIAL MANHATTAN, Baseline, December 2005

						PM10
						g/bhp-hr
	-	-	-	-	-	-
	-	-	-	-	-	-
	-	-	-	-	-	-
	-	-	-	-	-	-
						0.059
						0.043
						0.053
					-	-
						0.039
						0.040
						0.037
					-	-
						0.037
						0.038
						0.041
					-	-
						0.033
						0.036
						0.034
					-	-
						0.031
						0.033
						0.029
					-	-
						0.026
						0.023
						0.020
					-	-
						0.023
						0.025
						0.026
						0.021
						0.015
						0.021
						0.013
						0.012
						0.014
						0.019
						0.017
						0.020

CALCULATED EMISSIONS DATA: MV PORT IMPERIAL MANHATTAN, Post DOC, December 2005

													PM10
													[g/gal]
													0.90
													1.05
													1.02
					-	-						-	-
													0.66
													0.82
													0.76
					-	-						-	-
													0.68
													0.69
													0.67
					-	-						-	-
													0.67
													0.67
													0.65
					-	-						-	-
													0.60
													0.53
													0.59
					-	-						-	-
													0.57
													0.59
													0.60
					-	-						-	-
													0.43
													0.33
													0.48
					-	-						-	-
													0.57
													0.38
													0.30
													0.39
													0.26
	-	-	-	-	-	-	-	-	-	-	-	-	-
													0.23
					-	-							0.26
													0.20
													0.21
					-	-							0.00
													0.31
													0.38
													0.38

CALCULATED EMISSIONS DATA: MV PORT IMPERIAL MANHATTAN, Post DOC, December 2005						
						PM10
						g/bhp-hr
	-	-	-	-	-	-
	-	-	-	-	-	-
	-	-	-	-	-	-
	-	-	-	-	-	-
						0.037
						0.045
						0.042
					-	-
						0.034
						0.034
						0.033
					-	-
						0.033
						0.033
						0.032
					-	-
						0.029
						0.026
						0.028
					-	-
						0.027
						0.029
						0.029
					-	-
						0.030
						0.020
						0.026
					-	-
						0.029
						0.018
						0.015
						0.016
						0.012
						0.011
					-	-
						0.009
						0.010
					-	-
						0.015
						0.018
						0.018

CALCULATED EMISSIONS DATA: MV PORT IMPERIAL MANHATTAN, Pre DOC, With FBC, March 2005

													PM10
													[g/gal]
													1.59
													1.35
					-	-						-	-
													1.31
													1.04
					-	-						-	-
													0.69
													0.67
					-	-						-	-
													0.67
													0.65
					-	-						-	-
													0.66
													0.61
					-	-						-	-
													0.67
													0.63
					-	-						-	-
													0.53
													0.48
													0.47
													0.36
													0.39
					-	-						-	-
													0.40
													0.36
					-	-						-	-
													0.26
													0.26
					-	-						-	-
													0.33
													0.35
					-	-						-	-

CALCULATED EMISSIONS DATA: MV PORT IMPERIAL MANHATTAN, Pre DOC with FBC, March 2006						
						PM10
						g/bhp-hr
	-	-	-	-	-	-
	-	-	-	-	-	-
	-	-	-	-	-	-
	-	-	-	-	-	-
						0.079
						0.063
					-	-
						0.038
						0.037
					-	-
						0.034
						0.034
					-	-
						0.033
						0.031
					-	-
						0.034
						0.032
					-	-
						0.027
						0.024
						0.024
						0.020
						0.021
					-	-
						0.021
						0.020
					-	-
						0.013
						0.013
					-	-
						0.016
						0.017
					-	-

CALCULATED EMISSIONS DATA: MV PORT IMPERIAL MANHATTAN, Post DOC, With FBC, March 2005													
													PM10
													[g/gal]
													0.88
													1.09
					-	-						-	-
													0.69
													0.72
					-	-						-	-
													0.65
													0.57
					-	-						-	-
													0.64
													0.59
					-	-						-	-
													0.51
													0.63
												-	-
													0.53
													0.59
					-	-						-	-
													0.35
													0.36
					-	-						-	-
													0.33
													0.32
					-	-						-	-
													0.23
													0.25
					-	-						-	-
													0.19
													0.20
					-	-						-	-
													0.33
													0.38
					-	-						-	-

CALCULATED EMISSIONS DATA: MV PORT IMPERIAL MANHATTAN, Post DOC with FBC, March 2006						
						PM10
						g/bhp-hr
	-	-	-	-	-	-
	-	-	-	-	-	-
	-	-	-	-	-	-
	-	-	-	-	-	-
						0.041
						0.043
					-	-
						0.038
						0.033
					-	-
						0.033
						0.031
					-	-
						0.026
						0.032
					-	-
						0.028
						0.031
					-	-
						0.018
						0.022
					-	-
						0.019
						0.018
					-	-
						0.012
						0.013
					-	-
						0.010
						0.010
					-	-
						0.017
						0.020
					-	-

MV PORT IMPERIAL MANHATTAN Baseline Average Engine Operating Parameters and Fuel Consumption Rates											
Mode	Exh. Temp, C	Inlet Air Temp, C	Int. Mani. Temp, C	Exh. BP, IWC	Int. Mani. Press., PSIG	RPM	Fuel flow, lb/hr	Fuel flow, gph	Torq., ft-lb	BHP	BSFC, lb/bhp-hr
Idle	105.1	25.7	69.7	0.6	-1.0	699.0	8.1	1.15	-	-	-
SS-1000	221.7	27.8	71.9	1.8	-0.32	1000.0	41.9	5.92	1068	105	0.398
SS-1134	259.83	28.95	72.56	2.4	0.24	1125.2	56.6	8.01	1368	152	0.373
SS-1425	348.01	29.65	77.77	5.7	3.83	1433.8	113.2	16.02	2299	325	0.349
SS-1635	384.9	30.6	85.3	10.2	8.1	1640.6	167.7	23.7	2999	484	0.346
SS-1834	405.4	31.1	97.2	17.8	14.6	1830.2	234.6	33.2	3730	672	0.349
Push-750	228.4	35.7	72.5	0.9	-0.8	757.0	36.15	5.11	1319	98	0.368
Push-900	289.2	37.0	74.2	1.7	-0.4	893.6	56.37	7.97	1840	162	0.348
Push-1000	333.8	34.7	75.6	2.6	0.9	1009.4	79.92	11.30	2356	234	0.341
Push-1200	410.6	34.3	79.9	5.10	4.4	1202.0	132.12	18.69	3324	393	0.336
Transit	305.4	34.0	74.7	2.5	0.6	1024.9	70.35	14.21	-	196	0.359

MV PORT IMPERIAL MANHATTAN Post DOC Pre FBC Average Engine Operating Parameters and Fuel Consumption Rates											
Mode	Exh. Temp, C	Inlet Air Temp, C	Int. Mani. Temp, C	Exh. BP, IWC	Int. Mani. Press., PSIG	RPM	Fuel flow, lb/hr	Fuel flow, gph	Torq., ft-lb	BHP	BSFC, lb/bhp-hr
Idle	117.5	39.3	71.9	0.4	-1.4	700.4	8.2	1.16	-	-	-
SS-1000	223.9	23.2	71.3	1.7	0.07	995.8	42.2	5.97	1093	107	0.394
SS-1134	266.65	25.82	72.72	2.5	0.53	1135.8	59.1	8.36	1429	160	0.370
SS-1425	347.86	28.52	77.71	5.5	4.02	1433.2	113.2	16.00	2308	326	0.347
SS-1635	386.6	34.4	85.4	9.9	8.3	1635.1	167.8	23.7	3035	489	0.343
SS-1834	409.6	35.5	97.9	17.4	14.8	1829.9	236.8	33.5	3784	682	0.347
Push-750	235.5	35.4	72.6	1.0	-0.8	751.4	39.20	5.54	1391	103	0.381
Push-900	288.8	34.3	74.1	1.6	0.0	898.1	59.01	8.35	1937	171	0.344
Push-1000	336.1	34.1	75.9	2.4	0.8	1002.4	78.80	11.15	2367	234	0.337
Push-1200	419.4	35.7	80.7	5.02	4.3	1196.7	132.00	18.67	3338	393	0.336
Transit	295.3	34.1	74.9	2.4	0.6	1013.1	65.55	9.27	-	170	0.386

MV PORT IMPERIAL MANHATTAN Pre DOC Post FBC Average Engine Operating Parameters and Fuel Consumption Rates											
Mode	**Exh. Temp, C**	**Inlet Air Temp, C**	**Int. Mani. Temp, C**	**Exh. BP, IWC**	**Int. Mani. Press., PSIG**	**RPM**	**Fuel flow, lb/hr**	**Fuel flow, gph**	**Torq., ft-lb**	**BHP**	**BSFC, lb/bhp-hr**
Idle	95.11	21.78	57.93	0.9	NMF	700.0	9.71	1.37	-	-	-
SS-1000	229.54	26.72	71.35	2.2	NMF	1012.0	42.67	6.04	1008.1	100.48	0.425
SS-1134	265.37	26.77	72.67	2.9	NMF	1142.0	58.46	8.27	1332.0	149.81	0.390
SS-1425	340.01	27.62	77.51	5.6	NMF	1417.0	107.27	15.17	2091.6	291.89	0.368
SS-1635	380.55	29.56	85.28	9.8	NMF	1631.7	162.62	22.83	2834.5	455.48	0.357
SS-1834	408.42	31.07	98.01	16.7	NMF	1830.5	235.79	33.20	3644.4	657.02	0.359
Push-750	217.42	21.93	70.83	1.4	NMF	754.0	36.44	5.15	1258.8	93.48	0.390
Push-900	281.92	25.40	72.65	2.3	NMF	901.3	58.08	8.22	1721.8	152.84	0.380
Push-1000	328.52	28.20	74.53	3.1	NMF	1001.7	77.77	11.00	2241.5	221.12	0.352
Push-1200	413.00	31.04	80.13	5.9	NMF	1205.7	134.43	19.01	3297.9	391.59	0.343
Transit	274.64	28.99	73.50	2.5	NMF	1016.4	53.60	7.58	1482.3	148.38	0.361

MV PORT IMPERIAL MANHATTAN Post DOC Post FBC Engine Operating Parameters and Fuel Consumption Rates											
Mode	**Exh. Temp, C**	**Inlet Air Temp, C**	**Int. Mani. Temp, C**	**Exh. BP, IWC**	**Int. Mani. Press., PSIG**	**RPM**	**Fuel flow, lb/hr**	**Fuel flow, gph**	**Torq., ft-lb**	**BHP**	**BSFC, lb/bhp-hr**
Idle	95.1	21.78	57.93	0.9	NMF	700.0	9.71	1.17	-	-	-
SS-1000	229.4	25.72	71.16	2.2	1.60	1013.0	43.03	6.09	1069.9	106.74	0.403
SS-1134	259.8	26.35	72.14	2.8	2.29	1131.0	57.09	8.08	1339.5	149.20	0.383
SS-1425	339.3	27.56	76.99	5.7	6.08	1428.0	110.01	15.56	2200.9	309.54	0.355
SS-1635	379.5	29.04	85.07	10.0	10.75	1638.3	164.08	23.21	2916.9	470.65	0.349
SS-1834	404.8	29.51	97.69	16.9	17.60	1832.0	232.69	32.91	3663.1	660.91	0.352
Push-750	222.0	26.11	71.38	1.4	1.03	747.7	35.97	5.09	1280.1	94.26	0.382
Push-900	286.9	28.72	73.14	2.2	1.90	901.3	59.20	8.37	1840.0	163.33	0.363
Push-1000	338.4	31.62	75.28	3.0	2.83	1001.0	79.92	11.30	2265.7	223.36	0.358
Push-1200	421.3	33.06	80.54	5.8	6.73	1205.0	136.1	19.25	3198.2	379.55	0.359
Transit	274.6	28.99	73.50	2.5	NMF	1016.4	53.60	6.98	1400.7	134.82	0.367

MV PORT IMPERIAL MANHATTAN Baseline Transit Test Averages (December 2005).

Mode	Time, sec	% of Time	RPM	Torque	BHP	Fuel Cons., lb	NOx, kg/hr	PM 2.5, g/hr	HC, g/hr
Push	1441	49.50%	1006	2390	237	7.97	3.2	2.76	299
Maneuver	610	21.00%	941	1714	161	2.72	2.07	0.86	340
Cruise	859	29.50%	1133	1670	188	3.48	1.99	6.29	628
Total	2910	100.00%				14.17			

MV PORT IMPERIAL MANHATTAN Baseline December 2005 Transit Test

Mode	Transit 1				Transit 2				Transit 3				Transit 4			
	Start , sec	Stop, sec	Duration, sec	% of Time	Start , sec	Stop, sec	Duration, sec	% of Time	Start , sec	Stop, sec	Duration, sec	% of Time	Start , sec	Stop, sec	Duration, sec	% of Time
Push	0	180	180	24.0	0	180	180	26.1	0	180	180	24.0	0	180	180	25.0
Maneuver, Out	180	260	80	10.7	180	246	66	9.6	180	247	67	8.9	180	262	82	11.4
Cruise	260	462	202	26.9	246	438	192	27.8	247	498	251	33.5	262	476	214	29.7
Maneuver, In	462	569	107	14.3	438	510	72	10.4	498	570	72	9.6	476	540	64	8.9
Push	569	750	181	24.1	510	690	180	26.1	570	750	180	24.0	540	720	180	25.0

Mode	Transit 1				Transit 2				Transit 3				Transit 4			
	RPM	Torque	rpm	Fuel Consumed, lb	RPM	Torque	rpm	Fuel Consumed, lb	RPM	Torque	rpm	Fuel Consumed, lb	RPM	Torque	rpm	Fuel Consumed, lb
Push	1014	2357	235	4.07	994	2394	234	3.85	998	2323	228	3.89	1004	2368	234	3.95
Maneuver, Out	1093	2442	263	1.74	1076	2206	234	1.83	963	1841	175	1.65	1032	1800	158	1.60
Cruise	1171	2381	275	3.62	1140	1436	161	3.18	1043	1271	131	3.23	1179	1591	185	3.91
Maneuver, In	899	2359	209	1.85	874	1237	106	0.91	786	899	70	0.71	809	930	74	0.59
Push	1021	2391	240	4.17	998	2328	229	3.89	1019	2582	259	4.12	1004	2376	235	3.96

Table 4.41. MV PORT IMPERIAL MANHATTAN Post DOC Transit Test Averages (December 2005).

Mode	Time, sec	% of Time	RPM	Torque	BHP	Fuel Cons., lb	NOx, kg/hr	PM 2.5, g/hr	HC, g/hr
Push	1510	50.00%	990	1997	195	7.97	2.96	1.58	150
Maneuver	795	26.30%	854	1309	114	3.21	2.1	0.71	0.19
Cruise	715	23.70%	1077	1563	167	2.54	1.84	5.07	139
Total	3020	100.00%				13.72			

MV PORT IMPERIAL MANHATTAN PreDOC December 2005 Transit Test

Mode	Transit 1	Transit 2	Transit 3	Transit 4

	Start , sec	Stop, sec	Duration, sec	% of Time	Start , sec	Stop, sec	Duration, sec	% of Time	Start , sec	Stop, sec	Duration, sec	% of Time	Start , sec	Stop, sec	Duration, sec	% of Time
Push	0	180	180	23.1	0	180	180	25.0	0	180	180	21.4	0	180	180	26.5 %
Maneuver, Out	180	263	83	6	180	265	85	11.8	180	269	89	10.6	180	265	85	12.5
Cruise	263	451	188	24.1	265	447	182	25.3	269	433	164	19.5	265	446	181	26.6
Maneuver, In	451	572	121	15.5	447	548	101	14.0	433	560	127	15.1	446	550	104	15.3
Push	572	780	208	26.7	548	720	172	23.9	560	840	280	33.3	550	680	130	19.1

Mode	Transit 1				Transit 2				Transit 3				Transit 4			
	RPM	Torque	rpm	Fuel Consumed, lb	RPM	Torque	rpm	Fuel Consumed, lb	RPM	Torque	rpm	Fuel Consumed, lb	RPM	Torque	rpm	Fuel Consumed, lb
Push	963	1728	164	3.52	1000	2233	220	3.91	994	2384	233	3.85	998	2235	220	3.89
Maneuver, Out	873	952	82	3.29	864	2215	188	1.11	969	1021	97	1.73	970	1586	151	1.47
Cruise	960	870	82	1.91	1019	2213	222	2.19	1187	1676	196	3.05	1143	1495	168	3.02
Maneuver, In	629	311	19	1.13	915	2248	203	1.42	762	608	46	1.15	853	1532	129	1.53
Push	964	1793	170	4.08	998	2240	220	3.72	996	1037	102	6.01	1008	2328	231	2.89

MV PORT IMPERIAL MANHATTAN Pre DOC with FBC Transit Test Averages (March 2006).

Mode	Time, sec	% of Time	RPM	Torque	BHP	Fuel Cons., lb	NOx, kg/hr	PM 2.5, g/hr	HC, g/hr
Push	1080	48.60%	970	1848	176	7.24	2.97	5.5	204
Maneuver	755	34.00%	991	1349	133	1.49	0.77	4.39	160
Cruise	385	17.30%	1189	1326	157	2.25	2.13	33.7	540
Total	2220	100.00%				10.98			

MV PORT IMPERIAL MANHATTAN Pre DOC with FBC March 2006 Transit Test

Mode	Transit 1				Transit 2				Transit 3			
	Start , sec	Stop, sec	Duration, sec	% of Time	Start , sec	Stop, sec	Duration, sec	% of Time	Start , sec	Stop, sec	Duration, sec	% of Time
Push	0	180	180	25.0	0	180	180	24.0	0	180	180	24.0
Maneuver, Out	180	290	110	15.3	180	271	91	12.1	180	321	141	18.8
Cruise	290	362	72	10.0	271	445	174	23.2	321	460	139	18.5
Maneuver, In	362	540	178	24.7	445	570	125	16.7	460	570	110	14.7
Push	540	720	180	25.0	570	750	180	24.0	570	750	180	24.0

Mode	Transit 1	Transit 2	Transit 3

	RPM	Torque	bhp	Fuel Consumed, lb	RPM	Torque	bhp	Fuel Consumed, lb	RPM	Torque	bhp	Fuel Consumed, lb
Push	980	1828	176	3.72	946	1926	179.41	3.37	956.4	1799.9	169.53	3.48
Maneuver, Out	1115	1607	176	1.06	1086	1553	166.09	0.78	1034.4	1290.2	131.43	0.61
Cruise	1290	1703	216	1.68	1113	1095	120.00	2.65	1166.1	1180.9	135.62	2.42
Maneuver, In	905	965	86	0.83	921	1269	115.14	0.74	889.2	1412.1	123.66	0.45
Push	976	1875	180	3.68	954	1823	171.26	3.45	1008.7	1840.9	182.88	4.03

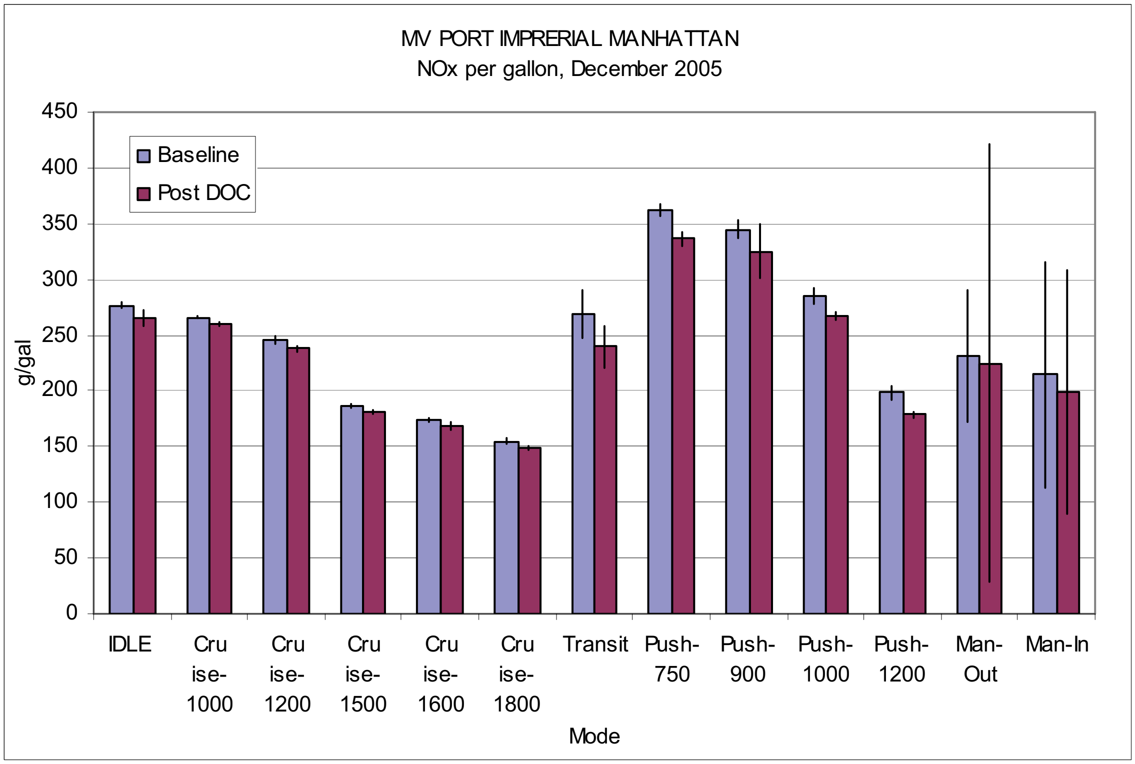
MV PORT IMPERIAL MANHATTAN Post DOC with FBC Transit Test Averages (March 2006).

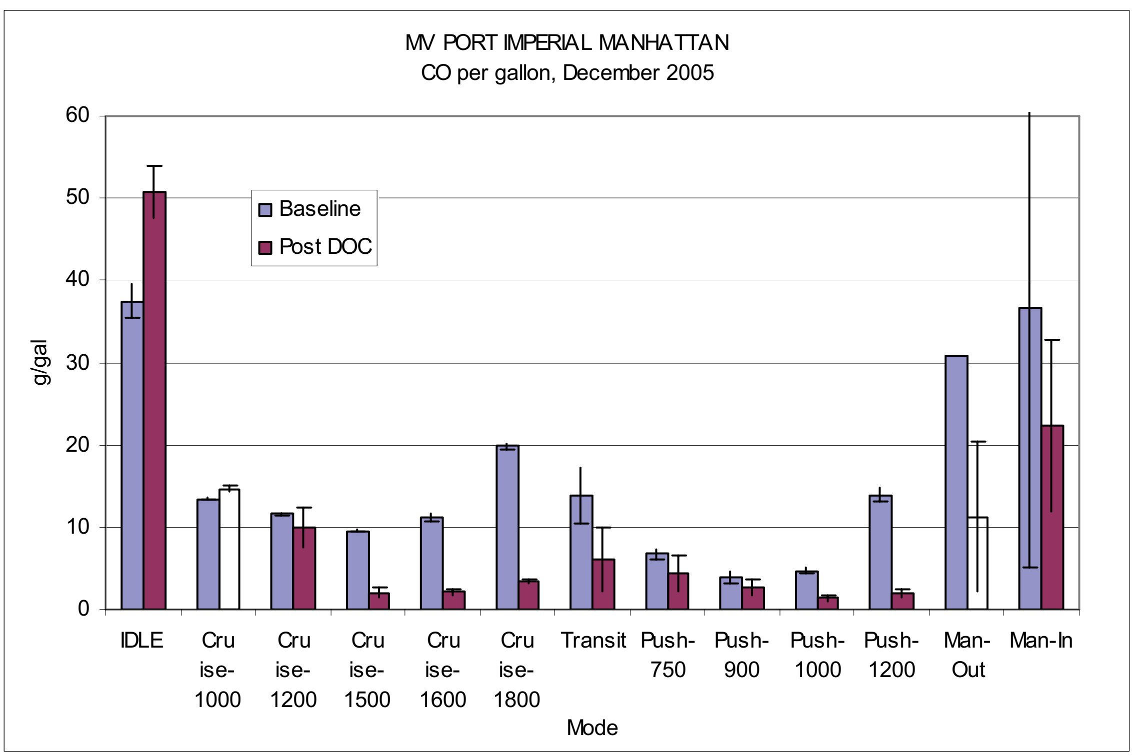
Mode	Time, sec	% of Time	RPM	Torque	BHP	Fuel Cons., lb	NOx, kg/hr	PM 2.5, g/hr	HC, kg/hr
Push	1080	46.20%	973	1845	177	7.28	2.77	5.5	143
Maneuver	710	30.30%	944	1218	116	1.48	0.69	4.55	0.09
Cruise	550	23.50%	970	860	83	1.88	1.36	33.7	36
Total	2340	100%				10.64			

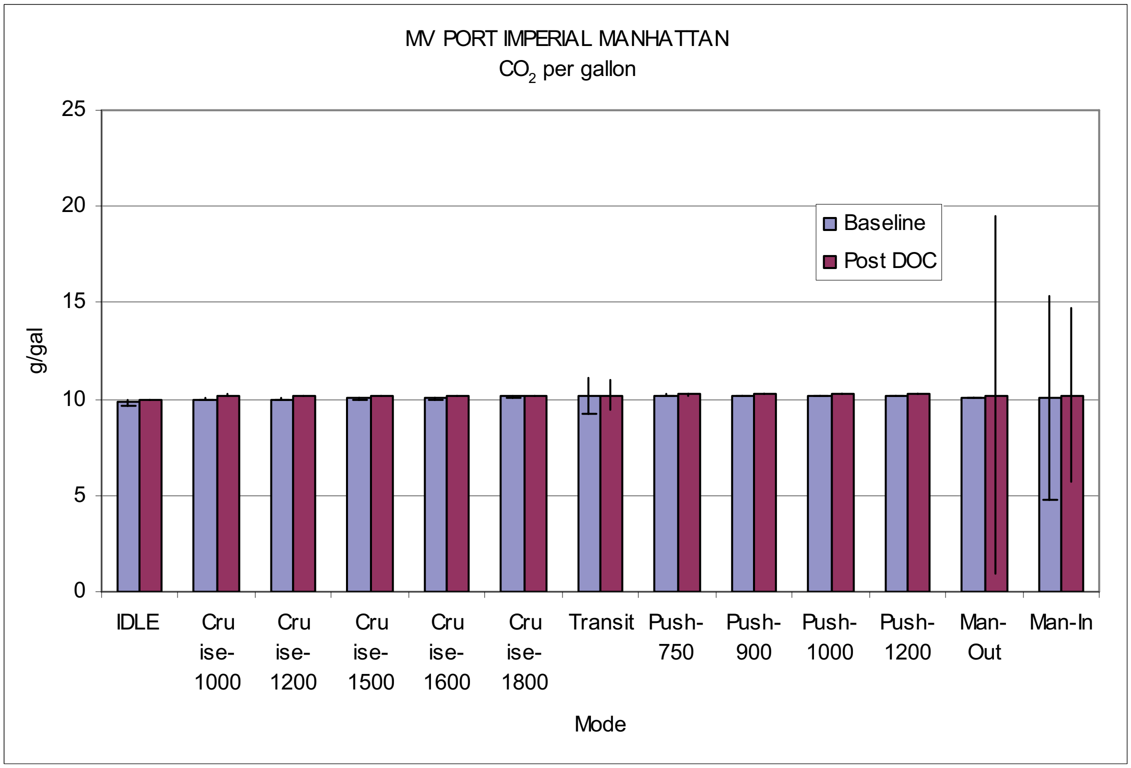
MV PORT IMPERIAL MANHATTAN Post DOC with FBC March 2006 Transit Test

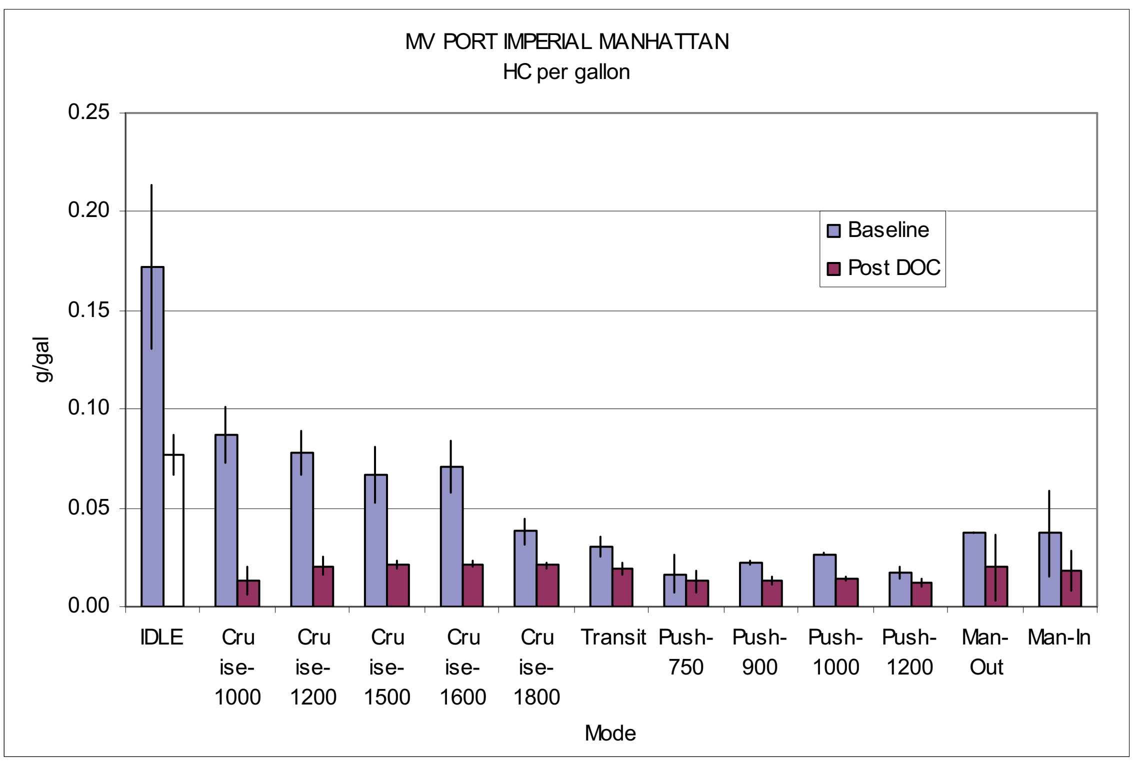
Mode	Transit 1				Transit 2				Transit 3			
	Start , sec	Stop, sec	Duration, sec	% of Time	Start , sec	Stop, sec	Duration, sec	% of Time	Start , sec	Stop, sec	Duration, sec	% of Time
Push	0	180	180	24.0	0	180	180	22.2	0	180	180	23.1
Maneuver, Out	180	315	135	18.0	180	333	153	18.9	180	304	124	15.9
Cruise	315	474	159	21.2	333	543	210	25.9	304	485	181	23.2
Maneuver, In	474	570	96	12.8	543	630	87	10.7	485	600	115	14.7
Push	570	750	180	24.0	630	810	180	22.2	600	780	180	23.1

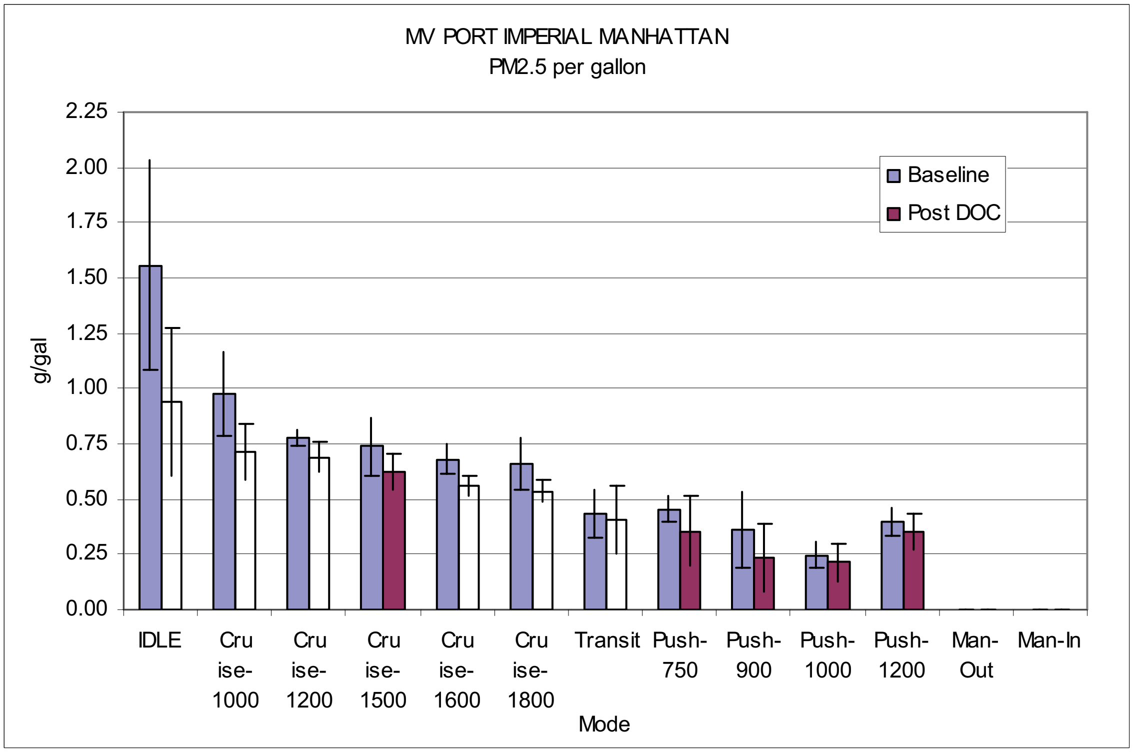
Mode	Transit 1				Transit 2				Transit 3			
	RPM	Torque	bhp	Fuel Consumed, lb	RPM	Torque	bhp	Fuel Consumed, lb	RPM	Torque	bhp	Fuel Consumed, lb
Push	963	1872	177	3.54	945	1959	182	3.34	1010	1809	180	4.03
Maneuver, Out	1114	2043	224	2.00	976	1279	123	0.59	944	1064	99	0.29
Cruise	1046	978	101	2.03	946	863	80	2.01	919	739	67	1.59
Maneuver, In	917	1020	92	0.59	858	1001	85	0.69	854	900	76	0.29
Push	968	1925	184	3.59	971	1852	177	3.63	981	1654	160	3.73

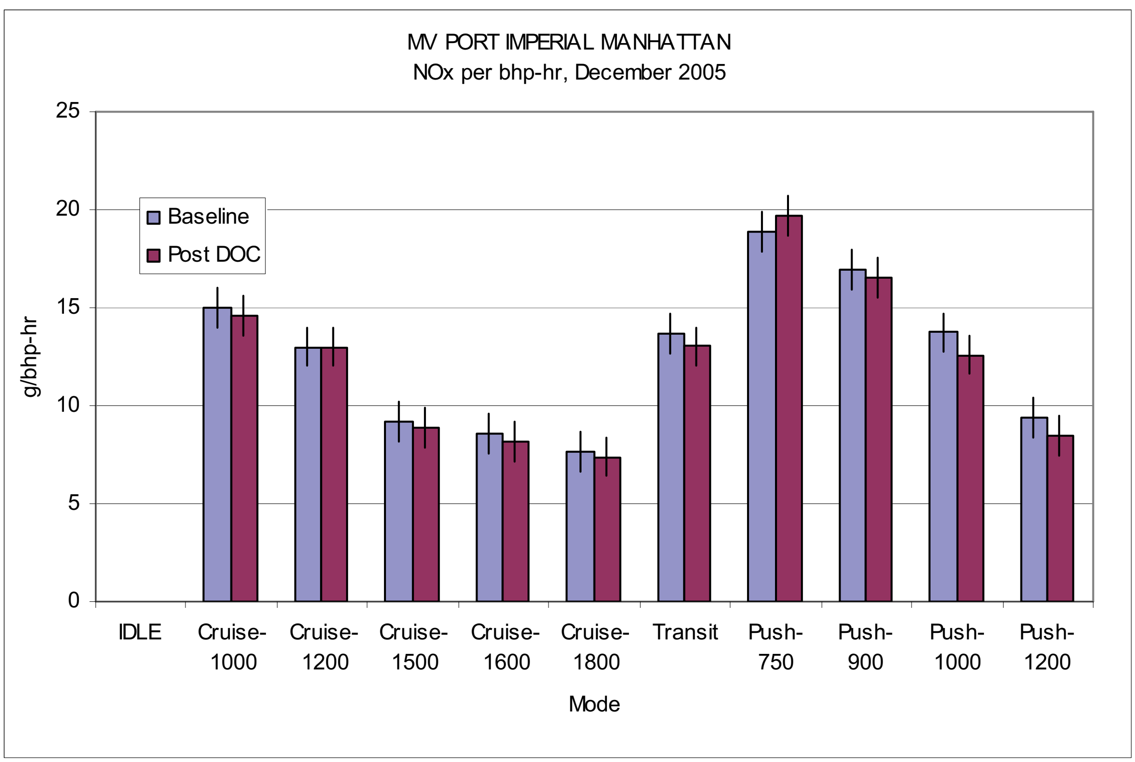

MV PORT IMPRERIAL MANHATTAN
NOx per gallon, December 2005
Baseline
Post DOC
g/gal
450
400
350
300
250
200
150
100
50
0
IDLE
Cru ise-1000
Cru ise-1200
Cru ise-1500
Cru ise-1600
Cru ise-1800
Transit
Push-750
Push-900
Push-1000
Push-1200
Man-Out
Man-In
Mode

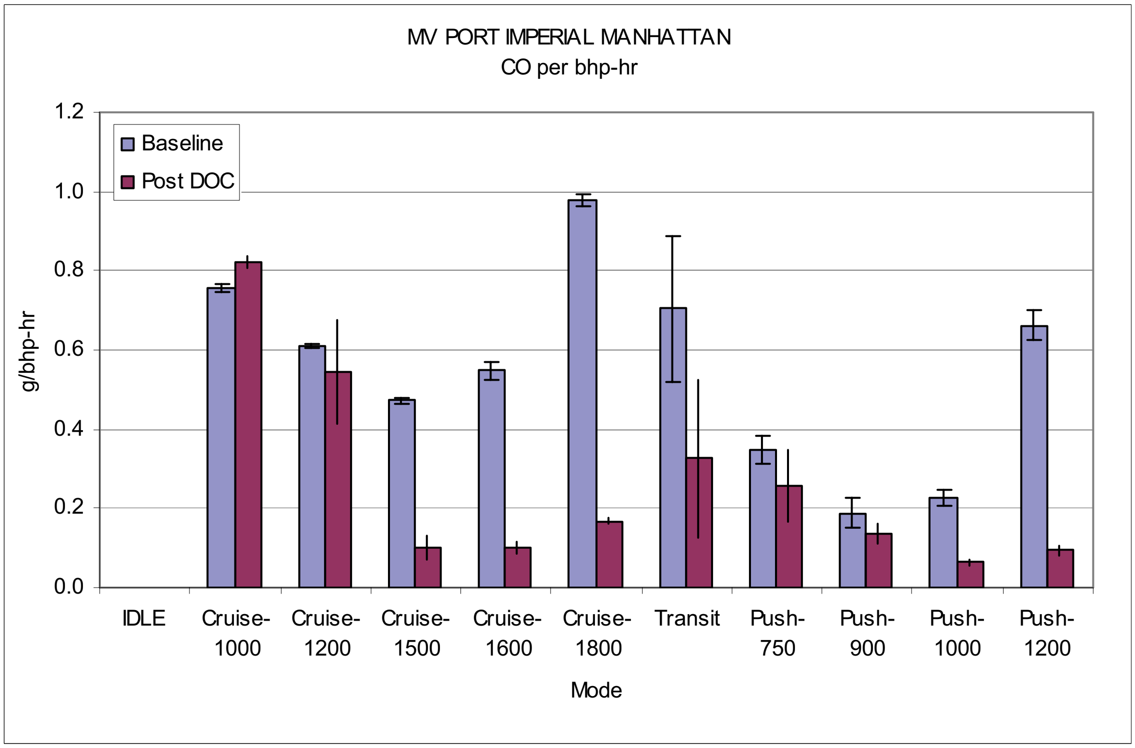

MV PORT IMPERIAL MANHATTAN
CO per gallon, December 2005
Baseline
Post DOC
g/gal
60
50
40
30
20
10
0
IDLE
Cru ise-1000
Cru ise-1200
Cru ise-1500
Cru ise-1600
Cru ise-1800
Transit
Push-750
Push-900
Push-1000
Push-1200
Man-Out
Man-In
Mode

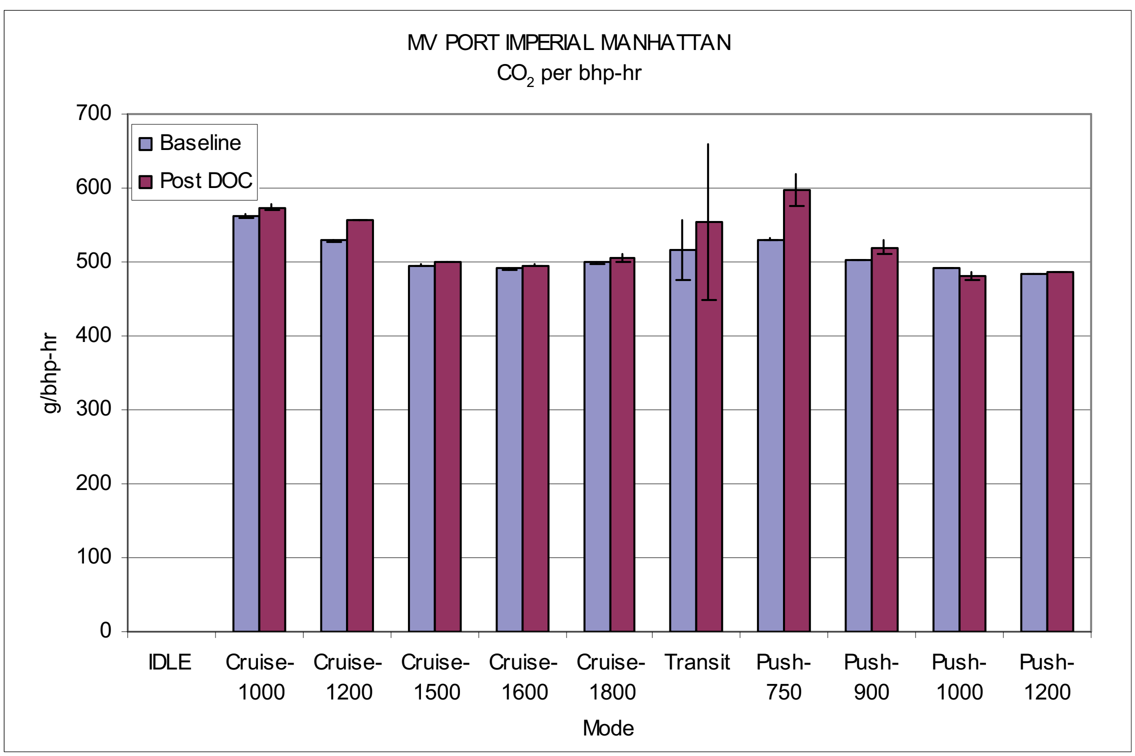

MV PORT IMPERIAL MANHATTAN
CO_2 per gallon
g/gal
25
20
15
10
5
0
Baseline
Post DOC
IDLE
Cru ise-1000
Cru ise-1200
Cru ise-1500
Cru ise-1600
Cru ise-1800
Transit
Push-750
Push-900
Push-1000
Push-1200
Man-Out
Man-In
Mode

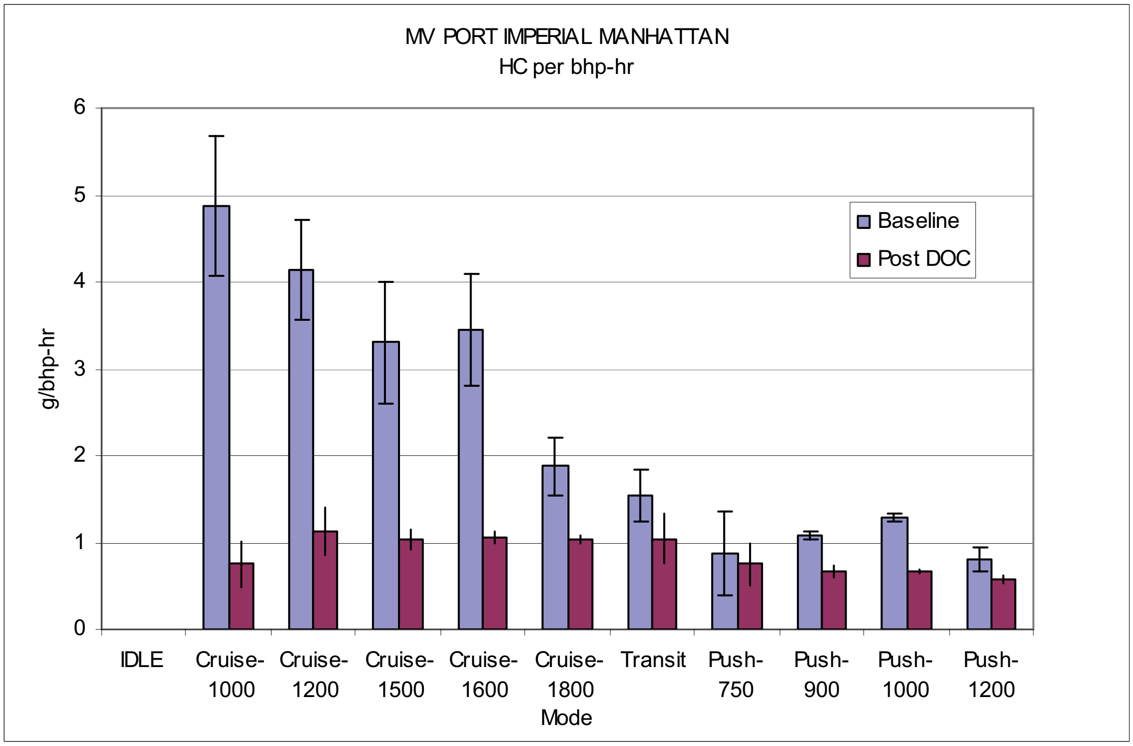

MV PORT IMPERIAL MANHATTAN
HC per gallon
g/gal
0.25
0.20
0.15
0.10
0.05
0.00
Baseline
Post DOC
IDLE
Cru ise-1000
Cru ise-1200
Cru ise-1500
Cru ise-1600
Cru ise-1800
Transit
Push-750
Push-900
Push-1000
Push-1200
Man-Out
Man-In
Mode

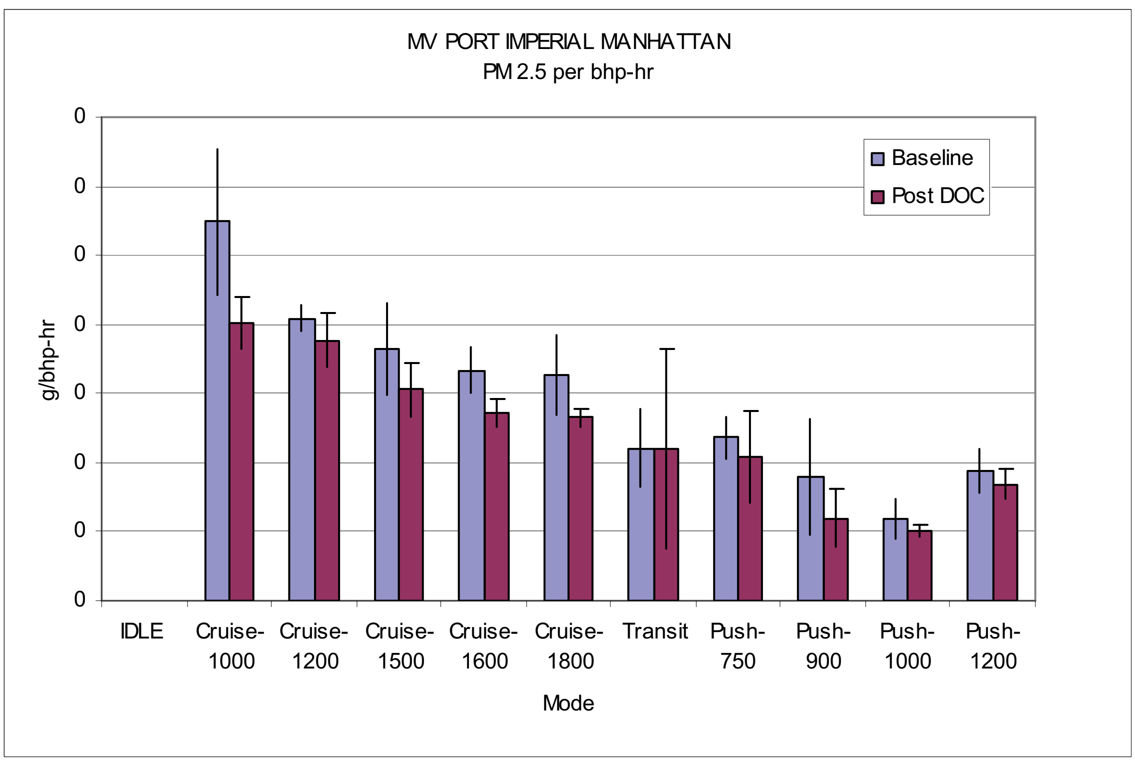

MV PORT IMPERIAL MANHATTAN
PM2.5 per gallon
g/gal
2.25
2.00
1.75
1.50
1.25
1.00
0.75
0.50
0.25
0.00
Baseline
Post DOC
IDLE
Cru ise- 1000
Cru ise- 1200
Cru ise- 1500
Cru ise- 1600
Cru ise- 1800
Transit
Push- 750
Push- 900
Push- 1000
Push- 1200
Man- Out
Man-In
Mode

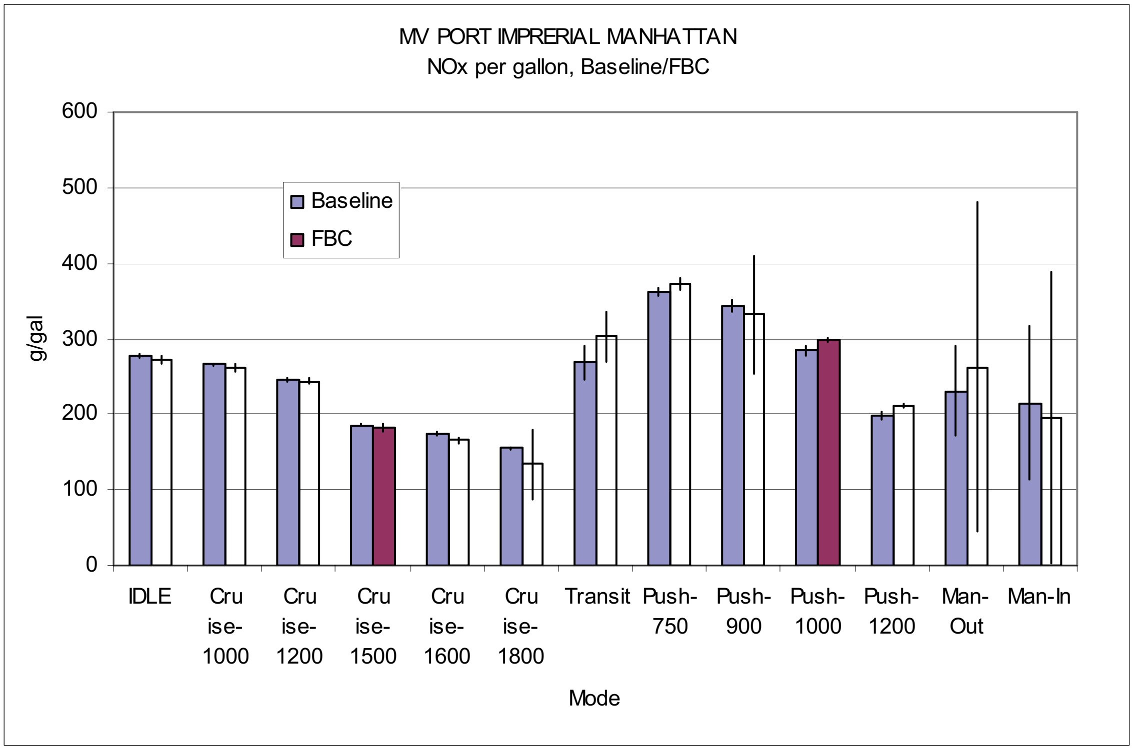

MV PORT IMPERIAL MANHATTAN
NOx per bhp-hr, December 2005
g/bhp-hr
25
20
15
10
5
0
Baseline
Post DOC
IDLE
Cruise- 1000
Cruise- 1200
Cruise- 1500
Cruise- 1600
Cruise- 1800
Transit
Push- 750
Push- 900
Push- 1000
Push- 1200
Mode

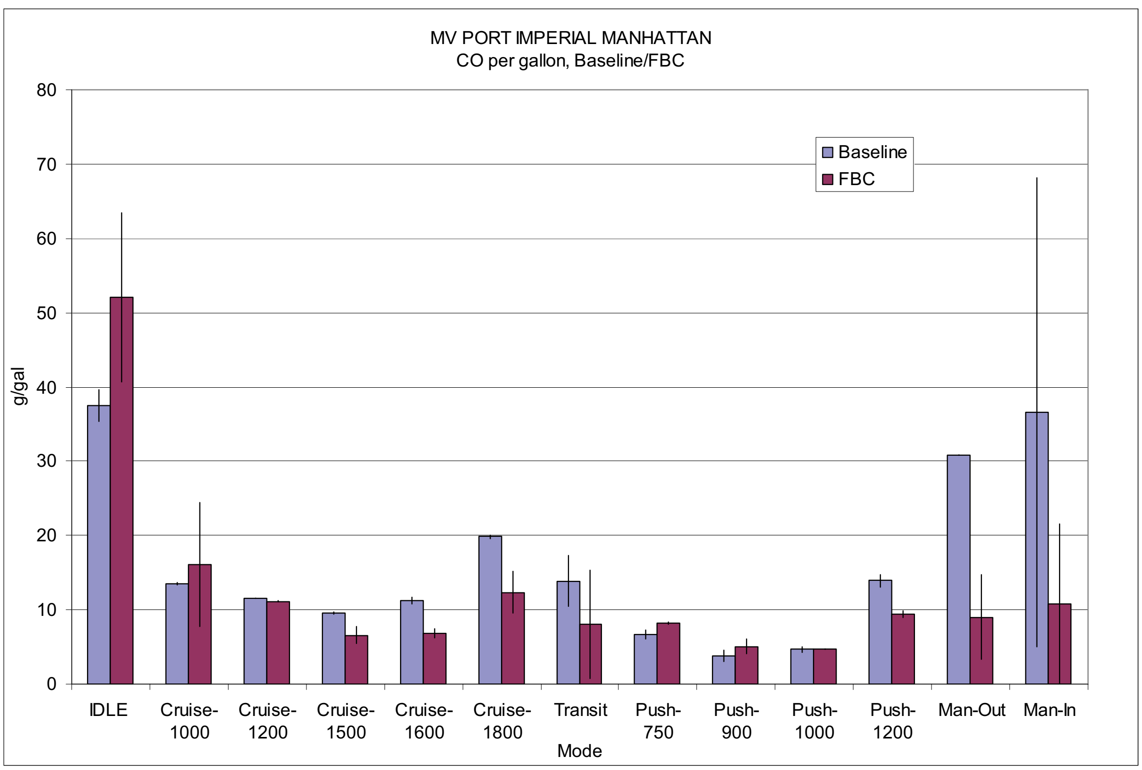

MV PORT IMPERIAL MANHATTAN
CO per bhp-hr
Baseline
Post DOC
g/bhp-hr
1.2
1.0
0.8
0.6
0.4
0.2
0.0
IDLE
Cruise-1000
Cruise-1200
Cruise-1500
Cruise-1600
Cruise-1800
Transit
Push-750
Push-900
Push-1000
Push-1200
Mode

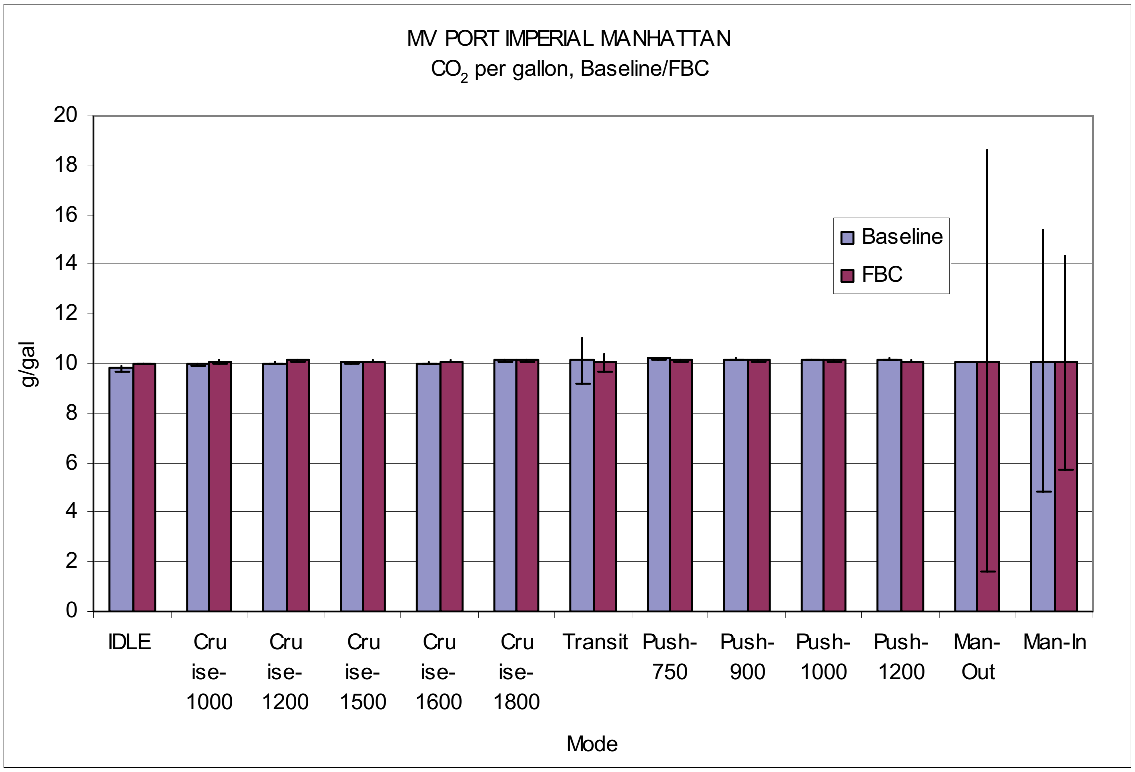

MV PORT IMPERIAL MANHATTAN
CO_2 per bhp-hr
Baseline
Post DOC
g/bhp-hr
700
600
500
400
300
200
100
0
IDLE
Cruise-1000
Cruise-1200
Cruise-1500
Cruise-1600
Cruise-1800
Transit
Push-750
Push-900
Push-1000
Push-1200
Mode

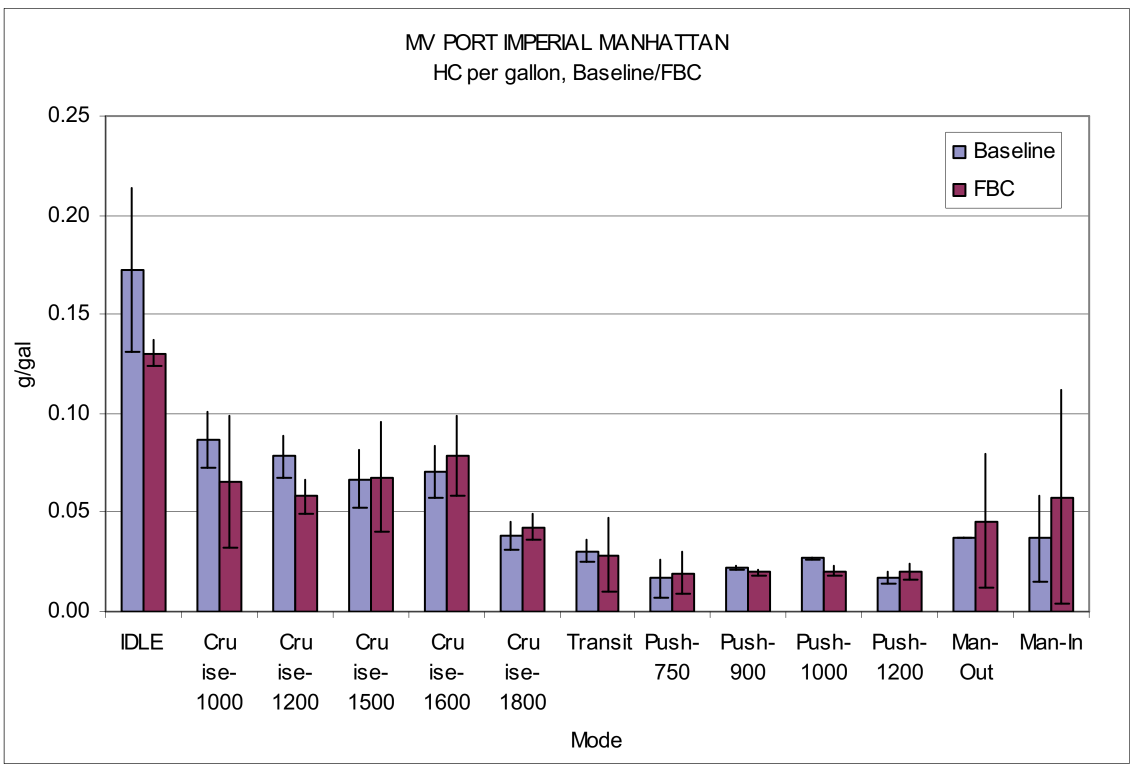

MV PORT IMPERIAL MANHATTAN
HC per bhp-hr
g/bhp-hr
6
5
4
3
2
1
0
Baseline
Post DOC
IDLE
Cruise-1000
Cruise-1200
Cruise-1500
Cruise-1600
Cruise-1800
Transit
Push-750
Push-900
Push-1000
Push-1200
Mode

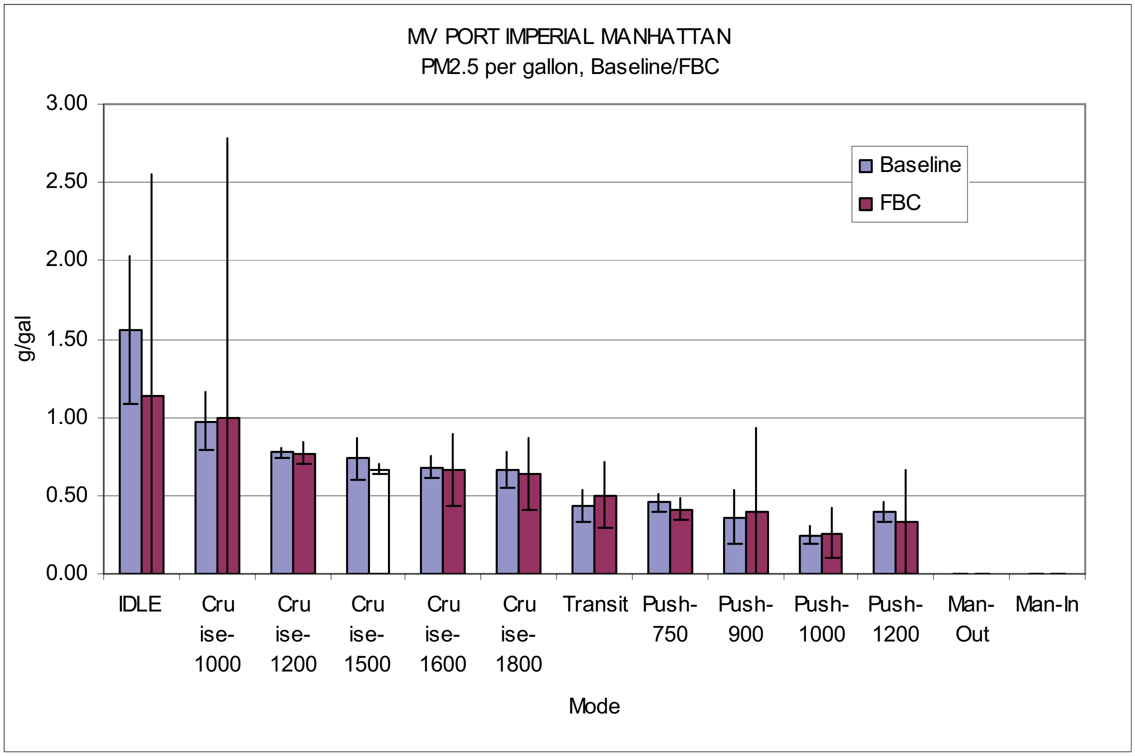

MV PORT IMPERIAL MANHATTAN
PM 2.5 per bhp-hr
g/bhp-hr
0
0
0
0
0
0
0
0
Baseline
Post DOC
IDLE
Cruise-1000
Cruise-1200
Cruise-1500
Cruise-1600
Cruise-1800
Transit
Push-750
Push-900
Push-1000
Push-1200
Mode

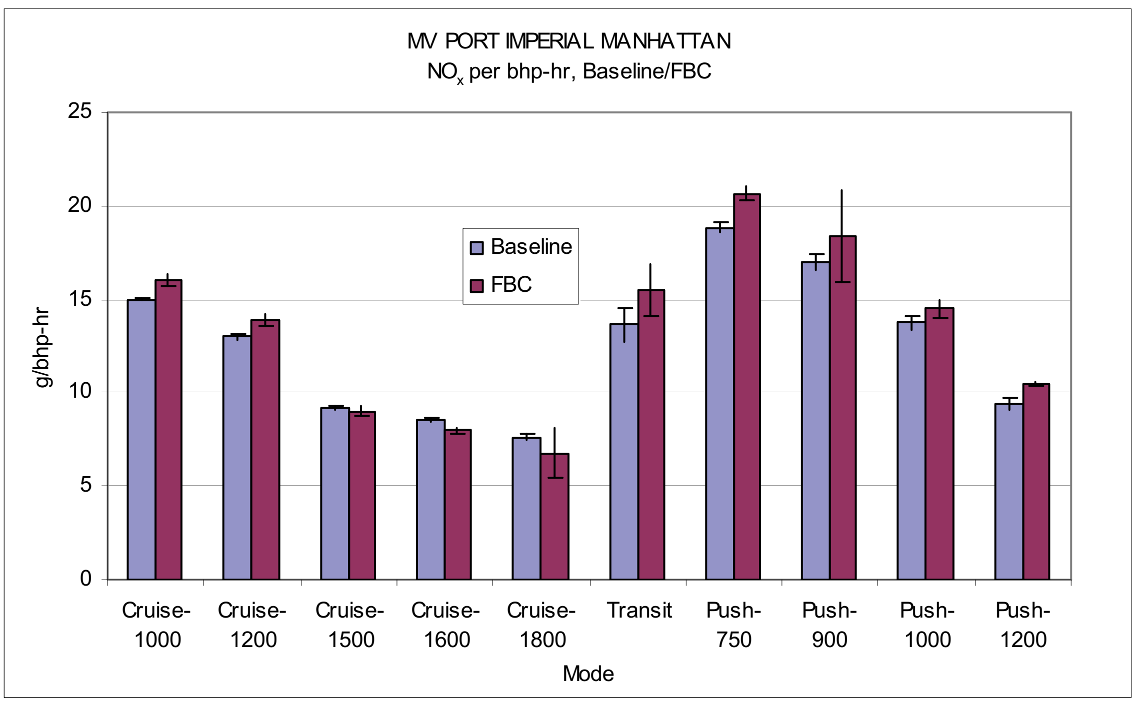

MV PORT IMPRERIAL MANHATTAN
NOx per gallon, Baseline/FBC
g/gal
600
500
400
300
200
100
0
Baseline
FBC
IDLE
Cru ise- 1000
Cru ise- 1200
Cru ise- 1500
Cru ise- 1600
Cru ise- 1800
Transit
Push- 750
Push- 900
Push- 1000
Push- 1200
Man- Out
Man-In
Mode

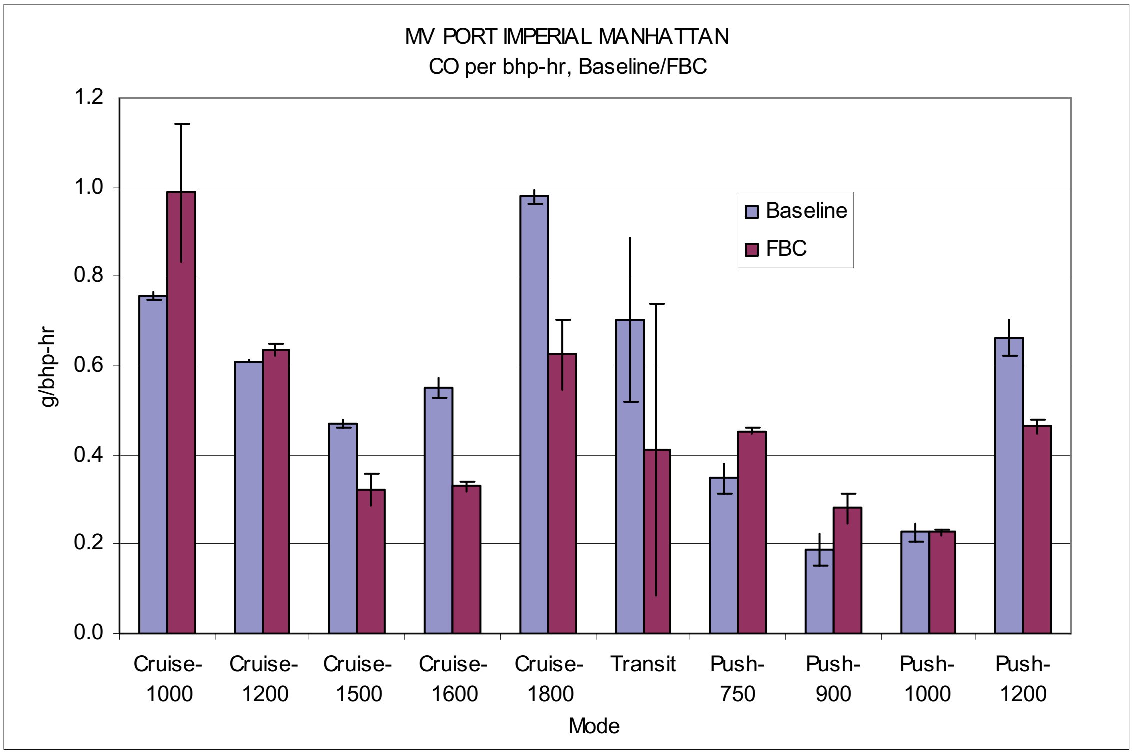

MV PORT IMPERIAL MANHATTAN
CO per gallon, Baseline/FBC
g/gal
80
70
60
50
40
30
20
10
0
Baseline
FBC
IDLE
Cruise- 1000
Cruise- 1200
Cruise- 1500
Cruise- 1600
Cruise- 1800
Transit
Push- 750
Push- 900
Push- 1000
Push- 1200
Man-Out
Man-In
Mode

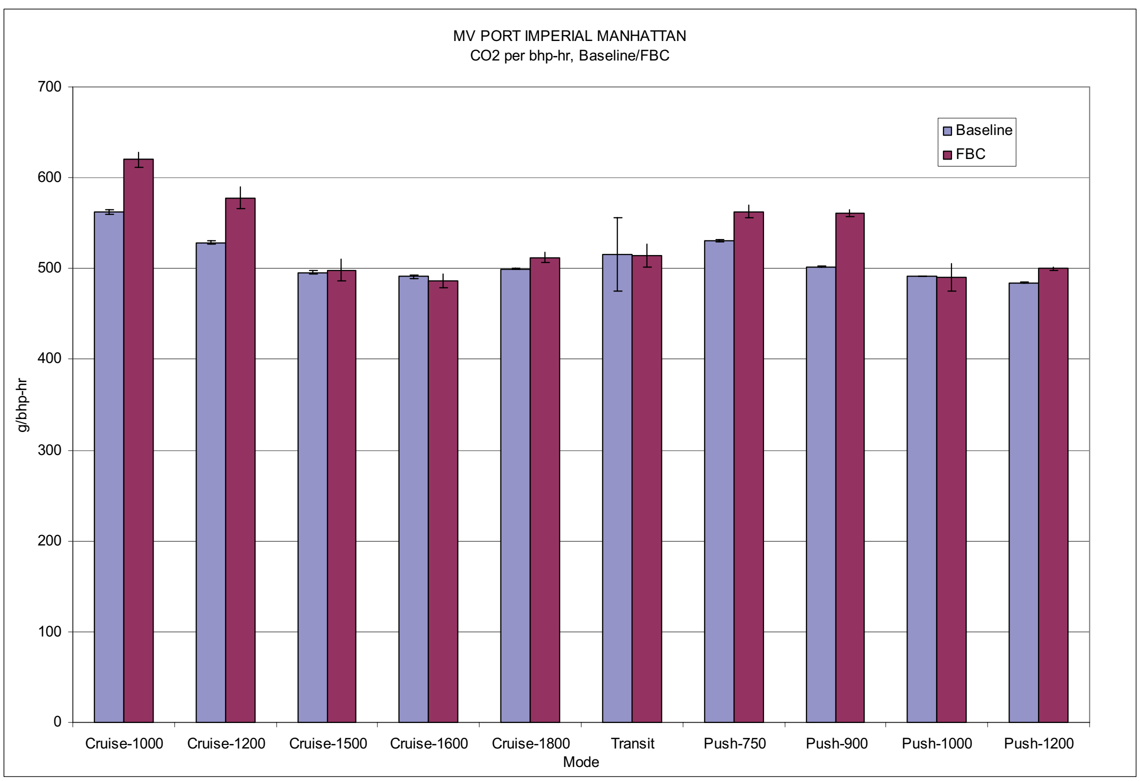

MV PORT IMPERIAL MANHATTAN
CO_2 per gallon, Baseline/FBC
g/gal
0
2
4
6
8
10
12
14
16
18
20
Baseline
FBC
IDLE
Cruise-1000
Cruise-1200
Cruise-1500
Cruise-1600
Cruise-1800
Transit
Push-750
Push-900
Push-1000
Push-1200
Man-Out
Man-In
Mode

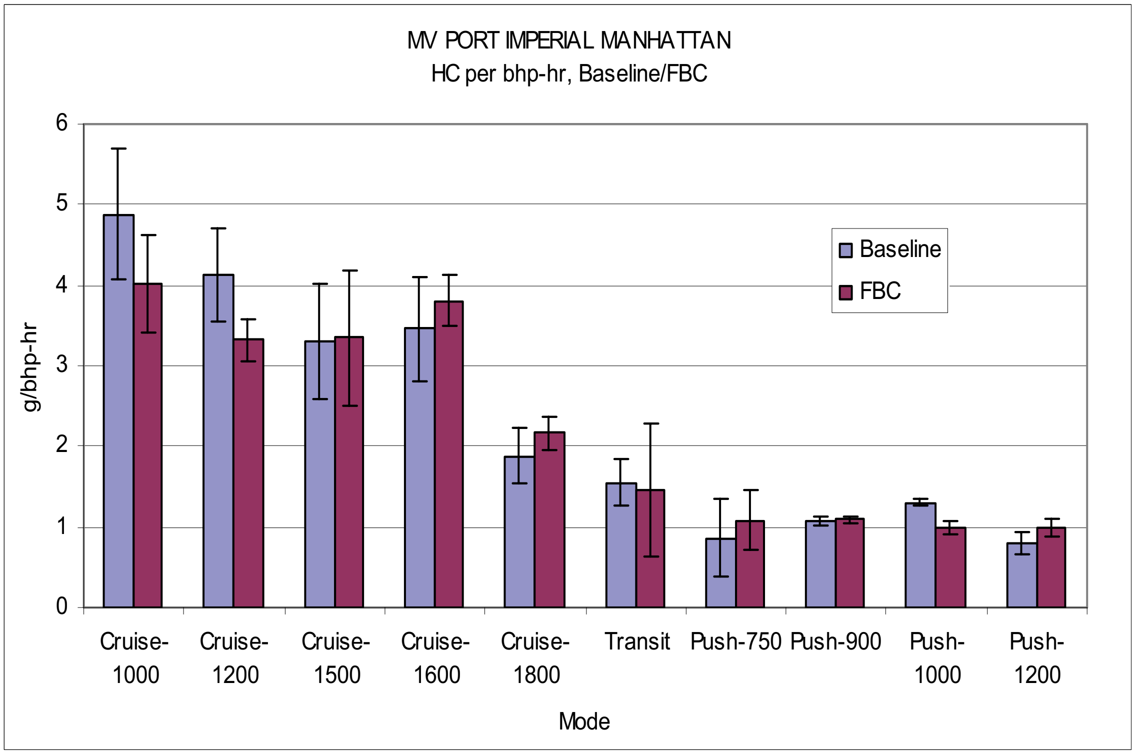

MV PORT IMPERIAL MANHATTAN
HC per gallon, Baseline/FBC
g/gal
0.00
0.05
0.10
0.15
0.20
0.25
Baseline
FBC
IDLE
Cruise-1000
Cruise-1200
Cruise-1500
Cruise-1600
Cruise-1800
Transit
Push-750
Push-900
Push-1000
Push-1200
Man-Out
Man-In
Mode

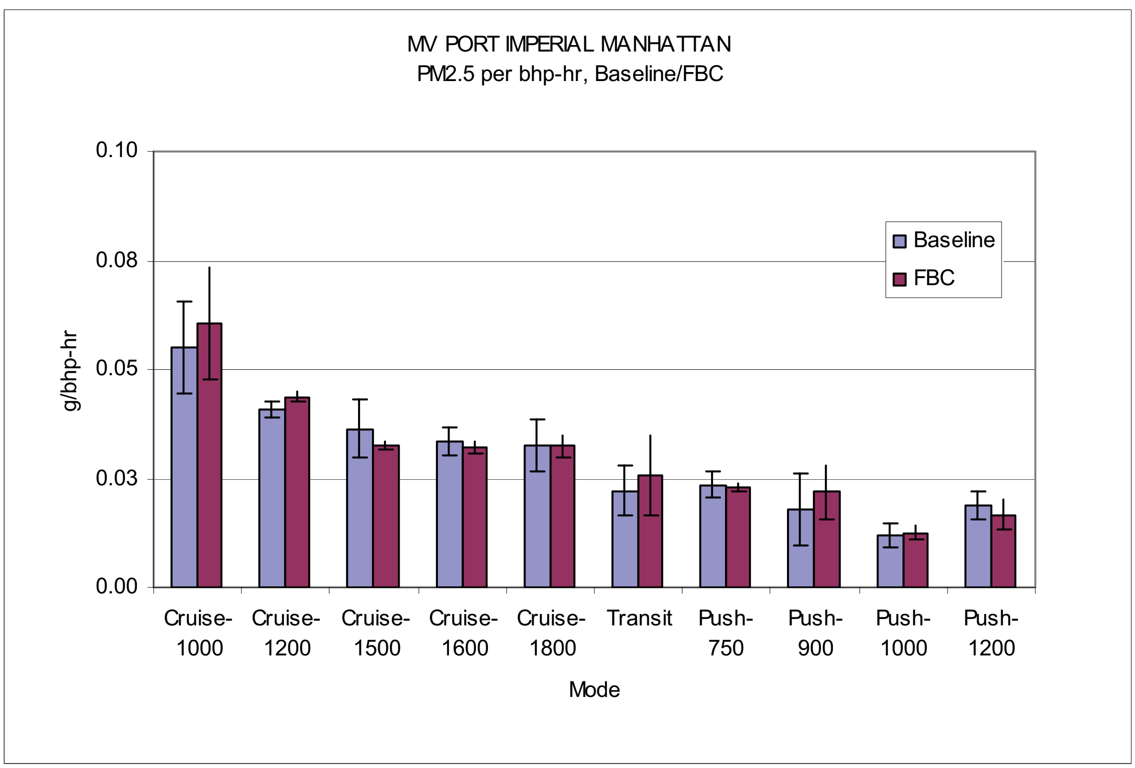

MV PORT IMPERIAL MANHATTAN
PM2.5 per gallon, Baseline/FBC
g/gal
3.00
2.50
2.00
1.50
1.00
0.50
0.00
Baseline
FBC
IDLE
Cru ise- 1000
Cru ise- 1200
Cru ise- 1500
Cru ise- 1600
Cru ise- 1800
Transit
Push- 750
Push- 900
Push- 1000
Push- 1200
Man- Out
Man-In
Mode

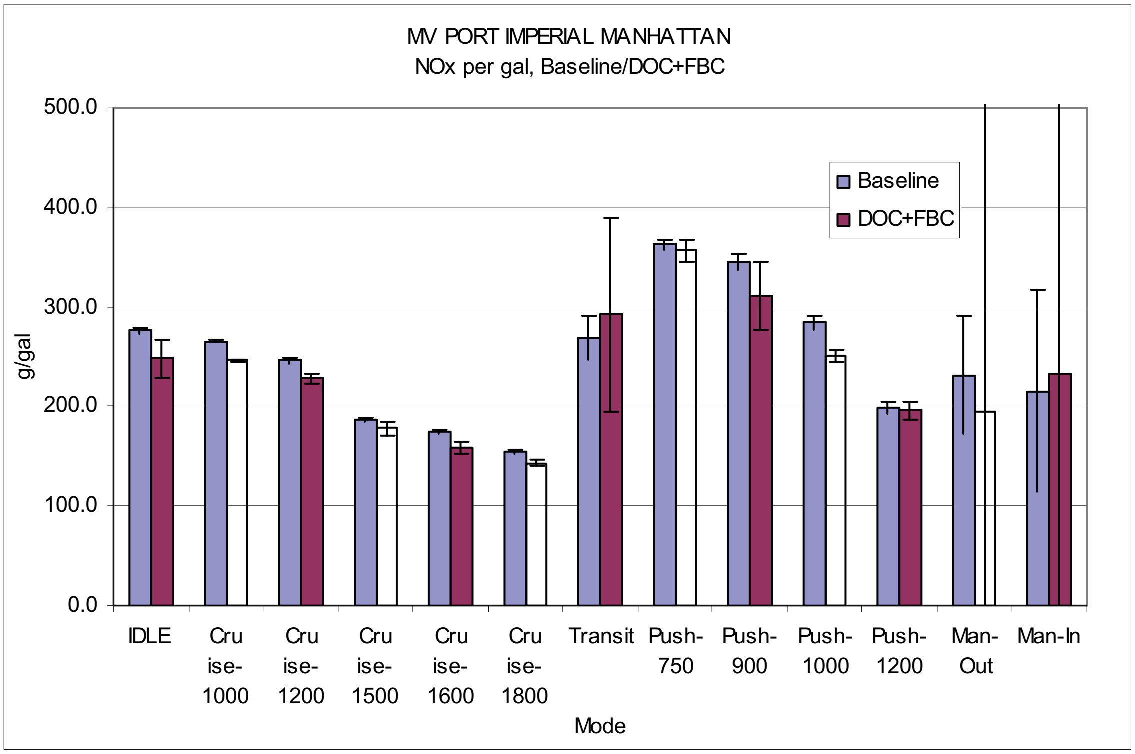

MV PORT IMPERIAL MANHATTAN
NO_x per bhp-hr, Baseline/FBC
g/bhp-hr
25
20
15
10
5
0
Baseline
FBC
Cruise- 1000
Cruise- 1200
Cruise- 1500
Cruise- 1600
Cruise- 1800
Transit
Push- 750
Push- 900
Push- 1000
Push- 1200
Mode

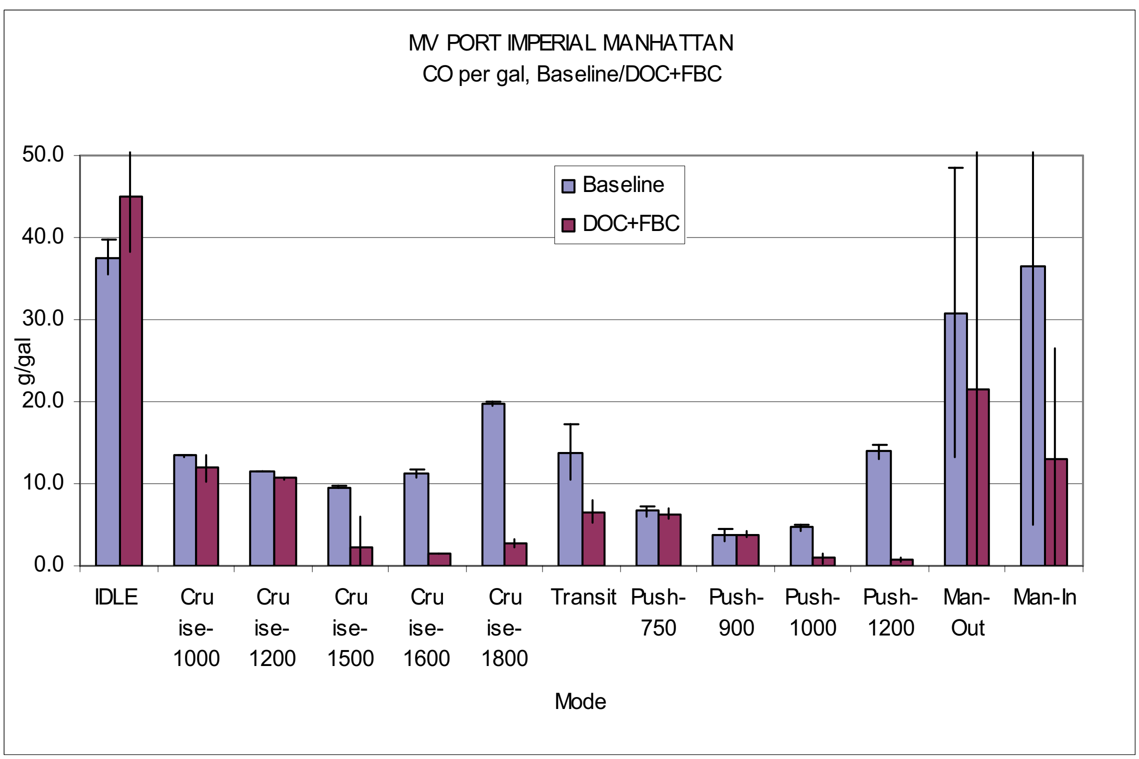

MV PORT IMPERIAL MANHATTAN
CO per bhp-hr, Baseline/FBC
g/bhp-hr
1.2
1.0
0.8
0.6
0.4
0.2
0.0
Baseline
FBC
Cruise-1000
Cruise-1200
Cruise-1500
Cruise-1600
Cruise-1800
Transit
Push-750
Push-900
Push-1000
Push-1200
Mode

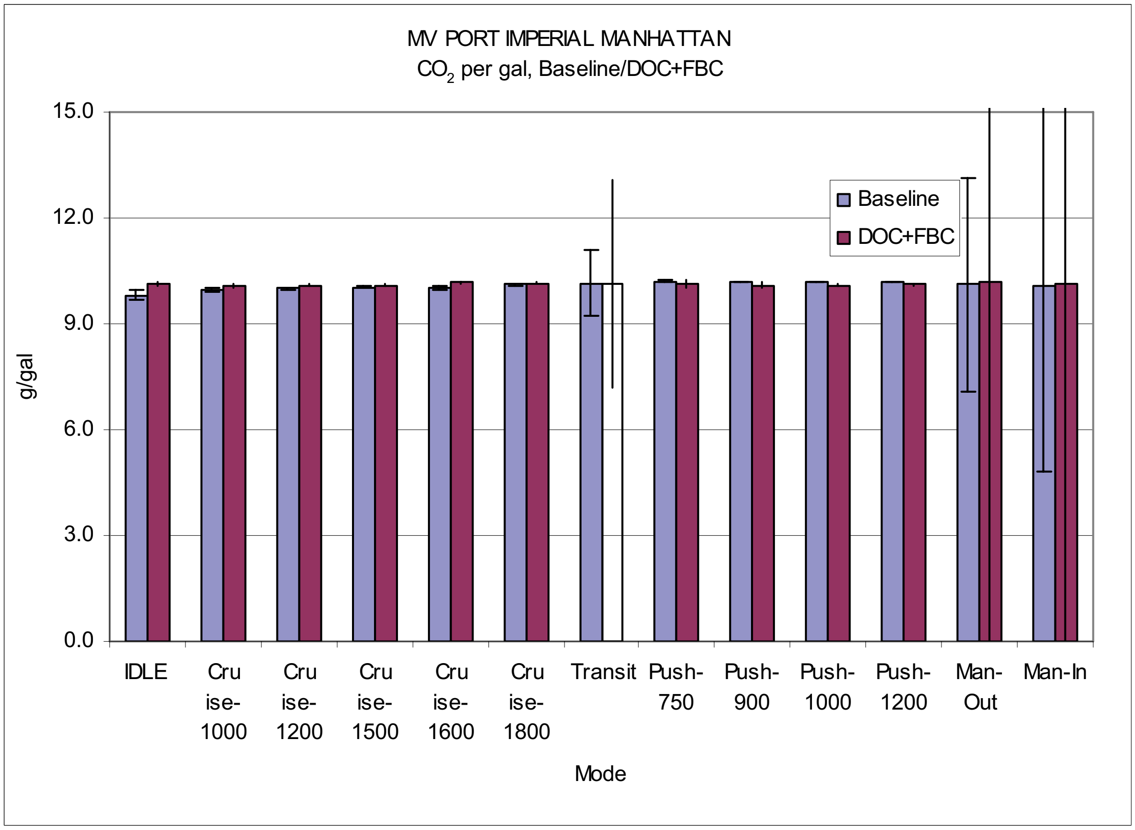

MV PORT IMPERIAL MANHATTAN
CO2 per bhp-hr, Baseline/FBC
g/bhp-hr
700
600
500
400
300
200
100
0
Baseline
FBC
Cruise-1000
Cruise-1200
Cruise-1500
Cruise-1600
Cruise-1800
Transit
Push-750
Push-900
Push-1000
Push-1200
Mode

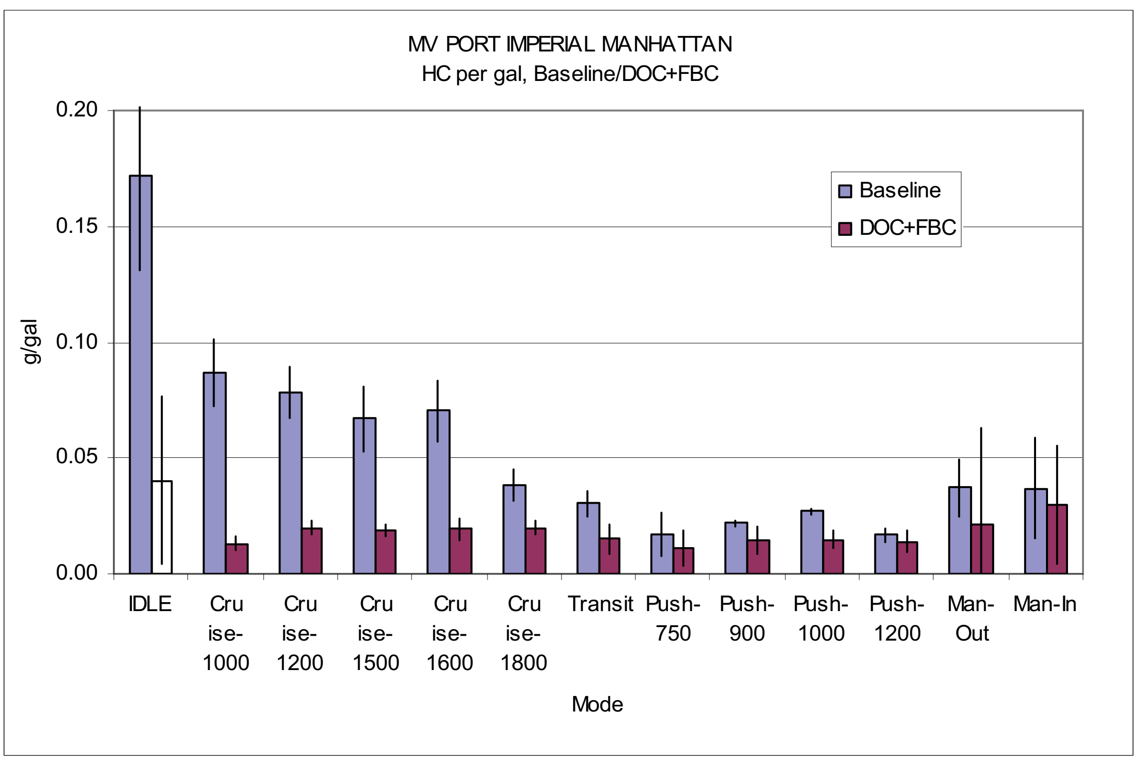

MV PORT IMPERIAL MANHATTAN
HC per bhp-hr, Baseline/FBC
g/bhp-hr
0
1
2
3
4
5
6
Baseline
FBC
Cruise-1000
Cruise-1200
Cruise-1500
Cruise-1600
Cruise-1800
Transit
Push-750
Push-900
Push-1000
Push-1200
Mode

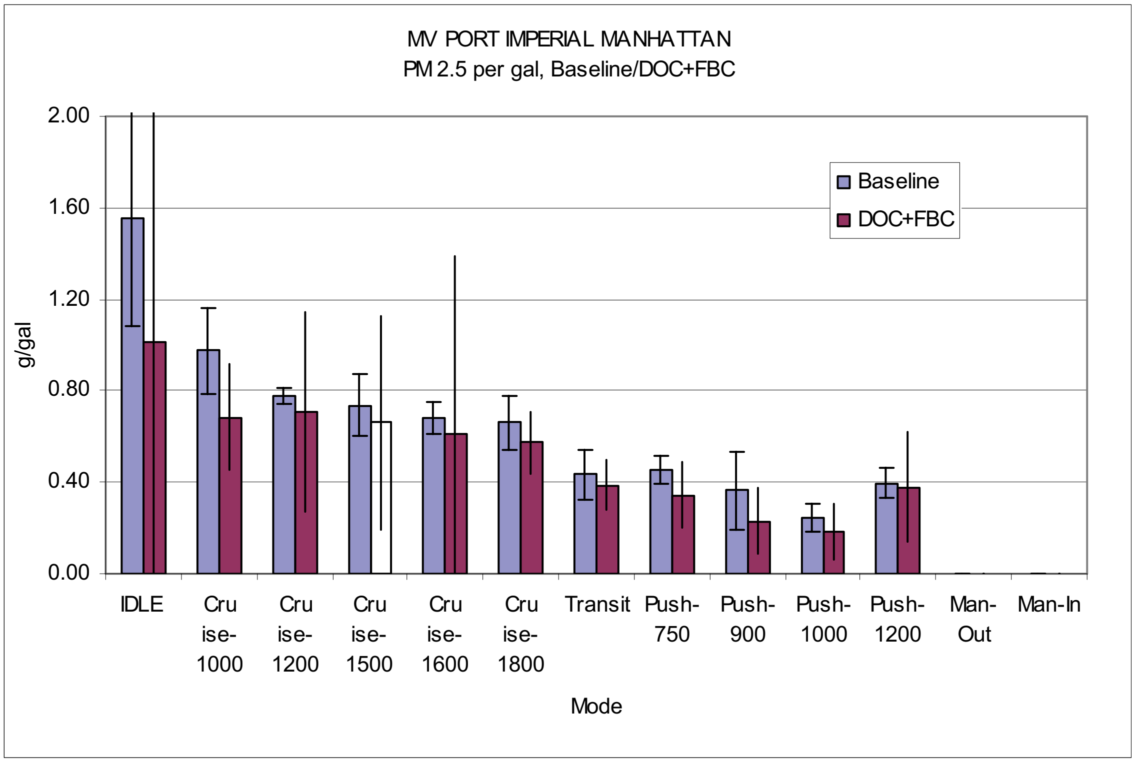

MV PORT IMPERIAL MANHATTAN
PM2.5 per bhp-hr, Baseline/FBC
g/bhp-hr
0.00
0.03
0.05
0.08
0.10
Baseline
FBC
Cruise-1000
Cruise-1200
Cruise-1500
Cruise-1600
Cruise-1800
Transit
Push-750
Push-900
Push-1000
Push-1200
Mode


MV PORT IMPERIAL MANHATTAN
NOx per gal, Baseline/DOC+FBC
500.0
400.0
300.0
200.0
100.0
0.0
g/gal
Baseline
DOC+FBC
IDLE
Cru ise-1000
Cru ise-1200
Cru ise-1500
Cru ise-1600
Cru ise-1800
Transit
Push-750
Push-900
Push-1000
Push-1200
Man-Out
Man-In
Mode

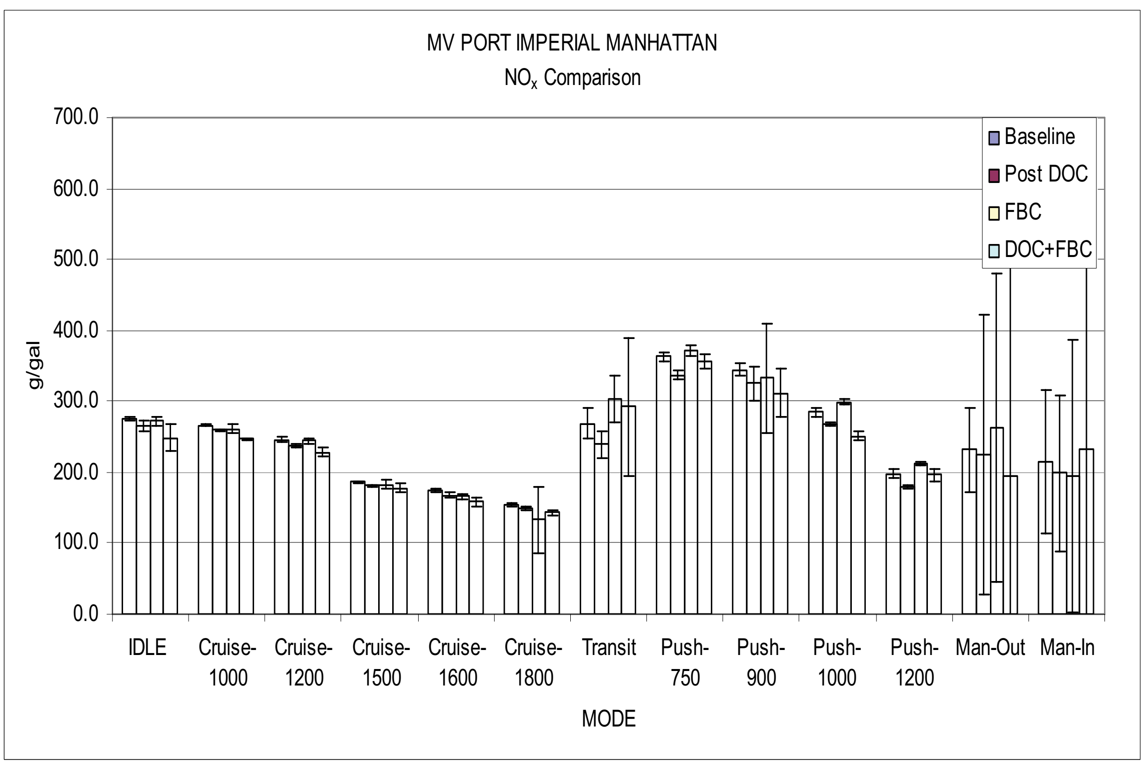

MV PORT IMPERIAL MANHATTAN
CO per gal, Baseline/DOC+FBC
50.0
40.0
30.0
20.0
10.0
0.0
g/gal
Baseline
DOC+FBC
IDLE
Cru ise-1000
Cru ise-1200
Cru ise-1500
Cru ise-1600
Cru ise-1800
Transit
Push-750
Push-900
Push-1000
Push-1200
Man-Out
Man-In
Mode


MV PORT IMPERIAL MANHATTAN
CO_2 per gal, Baseline/DOC+FBC
15.0
12.0
9.0
6.0
3.0
0.0
g/gal
Baseline
DOC+FBC
IDLE
Cru ise-1000
Cru ise-1200
Cru ise-1500
Cru ise-1600
Cru ise-1800
Transit
Push-750
Push-900
Push-1000
Push-1200
Man-Out
Man-In
Mode

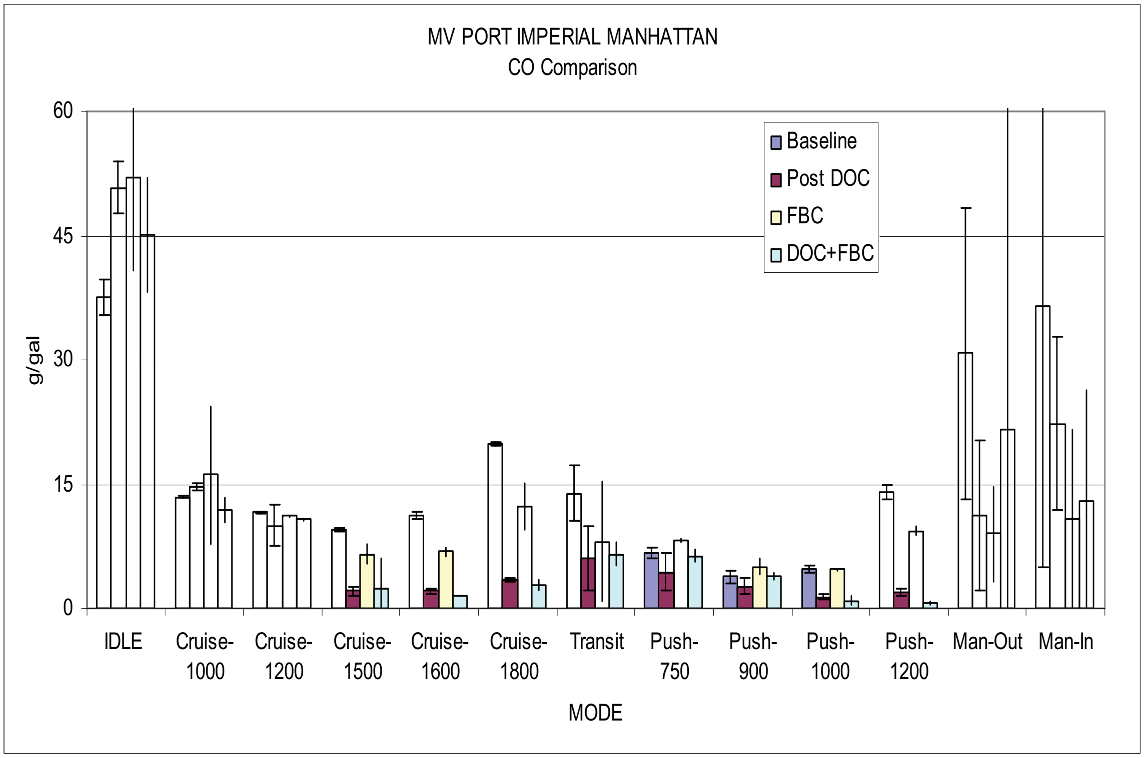

MV PORT IMPERIAL MANHATTAN
HC per gal, Baseline/DOC+FBC
0.20
0.15
0.10
0.05
0.00
g/gal
Baseline
DOC+FBC
IDLE
Cru ise-1000
Cru ise-1200
Cru ise-1500
Cru ise-1600
Cru ise-1800
Transit
Push-750
Push-900
Push-1000
Push-1200
Man-Out
Man-In
Mode

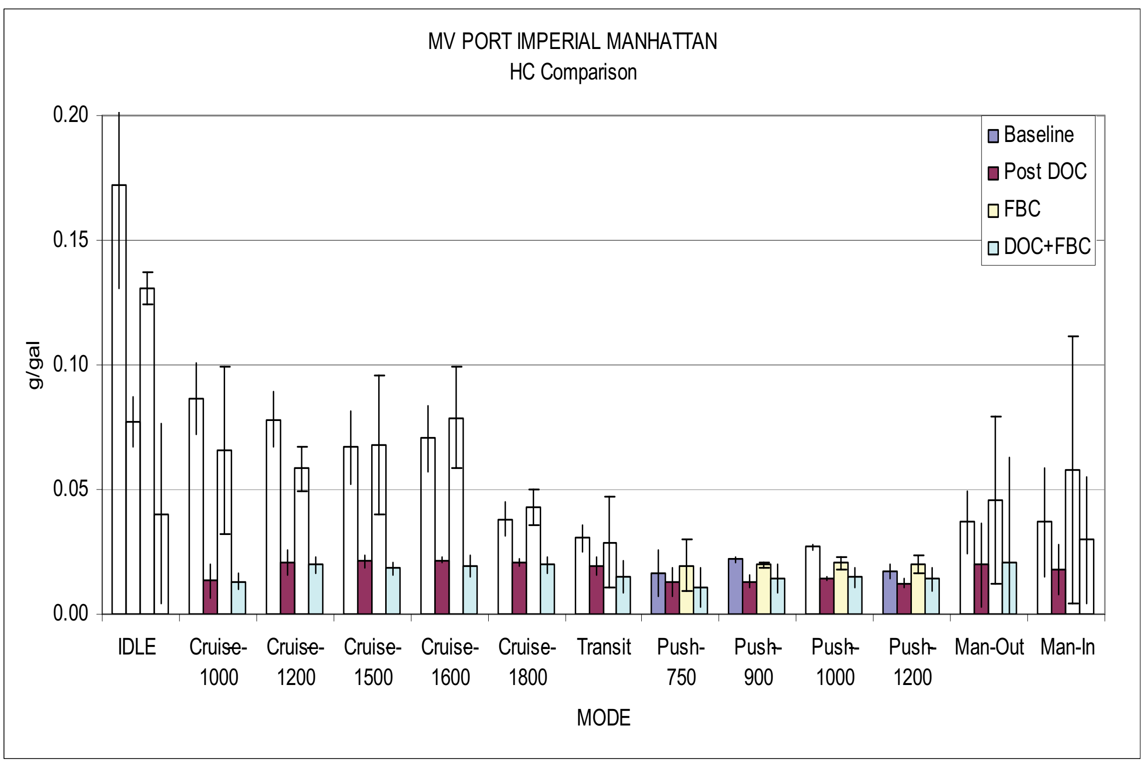


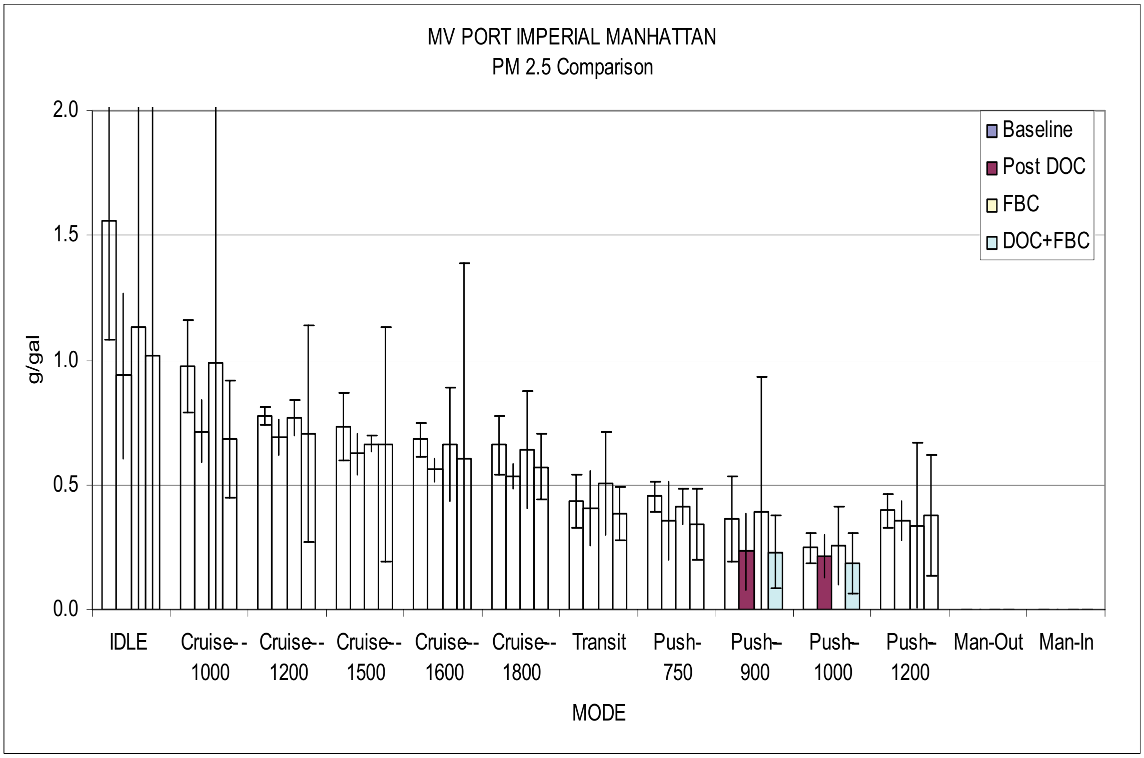
MV PORT IMPERIAL MANHATTAN
PM 2.5 per gal, Baseline/DOC+FBC
Baseline
DOC+FBC
g/gal
2.00
1.60
1.20
0.80
0.40
0.00
IDLE
Cruise-1000
Cruise-1200
Cruise-1500
Cruise-1600
Cruise-1800
Transit
Push-750
Push-900
Push-1000
Push-1200
Man-Out
Man-In
Mode

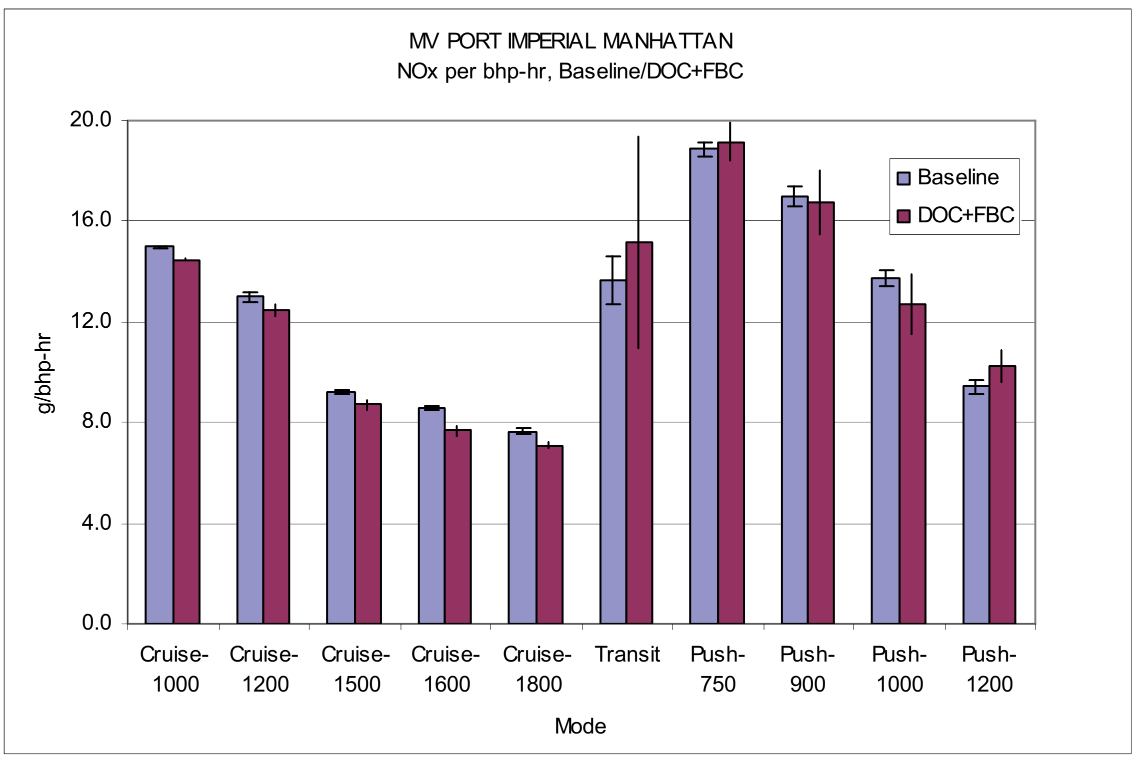


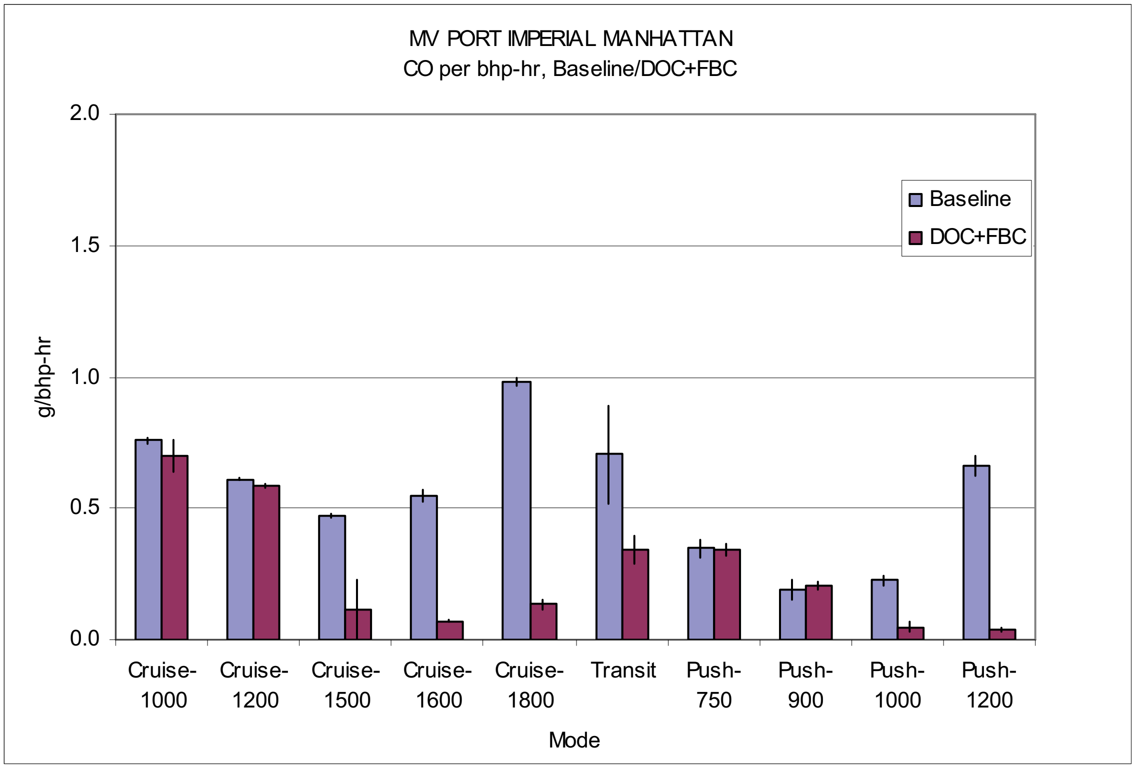
MV PORT IMPERIAL MANHATTAN
NO$_x$ Comparison
Baseline
Post DOC
FBC
DOC+FBC
g/gal
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
IDLE
Cruise-1000
Cruise-1200
Cruise-1500
Cruise-1600
Cruise-1800
Transit
Push-750
Push-900
Push-1000
Push-1200
Man-Out
Man-In
MODE

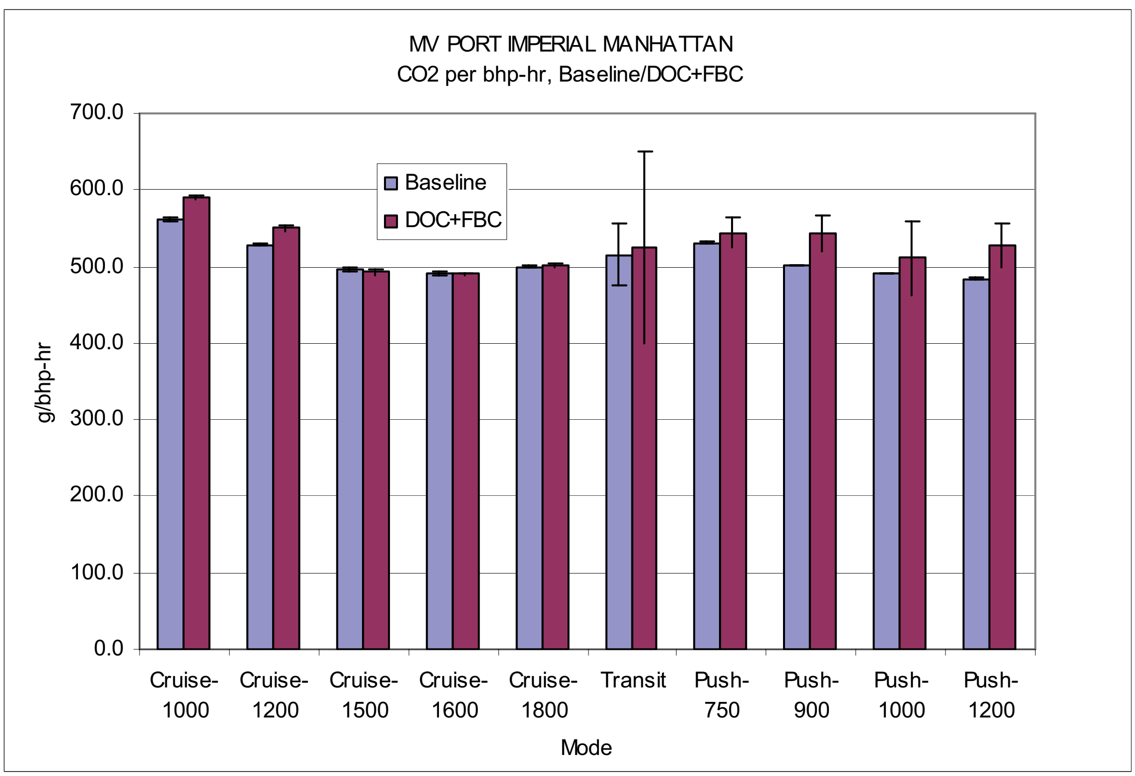

MV PORT IMPERIAL MANHATTAN
CO Comparison
60
45
30
15
0
g/gal
Baseline
Post DOC
FBC
DOC+FBC
IDLE
Cruise-1000
Cruise-1200
Cruise-1500
Cruise-1600
Cruise-1800
Transit
Push-750
Push-900
Push-1000
Push-1200
Man-Out
Man-In
MODE

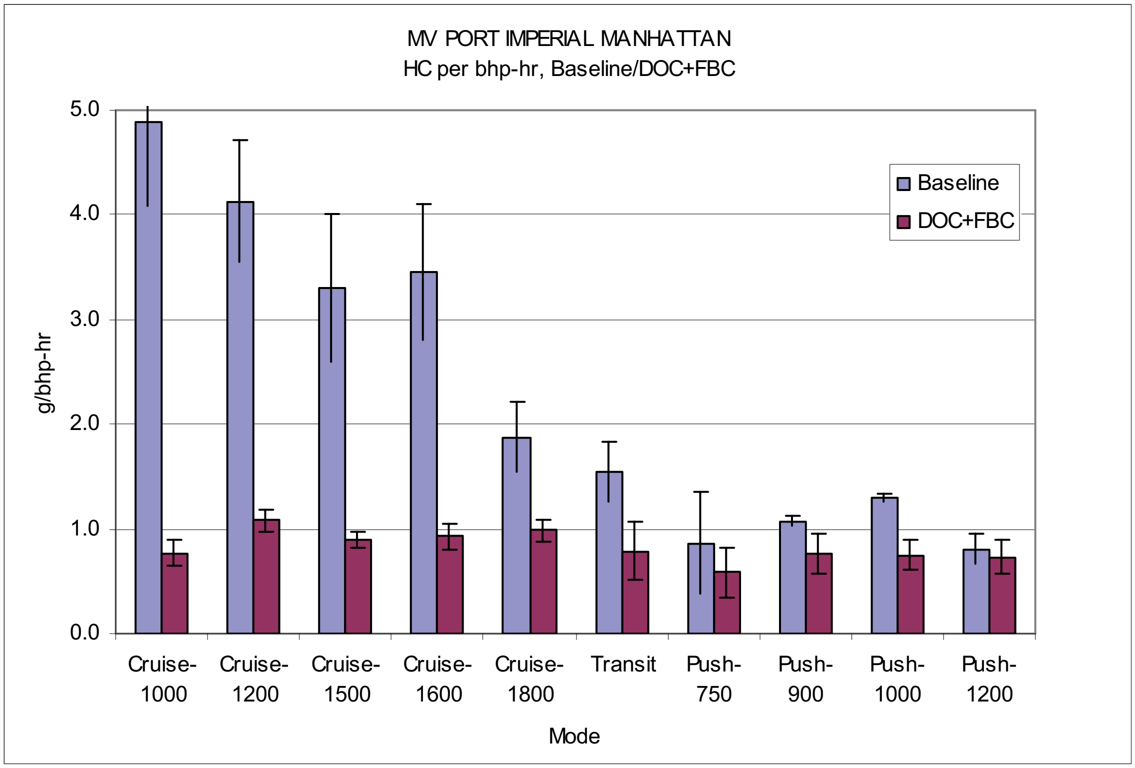

MV PORT IMPERIAL MANHATTAN
HC Comparison
0.20
0.15
0.10
0.05
0.00
g/gal
Baseline
Post DOC
FBC
DOC+FBC
IDLE
Cruise-1000
Cruise-1200
Cruise-1500
Cruise-1600
Cruise-1800
Transit
Push-750
Push-900
Push-1000
Push-1200
Man-Out
Man-In
MODE

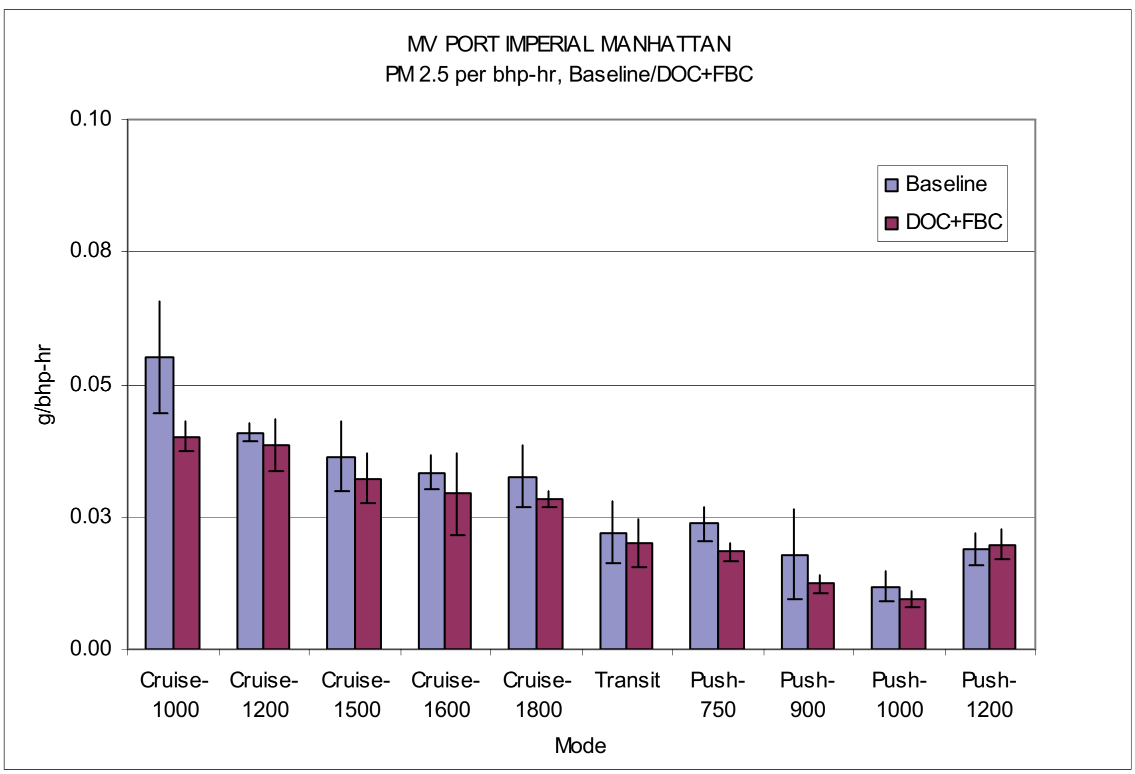

MV PORT IMPERIAL MANHATTAN
PM 2.5 Comparison
g/gal
2.0
1.5
1.0
0.5
0.0
Baseline
Post DOC
FBC
DOC+FBC
IDLE
Cruise--1000
Cruise--1200
Cruise--1500
Cruise--1600
Cruise--1800
Transit
Push-750
Push--900
Push--1000
Push-1200
Man-Out
Man-In
MODE

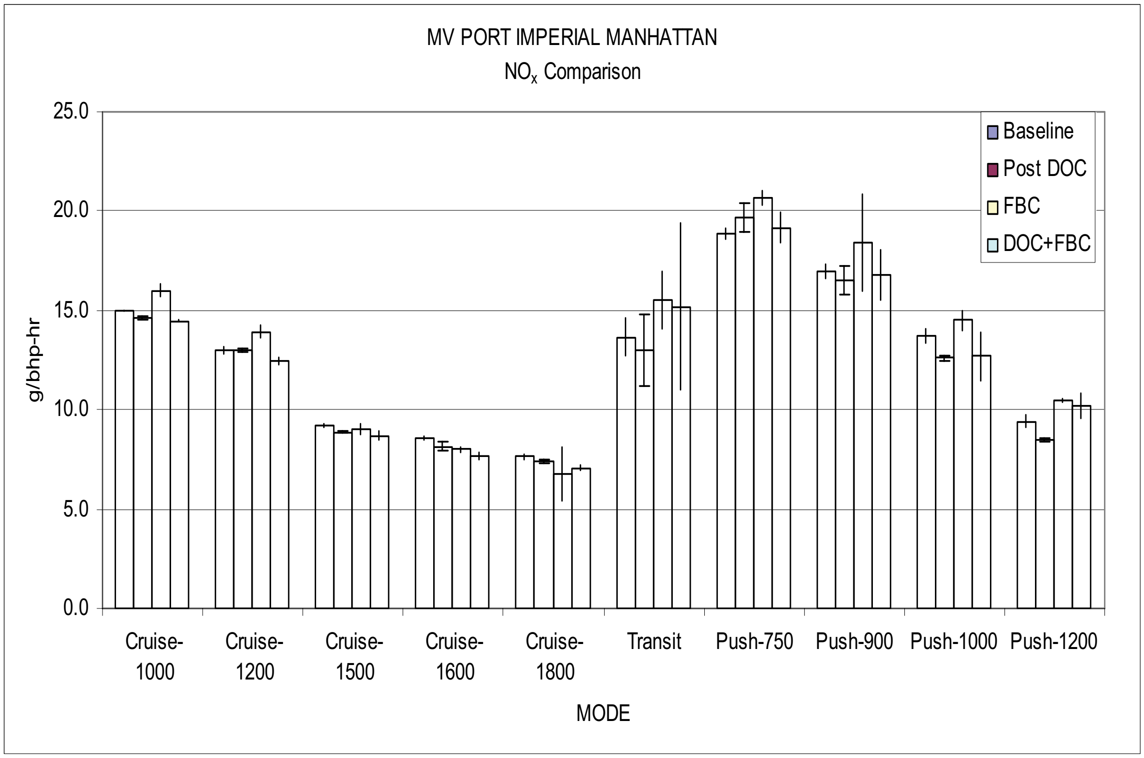

MV PORT IMPERIAL MANHATTAN
NOx per bhp-hr, Baseline/DOC+FBC
g/bhp-hr
20.0
16.0
12.0
8.0
4.0
0.0
Baseline
DOC+FBC
Cruise-1000
Cruise-1200
Cruise-1500
Cruise-1600
Cruise-1800
Transit
Push-750
Push-900
Push-1000
Push-1200
Mode


MV PORT IMPERIAL MANHATTAN
CO per bhp-hr, Baseline/DOC+FBC
g/bhp-hr
2.0
1.5
1.0
0.5
0.0
Baseline
DOC+FBC
Cruise-1000
Cruise-1200
Cruise-1500
Cruise-1600
Cruise-1800
Transit
Push-750
Push-900
Push-1000
Push-1200
Mode

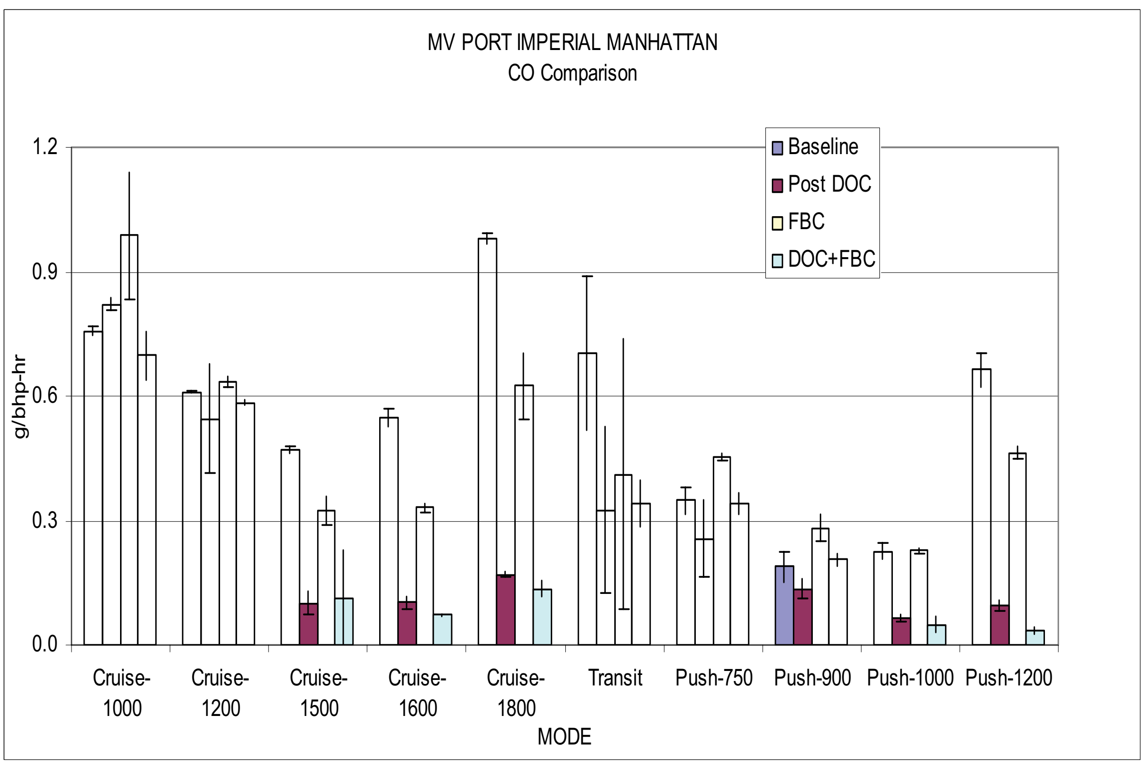

MV PORT IMPERIAL MANHATTAN
CO2 per bhp-hr, Baseline/DOC+FBC
g/bhp-hr
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
Baseline
DOC+FBC
Cruise-1000
Cruise-1200
Cruise-1500
Cruise-1600
Cruise-1800
Transit
Push-750
Push-900
Push-1000
Push-1200
Mode


MV PORT IMPERIAL MANHATTAN
HC per bhp-hr, Baseline/DOC+FBC
g/bhp-hr
5.0
4.0
3.0
2.0
1.0
0.0
Baseline
DOC+FBC
Cruise-1000
Cruise-1200
Cruise-1500
Cruise-1600
Cruise-1800
Transit
Push-750
Push-900
Push-1000
Push-1200
Mode

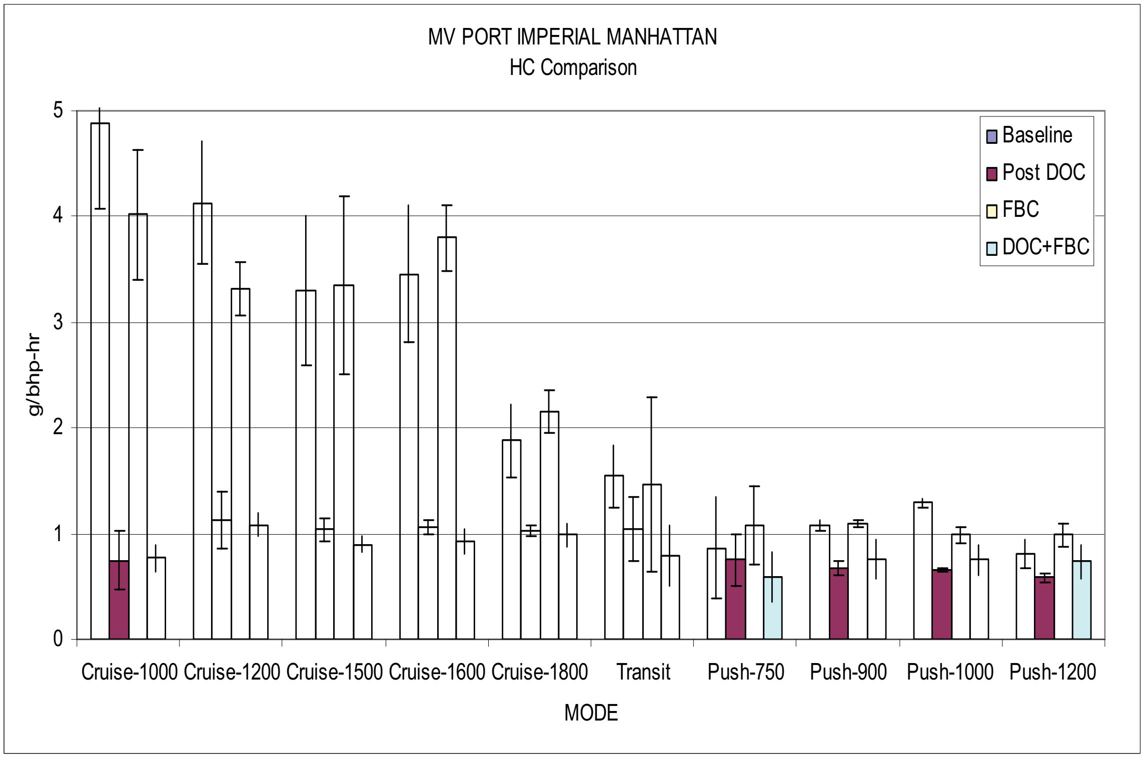

MV PORT IMPERIAL MANHATTAN
PM 2.5 per bhp-hr, Baseline/DOC+FBC
g/bhp-hr
0.10
0.08
0.05
0.03
0.00
Baseline
DOC+FBC
Cruise-1000
Cruise-1200
Cruise-1500
Cruise-1600
Cruise-1800
Transit
Push-750
Push-900
Push-1000
Push-1200
Mode

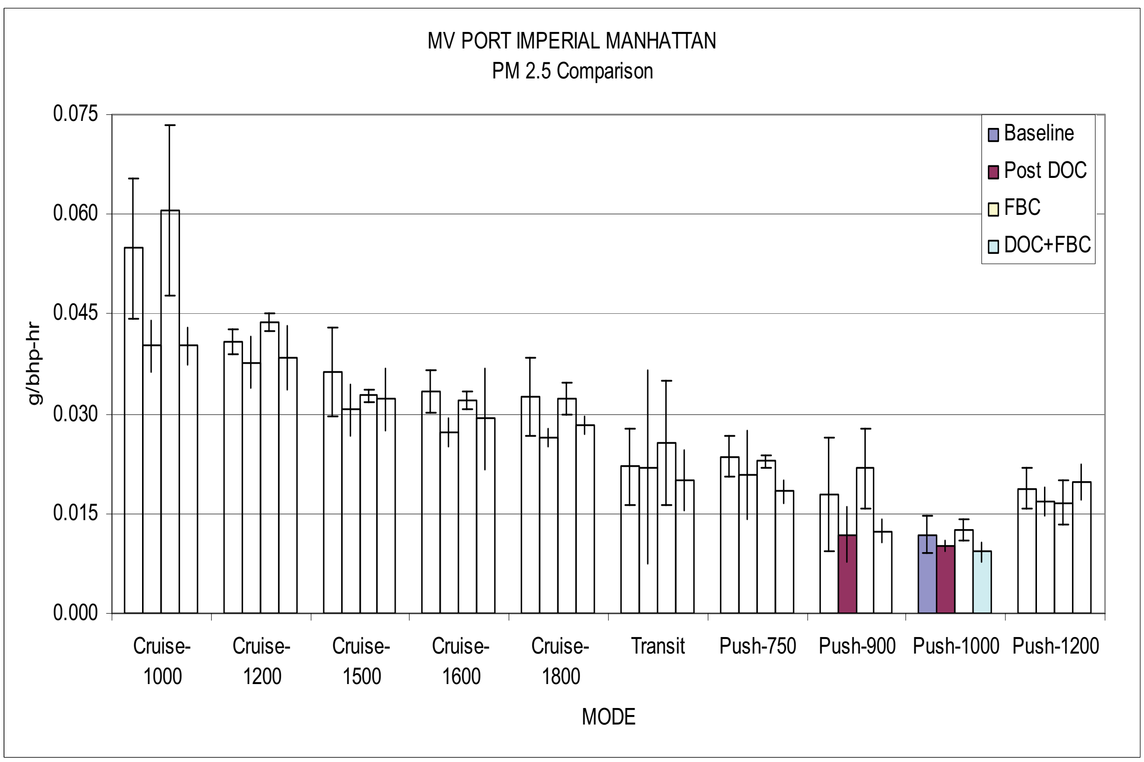


MV PORT IMPERIAL MANHATTAN
NOx Comparison
25.0
20.0
15.0
10.0
5.0
0.0
g/bhp-hr
Baseline
Post DOC
FBC
DOC+FBC
Cruise-1000
Cruise-1200
Cruise-1500
Cruise-1600
Cruise-1800
Transit
Push-750
Push-900
Push-1000
Push-1200
MODE



MV PORT IMPERIAL MANHATTAN
CO Comparison
1.2
0.9
0.6
0.3
0.0
g/bhp-hr
Baseline
Post DOC
FBC
DOC+FBC
Cruise-1000
Cruise-1200
Cruise-1500
Cruise-1600
Cruise-1800
Transit
Push-750
Push-900
Push-1000
Push-1200
MODE


MV PORT IMPERIAL MANHATTAN
HC Comparison
g/bhp-hr
0
1
2
3
4
5
Baseline
Post DOC
FBC
DOC+FBC
Cruise-1000
Cruise-1200
Cruise-1500
Cruise-1600
Cruise-1800
Transit
Push-750
Push-900
Push-1000
Push-1200
MODE


MV PORT IMPERIAL MANHATTAN
PM 2.5 Comparison
g/bhp-hr
0.000
0.015
0.030
0.045
0.060
0.075
Baseline
Post DOC
FBC
DOC+FBC
Cruise-1000
Cruise-1200
Cruise-1500
Cruise-1600
Cruise-1800
Transit
Push-750
Push-900
Push-1000
Push-1200
MODE

MV JOHN KEITH

													PM10
													[g/gal]
													2.18
													2.21
					-	-						-	-
													1.67
													1.72
					-	-						-	-
													2.19
													2.15
					-	-						-	-
													2.90
													2.93
					-	-						-	-
													2.39
													2.04
					-	-						-	-
													2.13
													2.16
					-	-						-	-
													1.29
													1.73
					-	-						-	-
													0.73
													0.84
					-	-						-	-
													1.09
													0.93
					-	-						-	-
													1.58
													1.34
					-	-						-	-

CALCULATED EMISSIONS DATA: MV JOHN KEITH, Baseline, April 2006						
						PM10
						g/bhp-hr
	-	-	-	-	-	-
	-	-	-	-	-	-
	-	-	-	-	-	-
	-	-	-	-	-	-
						0.084
						0.085
					-	-
						0.104
						0.101
					-	-
						0.091
						0.131
					-	-
						0.108
						0.093
					-	-
						0.103
						0.113
					-	-
						0.062
						0.082
					-	-
						0.038
						0.044
					-	-
						0.036
						0.031
					-	-
						0.070
						0.058
					-	-

CALCULATED EMISSIONS DATA: MV JOHN KEITH, Post DOC, April 2006													
													PM10
													[g/gal]
													1.36
													1.76
					-	-						-	-
													0.23
													0.27
					-	-						-	-
													0.78
													0.76
					-	-						-	-
													2.14
													2.26
					-	-						-	-
													1.65
													1.66
					-	-						-	-
													1.18
													1.48
					-	-						-	-
													1.19
													1.01
					-	-							0.00
													0.46
													0.42
					-	-						-	-
													0.55
													0.55
						-						-	-
													1.30
													1.25
					-	-						-	-

CALCULATED EMISSIONS DATA: MV JOHN KEITH, PostDOC, April 2006						
						PM10
						g/bhp-hr
	-	-	-	-	-	-
	-	-	-	-	-	-
	-	-	-	-	-	-
	-	-	-	-	-	-
						0.011
						0.013
					-	-
						0.037
						0.036
					-	-
						0.096
						0.102
					-	-
						0.074
						0.075
					-	-
						0.061
						0.076
					-	-
						0.061
						0.052
					-	-
						0.025
						0.023
					-	-
						0.025
						0.025
					-	-
						0.058
						0.054
					-	-

MV JOHN KEITH Pre DOC Engine Operating Parameters and Fuel Consumption Rates

Mode	Exh. Temp, C	Inlet Air Temp, C	Exh. BP,, PSIG	RPM	Fuel flow, lb/hr	Fuel flow, gph	Torq., ft-lb	BHP	BSFC, lb/bhp-hr
Idle	80.5	31.4	0.38	599.9	4.20	0.59			
SS-1000	178.5	33.9	0.41	997.9	22.77	3.20	NMF	64.3	0.354
SS-1350	259.9	31.9	0.88	1353.5	51.02	7.18	NMF	152.1	0.335
SS-1700	265.8	42.0	-0.06	1702.5	91.64	12.89	NMF	328.3	0.287
SS-1950	254.5	47.1	-3.58	1944.2	123.39	17.35	NMF	382.5	0.323
SS-2150	265.8	49.7	-3.06	2148.6	163.26	22.96	NMF	454.4	0.360
Push-820	201.5	45.2	0.51	839.7	22.69	3.19	NMF	60.4	0.376
Push-1000	258.5	45.3	0.56	1006.9	36.35	5.11	NMF	114.4	0.318
Push-1200	331.4	41.1	-0.07	1205.7	63.63	8.95	NMF	204.8	0.311
Transit	260.6	46.9	-0.07	1303.0	63.25	8.90	NMF	186.5	0.339

MV JOHN KEITH Post DOC Engine Operating Parameters and Fuel Consumption Rates

Mode	Exh. Temp, C	Inlet Air Temp, C	Exh. BP,, PSIG	RPM	Fuel flow, lb/hr	Fuel flow, gph	Torq., ft-lb	BHP	BSFC, lb/bhp-hr
Idle	78.0	24.3	0.16	642.3	4.57	0.64	NMF		
SS-1000	179.8	31.1	0.58	1005.7	23.13	3.25	NMF	65.5	0.353
SS-1350	258.3	30.0	0.58	1354.3	51.10	7.19	NMF	152.4	0.335
SS-1700	264.5	37.5	0.57	1703.3	91.75	12.90	NMF	287.0	0.320
SS-1950	253.6	39.0	-3.49	1955.7	124.90	17.57	NMF	386.6	0.323
SS-2150	259.2	35.0	-3.45	2149.7	163.65	23.02	NMF	445.4	0.367
Push-820	200.2	39.5	0.42	822.3	22.69	3.19	NMF	60.4	0.376
Push-1000	273.8	40.0	0.67	1001.7	35.80	5.04	NMF	114.4	0.318
Push-1200	338.1	38.1	1.10	1205.0	63.63	8.95	NMF	204.8	0.311
Transit	256.9	43.4	-0.02	1282.4	61.45	8.64	NMF	180.3	0.341

MV JOHN KEITH Baseline Transit Test Averages (April 2006).

Mode	Time, sec	% of Time	RPM	Torque	BHP	Fuel Cons., lb	NOx, kg/hr	PM 2.5, g/hr	HC, g/hr
Push	1056	45.10%	1026	821	164	3.89	1.06	5.51	79
Maneuver	520	22.20%	1160	730	170	2.11	1.23	3.85	340
Cruise	767	32.70%	1808	1331	458	8.03	0.84	33.7	285
Total	2343	100.00%				14.04			

MV JOHN KEITH Pre DOC April 2006 Transit Test

Mode	Transit 1				Transit 2				Transit 3			
	Start , sec	Stop, sec	Duration, sec	% of Time	Start , sec	Stop, sec	Duration, sec	% of Time	Start , sec	Stop, sec	Duration, sec	% of Time
Push	0	180	180	24.1	0	180	180	21.5	0	180	180	23.7
Maneuver, Out	181	266	85	11.4	181	272	91	10.9	181	260	79	10.4
Cruise	267	484	217	29.1	273	584	311	37.2	261	500	239	31.4
Maneuver, In	485	570	85	11.4	585	672	87	10.4	501	594	93	12.2
Push	571	750	179	24.0	673	840	167	20.0	595	765	170	22.3

Mode	Transit 1				Transit 2				Transit 3			
	RPM	Torque	bhp	Fuel Consumed, lb	RPM	Torque	bhp	Fuel Consumed, lb	RPM	Torque	bhp	Fuel Consumed, lb
Push	1001	746	149	1.85	1072	931	190	2.24	1001	783	149	1.84
Maneuver, Out	1521	1049	304	2.27	1221	776	180	1.72	1358	898	232	1.84
Cruise	1803	1326	455	6.29	1814	1337	462	9.15	1806	1329	457	6.95
Maneuver, In	949	549	99	0.61	969	565	104	0.53	942	543	97	0.55
Push	1071	886	190	2.22	1003	786	150	1.72	1008	796	153	1.77

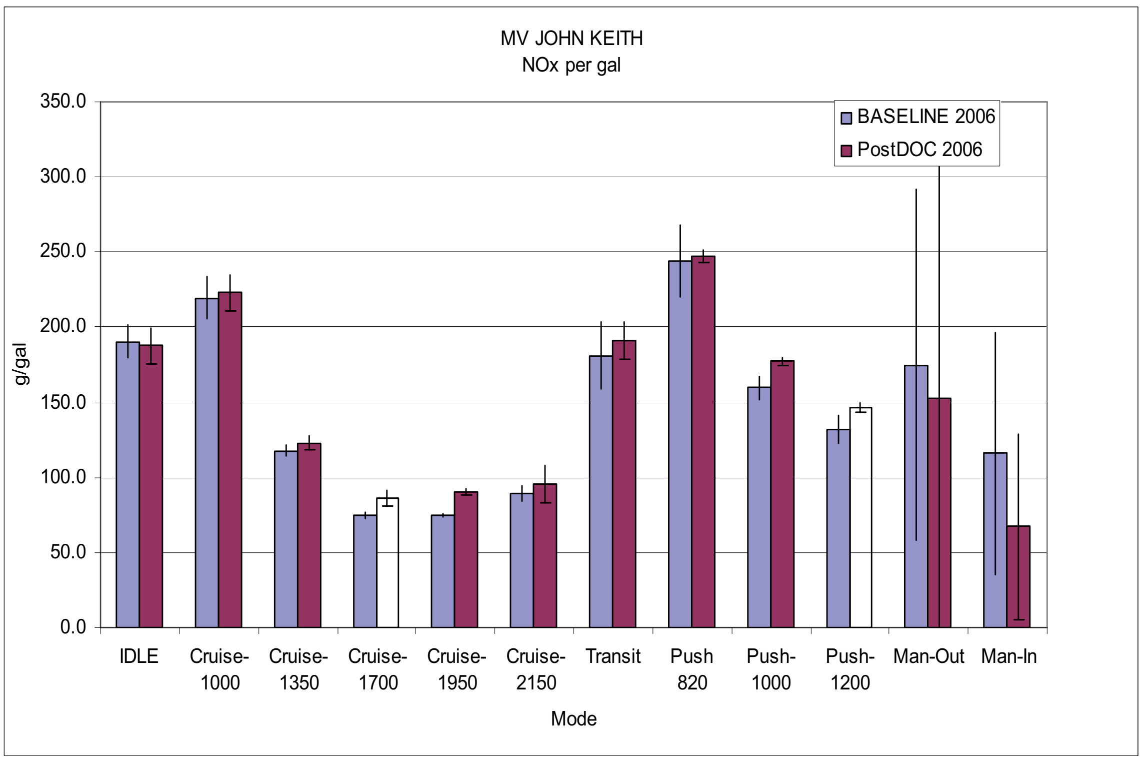
MV JOHN KEITH Post DOC Transit Test Averages (April 2006).

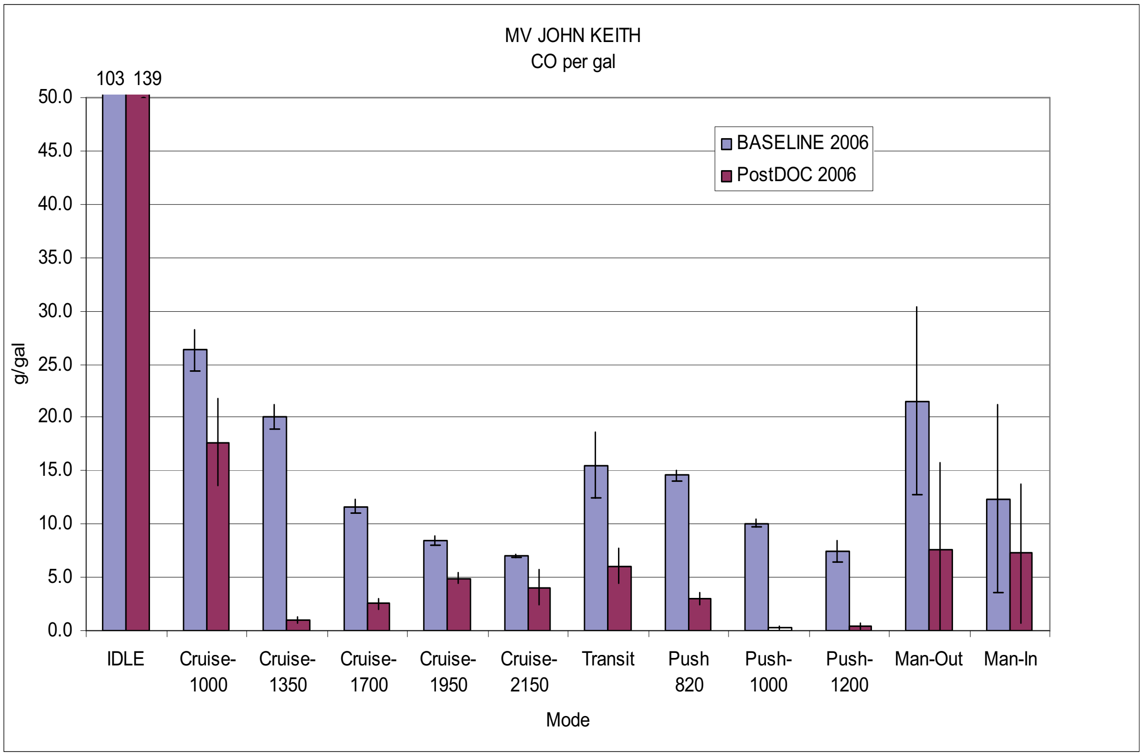
Mode	Time, sec	% of Time	RPM	Torque	BHP	Fuel Cons., lb	NOx, kg/hr	PM 2.5, g/hr	HC, kg/hr
Push	1083	44.00%	1019	819	159	3.88	0.93	4.06	33.8
Maneuver	535	21.70%	1031	621	128	2.51	0.95	2.34	110
Cruise	842	34.20%	1795	1317	450	7.46	1.24	19.48	97
Total	2460	100.00%				13.85			

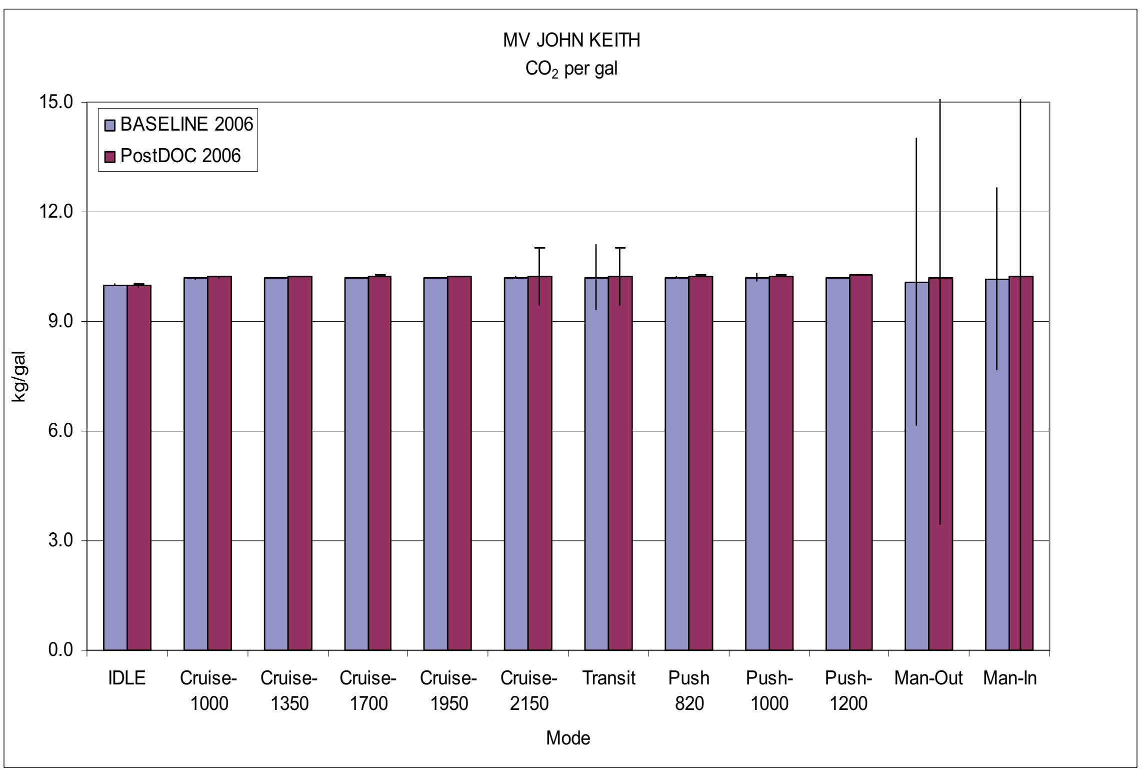
MV JOHN KEITH Post DOC April 2006 Transit Test

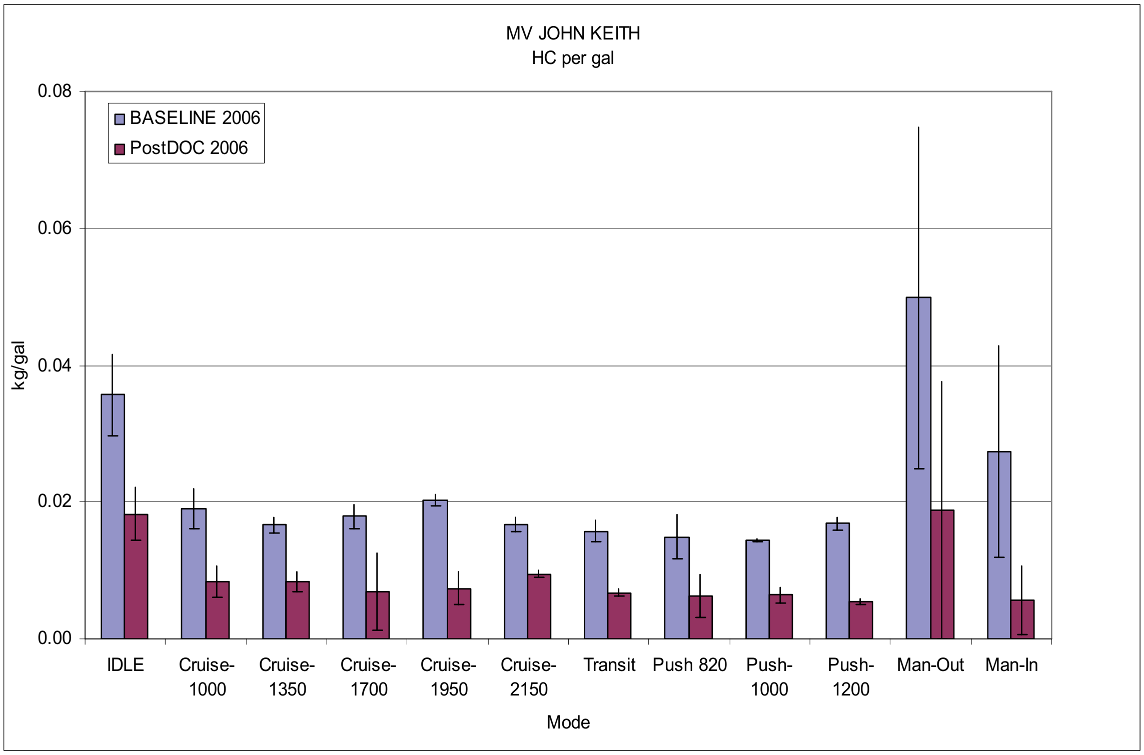
Mode	Transit 1				Transit 2				Transit 3			
	Start , sec	Stop, sec	Duration, sec	% of Time	Start , sec	Stop, sec	Duration, sec	% of Time	Start , sec	Stop, sec	Duration, sec	% of Time
Push	0	180	180	21.1	0	180	180	23.1	0	180	180	21.8
Maneuver, Out	180	276	96	11.2	180	278	98	12.6	180	274	94	11.4
Cruise	276	580	304	35.6	278	510	232	29.7	274	580	306	37.1
Maneuver, In	580	674	94	11.0	510	598	88	11.3	580	645	65	7.9
Push	674	855	181	21.2 %	598	780	182	23.3 %	645	825	180	21.8 %

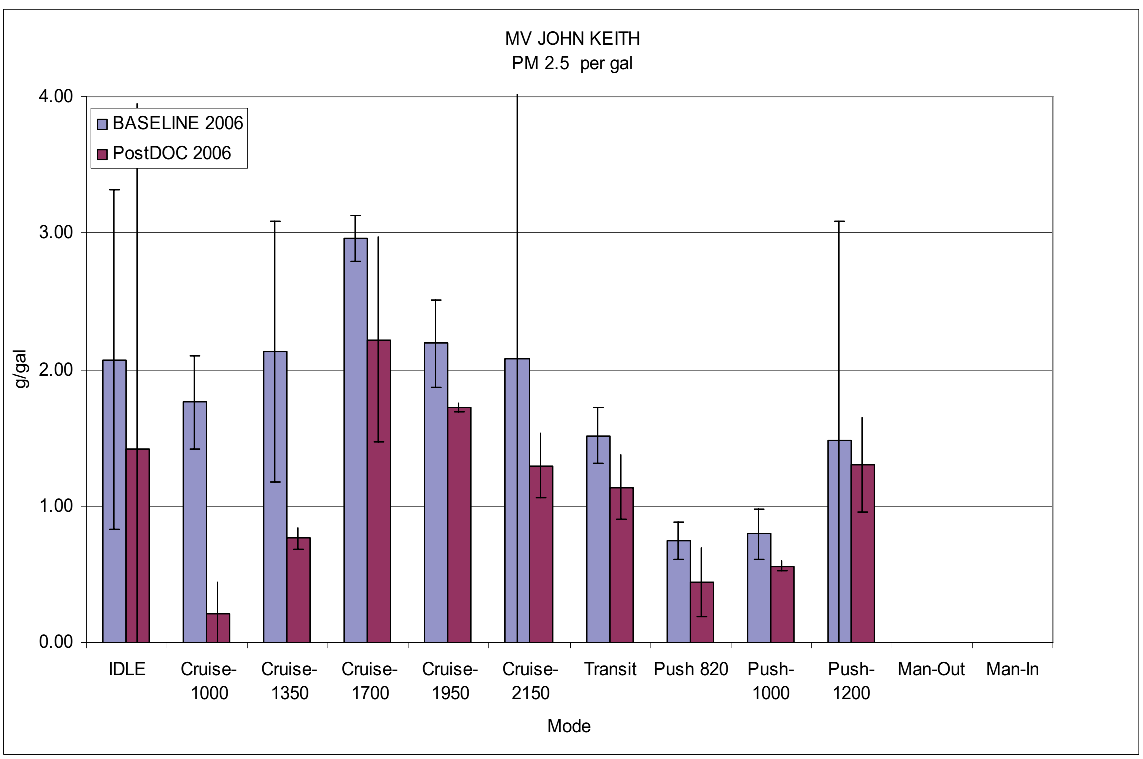
Mode	Transit 1				Transit 2				Transit 3			
	RPM	Torque	bhp	Fuel Consumed, lb	RPM	Torque	bhp	Fuel Consumed, lb	RPM	Torque	bhp	Fuel Consumed, lb
Push	1005	790	151	1.86	1021	823	160	1.95	1004	790	151	1.86
Maneuver, Out	1222	777	181	1.48	1354	894	230	2.18	1019	605	117	1.20
Cruise	1787	1309	445	8.60	1797	1319	451	6.66	1801	1324	454	8.84
Maneuver, In	777	417	62	0.30	875	491	82	0.61	942	544	98	0.59
Push	1022	825	161	1.97	1005	791	151	1.89	1056	898	181	2.15

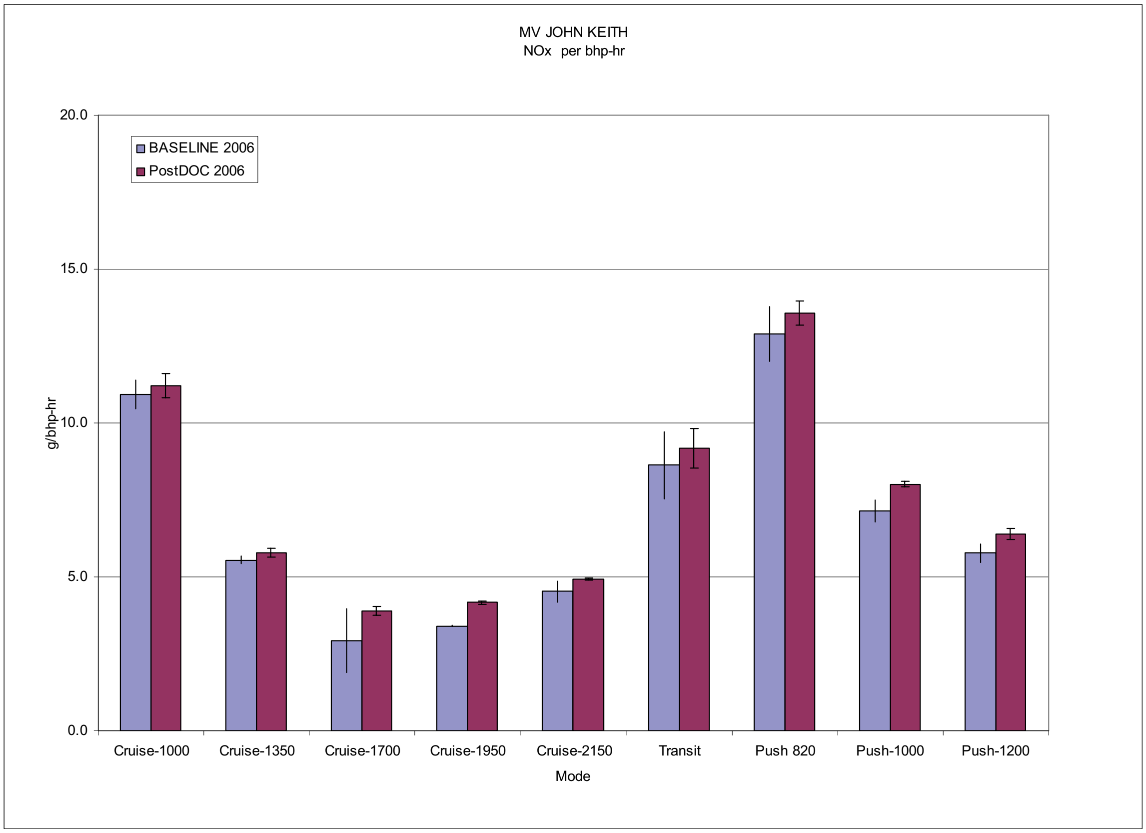



MV JOHN KEITH
CO per gal
103
139
50.0
45.0
40.0
35.0
30.0
25.0
20.0
15.0
10.0
5.0
0.0
g/gal
BASELINE 2006
PostDOC 2006
IDLE
Cruise-1000
Cruise-1350
Cruise-1700
Cruise-1950
Cruise-2150
Transit
Push 820
Push-1000
Push-1200
Man-Out
Man-In
Mode

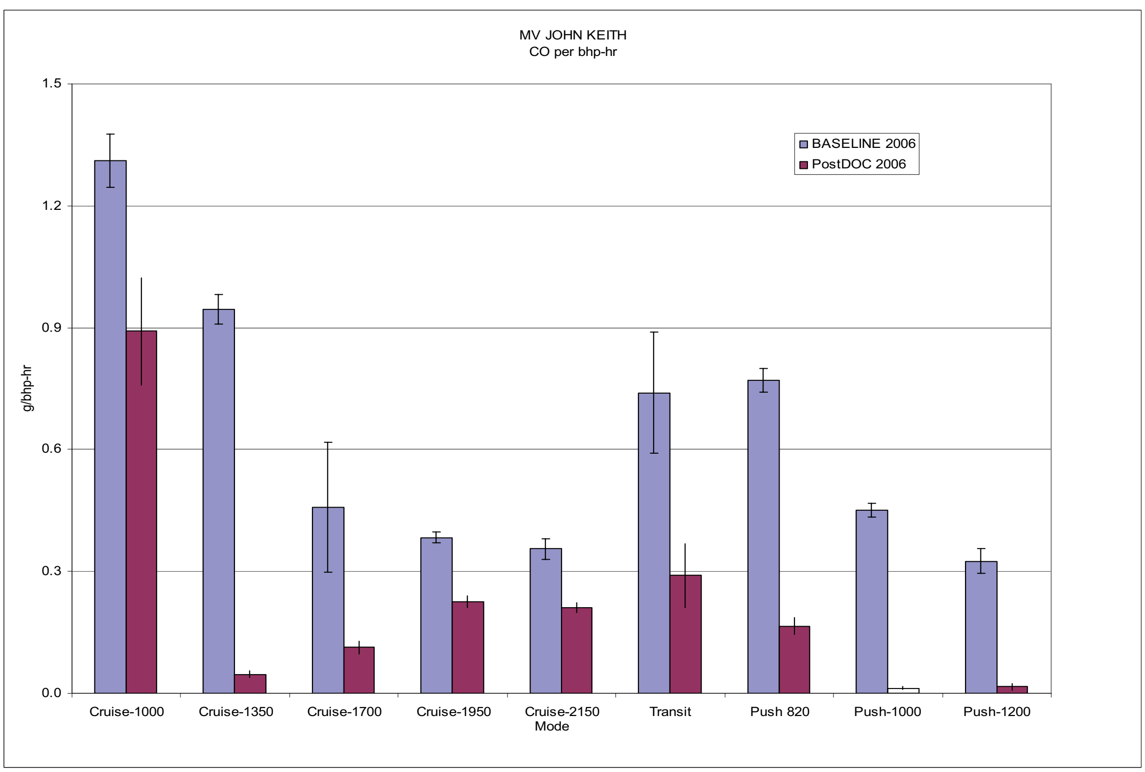

MV JOHN KEITH
CO2 per gal
15.0
12.0
9.0
6.0
3.0
0.0
kg/gal
BASELINE 2006
PostDOC 2006
IDLE
Cruise-1000
Cruise-1350
Cruise-1700
Cruise-1950
Cruise-2150
Transit
Push 820
Push-1000
Push-1200
Man-Out
Man-In
Mode


MV JOHN KEITH
HC per gal
0.08
0.06
0.04
0.02
0.00
kg/gal
BASELINE 2006
PostDOC 2006
IDLE
Cruise-1000
Cruise-1350
Cruise-1700
Cruise-1950
Cruise-2150
Transit
Push 820
Push-1000
Push-1200
Man-Out
Man-In
Mode

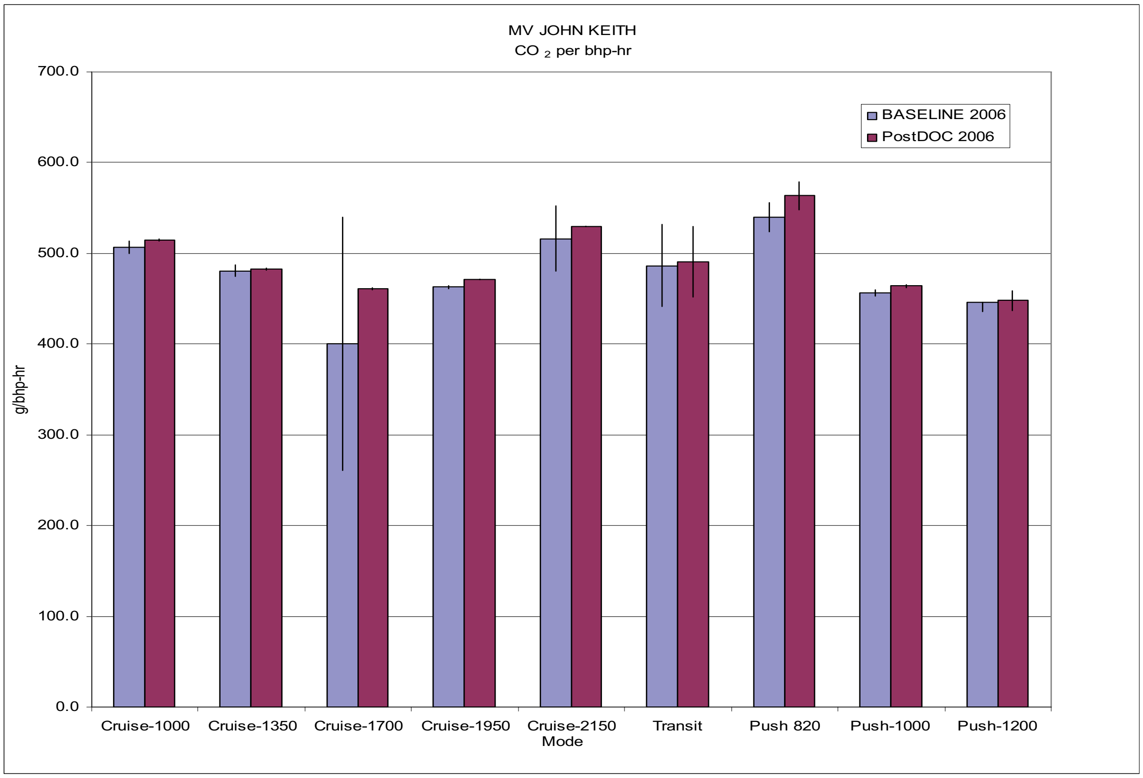

MV JOHN KEITH
PM 2.5 per gal
4.00
3.00
2.00
1.00
0.00
g/gal
BASELINE 2006
PostDOC 2006
IDLE
Cruise-1000
Cruise-1350
Cruise-1700
Cruise-1950
Cruise-2150
Transit
Push 820
Push-1000
Push-1200
Man-Out
Man-In
Mode

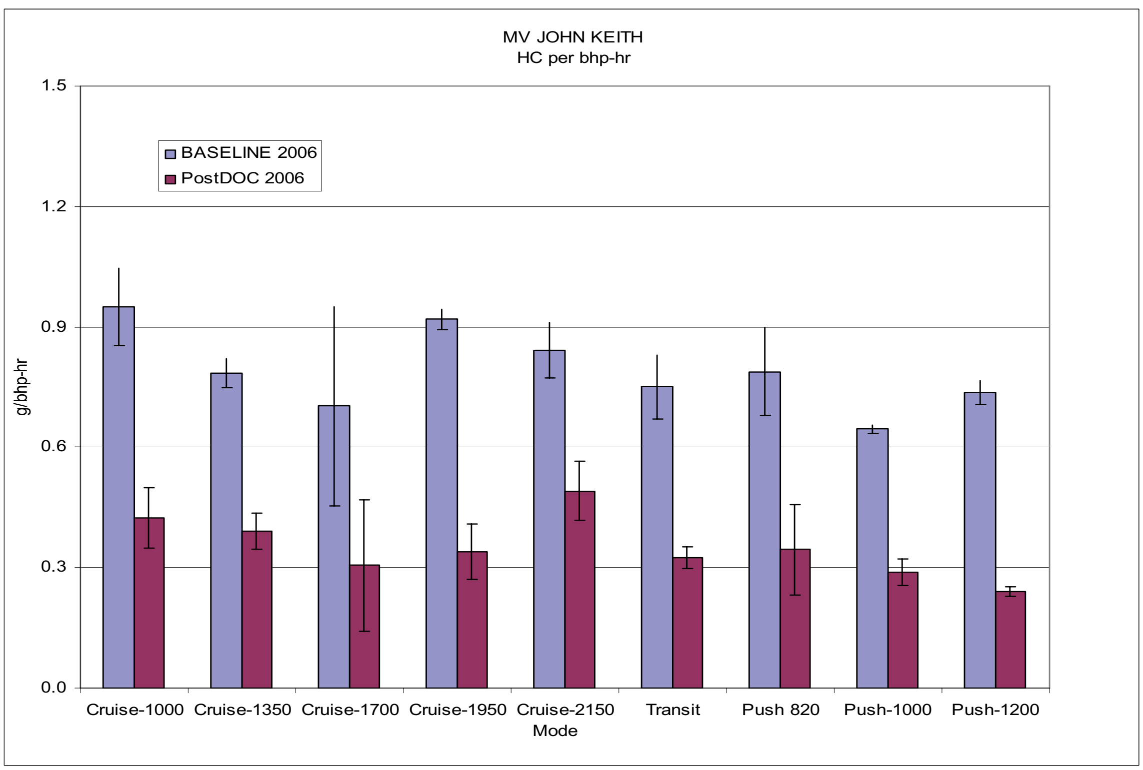


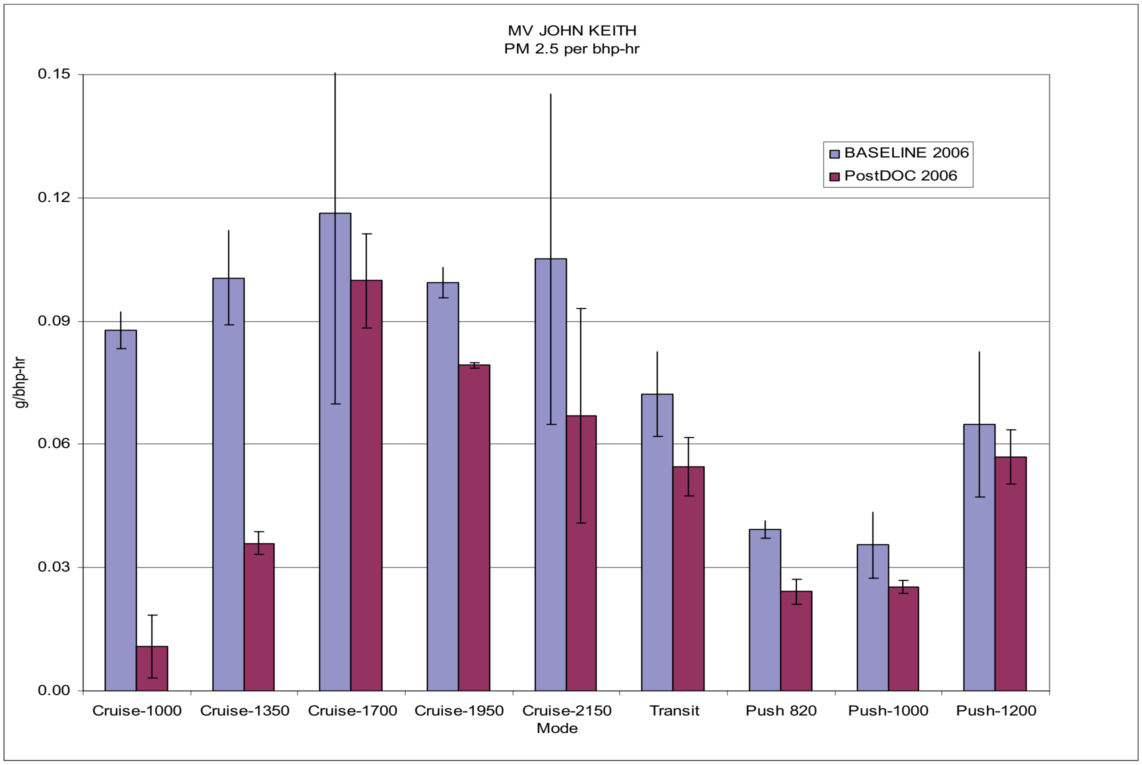
MV JOHN KEITH
NOx per bhp-hr
BASELINE 2006
PostDOC 2006
g/bhp-hr
20.0
15.0
10.0
5.0
0.0
Cruise-1000
Cruise-1350
Cruise-1700
Cruise-1950
Cruise-2150
Transit
Push 820
Push-1000
Push-1200
Mode



MV JOHN KEITH
CO per bhp-hr
BASELINE 2006
PostDOC 2006
g/bhp-hr
1.5
1.2
0.9
0.6
0.3
0.0
Cruise-1000
Cruise-1350
Cruise-1700
Cruise-1950
Cruise-2150
Transit
Push 820
Push-1000
Push-1200
Mode


MV JOHN KEITH
CO 2 per bhp-hr
g/bhp-hr
BASELINE 2006
PostDOC 2006
700.0
600.0
500.0
400.0
300.0
200.0
100.0
0.0
Cruise-1000
Cruise-1350
Cruise-1700
Cruise-1950
Cruise-2150
Transit
Push 820
Push-1000
Push-1200
Mode


MV JOHN KEITH
HC per bhp-hr
g/bhp-hr
BASELINE 2006
PostDOC 2006
1.5
1.2
0.9
0.6
0.3
0.0
Cruise-1000
Cruise-1350
Cruise-1700
Cruise-1950
Cruise-2150
Transit
Push 820
Push-1000
Push-1200
Mode


MV JOHN KEITH
PM 2.5 per bhp-hr
0.15
0.12
0.09
0.06
0.03
0.00
g/bhp-hr
BASELINE 2006
PostDOC 2006
Cruise-1000
Cruise-1350
Cruise-1700
Cruise-1950
Cruise-2150
Transit
Push 820
Push-1000
Push-1200
Mode

APPENDIX Y

BINSFELD ENGINEERING
Torque Trak 9000
WIRELESS SHAFT TORQUE METER

TorqueTrak 9000 Torque Telemetry System

SPECIFICATIONS

BT9000 Transmitter

Sensor Input: Full (four-arm) Wheatstone Bridge strain gage (350 standard)

Bridge Input: 5.0 VDC, Regulated

Sensor Range: User selectable per chart below (chart based on gage factor = 2.0):

Transmitter Gain Level	Transmitter Gain	Full Bridge 4 Active Arms (Torque or Bending)	Full Bridge 2.6 Active Arms (Tension or Compression)	1/4 Bridge 1 Active Arm (Single Gage)
6	8000	±125 microstrain	±192 microstrain	±500 microstrain
5	4000	±250 microstrain	±385 microstrain	±1000 microstrain
4	2000	±500 microstrain	±769 microstrain	±2000 microstrain
3	1000	±1000 microstrain	±1538 microstrain	±4000 microstrain
2	500	±2000 microstrain	±3077 microstrain	±8000 microstrain
1	250	±4000 microstrain	±6154 microstrain	±16,000 microstrain
0	125	±8000 microstrain	±12,307 microstrain	±32,000 microstrain

Sensor & Power Connection: Screw terminal block Transmitter Power Input: 7.5 to 12VDC, 60mA max with 350 bridge (9V battery typical) Transmission Frequency: 903-922 MHz Transmitter Battery Life: 12 hours (9V lithium, 350 bridge, 25°C) Transmit Distance: 20 feet or more G-force Rating: 3000 g's (steady state) (e.g. 6500 rpm on a 5 inch diameter shaft)

Operating Temperature: 0 – 70°C (32 – 158°F)

Size and Weight: 1.05" x 1.95" x 0.70" 2 oz

RD9000 Receiver

Receiver Output Signal: ±10 VDC, field adjustable down to ±5 VDC

Receiver Output Connection: 5-way binding posts (banana jacks)

Receiver Power Input: 12VDC nominal (10 - 18VDC acceptable), 250mA max (110VAC or 220VAC adapter provided)

Operating Temperature: 0 – 70°C (32 – 158°F)

Size and Weight: 5.5" x 7.5" x 1.5" 3 lbs

TT9000 System

Resolution: 14 bits (±full scale = 16,384 points)

Gain Error: ±0.1% (±0.5% before scale calibration)

Gain Drift: ±0.02%FS/°C over operating temperature range

Zero Error: ±0.1%FS (±1% typical before activating AutoZero)

Zero Drift: ±0.02%FS/°C over operating temperature range

Frequency Response: 0 - 250 Hz (-3dB max @ 250Hz)

Delay: 5.4 msec, typical

Slew Rate: 6V/msec, typical

Sample Rate: 1276 samples/sec

BINSFELD ENGINEERING INC

4571 W. MacFarlane Rd. ▪ Maple City, MI 49664 ▪ USA Phone: (+1) 231.334.4383 ▪ Fax: (+1) 231.334.4903 ▪ Toll Free: 800.524.3327 ▪ www.binsfeld.com 8690013A

APPENDIX Z

MICROMOTION ELITE CORIOLIS MASS FLOW METER

Coriolis detailed results						
Base Model #: CMF050M						
		Min	**Operating**	**Max***	**Design**	**Units**
Flow Rate:				1000.000		lb/hr
Pressure:				100.000		psi
Temperature:				100.0		F
Density:				0.9935		g/cm3
Viscosity:				0.68149915		cP
Gas Only	**Base Reference Temperature:**					
	Base Reference Pressure:					
	Base Reference Density:					

Flow Rate lb/hr	**Mass Flow Accuracy +/- % of Rate**	**Pressure Drop* psi**	**Velocity* ft/sec**
1000.000	0.10	0.46	3.5
905.556	0.10	0.40	3.1
811.111	0.10	0.34	2.8
716.667	0.10	0.28	2.5
622.222	0.10	0.23	2.1
527.778	0.10	0.18	1.8
433.333	0.10	0.13	1.5
338.889	0.11	0.09	1.2
244.444	0.15	0.05	0.8
150.000	0.24	0.02	0.5

*All pressure drop and velocity results represent the highest possible values, based on the maximum simultaneously occurring conditions of flow rate, temperature, and pressure.

*The accuracy and/or pressure drop may change with full part # selection.
Please Review the Calculation summary sheet after you have configured your model.

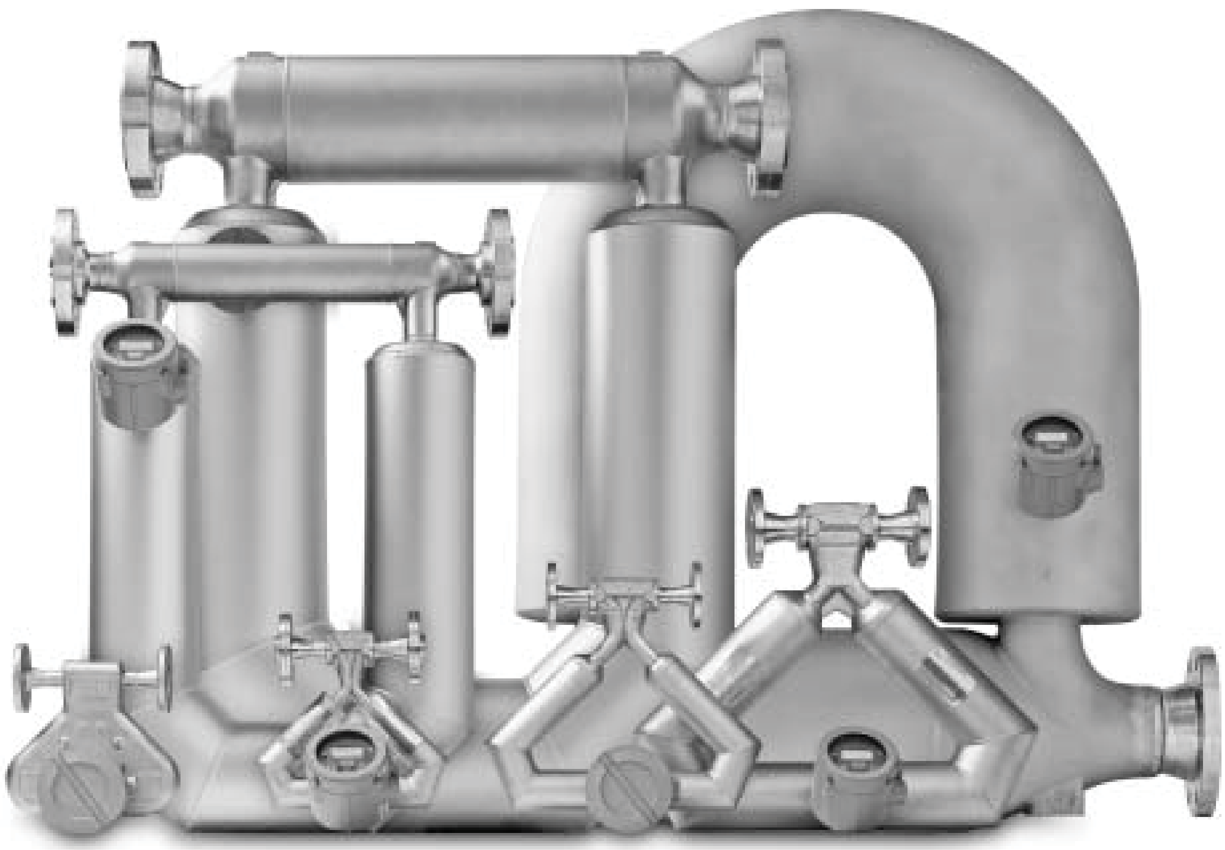
Prepared by: **Instrument Toolkit**		**Project ID:** **Application:**	ToolkitWeb73505

Product Data Sheet
PS-00374, Rev. E September 2005

Micro Motion® ELITE®

Mass Flow and Density Meters

With MVD™ Technology



- Unsurpassed performance: mass flow accuracy to ±0.05% of rate, and density accuracy to ±0.0002 g/cm^3 (±0.2 kg/m^3)
- For mass and volume flow measurement of both gases and liquids
- Wide range of sizes from 1/8″ to 4″ (3 mm to 100 mm)
- Now available with Micro Motion's newest transmitter, the Model 2400S

Micro Motion® ELITE® mass flow and density meters

Micro Motion® ELITE® meters are the leading meters for precision flow and density measurement. ELITE meters offer the most accurate measurement available for virtually any process fluid, while exhibiting exceptionally low pressure drop. Every ELITE meter features standard secondary containment, and is available with stainless steel or nickel alloy wetted parts and a wide variety of process connections to meet your every need.

ELITE meters have been designed for special applications. The CMF010 provides remarkably high performance in low-flow applications. The high-pressure CMF010P is suitable for applications up to 6000 psi (413 bar). The CMF400 4-inch meter offers the most accurate measurement available in a high-capacity meter. The CMF200A, CMF300A, and CMF400A high-temperature meters provide accurate measurements in severe environments up to 800 °F (427 °C).

Sizing program

Micro Motion offers an on-line sizing program for finding the best products to fit your application. The sizing program allows you to specify the parameters that matter to you, such as accuracy, flow capacity, pressure drop, or turndown. To use the sizing program, visit our web site at **www.micromotion.com**.

Contents

Liquid flow performance

		Mass		Volume(1)			
		lb/min	kg/h	gal/min	l/h	bbl/hr	m^3/h
Maximum flow rate	CMF010	4	108	0.4	108		
	CMF025	80	2180	10	2180		
	CMF050	250	6800	30	6800		
	CMF100	1000	27,200	120	27,200		
	CMF200	3200	87,100	385	87,100	550	87
	CMF300	10,000	272,000	1200	272,000	1700	272
	CMF400	20,000	545,000	2400	545,000	3400	545

Mass and volume flow accuracy(2)	Model 2400S transmitter or enhanced core processor	±0.05% of rate(3)(4)
	Transmitter with MVD Technology	±0.10% of rate(5)
	All other transmitters	±0.10% ±[(zero stability / flow rate) × 100]% of rate
Mass and volume flow repeatability	Model 2400S transmitter or enhanced core processor	±0.025% of rate(3) (4)
	Transmitter with MVD Technology	±0.05% of rate(5)
	All other transmitters	±0.05% ±[½(zero stability / flow rate) × 100]% of rate

		lb/min	kg/h
Zero stability	CMF010	0.000075	0.002
	CMF010P	0.00015	0.004
	CMF025	0.001	0.027
	CMF050	0.006	0.163
	CMF100	0.025	0.680
	CMF200	0.08	2.18
	CMF300	0.25	6.80
	CMF400	1.50	40.91

(1) Specifications for volumetric flow rate are based on a process-fluid density of 1 g/cm³ (1000 kg/m³). For fluids with density other than 1 g/cm³ (1000 kg/m³), the volumetric flow rate equals the mass flow rate divided by the fluid's density.

(2) Stated flow accuracy includes the combined effects of repeatability, linearity, and hysteresis. All specifications for liquids are based on reference conditions of water at 68 to 77 °F (20 to 25 °C) and 15 to 30 psig (1 to 2 bar), unless otherwise noted.

(3) When flow rate is less than zero stability / 0.0005, accuracy = ±[(zero stability / flow rate) × 100]% of rate, and repeatability = ±[½(zero stability / flow rate) × 100]%

(4) When ordered with the ±0.10% factory calibration option, accuracy on liquid = ±0.10% when flow rate ≥ zero stability / 0.001. When flow rate < zero stability / 0.001, accuracy equals ±[(zero stability / flow rate) × 100]% of rate and repeatability equals ±[½(zero stability / flow rate) × 100]% of rate.

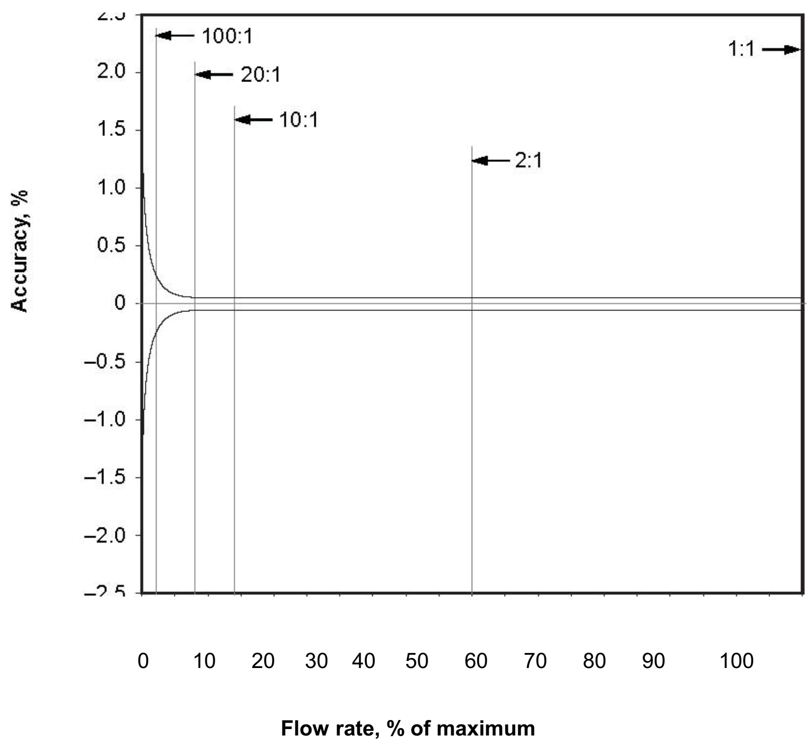
(5) When flow rate is less than zero stability / 0.001, accuracy equals ±[(zero stability / flow rate) × 100]% of rate and repeatability equals ±[½(zero stability / flow rate) × 100]% of rate.

Liquid flow performance *continued*

Typical accuracy, turndown, and pressure drop with CMF100 and 2400S transmitter or enhanced core processor

The graph below is an example of the relationship between accuracy, turndown, and pressure drop when measuring the flow of water with a Model CMF100 sensor and Model 2400S transmitter or enhanced core processor.

Actual pressure drop is dependent on process conditions. To determine accuracy, turndown, and pressure drop with your process variables, use Micro Motion's product selector, available at **www.micromotion.com**.



Turndown from maximum flow rate	***500:1***	***100:1***	***20:1***	***10:1***	***2:1***
Accuracy (±%)	1.25	0.25	0.05	0.05	0.05
Pressure drop					
psi	~0	~0	0.2	0.7	13.5
bar	~0	~0	0.01	0.05	0.93

Micro Motion® ELITE® Mass Flow and Density Meters

Pressure ratings

Flow tube rating [1] psi bar

316L and 304L 1450 100 stainless steel sensors Hastelloy C-22 sensors 2160 148
High-pressure CMF010P 6000 413

PED compliance Sensors comply with council directive 97/23/EC of 29 May 1997 on Pressure Equipment

Housing rating			**ASME B31.3 secondary containment rating[1] Burst pressure**	
	psi	**bar**	**psi**	**bar**
CMF010[2]	425	29	3042	209
CMF025	850	58	5480	377
CMF050	850	58	5286	364
CMF100	625	43	3299	227
CMF200	550	37	2786	192
CMF300	275	18	1568	108
CMF400	250	17	1556	107

(1) For operating temperatures above 300 °F (148 °C), pressure needs to be derated as follows.

Flow tubes Housing

316L sensors

up to 300 °F (up to 148 °C) None at 400 °F (at 204 °C) 7.2% derating

at 500 °F (at 260 °C) 13.8% derating at 600 °F (at 316 °C) 19.2% derating at 650 °F (at 343 °C) 21.0% derating at 700 °F (at 371 °C) 22.8% derating at 750 °F (at 399 °C) 24.6% derating at 800 °F (at 427 °C) 25.7% derating

(2) Optional rupture disks for high-pressure CMF010P will

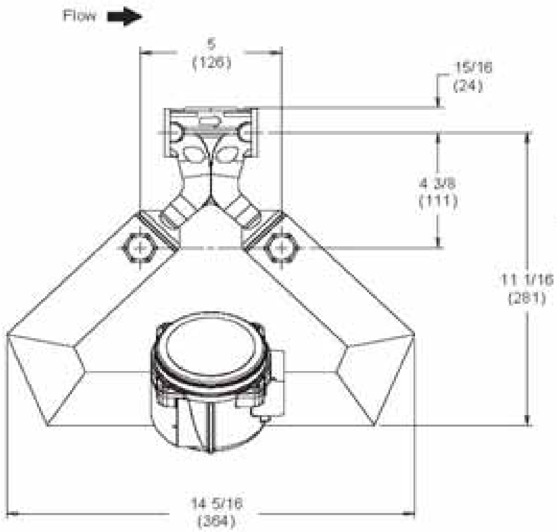
304L sensors	***Hastelloy C-22 sensors***	***All sensors***
None	*None*	*None*
5.4% derating	*None*	*5.4% derating*
11.4% derating	*4.7% derating*	*11.4% derating*
16.2% derating	*9.7% derating*	*16.2% derating*
18.0% derating	*11.7% derating*	*18.0% derating*
19.2% derating	*13.7% derating*	*19.2% derating*
20.4% derating	*15.0% derating*	*20.4% derating*
22.2% derating	*16.3% derating*	*22.2% derating*

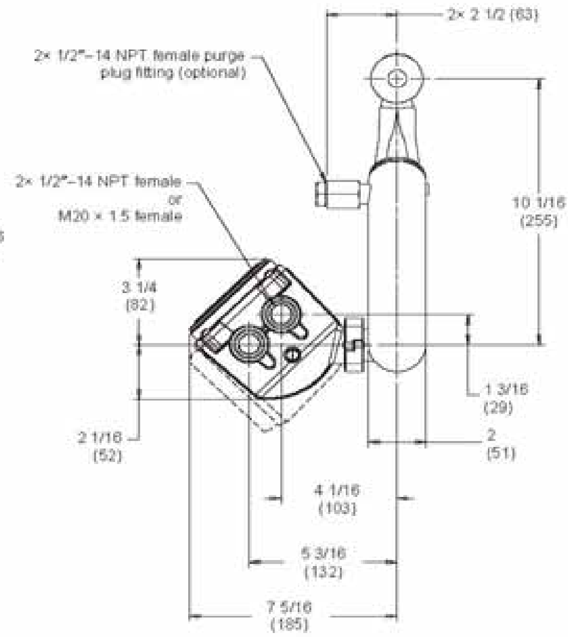
burst if pressure inside sensor housing reaches 400 psi (27 bar).

Dimensions *continued*

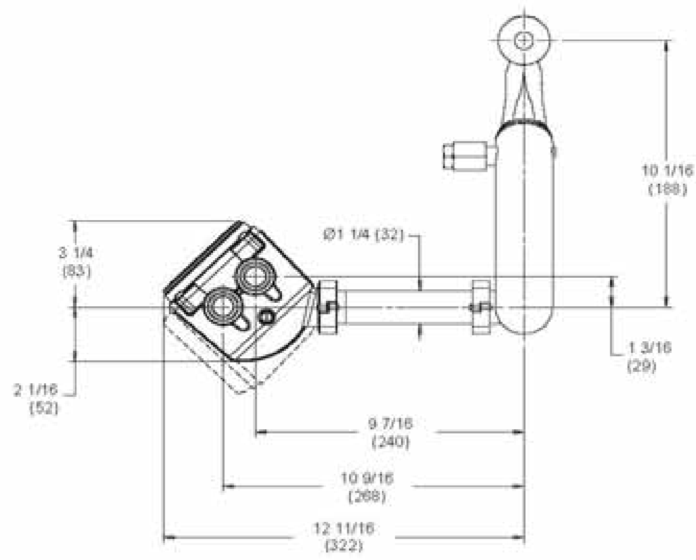
Dimensions in *inches (mm)*

CMF050 with enhanced core processor or Model 2400S transmitter





Refer to CMF050 drawings on page 25 for additional sensor dimensions. For CMF050 fitting options and dimensions, see page 40.

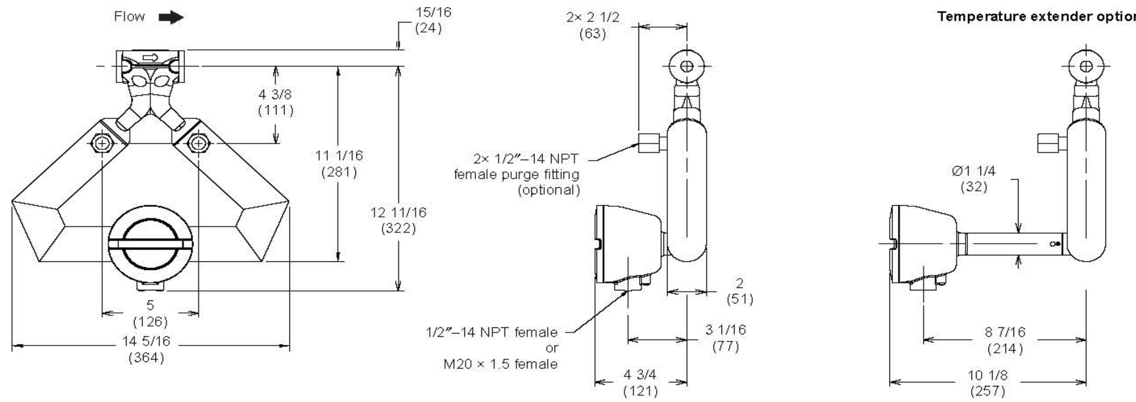


Temperature extender option

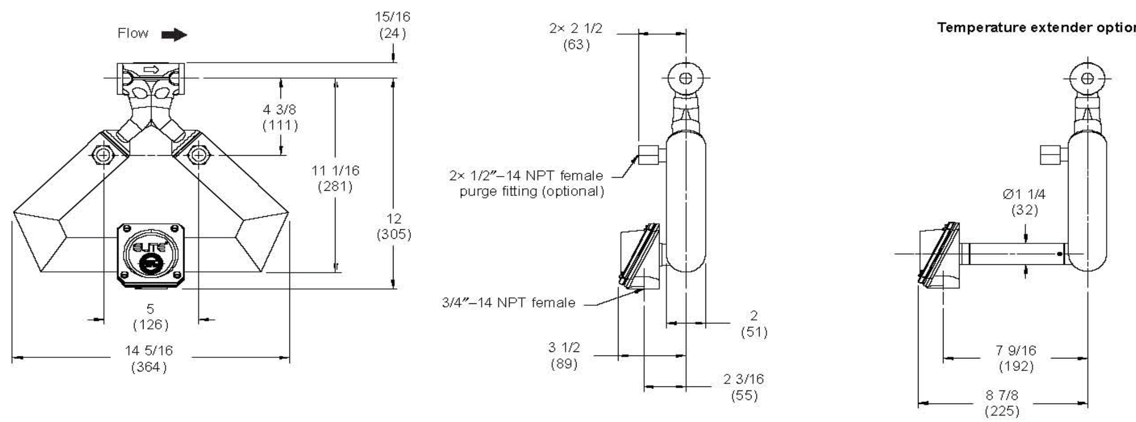
Dimensions *continued*

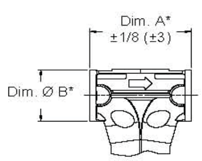
Dimensions in *inches (mm)*

CMF050 with core processor

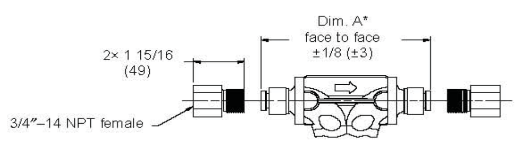


CMF050 with junction box

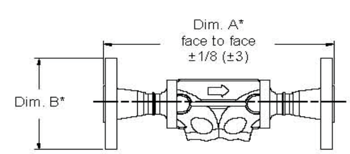




Wafer detail



Union detail



Flange detail

*For dimensions A and B, see page 40.

appendix aa

APPENDIX AA

NOVA PORTABLE ENGINE EXHAUST GAS ANALYZER

NOVA MODEL 7460 Series

PORTABLE ENGINE EXHAUST ANALYZERS

APPLICATIONS

For checking engine exhaust emissions for diesel, gasoline, propane or natural gas powered 2 and 4 cycle engines.

Model 7465P shown
(Bench top style cabinet also available)

OPTIONS

- Analog 4-20 ma outputs
- Built in printer (add 'P' suffix)
- Plug in smoke meter (add 'S' suffix)
- Datalogger for PC computer
- Add NO_x (as NO) to any analyzer (add 'N' suffix)
- Add NO_2 to any analyzer (add 'X' suffix)
- PPM CO in place of '%' (add 'L' suffix)

MODELS

7461: CO only
7462: CO and Hydrocarbons (HC's)
7463: CO, CO_2 and HC's
7464: O_2, CO, CO_2 and HC's
7465: O_2, CO, CO_2, HC's and NO_x (as NO)
7466: O_2, CO, CO_2, HC's and NO_x (as NO + NO_2)

FEATURES

- Fast and accurate response
- Rechargeable battery operation (recharge from vehicle or from AC adapter)
- Fast warm up
- Simple to operate, compact size
- Large LCD digital readouts for each gas
- Microprocessor infra red detectors for CO, CO_2 and HC's
- Provided with sample filter, hose, probe, built in sample pump and automatic condensate removal
- Meets Bar 97 and OIML specifications

DESCRIPTION

The 7460 Series Portable Analyzers are available in four versions for the measurement of 2-6 of the gases found in the exhaust gases from internal combustion engines. CO, CO_2 and hydrocarbons are detected by a single, dual wavelength infra red detector. Oxygen and NO_X (as NO) are detected by customer replaceable electrochemical sensors. NO_2 is also by an electro-chemical sensor if this option is selected.

All detector outputs are then displayed on separate front panel digital meters. Optional built in printer, datalogger and 4-20 ma recorder outputs are also available.

The 7460 Series Analyzers come complete with built in sampling pump, flowmeter, condensate trap, automatic condensate removal, filters, teflon liquid block, 12 ft. (4m) sampling hose and stainless steel probe.

An optional smoke meter is also available which can plug into the 7460 Series Analyzer. Add 'S' suffix to model number.

SPECIFICATIONS

DESCRIPTION	
Standard Ranges: **(Other ranges available)**	CO: 0-10.00% (special low range PPM CO available) CO_2: 0-20.0% HC's: 0-2000 to 0-20,000 PPM (as propane or hexane) O_2: 0-25.0% NO_X: 0-2000 PPM (as NO) 0-800 PPM NO_2 is optional 0-100% opacity smoke meter
Readout:	LCD digital for each gas with switchable backlight
Accuracy and Repeatability:	± 1% of full scale for O_2, CO, CO_2 and HC's ± 2% of full scale for NO_X
Zero and Span Drift:	< ± 1% in 8 hours after full warmup
Response Time:	8-10 seconds
Warm Up Time:	1-2 minutes to useability, 10 minutes for full warmup
Ambient Temperature Range:	0 to 40°C
Humidity Range:	0-90% non-condensing
Linearity:	± .05% of full scale each gas measured
Size:	14"W x 6"H x 10 1/2"D (35.5 x 15.2 x 26.6 cm)
Weight:	12 lbs (5.5 kg)
Optional Output:	RS-232, RS-485 or 4-20 ma
Power:	115VAC or 230VAC 50/60 Hz for recharging Also 12VDC from cigarette lighter socket

Nova reserves the right to specification changes which may occur with advances in design without prior notice.

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IN CANADA • 270 Sherman Avenue North, Hamilton, Ontario L8L 6N5 • Tel.: 1-800-295-3771 (905) 545-2003 • Fax: (905) 545-4248
Website: www.nova-gas.com • Email: sales@nova-gas.com

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APPENDIX AB

NY HARBOR EMISSIONS REDUCTIONS TABLES BASELINE and CONTROLLED

BASELINE NOx EMISSION RATES

Route No.	Route Origin / Destination / End	Operator	Route Description	Route Distance (NM)	Propulsion Engine Type	NOx at Push, per Engine (kg/hr)	NOx at Push STD Deviation (kg/hr)	NOx at Push ± 95.0% C.I. (± kg/hr)	NOx at Manuever, per Engine (kg/hr)	NOx at Manuever STD Deviation (kg/hr)	NOx at Manuever ± 95.0% C.I. (± kg/hr)	NOx at Cruise, per Engine (kg/hr)	NOx at Cruise STD Deviation (kg/hr)	NOx at Cruise ± 95.0% C.I. (± kg/hr)
1	Belford, NJ to Pier 11 to Belford, NJ	NY Waterway	Long Haul	45.8	Caterpillar 3412E	2.94	0.0152	0.0653	2.07	0.127	0.31	1.94	0.0088	0.0279
2	Port Liberte to Pier 11 to Port Libete	NY Waterway	Medium Haul	9.40	Caterpillar 3406E	1.35	0.00597	0.0257	0.906	0.133	0.37	2.48	0.0219	0.0944
3	Pier 11 to Port Liberte to Pier 11	NY Waterway	Medium Haul	9.40	Caterpillar 3406E	1.35	0.00597	0.0257	0.906	0.133	0.37	2.48	0.0219	0.0944
4	Hoboken-South to (via WFC & Pier 11) WFC to Hoboken-South	NY Waterway	Medium Haul	7.70	Caterpillar 3412(2)	1.95	0.0096	0.0305	2.06	0.62	1.5	3.10	0.0128	0.0406
5	38th Street to (via Newport & Harborside) Colgate to 38th Street	NY Waterway	Medium Haul	7.60	Caterpillar 3406E	1.35	0.00597	0.0257	0.906	0.133	0.37	2.48	0.0219	0.0944
6	38th Street to (via Newport) Harborside to 38th Street	NY Waterway	Medium Haul	6.70	Caterpillar 3406E	1.35	0.00597	0.0257	0.906	0.133	0.37	2.48	0.0219	0.0944
7	38th Street to (via Harborside) Newport to 38th Street	NY Waterway	Medium Haul	6.70	Caterpillar 3406E	1.35	0.00597	0.0257	0.906	0.133	0.37	2.48	0.0219	0.0944
8	38th Street to Harborside to 38th Street	NY Waterway	Medium Haul	6.60	Caterpillar 3406E	1.35	0.00597	0.0257	0.906	0.133	0.37	2.48	0.0219	0.0944
9	Liberty Harbor to Pier 11 to Liberty Harbor	NY Waterway	Medium Haul	5.80	Caterpillar 3406E	1.35	0.00597	0.0257	0.906	0.133	0.37	2.48	0.0219	0.0944
10	38th Street to Newport to 38th Street	NY Waterway	Medium Haul	5.60	Caterpillar 3406E	1.35	0.00597	0.0257	0.906	0.133	0.37	2.48	0.0219	0.0944
11	Hoboken-South to WFC to Hoboken-South	NY Waterway	Medium Haul	5.00	Caterpillar 3412(2)	1.95	0.0096	0.0305	2.06	0.62	1.5	3.10	0.0128	0.0406
12	38th Street to (via Lincoln Harbor) Hoboken North to 38th Street	NY Waterway	Medium Haul	3.10	Caterpillar 3406E	1.35	0.00597	0.0257	0.906	0.133	0.37	2.48	0.0219	0.0944
13	Hoboken-North to 38th Street to Hoboken-North	NY Waterway	Medium Haul	2.40	Caterpillar 3406E	1.35	0.00597	0.0257	0.906	0.133	0.37	2.48	0.0219	0.0944
14	38th Street to Lincoln Harbor to 38th Street	NY Waterway	Medium Haul	2.40	Caterpillar 3412(2)	1.95	0.0096	0.0305	2.06	0.62	1.5	3.10	0.0128	0.0406
15	Port Imperial to 38th Street to Port Imperial (weekdays)	NY Waterway	Short Haul	2.00	Caterpillar 3412E	2.94	0.0152	0.0653	2.07	0.127	0.31	1.94	0.0088	0.0279
16	Port Imperial to 38th Street to Port Imperial (saturdays)	NY Waterway	Short Haul	2.00	Caterpillar 3412E	2.94	0.0152	0.0653	2.07	0.127	0.31	1.94	0.0088	0.0279
17	Port Imperial to 38th Street to Port Imperial (sundays)	NY Waterway	Short Haul	2.00	Caterpillar 3412E	2.94	0.0152	0.0653	2.07	0.127	0.31	1.94	0.0088	0.0279
18	Colgate to WFC to Colgate	NY Waterway	Short Haul	1.60	Caterpillar 3412(2)	1.95	0.0096	0.0305	2.06	0.62	1.5	3.10	0.0128	0.0406
	Totals, NY Waterway					**33.0**	**0.0406**	**0.096**	**25.6**	**1.33**	**2.81**	**45.0**	**0.0760**	**0.175**
19	Port Imperial to (via Hoboken-North, WFC) Pier 11 to (via WFC, Hoboken-North) Port Imperial	Billy Bey	Long Haul	13.1	Caterpillar 3406E	1.35	0.00597	0.0257	0.906	0.133	0.37	2.48	0.0219	0.0944
20	Port Imperial to Pier 11 to Port Imperial	Billy Bey	Long Haul	12.8	Caterpillar 3406E	1.35	0.00597	0.0257	0.906	0.133	0.37	2.48	0.0219	0.0944
21	Pier 11 to 38th Street to Pier 11	Billy Bey	Long Haul	11.8	Caterpillar 3406E	1.35	0.00597	0.0257	0.906	0.133	0.37	2.48	0.0219	0.0944
22	Port Imperial to (via Hoboken-North) WFC to Port Imperial	Billy Bey	Medium Haul	8.00	Caterpillar 3406E	1.35	0.00597	0.0257	0.906	0.133	0.37	2.48	0.0219	0.0944
23	WFC to (via Hoboken-North) Port Imperial to WFC	Billy Bey	Medium Haul	8.00	Caterpillar 3406E	1.35	0.00597	0.0257	0.906	0.133	0.37	2.48	0.0219	0.0944
24	Hoboken-South to Pier 11 to Hoboken-South	Billy Bey	Medium Haul	7.40	Caterpillar 3406E	1.35	0.00597	0.0257	0.906	0.133	0.37	2.48	0.0219	0.0944
25	38th Street to Colgate to 38th Street	Billy Bey	Medium Haul	7.40	Caterpillar 3406E	1.35	0.00597	0.0257	0.906	0.133	0.37	2.48	0.0219	0.0944
26	38th St. to (via Newport Hoboken-South) Hoboken-North to 38th St.	Billy Bey	Medium Haul	6.20	Caterpillar 3412(2)	1.95	0.0096	0.0305	2.06	0.62	1.5	3.10	0.0128	0.0406
27	38th St. to (via Hoboken North & Hoboken South) Newport to 38th St.	Billy Bey	Medium Haul	6.20	Caterpillar 3412(2)	1.95	0.0096	0.0305	2.06	0.62	1.5	3.10	0.0128	0.0406
	Totals, Billy Bey Ferry Company					**13.3**	**0.0208**	**0.0535**	**10.5**	**0.94**	**2.10**	**23.5**	**0.0608**	**0.1562**
28	Various weekday routes [(1)]	NY Water Taxi	Medium Haul	-	DD Series 60	0.771	0.0175	0.0754	1.23	0.228	0.63	1.19	0.0030	0.0130
29	Various weekend routes [(1)]	NY Water Taxi	Medium Haul	-	DD Series 60	0.771	0.0175	0.0754	1.23	0.228	0.63	1.19	0.0030	0.0130
	Totals, New York Water Taxi					**1.54**	**0.0248**	**0.107**	**2.45**	**0.322**	**0.90**	**2.38**	**0.0043**	**0.0183**
	Grand Totals, New York City Harbor					**47.9**	**0.0519**	**0.117**	**38.5**	**1.66**	**3.46**	**70.9**	**0.0974**	**0.217**

Route No.	NOx at Push, per vessel (kg/rte)	NOx at Push STD Deviation, per vessel (kg/rte)	NOx at Push, per vessel ± 95.0% C.I. (± kg/rte)	NOx at Manuever, per vessel (kg/rte)	NOx at Manuever STD Deviation, per vessel (kg/rte)	NOx at Manuever, /vessel ± 95.0% C.I. (± kg/rte)	NOx at Cruise, per vessel (kg/rte)	NOx at Cruise STD Deviation, per vessel (kg/rte)	NOx at Cruise, /vessel ± 95.0% C.I. (± kg/rte)	Total Annual NOx, per route (kg/yr)	Total Annual NOx STD Deviation, per route (kg/yr)	Total NOx, per route ± 95.0% C.I. (± kg/yr)	Total Annual NOx, per route (lbs/yr)	Total Annual NOx STD Deviation, per route (lbs/yr)	Total NOx, per route ± 95.0% C.I. (± lbs/yr)	Total Current Annual NOx, per route (short tons/yr)	Total Current Annual NOx STD Deviation (short tons/yr)	Total NOx, per route ± 95.0% C.I. (± short tons/yr)
1	1.82	0.00937	0.0403	1.60	0.098	0.24	8.25	0.0373	0.119	42,470	384	846	93,631	848	1,866	46.8	0.424	0.93
2	1.03	0.00459	0.0197	0.943	0.138	0.38	2.58	0.0229	0.0984	8,298	255	589	18,294	563	1,298	9.15	0.282	0.65
3	0.889	0.00394	0.01696	0.809	0.119	0.33	2.64	0.0234	0.1006	11,280	315	726	24,869	694	1,601	12.4	0.347	0.80
4	0.828	0.00408	0.0130	0.633	0.190	0.46	2.08	0.0085	0.0272	11,049	593	1,292	24,359	1,307	2,848	12.2	0.65	1.42
5	0.720	0.00319	0.01374	0.401	0.059	0.16	2.55	0.0226	0.0973	21,976	377	870	48,449	832	1,919	24.2	0.416	0.96
6	0.443	0.00196	0.00845	0.264	0.0387	0.107	2.16	0.01912	0.0823	12,668	191	440	27,927	421	971	14.0	0.211	0.485
7	0.444	0.00197	0.00846	0.297	0.0436	0.121	2.05	0.01812	0.0780	4,349	74	170	9,587	163	375	4.79	0.081	0.188
8	0.326	0.00144	0.00621	0.169	0.0248	0.069	1.72	0.01521	0.0654	3,451	45.5	105	7,608	100	231	3.80	0.0501	0.116
9	0.448	0.00199	0.00854	0.436	0.064	0.18	1.31	0.01157	0.0498	13,666	406	935	30,129	894	2,062	15.1	0.447	1.03
10	0.310	0.00137	0.00591	0.242	0.0355	0.098	1.28	0.01133	0.0488	8,094	165	380	17,844	363	837	8.92	0.182	0.419
11	0.406	0.00200	0.00637	0.267	0.080	0.20	1.20	0.00492	0.0157	30,647	1,316	2,867	67,566	2,901	6,321	33.8	1.45	3.16
12	0.730	0.00324	0.01394	0.520	0.076	0.21	0.528	0.00468	0.02012	12,948	557	1,285	28,545	1,228	2,832	14.3	0.61	1.42
13	0.733	0.00325	0.01399	0.299	0.0438	0.122	0.551	0.00488	0.02099	11,933	333	769	26,307	735	1,695	13.2	0.367	0.85
14	0.376	0.00185	0.00590	0.373	0.112	0.27	0.438	0.00180	0.00573	8,030	756	1,648	17,704	1,667	3,633	8.85	0.83	1.82
15	0.649	0.00335	0.0144	0.380	0.0233	0.057	0.492	0.00222	0.00708	35,204	548	1,207	77,612	1,209	2,660	38.8	0.60	1.33
16	0.736	0.00380	0.0163	0.244	0.0150	0.037	0.595	0.00269	0.0086	4,260	42.4	93	9,391	94	206	4.70	0.0468	0.103
17	0.754	0.00389	0.0167	0.335	0.0206	0.050	0.500	0.00226	0.00720	4,051	54	118	8,932	118	261	4.47	0.059	0.130
18	0.376	0.00185	0.00590	0.244	0.073	0.18	0.662	0.00272	0.0087	21,013	1,199	2,613	46,326	2,644	5,760	23.2	1.32	2.88
Totals, NY Waterway	**12.0**	**0.0155**	**0.0350**	**0.083**	**0.354**	**0.75**	**31.6**	**0.0658**	**0.152**	**265,387**	**2,347**	**4,788**	**585,077**	**5,175**	**10,555**	**293**	**2.59**	**5.3**
19	1.11	0.00493	0.0212	0.857	0.126	0.35	3.70	0.0327	0.1408	8,837	203	468	19,483	447	1,032	9.74	0.224	0.516
20	0.637	0.00283	0.01216	0.450	0.066	0.18	4.08	0.0361	0.1553	33,560	490	1,130	73,986	1,080	2,491	37.0	0.540	1.25
21	0.637	0.00283	0.01216	0.450	0.066	0.18	2.82	0.0250	0.1074	8,128	147	339	17,919	324	748	8.96	0.162	0.374
22	0.595	0.00264	0.01135	0.505	0.074	0.21	2.29	0.02026	0.0872	7,046	160	369	15,533	352	813	7.77	0.176	0.406
23	0.589	0.00261	0.01124	0.539	0.079	0.22	2.35	0.0208	0.0895	7,231	170	392	15,942	375	865	7.97	0.188	0.433
24	0.803	0.00356	0.01532	0.408	0.060	0.17	2.38	0.0211	0.0906	56,924	1,008	2,325	125,497	2,223	5,126	62.7	1.11	2.56
25	0.673	0.00298	0.01283	0.331	0.049	0.13	1.58	0.0140	0.0603	8,744	171	395	19,277	377	870	9.64	0.189	0.435
26	0.807	0.00398	0.0127	0.949	0.284	0.70	2.11	0.0087	0.0276	3,217	237	516	7,093	522	1,137	3.55	0.261	0.57
27	0.651	0.00321	0.0102	0.925	0.277	0.68	2.17	0.0089	0.0283	5,837	433	943	12,869	954	2,079	6.43	0.477	1.04
Totals, Billy Bey Ferry Company	**6.50**	**0.01008**	**0.0259**	**5.41**	**0.447**	**1.00**	**23.5**	**0.0681**	**0.1750**	**139,525**	**1,283**	**2,677**	**307,599**	**2,829**	**5,901**	**154**	**1.41**	**2.95**
28	6.25	0.142	0.611	3.25	0.60	1.7	8.63	0.0218	0.094	23,566	806	1,859	51,955	1,777	4,098	26.0	0.89	2.05
29	6.25	0.142	0.611	3.25	0.60	1.7	8.63	0.0218	0.094	5,656	193	446	12,469	427	984	6.2	0.213	0.492
Totals, New York Water Taxi	**12.5**	**0.201**	**0.863**	**6.49**	**0.85**	**2.4**	**17.3**	**0.031**	**0.133**	**29,222**	**829**	**1,912**	**64,424**	**1,828**	**4,214**	**32.2**	**0.91**	**2.11**
Grand Totals, New York City Harbor	**31.0**	**0.202**	**0.456**	**12.0**	**1.03**	**2.14**	**72.3**	**0.100**	**0.222**	**434,134**	**2,801**	**5,665**	**957,100**	**6,175**	**12,489**	**479**	**3.09**	**6.2**

Notes: (1): GPS data for respective route was unavailable for specific route; therefore route times estimated from vessels operating on similar routes.
(2): Emission data for mechanically controlled Caterpillar 3412 engines from actual baseline testing.
(3): Because NY Watertaxi vessels do not typically complete a closed circuit route the operating profile of the three modes of operation are presented as the total time in hours in each mode during the typical 9 hours of daily operation as determined during data logging. Therefore, route definitions and frequency are presented as various and on a hrs/day basis.

Route No.	Route: Origin / Destination / End	Operator	Route Description	Route Distance (NM)	Propulsion Engine Type	NOx at Push, per Engine (kg/hr)	NOx at Push STD Deviation (kg/hr)	NOx at Push ± 95.0% C.I. (± kg/hr)	NOx at Manuever, per Engine (kg/hr)	NOx at Manuever STD Deviation (kg/hr)	NOx at Manuever ± 95.0% C.I. (± kg/hr)	NOx at Cruise, per Engine (kg/hr)	NOx at Cruise STD Deviation (kg/hr)	NOx at Cruise ± 95.0% C.I. (± kg/hr)	NOx at Push, per vessel (kg/rte)	NOx at Push STD Deviation, per vessel (kg/rte)	NOx at Push, per vessel ± 95.0% C.I. (± kg/rte)	NOx at Manuever, per vessel (kg/rte)	NOx at Manuever STD Deviation, per vessel (kg/rte)	NOx at Manuever, /vessel ± 95.0% C.I. (± kg/rte)	NOx at Cruise, per vessel (kg/rte)	NOx at Cruise STD Deviation, per vessel (kg/rte)	NOx at Cruise, /vessel ± 95.0% C.I. (± kg/rte)	Total Annual NOx, per route (kg/yr)	Total Annual NOx STD Deviation (kg/yr)	Total Annual NOx 95.0% C.I. (± kg/yr)	Total Annual NOx, per route (lbs/yr)	Total Annual NOx STD Deviation (lbs/yr)	Total Annual NOx 95.0% C.I. (± lbs/yr)	Total Annual NOx, per route (short tons/yr)	Total Annual NOx STD Deviation (short tons/yr)	Total Annual NOx 95.0% C.I. (± short tons/yr)
1	Belford, NJ to Pier 11 to Belford, NJ	NY Waterway	Long Haul	45.8	Caterpillar 3412E	2.83	0.0500	0.2149	2.10	0.328	0.80	1.94	0.0064	0.0205	1.75	0.0309	0.1327	1.62	0.254	0.62	8.23	0.0274	0.087	42,229	938	2,064	93,098	2,067	4,550	46.5	1.03	2.27
2	Port Liberte to Pier 11 to Port Libete	NY Waterway	Medium Haul	9.40	Caterpillar 3406E	1.36	0.00576	0.02479	0.984	0.0235	0.065	2.52	0.0121	0.0520	1.04	0.00443	0.01904	1.02	0.0244	0.068	2.63	0.0126	0.0542	8,546	50.7	117	18,840	112	258	9.42	0.0559	0.129
3	Pier 11 to Port Liberte to Pier 11	NY Waterway	Medium Haul	9.40	Caterpillar 3406E	1.36	0.00576	0.02479	0.984	0.0235	0.065	2.52	0.0121	0.0520	0.898	0.00380	0.01636	0.879	0.0210	0.058	2.69	0.0129	0.0555	11,603	65	149	25,581	143	329	12.8	0.071	0.165
4	Hoboken-South to (via WFC & Pier 11) WFC to Hoboken-South	NY Waterway	Medium Haul	7.70	Caterpillar 3412(2)	1.84	0.0114	0.0490	1.55	0.095	0.23	2.19	0.00659	0.0210	0.782	0.00485	0.0208	0.477	0.0293	0.072	1.47	0.00441	0.0140	8,508	94	206	18,758	207	455	9.4	0.103	0.227
5	38th Street to (via Newport & Harborside) Colgate to 38th Street	NY Waterway	Medium Haul	7.60	Caterpillar 3406E	1.36	0.00576	0.02479	0.984	0.0235	0.065	2.52	0.0121	0.0520	0.727	0.00308	0.01325	0.435	0.0104	0.029	2.60	0.0125	0.0536	22,490	99	228	49,582	218	502	24.8	0.109	0.251
6	38th Street to (via Newport) Harborside to 38th Street	NY Waterway	Medium Haul	6.70	Caterpillar 3406E	1.36	0.00576	0.02479	0.984	0.0235	0.065	2.52	0.0121	0.0520	0.447	0.001894	0.00815	0.286	0.0068	0.019	2.20	0.0105	0.0453	12,953	56.1	129	28,556	124	285	14.3	0.0619	0.143
7	38th Street to (via Harborside) Newport to 38th Street	NY Waterway	Medium Haul	6.70	Caterpillar 3406E	1.36	0.00576	0.02479	0.984	0.0235	0.065	2.52	0.0121	0.0520	0.448	0.001898	0.00817	0.323	0.0077	0.021	2.08	0.0100	0.0430	4,451	19.9	45.9	9,812	43.9	101	4.91	0.0219	0.051
8	38th Street to Harborside to 38th Street	NY Waterway	Medium Haul	6.60	Caterpillar 3406E	1.36	0.00576	0.02479	0.984	0.0235	0.065	2.52	0.0121	0.0520	0.329	0.001393	0.00599	0.184	0.00438	0.0122	1.75	0.00838	0.0361	3,525	14.9	34.4	7,771	32.9	75.8	3.89	0.0164	0.038
9	Liberty Harbor to Pier 11 to Liberty Harbor	NY Waterway	Medium Haul	5.80	Caterpillar 3406E	1.36	0.00576	0.02479	0.984	0.0235	0.065	2.52	0.0121	0.0520	0.452	0.001915	0.00824	0.473	0.0113	0.031	1.33	0.00638	0.0274	14,069	82	189	31,018	180	416	15.5	0.090	0.208
10	38th Street to Newport to 38th Street	NY Waterway	Medium Haul	5.60	Caterpillar 3406E	1.36	0.00576	0.02479	0.984	0.0235	0.065	2.52	0.0121	0.0520	0.313	0.001326	0.00570	0.262	0.0063	0.017	1.30	0.00625	0.0269	8,297	39.5	91	18,292	87	201	9.15	0.0436	0.100
11	Hoboken-South to WFC to Hoboken-South	NY Waterway	Medium Haul	5.00	Caterpillar 3412(2)	1.84	0.0114	0.0490	1.55	0.095	0.23	2.19	0.00659	0.0210	0.383	0.00237	0.01022	0.202	0.0124	0.030	0.845	0.00254	0.00809	23,423	211	464	51,640	465	1,023	25.8	0.232	0.51
12	38th Street to (via Lincoln Harbor) Hoboken North to 38th Street	NY Waterway	Medium Haul	3.10	Caterpillar 3406E	1.36	0.00576	0.02479	0.984	0.0235	0.065	2.52	0.0121	0.0520	0.738	0.00313	0.01345	0.565	0.0135	0.037	0.537	0.00258	0.01109	13,393	102	236	29,527	226	521	14.8	0.113	0.260
13	Hoboken-North to 38th Street to Hoboken-North	NY Waterway	Medium Haul	2.40	Caterpillar 3406E	1.36	0.00576	0.02479	0.984	0.0235	0.065	2.52	0.0121	0.0520	0.740	0.00314	0.01350	0.324	0.0077	0.021	0.560	0.00269	0.01157	12,254	66	153	27,015	146	336	13.5	0.073	0.168
14	38th Street to Lincoln Harbor to 38th Street	NY Waterway	Medium Haul	2.40	Caterpillar 3412(2)	1.84	0.0114	0.0490	1.55	0.095	0.23	2.19	0.00659	0.0210	0.355	0.00220	0.00947	0.281	0.0173	0.042	0.309	0.00093	0.00296	6,395	118	260	14,099	260	572	7.05	0.130	0.286
15	Port Imperial to 38th Street to Port Imperial (weekdays)	NY Waterway	Short Haul	2.00	Caterpillar 3412E	2.83	0.0500	0.2149	2.10	0.328	0.80	1.94	0.0064	0.0205	0.625	0.01102	0.0474	0.385	0.060	0.15	0.491	0.00163	0.00520	34,728	1,420	3,125	76,561	3,131	6,890	38.3	1.57	3.45
16	Port Imperial to 38th Street to Port Imperial (saturdays)	NY Waterway	Short Haul	2.00	Caterpillar 3412E	2.83	0.0500	0.2149	2.10	0.328	0.80	1.94	0.0064	0.0205	0.709	0.01250	0.0538	0.247	0.0387	0.095	0.593	0.00197	0.0063	4,189	110	243	9,236	243	535	4.62	0.121	0.267
17	Port Imperial to 38th Street to Port Imperial (sundays)	NY Waterway	Short Haul	2.00	Caterpillar 3412E	2.83	0.0500	0.2149	2.10	0.328	0.80	1.94	0.0064	0.0205	0.726	0.01280	0.0551	0.340	0.053	0.13	0.499	0.00166	0.00529	3,987	140	307	8,790	308	677	4.40	0.154	0.339
18	Colgate to WFC to Colgate	NY Waterway	Short Haul	1.60	Caterpillar 3412(2)	1.84	0.0114	0.0490	1.55	0.095	0.23	2.19	0.00659	0.0210	0.355	0.00220	0.00947	0.184	0.0113	0.028	0.467	0.00141	0.00447	16,491	190	418	36,356	419	922	18.2	0.209	0.461
	Totals, NY Waterway					**32.3**	**0.1041**	**0.255**	**24.4**	**0.69**	**1.46**	**41.7**	**0.0424**	**0.098**	**11.8**	**0.0389**	**0.0951**	**8.50**	**0.275**	**0.58**	**30.6**	**0.0405**	**0.093**	**251,531**	**1,753**	**3,581**	**554,531**	**3,865**	**7,894**	**277**	**1.93**	**3.95**
19	Port Imperial to (via Hoboken-North, WFC) Pier 11 to (via WFC, Hoboken-North) Port Imperial	Billy Bey	Long Haul	13.1	Caterpillar 3406E	1.36	0.00576	0.02479	0.984	0.0235	0.065	2.52	0.0121	0.0520	1.12	0.00475	0.02045	0.931	0.0222	0.062	3.76	0.0180	0.0776	9,070	45.3	104	19,995	100	230	10.00	0.0499	0.115
20	Port Imperial to Pier 11 to Port Imperial	Billy Bey	Long Haul	12.8	Caterpillar 3406E	1.36	0.00576	0.02479	0.984	0.0235	0.065	2.52	0.0121	0.0520	0.644	0.00273	0.01173	0.489	0.0117	0.032	4.15	0.0199	0.0856	34,312	151	348	75,644	333	767	37.8	0.166	0.384
21	Pier 11 to 38th Street to Pier 11	Billy Bey	Long Haul	11.8	Caterpillar 3406E	1.36	0.00576	0.02479	0.984	0.0235	0.065	2.52	0.0121	0.0520	0.644	0.00273	0.01173	0.489	0.0117	0.032	2.87	0.0138	0.0592	8,323	38.0	88	18,350	84	193	9.17	0.0418	0.097
22	Port Imperial to (via Hoboken-North) WFC to Port Imperial	Billy Bey	Medium Haul	8.00	Caterpillar 3406E	1.36	0.00576	0.02479	0.984	0.0235	0.065	2.52	0.0121	0.0520	0.601	0.00254	0.01095	0.548	0.0131	0.036	2.33	0.0112	0.0480	7,231	36.2	83	15,941	80	184	7.97	0.0399	0.092
23	WFC to (via Hoboken-North) Port Imperial to WFC	Billy Bey	Medium Haul	8.00	Caterpillar 3406E	1.36	0.00576	0.02479	0.984	0.0235	0.065	2.52	0.0121	0.0520	0.595	0.00252	0.01085	0.585	0.0140	0.039	2.39	0.0115	0.0493	7,424	37.9	87	16,368	84	193	8.18	0.0418	0.096
24	Hoboken-South to Pier 11 to Hoboken-South	Billy Bey	Medium Haul	7.40	Caterpillar 3406E	1.36	0.00576	0.02479	0.984	0.0235	0.065	2.52	0.0121	0.0520	0.811	0.00344	0.01479	0.443	0.0106	0.029	2.42	0.0116	0.0499	58,262	255	588	128,445	562	1,296	64.2	0.281	0.648
25	38th Street to Colgate to 38th Street	Billy Bey	Medium Haul	7.40	Caterpillar 3406E	1.36	0.00576	0.02479	0.984	0.0235	0.065	2.52	0.0121	0.0520	0.679	0.00288	0.01238	0.359	0.0086	0.024	1.61	0.00773	0.0333	8,956	40.2	93	19,744	89	204	9.87	0.0443	0.102
26	38th St. to (via Newport Hoboken-South) Hoboken-North to 38th St.	Billy Bey	Medium Haul	6.20	Caterpillar 3412(2)	1.84	0.0114	0.0490	1.55	0.095	0.23	2.19	0.00659	0.0210	0.762	0.00472	0.0203	0.715	0.0439	0.11	1.49	0.00448	0.0143	2,469	37.0	81	5,442	81	179	2.72	0.0407	0.090
27	38th St. to (via Hoboken North & Hoboken South) Newport to 38th St.	Billy Bey	Medium Haul	6.20	Caterpillar 3412(2)	1.84	0.0114	0.0490	1.55	0.095	0.23	2.19	0.00659	0.0210	0.614	0.00381	0.0164	0.697	0.0428	0.10	1.53	0.00460	0.0146	4,431	67	149	9,768	149	327	4.88	0.074	0.164
	Totals, Billy Bey Ferry Company					**13.2**	**0.0222**	**0.0616**	**10.0**	**0.148**	**0.33**	**22.0**	**0.0333**	**0.0856**	**6.47**	**0.01035**	**0.0287**	**5.26**	**0.071**	**0.159**	**22.5**	**0.0374**	**0.0963**	**140,476**	**319**	**667**	**309,697**	**703**	**1,470**	**155**	**0.351**	**0.74**
28	Various weekday routes [1]	NY Water Taxi	Medium Haul	-	DD Series 60	0.793	0.00306	0.0132	0.949	0.216	0.60	1.42	0.00774	0.0333	6.43	0.0248	0.107	2.51	0.572	1.6	10.3	0.0561	0.241	25,046	748	1,724	55,217	1,648	3,800	27.6	0.82	1.90
29	Various weekend routes [1]	NY Water Taxi	Medium Haul	-	DD Series 60	0.793	0.00306	0.0132	0.949	0.216	0.60	1.42	0.00774	0.0333	6.43	0.0248	0.107	2.51	0.572	1.6	10.3	0.0561	0.241	6,011	179	414	13,252	396	912	6.63	0.198	0.456
	Totals, New York Water Taxi					**1.59**	**0.00433**	**0.0186**	**1.90**	**0.306**	**0.85**	**2.85**	**0.0109**	**0.047**	**12.9**	**0.0351**	**0.1511**	**5.02**	**0.81**	**2.2**	**20.7**	**0.0794**	**0.342**	**31,057**	**769**	**1,773**	**68,469**	**1,695**	**3,908**	**34.2**	**0.85**	**1.95**
	Grand Totals, New York City Harbor					**47.1**	**0.1065**	**0.246**	**36.3**	**0.77**	**1.60**	**66.6**	**0.0551**	**0.123**	**31.1**	**0.0534**	**0.123**	**18.8**	**0.86**	**1.79**	**73.8**	**0.097**	**0.215**	**423,065**	**1,941**	**3,929**	**932,698**	**4,279**	**8,661**	**466**	**2.14**	**4.33**

Notes:
(1): GPS data for respective route was unavailable for specific route; therefore route times estimated from vessels operating on similar routes.
(2): Emission data for mechanically controlled Caterpillar 3412 engines from actual baseline testing.
(3): Because NY Watertaxi vessels do not typically complete a closed circuit route the operating profile of the three modes of operation are presented as the total time in hours in each mode during the typical 9 hours of daily operation as determined during data logging. Therefore, route definitions and frequency are presented as various and on a hrs/day basis.

BASELINE PM2.5 EMISSION RATES

Route No.	Route Origin / Destination / End	Operator	Route Description	Route Distance (NM)	Propulsion Engine Type	PM 2.5 at Push, per Engine (g/hr)	PM 2.5 at Push STD Deviation (g/hr)	PM 2.5 at Push ± 95.0% C.I. (± g/hr)	PM 2.5 at Man, per Engine (g/hr)	PM 2.5 at Man. STD Deviation (g/hr)	PM 2.5 at Maneuver ± 95.0% C.I. (± g/hr)	PM 2.5 at Cruise, per Engine (g/hr)	PM 2.5 at Cruise STD Deviation (g/hr)	PM 2.5 at Cruise ± 95.0% C.I. (± g/hr)
1	Belford, NJ to Pier 11 to Belford, NJ	NY Waterway	Long Haul	45.8	Caterpillar 3412E	2.79	0.316	1.362	4.466	0.399	1.72	6.09	0.064	0.276
2	Port Liberte to Pier 11 to Port Libete	NY Waterway	Medium Haul	9.40	Caterpillar 3406E	11.3	0.264	1.134	10.29	1.31	5.65	24.9	1.161	5.00
3	Pier 11 to Port Liberte to Pier 11	NY Waterway	Medium Haul	9.40	Caterpillar 3406E	11.3	0.264	1.134	10.29	1.31	5.65	24.9	1.161	5.00
4	Hoboken-South to (via WFC & Pier 11) WFC to Hoboken-South	NY Waterway	Medium Haul	7.70	Caterpillar 3412(2)	50.4	0.62	2.66	40.89	2.05	8.80	17.6	0.389	1.67
5	38th Street to (via Newport & Harborside) Colgate to 38th Street	NY Waterway	Medium Haul	7.60	Caterpillar 3406E	11.3	0.264	1.134	10.29	1.31	5.65	24.9	1.161	5.00
6	38th Street to (via Newport) Harborside to 38th Street	NY Waterway	Medium Haul	6.70	Caterpillar 3406E	11.3	0.264	1.134	10.29	1.31	5.65	24.9	1.161	5.00
7	38th Street to (via Harborside) Newport to 38th Street	NY Waterway	Medium Haul	6.70	Caterpillar 3406E	11.3	0.264	1.134	10.29	1.31	5.65	24.9	1.161	5.00
8	38th Street to Harborside to 38th Street	NY Waterway	Medium Haul	6.60	Caterpillar 3406E	11.3	0.264	1.134	10.29	1.31	5.65	24.9	1.161	5.00
9	Liberty Harbor to Pier 11 to Liberty Harbor	NY Waterway	Medium Haul	5.80	Caterpillar 3406E	11.3	0.264	1.134	10.29	1.31	5.65	24.9	1.161	5.00
10	38th Street to Newport to 38th Street	NY Waterway	Medium Haul	5.60	Caterpillar 3406E	11.3	0.264	1.134	10.29	1.31	5.65	24.9	1.161	5.00
11	Hoboken-South to WFC to Hoboken-South	NY Waterway	Medium Haul	5.00	Caterpillar 3412(2)	50.4	0.62	2.66	40.89	2.05	8.80	17.6	0.389	1.67
12	38th Street to (via Lincoln Harbor) Hoboken North to 38th Street	NY Waterway	Medium Haul	3.10	Caterpillar 3406E	11.3	0.264	1.134	10.29	1.31	5.65	24.9	1.161	5.00
13	Hoboken-North to 38th Street to Hoboken-North	NY Waterway	Medium Haul	2.40	Caterpillar 3406E	11.3	0.264	1.134	10.29	1.31	5.65	24.9	1.161	5.00
14	38th Street to Lincoln Harbor to 38th Street	NY Waterway	Medium Haul	2.40	Caterpillar 3412(2)	50.4	0.62	2.66	40.89	2.05	8.80	17.6	0.389	1.67
15	Port Imperial to 38th Street to Port Imperial (weekdays)	NY Waterway	Short Haul	2.00	Caterpillar 3412E	2.79	0.316	1.362	4.466	0.399	1.72	6.09	0.064	0.276
16	Port Imperial to 38th Street to Port Imperial (saturdays)	NY Waterway	Short Haul	2.00	Caterpillar 3412E	2.79	0.316	1.362	4.466	0.399	1.72	6.09	0.064	0.276
17	Port Imperial to 38th Street to Port Imperial (sundays)	NY Waterway	Short Haul	2.00	Caterpillar 3412E	2.79	0.316	1.362	4.466	0.399	1.72	6.09	0.064	0.276
18	Colgate to WFC to Colgate	NY Waterway	Short Haul	1.60	Caterpillar 3412(2)	50.4	0.62	2.66	40.89	2.05	8.80	17.6	0.389	1.67
Totals, NY Waterway						**325**	**1.62**	**4.0**	**284.4**	**5.89**	**14.4**	**344**	**3.76**	**9.19**
19	Port Imperial to (via Hoboken-North, WFC) Pier 11 to (via WFC, Hoboken-North) Port Imperial	Billy Bey	Long Haul	13.1	Caterpillar 3406E	11.3	0.264	1.134	10.29	1.31	5.65	24.9	1.161	5.00
20	Port Imperial to Pier 11 to Port Imperial	Billy Bey	Long Haul	12.8	Caterpillar 3406E	11.3	0.264	1.134	10.29	1.31	5.65	24.9	1.161	5.00
21	Pier 11 to 38th Street to Pier 11	Billy Bey	Long Haul	11.8	Caterpillar 3406E	11.3	0.264	1.134	10.29	1.31	5.65	24.9	1.161	5.00
22	Port Imperial to (via Hoboken-North) WFC to Port Imperial	Billy Bey	Medium Haul	8.00	Caterpillar 3406E	11.3	0.264	1.134	10.29	1.31	5.65	24.9	1.161	5.00
23	WFC to (via Hoboken-North) Port Imperial to WFC	Billy Bey	Medium Haul	8.00	Caterpillar 3406E	11.3	0.264	1.134	10.29	1.31	5.65	24.9	1.161	5.00
24	Hoboken-South to Pier 11 to Hoboken-South	Billy Bey	Medium Haul	7.40	Caterpillar 3406E	11.3	0.264	1.134	10.29	1.31	5.65	24.9	1.161	5.00
25	38th Street to Colgate to 38th Street	Billy Bey	Medium Haul	7.40	Caterpillar 3406E	11.3	0.264	1.134	10.29	1.31	5.65	24.9	1.161	5.00
26	38th St. to (via Newport Hoboken-South) Hoboken-North to 38th St.	Billy Bey	Medium Haul	6.20	Caterpillar 3412(2)	50.4	0.62	2.66	40.89	2.05	8.80	17.6	0.389	1.67
27	38th St. to (via Hoboken North & Hoboken South) Newport to 38th St.	Billy Bey	Medium Haul	6.20	Caterpillar 3412(2)	50.4	0.62	2.66	40.89	2.05	8.80	17.6	0.389	1.67
Totals, Billy Bey Ferry Company						**180**	**1.12**	**3.11**	**153.8**	**4.52**	**12.56**	**209**	**3.12**	**8.67**
28	Various weekday routes [1]	NY Water Taxi	Medium Haul	-	DD Series 60	2.33	0.034	0.43	13.46	0.491	6.24	38.4	0.44	5.53
29	Various weekend routes [1]	NY Water Taxi	Medium Haul	-	DD Series 60	2.33	0.034	0.43	13.46	0.491	6.24	38.4	0.44	5.53
Totals, New York Water Taxi						**4.66**	**0.048**	**0.60**	**26.92**	**0.694**	**8.82**	**76.7**	**0.62**	**7.82**
Grand Totals, New York City Harbor						**510**	**1.97**	**4.7**	**465**	**7.45**	**17.6**	**630**	**4.92**	**11.64**

Route No.	PM 2.5 at Push, per vessel (g/route)	PM 2.5 at Push STD Deviation (g/route)	PM 2.5 at Push ± 95.0% C.I. (± g/route)	PM 2.5 at Manuever, per vessel (g/route)	PM 2.5 at Man. STD Deviation (g/route)	PM 2.5 at Maneuver ± 95.0% C.I. (± g/route)	PM 2.5 at Cruise, per vessel (g/route)	PM 2.5 at Cruise STD Deviation (g/route)	PM 2.5 at Cruise ± 95.0% C.I. (± g/route)
1	1.72	0.195	0.841	3.459	0.309	1.329	25.9	0.27	1.17
2	8.65	0.202	0.871	10.71	1.37	5.89	26.0	1.211	5.21
3	7.43	0.174	0.749	9.19	1.17	5.05	26.6	1.238	5.33
4	21.5	0.26	1.13	12.59	0.629	2.71	11.8	0.261	1.12
5	6.02	0.141	0.606	4.555	0.582	2.50	25.7	1.197	5.15
6	3.70	0.087	0.373	2.996	0.382	1.65	21.7	1.012	4.36
7	3.71	0.087	0.374	3.379	0.431	1.86	20.6	0.959	4.13
8	2.72	0.0637	0.274	1.921	0.245	1.06	17.3	0.805	3.46
9	3.74	0.088	0.377	4.95	0.632	2.72	13.1	0.613	2.64
10	2.59	0.0607	0.261	2.745	0.350	1.51	12.9	0.600	2.58
11	10.5	0.129	0.56	5.32	0.266	1.14	6.78	0.150	0.646
12	6.11	0.143	0.615	5.91	0.754	3.25	5.31	0.248	1.065
13	6.13	0.144	0.617	3.393	0.433	1.86	5.54	0.258	1.111
14	9.75	0.120	0.52	7.42	0.371	1.60	2.48	0.055	0.236
15	0.616	0.0698	0.300	0.821	0.073	0.315	1.54	0.016	0.070
16	0.698	0.0792	0.341	0.527	0.0471	0.202	1.86	0.020	0.085
17	0.715	0.0811	0.349	0.724	0.065	0.278	1.57	0.017	0.071
18	9.75	0.120	0.52	4.85	0.243	1.04	3.75	0.083	0.357
Totals, NY Waterway	**106**	**0.58**	**1.41**	**85.5**	**2.46**	**6.01**	**230**	**2.84**	**6.95**
19	9.28	0.217	0.935	9.74	1.24	5.35	37.2	1.73	7.46
20	5.33	0.125	0.537	5.12	0.653	2.81	41.0	1.91	8.22
21	5.33	0.125	0.537	5.12	0.653	2.81	28.4	1.322	5.69
22	4.97	0.116	0.501	5.74	0.732	3.15	23.0	1.073	4.61
23	4.93	0.115	0.496	6.12	0.782	3.36	23.6	1.101	4.74
24	6.71	0.157	0.676	4.64	0.592	2.55	23.9	1.115	4.80
25	5.62	0.132	0.567	3.758	0.480	2.06	15.9	0.742	3.19
26	20.9	0.26	1.10	18.86	0.943	4.06	12.0	0.265	1.14
27	16.9	0.207	0.89	18.39	0.919	3.96	12.3	0.271	1.17
Totals, Billy Bey Ferry Company	**79.9**	**0.51**	**1.40**	**77.5**	**2.42**	**6.72**	**217**	**3.56**	**9.90**
28	18.9	0.27	3.5	35.6	1.30	16.50	278	3.16	40.1
29	18.9	0.27	3.5	35.6	1.30	16.50	278	3.16	40.1
Totals, New York Water Taxi	**37.8**	**0.39**	**4.9**	**71.2**	**1.84**	**23.33**	**557**	**4.5**	**56.7**
Grand Totals, New York City Harbor	**224**	**0.86**	**2.0**	**234.2**	**3.91**	**9.24**	**1,004**	**6.4**	**15.1**

Route No.	Total Annual PM 2.5, per route (g/yr)	Total Annual PM 2.5 STD Deviation (g/yr)	Total Annual PM 2.5 ± 95.0% C.I. (± g/yr)	Total Annual PM 2.5, per route (lbs/yr)	Total Annual PM 2.5 STD Deviation (lbs/yr)	Total Annual PM 2.5 ± 95.0% C.I. (± lbs/yr)	Total Current Annual PM 2.5, per route (short tons/yr)	Total Current Annual PM 2.5 STD Deviation (short tons/yr)	Total Annual PM 2.5 ± 95.0% C.I. (± short tons/yr)
1	112,980	1,660	4,063	249	3.7	9.0	0.125	0.0018	0.0045
2	82,485	3,345	8,184	182	7.37	18.0	0.0909	0.00369	0.00902
3	112,253	4,459	10,910	247	9.83	24.1	0.124	0.00491	0.01203
4	142,964	2,279	5,577	315	5.02	12.3	0.158	0.0025	0.0061
5	216,798	8,005	19,587	478	17.6	43.2	0.239	0.0088	0.0216
6	125,573	4,799	11,742	277	10.58	25.9	0.138	0.00529	0.01294
7	43,156	1,647	4,029	95.1	3.63	8.88	0.0476	0.00182	0.00444
8	34,180	1,317	3,222	75.4	2.90	7.10	0.0377	0.00145	0.00355
9	136,230	5,519	13,505	300	12.2	29.8	0.150	0.00608	0.0149
10	80,454	3,083	7,543	177	6.80	16.6	0.0887	0.00340	0.00831
11	370,429	5,430	13,286	817	12.0	29.3	0.408	0.0060	0.0146
12	126,122	5,873	14,370	278	12.9	31.7	0.139	0.0065	0.0158
13	113,554	3,953	9,674	250	8.72	21.3	0.125	0.00436	0.01066
14	132,841	2,661	6,512	293	5.87	14.4	0.146	0.0029	0.0072
15	68,923	2,372	5,805	152	5.23	12.8	0.0760	0.00262	0.00640
16	8,355	255	623	18.4	0.561	1.37	0.0092	0.000281	0.000687
17	7,665	268	655	16.9	0.590	1.44	0.00845	0.000295	0.000722
18	300,604	4,634	11,340	663	10.2	25.0	0.331	0.0051	0.0125
Totals, NY Waterway	**2,215,566**	**16,866**	**35,434**	**4,884**	**37.2**	**78.1**	**2.44**	**0.0186**	**0.0391**
19	110,624	3,345	8,185	244	7.37	18.0	0.122	0.003687	0.00902
20	455,611	13,150	32,177	1,004	29.0	70.9	0.502	0.0145	0.0355
21	119,541	3,078	7,532	264	6.79	16.6	0.132	0.00339	0.00830
22	109,698	2,712	6,636	242	5.98	14.6	0.121	0.00299	0.00732
23	111,767	2,819	6,897	246	6.21	15.2	0.123	0.00311	0.00760
24	833,388	20,174	49,364	1,837	44.5	108.8	0.919	0.0222	0.0544
25	147,642	3,021	7,392	325	6.66	16.3	0.163	0.00333	0.00815
26	45,604	843	2,062	100.5	1.86	4.55	0.0503	0.00093	0.00227
27	85,256	1,530	3,744	188	3.37	8.3	0.0940	0.00169	0.00413
Totals, Billy Bey Ferry Company	**2,019,130**	**25,061**	**54,603**	**4,451**	**55.2**	**120.4**	**2.23**	**0.0276**	**0.0602**
28	432,630	4,453	14,171	954	9.8	31.2	0.477	0.0049	0.0156
29	103,831	1,069	3,401	229	2.36	7.5	0.114	0.00118	0.00375
Totals, New York Water Taxi	**536,461**	**4,579**	**14,574**	**1,183**	**10.1**	**32.1**	**0.591**	**0.0050**	**0.0161**
Grand Totals, New York City Harbor	**4,771,157**	**30,553**	**63,538**	**10,519**	**67.4**	**140**	**5.26**	**0.0337**	**0.0700**

Notes:
(1): GPS data for respective route was unavailable for specific route; therefore route times estimated from vessels operating on similar routes.
(2): Emission data for mechanically controlled Caterpillar 3412 engines from actual baseline testing.
(3): Because NY Watertaxi vessels do not typically complete a closed circuit route the operating profile of the three modes of operation are presented as the total time in hours in each mode during the typical 9 hours of daily operation as determined during data logging. Therefore, route definitions and frequency are presented as various and on a hrs/day basis.

Route Origin / Destination / End	Operator	Route Description	Route Distance (NM)	Propulsion Engine Type	PM 2.5 at Push, per Engine (g/hr)	PM 2.5 at Push STD Deviation (g/hr)	PM 2.5 at Push ± 95.0% C.I. (± g/hr)	PM 2.5 at Man, per Engine (g/hr)	PM 2.5 at Man. STD Deviation (g/hr)	PM 2.5 at Maneuver ± 95.0% C.I. (± g/hr)	PM 2.5 at Cruise, per Engine (g/hr)	PM 2.5 at Cruise STD Deviation (g/hr)	PM 2.5 at Cruise ± 95.0% C.I. (± g/hr)	PM 2.5 at Push, per vessel (g/route)	PM 2.5 at Push STD Deviation (g/route)	PM 2.5 at Push ± 95.0% C.I. (± g/route)	PM 2.5 at Man. STD Deviation (g/route)	PM 2.5 at Maneuver ± 95.0% C.I. (± g/route)	PM 2.5 at Cruise, per vessel (g/route)	PM 2.5 at Cruise STD Deviation (g/route)	PM 2.5 at Cruise ± 95.0% C.I. (± g/route)	Total Annual PM 2.5, per route (g/yr)	Total Annual PM 2.5 STD Deviation (g/yr)	Total Annual PM 2.5 ± 95.0% C.I. (± g/yr)	Total Annual PM 2.5, per route (lbs/yr)	Total Annual PM 2.5 STD Deviation (lbs/yr)	Total Annual PM 2.5 ± 95.0% C.I. (± lbs/yr)	Total Annual PM 2.5, per route (short tons/yr)	Total Annual PM 2.5 STD Deviation (short tons/yr)	Total PM 2.5 ± 95.0% C.I. (± short tons/yr)
Belford, NJ to Pier 11 to Belford, NJ	NY Waterway	Long Haul	45.8	Caterpillar 3412E	1.74	0.313	1.346	4.072	0.538	2.31	5.51	0.146	0.6302	1.07	0.193	0.831	0.417	1.792	23.4	0.622	2.68	100,550	2,815	6,888	222	6.21	15.2	0.111	0.00310	0.00759
Port Liberte to Pier 11 to Port Libete	NY Waterway	Medium Haul	9.40	Caterpillar 3406E	1.70	0.283	1.217	3.54	0.227	0.975	18.1	0.497	2.1401	1.31	0.217	0.934	0.236	1.01	18.9	0.518	2.23	43,459	1,110	2,715	95.8	2.45	5.99	0.0479	0.00122	0.00299
Pier 11 to Port Liberte to Pier 11	NY Waterway	Medium Haul	9.40	Caterpillar 3406E	1.70	0.283	1.217	3.54	0.227	0.975	18.1	0.497	2.1401	1.12	0.187	0.803	0.202	0.871	19.3	0.530	2.28	61,360	1,553	3,801	135	3.42	8.38	0.0676	0.00171	0.00419
Hoboken-South to (via WFC & Pier 11) WFC to Hoboken-South	NY Waterway	Medium Haul	7.70	Caterpillar 3412(2)	2.20	0.237	1.021	3.35	0.299	1.287	8.66	0.048	0.2073	0.936	0.101	0.435	0.092	0.396	5.80	0.032	0.139	24,233	438	1,072	53.4	0.97	2.36	0.0267	0.00048	0.00118
38th Street to (via Newport & Harborside) Colgate to 38th Street	NY Waterway	Medium Haul	7.60	Caterpillar 3406E	1.70	0.283	1.217	3.54	0.227	0.975	18.1	0.497	2.1401	0.909	0.151	0.650	0.100	0.432	18.7	0.513	2.21	126,530	3,253	7,960	279	7.2	17.5	0.139	0.00359	0.00877
38th Street to (via Newport) Harborside to 38th Street	NY Waterway	Medium Haul	6.70	Caterpillar 3406E	1.70	0.283	1.217	3.54	0.227	0.975	18.1	0.497	2.1401	0.559	0.093	0.400	0.066	0.284	15.8	0.434	1.87	76,847	1,982	4,849	169	4.37	10.69	0.0847	0.00218	0.00535
38th Street to (via Harborside) Newport to 38th Street	NY Waterway	Medium Haul	6.70	Caterpillar 3406E	1.70	0.283	1.217	3.54	0.227	0.975	18.1	0.497	2.1401	0.560	0.093	0.401	0.074	0.320	15.0	0.411	1.77	26,040	668	1,633	57.4	1.47	3.60	0.0287	0.00074	0.00180
38th Street to Harborside to 38th Street	NY Waterway	Medium Haul	6.60	Caterpillar 3406E	1.70	0.283	1.217	3.54	0.227	0.975	18.1	0.497	2.1401	0.411	0.068	0.294	0.0423	0.182	12.6	0.345	1.48	21,269	552	1,352	46.9	1.22	2.98	0.0234	0.00061	0.00149
Liberty Harbor to Pier 11 to Liberty Harbor	NY Waterway	Medium Haul	5.80	Caterpillar 3406E	1.70	0.283	1.217	3.54	0.227	0.975	18.1	0.497	2.1401	0.565	0.094	0.404	0.109	0.469	9.56	0.262	1.129	73,802	1,868	4,570	163	4.12	10.07	0.0814	0.00206	0.00504
38th Street to Newport to 38th Street	NY Waterway	Medium Haul	5.60	Caterpillar 3406E	1.70	0.283	1.217	3.54	0.227	0.975	18.1	0.497	2.1401	0.391	0.065	0.280	0.060	0.260	9.36	0.257	1.106	47,277	1,202	2,940	104.2	2.65	6.48	0.0521	0.00132	0.00324
Hoboken-South to WFC to Hoboken-South	NY Waterway	Medium Haul	5.00	Caterpillar 3412(2)	2.20	0.237	1.021	3.35	0.299	1.287	8.66	0.048	0.2073	0.459	0.0495	0.213	0.0389	0.1673	3.34	0.019	0.080	69,350	1,075	2,631	153	2.37	5.80	0.0764	0.00119	0.00290
38th Street to (via Lincoln Harbor) Hoboken North to 38th Street	NY Waterway	Medium Haul	3.10	Caterpillar 3406E	1.70	0.283	1.217	3.54	0.227	0.975	18.1	0.497	2.1401	0.922	0.153	0.660	0.130	0.560	3.86	0.1060	0.456	49,629	1,655	4,050	109.4	3.65	8.93	0.0547	0.00182	0.00446
Hoboken-North to 38th Street to Hoboken-North	NY Waterway	Medium Haul	2.40	Caterpillar 3406E	1.70	0.283	1.217	3.54	0.227	0.975	18.1	0.497	2.1401	0.925	0.154	0.662	0.075	0.321	4.03	0.111	0.476	46,161	1,536	3,759	101.8	3.39	8.29	0.0509	0.00169	0.00414
38th Street to Lincoln Harbor to 38th Street	NY Waterway	Medium Haul	2.40	Caterpillar 3412(2)	2.20	0.237	1.021	3.35	0.299	1.287	8.66	0.048	0.2073	0.426	0.0459	0.198	0.0543	0.233	1.22	0.0068	0.029	15,246	483	1,181	33.6	1.064	2.60	0.0168	0.00053	0.00130
Port Imperial to 38th Street to Port Imperial (weekdays)	NY Waterway	Short Haul	2.00	Caterpillar 3412E	1.74	0.313	1.346	4.072	0.538	2.31	5.51	0.146	0.6302	0.383	0.069	0.297	0.099	0.425	1.40	0.0371	0.160	58,469	2,919	7,143	128.9	6.44	15.7	0.0645	0.00322	0.00787
Port Imperial to 38th Street to Port Imperial (saturdays)	NY Waterway	Short Haul	2.00	Caterpillar 3412E	1.74	0.313	1.346	4.072	0.538	2.31	5.51	0.146	0.6302	0.434	0.078	0.337	0.0635	0.273	1.69	0.0449	0.193	7,036	298	730	15.5	0.658	1.61	0.00776	0.000329	0.000804
Port Imperial to 38th Street to Port Imperial (sundays)	NY Waterway	Short Haul	2.00	Caterpillar 3412E	1.74	0.313	1.346	4.072	0.538	2.31	5.51	0.146	0.6302	0.445	0.080	0.345	0.0873	0.375	1.42	0.0378	0.162	6,433	317	775	14.2	0.698	1.71	0.00709	0.000349	0.000855
Colgate to WFC to Colgate	NY Waterway	Short Haul	1.60	Caterpillar 3412(2)	2.20	0.237	1.021	3.35	0.299	1.287	8.66	0.048	0.2073	0.426	0.0459	0.198	0.0355	0.1526	1.85	0.0103	0.044	43,734	965	2,361	96.4	2.13	5.21	0.0482	0.00106	0.00260
Totals, NY Waterway					**32.7**	**1.190**	**2.91**	**65.1**	**1.42**	**3.49**	**238**	**1.60**	**3.922**	**12.3**	**0.509**	**1.24**	**0.605**	**1.48**	**167**	**1.36**	**3.32**	**897,425**	**6,934**	**14,568**	**1,978**	**15.3**	**32.1**	**0.989**	**0.00764**	**0.0161**
Port Imperial to (via Hoboken-North, WFC) Pier 11 to (via WFC, Hoboken-North) Port Imperial	Billy Bey	Long Haul	13.1	Caterpillar 3406E	1.70	0.283	1.217	3.54	0.227	0.975	18.1	0.497	2.1401	1.40	0.233	1.003	0.214	0.923	27.0	0.742	3.19	49,600	1,259	3,081	109	2.78	6.79	0.0547	0.00139	0.00340
Port Imperial to Pier 11 to Port Imperial	Billy Bey	Long Haul	12.8	Caterpillar 3406E	1.70	0.283	1.217	3.54	0.227	0.975	18.1	0.497	2.1401	0.804	0.134	0.576	0.113	0.485	29.8	0.818	3.52	210,441	5,439	13,309	464	12.0	29.3	0.232	0.0060	0.0147
Pier 11 to 38th Street to Pier 11	Billy Bey	Long Haul	11.8	Caterpillar 3406E	1.70	0.283	1.217	3.54	0.227	0.975	18.1	0.497	2.1401	0.804	0.134	0.576	0.113	0.485	20.6	0.566	2.44	48,240	1,233	3,016	106	2.72	6.65	0.0532	0.00136	0.00332
Port Imperial to (via Hoboken-North) WFC to Port Imperial	Billy Bey	Medium Haul	8.00	Caterpillar 3406E	1.70	0.283	1.217	3.54	0.227	0.975	18.1	0.497	2.1401	0.751	0.125	0.537	0.126	0.543	16.7	0.459	1.98	40,474	1,024	2,507	89.2	2.26	5.53	0.0446	0.00113	0.00276
WFC to (via Hoboken-North) Port Imperial to WFC	Billy Bey	Medium Haul	8.00	Caterpillar 3406E	1.70	0.283	1.217	3.54	0.227	0.975	18.1	0.497	2.1401	0.744	0.124	0.532	0.135	0.580	17.2	0.472	2.03	41,657	1,052	2,574	91.8	2.32	5.68	0.0459	0.00116	0.00284
Hoboken-South to Pier 11 to Hoboken-South	Billy Bey	Medium Haul	7.40	Caterpillar 3406E	1.70	0.283	1.217	3.54	0.227	0.975	18.1	0.497	2.1401	1.01	0.169	0.726	0.102	0.439	17.4	0.478	2.05	317,255	8,193	20,048	699	18.1	44.2	0.350	0.00903	0.0221
38th Street to Colgate to 38th Street	Billy Bey	Medium Haul	7.40	Caterpillar 3406E	1.70	0.283	1.217	3.54	0.227	0.975	18.1	0.497	2.1401	0.849	0.141	0.608	0.083	0.356	11.6	0.318	1.368	46,393	1,209	2,958	102.3	2.67	6.52	0.0511	0.00133	0.00326
38th St. to (via Newport Hoboken-South) Hoboken-North to 38th St.	Billy Bey	Medium Haul	6.20	Caterpillar 3412(2)	2.20	0.237	1.021	3.35	0.299	1.287	8.66	0.048	0.2073	0.913	0.098	0.424	0.138	0.593	5.89	0.033	0.141	6,942	144	351	15.3	0.317	0.775	0.00765	0.000158	0.000387
38th St. to (via Hoboken North & Hoboken South) Newport to 38th St.	Billy Bey	Medium Haul	6.20	Caterpillar 3412(2)	2.20	0.237	1.021	3.35	0.299	1.287	8.66	0.048	0.2073	0.736	0.079	0.342	0.134	0.579	6.04	0.034	0.145	12,920	249	610	28.5	0.549	1.34	0.0142	0.000275	0.000672
Totals, Billy Bey Ferry Company					**16.3**	**0.820**	**2.28**	**31.5**	**0.734**	**2.04**	**144**	**1.32**	**3.6587**	**8.02**	**0.431**	**1.20**	**0.400**	**1.110**	**152**	**1.52**	**4.22**	**773,922**	**10,174**	**22,168**	**1,706**	**22.4**	**48.9**	**0.853**	**0.0112**	**0.0244**
Various weekday routes (1)	NY Water Taxi	Medium Haul	-	DD Series 60	1.55	0.054	0.687	9.84	0.341	4.327	25.6	0.080	1.0203	12.6	0.44	5.568	0.901	11.45	186	0.58	7.4	291,984	1,507	4,795	644	3.3	10.6	0.322	0.00166	0.0053
Various weekend routes (1)	NY Water Taxi	Medium Haul	-	DD Series 60	1.55	0.054	0.687	9.84	0.341	4.327	25.6	0.080	1.0203	12.6	0.44	5.568	0.901	11.45	186	0.58	7.4	70,076	362	1,151	154	0.80	2.54	0.0772	0.00040	0.00127
Totals, New York Water Taxi					**3.11**	**0.077**	**0.972**	**19.67**	**0.482**	**6.12**	**51.3**	**0.11**	**1.443**	**25.2**	**0.62**	**7.874**	**1.274**	**16.19**	**372**	**0.82**	**10.5**	**362,060**	**1,549**	**4,931**	**798**	**3.4**	**10.9**	**0.399**	**0.00171**	**0.0054**
Grand Totals, New York City Harbor					**52.1**	**1.45**	**3.42**	**116.2**	**1.67**	**3.96**	**433**	**2.08**	**4.914**	**45.4**	**0.91**	**2.15**	**1.466**	**3.47**	**691**	**2.20**	**5.2**	**2,033,406**	**12,410**	**25,808**	**4,483**	**27.4**	**56.9**	**2.24**	**0.0137**	**0.0284**

CONTROLLED PM2.5 EMISSION RATES

(1): GPS data for respective route was unavailable for specific route; therefore route times estimated from vessels operating on similar routes.

(2): Emission data for mechanically controlled Caterpillar 3412 engines from actual baseline testing.

(3): Because NY Watertaxi vessels do not typically complete a closed circuit route the operating profile of the three modes of operation are presented as the total time in hours in each mode during the typical 9 hours of daily operation as determined during data logging. Therefore, route definitions and frequency are presented as various and on a hrs/day basis.

BASELINE HC EMISSION RATES

Route No.	Route Origin / Destination / End	Operator	Route Description	Route Distance (NM)	Propulsion Engine Type	HC at Push, per Engine (g/hr)	HC at Push STD Deviation (g/hr)	HC at Push 95.0% C.I. (± g/hr)	HC at Maneuver, per Engine (g/hr)	HC at Maneuver STD Deviation (g/hr)	HC at Maneuver 95.0% C.I. (± g/hr)	HC at Cruise, per Engine (g/hr)	HC at Cruise STD Deviation (g/hr)	HC at Cruise 95.0% C.I. (± g/hr)	HC at Push, per vessel (g/route)	HC at Push STD Deviation (g/route)	HC at Push 95.0% C.I. (± g/route)	HC at Manuever, per vessel (g/route)	HC at Maneuver STD Deviation (g/route)	HC at Maneuver 95.0% C.I. (± g/route)	HC at Cruise, per vessel (g/route)	HC at Cruise STD Deviation (g/route)	HC at Cruise 95.0% C.I. (± g/route)	Total Annual HC, per route (g/yr)	Total Annual HC STD Deviation, per route (g/yr)	Total Annual HC 95.0% C.I. (± g/yr)	Total Annual HC, per route (lbs/yr)	Total Annual HC STD Deviation, per route (lbs/yr)	Total Annual HC 95.0% C.I. (± lbs/yr)	Total Current Annual HC, per route (short tons/yr)	Total Current Annual HC STD Deviation (short tons/yr)	Total Current Annual HC 95.0% C.I. (± short tons/yr)
1	Belford, NJ to Pier 11 to Belford, NJ	NY Waterway	Long Haul	45.8	Caterpillar 3412E	222	1.86	8.0	339	29.8	73	622	27.5	88	137	1.15	4.9	263	23.1	56	2,642	117	371.8	11,072,960	433,500	954,128	24,412	956	2,103	12.2	0.48	1.05
2	Port Liberte to Pier 11 to Port Libete	NY Waterway	Medium Haul	9.40	Caterpillar 3406E	359	1.70	7.3	231	12.0	33	743	18.10	77.9	275	1.31	5.6	240	12.5	35	774	18.87	81.2	2,347,776	41,281	95,194	5,176	91.0	210	2.59	0.0455	0.105
3	Pier 11 to Port Liberte to Pier 11	NY Waterway	Medium Haul	9.40	Caterpillar 3406E	359	1.70	7.3	231	12.0	33	743	18.10	77.9	237	1.12	4.8	206	10.7	30	792	19.30	83.0	3,210,224	57,497	132,589	7,077	127	292	3.54	0.063	0.146
4	Hoboken-South to (via WFC & Pier 11) WFC to Hoboken-South	NY Waterway	Medium Haul	7.70	Caterpillar 3412(2)	103	6.14	19.5	343	100	246	318	15.8	50.2	43.9	2.61	8.3	106	30.90	76	213	10.6	33.6	1,130,850	102,213	222,702	2,493	225	491	1.25	0.113	0.245
5	38th Street to (via Newport & Harborside) Colgate to 38th Street	NY Waterway	Medium Haul	7.60	Caterpillar 3406E	359	1.70	7.3	231	12.0	33	743	18.10	77.9	192	0.91	3.9	102	5.32	15	766	18.67	80.3	6,337,154	116,196	267,950	13,971	256	591	6.99	0.128	0.295
6	38th Street to (via Newport) Harborside to 38th Street	NY Waterway	Medium Haul	6.70	Caterpillar 3406E	359	1.70	7.3	231	12.0	33	743	18.10	77.9	118	0.56	2.40	67.2	3.50	9.7	648	15.78	67.9	3,680,198	71,494	164,865	8,113	157.6	363	4.06	0.079	0.182
7	38th Street to (via Harborside) Newport to 38th Street	NY Waterway	Medium Haul	6.70	Caterpillar 3406E	359	1.70	7.3	231	12.0	33	743	18.10	77.9	118	0.56	2.41	75.8	3.95	11.0	614	14.96	64.4	1,259,796	24,147	55,683	2,777	53.2	123	1.39	0.0266	0.0614
8	38th Street to Harborside to 38th Street	NY Waterway	Medium Haul	6.60	Caterpillar 3406E	359	1.70	7.3	231	12.0	33	743	18.10	77.9	86.7	0.41	1.77	43.1	2.24	6.2	515	12.55	54.0	1,005,792	19,900	45,889	2,217	43.9	101	1.11	0.0219	0.0506
9	Liberty Harbor to Pier 11 to Liberty Harbor	NY Waterway	Medium Haul	5.80	Caterpillar 3406E	359	1.70	7.3	231	12.0	33	743	18.10	77.9	119	0.57	2.43	111	5.8	16	392	9.55	41.1	3,881,899	69,759	160,864	8,558	154	355	4.28	0.077	0.177
10	38th Street to Newport to 38th Street	NY Waterway	Medium Haul	5.60	Caterpillar 3406E	359	1.70	7.3	231	12.0	33	743	18.10	77.9	82.5	0.39	1.68	61.6	3.21	8.9	384	9.35	40.2	2,332,878	43,733	100,849	5,143	96.4	222	2.57	0.0482	0.1112
11	Hoboken-South to WFC to Hoboken-South	NY Waterway	Medium Haul	5.00	Caterpillar 3412(2)	103	6.14	19.5	343	100	246	318	15.8	50.2	21.5	1.28	4.08	44.6	13.1	32	123	6.08	19.4	3,091,760	236,784	515,909	6,816	522	1,137	3.41	0.26	0.57
12	38th Street to (via Lincoln Harbor) Hoboken North to 38th Street	NY Waterway	Medium Haul	3.10	Caterpillar 3406E	359	1.70	7.3	231	12.0	33	743	18.10	77.9	194	0.92	4.0	133	6.9	19	158	3.86	16.6	3,533,752	57,965	133,669	7,791	128	295	3.90	0.064	0.147
13	Hoboken-North to 38th Street to Hoboken-North	NY Waterway	Medium Haul	2.40	Caterpillar 3406E	359	1.70	7.3	231	12.0	33	743	18.10	77.9	195	0.93	4.0	76.1	3.96	11.0	165	4.03	17.3	3,291,290	43,168	99,545	7,256	95	219	3.63	0.048	0.110
14	38th Street to Lincoln Harbor to 38th Street	NY Waterway	Medium Haul	2.40	Caterpillar 3412(2)	103	6.14	19.5	343	100	246	318	15.8	50.2	19.9	1.19	3.78	62.2	18.2	45	44.9	2.23	7.1	858,722	124,280	270,784	1,893	274	597	0.947	0.137	0.298
15	Port Imperial to 38th Street to Port Imperial (weekdays)	NY Waterway	Short Haul	2.00	Caterpillar 3412E	222	1.86	8.0	339	29.8	73	622	27.5	88	49.0	0.41	1.77	62.4	5.5	13	158	7.0	22.2	6,222,896	205,320	451,906	13,719	453	996	6.86	0.23	0.50
16	Port Imperial to 38th Street to Port Imperial (saturdays)	NY Waterway	Short Haul	2.00	Caterpillar 3412E	222	1.86	8.0	339	29.8	73	622	27.5	88	55.5	0.47	2.00	40.1	3.52	8.6	191	8.4	26.8	773,663	24,719	54,406	1,706	54	120	0.853	0.027	0.060
17	Port Imperial to 38th Street to Port Imperial (sundays)	NY Waterway	Short Haul	2.00	Caterpillar 3412E	222	1.86	8.0	339	29.8	73	622	27.5	88	56.9	0.48	2.05	55.1	4.83	12	160	7.1	22.6	693,642	21,896	48,194	1,529	48	106	0.765	0.024	0.053
18	Colgate to WFC to Colgate	NY Waterway	Short Haul	1.60	Caterpillar 3412(2)	103	6.14	19.5	343	100	246	318	15.8	50.2	19.9	1.19	3.78	40.7	11.9	29	67.9	3.36	10.7	2,104,104	203,594	443,593	4,639	449	978	2.32	0.224	0.49
	Totals, NY Waterway					**4,886**	**13.9**	**32.9**	**5,039**	**213**	**451**	**11,187**	**85**	**197**	**2,021**	**4.5**	**10.6**	**1,790**	**51**	**109**	**8,806**	**126**	**290.8**	**56,829,355**	**625,447**	**1,275,608**	**125,287**	**1,379**	**2,812**	**62.6**	**0.69**	**1.41**
19	Port Imperial to (via Hoboken-North, WFC) Pier 11 to (via WFC, Hoboken-North) Port Imperial	Billy Bey	Long Haul	13.1	Caterpillar 3406E	359	1.70	7.3	231	12.0	33	743	18.10	77.9	296	1.4	6.0	219	11.4	32	1,108	27.0	116.2	2,531,543	45,786	105,582	5,581	100.9	233	2.79	0.0505	0.1164
20	Port Imperial to Pier 11 to Port Imperial	Billy Bey	Long Haul	12.8	Caterpillar 3406E	359	1.70	7.3	231	12.0	33	743	18.10	77.9	170	0.80	3.5	115	6.0	17	1,222	29.8	128.1	9,791,978	197,520	455,482	21,588	435	1,004	10.8	0.218	0.502
21	Pier 11 to 38th Street to Pier 11	Billy Bey	Long Haul	11.8	Caterpillar 3406E	359	1.70	7.3	231	12.0	33	743	18.10	77.9	170	0.80	3.5	115	6.0	17	846	20.61	88.7	2,350,479	44,664	102,996	5,182	98.5	227	2.59	0.0492	0.1135
22	Port Imperial to (via Hoboken-North) WFC to Port Imperial	Billy Bey	Medium Haul	8.00	Caterpillar 3406E	359	1.70	7.3	231	12.0	33	743	18.10	77.9	158	0.75	3.23	129	6.7	19	686	16.72	71.9	2,023,890	37,499	86,472	4,462	82.7	191	2.23	0.0413	0.0953
23	WFC to (via Hoboken-North) Port Imperial to WFC	Billy Bey	Medium Haul	8.00	Caterpillar 3406E	359	1.70	7.3	231	12.0	33	743	18.10	77.9	157	0.74	3.20	137	7.2	20	704	17.16	73.8	2,076,665	38,704	89,251	4,578	85.3	197	2.29	0.0427	0.0984
24	Hoboken-South to Pier 11 to Hoboken-South	Billy Bey	Medium Haul	7.40	Caterpillar 3406E	359	1.70	7.3	231	12.0	33	743	18.10	77.9	214	1.01	4.4	104	5.42	15	713	17.38	74.8	16,350,070	289,151	666,784	36,046	637	1,470	18.0	0.319	0.735
25	38th Street to Colgate to 38th Street	Billy Bey	Medium Haul	7.40	Caterpillar 3406E	359	1.70	7.3	231	12.0	33	743	18.10	77.9	179	0.85	3.7	84.3	4.39	12.2	475	11.57	49.8	2,495,312	41,936	96,705	5,501	92.5	213	2.75	0.0462	0.1066
26	38th St. to (via Newport Hoboken-South) Hoboken-North to 38th St.	Billy Bey	Medium Haul	6.20	Caterpillar 3412(2)	103	6.14	19.5	343	100	246	318	15.8	50.2	42.7	2.55	8.1	158	46	113	216	10.7	34.1	347,041	39,598	86,276	765	87	190	0.383	0.044	0.095
27	38th St. to (via Hoboken North & Hoboken South) Newport to 38th St.	Billy Bey	Medium Haul	6.20	Caterpillar 3412(2)	103	6.14	19.5	343	100	246	318	15.8	50.2	34.5	2.05	6.54	154	45	110	222	11.0	35.0	640,401	72,544	158,059	1,412	160	348	0.706	0.080	0.174
	Totals, Billy Bey Ferry Company					**2,716**	**9.8**	**25.1**	**2,302**	**145**	**324**	**5,835**	**52.8**	**135.8**	**1,421**	**4.1**	**10.5**	**1,215**	**67**	**150**	**6,192**	**57.3**	**147.4**	**38,607,380**	**371,762**	**775,482**	**85,115**	**820**	**1,710**	**42.6**	**0.410**	**0.855**
28	Various weekday routes [(1)]	NY Water Taxi	Medium Haul	-	DD Series 60	48.6	2.34	10.09	341	44.8	125	328	3.48	14.98	394	19.0	81.7	902	119	329	2,380	25.3	108.7	4,777,468	159,651	368,156	10,533	352	812	5.27	0.176	0.406
29	Various weekend routes [(1)]	NY Water Taxi	Medium Haul	-	DD Series 60	48.6	2.34	10.09	341	44.8	125	328	3.48	14.98	394	19.0	81.7	902	119	329	2,380	25.3	108.7	1,146,592	38,316	88,358	2,528	84	195	1.26	0.0422	0.097
	Totals, New York Water Taxi					**97.2**	**3.32**	**14.3**	**682**	**63**	**176**	**656**	**4.92**	**21.2**	**787**	**26.9**	**115.6**	**1,803**	**168**	**466**	**4,759**	**35.7**	**153.7**	**5,924,060**	**164,185**	**378,611**	**13,060**	**362**	**835**	**6.53**	**0.181**	**0.417**
	Grand Totals, New York City Harbor					**7,699**	**17.3**	**39.2**	**8,023**	**266**	**554**	**17,678**	**101**	**224**	**4,229**	**27.5**	**62.3**	**4,808**	**188**	**392**	**19,758**	**143**	**318.7**	**#########**	**745,887**	**1,508,697**	**223,462**	**1,644**	**3,326**	**112**	**0.82**	**1.66**

Notes: (1): GPS data for respective route was unavailable for specific route; therefore route times estimated from vessels operating on similar routes.
(2): Emission data for mechanically controlled Caterpillar 3412 engines from actual baseline testing.
(3): Because NY Watertaxi vessels do not typically complete a closed circuit route the operating profile of the three modes of operation are presented as the total time in hours in each mode during the typical 9 hours of daily operation as determined during data logging. Therefore, route definitions and frequency are presented as various and on a hrs/day basis.

CONTROLLED HC EMISSION RATES

Route No.	Route Origin / Destination / End	Operator	Route Description	Route Distance	Propulsion Engine Type	HC at Push, per Engine	HC at Push STD Deviation	HC at Push ± 95.0% C.I.	HC at Maneuver, per Engine	HC at Maneuver STD Deviation	HC at Maneuver ± 95.0% C.I.	HC at Cruise, per Engine	HC at Cruise STD Deviation	HC at Cruise ± 95.0% C.I.	HC at Push, per vessel	HC at Push STD Deviation	HC at Push ± 95.0% C.I.	HC at Manuever, per vessel	HC at Maneuver STD Deviation	HC at Maneuver ± 95.0% C.I.	HC at Cruise, per vessel	HC at Cruise STD Deviation	HC at Cruise ± 95.0% C.I.	Total Annual HC, per route	Total Annual HC STD Deviation, per route	Total Annual HC ± 95.0% C.I.	Total Annual HC, per route	Total Annual HC STD Deviation, per route	Total Annual HC ± 95.0% C.I.	Total Annual HC, per route	Total Annual HC STD Deviation	Total Annual HC ± 95.0% C.I.
				NM		(g/hr)	(g/hr)	(± g/hr)	(g/hr)	(g/hr)	(± g/hr)	(g/hr)	(g/hr)	(± g/hr)	(g/route)	(g/route)	(± g/route)	(g/route)	(g/route)	(± g/route)	(g/route)	(g/route)	(± g/route)	(g/yr)	(g/yr)	(± g/yr)	(lbs/yr)	(lbs/yr)	(± lbs/yr)	(short tons/yr)	(short tons/yr)	(± short tons/yr)
1	Belford, NJ to Pier 11 to Belford, NJ	NY Waterway	Long Haul	45.8	Caterpillar 3412E	126	5.00	21.5	190	27.1	66	161	13.4	43	77.8	3.09	13.3	147	21.0	51	684	57.1	182	3,305,605	221,850	488,290	7,288	489	1,076	3.64	0.245	0.538
2	Port Liberte to Pier 11 to Port Libete	NY Waterway	Medium Haul	9.40	Caterpillar 3406E	130	1.77	7.61	116	13.2	37	477	33.7	145	100	1.36	5.85	121	13.8	38	497	35.1	151.0	1,306,577	68,643	158,290	2,881	151	349	1.44	0.076	0.174
3	Pier 11 to Port Liberte to Pier 11	NY Waterway	Medium Haul	9.40	Caterpillar 3406E	130	1.77	7.61	116	13.2	37	477	33.7	145	86	1.17	5.02	104	11.8	33	508	35.9	154.4	1,814,615	98,267	226,604	4,001	217	500	2.00	0.108	0.250
4	Hoboken-South to (via WFC & Pier 11) WFC to Hoboken-South	NY Waterway	Medium Haul	7.70	Caterpillar 3412(2)	92	0.569	2.45	77.6	4.76	12	110	0.329	1.05	39.1	0.242	1.04	23.9	1.47	4	73.4	0.221	0.702	425,417	4,688	10,318	938	10.3	22.7	0.469	0.0052	0.0114
5	38th Street to (via Newport & Harborside) Colgate to 38th Street	NY Waterway	Medium Haul	7.60	Caterpillar 3406E	130	1.77	7.61	116	13.2	37	477	33.7	145	69.5	0.946	4.07	51.5	5.9	16	492	34.7	149.3	3,662,927	210,559	485,551	8,075	464	1,070	4.04	0.232	0.535
6	38th Street to (via Newport) Harborside to 38th Street	NY Waterway	Medium Haul	6.70	Caterpillar 3406E	130	1.77	7.61	116	13.2	37	477	33.7	145	42.7	0.582	2.50	33.9	3.85	11	416	29.3	126.3	2,175,537	130,844	301,728	4,796	288	665	2.40	0.144	0.333
7	38th Street to (via Harborside) Newport to 38th Street	NY Waterway	Medium Haul	6.70	Caterpillar 3406E	130	1.77	7.61	116	13.2	37	477	33.7	145	42.8	0.583	2.51	38.2	4.34	12	394	27.8	119.7	740,803	43,919	101,279	1,633	96.8	223	0.817	0.0484	0.1116
8	38th Street to Harborside to 38th Street	NY Waterway	Medium Haul	6.60	Caterpillar 3406E	130	1.77	7.61	116	13.2	37	477	33.7	145	31.4	0.428	1.84	21.7	2.47	7	330	23.3	100.4	598,494	36,615	84,435	1,319	80.7	186.1	0.660	0.0404	0.0931
9	Liberty Harbor to Pier 11 to Liberty Harbor	NY Waterway	Medium Haul	5.80	Caterpillar 3406E	130	1.77	7.61	116	13.2	37	477	33.7	145	43.2	0.588	2.53	56.0	6.4	18	252	17.76	76.4	2,188,263	117,765	271,567	4,824	260	599	2.41	0.130	0.299
10	38th Street to Newport to 38th Street	NY Waterway	Medium Haul	5.60	Caterpillar 3406E	130	1.77	7.61	116	13.2	37	477	33.7	145	29.9	0.407	1.75	31.0	3.53	10	246	17.39	74.8	1,357,911	78,446	180,898	2,994	172.9	399	1.50	0.086	0.199
11	Hoboken-South to WFC to Hoboken-South	NY Waterway	Medium Haul	5.00	Caterpillar 3412(2)	92	0.569	2.45	77.6	4.76	12	110	0.329	1.05	19.2	0.119	0.51	10.1	0.62	2	42.3	0.127	0.404	1,171,173	10,536	23,191	2,582	23.2	51	1.29	0.0116	0.0256
12	38th Street to (via Lincoln Harbor) Hoboken North to 38th Street	NY Waterway	Medium Haul	3.10	Caterpillar 3406E	130	1.77	7.61	116	13.2	37	477	33.7	145	70.5	0.960	4.13	66.8	7.6	21	102	7.18	30.9	1,739,606	76,367	176,103	3,835	168	388	1.92	0.084	0.194
13	Hoboken-North to 38th Street to Hoboken-North	NY Waterway	Medium Haul	2.40	Caterpillar 3406E	130	1.77	7.61	116	13.2	37	477	33.7	145	70.8	0.963	4.14	38.4	4.36	12	106	7.49	32.2	1,622,268	65,719	151,547	3,576	145	334	1.79	0.072	0.167
14	38th Street to Lincoln Harbor to 38th Street	NY Waterway	Medium Haul	2.40	Caterpillar 3412(2)	92	0.569	2.45	77.6	4.76	12	110	0.329	1	17.8	0.110	0.47	14.1	0.86	2	15.5	0.046	0.148	319,753	5,897	12980	705	13.0	28.6	0.352	0.0065	0.0143
15	Port Imperial to 38th Street to Port Imperial (weekdays)	NY Waterway	Short Haul	2.00	Caterpillar 3412E	126	5.00	21.5	190	27.1	66	161	13.4	43	27.8	1.10	4.7	34.9	5.0	12	40.8	3.41	10.84	2,392,622	142,091	312,740	5,275	313	689	2.64	0.157	0.345
16	Port Imperial to 38th Street to Port Imperial (saturdays)	NY Waterway	Short Haul	2.00	Caterpillar 3412E	126	5.00	21.5	190	27.1	66	161	13.4	43	31.5	1.25	5.4	22.4	3.20	8	49.3	4.12	13.11	278,978	14,509	31,934	615	32.0	70	0.308	0.0160	0.0352
17	Port Imperial to 38th Street to Port Imperial (sundays)	NY Waterway	Short Haul	2.00	Caterpillar 3412E	126	5.00	21.5	190	27.1	66	161	13.4	43	32.3	1.28	5.5	30.8	4.40	11	41.5	3.47	11.03	266,245	14,644	32,232	587	32.3	71	0.293	0.0161	0.0355
18	Colgate to WFC to Colgate	NY Waterway	Short Haul	1.60	Caterpillar 3412(2)	92	0.569	2.45	77.6	4.76	20.5	110	0.329	1.0	17.8	0.110	0.47	9.20	0.56	2.4	23.4	0.070	0.224	824,535	9,499	20,906	1,818	20.9	46.1	0.91	0.0105	0.0230
	Totals, NY Waterway					**2,171**	**11.5**	**28.2**	**2,233**	**69**	**147**	**5,849**	**109.8**	**253**	**850**	**4.62**	**11.3**	**855**	**32.1**	**68**	**4,311**	**99.7**	**230**	**26,191,328**	**423,505**	**864,912**	**57,742**	**934**	**1,907**	**28.9**	**0.467**	**0.953**
19	Port Imperial to (via Hoboken-North, WFC) Pier 11 to (via WFC, Hoboken-North) Port Imperial	Billy Bey	Long Haul	13.1	Caterpillar 3406E	130	1.77	7.61	116	13.2	37	477	33.7	145	107.22	1.46	6.28	110	12.5	35	711	50.2	216.1	1,448,944	80,795	186,315	3,194	178	411	1.60	0.089	0.205
20	Port Imperial to Pier 11 to Port Imperial	Billy Bey	Long Haul	12.8	Caterpillar 3406E	130	1.77	7.61	116	13.2	37	477	33.7	145	61.52	0.837	3.60	57.9	6.6	18	784	55.4	238.3	5,873,766	362,535	836,008	12,949	799	1,843	6.47	0.400	0.922
21	Pier 11 to 38th Street to Pier 11	Billy Bey	Long Haul	11.8	Caterpillar 3406E	130	1.77	7.61	116	13.2	37	477	33.7	145	61.52	0.837	3.60	57.9	6.6	18	543	38.3	164.9	1,377,094	80,889	186,530	3,036	178.3	411	1.52	0.089	0.206
22	Port Imperial to (via Hoboken-North) WFC to Port Imperial	Billy Bey	Medium Haul	8.00	Caterpillar 3406E	130	1.77	7.61	116	13.2	37	477	33.7	145	57.41	0.781	3.36	64.9	7.4	20	440	31.1	133.8	1,170,094	66,477	153,297	2,580	146.6	338	1.29	0.0733	0.169
23	WFC to (via Hoboken-North) Port Imperial to WFC	Billy Bey	Medium Haul	8.00	Caterpillar 3406E	130	1.77	7.61	116	13.2	37	477	33.7	145	56.89	0.774	3.33	69.2	7.9	22	452	31.9	137.3	1,202,309	68,380	157,685	2,651	150.8	348	1.33	0.0754	0.174
24	Hoboken-South to Pier 11 to Hoboken-South	Billy Bey	Medium Haul	7.40	Caterpillar 3406E	130	1.77	7.61	116	13.2	37	477	33.7	145	77.53	1.055	4.54	52.4	6.0	17	458	32.3	139.0	9,319,175	521,413	1,202,381	20,545	1,150	2,651	10.3	0.575	1.325
25	38th Street to Colgate to 38th Street	Billy Bey	Medium Haul	7.40	Caterpillar 3406E	130	1.77	7.61	116	13.2	37	477	33.7	145	64.94	0.884	3.80	42.5	4.8	13	305	21.52	92.6	1,393,190	74,604	172,038	3,071	164.5	379	1.54	0.082	0.190
26	38th St. to (via Newport Hoboken-South) Hoboken-North to 38th St.	Billy Bey	Medium Haul	6.20	Caterpillar 3412(2)	92	0.569	2.45	77.6	4.76	12	110	0.329	1	38.1	0.236	1.02	35.8	2.20	5	74.5	0.224	0.713	123,428	1,848	4,067	272	4.07	9.0	0.136	0.00204	0.00448
27	38th St. to (via Hoboken North & Hoboken South) Newport to 38th St.	Billy Bey	Medium Haul	6.20	Caterpillar 3412(2)	92	0.569	2.45	77.6	4.76	12	110	0.329	1	30.7	0.190	0.82	34.9	2.14	5	76.4	0.230	0.731	221,543	3,374	7,425	488	7.4	16.4	0.244	0.0037	0.0082
	Totals, Billy Bey Ferry Company					**1,094**	**4.75**	**13.2**	**970**	**35.6**	**79**	**3,556**	**89.1**	**229**	**556**	**2.59**	**7.2**	**526**	**20.7**	**46**	**3,844**	**102.7**	**264**	**22,129,543**	**656,544**	**1,374,162**	**48,787**	**1,447**	**3,030**	**24.4**	**0.724**	**1.515**
28	Various weekday routes [(1)]	NY Water Taxi	Medium Haul	-	DD Series 60	22.2	2.34	10.07	113	25.5	110	113	9.70	27	180	19.0	81.60	300	68	188	817	70.3	303	1,686,302	129,186	297,905	3,718	285	657	1.86	0.142	0.328
29	Various weekend routes [(1)]	NY Water Taxi	Medium Haul	-	DD Series 60	22.2	2.34	10.07	113	25.5	110	113	9.70	27	180	19.0	81.60	300	68	188	817	70.3	303	404,713	31,005	71,497	892	68.4	158	0.446	0.0342	0.079
	Totals, New York Water Taxi					**44.5**	**3.31**	**14.25**	**227**	**36.1**	**100**	**225**	**13.7**	**59**	**360**	**26.8**	**115.39**	**600**	**96**	**265**	**1,634**	**99.5**	**428**	**2,091,015**	**132,855**	**306,364**	**4,610**	**293**	**675**	**2.305**	**0.146**	**0.338**
	Grand Totals, New York City Harbor					**3,309**	**12.9**	**29.7**	**3,429**	**86**	**179**	**9,630**	**142.0**	**316**	**1,766**	**27.3**	**63.0**	**1,980**	**103**	**215**	**9,789**	**174**	**388**	**50,411,886**	**792,500**	**1,604,333**	**111,139**	**1,747**	**3,537**	**55.6**	**0.8736**	**1.768**

Notes: (1): GPS data for respective route was unavailable for specific route; therefore route times estimated from vessels operating on similar routes.
(2): Emission data for mechanically controlled Caterpillar 3412 engines from actual baseline testing.
(3): Because NY Watertaxi vessels do not typically complete a closed circuit route the operating profile of the three modes of operation are presented as the total time in hours in each mode during the typical 9 hours of daily operation as determined during data logging. Therefore, route definitions and frequency are presented as various and on a hrs/day basis.

Route No.	Route Origin / Destination / End	Operator	Route Description	Route Distance (NM)	Propulsion Engine Type	Emissions Control Technology	Current Total Annual NOx, per route (short tons/yr)	Current NOx STD Deviation (short tons/yr)	Current NOx ± 95.0% C.I. (± short tons/yr)	New Total Annual NOx, per route (short tons/yr)	New NOx STD Deviation (short tons/yr)	New NOx ± 95.0% C.I. (± short tons/yr)	NOx Reduction (short tons/yr)	NOx Reduction STD Deviation (short tons/yr)	NOx Reduction ± 95.0% C.I. (± short tons/yr)	% NOx Reduction (%)	% NOx Reduction STD Deviation (%)	% NOx Reduction ± 95.0% C.I. (± %)
1	Belford, NJ to Pier 11 to Belford, NJ	NY Waterway	Long Haul	45.8	Caterpillar 3412E	DOC	46.8	0.424	0.9	46.5	1.03	2.27	0.267	1.12	2.32	0.570%	2.39%	4.9%
2	Port Liberte to Pier 11 to Port Libete	NY Waterway	Medium Haul	9.40	Caterpillar 3406E	DOC	9.15	0.282	0.65	9.42	0.0559	0.129	-0.273	0.287	0.61	-2.99%	3.14%	6.7%
3	Pier 11 to Port Liberte to Pier 11	NY Waterway	Medium Haul	9.40	Caterpillar 3406E	DOC	12.4	0.347	0.80	12.8	0.071	0.165	-0.356	0.354	0.75	-2.86%	2.85%	6.0%
4	Hoboken-South to (via WFC & Pier 11) WFC to Hoboken-South	NY Waterway	Medium Haul	7.70	Caterpillar 3412(2)	Tier 2 Eng	12.2	0.65	1.42	9.4	0.103	0.227	2.80	0.66	1.37	23.0%	5.6%	11.5%
5	38th Street to (via Newport & Harborside) Colgate to 38th Street	NY Waterway	Medium Haul	7.60	Caterpillar 3406E	DOC	24.2	0.416	0.96	24.8	0.109	0.251	-0.566	0.430	0.91	-2.34%	1.78%	3.76%
6	38th Street to (via Newport) Harborside to 38th Street	NY Waterway	Medium Haul	6.70	Caterpillar 3406E	DOC	14.0	0.211	0.485	14.3	0.0619	0.143	-0.314	0.219	0.465	-2.25%	1.57%	3.33%
7	38th Street to (via Harborside) Newport to 38th Street	NY Waterway	Medium Haul	6.70	Caterpillar 3406E	DOC	4.79	0.081	0.188	4.91	0.0219	0.0506	-0.1125	0.084	0.179	-2.35%	1.76%	3.73%
8	38th Street to Harborside to 38th Street	NY Waterway	Medium Haul	6.60	Caterpillar 3406E	DOC	3.80	0.050	0.116	3.89	0.0164	0.0379	-0.0817	0.0527	0.112	-2.15%	1.39%	2.94%
9	Liberty Harbor to Pier 11 to Liberty Harbor	NY Waterway	Medium Haul	5.80	Caterpillar 3406E	DOC	15.1	0.447	1.03	15.5	0.090	0.208	-0.444	0.456	0.97	-2.95%	3.03%	6.4%
10	38th Street to Newport to 38th Street	NY Waterway	Medium Haul	5.60	Caterpillar 3406E	DOC	8.92	0.182	0.419	9.15	0.0436	0.100	-0.224	0.187	0.396	-2.51%	2.09%	4.44%
11	Hoboken-South to WFC to Hoboken-South	NY Waterway	Medium Haul	5.00	Caterpillar 3412(2)	Tier 2 Eng	33.8	1.45	3.16	25.8	0.232	0.51	7.96	1.47	3.04	23.6%	4.46%	9.2%
12	38th Street to (via Lincoln Harbor) Hoboken North to 38th Street	NY Waterway	Medium Haul	3.10	Caterpillar 3406E	DOC	14.3	0.61	1.42	14.8	0.113	0.260	-0.491	0.62	1.32	-3.44%	4.38%	9.3%
13	Hoboken-North to 38th Street to Hoboken-North	NY Waterway	Medium Haul	2.40	Caterpillar 3406E	DOC	13.2	0.367	0.85	13.5	0.073	0.168	-0.354	0.375	0.79	-2.69%	2.85%	6.0%
14	38th Street to Lincoln Harbor to 38th Street	NY Waterway	Medium Haul	2.40	Caterpillar 3412(2)	Tier 2 Eng	8.85	0.83	1.82	7.05	0.130	0.286	1.80	0.84	1.75	20.4%	9.7%	20.1%
15	Port Imperial to 38th Street to Port Imperial (weekdays)	NY Waterway	Short Haul	2.00	Caterpillar 3412E	DOC	38.8	0.60	1.33	38.3	1.57	3.45	0.525	1.68	3.48	1.35%	4.32%	9.0%
16	Port Imperial to 38th Street to Port Imperial (saturdays)	NY Waterway	Short Haul	2.00	Caterpillar 3412E	DOC	4.70	0.047	0.103	4.62	0.121	0.267	0.0773	0.130	0.270	1.65%	2.77%	5.7%
17	Port Imperial to 38th Street to Port Imperial (sundays)	NY Waterway	Short Haul	2.00	Caterpillar 3412E	DOC	4.47	0.059	0.130	4.40	0.154	0.339	0.0707	0.165	0.342	1.58%	3.69%	7.7%
18	Colgate to WFC to Colgate	NY Waterway	Short Haul	1.60	Caterpillar 3412(2)	Tier 2 Eng	23.2	1.32	2.88	18.2	0.209	0.461	4.98	1.34	2.77	21.5%	5.9%	12.2%
Totals, NY Waterway							**293**	**2.59**	**3.95**	**277**	**1.93**	**4.26**	**15.27**	**3.23**	**6.46**	**5.22%**	**1.10%**	**2.21%**
19	Port Imperial to (via Hoboken-North, WFC) Pier 11 to (via WFC, Hoboken-North) Port Imperial	Billy Bey	Long Haul	13.1	Caterpillar 3406E	DOC	9.74	0.224	0.516	10.00	0.0499	0.115	-0.256	0.229	0.486	-2.63%	2.35%	4.99%
20	Port Imperial to Pier 11 to Port Imperial	Billy Bey	Long Haul	12.8	Caterpillar 3406E	DOC	37.0	0.540	1.25	37.8	0.166	0.384	-0.829	0.565	1.20	-2.24%	1.53%	3.24%
21	Pier 11 to 38th Street to Pier 11	Billy Bey	Long Haul	11.8	Caterpillar 3406E	DOC	8.96	0.162	0.374	9.17	0.0418	0.097	-0.215	0.167	0.355	-2.40%	1.87%	3.96%
22	Port Imperial to (via Hoboken-North) WFC to Port Imperial	Billy Bey	Medium Haul	8.00	Caterpillar 3406E	DOC	7.77	0.176	0.406	7.97	0.0399	0.092	-0.204	0.181	0.383	-2.63%	2.33%	4.93%
23	WFC to (via Hoboken-North) Port Imperial to WFC	Billy Bey	Medium Haul	8.00	Caterpillar 3406E	DOC	7.97	0.188	0.433	8.18	0.0418	0.096	-0.213	0.192	0.407	-2.67%	2.41%	5.11%
24	Hoboken-South to Pier 11 to Hoboken-South	Billy Bey	Medium Haul	7.40	Caterpillar 3406E	DOC	62.7	1.11	2.56	64.2	0.281	0.648	-1.47	1.15	2.43	-2.35%	1.83%	3.87%
25	38th Street to Colgate to 38th Street	Billy Bey	Medium Haul	7.40	Caterpillar 3406E	DOC	9.64	0.189	0.435	9.87	0.0443	0.102	-0.233	0.194	0.411	-2.42%	2.01%	4.26%
26	38th St. to (via Newport Hoboken-South) Hoboken-North to 38th St.	Billy Bey	Medium Haul	6.20	Caterpillar 3412(2)	Tier 2 Eng	3.55	0.261	0.57	2.72	0.0407	0.090	0.825	0.264	0.55	23.3%	7.6%	15.8%
27	38th St. to (via Hoboken North & Hoboken South) Newport to 38th St.	Billy Bey	Medium Haul	6.20	Caterpillar 3412(2)	Tier 2 Eng	6.43	0.477	1.04	4.88	0.074	0.164	1.550	0.483	1.00	24.1%	7.7%	16.0%
Totals, Billy Bey Ferry Company							**154**	**1.41**	**2.95**	**155**	**0.351**	**0.735**	**-1.05**	**1.46**	**2.95**	**-0.682%**	**0.95%**	**1.92%**
28	Various weekday routes (1)	NY Water Taxi	Medium Haul	-	DD Series 60	DOC	26.0	0.89	2.05	27.6	0.82	1.90	-1.63	1.21	2.57	-6.28%	4.67%	9.9%
29	Various weekend routes (1)	NY Water Taxi	Medium Haul	-	DD Series 60	DOC	6.23	0.213	0.492	6.63	0.198	0.456	-0.391	0.291	0.62	-6.28%	4.67%	9.9%
Totals, New York Water Taxi							**32.2**	**0.91**	**2.11**	**34.2**	**0.85**	**1.95**	**-2.02**	**1.25**	**2.64**	**-6.28%**	**3.87%**	**8.21%**
Grand Totals, New York City Harbor							**479**	**3.09**	**6.24**	**466**	**2.14**	**4.33**	**12.20**	**3.76**	**7.48**	**2.55%**	**0.79%**	**1.56%**

PM2.5 EMISSION RATE REDUCTIONS

Route No.	Current Total Annual PM2.5, per route (short tons/yr)	Current PM2.5 STD Deviation (short tons/yr)	Current PM2.5 95.0% C.I. (± short tons/yr)	New Total Annual PM2.5, per route (short tons/yr)	New PM2.5 STD Deviation (short tons/yr)	New PM2.5 95.0% C.I. (± short tons/yr)	PM2.5 Reduction (short tons/yr)	PM2.5 Reduction STD Deviation (short tons/yr)	PM2.5 Reduction 95.0% C.I. (± short tons/yr)	% PM2.5 Reduction (%)	% PM2.5 Reduction STD Deviation (%)	% PM2.5 Reduction 95.0% C.I. (± %)
1	0.125	0.00183	0.0045	0.111	0.00310	0.00759	0.0137	0.00360	0.0078	11.0%	2.9%	6.3%
2	0.0909	0.00369	0.00902	0.0479	0.00122	0.00299	0.0430	0.00388	0.00846	47.3%	4.68%	10.2%
3	0.124	0.00491	0.01203	0.0676	0.00171	0.00419	0.0561	0.00520	0.01134	45.3%	4.58%	9.97%
4	0.158	0.00251	0.0061	0.0267	0.000483	0.00118	0.1309	0.00256	0.0056	83.0%	2.1%	4.6%
5	0.239	0.00882	0.0216	0.139	0.00359	0.00877	0.0995	0.00952	0.0208	41.6%	4.27%	9.31%
6	0.138	0.00529	0.01294	0.0847	0.00218	0.00535	0.0537	0.00572	0.01247	38.8%	4.39%	9.57%
7	0.0476	0.00182	0.00444	0.0287	0.000736	0.00180	0.0189	0.00196	0.00427	39.7%	4.39%	9.56%
8	0.0377	0.001451	0.0036	0.0234	0.000609	0.00149	0.0142	0.00157	0.00343	37.8%	4.42%	9.64%
9	0.150	0.00608	0.0149	0.0814	0.00206	0.00504	0.0688	0.00642	0.0140	45.8%	4.66%	10.16%
10	0.0887	0.00340	0.00831	0.0521	0.00132	0.00324	0.0366	0.00365	0.00795	41.2%	4.41%	9.60%
11	0.408	0.0060	0.0146	0.0764	0.00119	0.00290	0.332	0.0061	0.0133	81.3%	1.91%	4.16%
12	0.139	0.00647	0.0158	0.0547	0.00182	0.00446	0.0843	0.00673	0.0147	60.6%	5.6%	12.2%
13	0.125	0.00436	0.01066	0.0509	0.00169	0.00414	0.0743	0.00468	0.01019	59.3%	4.27%	9.3%
14	0.146	0.00293	0.00718	0.0168	0.000532	0.00130	0.1296	0.00298	0.0065	88.5%	2.7%	5.9%
15	0.0760	0.00262	0.00640	0.0645	0.00322	0.00787	0.0115	0.00415	0.00903	15.2%	5.5%	11.9%
16	0.00921	0.000281	0.000687	0.00776	0.000329	0.000804	0.00145	0.000432	0.000942	15.8%	4.7%	10.3%
17	0.00845	0.000295	0.000722	0.00709	0.000349	0.000855	0.00136	0.000457	0.000996	16.1%	5.4%	11.9%
18	0.331	0.00511	0.01250	0.0482	0.00106	0.00260	0.283	0.0052	0.0114	85.5%	2.1%	4.5%
Totals, NY Waterway	**2.44**	**0.0186**	**0.0391**	**0.989**	**0.00764**	**0.0161**	**1.45**	**0.0201**	**0.0408**	**59.5%**	**0.94%**	**1.91%**
19	0.122	0.00369	0.00902	0.0547	0.00139	0.00340	0.0673	0.00394	0.00858	55.2%	3.64%	7.92%
20	0.502	0.01450	0.0355	0.232	0.00600	0.0147	0.270	0.0157	0.0342	53.8%	3.49%	7.60%
21	0.132	0.00339	0.00830	0.0532	0.00136	0.00332	0.0786	0.00366	0.00796	59.6%	3.17%	6.91%
22	0.121	0.00299	0.00732	0.0446	0.00113	0.00276	0.0763	0.00320	0.00696	63.1%	3.07%	6.69%
23	0.123	0.00311	0.00760	0.0459	0.00116	0.00284	0.0773	0.00332	0.00723	62.7%	3.12%	6.80%
24	0.919	0.0222	0.0544	0.350	0.0090	0.0221	0.569	0.0240	0.0523	61.9%	3.01%	6.56%
25	0.163	0.00333	0.00815	0.0511	0.00133	0.00326	0.112	0.00359	0.00781	68.6%	2.61%	5.69%
26	0.0503	0.00093	0.00227	0.00765	0.000158	0.000387	0.0426	0.00094	0.00205	84.8%	2.4%	5.3%
27	0.0940	0.00169	0.00413	0.0142	0.000275	0.000672	0.0797	0.00171	0.00372	84.8%	2.4%	5.17%
Totals, Billy Bey Ferry Company	**2.23**	**0.0276**	**0.0602**	**0.853**	**0.0112**	**0.0244**	**1.37**	**0.0298**	**0.0615**	**61.7%**	**1.54%**	**3.18%**
28	0.477	0.0049	0.01562	0.322	0.0017	0.0053	0.155	0.0052	0.0127	32.5%	1.14%	2.78%
29	0.114	0.00118	0.00375	0.0772	0.0004	0.00127	0.0372	0.00124	0.00304	32.5%	1.14%	2.78%
Totals, New York Water Taxi	**0.591**	**0.0050**	**0.0161**	**0.399**	**0.00171**	**0.00544**	**0.192**	**0.0053**	**0.0130**	**32.5%**	**0.94%**	**2.31%**
Grand Totals, New York City Harbor	**5.26**	**0.0337**	**0.0700**	**2.24**	**0.0137**	**0.0284**	**3.02**	**0.0364**	**0.0734**	**57.4%**	**0.78%**	**1.58%**

HC EMISSION RATE REDUCTIONS

Route No.	Current Total Annual HC, per route (short tons/yr)	Current HC STD Deviation (short tons/yr)	Current HC 95.0% C.I. (± short tons/yr)	New Total Annual HC, per route (short tons/yr)	New HC STD Deviation (short tons/yr)	New HC 95.0% C.I. (± short tons/yr)	HC Reduction (short tons/yr)	HC Reduction STD Deviation (short tons/yr)	HC Reduction 95.0% C.I. (± short tons/yr)	% HC Reduction (%)	% HC Reduction STD Deviation (%)	% HC Reduction 95.0% C.I. (± %)
1	12.2	0.48	1.05	3.64	0.245	0.538	8.56	0.54	1.11	70.1%	5.2%	10.8%
2	2.59	0.0455	0.1049	1.44	0.076	0.174	1.15	0.0883	0.187	44.3%	3.50%	7.42%
3	3.54	0.063	0.146	2.00	0.108	0.250	1.54	0.1255	0.266	43.5%	3.63%	7.70%
4	1.25	0.113	0.245	0.469	0.0052	0.0114	0.778	0.113	0.233	62.4%	10.7%	22.1%
5	6.99	0.128	0.295	4.04	0.232	0.535	2.95	0.265	0.562	42.2%	3.87%	8.21%
6	4.06	0.079	0.182	2.40	0.144	0.333	1.66	0.164	0.348	40.9%	4.13%	8.75%
7	1.39	0.0266	0.0614	0.817	0.0484	0.1116	0.572	0.0552	0.1171	41.2%	4.06%	8.60%
8	1.11	0.0219	0.0506	0.660	0.0404	0.0931	0.449	0.0459	0.0974	40.5%	4.22%	8.95%
9	4.28	0.077	0.177	2.41	0.130	0.299	1.87	0.151	0.320	43.6%	3.61%	7.66%
10	2.57	0.0482	0.1112	1.50	0.086	0.199	1.07	0.0990	0.210	41.8%	3.93%	8.33%
11	3.41	0.261	0.57	1.29	0.0116	0.0256	2.12	0.261	0.54	62.1%	9.0%	18.7%
12	3.90	0.064	0.147	1.92	0.084	0.194	1.98	0.106	0.224	50.8%	2.84%	6.02%
13	3.63	0.0476	0.110	1.79	0.0724	0.167	1.84	0.087	0.184	50.7%	2.48%	5.26%
14	0.947	0.137	0.298	0.352	0.0065	0.0143	0.594	0.137	0.284	62.8%	17.1%	35.4%
15	6.86	0.23	0.50	2.64	0.157	0.345	4.22	0.275	0.57081	61.6%	4.50%	9.3%
16	0.853	0.027	0.060	0.308	0.0160	0.0352	0.545	0.0316	0.066	63.9%	4.23%	8.8%
17	0.765	0.024	0.053	0.293	0.0161	0.0355	0.471	0.0290	0.060	61.6%	4.27%	8.8%
18	2.32	0.224	0.489	0.91	0.0105	0.0230	1.41	0.225	0.465	60.8%	11.3%	23.4%
Totals, NY Waterway	**62.6**	**0.69**	**1.41**	**28.9**	**0.467**	**0.953**	**33.8**	**0.83**	**1.6649**	**53.9%**	**1.46%**	**2.91%**
19	2.79	0.0505	0.1164	1.60	0.089	0.205	1.19	0.102	0.217	42.8%	3.75%	7.95%
20	10.8	0.218	0.502	6.47	0.400	0.922	4.32	0.455	0.965	40.0%	4.29%	9.10%
21	2.59	0.0492	0.1135	1.52	0.0892	0.206	1.07	0.1019	0.216	41.4%	4.01%	8.50%
22	2.23	0.0413	0.0953	1.29	0.0733	0.1690	0.941	0.0841	0.178	42.2%	3.85%	8.16%
23	2.29	0.0427	0.0984	1.33	0.0754	0.1738	0.964	0.0866	0.184	42.1%	3.86%	8.19%
24	18.0	0.319	0.735	10.3	0.575	1.325	7.75	0.657	1.393	43.0%	3.73%	7.90%
25	2.75	0.0462	0.1066	1.54	0.082	0.190	1.21	0.0943	0.200	44.2%	3.51%	7.44%
26	0.383	0.044	0.095	0.136	0.00204	0.00448	0.246	0.0437	0.090	64.4%	13.6%	28.1%
27	0.706	0.080	0.174	0.244	0.0037	0.0082	0.462	0.080	0.166	65.4%	13.5%	28.0%
Totals, Billy Bey Ferry Company	**42.6**	**0.410**	**0.855**	**24.4**	**0.724**	**1.515**	**18.2**	**0.832**	**1.68**	**42.7%**	**2.00%**	**4.04%**
28	5.27	0.176	0.406	1.86	0.142	0.328	3.41	0.226	0.480	64.7%	4.81%	10.2%
29	1.26	0.042	0.097	0.446	0.0342	0.079	0.818	0.0543	0.115	64.7%	4.81%	10.2%
Totals, New York Water Taxi	**6.53**	**0.181**	**0.417**	**2.30**	**0.146**	**0.338**	**4.23**	**0.233**	**0.494**	**64.7%**	**3.99%**	**8.46%**
Grand Totals, New York City Harbor	**112**	**0.82**	**1.66**	**55.6**	**0.8736**	**1.77**	**56.2**	**1.20**	**2.3888**	**50.3%**	**1.14%**	**2.26%**

Notes: (1): GPS data for respective route was unavailable for specific route; therefore route times estimated from vessels operating on similar routes.
(2): Emission data for mechanically controlled Caterpillar 3412 engines from actual baseline testing. Reductions from Tier 2 engine replacement are based on the best available data.
(3): Because NY Watertaxi vessels do not typically complete a closed circuit route the operating profile of the three modes of operation are presented as the total time in hours in each mode during the typical 9 hours of daily operation as determined during data logging. Therefore, route definitions and frequency are presented as various and on a hrs/day basis.

APPENDIX AC

NY HARBOR EMISSIONS REDUCTIONS TABLES BASELINE and CONTROLLED with FBC

BASELINE NOx EMISSION RATES

Route No.	Route Origin / Destination / End	Operator	Route Description	Route Distance (NM)	Propulsion Engine Type	NOx at Push, per Engine (kg/hr)	NOx at Push STD Deviation (kg/hr)	NOx at Push ± 95.0% C.I. (± kg/hr)	NOx at Manuever, per Engine (kg/hr)	NOx at Manuever STD Deviation (kg/hr)	NOx at Manuever ± 95.0% C.I. (± kg/hr)	NOx at Cruise, per Engine (kg/hr)	NOx at Cruise STD Deviation (kg/hr)	NOx at Cruise ± 95.0% C.I. (± kg/hr)
1	Belford, NJ to Pier 11 to Belford, NJ	NY Waterway	Long Haul	45.8	Caterpillar 3412E	2.94	0.0152	0.0653	2.07	0.127	0.31	1.94	0.0088	0.0279
2	Port Liberte to Pier 11 to Port Libete	NY Waterway	Medium Haul	9.40	Caterpillar 3406E	1.35	0.00597	0.0257	0.906	0.133	0.37	2.48	0.0219	0.0944
3	Pier 11 to Port Liberte to Pier 11	NY Waterway	Medium Haul	9.40	Caterpillar 3406E	1.35	0.00597	0.0257	0.906	0.133	0.37	2.48	0.0219	0.0944
4	Hoboken-South to (via WFC & Pier 11) WFC to Hoboken-South	NY Waterway	Medium Haul	7.70	Caterpillar 3412(2)	1.95	0.0096	0.0305	2.06	0.62	1.5	3.10	0.0128	0.0406
5	38th Street to (via Newport & Harborside) Colgate to 38th Street	NY Waterway	Medium Haul	7.60	Caterpillar 3406E	1.35	0.00597	0.0257	0.906	0.133	0.37	2.48	0.0219	0.0944
6	38th Street to (via Newport) Harborside to 38th Street	NY Waterway	Medium Haul	6.70	Caterpillar 3406E	1.35	0.00597	0.0257	0.906	0.133	0.37	2.48	0.0219	0.0944
7	38th Street to (via Harborside) Newport to 38th Street	NY Waterway	Medium Haul	6.70	Caterpillar 3406E	1.35	0.00597	0.0257	0.906	0.133	0.37	2.48	0.0219	0.0944
8	38th Street to Harborside to 38th Street	NY Waterway	Medium Haul	6.60	Caterpillar 3406E	1.35	0.00597	0.0257	0.906	0.133	0.37	2.48	0.0219	0.0944
9	Liberty Harbor to Pier 11 to Liberty Harbor	NY Waterway	Medium Haul	5.80	Caterpillar 3406E	1.35	0.00597	0.0257	0.906	0.133	0.37	2.48	0.0219	0.0944
10	38th Street to Newport to 38th Street	NY Waterway	Medium Haul	5.60	Caterpillar 3406E	1.35	0.00597	0.0257	0.906	0.133	0.37	2.48	0.0219	0.0944
11	Hoboken-South to WFC to Hoboken-South	NY Waterway	Medium Haul	5.00	Caterpillar 3412(2)	1.95	0.0096	0.0305	2.06	0.62	1.5	3.10	0.0128	0.0406
12	38th Street to (via Lincoln Harbor) Hoboken North to 38th Street	NY Waterway	Medium Haul	3.10	Caterpillar 3406E	1.35	0.00597	0.0257	0.906	0.133	0.37	2.48	0.0219	0.0944
13	Hoboken-North to 38th Street to Hoboken-North	NY Waterway	Medium Haul	2.40	Caterpillar 3406E	1.35	0.00597	0.0257	0.906	0.133	0.37	2.48	0.0219	0.0944
14	38th Street to Lincoln Harbor to 38th Street	NY Waterway	Medium Haul	2.40	Caterpillar 3412(2)	1.95	0.0096	0.0305	2.06	0.62	1.5	3.10	0.0128	0.0406
15	Port Imperial to 38th Street to Port Imperial (weekdays)	NY Waterway	Short Haul	2.00	Caterpillar 3412E	2.94	0.0152	0.0653	2.07	0.127	0.31	1.94	0.0088	0.0279
16	Port Imperial to 38th Street to Port Imperial (saturdays)	NY Waterway	Short Haul	2.00	Caterpillar 3412E	2.94	0.0152	0.0653	2.07	0.127	0.31	1.94	0.0088	0.0279
17	Port Imperial to 38th Street to Port Imperial (sundays)	NY Waterway	Short Haul	2.00	Caterpillar 3412E	2.94	0.0152	0.0653	2.07	0.127	0.31	1.94	0.0088	0.0279
18	Colgate to WFC to Colgate	NY Waterway	Short Haul	1.60	Caterpillar 3412(2)	1.95	0.0096	0.0305	2.06	0.62	1.5	3.10	0.0128	0.0406
	Totals, NY Waterway					**33.0**	**0.0406**	**0.096**	**25.6**	**1.33**	**2.81**	**45.0**	**0.0760**	**0.175**
19	Port Imperial to (via Hoboken-North, WFC) Pier 11 to (via WFC, Hoboken-North) Port Imperial	Billy Bey	Long Haul	13.1	Caterpillar 3406E	1.35	0.00597	0.0257	0.906	0.133	0.37	2.48	0.0219	0.0944
20	Port Imperial to Pier 11 to Port Imperial	Billy Bey	Long Haul	12.8	Caterpillar 3406E	1.35	0.00597	0.0257	0.906	0.133	0.37	2.48	0.0219	0.0944
21	Pier 11 to 38th Street to Pier 11	Billy Bey	Long Haul	11.8	Caterpillar 3406E	1.35	0.00597	0.0257	0.906	0.133	0.37	2.48	0.0219	0.0944
22	Port Imperial to (via Hoboken-North) WFC to Port Imperial	Billy Bey	Medium Haul	8.00	Caterpillar 3406E	1.35	0.00597	0.0257	0.906	0.133	0.37	2.48	0.0219	0.0944
23	WFC to (via Hoboken-North) Port Imperial to WFC	Billy Bey	Medium Haul	8.00	Caterpillar 3406E	1.35	0.00597	0.0257	0.906	0.133	0.37	2.48	0.0219	0.0944
24	Hoboken-South to Pier 11 to Hoboken-South	Billy Bey	Medium Haul	7.40	Caterpillar 3406E	1.35	0.00597	0.0257	0.906	0.133	0.37	2.48	0.0219	0.0944
25	38th Street to Colgate to 38th Street	Billy Bey	Medium Haul	7.40	Caterpillar 3406E	1.35	0.00597	0.0257	0.906	0.133	0.37	2.48	0.0219	0.0944
26	38th St. to (via Newport Hoboken-South) Hoboken-North to 38th St.	Billy Bey	Medium Haul	6.20	Caterpillar 3412(2)	1.95	0.0096	0.0305	2.06	0.62	1.5	3.10	0.0128	0.0406
27	38th St. to (via Hoboken North & Hoboken South) Newport to 38th St.	Billy Bey	Medium Haul	6.20	Caterpillar 3412(2)	1.95	0.0096	0.0305	2.06	0.62	1.5	3.10	0.0128	0.0406
	Totals, Billy Bey Ferry Company					**13.3**	**0.0208**	**0.0535**	**10.5**	**0.94**	**2.10**	**23.5**	**0.0608**	**0.1562**
28	Various weekday routes [1]	NY Water Taxi	Medium Haul	-	DD Series 60	0.771	0.0175	0.0754	1.23	0.228	0.63	1.19	0.0030	0.0130
29	Various weekend routes [1]	NY Water Taxi	Medium Haul	-	DD Series 60	0.771	0.0175	0.0754	1.23	0.228	0.63	1.19	0.0030	0.0130
	Totals, New York Water Taxi					**1.54**	**0.0248**	**0.107**	**2.45**	**0.322**	**0.90**	**2.38**	**0.0043**	**0.0183**
	Grand Totals, New York City Harbor					**47.9**	**0.0519**	**0.117**	**38.5**	**1.66**	**3.46**	**70.9**	**0.0974**	**0.217**

Route No.	NOx at Push, per vessel (kg/rte)	NOx at Push STD Deviation, per vessel (kg/rte)	NOx at Push, per vessel ± 95.0% C.I. (± kg/rte)	NOx at Manuever, per vessel (kg/rte)	NOx at Manuever STD Deviation, per vessel (kg/rte)	NOx at Manuever, /vessel ± 95.0% C.I. (± kg/rte)	NOx at Cruise, per vessel (kg/rte)	NOx at Cruise STD Deviation, per vessel (kg/rte)	NOx at Cruise, /vessel ± 95.0% C.I. (± kg/rte)
1	1.82	0.00937	0.0403	1.60	0.098	0.24	8.25	0.0373	0.119
2	1.03	0.00459	0.0197	0.943	0.138	0.38	2.58	0.0229	0.0984
3	0.889	0.00394	0.01696	0.809	0.119	0.33	2.64	0.0234	0.1006
4	0.828	0.00408	0.0130	0.633	0.190	0.46	2.08	0.0085	0.0272
5	0.720	0.00319	0.01374	0.401	0.059	0.16	2.55	0.0226	0.0973
6	0.443	0.00196	0.00845	0.264	0.0387	0.107	2.16	0.01912	0.0823
7	0.444	0.00197	0.00846	0.297	0.0436	0.121	2.05	0.01812	0.0780
8	0.326	0.00144	0.00621	0.169	0.0248	0.069	1.72	0.01521	0.0654
9	0.448	0.00199	0.00854	0.436	0.064	0.18	1.31	0.01157	0.0498
10	0.310	0.00137	0.00591	0.242	0.0355	0.098	1.28	0.01133	0.0488
11	0.406	0.00200	0.00637	0.267	0.080	0.20	1.20	0.00492	0.0157
12	0.730	0.00324	0.01394	0.520	0.076	0.21	0.528	0.00468	0.02012
13	0.733	0.00325	0.01399	0.299	0.0438	0.122	0.551	0.00488	0.02099
14	0.376	0.00185	0.00590	0.373	0.112	0.27	0.438	0.00180	0.00573
15	0.649	0.00335	0.0144	0.380	0.0233	0.057	0.492	0.00222	0.00708
16	0.736	0.00380	0.0163	0.244	0.0150	0.037	0.595	0.00269	0.0086
17	0.754	0.00389	0.0167	0.335	0.0206	0.050	0.500	0.00226	0.00720
18	0.376	0.00185	0.00590	0.244	0.073	0.18	0.662	0.00272	0.0087
Totals, NY Waterway	**12.0**	**0.0155**	**0.0350**	**0.083**	**0.354**	**0.75**	**31.6**	**0.0658**	**0.152**
19	1.11	0.00493	0.0212	0.857	0.126	0.35	3.70	0.0327	0.1408
20	0.637	0.00283	0.01216	0.450	0.066	0.18	4.08	0.0361	0.1553
21	0.637	0.00283	0.01216	0.450	0.066	0.18	2.82	0.0250	0.1074
22	0.595	0.00264	0.01135	0.505	0.074	0.21	2.29	0.02026	0.0872
23	0.589	0.00261	0.01124	0.539	0.079	0.22	2.35	0.0208	0.0895
24	0.803	0.00356	0.01532	0.408	0.060	0.17	2.38	0.0211	0.0906
25	0.673	0.00298	0.01283	0.331	0.049	0.13	1.58	0.0140	0.0603
26	0.807	0.00398	0.0127	0.949	0.284	0.70	2.11	0.0087	0.0276
27	0.651	0.00321	0.0102	0.925	0.277	0.68	2.17	0.0089	0.0283
Totals, Billy Bey Ferry Company	**6.50**	**0.01008**	**0.0259**	**5.41**	**0.447**	**1.00**	**23.5**	**0.0681**	**0.1750**
28	6.25	0.142	0.611	3.25	0.60	1.7	8.63	0.0218	0.094
29	6.25	0.142	0.611	3.25	0.60	1.7	8.63	0.0218	0.094
Totals, New York Water Taxi	**12.5**	**0.201**	**0.863**	**6.49**	**0.85**	**2.4**	**17.3**	**0.031**	**0.133**
Grand Totals, New York City Harbor	**31.0**	**0.202**	**0.456**	**12.0**	**1.03**	**2.14**	**72.3**	**0.100**	**0.222**

Route No.	Total Annual NOx, per route (kg/yr)	Total Annual NOx STD Deviation, per route (kg/yr)	Total NOx, per route ± 95.0% C.I. (± kg/yr)	Total Annual NOx, per route (lbs/yr)	Total Annual NOx STD Deviation, per route (lbs/yr)	Total NOx, per route ± 95.0% C.I. (± lbs/yr)	Total Current Annual NOx, per route (short tons/yr)	Total Current Annual NOx STD Deviation (short tons/yr)	Total NOx, per route ± 95.0% C.I. (± short tons/yr)
1	42,470	384	846	93,631	848	1,866	46.8	0.424	0.93
2	8,298	255	589	18,294	563	1,298	9.15	0.282	0.65
3	11,280	315	726	24,869	694	1,601	12.4	0.347	0.80
4	11,049	593	1,292	24,359	1,307	2,848	12.2	0.65	1.42
5	21,976	377	870	48,449	832	1,919	24.2	0.416	0.96
6	12,668	191	440	27,927	421	971	14.0	0.211	0.485
7	4,349	74	170	9,587	163	375	4.79	0.081	0.188
8	3,451	45.5	105	7,608	100	231	3.80	0.0501	0.116
9	13,666	406	935	30,129	894	2,062	15.1	0.447	1.03
10	8,094	165	380	17,844	363	837	8.92	0.182	0.419
11	30,647	1,316	2,867	67,566	2,901	6,321	33.8	1.45	3.16
12	12,948	557	1,285	28,545	1,228	2,832	14.3	0.61	1.42
13	11,933	333	769	26,307	735	1,695	13.2	0.367	0.85
14	8,030	756	1,648	17,704	1,667	3,633	8.85	0.83	1.82
15	35,204	548	1,207	77,612	1,209	2,660	38.8	0.60	1.33
16	4,260	42.4	93	9,391	94	206	4.70	0.0468	0.103
17	4,051	54	118	8,932	118	261	4.47	0.059	0.130
18	21,013	1,199	2,613	46,326	2,644	5,760	23.2	1.32	2.88
Totals, NY Waterway	**265,387**	**2,347**	**4,788**	**585,077**	**5,175**	**10,555**	**293**	**2.59**	**5.3**
19	8,837	203	468	19,483	447	1,032	9.74	0.224	0.516
20	33,560	490	1,130	73,986	1,080	2,491	37.0	0.540	1.25
21	8,128	147	339	17,919	324	748	8.96	0.162	0.374
22	7,046	160	369	15,533	352	813	7.77	0.176	0.406
23	7,231	170	392	15,942	375	865	7.97	0.188	0.433
24	56,924	1,008	2,325	125,497	2,223	5,126	62.7	1.11	2.56
25	8,744	171	395	19,277	377	870	9.64	0.189	0.435
26	3,217	237	516	7,093	522	1,137	3.55	0.261	0.57
27	5,837	433	943	12,869	954	2,079	6.43	0.477	1.04
Totals, Billy Bey Ferry Company	**139,525**	**1,283**	**2,677**	**307,599**	**2,829**	**5,901**	**154**	**1.41**	**2.95**
28	23,566	806	1,859	51,955	1,777	4,098	26.0	0.89	2.05
29	5,656	193	446	12,469	427	984	6.2	0.213	0.492
Totals, New York Water Taxi	**29,222**	**829**	**1,912**	**64,424**	**1,828**	**4,214**	**32.2**	**0.91**	**2.11**
Grand Totals, New York City Harbor	**434,134**	**2,801**	**5,665**	**957,100**	**6,175**	**12,489**	**479**	**3.09**	**6.2**

Notes: (1): GPS data for respective route was unavailable for specific route; therefore route times estimated from vessels operating on similar routes.

(2): Emission data for mechanically controlled Caterpillar 3412 engines from actual baseline testing.

(3): Because NY Watertaxi vessels do not typically complete a closed circuit route the operating profile of the three modes of operation are presented as the total time in hours in each mode during the typical 9 hours of daily operation as determined during data logging. Therefore, route definitions and frequency are presented as various and on a hrs/day basis.

Route No.	Route: Origin / Destination / End	Operator	Route Description	Route Distance (NM)	Propulsion Engine Type	NOx at Push, per Engine (kg/hr)	NOx at Push STD Deviation (kg/hr)	NOx at Push ± 95.0% C.I. (± kg/hr)	NOx at Manuever, per Engine (kg/hr)	NOx at Manuever STD Deviation (kg/hr)	NOx at Manuever ± 95.0% C.I. (± kg/hr)	NOx at Cruise, per Engine (kg/hr)	NOx at Cruise STD Deviation (kg/hr)	NOx at Cruise ± 95.0% C.I. (± kg/hr)	NOx at Push, per vessel (kg/rte)	NOx at Push STD Deviation, per vessel (kg/rte)	NOx at Push, per vessel ± 95.0% C.I. (± kg/rte)	NOx at Manuever, per vessel (kg/rte)	NOx at Manuever STD Deviation, per vessel (kg/rte)	NOx at Manuever, /vessel ± 95.0% C.I. (± kg/rte)	NOx at Cruise, per vessel (kg/rte)	NOx at Cruise STD Deviation, per vessel (kg/rte)	NOx at Cruise, /vessel ± 95.0% C.I. (± kg/rte)	Total Annual NOx, per route (kg/yr)	Total Annual NOx STD Deviation (kg/yr)	Total Annual NOx 95.0% C.I. (± kg/yr)	Total Annual NOx, per route (lbs/yr)	Total Annual NOx STD Deviation (lbs/yr)	Total Annual NOx 95.0% C.I. (± lbs/yr)	Total Annual NOx, per route (short tons/yr)	Total Annual NOx STD Deviation (short tons/yr)	Total Annual NOx 95.0% C.I. (± short tons/yr)
						CONTROLLED NOx EMISSION RATES																										
1	Belford, NJ to Pier 11 to Belford, NJ	NY Waterway	Long Haul	45.8	Caterpillar 3412E	2.61	0.0702	0.3018	0.69	0.187	0.52	1.80	0.0103	0.0444	1.61	0.0433	0.1864	0.53	0.145	0.40	7.63	0.0438	0.188	35,579	574	1,323	78,438	1,265	2,916	39.2	0.63	1.46
2	Port Liberte to Pier 11 to Port Libete	NY Waterway	Medium Haul	9.40	Caterpillar 3406E	1.36	0.00576	0.02479	0.984	0.0235	0.065	2.52	0.0121	0.0520	1.04	0.00443	0.01904	1.02	0.0244	0.068	2.63	0.0126	0.0542	8,546	50.7	117	18,840	112	258	9.42	0.0559	0.129
3	Pier 11 to Port Liberte to Pier 11	NY Waterway	Medium Haul	9.40	Caterpillar 3406E	1.36	0.00576	0.02479	0.984	0.0235	0.065	2.52	0.0121	0.0520	0.898	0.00380	0.01636	0.879	0.0210	0.058	2.69	0.0129	0.0555	11,603	65	149	25,581	143	329	12.8	0.071	0.165
4	Hoboken-South to (via WFC & Pier 11) WFC to Hoboken-South	NY Waterway	Medium Haul	7.70	Caterpillar 3412(2)	1.84	0.0114	0.0490	1.55	0.095	0.23	2.19	0.00659	0.0210	0.782	0.00485	0.0208	0.477	0.0293	0.072	1.47	0.00441	0.0140	8,508	94	206	18,758	207	455	9.4	0.103	0.227
5	38th Street to (via Newport & Harborside) Colgate to 38th Street	NY Waterway	Medium Haul	7.60	Caterpillar 3406E	1.36	0.00576	0.02479	0.984	0.0235	0.065	2.52	0.0121	0.0520	0.727	0.00308	0.01325	0.435	0.0104	0.029	2.60	0.0125	0.0536	22,490	99	228	49,582	218	502	24.8	0.109	0.251
6	38th Street to (via Newport) Harborside to 38th Street	NY Waterway	Medium Haul	6.70	Caterpillar 3406E	1.36	0.00576	0.02479	0.984	0.0235	0.065	2.52	0.0121	0.0520	0.447	0.001894	0.00815	0.286	0.0068	0.019	2.20	0.0105	0.0453	12,953	56.1	129	28,556	124	285	14.3	0.0619	0.143
7	38th Street to (via Harborside) Newport to 38th Street	NY Waterway	Medium Haul	6.70	Caterpillar 3406E	1.36	0.00576	0.02479	0.984	0.0235	0.065	2.52	0.0121	0.0520	0.448	0.001898	0.00817	0.323	0.0077	0.021	2.08	0.0100	0.0430	4,451	19.9	45.9	9,812	43.9	101	4.91	0.0219	0.051
8	38th Street to Harborside to 38th Street	NY Waterway	Medium Haul	6.60	Caterpillar 3406E	1.36	0.00576	0.02479	0.984	0.0235	0.065	2.52	0.0121	0.0520	0.329	0.001393	0.00599	0.184	0.00438	0.0122	1.75	0.00838	0.0361	3,525	14.9	34.4	7,771	32.9	75.8	3.89	0.0164	0.038
9	Liberty Harbor to Pier 11 to Liberty Harbor	NY Waterway	Medium Haul	5.80	Caterpillar 3406E	1.36	0.00576	0.02479	0.984	0.0235	0.065	2.52	0.0121	0.0520	0.452	0.001915	0.00824	0.473	0.0113	0.031	1.33	0.00638	0.0274	14,069	82	189	31,018	180	416	15.5	0.090	0.208
10	38th Street to Newport to 38th Street	NY Waterway	Medium Haul	5.60	Caterpillar 3406E	1.36	0.00576	0.02479	0.984	0.0235	0.065	2.52	0.0121	0.0520	0.313	0.001326	0.00570	0.262	0.0063	0.017	1.30	0.00625	0.0269	8,297	39.5	91	18,292	87	201	9.15	0.0436	0.100
11	Hoboken-South to WFC to Hoboken-South	NY Waterway	Medium Haul	5.00	Caterpillar 3412(2)	1.84	0.0114	0.0490	1.55	0.095	0.23	2.19	0.00659	0.0210	0.383	0.00237	0.01022	0.202	0.0124	0.030	0.845	0.00254	0.00809	23,423	211	464	51,640	465	1,023	25.8	0.232	0.51
12	38th Street to (via Lincoln Harbor) Hoboken North to 38th Street	NY Waterway	Medium Haul	3.10	Caterpillar 3406E	1.36	0.00576	0.02479	0.984	0.0235	0.065	2.52	0.0121	0.0520	0.738	0.00313	0.01345	0.565	0.0135	0.037	0.537	0.00258	0.01109	13,393	102	236	29,527	226	521	14.8	0.113	0.260
13	Hoboken-North to 38th Street to Hoboken-North	NY Waterway	Medium Haul	2.40	Caterpillar 3406E	1.36	0.00576	0.02479	0.984	0.0235	0.065	2.52	0.0121	0.0520	0.740	0.00314	0.01350	0.324	0.0077	0.021	0.560	0.00269	0.01157	12,254	66	153	27,015	146	336	13.5	0.073	0.168
14	38th Street to Lincoln Harbor to 38th Street	NY Waterway	Medium Haul	2.40	Caterpillar 3412(2)	1.84	0.0114	0.0490	1.55	0.095	0.23	2.19	0.00659	0.0210	0.355	0.00220	0.00947	0.281	0.0173	0.042	0.309	0.00093	0.00296	6,395	118	260	14,099	260	572	7.05	0.130	0.286
15	Port Imperial to 38th Street to Port Imperial (weekdays)	NY Waterway	Short Haul	2.00	Caterpillar 3412E	2.61	0.0702	0.3018	0.69	0.187	0.52	1.80	0.0103	0.0444	0.576	0.01548	0.0666	0.126	0.034	0.10	0.455	0.00261	0.01124	26,770	876	2,019	59,018	1,930	4,451	29.5	0.97	2.23
16	Port Imperial to 38th Street to Port Imperial (saturdays)	NY Waterway	Short Haul	2.00	Caterpillar 3412E	2.61	0.0702	0.3018	0.69	0.187	0.52	1.80	0.0103	0.0444	0.653	0.01755	0.0755	0.081	0.0221	0.061	0.550	0.00316	0.0136	3,473	77	177	7,656	169	390	3.83	0.085	0.195
17	Port Imperial to 38th Street to Port Imperial (sundays)	NY Waterway	Short Haul	2.00	Caterpillar 3412E	2.61	0.0702	0.3018	0.69	0.187	0.52	1.80	0.0103	0.0444	0.669	0.01797	0.0773	0.111	0.030	0.08	0.463	0.00266	0.01143	3,167	90	208	6,982	199	459	3.49	0.099	0.229
18	Colgate to WFC to Colgate	NY Waterway	Short Haul	1.60	Caterpillar 3412(2)	1.84	0.0114	0.0490	1.55	0.095	0.23	2.19	0.00659	0.0210	0.355	0.00220	0.00947	0.184	0.0113	0.028	0.467	0.00141	0.00447	16,491	190	418	36,356	419	922	18.2	0.209	0.461
	Totals, NY Waterway					**31.4**	**0.1433**	**0.351**	**18.8**	**0.43**	**0.92**	**41.1**	**0.0454**	**0.107**	**11.5**	**0.0535**	**0.1310**	**6.75**	**0.164**	**0.35**	**29.9**	**0.0532**	**0.126**	**235,387**	**1,121**	**2,300**	**518,939**	**2,471**	**5,070**	**259**	**1.24**	**2.54**
19	Port Imperial to (via Hoboken-North, WFC) Pier 11 to (via WFC, Hoboken-North) Port Imperial	Billy Bey	Long Haul	13.1	Caterpillar 3406E	1.36	0.00576	0.02479	0.984	0.0235	0.065	2.52	0.0121	0.0520	1.12	0.00475	0.02045	0.931	0.0222	0.062	3.76	0.0180	0.0776	9,070	45.3	104	19,995	100	230	10.00	0.0499	0.115
20	Port Imperial to Pier 11 to Port Imperial	Billy Bey	Long Haul	12.8	Caterpillar 3406E	1.36	0.00576	0.02479	0.984	0.0235	0.065	2.52	0.0121	0.0520	0.644	0.00273	0.01173	0.489	0.0117	0.032	4.15	0.0199	0.0856	34,312	151	348	75,644	333	767	37.8	0.166	0.384
21	Pier 11 to 38th Street to Pier 11	Billy Bey	Long Haul	11.8	Caterpillar 3406E	1.36	0.00576	0.02479	0.984	0.0235	0.065	2.52	0.0121	0.0520	0.644	0.00273	0.01173	0.489	0.0117	0.032	2.87	0.0138	0.0592	8,323	38.0	88	18,350	84	193	9.17	0.0418	0.097
22	Port Imperial to (via Hoboken-North) WFC to Port Imperial	Billy Bey	Medium Haul	8.00	Caterpillar 3406E	1.36	0.00576	0.02479	0.984	0.0235	0.065	2.52	0.0121	0.0520	0.601	0.00254	0.01095	0.548	0.0131	0.036	2.33	0.0112	0.0480	7,231	36.2	83	15,941	80	184	7.97	0.0399	0.092
23	WFC to (via Hoboken-North) Port Imperial to WFC	Billy Bey	Medium Haul	8.00	Caterpillar 3406E	1.36	0.00576	0.02479	0.984	0.0235	0.065	2.52	0.0121	0.0520	0.595	0.00252	0.01085	0.585	0.0140	0.039	2.39	0.0115	0.0493	7,424	37.9	87	16,368	84	193	8.18	0.0418	0.096
24	Hoboken-South to Pier 11 to Hoboken-South	Billy Bey	Medium Haul	7.40	Caterpillar 3406E	1.36	0.00576	0.02479	0.984	0.0235	0.065	2.52	0.0121	0.0520	0.811	0.00344	0.01479	0.443	0.0106	0.029	2.42	0.0116	0.0499	58,262	255	588	128,445	562	1,296	64.2	0.281	0.648
25	38th Street to Colgate to 38th Street	Billy Bey	Medium Haul	7.40	Caterpillar 3406E	1.36	0.00576	0.02479	0.984	0.0235	0.065	2.52	0.0121	0.0520	0.679	0.00288	0.01238	0.359	0.0086	0.024	1.61	0.00773	0.0333	8,956	40.2	93	19,744	89	204	9.87	0.0443	0.102
26	38th St. to (via Newport Hoboken-South) Hoboken-North to 38th St.	Billy Bey	Medium Haul	6.20	Caterpillar 3412(2)	1.84	0.0114	0.0490	1.55	0.095	0.23	2.19	0.00659	0.0210	0.762	0.00472	0.0203	0.715	0.0439	0.11	1.49	0.00448	0.0143	2,469	37.0	81	5,442	81	179	2.72	0.0407	0.090
27	38th St. to (via Hoboken North & Hoboken South) Newport to 38th St.	Billy Bey	Medium Haul	6.20	Caterpillar 3412(2)	1.84	0.0114	0.0490	1.55	0.095	0.23	2.19	0.00659	0.0210	0.614	0.00381	0.0164	0.697	0.0428	0.10	1.53	0.00460	0.0146	4,431	67	149	9,768	149	327	4.88	0.074	0.164
	Totals, Billy Bey Ferry Company					**13.2**	**0.0222**	**0.0616**	**10.0**	**0.148**	**0.33**	**22.0**	**0.0333**	**0.0856**	**6.47**	**0.01035**	**0.0287**	**5.26**	**0.071**	**0.159**	**22.5**	**0.0374**	**0.0963**	**140,476**	**319**	**667**	**309,697**	**703**	**1,470**	**155**	**0.351**	**0.74**
28	Various weekday routes [1]	NY Water Taxi	Medium Haul	-	DD Series 60	0.793	0.00306	0.0132	0.949	0.216	0.60	1.42	0.00774	0.0333	6.43	0.0248	0.107	2.51	0.572	1.6	10.3	0.0561	0.241	25,046	748	1,724	55,217	1,648	3,800	27.6	0.82	1.90
29	Various weekend routes [1]	NY Water Taxi	Medium Haul	-	DD Series 60	0.793	0.00306	0.0132	0.949	0.216	0.60	1.42	0.00774	0.0333	6.43	0.0248	0.107	2.51	0.572	1.6	10.3	0.0561	0.241	6,011	179	414	13,252	396	912	6.63	0.198	0.456
	Totals, New York Water Taxi					**1.59**	**0.00433**	**0.0186**	**1.90**	**0.306**	**0.85**	**2.85**	**0.0109**	**0.047**	**12.9**	**0.0351**	**0.1511**	**5.02**	**0.81**	**2.2**	**20.7**	**0.0794**	**0.342**	**31,057**	**769**	**1,773**	**68,469**	**1,695**	**3,908**	**34.2**	**0.85**	**1.95**
	Grand Totals, New York City Harbor					**46.2**	**0.1451**	**0.335**	**30.7**	**0.55**	**1.15**	**66.0**	**0.0574**	**0.130**	**30.8**	**0.0648**	**0.150**	**17.0**	**0.83**	**1.74**	**73.1**	**0.103**	**0.232**	**406,921**	**1,396**	**2,834**	**897,105**	**3,078**	**6,248**	**449**	**1.54**	**3.12**

Notes: (1): GPS data for respective route was unavailable for specific route; therefore route times estimated from vessels operating on similar routes.
(2): Emission data for mechanically controlled Caterpillar 3412 engines from actual baseline testing.
(3): Because NY Watertaxi vessels do not typically complete a closed circuit route the operating profile of the three modes of operation are presented as the total time in hours in each mode during the typical 9 hours of daily operation as determined during data logging. Therefore, route definitions and frequency are presented as various and on a hrs/day basis.

BASELINE PM2.5 EMISSION RATES

Route No.	Route Origin / Destination / End	Operator	Route Description	Route Distance (NM)	Propulsion Engine Type	PM 2.5 at Push, per Engine (g/hr)	PM 2.5 at Push STD Deviation (g/hr)	PM 2.5 at Push ± 95.0% C.I. (± g/hr)	PM 2.5 at Man, per Engine (g/hr)	PM 2.5 at Man. STD Deviation (g/hr)	PM 2.5 at Maneuver ± 95.0% C.I. (± g/hr)	PM 2.5 at Cruise, per Engine (g/hr)	PM 2.5 at Cruise STD Deviation (g/hr)	PM 2.5 at Cruise ± 95.0% C.I. (± g/hr)
1	Belford, NJ to Pier 11 to Belford, NJ	NY Waterway	Long Haul	45.8	Caterpillar 3412E	2.79	0.316	1.362	4.466	0.399	1.72	6.09	0.064	0.276
2	Port Liberte to Pier 11 to Port Libete	NY Waterway	Medium Haul	9.40	Caterpillar 3406E	11.3	0.264	1.134	10.29	1.31	5.65	24.9	1.161	5.00
3	Pier 11 to Port Liberte to Pier 11	NY Waterway	Medium Haul	9.40	Caterpillar 3406E	11.3	0.264	1.134	10.29	1.31	5.65	24.9	1.161	5.00
4	Hoboken-South to (via WFC & Pier 11) WFC to Hoboken-South	NY Waterway	Medium Haul	7.70	Caterpillar 3412(2)	50.4	0.62	2.66	40.89	2.05	8.80	17.6	0.389	1.67
5	38th Street to (via Newport & Harborside) Colgate to 38th Street	NY Waterway	Medium Haul	7.60	Caterpillar 3406E	11.3	0.264	1.134	10.29	1.31	5.65	24.9	1.161	5.00
6	38th Street to (via Newport) Harborside to 38th Street	NY Waterway	Medium Haul	6.70	Caterpillar 3406E	11.3	0.264	1.134	10.29	1.31	5.65	24.9	1.161	5.00
7	38th Street to (via Harborside) Newport to 38th Street	NY Waterway	Medium Haul	6.70	Caterpillar 3406E	11.3	0.264	1.134	10.29	1.31	5.65	24.9	1.161	5.00
8	38th Street to Harborside to 38th Street	NY Waterway	Medium Haul	6.60	Caterpillar 3406E	11.3	0.264	1.134	10.29	1.31	5.65	24.9	1.161	5.00
9	Liberty Harbor to Pier 11 to Liberty Harbor	NY Waterway	Medium Haul	5.80	Caterpillar 3406E	11.3	0.264	1.134	10.29	1.31	5.65	24.9	1.161	5.00
10	38th Street to Newport to 38th Street	NY Waterway	Medium Haul	5.60	Caterpillar 3406E	11.3	0.264	1.134	10.29	1.31	5.65	24.9	1.161	5.00
11	Hoboken-South to WFC to Hoboken-South	NY Waterway	Medium Haul	5.00	Caterpillar 3412(2)	50.4	0.62	2.66	40.89	2.05	8.80	17.6	0.389	1.67
12	38th Street to (via Lincoln Harbor) Hoboken North to 38th Street	NY Waterway	Medium Haul	3.10	Caterpillar 3406E	11.3	0.264	1.134	10.29	1.31	5.65	24.9	1.161	5.00
13	Hoboken-North to 38th Street to Hoboken-North	NY Waterway	Medium Haul	2.40	Caterpillar 3406E	11.3	0.264	1.134	10.29	1.31	5.65	24.9	1.161	5.00
14	38th Street to Lincoln Harbor to 38th Street	NY Waterway	Medium Haul	2.40	Caterpillar 3412(2)	50.4	0.62	2.66	40.89	2.05	8.80	17.6	0.389	1.67
15	Port Imperial to 38th Street to Port Imperial (weekdays)	NY Waterway	Short Haul	2.00	Caterpillar 3412E	2.79	0.316	1.362	4.466	0.399	1.72	6.09	0.064	0.276
16	Port Imperial to 38th Street to Port Imperial (saturdays)	NY Waterway	Short Haul	2.00	Caterpillar 3412E	2.79	0.316	1.362	4.466	0.399	1.72	6.09	0.064	0.276
17	Port Imperial to 38th Street to Port Imperial (sundays)	NY Waterway	Short Haul	2.00	Caterpillar 3412E	2.79	0.316	1.362	4.466	0.399	1.72	6.09	0.064	0.276
18	Colgate to WFC to Colgate	NY Waterway	Short Haul	1.60	Caterpillar 3412(2)	50.4	0.62	2.66	40.89	2.05	8.80	17.6	0.389	1.67
Totals, NY Waterway						**325**	**1.62**	**4.0**	**284.4**	**5.89**	**14.4**	**344**	**3.76**	**9.19**
19	Port Imperial to (via Hoboken-North, WFC) Pier 11 to (via WFC, Hoboken-North) Port Imperial	Billy Bey	Long Haul	13.1	Caterpillar 3406E	11.3	0.264	1.134	10.29	1.31	5.65	24.9	1.161	5.00
20	Port Imperial to Pier 11 to Port Imperial	Billy Bey	Long Haul	12.8	Caterpillar 3406E	11.3	0.264	1.134	10.29	1.31	5.65	24.9	1.161	5.00
21	Pier 11 to 38th Street to Pier 11	Billy Bey	Long Haul	11.8	Caterpillar 3406E	11.3	0.264	1.134	10.29	1.31	5.65	24.9	1.161	5.00
22	Port Imperial to (via Hoboken-North) WFC to Port Imperial	Billy Bey	Medium Haul	8.00	Caterpillar 3406E	11.3	0.264	1.134	10.29	1.31	5.65	24.9	1.161	5.00
23	WFC to (via Hoboken-North) Port Imperial to WFC	Billy Bey	Medium Haul	8.00	Caterpillar 3406E	11.3	0.264	1.134	10.29	1.31	5.65	24.9	1.161	5.00
24	Hoboken-South to Pier 11 to Hoboken-South	Billy Bey	Medium Haul	7.40	Caterpillar 3406E	11.3	0.264	1.134	10.29	1.31	5.65	24.9	1.161	5.00
25	38th Street to Colgate to 38th Street	Billy Bey	Medium Haul	7.40	Caterpillar 3406E	11.3	0.264	1.134	10.29	1.31	5.65	24.9	1.161	5.00
26	38th St. to (via Newport Hoboken-South) Hoboken-North to 38th St.	Billy Bey	Medium Haul	6.20	Caterpillar 3412(2)	50.4	0.62	2.66	40.89	2.05	8.80	17.6	0.389	1.67
27	38th St. to (via Hoboken North & Hoboken South) Newport to 38th St.	Billy Bey	Medium Haul	6.20	Caterpillar 3412(2)	50.4	0.62	2.66	40.89	2.05	8.80	17.6	0.389	1.67
Totals, Billy Bey Ferry Company						**180**	**1.12**	**3.11**	**153.8**	**4.52**	**12.56**	**209**	**3.12**	**8.67**
28	Various weekday routes [1]	NY Water Taxi	Medium Haul	-	DD Series 60	2.33	0.034	0.43	13.46	0.491	6.24	38.4	0.44	5.53
29	Various weekend routes [1]	NY Water Taxi	Medium Haul	-	DD Series 60	2.33	0.034	0.43	13.46	0.491	6.24	38.4	0.44	5.53
Totals, New York Water Taxi						**4.66**	**0.048**	**0.60**	**26.92**	**0.694**	**8.82**	**76.7**	**0.62**	**7.82**
Grand Totals, New York City Harbor						**510**	**1.97**	**4.7**	**465**	**7.45**	**17.6**	**630**	**4.92**	**11.64**

Route No.	PM 2.5 at Push, per vessel (g/route)	PM 2.5 at Push STD Deviation (g/route)	PM 2.5 at Push ± 95.0% C.I. (± g/route)	PM 2.5 at Maneuver, per vessel (g/route)	PM 2.5 at Man. STD Deviation (g/route)	PM 2.5 at Maneuver ± 95.0% C.I. (± g/route)	PM 2.5 at Cruise, per vessel (g/route)	PM 2.5 at Cruise STD Deviation (g/route)	PM 2.5 at Cruise ± 95.0% C.I. (± g/route)
1	1.72	0.195	0.841	3.459	0.309	1.329	25.9	0.27	1.17
2	8.65	0.202	0.871	10.71	1.37	5.89	26.0	1.211	5.21
3	7.43	0.174	0.749	9.19	1.17	5.05	26.6	1.238	5.33
4	21.5	0.26	1.13	12.59	0.629	2.71	11.8	0.261	1.12
5	6.02	0.141	0.606	4.555	0.582	2.50	25.7	1.197	5.15
6	3.70	0.087	0.373	2.996	0.382	1.65	21.7	1.012	4.36
7	3.71	0.087	0.374	3.379	0.431	1.86	20.6	0.959	4.13
8	2.72	0.0637	0.274	1.921	0.245	1.06	17.3	0.805	3.46
9	3.74	0.088	0.377	4.95	0.632	2.72	13.1	0.613	2.64
10	2.59	0.0607	0.261	2.745	0.350	1.51	12.9	0.600	2.58
11	10.5	0.129	0.56	5.32	0.266	1.14	6.78	0.150	0.646
12	6.11	0.143	0.615	5.91	0.754	3.25	5.31	0.248	1.065
13	6.13	0.144	0.617	3.393	0.433	1.86	5.54	0.258	1.111
14	9.75	0.120	0.52	7.42	0.371	1.60	2.48	0.055	0.236
15	0.616	0.0698	0.300	0.821	0.073	0.315	1.54	0.016	0.070
16	0.698	0.0792	0.341	0.527	0.0471	0.202	1.86	0.020	0.085
17	0.715	0.0811	0.349	0.724	0.065	0.278	1.57	0.017	0.071
18	9.75	0.120	0.52	4.85	0.243	1.04	3.75	0.083	0.357
Totals, NY Waterway	**106**	**0.58**	**1.41**	**85.5**	**2.46**	**6.01**	**230**	**2.84**	**6.95**
19	9.28	0.217	0.935	9.74	1.24	5.35	37.2	1.73	7.46
20	5.33	0.125	0.537	5.12	0.653	2.81	41.0	1.91	8.22
21	5.33	0.125	0.537	5.12	0.653	2.81	28.4	1.322	5.69
22	4.97	0.116	0.501	5.74	0.732	3.15	23.0	1.073	4.61
23	4.93	0.115	0.496	6.12	0.782	3.36	23.6	1.101	4.74
24	6.71	0.157	0.676	4.64	0.592	2.55	23.9	1.115	4.80
25	5.62	0.132	0.567	3.758	0.480	2.06	15.9	0.742	3.19
26	20.9	0.26	1.10	18.86	0.943	4.06	12.0	0.265	1.14
27	16.9	0.207	0.89	18.39	0.919	3.96	12.3	0.271	1.17
Totals, Billy Bey Ferry Company	**79.9**	**0.51**	**1.40**	**77.5**	**2.42**	**6.72**	**217**	**3.56**	**9.90**
28	18.9	0.27	3.5	35.6	1.30	16.50	278	3.16	40.1
29	18.9	0.27	3.5	35.6	1.30	16.50	278	3.16	40.1
Totals, New York Water Taxi	**37.8**	**0.39**	**4.9**	**71.2**	**1.84**	**23.33**	**557**	**4.5**	**56.7**
Grand Totals, New York City Harbor	**224**	**0.86**	**2.0**	**234.2**	**3.91**	**9.24**	**1,004**	**6.4**	**15.1**

Route No.	Total Annual PM 2.5, per route (g/yr)	Total Annual PM 2.5 STD Deviation (g/yr)	Total Annual PM 2.5 ± 95.0% C.I. (± g/yr)	Total Annual PM 2.5, per route (lbs/yr)	Total Annual PM 2.5 STD Deviation (lbs/yr)	Total Annual PM 2.5 ± 95.0% C.I. (± lbs/yr)	Total Current Annual PM 2.5, per route (short tons/yr)	Total Current Annual PM 2.5 STD Deviation (short tons/yr)	Total Annual PM 2.5 ± 95.0% C.I. (± short tons/yr)
1	112,980	1,660	4,063	249	3.7	9.0	0.125	0.0018	0.0045
2	82,485	3,345	8,184	182	7.37	18.0	0.0909	0.00369	0.00902
3	112,253	4,459	10,910	247	9.83	24.1	0.124	0.00491	0.01203
4	142,964	2,279	5,577	315	5.02	12.3	0.158	0.0025	0.0061
5	216,798	8,005	19,587	478	17.6	43.2	0.239	0.0088	0.0216
6	125,573	4,799	11,742	277	10.58	25.9	0.138	0.00529	0.01294
7	43,156	1,647	4,029	95.1	3.63	8.88	0.0476	0.00182	0.00444
8	34,180	1,317	3,222	75.4	2.90	7.10	0.0377	0.00145	0.00355
9	136,230	5,519	13,505	300	12.2	29.8	0.150	0.00608	0.0149
10	80,454	3,083	7,543	177	6.80	16.6	0.0887	0.00340	0.00831
11	370,429	5,430	13,286	817	12.0	29.3	0.408	0.0060	0.0146
12	126,122	5,873	14,370	278	12.9	31.7	0.139	0.0065	0.0158
13	113,554	3,953	9,674	250	8.72	21.3	0.125	0.00436	0.01066
14	132,841	2,661	6,512	293	5.87	14.4	0.146	0.0029	0.0072
15	68,923	2,372	5,805	152	5.23	12.8	0.0760	0.00262	0.00640
16	8,355	255	623	18.4	0.561	1.37	0.0092	0.000281	0.000687
17	7,665	268	655	16.9	0.590	1.44	0.00845	0.000295	0.000722
18	300,604	4,634	11,340	663	10.2	25.0	0.331	0.0051	0.0125
Totals, NY Waterway	**2,215,566**	**16,866**	**35,434**	**4,884**	**37.2**	**78.1**	**2.44**	**0.0186**	**0.0391**
19	110,624	3,345	8,185	244	7.37	18.0	0.122	0.003687	0.00902
20	455,611	13,150	32,177	1,004	29.0	70.9	0.502	0.0145	0.0355
21	119,541	3,078	7,532	264	6.79	16.6	0.132	0.00339	0.00830
22	109,698	2,712	6,636	242	5.98	14.6	0.121	0.00299	0.00732
23	111,767	2,819	6,897	246	6.21	15.2	0.123	0.00311	0.00760
24	833,388	20,174	49,364	1,837	44.5	108.8	0.919	0.0222	0.0544
25	147,642	3,021	7,392	325	6.66	16.3	0.163	0.00333	0.00815
26	45,604	843	2,062	100.5	1.86	4.55	0.0503	0.00093	0.00227
27	85,256	1,530	3,744	188	3.37	8.3	0.0940	0.00169	0.00413
Totals, Billy Bey Ferry Company	**2,019,130**	**25,061**	**54,603**	**4,451**	**55.2**	**120.4**	**2.23**	**0.0276**	**0.0602**
28	432,630	4,453	14,171	954	9.8	31.2	0.477	0.0049	0.0156
29	103,831	1,069	3,401	229	2.36	7.5	0.114	0.00118	0.00375
Totals, New York Water Taxi	**536,461**	**4,579**	**14,574**	**1,183**	**10.1**	**32.1**	**0.591**	**0.0050**	**0.0161**
Grand Totals, New York City Harbor	**4,771,157**	**30,553**	**63,538**	**10,519**	**67.4**	**140**	**5.26**	**0.0337**	**0.0700**

Notes: (1): GPS data for respective route was unavailable for specific route; therefore route times estimated from vessels operating on similar routes.
(2): Emission data for mechanically controlled Caterpillar 3412 engines from actual baseline testing.
(3): Because NY Watertaxi vessels do not typically complete a closed circuit route the operating profile of the three modes of operation are presented as the total time in hours in each mode during the typical 9 hours of daily operation as determined during data logging. Therefore, route definitions and frequency are presented as various and on a hrs/day basis.

CONTROLLED PM2.5 EMISSION RATES

Route Origin / Destination / End	Operator	Route Description	Route Distance NM	Propulsion Engine Type	PM 2.5 at Push, per Engine (g/hr)	PM 2.5 at Push STD Deviation (g/hr)	PM 2.5 at Push ± 95.0% C.I. (± g/hr)	PM 2.5 at Man, per Engine (g/hr)	PM 2.5 at Man. STD Deviation (g/hr)	PM 2.5 at Maneuver ± 95.0% C.I. (± g/hr)	PM 2.5 at Cruise, per Engine (g/hr)	PM 2.5 at Cruise STD Deviation (g/hr)	PM 2.5 at Cruise ± 95.0% C.I. (± g/hr)	PM 2.5 at Push, per vessel (g/route)	PM 2.5 at Push STD Deviation (g/route)	PM 2.5 at Push ± 95.0% C.I. (± g/route)	PM 2.5 at Man. STD Deviation (g/route)	PM 2.5 at Maneuver ± 95.0% C.I. (± g/route)	PM 2.5 at Cruise, per vessel (g/route)	PM 2.5 at Cruise STD Deviation (g/route)	PM 2.5 at Cruise ± 95.0% C.I. (± g/route)	Total Annual PM 2.5, per route (g/yr)	Total Annual PM 2.5 STD Deviation (g/yr)	Total Annual PM 2.5 ± 95.0% C.I. (± g/yr)	Total Annual PM 2.5, per route (lbs/yr)	Total Annual PM 2.5 STD Deviation (lbs/yr)	Total Annual PM 2.5 ± 95.0% C.I. (± lbs/yr)	Total Annual PM 2.5, per route (short tons/yr)	Total Annual PM 2.5 STD Deviation (short tons/yr)	Total PM 2.5 ± 95.0% C.I. (± short tons/yr)
Belford, NJ to Pier 11 to Belford, NJ	NY Waterway	Long Haul	45.8	Caterpillar 3412E	1.99	0.099	1.263	2.999	0.188	2.39	5.46	0.279	3.5427	1.23	0.061	0.780	0.145	1.847	23.2	1.185	15.05	97,394	4,350	13,844	215	9.59	30.5	0.107	0.00480	0.01526
Port Liberte to Pier 11 to Port Libete	NY Waterway	Medium Haul	9.40	Caterpillar 3406E	1.70	0.283	1.217	3.54	0.227	0.975	18.1	0.497	2.1401	1.31	0.217	0.934	0.236	1.01	18.9	0.518	2.23	43,459	1,110	2,715	95.8	2.45	5.99	0.0479	0.00122	0.00299
Pier 11 to Port Liberte to Pier 11	NY Waterway	Medium Haul	9.40	Caterpillar 3406E	1.70	0.283	1.217	3.54	0.227	0.975	18.1	0.497	2.1401	1.12	0.187	0.803	0.202	0.871	19.3	0.530	2.28	61,360	1,553	3,801	135	3.42	8.38	0.0676	0.00171	0.00419
Hoboken-South to (via WFC & Pier 11) WFC to Hoboken-South	NY Waterway	Medium Haul	7.70	Caterpillar 3412(2)	2.20	0.237	1.021	3.35	0.299	1.287	8.66	0.048	0.2073	0.936	0.101	0.435	0.092	0.396	5.80	0.032	0.139	24,233	438	1,072	53.4	0.97	2.36	0.0267	0.00048	0.00118
38th Street to (via Newport & Harborside) Colgate to 38th Street	NY Waterway	Medium Haul	7.60	Caterpillar 3406E	1.70	0.283	1.217	3.54	0.227	0.975	18.1	0.497	2.1401	0.909	0.151	0.650	0.100	0.432	18.7	0.513	2.21	126,530	3,253	7,960	279	7.2	17.5	0.139	0.00359	0.00877
38th Street to (via Newport) Harborside to 38th Street	NY Waterway	Medium Haul	6.70	Caterpillar 3406E	1.70	0.283	1.217	3.54	0.227	0.975	18.1	0.497	2.1401	0.559	0.093	0.400	0.066	0.284	15.8	0.434	1.87	76,847	1,982	4,849	169	4.37	10.69	0.0847	0.00218	0.00535
38th Street to (via Harborside) Newport to 38th Street	NY Waterway	Medium Haul	6.70	Caterpillar 3406E	1.70	0.283	1.217	3.54	0.227	0.975	18.1	0.497	2.1401	0.560	0.093	0.401	0.074	0.320	15.0	0.411	1.77	26,040	668	1,633	57.4	1.47	3.60	0.0287	0.00074	0.00180
38th Street to Harborside to 38th Street	NY Waterway	Medium Haul	6.60	Caterpillar 3406E	1.70	0.283	1.217	3.54	0.227	0.975	18.1	0.497	2.1401	0.411	0.068	0.294	0.0423	0.182	12.6	0.345	1.48	21,269	552	1,352	46.9	1.22	2.98	0.0234	0.00061	0.00149
Liberty Harbor to Pier 11 to Liberty Harbor	NY Waterway	Medium Haul	5.80	Caterpillar 3406E	1.70	0.283	1.217	3.54	0.227	0.975	18.1	0.497	2.1401	0.565	0.094	0.404	0.109	0.469	9.56	0.262	1.129	73,802	1,868	4,570	163	4.12	10.07	0.0814	0.00206	0.00504
38th Street to Newport to 38th Street	NY Waterway	Medium Haul	5.60	Caterpillar 3406E	1.70	0.283	1.217	3.54	0.227	0.975	18.1	0.497	2.1401	0.391	0.065	0.280	0.060	0.260	9.36	0.257	1.106	47,277	1,202	2,940	104.2	2.65	6.48	0.0521	0.00132	0.00324
Hoboken-South to WFC to Hoboken-South	NY Waterway	Medium Haul	5.00	Caterpillar 3412(2)	2.20	0.237	1.021	3.35	0.299	1.287	8.66	0.048	0.2073	0.459	0.0495	0.213	0.0389	0.1673	3.34	0.019	0.080	69,350	1,075	2,631	153	2.37	5.80	0.0764	0.00119	0.00290
38th Street to (via Lincoln Harbor) Hoboken North to 38th Street	NY Waterway	Medium Haul	3.10	Caterpillar 3406E	1.70	0.283	1.217	3.54	0.227	0.975	18.1	0.497	2.1401	0.922	0.153	0.660	0.130	0.560	3.86	0.1060	0.456	49,629	1,655	4,050	109.4	3.65	8.93	0.0547	0.00182	0.00446
Hoboken-North to 38th Street to Hoboken-North	NY Waterway	Medium Haul	2.40	Caterpillar 3406E	1.70	0.283	1.217	3.54	0.227	0.975	18.1	0.497	2.1401	0.925	0.154	0.662	0.075	0.321	4.03	0.111	0.476	46,161	1,536	3,759	101.8	3.39	8.29	0.0509	0.00169	0.00414
38th Street to Lincoln Harbor to 38th Street	NY Waterway	Medium Haul	2.40	Caterpillar 3412(2)	2.20	0.237	1.021	3.35	0.299	1.287	8.66	0.048	0.2073	0.426	0.0459	0.198	0.0543	0.233	1.22	0.0068	0.029	15,246	483	1,181	33.6	1.064	2.60	0.0168	0.00053	0.00130
Port Imperial to 38th Street to Port Imperial (weekdays)	NY Waterway	Short Haul	2.00	Caterpillar 3412E	1.99	0.099	1.263	2.999	0.188	2.39	5.46	0.279	3.5427	0.438	0.022	0.279	0.035	0.438	1.38	0.0707	0.898	54,925	1,889	6,011	121.1	4.16	13.3	0.0605	0.00208	0.00663
Port Imperial to 38th Street to Port Imperial (saturdays)	NY Waterway	Short Haul	2.00	Caterpillar 3412E	1.99	0.099	1.263	2.999	0.188	2.39	5.46	0.279	3.5427	0.497	0.025	0.316	0.0222	0.281	1.67	0.0854	1.085	6,826	248	789	15.0	0.547	1.74	0.00752	0.000273	0.000870
Port Imperial to 38th Street to Port Imperial (sundays)	NY Waterway	Short Haul	2.00	Caterpillar 3412E	1.99	0.099	1.263	2.999	0.188	2.39	5.46	0.279	3.5427	0.509	0.025	0.324	0.0305	0.387	1.41	0.0719	0.913	6,124	209	666	13.5	0.461	1.47	0.00675	0.000231	0.000734
Colgate to WFC to Colgate	NY Waterway	Short Haul	1.60	Caterpillar 3412(2)	2.20	0.237	1.021	3.35	0.299	1.287	8.66	0.048	0.2073	0.426	0.0459	0.198	0.0355	0.1526	1.85	0.0103	0.044	43,734	965	2,361	96.4	2.13	5.21	0.0482	0.00106	0.00260
Totals, NY Waterway					**33.7**	**1.032**	**2.65**	**60.8**	**1.01**	**2.59**	**238**	**1.67**	**4.297**	**12.6**	**0.458**	**1.18**	**0.441**	**1.13**	**167**	**1.69**	**4.35**	**890,205**	**7,352**	**15,670**	**1,963**	**16.2**	**34.5**	**0.981**	**0.00810**	**0.0173**
Port Imperial to (via Hoboken-North, WFC) Pier 11 to (via WFC, Hoboken-North) Port Imperial	Billy Bey	Long Haul	13.1	Caterpillar 3406E	1.70	0.283	1.217	3.54	0.227	0.975	18.1	0.497	2.1401	1.40	0.233	1.003	0.214	0.923	27.0	0.742	3.19	49,600	1,259	3,081	109	2.78	6.79	0.0547	0.00139	0.00340
Port Imperial to Pier 11 to Port Imperial	Billy Bey	Long Haul	12.8	Caterpillar 3406E	1.70	0.283	1.217	3.54	0.227	0.975	18.1	0.497	2.1401	0.804	0.134	0.576	0.113	0.485	29.8	0.818	3.52	210,441	5,439	13,309	464	12.0	29.3	0.232	0.0060	0.0147
Pier 11 to 38th Street to Pier 11	Billy Bey	Long Haul	11.8	Caterpillar 3406E	1.70	0.283	1.217	3.54	0.227	0.975	18.1	0.497	2.1401	0.804	0.134	0.576	0.113	0.485	20.6	0.566	2.44	48,240	1,233	3,016	106	2.72	6.65	0.0532	0.00136	0.00332
Port Imperial to (via Hoboken-North) WFC to Port Imperial	Billy Bey	Medium Haul	8.00	Caterpillar 3406E	1.70	0.283	1.217	3.54	0.227	0.975	18.1	0.497	2.1401	0.751	0.125	0.537	0.126	0.543	16.7	0.459	1.98	40,474	1,024	2,507	89.2	2.26	5.53	0.0446	0.00113	0.00276
WFC to (via Hoboken-North) Port Imperial to WFC	Billy Bey	Medium Haul	8.00	Caterpillar 3406E	1.70	0.283	1.217	3.54	0.227	0.975	18.1	0.497	2.1401	0.744	0.124	0.532	0.135	0.580	17.2	0.472	2.03	41,657	1,052	2,574	91.8	2.32	5.68	0.0459	0.00116	0.00284
Hoboken-South to Pier 11 to Hoboken-South	Billy Bey	Medium Haul	7.40	Caterpillar 3406E	1.70	0.283	1.217	3.54	0.227	0.975	18.1	0.497	2.1401	1.01	0.169	0.726	0.102	0.439	17.4	0.478	2.05	317,255	8,193	20,048	699	18.1	44.2	0.350	0.00903	0.0221
38th Street to Colgate to 38th Street	Billy Bey	Medium Haul	7.40	Caterpillar 3406E	1.70	0.283	1.217	3.54	0.227	0.975	18.1	0.497	2.1401	0.849	0.141	0.608	0.083	0.356	11.6	0.318	1.368	46,393	1,209	2,958	102.3	2.67	6.52	0.0511	0.00133	0.00326
38th St. to (via Newport Hoboken-South) Hoboken-North to 38th St.	Billy Bey	Medium Haul	6.20	Caterpillar 3412(2)	2.20	0.237	1.021	3.35	0.299	1.287	8.66	0.048	0.2073	0.913	0.098	0.424	0.138	0.593	5.89	0.033	0.141	6,942	144	351	15.3	0.317	0.775	0.00765	0.000158	0.000387
38th St. to (via Hoboken North & Hoboken South) Newport to 38th St.	Billy Bey	Medium Haul	6.20	Caterpillar 3412(2)	2.20	0.237	1.021	3.35	0.299	1.287	8.66	0.048	0.2073	0.736	0.079	0.342	0.134	0.579	6.04	0.034	0.145	12,920	249	610	28.5	0.549	1.34	0.0142	0.000275	0.000672
Totals, Billy Bey Ferry Company					**16.3**	**0.820**	**2.28**	**31.5**	**0.734**	**2.04**	**144**	**1.32**	**3.6587**	**8.02**	**0.431**	**1.20**	**0.400**	**1.110**	**152**	**1.52**	**4.22**	**773,922**	**10,174**	**22,168**	**1,706**	**22.4**	**48.9**	**0.853**	**0.0112**	**0.0244**
Various weekday routes [(1)]	NY Water Taxi	Medium Haul	-	DD Series 60	1.55	0.054	0.687	9.84	0.341	4.327	25.6	0.080	1.0203	12.6	0.44	5.568	0.901	11.45	186	0.58	7.4	291,984	1,507	4,795	644	3.3	10.6	0.322	0.00166	0.0053
Various weekend routes [(1)]	NY Water Taxi	Medium Haul	-	DD Series 60	1.55	0.054	0.687	9.84	0.341	4.327	25.6	0.080	1.0203	12.6	0.44	5.568	0.901	11.45	186	0.58	7.4	70,076	362	1,151	154	0.80	2.54	0.0772	0.00040	0.00127
Totals, New York Water Taxi					**3.11**	**0.077**	**0.972**	**19.67**	**0.482**	**6.12**	**51.3**	**0.11**	**1.443**	**25.2**	**0.62**	**7.874**	**1.274**	**16.19**	**372**	**0.82**	**10.5**	**362,060**	**1,549**	**4,931**	**798**	**3.4**	**10.9**	**0.399**	**0.00171**	**0.0054**
Grand Totals, New York City Harbor					**53.2**	**1.32**	**3.23**	**111.9**	**1.34**	**3.27**	**433**	**2.13**	**5.216**	**45.8**	**0.88**	**2.16**	**1.406**	**3.44**	**691**	**2.42**	**5.9**	**2,026,187**	**12,648**	**26,572**	**4,467**	**27.9**	**58.6**	**2.23**	**0.0139**	**0.0293**

(1): GPS data for respective route was unavailable for specific route; therefore route times estimated from vessels operating on similar routes.
(2): Emission data for mechanically controlled Caterpillar 3412 engines from actual baseline testing.
(3): Because NY Watertaxi vessels do not typically complete a closed circuit route the operating profile of the three modes of operation are presented as the total time in hours in each mode during the typical 9 hours of daily operation as determined during data logging. Therefore, route definitions and frequency are presented as various and on a hrs/day basis.

BASELINE HC EMISSION RATES

Route No.	Route Origin / Destination / End	Operator	Route Description	Route Distance NM	Propulsion Engine Type	HC at Push, per Engine (g/hr)	HC at Push STD Deviation (g/hr)	HC at Push 95.0% C.I. (± g/hr)	HC at Maneuver, per Engine (g/hr)	HC at Maneuver STD Deviation (g/hr)	HC at Maneuver 95.0% C.I. (± g/hr)	HC at Cruise, per Engine (g/hr)	HC at Cruise STD Deviation (g/hr)	HC at Cruise 95.0% C.I. (± g/hr)	HC at Push, per vessel (g/route)	HC at Push STD Deviation (g/route)	HC at Push 95.0% C.I. (± g/route)	HC at Maneuver, per vessel (g/route)	HC at Maneuver STD Deviation (g/route)	HC at Maneuver 95.0% C.I. (± g/route)	HC at Cruise, per vessel (g/route)	HC at Cruise STD Deviation (g/route)	HC at Cruise 95.0% C.I. (± g/route)	Total Annual HC, per route (g/yr)	Total Annual HC STD Deviation, per route (g/yr)	Total Annual HC 95.0% C.I. (± g/yr)	Total Annual HC, per route (lbs/yr)	Total Annual HC STD Deviation, per route (lbs/yr)	Total Annual HC 95.0% C.I. (± lbs/yr)	Total Current Annual HC, per route (short tons/yr)	Total Current Annual HC STD Deviation (short tons/yr)	Total Current Annual HC 95.0% C.I. (± short tons/yr)
1	Belford, NJ to Pier 11 to Belford, NJ	NY Waterway	Long Haul	45.8	Caterpillar 3412E	222	1.86	8.0	339	29.8	73	622	27.5	88	137	1.15	4.9	263	23.1	56	2,642	117	371.8	11,072,960	433,500	954,128	24,412	956	2,103	12.2	0.48	1.05
2	Port Liberte to Pier 11 to Port Libete	NY Waterway	Medium Haul	9.40	Caterpillar 3406E	359	1.70	7.3	231	12.0	33	743	18.10	77.9	275	1.31	5.6	240	12.5	35	774	18.87	81.2	2,347,776	41,281	95,194	5,176	91.0	210	2.59	0.0455	0.105
3	Pier 11 to Port Liberte to Pier 11	NY Waterway	Medium Haul	9.40	Caterpillar 3406E	359	1.70	7.3	231	12.0	33	743	18.10	77.9	237	1.12	4.8	206	10.7	30	792	19.30	83.0	3,210,224	57,497	132,589	7,077	127	292	3.54	0.063	0.146
4	Hoboken-South to (via WFC & Pier 11) WFC to Hoboken-South	NY Waterway	Medium Haul	7.70	Caterpillar 3412(2)	103	6.14	19.5	343	100	246	318	15.8	50.2	43.9	2.61	8.3	106	30.90	76	213	10.6	33.6	1,130,850	102,213	222,702	2,493	225	491	1.25	0.113	0.245
5	38th Street to (via Newport & Harborside) Colgate to 38th Street	NY Waterway	Medium Haul	7.60	Caterpillar 3406E	359	1.70	7.3	231	12.0	33	743	18.10	77.9	192	0.91	3.9	102	5.32	15	766	18.67	80.3	6,337,154	116,196	267,950	13,971	256	591	6.99	0.128	0.295
6	38th Street to (via Newport) Harborside to 38th Street	NY Waterway	Medium Haul	6.70	Caterpillar 3406E	359	1.70	7.3	231	12.0	33	743	18.10	77.9	118	0.56	2.40	67.2	3.50	9.7	648	15.78	67.9	3,680,198	71,494	164,865	8,113	157.6	363	4.06	0.079	0.182
7	38th Street to (via Harborside) Newport to 38th Street	NY Waterway	Medium Haul	6.70	Caterpillar 3406E	359	1.70	7.3	231	12.0	33	743	18.10	77.9	118	0.56	2.41	75.8	3.95	11.0	614	14.96	64.4	1,259,796	24,147	55,683	2,777	53.2	123	1.39	0.0266	0.0614
8	38th Street to Harborside to 38th Street	NY Waterway	Medium Haul	6.60	Caterpillar 3406E	359	1.70	7.3	231	12.0	33	743	18.10	77.9	86.7	0.41	1.77	43.1	2.24	6.2	515	12.55	54.0	1,005,792	19,900	45,889	2,217	43.9	101	1.11	0.0219	0.0506
9	Liberty Harbor to Pier 11 to Liberty Harbor	NY Waterway	Medium Haul	5.80	Caterpillar 3406E	359	1.70	7.3	231	12.0	33	743	18.10	77.9	119	0.57	2.43	111	5.8	16	392	9.55	41.1	3,881,899	69,759	160,864	8,558	154	355	4.28	0.077	0.177
10	38th Street to Newport to 38th Street	NY Waterway	Medium Haul	5.60	Caterpillar 3406E	359	1.70	7.3	231	12.0	33	743	18.10	77.9	82.5	0.39	1.68	61.6	3.21	8.9	384	9.35	40.2	2,332,878	43,733	100,849	5,143	96.4	222	2.57	0.0482	0.1112
11	Hoboken-South to WFC to Hoboken-South	NY Waterway	Medium Haul	5.00	Caterpillar 3412(2)	103	6.14	19.5	343	100	246	318	15.8	50.2	21.5	1.28	4.08	44.6	13.1	32	123	6.08	19.4	3,091,760	236,784	515,909	6,816	522	1,137	3.41	0.26	0.57
12	38th Street to (via Lincoln Harbor) Hoboken North to 38th Street	NY Waterway	Medium Haul	3.10	Caterpillar 3406E	359	1.70	7.3	231	12.0	33	743	18.10	77.9	194	0.92	4.0	133	6.9	19	158	3.86	16.6	3,533,752	57,965	133,669	7,791	128	295	3.90	0.064	0.147
13	Hoboken-North to 38th Street to Hoboken-North	NY Waterway	Medium Haul	2.40	Caterpillar 3406E	359	1.70	7.3	231	12.0	33	743	18.10	77.9	195	0.93	4.0	76.1	3.96	11.0	165	4.03	17.3	3,291,290	43,168	99,545	7,256	95	219	3.63	0.048	0.110
14	38th Street to Lincoln Harbor to 38th Street	NY Waterway	Medium Haul	2.40	Caterpillar 3412(2)	103	6.14	19.5	343	100	246	318	15.8	50.2	19.9	1.19	3.78	62.2	18.2	45	44.9	2.23	7.1	858,722	124,280	270,784	1,893	274	597	0.947	0.137	0.298
15	Port Imperial to 38th Street to Port Imperial (weekdays)	NY Waterway	Short Haul	2.00	Caterpillar 3412E	222	1.86	8.0	339	29.8	73	622	27.5	88	49.0	0.41	1.77	62.4	5.5	13	158	7.0	22.2	6,222,896	205,320	451,906	13,719	453	996	6.86	0.23	0.50
16	Port Imperial to 38th Street to Port Imperial (saturdays)	NY Waterway	Short Haul	2.00	Caterpillar 3412E	222	1.86	8.0	339	29.8	73	622	27.5	88	55.5	0.47	2.00	40.1	3.52	8.6	191	8.4	26.8	773,663	24,719	54,406	1,706	54	120	0.853	0.027	0.060
17	Port Imperial to 38th Street to Port Imperial (sundays)	NY Waterway	Short Haul	2.00	Caterpillar 3412E	222	1.86	8.0	339	29.8	73	622	27.5	88	56.9	0.48	2.05	55.1	4.83	12	160	7.1	22.6	693,642	21,896	48,194	1,529	48	106	0.765	0.024	0.053
18	Colgate to WFC to Colgate	NY Waterway	Short Haul	1.60	Caterpillar 3412(2)	103	6.14	19.5	343	100	246	318	15.8	50.2	19.9	1.19	3.78	40.7	11.9	29	67.9	3.36	10.7	2,104,104	203,594	443,593	4,639	449	978	2.32	0.224	0.49
Totals, NY Waterway						**4,886**	**13.9**	**32.9**	**5,039**	**213**	**451**	**11,187**	**85**	**197**	**2,021**	**4.5**	**10.6**	**1,790**	**51**	**109**	**8,806**	**126**	**290.8**	**56,829,355**	**625,447**	**1,275,608**	**125,287**	**1,379**	**2,812**	**62.6**	**0.69**	**1.41**
19	Port Imperial to (via Hoboken-North, WFC) Pier 11 to (via WFC, Hoboken-North) Port Imperial	Billy Bey	Long Haul	13.1	Caterpillar 3406E	359	1.70	7.3	231	12.0	33	743	18.10	77.9	296	1.4	6.0	219	11.4	32	1,108	27.0	116.2	2,531,543	45,786	105,582	5,581	100.9	233	2.79	0.0505	0.1164
20	Port Imperial to Pier 11 to Port Imperial	Billy Bey	Long Haul	12.8	Caterpillar 3406E	359	1.70	7.3	231	12.0	33	743	18.10	77.9	170	0.80	3.5	115	6.0	17	1,222	29.8	128.1	9,791,978	197,520	455,482	21,588	435	1,004	10.8	0.218	0.502
21	Pier 11 to 38th Street to Pier 11	Billy Bey	Long Haul	11.8	Caterpillar 3406E	359	1.70	7.3	231	12.0	33	743	18.10	77.9	170	0.80	3.5	115	6.0	17	846	20.61	88.7	2,350,479	44,664	102,996	5,182	98.5	227	2.59	0.0492	0.1135
22	Port Imperial to (via Hoboken-North) WFC to Port Imperial	Billy Bey	Medium Haul	8.00	Caterpillar 3406E	359	1.70	7.3	231	12.0	33	743	18.10	77.9	158	0.75	3.23	129	6.7	19	686	16.72	71.9	2,023,890	37,499	86,472	4,462	82.7	191	2.23	0.0413	0.0953
23	WFC to (via Hoboken-North) Port Imperial to WFC	Billy Bey	Medium Haul	8.00	Caterpillar 3406E	359	1.70	7.3	231	12.0	33	743	18.10	77.9	157	0.74	3.20	137	7.2	20	704	17.16	73.8	2,076,665	38,704	89,251	4,578	85.3	197	2.29	0.0427	0.0984
24	Hoboken-South to Pier 11 to Hoboken-South	Billy Bey	Medium Haul	7.40	Caterpillar 3406E	359	1.70	7.3	231	12.0	33	743	18.10	77.9	214	1.01	4.4	104	5.42	15	713	17.38	74.8	16,350,070	289,151	666,784	36,046	637	1,470	18.0	0.319	0.735
25	38th Street to Colgate to 38th Street	Billy Bey	Medium Haul	7.40	Caterpillar 3406E	359	1.70	7.3	231	12.0	33	743	18.10	77.9	179	0.85	3.7	84.3	4.39	12.2	475	11.57	49.8	2,495,312	41,936	96,705	5,501	92.5	213	2.75	0.0462	0.1066
26	38th St. to (via Newport Hoboken-South) Hoboken-North to 38th St.	Billy Bey	Medium Haul	6.20	Caterpillar 3412(2)	103	6.14	19.5	343	100	246	318	15.8	50.2	42.7	2.55	8.1	158	46	113	216	10.7	34.1	347,041	39,598	86,276	765	87	190	0.383	0.044	0.095
27	38th St. to (via Hoboken North & Hoboken South) Newport to 38th St.	Billy Bey	Medium Haul	6.20	Caterpillar 3412(2)	103	6.14	19.5	343	100	246	318	15.8	50.2	34.5	2.05	6.54	154	45	110	222	11.0	35.0	640,401	72,544	158,059	1,412	160	348	0.706	0.080	0.174
Totals, Billy Bey Ferry Company						**2,716**	**9.8**	**25.1**	**2,302**	**145**	**324**	**5,835**	**52.8**	**135.8**	**1,421**	**4.1**	**10.5**	**1,215**	**67**	**150**	**6,192**	**57.3**	**147.4**	**38,607,380**	**371,762**	**775,482**	**85,115**	**820**	**1,710**	**42.6**	**0.410**	**0.855**
28	Various weekday routes [1]	NY Water Taxi	Medium Haul	-	DD Series 60	48.6	2.34	10.09	341	44.8	125	328	3.48	14.98	394	19.0	81.7	902	119	329	2,380	25.3	108.7	4,777,468	159,651	368,156	10,533	352	812	5.27	0.176	0.406
29	Various weekend routes [1]	NY Water Taxi	Medium Haul	-	DD Series 60	48.6	2.34	10.09	341	44.8	125	328	3.48	14.98	394	19.0	81.7	902	119	329	2,380	25.3	108.7	1,146,592	38,316	88,358	2,528	84	195	1.26	0.0422	0.097
Totals, New York Water Taxi						**97.2**	**3.32**	**14.3**	**682**	**63**	**176**	**656**	**4.92**	**21.2**	**787**	**26.9**	**115.6**	**1,803**	**168**	**466**	**4,759**	**35.7**	**153.7**	**5,924,060**	**164,185**	**378,611**	**13,060**	**362**	**835**	**6.53**	**0.181**	**0.417**
Grand Totals, New York City Harbor						**7,699**	**17.3**	**39.2**	**8,023**	**266**	**554**	**17,678**	**101**	**224**	**4,229**	**27.5**	**62.3**	**4,808**	**188**	**392**	**19,758**	**143**	**318.7**	**#########**	**745,887**	**1,508,697**	**223,462**	**1,644**	**3,326**	**112**	**0.82**	**1.66**

Notes: (1): GPS data for respective route was unavailable for specific route; therefore route times estimated from vessels operating on similar routes.
(2): Emission data for mechanically controlled Caterpillar 3412 engines from actual baseline testing.
(3): Because NY Watertaxi vessels do not typically complete a closed circuit route the operating profile of the three modes of operation are presented as the total time in hours in each mode during the typical 9 hours of daily operation as determined during data logging. Therefore, route definitions and frequency are presented as various and on a hrs/day basis.

CONTROLLED HC EMISSION RATES

Route No.	Route Origin / Destination / End	Operator	Route Description	Route Distance (NM)	Propulsion Engine Type	HC at Push, per Engine (g/hr)	HC at Push STD Deviation (g/hr)	HC at Push ± 95.0% C.I. (± g/hr)	HC at Maneuver, per Engine (g/hr)	HC at Maneuver STD Deviation (g/hr)	HC at Maneuver ± 95.0% C.I. (± g/hr)	HC at Cruise, per Engine (g/hr)	HC at Cruise STD Deviation (g/hr)	HC at Cruise ± 95.0% C.I. (± g/hr)	HC at Push, per vessel (g/route)	HC at Push STD Deviation (g/route)	HC at Push ± 95.0% C.I. (± g/route)	HC at Maneuver, per vessel (g/route)	HC at Maneuver STD Deviation (g/route)	HC at Maneuver ± 95.0% C.I. (± g/route)	HC at Cruise, per vessel (g/route)	HC at Cruise STD Deviation (g/route)	HC at Cruise ± 95.0% C.I. (± g/route)	Total Annual HC, per route (g/yr)	Total Annual HC STD Deviation, per route (g/yr)	Total Annual HC ± 95.0% C.I. (± g/yr)	Total Annual HC, per route (lbs/yr)	Total Annual HC STD Deviation, per route (lbs/yr)	Total Annual HC ± 95.0% C.I. (± lbs/yr)	Total Annual HC, per route (short tons/yr)	Total Annual HC STD Deviation (short tons/yr)	Total Annual HC ± 95.0% C.I. (± short tons/yr)
1	Belford, NJ to Pier 11 to Belford, NJ	NY Waterway	Long Haul	45.8	Caterpillar 3412E	125	12.08	52.0	88	17.2	48	151	5.8	25	77.4	7.46	32.1	69	13.4	37	642	24.6	106	2,869,602	105,363	242,967	6,326	232	536	3.16	0.116	0.268
2	Port Liberte to Pier 11 to Port Libete	NY Waterway	Medium Haul	9.40	Caterpillar 3406E	130	1.77	7.61	116	13.2	37	477	33.7	145	100	1.36	5.85	121	13.8	38	497	35.1	151.0	1,306,577	68,643	158,290	2,881	151	349	1.44	0.076	0.174
3	Pier 11 to Port Liberte to Pier 11	NY Waterway	Medium Haul	9.40	Caterpillar 3406E	130	1.77	7.61	116	13.2	37	477	33.7	145	86	1.17	5.02	104	11.8	33	508	35.9	154.4	1,814,615	98,267	226,604	4,001	217	500	2.00	0.108	0.250
4	Hoboken-South to (via WFC & Pier 11) WFC to Hoboken-South	NY Waterway	Medium Haul	7.70	Caterpillar 3412(2)	92	0.569	2.45	77.6	4.76	12	110	0.329	1.05	39.1	0.242	1.04	23.9	1.47	4	73.4	0.221	0.702	425,417	4,688	10,318	938	10.3	22.7	0.469	0.0052	0.0114
5	38th Street to (via Newport & Harborside) Colgate to 38th Street	NY Waterway	Medium Haul	7.60	Caterpillar 3406E	130	1.77	7.61	116	13.2	37	477	33.7	145	69.5	0.946	4.07	51.5	5.9	16	492	34.7	149.3	3,662,927	210,559	485,551	8,075	464	1,070	4.04	0.232	0.535
6	38th Street to (via Newport) Harborside to 38th Street	NY Waterway	Medium Haul	6.70	Caterpillar 3406E	130	1.77	7.61	116	13.2	37	477	33.7	145	42.7	0.582	2.50	33.9	3.85	11	416	29.3	126.3	2,175,537	130,844	301,728	4,796	288	665	2.40	0.144	0.333
7	38th Street to (via Harborside) Newport to 38th Street	NY Waterway	Medium Haul	6.70	Caterpillar 3406E	130	1.77	7.61	116	13.2	37	477	33.7	145	42.8	0.583	2.51	38.2	4.34	12	394	27.8	119.7	740,803	43,919	101,279	1,633	96.8	223	0.817	0.0484	0.1116
8	38th Street to Harborside to 38th Street	NY Waterway	Medium Haul	6.60	Caterpillar 3406E	130	1.77	7.61	116	13.2	37	477	33.7	145	31.4	0.428	1.84	21.7	2.47	7	330	23.3	100.4	598,494	36,615	84,435	1,319	80.7	186.1	0.660	0.0404	0.0931
9	Liberty Harbor to Pier 11 to Liberty Harbor	NY Waterway	Medium Haul	5.80	Caterpillar 3406E	130	1.77	7.61	116	13.2	37	477	33.7	145	43.2	0.588	2.53	56.0	6.4	18	252	17.76	76.4	2,188,263	117,765	271,567	4,824	260	599	2.41	0.130	0.299
10	38th Street to Newport to 38th Street	NY Waterway	Medium Haul	5.60	Caterpillar 3406E	130	1.77	7.61	116	13.2	37	477	33.7	145	29.9	0.407	1.75	31.0	3.53	10	246	17.39	74.8	1,357,911	78,446	180,898	2,994	172.9	399	1.50	0.086	0.199
11	Hoboken-South to WFC to Hoboken-South	NY Waterway	Medium Haul	5.00	Caterpillar 3412(2)	92	0.569	2.45	77.6	4.76	12	110	0.329	1.05	19.2	0.119	0.51	10.1	0.62	2	42.3	0.127	0.404	1,171,173	10,536	23,191	2,582	23.2	51	1.29	0.0116	0.0256
12	38th Street to (via Lincoln Harbor) Hoboken North to 38th Street	NY Waterway	Medium Haul	3.10	Caterpillar 3406E	130	1.77	7.61	116	13.2	37	477	33.7	145	70.5	0.960	4.13	66.8	7.6	21	102	7.18	30.9	1,739,606	76,367	176,103	3,835	168	388	1.92	0.084	0.194
13	Hoboken-North to 38th Street to Hoboken-North	NY Waterway	Medium Haul	2.40	Caterpillar 3406E	130	1.77	7.61	116	13.2	37	477	33.7	145	70.8	0.963	4.14	38.4	4.36	12	106	7.49	32.2	1,622,268	65,719	151,547	3,576	145	334	1.79	0.072	0.167
14	38th Street to Lincoln Harbor to 38th Street	NY Waterway	Medium Haul	2.40	Caterpillar 3412(2)	92	0.569	2.45	77.6	4.76	12	110	0.329	1	17.8	0.110	0.47	14.1	0.86	2	15.5	0.046	0.148	319,753	5,897	12,980	705	13.0	28.6	0.352	0.0065	0.0143
15	Port Imperial to 38th Street to Port Imperial (weekdays)	NY Waterway	Short Haul	2.00	Caterpillar 3412E	125	12.08	52.0	88	17.2	48	151	5.8	25	27.6	2.67	11.5	16.3	3.2	9	38.3	1.47	6.31	1,902,722	101,656	234,418	4,195	224	517	2.10	0.112	0.258
16	Port Imperial to 38th Street to Port Imperial (saturdays)	NY Waterway	Short Haul	2.00	Caterpillar 3412E	125	12.08	52.0	88	17.2	48	151	5.8	25	31.4	3.02	13.0	10.4	2.03	6	46.3	1.77	7.62	238,294	10,957	25,268	525	24.2	56	0.263	0.0121	0.0279
17	Port Imperial to 38th Street to Port Imperial (sundays)	NY Waterway	Short Haul	2.00	Caterpillar 3412E	125	12.08	52.0	88	17.2	48	151	5.8	25	32.1	3.10	13.3	14.4	2.80	8	39.0	1.49	6.42	217,706	11,289	26,033	480	24.9	57	0.240	0.0124	0.0287
18	Colgate to WFC to Colgate	NY Waterway	Short Haul	1.60	Caterpillar 3412(2)	92	0.569	2.45	77.6	4.76	20.5	110	0.329	1.0	17.8	0.110	0.47	9.20	0.56	2.4	23.4	0.070	0.224	824,535	9,499	20,906	1,818	20.9	46.1	0.91	0.0105	0.0230
	Totals, NY Waterway					**2,169**	**24.8**	**60.8**	**1,828**	**55**	**118**	**5,810**	**107.1**	**253**	**849**	**9.43**	**23.1**	**729**	**27.1**	**58**	**4,262**	**85.1**	**201**	**25,176,202**	**362,225**	**743,224**	**55,504**	**799**	**1,639**	**27.8**	**0.399**	**0.819**
19	Port Imperial to (via Hoboken-North, WFC) Pier 11 to (via WFC, Hoboken-North) Port Imperial	Billy Bey	Long Haul	13.1	Caterpillar 3406E	130	1.77	7.61	116	13.2	37	477	33.7	145	107.22	1.46	6.28	110	12.5	35	711	50.2	216.1	1,448,944	80,795	186,315	3,194	178	411	1.60	0.089	0.205
20	Port Imperial to Pier 11 to Port Imperial	Billy Bey	Long Haul	12.8	Caterpillar 3406E	130	1.77	7.61	116	13.2	37	477	33.7	145	61.52	0.837	3.60	57.9	6.6	18	784	55.4	238.3	5,873,766	362,535	836,008	12,949	799	1,843	6.47	0.400	0.922
21	Pier 11 to 38th Street to Pier 11	Billy Bey	Long Haul	11.8	Caterpillar 3406E	130	1.77	7.61	116	13.2	37	477	33.7	145	61.52	0.837	3.60	57.9	6.6	18	543	38.3	164.9	1,377,094	80,889	186,530	3,036	178.3	411	1.52	0.089	0.206
22	Port Imperial to (via Hoboken-North) WFC to Port Imperial	Billy Bey	Medium Haul	8.00	Caterpillar 3406E	130	1.77	7.61	116	13.2	37	477	33.7	145	57.41	0.781	3.36	64.9	7.4	20	440	31.1	133.8	1,170,094	66,477	153,297	2,580	146.6	338	1.29	0.0733	0.169
23	WFC to (via Hoboken-North) Port Imperial to WFC	Billy Bey	Medium Haul	8.00	Caterpillar 3406E	130	1.77	7.61	116	13.2	37	477	33.7	145	56.89	0.774	3.33	69.2	7.9	22	452	31.9	137.3	1,202,309	68,380	157,685	2,651	150.8	348	1.33	0.0754	0.174
24	Hoboken-South to Pier 11 to Hoboken-South	Billy Bey	Medium Haul	7.40	Caterpillar 3406E	130	1.77	7.61	116	13.2	37	477	33.7	145	77.53	1.055	4.54	52.4	6.0	17	458	32.3	139.0	9,319,175	521,413	1,202,381	20,545	1,150	2,651	10.3	0.575	1.325
25	38th Street to Colgate to 38th Street	Billy Bey	Medium Haul	7.40	Caterpillar 3406E	130	1.77	7.61	116	13.2	37	477	33.7	145	64.94	0.884	3.80	42.5	4.8	13	305	21.52	92.6	1,393,190	74,604	172,038	3,071	164.5	379	1.54	0.082	0.190
26	38th St. to (via Newport Hoboken-South) Hoboken-North to 38th St.	Billy Bey	Medium Haul	6.20	Caterpillar 3412(2)	92	0.569	2.45	77.6	4.76	12	110	0.329	1	38.1	0.236	1.02	35.8	2.20	5	74.5	0.224	0.713	123,428	1,848	4,067	272	4.07	9.0	0.136	0.00204	0.00448
27	38th St. to (via Hoboken North & Hoboken South) Newport to 38th St.	Billy Bey	Medium Haul	6.20	Caterpillar 3412(2)	92	0.569	2.45	77.6	4.76	12	110	0.329	1	30.7	0.190	0.82	34.9	2.14	5	76.4	0.230	0.731	221,543	3,374	7,425	488	7.4	16.4	0.244	0.0037	0.0082
	Totals, Billy Bey Ferry Company					**1,094**	**4.75**	**13.2**	**970**	**35.6**	**79**	**3,556**	**89.1**	**229**	**556**	**2.59**	**7.2**	**526**	**20.7**	**46**	**3,844**	**102.7**	**264**	**22,129,543**	**656,544**	**1,374,162**	**48,787**	**1,447**	**3,030**	**24.4**	**0.724**	**1.515**
28	Various weekday routes [(1)]	NY Water Taxi	Medium Haul	-	DD Series 60	22.2	2.34	10.07	113	25.5	110	113	9.70	27	180	19.0	81.60	300	68	188	817	70.3	303	1,686,302	129,186	297,905	3,718	285	657	1.86	0.142	0.328
29	Various weekend routes [(1)]	NY Water Taxi	Medium Haul	-	DD Series 60	22.2	2.34	10.07	113	25.5	110	113	9.70	27	180	19.0	81.60	300	68	188	817	70.3	303	404,713	31,005	71,497	892	68.4	158	0.446	0.0342	0.079
	Totals, New York Water Taxi					**44.5**	**3.31**	**14.25**	**227**	**36.1**	**100**	**225**	**13.7**	**59**	**360**	**26.8**	**115.39**	**600**	**96**	**265**	**1,634**	**99.5**	**428**	**2,091,015**	**132,855**	**306,364**	**4,610**	**293**	**675**	**2.305**	**0.146**	**0.338**
	Grand Totals, New York City Harbor					**3,307**	**25.5**	**58.8**	**3,025**	**75**	**157**	**9,591**	**139.9**	**317**	**1,765**	**28.5**	**65.8**	**1,855**	**102**	**213**	**9,740**	**166**	**376**	**49,396,760**	**761,516**	**1,545,962**	**108,901**	**1,679**	**3,408**	**54.5**	**0.8394**	**1.704**

Notes: (1): GPS data for respective route was unavailable for specific route; therefore route times estimated from vessels operating on similar routes.
(2): Emission data for mechanically controlled Caterpillar 3412 engines from actual baseline testing.
(3): Because NY Watertaxi vessels do not typically complete a closed circuit route the operating profile of the three modes of operation are presented as the total time in hours in each mode during the typical 9 hours of daily operation as determined during data logging. Therefore, route definitions and frequency are presented as various and on a hrs/day basis.

NOx EMISSION RATE REDUCTIONS

Route No.	Route Origin / Destination / End	Operator	Route Description	Route Distance (NM)	Propulsion Engine Type	Emissions Control Technology	Current Total Annual NOx, per route (short tons/yr)	Current NOx STD Deviation (short tons/yr)	Current NOx ± 95.0% C.I. (± short tons/yr)	New Total Annual NOx, per route (short tons/yr)	New NOx STD Deviation (short tons/yr)	New NOx ± 95.0% C.I. (± short tons/yr)	NOx Reduction (short tons/yr)	NOx Reduction STD Deviation (short tons/yr)	NOx Reduction ± 95.0% C.I. (± short tons/yr)	% NOx Reduction (%)	% NOx Reduction STD Deviation (%)	% NOx Reduction ± 95.0% C.I. (± %)
1	Belford, NJ to Pier 11 to Belford, NJ	NY Waterway	Long Haul	45.8	Caterpillar 3412E	DOC+FBC	46.8	0.424	0.9	39.2	0.63	1.46	7.597	0.76	1.59	16.227%	1.63%	3.4%
2	Port Liberte to Pier 11 to Port Libete	NY Waterway	Medium Haul	9.40	Caterpillar 3406E	DOC	9.15	0.282	0.65	9.42	0.0559	0.129	-0.273	0.287	0.61	-2.99%	3.14%	6.7%
3	Pier 11 to Port Liberte to Pier 11	NY Waterway	Medium Haul	9.40	Caterpillar 3406E	DOC	12.4	0.347	0.80	12.8	0.071	0.165	-0.356	0.354	0.75	-2.86%	2.85%	6.0%
4	Hoboken-South to (via WFC & Pier 11) WFC to Hoboken-South	NY Waterway	Medium Haul	7.70	Caterpillar 3412(2)	Tier 2 Eng	12.2	0.65	1.42	9.4	0.103	0.227	2.80	0.66	1.37	23.0%	5.6%	11.5%
5	38th Street to (via Newport & Harborside) Colgate to 38th Street	NY Waterway	Medium Haul	7.60	Caterpillar 3406E	DOC	24.2	0.416	0.96	24.8	0.109	0.251	-0.566	0.430	0.91	-2.34%	1.78%	3.76%
6	38th Street to (via Newport) Harborside to 38th Street	NY Waterway	Medium Haul	6.70	Caterpillar 3406E	DOC	14.0	0.211	0.485	14.3	0.0619	0.143	-0.314	0.219	0.465	-2.25%	1.57%	3.33%
7	38th Street to (via Harborside) Newport to 38th Street	NY Waterway	Medium Haul	6.70	Caterpillar 3406E	DOC	4.79	0.081	0.188	4.91	0.0219	0.0506	-0.1125	0.084	0.179	-2.35%	1.76%	3.73%
8	38th Street to Harborside to 38th Street	NY Waterway	Medium Haul	6.60	Caterpillar 3406E	DOC	3.80	0.050	0.116	3.89	0.0164	0.0379	-0.0817	0.0527	0.112	-2.15%	1.39%	2.94%
9	Liberty Harbor to Pier 11 to Liberty Harbor	NY Waterway	Medium Haul	5.80	Caterpillar 3406E	DOC	15.1	0.447	1.03	15.5	0.090	0.208	-0.444	0.456	0.97	-2.95%	3.03%	6.4%
10	38th Street to Newport to 38th Street	NY Waterway	Medium Haul	5.60	Caterpillar 3406E	DOC	8.92	0.182	0.419	9.15	0.0436	0.100	-0.224	0.187	0.396	-2.51%	2.09%	4.44%
11	Hoboken-South to WFC to Hoboken-South	NY Waterway	Medium Haul	5.00	Caterpillar 3412(2)	Tier 2 Eng	33.8	1.45	3.16	25.8	0.232	0.51	7.96	1.47	3.04	23.6%	4.46%	9.2%
12	38th Street to (via Lincoln Harbor) Hoboken North to 38th Street	NY Waterway	Medium Haul	3.10	Caterpillar 3406E	DOC	14.3	0.61	1.42	14.8	0.113	0.260	-0.491	0.62	1.32	-3.44%	4.38%	9.3%
13	Hoboken-North to 38th Street to Hoboken-North	NY Waterway	Medium Haul	2.40	Caterpillar 3406E	DOC	13.2	0.367	0.85	13.5	0.073	0.168	-0.354	0.375	0.79	-2.69%	2.85%	6.0%
14	38th Street to Lincoln Harbor to 38th Street	NY Waterway	Medium Haul	2.40	Caterpillar 3412(2)	Tier 2 Eng	8.85	0.83	1.82	7.05	0.130	0.286	1.80	0.84	1.75	20.4%	9.7%	20.1%
15	Port Imperial to 38th Street to Port Imperial (weekdays)	NY Waterway	Short Haul	2.00	Caterpillar 3412E	DOC+FBC	38.8	0.60	1.33	29.5	0.97	2.23	9.297	1.14	2.38	23.96%	2.96%	6.2%
16	Port Imperial to 38th Street to Port Imperial (saturdays)	NY Waterway	Short Haul	2.00	Caterpillar 3412E	DOC+FBC	4.70	0.047	0.103	3.83	0.085	0.195	0.8675	0.097	0.202	18.48%	2.07%	4.3%
17	Port Imperial to 38th Street to Port Imperial (sundays)	NY Waterway	Short Haul	2.00	Caterpillar 3412E	DOC+FBC	4.47	0.059	0.130	3.49	0.099	0.229	0.9749	0.116	0.242	21.83%	2.61%	5.5%
18	Colgate to WFC to Colgate	NY Waterway	Short Haul	1.60	Caterpillar 3412(2)	Tier 2 Eng	23.2	1.32	2.88	18.2	0.209	0.461	4.98	1.34	2.77	21.5%	5.9%	12.2%
Totals, NY Waterway							**293**	**2.59**	**2.54**	**259**	**1.24**	**2.84**	**33.07**	**2.87**	**5.7**	**11.30%**	**0.99%**	**1.97%**
19	Port Imperial to (via Hoboken-North, WFC) Pier 11 to (via WFC, Hoboken-North) Port Imperial	Billy Bey	Long Haul	13.1	Caterpillar 3406E	DOC	9.74	0.224	0.516	10.00	0.0499	0.115	-0.256	0.229	0.486	-2.63%	2.35%	4.99%
20	Port Imperial to Pier 11 to Port Imperial	Billy Bey	Long Haul	12.8	Caterpillar 3406E	DOC	37.0	0.540	1.25	37.8	0.166	0.384	-0.829	0.565	1.20	-2.24%	1.53%	3.24%
21	Pier 11 to 38th Street to Pier 11	Billy Bey	Long Haul	11.8	Caterpillar 3406E	DOC	8.96	0.162	0.374	9.17	0.0418	0.097	-0.215	0.167	0.355	-2.40%	1.87%	3.96%
22	Port Imperial to (via Hoboken-North) WFC to Port Imperial	Billy Bey	Medium Haul	8.00	Caterpillar 3406E	DOC	7.77	0.176	0.406	7.97	0.0399	0.092	-0.204	0.181	0.383	-2.63%	2.33%	4.93%
23	WFC to (via Hoboken-North) Port Imperial to WFC	Billy Bey	Medium Haul	8.00	Caterpillar 3406E	DOC	7.97	0.188	0.433	8.18	0.0418	0.096	-0.213	0.192	0.407	-2.67%	2.41%	5.11%
24	Hoboken-South to Pier 11 to Hoboken-South	Billy Bey	Medium Haul	7.40	Caterpillar 3406E	DOC	62.7	1.11	2.56	64.2	0.281	0.648	-1.47	1.15	2.43	-2.35%	1.83%	3.87%
25	38th Street to Colgate to 38th Street	Billy Bey	Medium Haul	7.40	Caterpillar 3406E	DOC	9.64	0.189	0.435	9.87	0.0443	0.102	-0.233	0.194	0.411	-2.42%	2.01%	4.26%
26	38th St. to (via Newport Hoboken-South) Hoboken-North to 38th St.	Billy Bey	Medium Haul	6.20	Caterpillar 3412(2)	Tier 2 Eng	3.55	0.261	0.57	2.72	0.0407	0.090	0.825	0.264	0.55	23.3%	7.6%	15.8%
27	38th St. to (via Hoboken North & Hoboken South) Newport to 38th St.	Billy Bey	Medium Haul	6.20	Caterpillar 3412(2)	Tier 2 Eng	6.43	0.477	1.04	4.88	0.074	0.164	1.550	0.483	1.00	24.1%	7.7%	16.0%
Totals, Billy Bey Ferry Company							**154**	**1.41**	**2.95**	**155**	**0.351**	**0.74**	**-1.05**	**1.46**	**2.95**	**-0.682%**	**0.95%**	**1.92%**
28	Various weekday routes [1]	NY Water Taxi	Medium Haul	-	DD Series 60	DOC	26.0	0.89	2.05	27.6	0.82	1.90	-1.63	1.21	2.57	-6.28%	4.67%	9.9%
29	Various weekend routes [1]	NY Water Taxi	Medium Haul	-	DD Series 60	DOC	6.23	0.213	0.492	6.63	0.198	0.456	-0.391	0.291	0.62	-6.28%	4.67%	9.9%
Totals, New York Water Taxi							**32.2**	**0.91**	**2.11**	**34.2**	**0.85**	**1.95**	**-2.02**	**1.25**	**2.64**	**-6.28%**	**3.87%**	**8.2%**
Grand Totals, New York City Harbor							**479**	**3.09**	**6.2**	**449**	**1.54**	**3.12**	**30.00**	**3.45**	**6.9**	**6.27%**	**0.72%**	**1.44%**

PM2.5 EMISSION RATE REDUCTIONS

Route No.	Current Total Annual PM2.5, per route (short tons/yr)	Current PM2.5 STD Deviation (short tons/yr)	Current PM2.5 95.0% C.I. (± short tons/yr)	New Total Annual PM2.5, per route (short tons/yr)	New PM2.5 STD Deviation (short tons/yr)	New PM2.5 95.0% C.I. (± short tons/yr)	PM2.5 Reduction (short tons/yr)	PM2.5 Reduction STD Deviation (short tons/yr)	PM2.5 Reduction 95.0% C.I. (± short tons/yr)	% PM2.5 Reduction (%)	% PM2.5 Reduction STD Deviation (%)	% PM2.5 Reduction 95.0% C.I. (± %)
1	0.125	0.00183	0.0045	0.107	0.00480	0.01526	0.0172	0.00513	0.0116	13.8%	4.1%	9.3%
2	0.0909	0.00369	0.00902	0.0479	0.00122	0.00299	0.0430	0.00388	0.00846	47.3%	4.68%	10.2%
3	0.124	0.00491	0.01203	0.0676	0.00171	0.00419	0.0561	0.00520	0.01134	45.3%	4.58%	9.97%
4	0.158	0.00251	0.0061	0.0267	0.000483	0.00118	0.1309	0.00256	0.0056	83.0%	2.1%	4.6%
5	0.239	0.00882	0.0216	0.139	0.00359	0.00877	0.0995	0.00952	0.0208	41.6%	4.27%	9.31%
6	0.138	0.00529	0.01294	0.0847	0.00218	0.00535	0.0537	0.00572	0.01247	38.8%	4.39%	9.57%
7	0.0476	0.00182	0.00444	0.0287	0.000736	0.00180	0.0189	0.00196	0.00427	39.7%	4.39%	9.56%
8	0.0377	0.001451	0.0036	0.0234	0.000609	0.00149	0.0142	0.00157	0.00343	37.8%	4.42%	9.64%
9	0.150	0.00608	0.0149	0.0814	0.00206	0.00504	0.0688	0.00642	0.0140	45.8%	4.66%	10.16%
10	0.0887	0.00340	0.00831	0.0521	0.00132	0.00324	0.0366	0.00365	0.00795	41.2%	4.41%	9.60%
11	0.408	0.0060	0.0146	0.0764	0.00119	0.00290	0.332	0.0061	0.0133	81.3%	1.91%	4.16%
12	0.139	0.00647	0.0158	0.0547	0.00182	0.00446	0.0843	0.00673	0.0147	60.6%	5.6%	12.2%
13	0.125	0.00436	0.01066	0.0509	0.00169	0.00414	0.0743	0.00468	0.01019	59.3%	4.27%	9.3%
14	0.146	0.00293	0.00718	0.0168	0.000532	0.00130	0.1296	0.00298	0.0065	88.5%	2.7%	5.9%
15	0.0760	0.00262	0.00640	0.0605	0.00208	0.00663	0.0154	0.00334	0.00756	20.3%	4.5%	10.1%
16	0.00921	0.000281	0.000687	0.00752	0.000273	0.000870	0.00168	0.000392	0.000886	18.3%	4.3%	9.7%
17	0.00845	0.000295	0.000722	0.00675	0.000231	0.000734	0.00170	0.000374	0.000847	20.1%	4.5%	10.2%
18	0.331	0.00511	0.01250	0.0482	0.00106	0.00260	0.283	0.0052	0.0114	85.5%	2.1%	4.5%
Totals, NY Waterway	**2.44**	**0.0186**	**0.0391**	**0.981**	**0.00810**	**0.0173**	**1.46**	**0.0203**	**0.0413**	**59.8%**	**0.95%**	**1.93%**
19	0.122	0.00369	0.00902	0.0547	0.00139	0.00340	0.0673	0.00394	0.00858	55.2%	3.64%	7.92%
20	0.502	0.01450	0.0355	0.232	0.00600	0.0147	0.270	0.0157	0.0342	53.8%	3.49%	7.60%
21	0.132	0.00339	0.00830	0.0532	0.00136	0.00332	0.0786	0.00366	0.00796	59.6%	3.17%	6.91%
22	0.121	0.00299	0.00732	0.0446	0.00113	0.00276	0.0763	0.00320	0.00696	63.1%	3.07%	6.69%
23	0.123	0.00311	0.00760	0.0459	0.00116	0.00284	0.0773	0.00332	0.00723	62.7%	3.12%	6.80%
24	0.919	0.0222	0.0544	0.350	0.0090	0.0221	0.569	0.0240	0.0523	61.9%	3.01%	6.56%
25	0.163	0.00333	0.00815	0.0511	0.00133	0.00326	0.112	0.00359	0.00781	68.6%	2.61%	5.69%
26	0.0503	0.00093	0.00227	0.00765	0.000158	0.000387	0.0426	0.00094	0.00205	84.8%	2.4%	5.3%
27	0.0940	0.00169	0.00413	0.0142	0.000275	0.000672	0.0797	0.00171	0.00372	84.8%	2.4%	5.17%
Totals, Billy Bey Ferry Company	**2.23**	**0.0276**	**0.0602**	**0.853**	**0.0112**	**0.0244**	**1.37**	**0.0298**	**0.0615**	**61.7%**	**1.54%**	**3.18%**
28	0.477	0.0049	0.01562	0.322	0.0017	0.0053	0.155	0.0052	0.0127	32.5%	1.14%	2.78%
29	0.114	0.00118	0.00375	0.0772	0.0004	0.00127	0.0372	0.00124	0.00304	32.5%	1.14%	2.78%
Totals, New York Water Taxi	**0.591**	**0.0050**	**0.0161**	**0.399**	**0.00171**	**0.0054**	**0.192**	**0.0053**	**0.0130**	**32.5%**	**0.94%**	**2.31%**
Grand Totals, New York City Harbor	**5.26**	**0.0337**	**0.0700**	**2.23**	**0.0139**	**0.0293**	**3.03**	**0.0365**	**0.0737**	**57.5%**	**0.78%**	**1.6%**

HC EMISSION RATE REDUCTIONS

Route No.	Current Total Annual HC, per route (short tons/yr)	Current HC STD Deviation (short tons/yr)	Current HC 95.0% C.I. (± short tons/yr)	New Total Annual HC, per route (short tons/yr)	New HC STD Deviation (short tons/yr)	New HC 95.0% C.I. (± short tons/yr)	HC Reduction (short tons/yr)	HC Reduction STD Deviation (short tons/yr)	HC Reduction 95.0% C.I. (± short tons/yr)	% HC Reduction (%)	% HC Reduction STD Deviation (%)	% HC Reduction 95.0% C.I. (± %)
1	12.2	0.48	1.05	3.16	0.116	0.268	9.04	0.49	1.03	74.1%	5.0%	10.4%
2	2.59	0.0455	0.1049	1.44	0.076	0.174	1.15	0.0883	0.187	44.3%	3.50%	7.42%
3	3.54	0.063	0.146	2.00	0.108	0.250	1.54	0.1255	0.266	43.5%	3.63%	7.70%
4	1.25	0.113	0.245	0.469	0.0052	0.0114	0.778	0.113	0.233	62.4%	10.7%	22.1%
5	6.99	0.128	0.295	4.04	0.232	0.535	2.95	0.265	0.562	42.2%	3.87%	8.21%
6	4.06	0.079	0.182	2.40	0.144	0.333	1.66	0.164	0.348	40.9%	4.13%	8.75%
7	1.39	0.0266	0.0614	0.817	0.0484	0.1116	0.572	0.0552	0.1171	41.2%	4.06%	8.60%
8	1.11	0.0219	0.0506	0.660	0.0404	0.0931	0.449	0.0459	0.0974	40.5%	4.22%	8.95%
9	4.28	0.077	0.177	2.41	0.130	0.299	1.87	0.151	0.320	43.6%	3.61%	7.66%
10	2.57	0.0482	0.1112	1.50	0.086	0.199	1.07	0.0990	0.210	41.8%	3.93%	8.33%
11	3.41	0.261	0.57	1.29	0.0116	0.0256	2.12	0.261	0.54	62.1%	9.0%	18.7%
12	3.90	0.064	0.147	1.92	0.084	0.194	1.98	0.106	0.224	50.8%	2.84%	6.02%
13	3.63	0.0476	0.110	1.79	0.0724	0.167	1.84	0.087	0.184	50.7%	2.48%	5.26%
14	0.947	0.137	0.298	0.352	0.0065	0.0143	0.594	0.137	0.284	62.8%	17.1%	35.4%
15	6.86	0.23	0.50	2.10	0.112	0.258	4.76	0.253	0.52859	69.4%	4.34%	9.1%
16	0.853	0.027	0.060	0.263	0.0121	0.0279	0.590	0.0298	0.062	69.2%	4.14%	8.7%
17	0.765	0.024	0.053	0.240	0.0124	0.0287	0.525	0.0272	0.057	68.6%	4.16%	8.7%
18	2.32	0.224	0.489	0.91	0.0105	0.0230	1.41	0.225	0.465	60.8%	11.3%	23.4%
Totals, NY Waterway	**62.6**	**0.69**	**1.41**	**27.8**	**0.399**	**0.819**	**34.9**	**0.80**	**1.5948**	**55.7%**	**1.41%**	**2.83%**
19	2.79	0.0505	0.1164	1.60	0.089	0.205	1.19	0.102	0.217	42.8%	3.75%	7.95%
20	10.8	0.218	0.502	6.47	0.400	0.922	4.32	0.455	0.965	40.0%	4.29%	9.10%
21	2.59	0.0492	0.1135	1.52	0.0892	0.206	1.07	0.1019	0.216	41.4%	4.01%	8.50%
22	2.23	0.0413	0.0953	1.29	0.0733	0.1690	0.941	0.0841	0.178	42.2%	3.85%	8.16%
23	2.29	0.0427	0.0984	1.33	0.0754	0.1738	0.964	0.0866	0.184	42.1%	3.86%	8.19%
24	18.0	0.319	0.735	10.3	0.575	1.325	7.75	0.657	1.393	43.0%	3.73%	7.90%
25	2.75	0.0462	0.1066	1.54	0.082	0.190	1.21	0.0943	0.200	44.2%	3.51%	7.44%
26	0.383	0.044	0.095	0.136	0.00204	0.00448	0.246	0.0437	0.090	64.4%	13.6%	28.1%
27	0.706	0.080	0.174	0.244	0.0037	0.0082	0.462	0.080	0.166	65.4%	13.5%	28.0%
Totals, Billy Bey Ferry Company	**42.6**	**0.410**	**0.855**	**24.4**	**0.724**	**1.515**	**18.2**	**0.832**	**1.68**	**42.7%**	**2.00%**	**4.04%**
28	5.27	0.176	0.406	1.86	0.142	0.328	3.41	0.226	0.480	64.7%	4.81%	10.2%
29	1.26	0.042	0.097	0.446	0.0342	0.079	0.818	0.0543	0.115	64.7%	4.81%	10.2%
Totals, New York Water Taxi	**6.53**	**0.181**	**0.417**	**2.30**	**0.146**	**0.338**	**4.23**	**0.233**	**0.494**	**64.7%**	**3.99%**	**8.5%**
Grand Totals, New York City Harbor	**112**	**0.82**	**1.66**	**54.5**	**0.8394**	**1.70**	**57.3**	**1.18**	**2.3413**	**51.3%**	**1.12%**	**2.23%**

APPENDIX AD

MINI DILUTION TUNNEL PARTIAL FLOW SAMPLING SYSTEM

Mini-Dilution Tunnel Partial Flow Sampling System:

The mini-dilution tunnel (MDT) sampling system is a partial flow sampling system constructed in-house at the Emissions Research and Measurement Division of Environment Canada.

Concept:

A known quantity of raw exhaust gas is pulled, through a heated sample line, into the nose of the MDT where a portable analyzer samples a portion of the gas and records the readings. The raw exhaust is then mixed with a known quantity of dilution air in order to collect the conditioned exhaust on particulate matter filters. A portable analyzer also simultaneously samples the dilute exhaust gas in order to verify the dilution rate has remained constant throughout the test.

The dilution rate is set using high quality mass flow controllers and sampling pumps. The total amount of particulate matter and/or water content, as well as dilute exhaust temperature, dictate the proper dilution rate for an individual test engine. Typically 15% to 30% raw exhaust is the normal dilution operating range.

Mass Flow Controllers:

Typically 35 LPM mass flow controllers (MFCs) are used in the partial sampling dilution tunnel system (50 or 100 LPM MFCs can be used if desired). In all the NY ferry testing 35 LPM MFCs were used.

The MFCs are manufactured by MKS. They are serviced bi-annually or when their proper operation is questioned. They control the mass flow rate of the various gas streams and display a volume per minute value corrected to 20 ºC. (Gas volume varies with temperature, mass does not).The MFCs use a laminar flow element and resistance heaters wound around a sensor tube. The mass-flow versus temperature profile is linear and the control valve is adjusted according to the desired set point. They are accurate to within 0.5% of full scale flow.

Additionally the MFCs are verified in the field with the use of a Dry-Cal flow calibration unit.

DryCal Piston & Laser Calibration Unit:

The primary flow verification unit for all field testing is a DryCal flow calibrator. It uses piston & laser technology for +/- 1% accuracy. In practice they normally arrive serviced at +/- 0.3 % accuracy at flows between 10 and 30 LPM. A PDF file is included. www.drycal.com

Leak and Flow Checks:

Upon assembly in the field, the system is leak/vacuum checked to a maximum of 0.1 LPM at -15 to -16 inches of water. Flow checks on the MFCs are performed using the DryCal flow calibrator. Dilution is calculated from the DryCal values and corroborated using the dilute analyzer versus raw analyzer displays.

Portable Analyzers:

The portable gas analyzers used for the NY ferry project were NOVA ™ 6 gas analyzers. The individual sensors contained within the units are CityTech sensors manufactured in the UK. NOVA assembled the sensors within a housing unit along with a sequence of moisture traps, high quality filters, sampling pumps and control systems to introduce the gas sample to the individual sensors.
The NOVA analyzers are accurate to +/1% of full scale for CO, O2, CO2 and +/- 2% for NOx.
A pdf file is attached.

Each NOVA analyzer going into the field is calibrated in-house against standards of known concentrations. In addition a 5-gas calibration gas is brought into the field to check the analyzers at the start and end of each day. Upon returning to the lab the each analyzer is rechecked versus the calibration standards.

System Repeatability and Accuracy:

The repeatability of the entire system, with a calibration gas, has been determined to be +/- 3%.

Given the accuracy of each component within of the system the overall MDT sampling system accuracy is deemed to be +/- 5%.

Additionally correlations are routinely performed versus our constant volume sampling (CVS) system operating in our heavy-duty test cells. The results from these tests show a < 10% discrepancy between the MDT and CVS systems for NOx, CO2 and PM and a < 20 % discrepancy for CO and HCs.

Instrument Calibration

By Harvey Padden

Assuring Instrument Accuracy

More and more, we rely on measuring instruments in the course of our work. People's safety and health depend upon it. That said, calibration is an important overhead function. Although it doesn't exactly get our job done, it does help assure us that in the end, we have results we can trust.

Of course, during the calibration process we want to spend the least amount of time, cost and effort, while guaranteeing our accuracy. So, how do we assure accurate instruments in our operation? The following is an overview of some key, and often misunderstood, concepts in measurement science.

"NIST Traceable"

In the end, all measuring equipment must have its calibration traceable to a national authority such as the National Institute of Standards and Technology (NIST). However, "NIST-traceable" is a term that is often abused. To be meaningful, NIST traceability must be established by tracking each calibration preformed in an unbroken chain from NIST to the instrument under calibration, including all the intermediate instruments used along the way. The calibration of your equipment may easily be several steps removed from the original NIST calibration, with each step contributing its own errors.

Uncertainty and Accuracy

Most people speak of accuracy, yet in this article I have continually referred to uncertainty. Is because there is no way to assure an "accuracy" within which all tests will fall. Just as nothing is ever totally certain, there can be no total knowledge of accuracy. Rather, we ask the question "How certain do you want to be?" and then do a statistical analysis to achieve the required certainty. NIST's guidelines, for example, assume that any uncertainty analysis is based upon a 95.5% probability of any reading falling within the specified limits (unless otherwise noted). For example, if a calibrator were rated for one percent expanded (total) uncertainty, we would expect 955 readings out of every 1000 to be within one percent of the true value.

Repeatability and Reproducibility

Repeatability and reproducibility are important, but they are only part of the total picture. It is easy to confuse repeatability with accuracy. In fact, studies have been published that examine reproducibility in detail but totally ignore other factors that contribute to overall uncertainty.

Because an instrument repeats readings very closely, it may seem to be quite accurate. However, a very inaccurate reading can be repeated perfectly. In real applications, the less accurate of two instruments can often be the more repeatable.

Reproducibility goes a step further than repeatability. Reproducibility refers to how well one instrument of a certain type compares to another. Still, excellent reproducibility is not enough to assure low uncertainty. An example might be a bubble flow calibrator that gives the same reading as several other bubble calibrators. However, all may be in error by the same amount due to something that affects them all in the same way. In this example, if the humidity of the air under test differed greatly from the humidity at which the devices were calibrated, the instruments could indicate an identical reading that had a sizeable error.

In fact, a complete instrument specification should be based upon an uncertainty analysis that includes all elements that could affect uncertainty, including drift with temperature and humidity, and drift with time since calibration.

Device Interactions?

Remember that any calibration device affects the instrument being measured. In most cases, this is not significant. However, such interactions should not be ignored. At extremely low-pressure loads, for example, a dry flow calibrator may affect the flow of an air sampler to a degree that may be significant. In this case, an additional load may need to be added to the sampling train to achieve the required uncertainty.

ISO, ANSI and GUM

It's easy to be confused by the many industry acronyms that are in use. In fact, these three all refer to standards that can help us sort out the calibration muddle. ISO 17025 is a standard set by the International Standards Organization (ISO) describing how measuring laboratories must perform their function to be effective. It covers certification of all of a laboratory's processes such that the accuracy of a calibration can be assured. The American National Standards Institute (ANSI) has similar specifications for laboratory performance.

ISO 17025 then refers to the International Guide to Uncertainty in Measurements (GUM) to define how measurement uncertainty (accuracy) is to be calculated. It explains how each source of error in each step of the traceability chain must be evaluated in exhaustive, precise and statistically significant detail. It further shows how to mathematically treat these many sources of error to arrive at a meaningful total measurement uncertainty. NIST requires adherence to the GUM for its own operations.

How the GUM Can Help Us

If we were to simply add up the prospective sources of error, we would have unnecessarily severe (and expensive) accuracy requirements at many steps in our processes. Yet, relaxing our overall standards would compromise the quality of our work and our ability to protect life and health.

These standards give us a tool for statistically assuring the optimum overall accuracy at the lowest cost. Quite simply, we can spend our accuracy budget the most wisely if we take guidance from the GUM. The GUM shows that the overall uncertainty of a measurement process is not simply the sum of the possible individual errors. Rather, it is the square root of the sum of all the error sources squared. The result is that accuracy depends upon controlling the largest sources of error even more than we would have thought, and small errors are less important.

Let's use an example. Suppose that the best uncertainty we can achieve in analyzing the contents of a personal air sampling tube is ten percent. The uncertainty of the air sampling process itself (the degree to which the air sampled is representative of the air breathed) is another ten percent. Our air sampler holds its calibration to five percent. Our flow calibrator is accurate to one percent. Finally, the uncertainty added when performing the calibration process itself is one percent. Simply adding these error figures would result in:

$$10 + 10 + 5 + 1 + 1 = 27$$

However, according to the GUM, the following calculation is used:

$$\sqrt{10^2 + 10^2 + 5^2 + 1^2 + 1^2} = \sqrt{100 + 100 + 25 + 1 + 1}$$ $10^2 + 10^2 + 5^2 + 1^2 + 1^2 = 100 + 100 + 25 + 1 + 1 = 15$

The GUM's statistically derived error is only 15%, not the 27% we might have expected. This calculation illustrates a statistical truth: The larger error sources account for almost all the error. Suppose, for example that the air sampler was only stable to seven percent, instead of five percent. Out total uncertainty would only go to 16%. In an example like this, we would be wise to pay closest attention to the quality of our tubes, our sampling train's design and our laboratory's uncertainty.

Bear in mind that we must still include the smaller uncertainties in our analysis. Such uncertainties are only insignificant if we remain assured that they truly are small. In this root-sum-square mathematics, error sources increase rapidly in importance when they become one of the larger uncertainty contributors.

NIST has GUM information online at www.physics.nist.gov/cuu/Uncertainty/basic.html

How ISO Can Help Us

We tend to think of error as resulting only from improper or missing calibration. However, you cannot calibrate accuracy into an instrument any more than you can inspect quality into a product. Each link in our measurement chain affects the overall validity of our measurements, yet we don't have direct control over many of the links. A manufacturer may claim that his flow calibrator has an uncertainty of one percent, but we cannot personally determine whether that is actually true. Similarly, a laboratory can claim that it has calibrated a noise dosimeter or toxic gas monitor to a certain uncertainty, but we have no direct knowledge. Whom do we trust?

The ISO standards were formulated to address this issue. ISO 9001-2000 requires that an instrument manufacturer not only has the ability to deliver a consistent product (as in the old ISO 9001), but also that the product performs its intended function properly. In the case of a measuring instrument, this would, of course, include the ability to meet its uncertainty specifications. Similarly, ISO 17025 requires a laboratory to perform a rigorous uncertainty analysis per the GUM (as in the old ISO 25), but also demonstrate proficiency through inter-laboratory comparisons. Once a company conforms to ISO standards, it is audited by external agencies to assure that it truly complies with the standards. Only then does the company have the right to claim that it is ISO-certified. Be careful here: Many companies will claim, "meets ISO standards". That may or may not be true. The relevant question is whether an ISO-accredited auditor has certified them to the correct standards. Only ISO 9001, not 9002 or 9003, addresses design quality, and ISO 25 or 17025 addresses laboratory quality. Ideally, an instrument maker would be accredited to both.

The earlier ISO standards (9000 series and 25) were criticized as assuring consistency, but not function. The new standards promise to address the problem by assuring real-world total quality. However, these newest ISO standards are just beginning to be implemented, and very few suppliers have been accredited to date. With time, though, will become increasingly helpful in selecting suppliers. These standards will help assure that the parts of the measurement uncertainty chain that are out of your direct control are being properly performed.

Summary

The main thing to remember is that measurement uncertainty must encompass everything from NIST to the final laboratory result. Every source of error along the way must be accounted for.

Our vendors do much of it for us, but we must make sure that they are doing their job properly. We must make certain that our vendors have performed rigorous uncertainty analyses and are performing in accordance with them. ISO 9001-2000 and 17025 accreditations can eventually help offer us assurance in this area.

Harvey Padden has presented uncertainty analyses at major international symposia. He is President of Bios International Corporation of Butler, New Jersey (www.biosint.com). The company manufactures precision laboratory and field flow calibrators, as well as automated air samplers. Bios will be happy to help in answering calibration and uncertainty questions, or in supplying a copy of its own detailed uncertainty analyses. Address requests to Mr. Padden at padh@biosint.com or call 973-492-8400.

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