California Environmental Protection Agency

Air Resources Board

Recommended Emissions Testing Guidelines for Ocean-going Vessels

California Air Resources Board

Stationary Source Division

Emissions Assessment Branch

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Introduction

The California Air Resources Board (ARB) staff has developed Recommended Emissions Testing Guidelines for Ocean-going Vessels (guidelines) to provide testing guidance in support of control equipment manufacturers, Port programs and regulatory requirements.[1] The development of the guidelines was aided by the technical support of the researchers at CE-CERT, University of California, Riverside.[2] Modeled after ARB's Diesel Emission Control Strategies Verification[3], these guidelines outline the information and testing needed to allow ARB staff to evaluate and quantify the emission reductions associated with ocean-going vessel emission control strategies. They include components to support the evaluation of control strategies that are not subject to regulatory requirements (non-regulatory applications) and those that are subject to regulatory requirements (regulatory applications). An example of a regulatory application is the evaluation of control strategies subject to regulatory requirements under the At Berth Equivalent Emissions Reduction Option (At-Berth Equivalency) in ARB's Airborne Toxic Control Measure for Auxiliary Diesel Engines Operated on Ocean-going Vessels At-Berth in a California Port.[4] The guidelines address the following information and data collection needed to evaluate and quantify the emission reductions for ocean-going vessel emission reduction technologies:

- Applicability-Range of Product Evaluation: establishing an emission control group,
- Emission Reduction Performance Testing: baseline and controlled testing using appropriate test cycles or test loads,
- In-Use Performance and Durability: demonstrating performance over an established time period, and
- Periodic Testing: generally required under regulatory programs or permitting.

The evaluation of control strategies either used for non-regulatory applications or regulatory applications should include all four components, and any additional requirements or supplemental analyses specified in the regulation(s). For the non-regulatory application, the fourth component is necessary to help facilitate accounting of the emission reduction benefits in emission inventories and current and future air quality planning efforts. In the following sections, the information needs, testing procedures, reporting, control device description and operational parameters, and quality controls necessary to evaluate the control technology are described.

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[1] Currently, the California Air Resources Board does not have a formal regulatory path for verification of control strategies for ocean-going vessels (OGVs).

[2] William A. Welch and M. Yusuf Khan, CE-CERT, University of California, Riverside, CA, 92507.

[3] ARB's Diesel Emission Control Strategies Verification at http://www.arb.ca.gov/diesel/verdev/verdev.htm

[4] ARB's Airborne Toxic Control Measure for Auxiliary Diesel Engines Operated on Ocean-Going Vessels at Berth in a California Port at http://www.arb.ca.gov/regact/2007/shorepwr07/93118-t17.pdf

There may also be additional requirements such as district permits or Experimental Exemptions (as described in Section 11) that may be required. Please check with the local air district, port and ARB to determine if there are additional requirements.

I. Emission Testing Guidelines

The test plan provided by the control technology provider should include the following information regarding the control technology and emission testing protocol. There is no specified format in which to provide the information, however it is recommended that at a minimum the test plan address all the information described in items 1 through 16 below.

1. Contact Information

Recommended contact information shall be provided as in Table 1.

Table 1. Contact Information

Organization Name	
Address	
City/State/Zip Code	
Contact 1-First Name	
Contact 1-Last Name	
Contact 1-Phone Number 1	
Contact 1-email address	
Contact 2-First Name	
Contact 2-Last Name	
Contact 2-Email	
Contact 2-Phone Number 1	
Contact 2-email address	

2. Overview of Test Program

A synopsis of the test plan shall be provided in this section. It should briefly layout following information:

- Purpose of the testing,
- Vessel type and engine category,
- Test cycle,
- Gaseous and particulate components, instruments, and test methods, and
- Expected reduction in emissions.

3. Description of Control Strategy

This section should describe the main components and operating principle(s) of the control strategy. It is required to provide a schematic illustrating the configuration of control strategy. Information on the strategy's development status and description of any prototype or commercial units that have been demonstrated or placed into operation would be beneficial for the evaluation process. For systems that have been deployed, please identify the type(s) of sources (e.g. stationary generator, ship auxiliary engine, land-based boiler, etc.) that they are operating on and the location(s) of the systems.

If the control strategy design includes a connection system that may result in collection losses (e.g. a hood or "bonnet" type system), a description of the connection design must be provided. Testing must be performed to evaluate and demonstrate the capture efficiency of the connection system and details of the evaluation must be provided. We recommend using a carbon balance method as described in Appendix D, although other methods will be considered. Results of the capture efficiency evaluation must be included with the other emission test results in the report.

If the control system is designed to operate with sources (engines or boilers) that may have variations in the engine load or exhaust flow rate over the operational period (variable duty cycle), include a description of how the system responds to the variable load duty cycle and any impact on the control efficiency or emissions reductions. Include typical ranges of backpressure over the load variations anticipated.

If the control strategy design includes consumables, list the consumables and the anticipated amounts per an operational metric (e.g. kg/hr, percent of fuel consumption, etc.). If the control strategy produces a waste stream or byproducts, describe these, their anticipated chemical composition, and anticipated amounts per an operational metric. Also describe the anticipated methods for collecting the waste stream/byproducts and final removal from the ship or site.

If there is confidential information in the test plan or test report, identify all information that should be considered confidential and include the confidential information submittal form provided in Appendix A.

4. Limitations of Control Strategy

This section should clearly state any known possible failure modes, process limitations (e.g. minimum heat requirements, maximum flow rates, etc.), issues or complications

that a control strategy might encounter during its operation. Recovery methods, specific procedures or guidelines to operate the control strategy should be outlined.

5. Maintenance

This section should set forth any routine and periodic maintenance required for the control strategy. Periodic inspection and maintenance schedules should be clearly specified. For parts that need to be replaced (e.g. catalyst), provide replacement guidelines and recommended useful life.

6. Expected Emissions Reduction

Benefits of the control technology in terms of the types of emission pollutants reduced/increased and the expected percent reduction/increase in emissions by pollutant should be clearly listed in a table. Supplementary data should be attached as an appendix to support the claimed emission reductions. Emissions reduction/increase should be based on comparing emissions under baseline condition (prior to the implementation of the controls) and with controls implemented, keeping testing variables as constant as possible.

7. Continuous Emission Measurements or Monitoring

Although not always required, it is recommended that a permanently installed continuous emission monitoring system is included as part of the control strategy system. However, for control strategies that reduce emissions of NOx, the mass emission rate of NOx, both upstream and downstream of the control strategy, must be measured and recorded for at least the first and last 100 hours of durability as discussed in Section 13. For any continuous emissions measurement or monitoring system used, whether permanent, temporary or portable, a description of the monitoring equipment must be provided, including the gaseous and/or particulate components that will be measured/monitored. The measurement principle, range, frequency, accuracy and location of the equipment and sampling ports must be provided. Calibration and measuring accuracy of continuous measuring/monitoring equipment should be in accordance with IMO's NOx Technical Code 2008[5] for gaseous pollutants and ISO 8178-1[6] for particulate matter (PM).

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[5] IMO Technical Code on Control of Emission of Nitrogen Oxides from Marine Diesel Engines International Maritime Organization, Marine Environment Protection Committee MEPC 58/23/Add.1, ANNEX 14, NOx TECHNICAL CODE (2008) is available at: http://www.imo.org/ourwork/environment/pollutionprevention/airpollution/documents/23-add-1.pdf

[6] International Standards Organization, IS0 8178, Reciprocating internal combustion engines – Exhaust Emission ISO 8178-1: 1996(E); ISO 8178-2:1996(E); and ISO 8178-4: 1996(E)

8. Test Vessel(s) Description

The ocean-going vessel(s) under study should be representative of those entering and leaving California ports and those specified in Table 4 in the "Applicability-Range of Product Evaluation" section.[7] It is required to provide basic features of the vessel(s) as listed in Table 2.

Table 2. Vessel Parameters

Number of Vessel Included in Test Plan:		
Vessel Parameters (for each vessel)		
IMO Number	Maximum draught (m)	Year of Build
Vessel Name	Dead weight (ton)	Flag
Vessel Type	Gross tonnage (ton)	Length (m)
Cargo Type and Capacity	Maximum vessel speed (knots)	Beam (m)

9. Test Engine Description

Essential technical parameters should be provided for engine(s) or boiler(s) that are subject to the emissions testing (Table 3). If the engine(s) is equipped with any additional control technology or upgraded components, they should be identified in this section (e.g. fuel slide valves or low NOx mode).

Table 3. Engine and Boiler Parameters

Engine Parameters		
Manufacturer	Number of Cylinders	Engine RPM at MCR
Model and Year	Maximum Power Rating (MW, kW or hp)	Bore
Technology (e.g. turbochargers, slide valves, etc.)	Maximum Exhaust Flow Rate (m^3/min)	Stroke (cm)
Displacement (l)	Brake Specific Fuel consumption at Full Load (g/kW-hr or g/hp-hr)	Stroke/Bore Ratio
Stroke (2 or 4)	Exhaust Temp at Full Load (℃)	Exhaust stack diameter (cm)
Boiler Parameters		
Manufacturer	Steam Generating Capacity (tonnes/hr)	Design Pressure (bar)
Model	Hot-water Capacity (kW)	Fuel Consumption (kg/hr)

http://www.iso.org/iso/iso_catalogue.htm

[7] Vessel types include auto carriers or roll-on roll-off (Ro-Ro), bulk, container, cruise (passenger), general, refrigerated cargo (reefer), and tanker.

10. Applicability-Range of Product Evaluation

In many cases, a control is evaluated with the goal of application to a wider set of engines or vessels than a single unit or single type category. The applicability of the control technology for a wider range of vessel types or engines is based on developing the applicable “emission control group” and the evaluation of the control strategy must be designed to evaluate the performance for the group. The “emission control group” means a set of diesel engines, engine types, and/or vessel types that can be effectively treated by the emission control strategy. It is important to note that each ship category may have unique operational profiles (e.g. engine load variation, exhaust flow rate range, engine type, or engine size and number) and that testing one ship type or engine category may not be sufficient to evaluate and demonstrate the performance of the control strategy on other ship types or engine categories. This section should include a discussion of the type of ships that are included in the “emission control group” and how the evaluation is designed to evaluate the performance for all the ship types included in the “emission control group.”

The parameters that affect the performance of a particular diesel emission control strategy must be defined, whether for a single unit or a set. Tables 4a, 4b and 4c provide guidance on the parameters needed to develop the emission control group. The exact parameters depend on the nature of the diesel emission control strategy and may include, but are not limited to, emission rate of the engine, combustion cycle, displacement, engine speed, aspiration, horsepower rating, duty cycle, exhaust temperature profile, fuel type, and exhaust flow rates and any pre-existing add-on controls or engine upgrades. The test plan should be designed to evaluate the control effectiveness for the emission control group’s representative operational parameters.

The information described in Table 4a must be provided for both types of strategies. The information described in Table 4b and Table 4c must be provided for port-based and vessel/engine-based systems, respectively. A port-based strategy is a control system that remains at a port or general location, such as dock or barge mounted equipment, and is not permanently installed on the vessel or engine. A vessel/engine-based strategy is a control system that is installed on a vessel or engine and remains with the vessel.

Table 4a. Operational Parameters to Define Applicability of Control Strategy for All Control Strategies

All Control Strategies: Provide Parameters or Limitations that Impact Performance (if Applicable)
1. Fuel composition limitations (e.g. fuel sulfur < 0.2 %)
2. Estimated operational life of control (hrs)
3. Engine exhaust temperature requirements
4. Other parameters that affect performance
5. If engine loads vary during control strategy operation, describe how control strategy responds to variations and if there are impacts to control efficiency.
5. Required maintenance and maintenance period of control or any additional engine maintenance requirements
6. Operational limitations of control (such as exhaust temperature, flow rate, engine configuration)
7. Total estimated average operation of control per year (hrs)
8. Consumables (lbs/yr or kg/yr)
9. Waste or byproducts (lbs/yr or kg/yr)

Table 4b. Operational Parameters to Define Applicability of Control Strategy for Port-based Control Emission Strategies

Port-based Control Emission Strategy	
Engine Control Strategy Name:	
Vessel Information	**Engine Type Information**
Vessel Type(s) that will be treated with control strategy (i.e. cargo, tanker, bulk, etc.)	Engine type(s) (i.e. main, auxiliary, boiler) and combustion cycle
List number of vessels that will be treated with emission control strategy per year	Maximum engine MCR (kW or hp) for each engine type
Fuel type and maximum sulfur content in ppm for each vessel and/or engine type	Typical operating range for each engine type (kW or hp) (Minimum load to Maximum Load)
Description of duty cycle for each engine type	Minimum to Maximum exhaust flow rate that can be treated (m^3/min)
Description of type of connection system between control strategy and vessel and any resulting losses in capture efficiency	Typical time needed to begin controlling emissions (e.g. attaching controls to vessel) and time period needed to disconnect strategy
Average Vessel Hoteling Time	Describe any variation in engine load or exhaust flow rate during operation

Table 4c. Operational Parameters to Define Applicability of Control Strategy for Vessel or Engine Based Control Strategies

Vessel/Engine-based Control Strategy	
Engine Control Strategy Name	
Vessel Information	**Engine Type Information**
Vessel Type(s) (i.e. cargo, tanker, bulk, etc.)	How many engines will be treated with a single control device?
Total estimated operation of control (hrs) Hoteling:_____ Per visit _____per year Transiting:_____ Per visit _____per year Maneuvering:____ Per visit _____per year	Engine type(s) (i.e. main, auxiliary, boiler) and combustion cycle
	Maximum engine MCR (kW or hp) and exhaust flow rate (m^3/min) for each engine type
Average speed (vessel speed in knots) and engine load (kW or hp) during maneuvering Average Maneuvering distance (nautical miles)	Typical operating range for each engine type (kW or hp) (Minimum load to Maximum Load)
Description of duty cycle for each engine type	Describe any variation in engine load or exhaust flow rate during vessel operation (e.g. variations in auxiliary engine load as refrigerated containers are loaded or unloaded)

11. Test Fuels

Fuel characteristics influence engine exhaust emissions. Therefore, the characteristics of the fuel used for the test should be determined, recorded, and presented with the results of the test. Prior to the testing, the type of fuel, estimate of sulfur content, and density of the fuel oil should be provided. During emission testing, fuel sample(s) should be drawn from the final filter drain of the engine, upstream of injector rail for analysis. Duplicate fuel samples should be drawn for each type of fuel (and specified sulfur content) used in the control strategy evaluation. At a minimum, it is recommended that the fuel samples be analyzed for fuel sulfur content and density. Analysis of fuel samples should be in accordance with Appendix B. Although not always necessary, if analysis of cylinder lubricant is specified, it should be in accordance with Appendix B. If additional analyses of the fuel or cylinder lubricant are required that are not listed in Appendix B, describe the type of analyses and test methods.

It is important to remember that in California, ocean-going vessels are subject to the regulation “Fuel Sulfur and Other Operational Requirements for Ocean-going Vessels within California Waters and 24 Nautical Miles of the California Baseline” (Ocean-going Vessel Clean Fuel Regulation or regulation). Under this regulation, ocean-going vessels may only use marine distillate fuels with specified fuel sulfur levels while

operating within approximately 24 nautical miles (nm) of the California coastline. Technology providers that wish to test a control technology using heavy oil fuels (HFO) while the vessel is operating within this 24 nm zone must obtain a Temporary Experimental or Research Exemption from the regulation. More information can be found at http://www.arb.ca.gov/ports/marinevess/documents/fuelogv13.pdf. In addition to California's Ocean-going Vessel Clean Fuel Regulation, ocean-going vessels are also subject to the requirements of the North American Emission Control Area (ECA) beginning August 1, 2012.[8]

12. Emission Testing

12.1 Components to be Measured

Gaseous and particulate related components to be measured should be listed and analyzed according to Section 12.2.1 and 12.2.2.

12.2 Sampling Methods

The sampling system should conform to the requirement of IMO's NO_x Technical Code and ISO 8178-1 and 2. Alternative methods can be considered if specified by regulatory requirements (e.g. At-Berth Equivalency[9]). If available, documentation of measurement equivalence shall be provided for alternative methods.

12.2.1 Gaseous Components

The gases to be measured shall be analyzed using the detectors/methods provided in the Table 5. Gaseous measurements shall be taken concurrently with particulate sampling. For these tests, the last three minutes of gaseous data acquired during each filter sampling period shall be averaged for determination of gaseous emission factors

[8] See 40 CFR part 1043 for the full text of regulations implementing MARPOL Annex VI and the North American ECA. See § 1043.60 Operating requirements for engines and vessels subject to this part for specific fuel requirements. Regulatory text is available at http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&sid=7f8c7c6e734f5895d3c05ba80d236210&tpl=/ecfrbrowse/Title40/40cfr1043_main_02.tpl

[9] ARB's At-Berth Equivalency specifies that NOx and CO_2 shall be measured using California Air Resources Board (CARB) Test Method 100, dated July 1997.

Table 5. Exhaust Gas Analyzer Types as Listed in Approved Method

Component	Detector/Method
Nitrogen Oxides (NO/NO_2)[10]	Chemiluminescent Detector (CLD) or Heated CLD
Carbon Dioxide (CO_2)	Non Dispersive Infrared Adsoprtion (NDIR)
Carbon Monoxide (CO)	Non Dispersive Infrared Adsoprtion (NDIR)
Hydrocarbons (HC)[11]	Heated Flame Ionization Detector (HFID) or Non Methane Cutter.
Oxygen (O2)	Paramagnetic Detector (PMD), Zirconium Oxide (ZRDO), or Electrochemical Sensor (ECS)
Sulfur Dioxide (SO_2)[12]	To be calculated from fuel sulfur content, pulsed fluorescence or Non-dispersive Infra-red (NDIR) or Non-dispersive Ultraviolet
Ammonia (NH_3)	Paramagnetic Detector (PMD), Zirconium Oxide (ZRDO), or Electrochemical Sensor (ECS)
Formaldehyde (HCHO)	Paramagnetic Detector (PMD), Zirconium Oxide (ZRDO), or Electrochemical Sensor (ECS)

12.2.2 Particulate Determination

The dilution system, sampling filters, weighing chamber and analytical balance specifications should conform to the requirements of ISO 8178-1 for appropriate determination of PM. A minimum of three (3) filter samples shall be acquired for each engine mode tested.

12.3 Description of Measurement Equipment and Sampling System

This section should describe the complete sampling apparatus, including sample location, sample extraction methods, sample conditioning, emissions analyzers, and support equipment. Describe the materials and dimensions of sample probes, transfer lines, and sample media. Provide details of operation, including warm-up, calibrations, sampling procedures, and quality control checks. A schematic of emission

[10] While Non-dispersive Ultraviolet (NDUV) analysis is generally accepted for NOx and SOx measurements, recent work conducted for the EPA by the University of California, Riverside and others indicates that there may be a positive bias in NOx measurements when significant concentrations of SOx are present. Therefore, at this time, we do not recommend NDUV methods for NOx or SOx emissions measurements for marine testing.

[11] It is recommended to sample for methane, in addition to total hydrocarbons, if methane sampling is available.

[12] Also see IMO 2009 Guidelines for Exhaust Gas Cleaning Systems
International Maritime Organization, Marine Environment Protection Committee ANNEX 9, RESOLUTION MEPC.184(59), Adopted on 17 July 2009 is available at:
http://www.imo.org/blast/blastDataHelper.asp?data_id=26469&filename=184%2859%29.pdf
MEPC 59/24/Add.1

measurement instrumentation set up is recommended.

12.4 Test Cycles

Standardized cycles shall be used to provide for direct comparisons across different data sets. Specifically, ISO 8178-4 E3 cycle shall be employed for main engines and ISO 8178-4 D2 cycle for auxiliary engines on ocean going vessels (Table 6). The test cycle (E3 or D2) shall be performed in ascending order of mode number of the cycle in question. Additional engine loads that are not specified in above cycles may be included based on the requirement of the study or when operating conditions are different than the included in the specified E3 and D2 cycles. Additional load points should be fully described. For example, during vessel speed reduction (VSR) mode, main engine shall be tested at loads below 25%. If equipment or testing constraints require modifications to the ISO test cycles, a full description of the basis for developing the modified cycle and a listing of the modified cycle, including speeds, powers, and weighting factors should be provided. Any modified cycle will need to span the full range (minimum to maximum) of control strategy design loads and exhaust flow rates.

For boiler testing, an emissions test cycle should be developed that is representative of typical operation. For example, large boilers on oil tankers typically operate at or near 100% load when discharging oil. Thus, emissions should be determined at this load point. Boilers on container ships, however, may operate at several different loads depending on the heat demand of the vessel. In this case, the test cycle should include the most common load points for the application.

The recommended test cycle for shore-based units or vessel-based units that treat multiple engines concurrently is provided in Table 7.

Table 6. Test Cycles for Main and Auxiliary Engines

Main Engine (ISO 8178-4 E3 Cycle)					
Mode Number	1	2	3	4	
Speed (%)	100†	91	80	63	
Power (%)	100†	75	50	25	
Weighting Factor	0.2	0.5	0.15	0.15	
Auxiliary Engine (ISO 8178-4 D2 Cycle)					
Mode Number	1	2	3	4	5
Speed (%)	Rated				
Power (%)	100†	75	50	25	10
Weighting Factor	0.05	0.25	0.3	0.3	0.1

†Operational considerations may prevent acquiring samples at the 100% point. The highest load point achievable will be determined at the time of testing. The load point depends on several factors (sea current, wind speed/direction, cargo load etc.)

Table 7. Test Cycles for Control Strategies that Treat Multiple Engines* or Engines/Boilers Concurrently

Hoteling-Combined-combined emissions from auxiliary engine(s) and auxiliary boiler(s)**	
Load 1***	Low Load
Load 2	Medium Load
Load 3	High Load
*For example, port-based systems or systems that treat multiple engines concurrently **Hoteling load is determined by combining the auxiliary engine load(s) and the auxiliary boiler load(s) that are treated concurrently. ***It may be necessary to test multiple vessels to evaluate required number of hoteling loads if all loads are not achievable with a single vessel	

12.5 Engine Operating Conditions

During each emission test, engine performance parameters should be recorded to ensure proper engine and steady state operating conditions for tests specified in Section 12.4. Similarly, parameters for the control strategy should also be recorded. The minimum recommended parameters to be recorded for engine/boiler and control strategy operating conditions are shown in Table 8.

Table 8. Engine and Boiler Operating Conditions

Engine Operating Parameters	
Engine Load (kW or hp)	Intake Manifold Temperature (℃)
Engine Speed (rpm)	Boost Pressure (bar)
Fuel Consumption rate (kg/hr)	Barometric Pressure (bar)
Ambient Temperature (℃)	Relative Humidity (%)
Boiler Operating Parameters	
Steam Pressure (bar)	Steam Temperature (℃)
Engine Room Temperature (℃)	Outside Temperature (° C)
Engine Room Pressure (bar)	Fuel Consumption rate (kg/hr)
Control Operating Parameters	
Back Pressure (bar)	pH Measurement (if applicable)
Reductant type and injection rate	Exhaust Temperature (℃)
Other consumable type and rate	

12.6 Exhaust Gas Flow

The exhaust gas flow shall be determined by one of the following methods:

- Direct Measurement Method (Pitot tube or equivalent metering system)

- Carbon Balance Method
- Air and Fuel Measurement Method
- Air Pump Method (engine displacement and rpm)

All of the above methods are described in Appendix C.

12.7 Supplemental Measurements

Additional measurements may be needed depending on the type of control strategy and regulatory requirements. Any additional measurements should be described, along with applicable test methods. For example, under the At-Berth Regulation equivalency, selective catalytic reduction systems require ammonia slip emissions testing at the same time as NOx testing.

12.8 Quality Assurance/Quality Control (QA/QC)

12.8.1 Exhaust Gas Analyzers

Analyzers should be calibrated before and after each mode, if possible. Otherwise, analyzers must be calibrated at the beginning and the end of emission testing. The analyzer curve must be established by at least three calibration points (excluding zero) spaced uniformly as possible.[13] Different calibration points can be achieved by using different span gases. The calibration results for each exhaust gas analyzer should be included in the report.

12.8.2 Emission Measurements

For the ISO cycles, the engine should be operated at rated speed and the highest power possible to warm the engine and stabilize emissions for about 30 minutes. For the E3 cycle, determine a plot or map of the peak power at each engine RPM, starting with rated speed. If the 100% load point at rated speed is unattainable, we recommend 85% load as an alternative, since it is typically attainable. If neither of these is attainable, then select the highest engine load possible as Mode 1.

Emissions should be measured while the engine operates according to the requirements of ISO 8178-4 test cycles. The highest power mode for the test cycle must run first and then each mode should run in sequence. The minimum time for samples is 5 minutes and if necessary, the time should be extended to collect sufficient particulate sample mass or filters. The gaseous exhaust emission concentration values

[13] Additionally, ISO 8178-1 and IMO's NOx Technical Code require 5 calibration points (excluding zero) at least every three months or whenever a system repair or change is made that could influence calibration.

should be measured and recorded for the last 3 minutes of each sample period. Emission factors should be reported in g/hp-h or g/kW-hr and concentration should be reported in ppm.

13. In-Use Performance and Durability

In-use performance and durability (durability) is the ability of the emission control strategy to maintain a level of emissions reduction performance and maintain its operational and physical integrity over some period of time or travel distance. The minimum durability testing periods are not necessarily meant to represent the entire useful life of the diesel emission control strategy in actual service.

Durability can be performed during actual in-use operation or using an approved simulated duty cycle. During the durability period, operating parameters (including operating engine loads) should be within targeted operating range. For reporting, continuous emissions monitoring data can be accepted and backpressure and exhaust temperature should be recorded during the entire period. For vessel-based equipment, the recommended length of the durability period is about 5 times an average operational cycle with minimum total of 200 hours. An operational cycle may be, for example, the portion of a trip that the control operates while complying with regional emissions reduction regulations. For port or barge-based systems, the recommended length of the durability period is about five times the average hoteling period (with a minimum of 200 hours) or up to 1000 hours. Where possible, durability requirements can be aligned with other regulatory requirements, such as At-Berth Equivalency requirements or EPA verification requirements.[14]

For each parameter recorded (i.e. exhaust temperature, NOx, CO2) during the durability period, charts should be provided for each parameter as a function of time and the minimum and maximum parameter values should be reported in a table format. For strategies that reduce emissions of NOx, the mass emission rates of NOx both upstream and downstream of the control strategy must be measured and recorded for at least the first and last 100 hours of the durability.

13.1 Additional Parameters for At-Berth Equivalency

For At-berth Equivalency evaluations, additional parameters should be recorded during the durability period. Additional parameters include, for each vessel visit, the total hoteling time, time to connect the control system, time to disconnect or shut down the control system, and power load of the engine during the operational periods. If control efficiency can be determined during the durability period for the gaseous or PM exhaust components, it should be gathered and reported.

[14] United States Environmental Protection Agency's Clean Diesel Verification Process http://epa.gov/cleandiesel/verification/index.htm

14. Periodic Testing

Periodic testing may be required under regulatory requirements, such as the At-Berth Regulation or district permitting. If periodic testing is required, the frequency, type of testing, and associated test methods should be included. For example, under the At-Berth equivalency, the control system must be tested annually; catalyst based systems installed on vessels must be tested after every 1000 hours of operation.

15. Test Contractor Selection and Qualifications

Provide information regarding the qualifications of the emission testing contractor. This should include any formal acknowledgements from regulatory agencies (e.g. “Approved Contractor” or equipment “Certification”), any prior experience with marine emissions testing and Curriculum Vitae for key technical personnel.

16. Results

16.1 Test Report

The recommended test report consists of 11 components that contain all the information pertinent to the emissions testing.

Table 9. Essential Report Components

Report Components
1. Executive Summary
2. Introduction (Background and Project Objective(s))
3. Control Strategy (Description, Limitations and Maintenance)
4. Test Plan
5. Data Analysis (Including Calculation of Exhaust Flow Rate and Emissions Data)
6. Results (Gaseous Emissions, Particulate Emissions, Emissions Reductions, Connection Capture Efficiency and Comparison of Data)
7. Durability Testing Results (including CEM data, engine backpressure and temperature). Provide results as they become available.
8. Periodic Testing Results (provide results of periodic testing as it becomes available)
9. Discussion
10. Conclusion/Summary
11. Appendices (Calibration Data, Raw Data and Calculations)

16.2 Data Evaluation

For the evaluation of the gaseous emissions, the readings of the last 3 minutes (at least 10 data points) of each filter sampling period are averaged. If the data is not automatically corrected for the calibration values, the exhaust gas concentrations (% or ppm) are determined from the average readings and the corresponding calibration data.

In order to verify that the emissions were really stable during the measuring period, it is recommended to calculate coefficient of variation (COV) for the last 3 minutes of each measuring period which should be reported together with the average emission data. The maximum acceptable value of COV is 5%.

For the evaluation of the particulates, the total masses or volume through the filters shall be recorded for each mode. The filters shall be returned to the weighing chamber and conditioned for at least 24 hour and then weighed per ISO 8178-1. The gross mass of the filters shall be recorded and the tare mass subtracted. If more than one measurement is made for each mode, then the average value shall be determined.

16.3 Calculations

Dry/wet correction for measured gases, humidity and temperature correction for NO_x and calculation/measurement of exhaust gas flow rate (see Section 12.6) should conformed to ISO 8178-2 or IMO's NO_x technical code for calculating emission factors of all components.

Emission levels and control efficiencies should be reported by individual mode and as a weighted emission factor as specified in the applicable test method. If using a modified or combined test cycle (as listed in Table 2), the individual mode and average of the individual modal emission factors should be reported. Determination of the At-Berth Equivalency Control Factor is described in Appendix E.

16.4 Supplemental Analysis

Any additional analysis such as measurement of ammonia slip should be presented in the results section of the report.

16.5 Comparison to Manufacturer's or Certification Data

If available, results from the evaluation testing shall be compared to independent test data. Emission values from this evaluation should be compared with previously published values, such as manufacturer or engine certification data.

II. Useful links and Contact Information

1. ARB Contacts

Bonnie Soriano, Staff Air Pollution Specialist
Technical Analysis Section
Stationary Source Division
(916) 327-6888
bsoriano@arb.ca.gov

2. Useful links

ARB's At-Berth Ocean-Going Vessel Regulation main page is available at:
http://www.arb.ca.gov/ports/shorepower/shorepower.htm

ARB's At-Berth Regulation is available at:
http://www.arb.ca.gov/regact/2007/shorepwr07/93118-t17.pdf

ARB's Diesel Emission Control Strategies Verification is available at:
http://www.arb.ca.gov/diesel/verdev/verdev.htm

ARB's Ocean-Going Vessels Emission Measurement, Reports and Publications are available at:
http://www.arb.ca.gov/ports/marinevess/ogv/ogvreports.htm

IMO 2009 Guidelines for Exhaust Gas Cleaning Systems
International Maritime Organization, Marine Environment Protection Committee ANNEX 9, RESOLUTION MEPC.184(59), Adopted on 17 July 2009 is available at:
http://www.imo.org/blast/blastDataHelper.asp?data_id=26469&filename=184%2859%29.pdf

IMO Technical Code on Control of Emission of Nitrogen Oxides from Marine Diesel Engines
International Maritime Organization, Marine Environment Protection Committee MEPC 58/23/Add.1, ANNEX 14, NOx TECHNICAL CODE (2008) is available at:
http://www.imo.org/ourwork/environment/pollutionprevention/airpollution/documents/23-add-1.pdf

International Standards Organization, IS0 8178-1, Reciprocating internal combustion engines – Exhaust emission
http://www.iso.org/iso/iso_catalogue.htm

EPA's Clean Diesel Verification Process is available at:
http://epa.gov/cleandiesel/verification/index.htm

MARPOL Annex VI and the North American ECA (40 CFR part 1043 for the full text of regulations implementing MARPOL Annex VI and the North American ECA. For specific fuel requirements see § 1043.60 Operating requirements for engines and vessels subject to this part). Regulatory text is available at
http://ecfr.gpoaccess.gov/cgi/t/text/text-idx?c=ecfr&sid=7f8c7c6e734f5895d3c05ba80d236210&tpl=/ecfrbrowse/Title40/40cfr1043_main_02.tpl

Appendix A

Confidential Information Submittal Form

If you wish to designate any information contained in your emission test plan as **CONFIDENTIAL INFORMATION**, please provide the information requested below and return it with your test plan.

In accordance with Title 17, California Code of Regulations (CCR), Sections 91000 to 91022, and the California Public Records Act (Government Code Section 6250 et seq.), the information that a company provides to the Air Resources Board (ARB) may be released (1) to the public upon request, except trade secrets which are not emissions data or other information which is exempt from disclosure or the disclosure of which is prohibited by law, and 2) to the Federal Environmental Protection Agency, which protects trade secrets as provided in Section 114(c) of the Clean Air Act and amendments thereto (42 USC 7401 et seq.) and in federal regulation, and 3) to other public agencies provided that those agencies preserve the protections afforded information which is identified as a trade secret, or otherwise exempt from disclosure by law (Section 39660(e)).

Trade Secrets as defined in Government Code 6254.7 are not public records and therefore will not be released to the public. However, the California Public Records Act provides that air pollution emission data are always public records, even if the data comes within the definition of trade secrets. On the other hand, the information used to calculate information is trade secret.

If any company believes that any of the information it may provide is a trade secret or otherwise exempt from disclosure under any provision of law, **it must identify the confidential information as such at the time of submission to the ARB and must provide the name, address, and telephone number of the individual to be consulted**, if the ARB receives a request for disclosure or seeks to disclose the data claimed to be confidential. The ARB may ask the company to provide documentation of its claim of trade secret or exemption at a later date. Data identified as confidential will not be disclosed unless the ARB determines, in accordance with the above referenced regulations, that the data do not qualify for a legal exemption from disclosure. The regulations establish substantial safeguards before any such disclosure.

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In accordance with the provisions of Title 17, California Code of Regulations, Sections 91000 to 91022, and the California Public Records Act (Government Code Sections 6250 et seq.)

Company Name: _____ declares that all the information submitted in response to the California Air Resources Board's information request on the Survey is confidential "trade secret" information, and request that it be protected as such from public disclosure. All inquiries pertaining to the confidentiality of this information should be directed to the following person:

Date: _____ Mailing Address:

_____ (Signature) _____

_____ (Printed Name) _____

(Title)

(Telephone Number)

Appendix B

Test Fuel Oil Analyses

Fuel and lube oil analysis should be in accordance with the following table.

Fuel Oil Analysis		Lube Oil Analysis	
Parameter	**Test Method**	**Parameter**	**Test Method**
Sulfur Content (% mass)	ASTM D 4294	Sulfur Content (% mass)	ASTM D 129
Ash Content (% mass)	ASTM D 482	Density at 15°C (kg/m^3)	ASTM D 4052
Density at 15°C (kg/m^3)	ASTM D 4052	Density at 20°C (kg/m^3)	ASTM D 4052
Density at 20°C (kg/m^3)	ASTM D 4052	Viscosity at 40°C	ASTM D 445
Heat of Combustion, Nett.	ASTM D 4868	Viscosity at 100°C	ASTM D 445
Viscosity at 40°C	ASTM D 445	Water Content (ppmm)	ASTM D 95
Viscosity at 100°C	ASTM D 445	Base Number	ASTM D 2896
Cetane Index	ASTM D 4737	Acid Number, total (TAN)	ASTM D 664
Conradson Carbon	ASTM D 189	Ash Content (% mass)	ASTM D 482
Flash Point (°C)	ASTM D 93	Sulfated Ash (% mass)	ASTM D 874
Water Content (ppmm)	ASTM D 1744	Pour Point (°C)	ASTM D 5949
C-content (% mass)	Elementary Analysis	Vn-content (% mass)	AAS/ICP
H-content (% mass)	Elementary Analysis	Ca-content (% mass)	AAS/ICP
N-content (% mass)	Elementary Analysis	Zn-content (% mass)	AAS/ICP
O-content (% mass)	Elementary Analysis	P-content (% mass)	AAS/ICP

Appendix C
Calculation of the Exhaust Flow Rate

The calculated emission factor is strongly dependent on the exhaust flow rate. The exhaust gas flow shall be determined by one of the following methods:

1. Direct Measurement Method
2. Carbon Balance Method
3. Air and Fuel Measurement Method
4. Air Pump method

Method 1-Direct Measurement Method: Actual exhaust velocity can be directly measured by either a Pitot tube/thermocouple traverse or other equivalent metering system. The exhaust flow rate can be determined from the exhaust velocity, cross-sectional area of the stack, and moisture and pressure measurements. The direct measurement method is a difficult technique, and precautions must be taken to minimize measurement errors. Details of the direct measurement method are provided in ISO 5167-1.

Method 2(a)-Carbon Balance: Carbon Balance is used to calculate the exhaust mass flow based on the measurement of fuel consumption and the exhaust gas concentrations with regard to the fuel characteristics (carbon balance method). The method given is only valid for fuels without oxygen and nitrogen content, based on procedures used for EPA and ECE calculations. Detailed calculation steps of the Carbon Balance method are provided in annex A of ISO 8178-1.

Method 2(b)-Universal Carbon/Oxygen Balance: The Universal Carbon/Oxygen Balance is used for the calculation of the exhaust mass flow. This method can be used when the fuel consumption is measurable and the fuel composition and the concentration of the exhaust components are known. It is applicable for fuels containing H, C, S, 0, N in known proportions. Detailed calculation steps of Carbon/Oxygen Balance method is provided in annex A of ISO 8178-1.

Method 3-Air and Fuel Measurement Method: This involves measurement of the air flow and the fuel flow. The calculation of the exhaust gas flow is provided in Section 7.2 of ISO 8178-1.

Method 4-Air Pump Method: Exhaust flow rate is calculated by assuming engine is an air pump, meaning that the exhaust flow is equal to the intake air flow. The flow rate is determined from the overall engine displacement, and rpm; corrected for temperature and pressure of the inlet air. In the case of turbocharged engines, this is the boost

pressure and intake manifold temperature. This method should not be used for diesel engines equipped with additional air input for cylinder exhaust discharge (purge air), unless the additional flow rate can be determined.

Appendix D
Determination of Capture Efficiency for Hood or Bonnet Systems

For external emission control systems that temporarily capture and treat exhaust pollutants, the capture efficiency of the control device must be determined. This is accomplished by comparing the mass emission rate of CO_2 from the engine exhaust with the mass emission rate of CO_2 in the control device ducting (at a location downstream of the capture system).

With the potential addition of an unknown amount of dilution air into the exhaust capture equipment, only Method 1 – Direct Measurement Method (Appendix C) is acceptable for determination of exhaust flow rate in the external control device.

The CO_2 mass emission rate shall be determined from the measured CO_2 concentration and flow rate determined as above. The capture efficiency is then determined as follows:

$$Capture_{eff} = 100\% \times M_{CO2C}/M_{CO2E}$$

Where
M_{CO2C} = mass emission rate of CO_2 in the control device (g/hr or lb/hr)
M_{CO2E} = mass emission rate of CO_2 in the engine or boiler exhaust (g/hr or lb/hr)

Appendix E
Determination of At-Berth Equivalency Control Factors

For At-Berth Equivalency, the control factor is based on the control effectiveness of the control strategy ($Control_{eff}$), the capture efficiency of the connection ($Capture_{eff}$), and the fraction of the hoteling period that the control system is connected and operational. Because port based systems are designed to service many vessels with potentially unique stack configurations and hoteling times, the information used to estimate the time needed to connect and disconnect, along with average hoteling times should be discussed in Section 3 (Description of Control Strategy) and Section 10 (Applicability-Range of Product Evaluation) and gathered and reported from the durability demonstration.

The At Berth Equivalency is determined by as follows.
At Berth Equivalency Control Factor =
$Strategy_{eff} * (T_c / T_B)$
T_B Is the total berthing time for a vessel (or average of a vessel group). Total berthing time is further described in the At-Berth regulation
T_c is the average time period that a vessel is hoteling with control strategy connected and operating
$Strategy_{eff}$ is the control efficiency of the strategy is calculated from the weighted emission factors as determined by emission testing

If the capture efficiency of the connection is measured separately from the control effectiveness of the control equipment, the $Strategy_{eff}$ is determined as the efficiency of the connection ($Capture_{eff}$) multiplied by the control efficiency of the control equipment ($Control_{eff}$)

For example, for a port-based system that requires, on average, 2 hours to connect, ½ hour to disconnect with an average hoteling time of 30.5 hours, a connection capture efficiency of 87% and a control device efficiency of 95%, the At-Berth Equivalency Control Factor is
(0.95 * 0.87) * (28/30.5)= 0.76 or 76%

Capture efficiency: If the control strategy design includes a connection system that may result in collection losses (e.g. a hood or “bonnet” type system on a port-based unit), the capture efficiency must be demonstrated using an approved procedure. We recommend a carbon balance as described in Appendix D.