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2007 MARINE EMISSIONS INVENTORY AND FORECAST STUDY

Prepared for
Transportation Development Centre
of
Transport Canada

by
Weir Marine Engineering
(a division of Weir Canada, Inc.)

May 2008

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2007 MARINE EMISSIONS INVENTORY AND FORECAST STUDY

by
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Since some of the accepted measures in the industry are imperial, metric measures are not always used in this report.

Un sommaire français se trouve avant la table des matières.

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16. Abstract

This report details the work done to update a 2006 marine emissions inventory and forecast for the Eastern Canada / Great Lakes region (EC/GL) for commercial marine vessels. The current work included vessel surveys and site visits, updating the marine economic growth forecast for the EG/GL, reviewing vessel emission factors, updating the Marine Emissions Inventory Tool, taking actual emission measurements from three vessels, and projecting emissions measurements to 2010 and 2020, with and without the application of a Sulphur Emission Control Area (SECA) and associated fuel sulphur restrictions in the EC/GL.

The updated vessel profiles and emission factors resulted in a reduction in calculated emissions for the base year (2002) for oxides of nitrogen (NOx), particulate matter (PM, $PM_{2.5}$, and PM_{10}) and hydrocarbons, and an increase in emissions for SO_2, CO and CO_2, compared to the previous study. The study found that designating the EC/GL as a SECA would have a significant impact on the emissions of SO_2 and PM, with reductions of about 29% and 21%, respectively, in 2010 compared to 2002. The emissions reductions would be offset by the projected growth in marine activity, but even in 2020, the reductions in SO_2 and PM would be approximately 18% and 9%, respectively, compared to 2002 levels.

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16. Résumé

Ce rapport présente le travail de mise à jour d'un inventaire et de prévisions touchant les émissions des navires commerciaux de la région de l'est du Canada et des Grands Lacs (EC/GL), inventaire effectué en 2006. Les présents travaux ont comporté le recensement des navires, des visites à bord des navires, la mise à jour des prévisions de croissance de l'activité maritime dans l'EC/GL, la revue des facteurs d'émission applicables aux navires, la mise à jour de l'outil d'inventaire des émissions des navires, la mesure des émissions réelles de trois navires et l'extrapolation de ces mesures vers 2010 et 2020, selon deux hypothèses, soit la désignation de l'EC/GL « zone de contrôle des émissions de soufre » (SECA, S*ulphur Emission Control Area*) et la limitation de la teneur en soufre du carburant qui s'ensuit, ou le statu quo.

La mise à jour des profils de navires et des facteurs d'émission a entraîné une réduction des émissions d'oxydes d'azote (NO_x), de particules (PM, $PM_{2,5}$, PM_{10}) et d'hydrocarbures (HC), et une augmentation des émissions de SO_2, de CO et de CO_2 calculées pour l'année de référence, par rapport aux données issues de l'étude de 2006. L'étude a révélé que de désigner l'EC/GL zone SECA entraînerait des réductions importantes des émissions de SO_2 et de PM, soit d'environ 29 % et 21 %, respectivement, en 2010, par rapport à 2002. Certes, ces réductions d'émissions seraient atténuées par la croissance prévue du transport maritime, mais même en 2020, les réductions de SO_2 et de particules atteindraient environ 18 % et 9 %, respectivement, par rapport aux niveaux de 2002.

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This project could not have been completed without the cooperation of stakeholders in the marine industry including, industry associations, shipping companies and ships' crews. The Shipping Federation of Canada helped to arrange the necessary access to information for international ships, and the support of the Canadian Shipowners Association was crucial to achieve 100% participation of the Canadian Great Lakes domestic fleet. Weir Marine Engineering wishes to thank all those who completed the ship surveys and responded to our many questions over the course of the project.

EXECUTIVE SUMMARY

The objective of this project was to update the marine emissions inventory and forecasts for the Eastern Canada and Great Lakes (EC/GL) region. This was to be an update to an earlier EC/GL marine emissions inventory completed in 2006 that used the best available information at the time, including marine activity data for the EC/GL from the Canadian Coast Guard (CCG) INNAV database, emission factors from previous studies, and generic marine vessel profiles that had been developed primarily on the West Coast of North America. The 2006 study recognized that the emissions inventory and forecast for the EC/GL region could be improved through surveys and measurements that would provide vessel profiles and emission factors that are more representative of the vessels and marine activity in the EC/GL. Subsequently, this 2007 update included the following work:

- Vessel mail-in surveys and site visits were completed to develop vessel profiles applicable to the EC/GL;
- The economic growth forecast for vessel activity in the EC/GL was updated;
- Emission factors were reviewed and updated as appropriate based on the latest information relevant to the vessels in the EC/GL;
- The database application for calculating the emissions inventory and forecast was updated; and
- The updated marine emissions inventory for the 2002 base year was calculated and forecasts were projected for 2010 and 2020, with and without the application of a Sulphur Emission Control Area (SECA) and associated fuel sulphur restrictions in the EC/GL.

A total of 167 vessel surveys, including mail-in questionnaires and site visits, were completed. This included 100% of the Canadian Great Lakes domestic fleet, which was an important accomplishment to address Canadian marine industry concerns about the validity of the emissions inventory.

The total emissions for all vessels and all operating modes (hotelling, manoeuvring and underway) for the base year (2002) and forecasted for 2010 and 2020 without the designation of a SECA in the EC/GL region are shown in Table 1. The base year emissions calculated in the 2006 study are also shown for comparison. The updated vessel profiles and emission factors resulted in a reduction in calculated emissions for the base year for oxides of nitrogen (NOx), particulate matter (PM, $PM_{2.5}$, PM_{10}) and hydrocarbons (HC). However, the calculated emissions for the base year for SO_2, CO and CO_2 increased compared to the 2006 study.

Table 1: Updated Emissions Inventory and Forecast (Emissions Reported in Tonnes)

Emission	2002 Base Year (2006 Study)	2002 Base Year (2007 Update)	2010 Forecast	2010 Change Relative to Base Year	2020 Forecast	2020 Change Relative to Base Year
SO_2	47,459	54,959	64,349	17.09%	74,344	35.27%
NOx	93,699	73,974	83,130	12.38%	91,253	23.36%
TPM	10,348	7,129	8,344	17.04%	9,640	35.22%
PM_{10}	8,157	6,844	8,010	17.04%	9,255	35.23%
$PM_{2.5}$	6,854	6,296	7,369	17.04%	8,514	35.23%
CO	3,092	6,165	7,154	16.04%	8,212	33.20%
HC	2,843	2,520	2,933	16.39%	3,376	33.97%
CO_2	3,298,991	3,620,092	4,212,740	16.37%	4,841,468	33.74%

Table 2 presents the emissions forecasts based on the designation of the EC/GL region as a SECA. The designation of the EC/GL as a SECA would have a significant impact on the emissions of SO_2 and PM, with reductions of about 29% and 21%, respectively, in 2010 compared to the base year. The emission reductions would be offset by the projected growth in marine activity, but even in 2020 the reductions in SO_2 and PM would be approximately 18% and 9%, respectively, compared to 2002 levels.

Table 2: Updated Emissions Inventory and SECA Forecast (Emissions Reported in Tonnes)

Emission	2002 Base Year (2006 Study)	2002 Base Year (2007 Update)	2010 SECA Forecast	2010 Change Relative to Base Year	2020 SECA Forecast	2020 Change Relative to Base Year
SO_2	47,459	54,959	39,080	-28.89%	44,939	-18.23%
NOx	93,699	73,974	83,130	12.38%	91,253	23.36%
TPM	10,348	7,1297	5,658	-20.63%	6,511	-8.67%
PM_{10}	8,157	6,844	5,431	-20.65%	6,251	-8.67%
$PM_{2.5}$	6,854	6,296	4,997	-20.63%	5,750	-8.67%
CO	3,092	6,165	7,154	16.05%	8,212	33.21%
HC	2,843	2,520	2,933	16.40%	3,376	34.00%
CO_2	3,298,991	3,620,092	4,212,740	16.37%	4,841,468	33.74%

SOMMAIRE

Ce projet avait pour objectif de mettre à jour l’inventaire et les prévisions des émissions des navires dans la région de l’est du Canada et des Grands Lacs (EC/GL). Cet inventaire et ces prévisions découlaient d’une étude réalisée en 2006 dans l’EC/GL. Celle-ci se fondait sur la meilleure information disponible à l’époque, soit les données de la base de données INNAV de la Garde côtière canadienne (GCC) concernant le transport maritime dans l’EC/GL, les facteurs d’émission établis au cours d’études antérieures, et les profils génériques des navires, principalement élaborés sur la Côte Ouest de l’Amérique du Nord. L’étude de 2006 reconnaissait qu’il était possible d’améliorer l’inventaire et les prévisions, avec de nouveaux recensements et de nouvelles mesures qui mèneraient à des profils de navires et des facteurs d’émission davantage représentatifs des navires et de l’activité maritime de l’EC/GL. La présente mise à jour, réalisée en 2007, a comporté les tâches suivantes :

- envoi de questionnaires par la poste et visites à bord pour élaborer les profils des navires évoluant dans l’EC/GL;
- mise à jour des prévisions de croissance économique en tant qu’indicateur de l’activité des navires dans l’EC/GL;
- revue et mise à jour, au besoin, des facteurs d’émission, à partir des données les plus récentes concernant les navires évoluant dans l’EC/GL;
- mise à jour de la base de données servant au calcul de l’inventaire et des prévisions des émissions;
- calcul du nouvel inventaire des émissions des navires pour l’année de référence 2002 et établissement de prévisions pour 2010 et 2020, avec et sans désignation SECA (zone de contrôle des émission de soufre) de la région EC/GL, et avec et sans la limitation de la teneur en soufre du carburant qui s’ensuit.

Au total, 167 navires ont été recensés, au moyen d’un questionnaire postal et de visites à bord. Ce chiffre comprend 100 % de la flotte nationale des Grands Lacs, ce qui était important pour répondre aux doutes de l’industrie maritime concernant la validité de l’inventaire des émissions.

Le tableau 1 montre les émissions totales de tous les navires, dans tous les modes d’exploitation (navires hôtels, navires en manœuvres et navires qui font route), au cours de l’année de référence (2002), et les émissions prévues pour 2010 et 2020, sans que la région EC/GL soit désignée SECA. Les émissions de l’année de référence, calculées en 2006, sont également incluses, à des fins de comparaison. La mise à jour des profils de navires et des facteurs d’émission a entraîné une réduction des émissions d’oxydes d’azote (NO_x), de particules (PM, $PM_{2,5}$, PM_{10}) et d’hydrocarbures (HC), et une augmentation des émissions de SO_2, de CO et de CO_2 calculées pour l’année de référence, par rapport aux données issues de l’étude de 2006.

Tableau 1 : Mise à jour de l’inventaire et des prévisions des émissions (émissions exprimées en tonnes)

Émission	Année de référence 2002 (Étude de 2006)	Année de référence 2002 (Mise à jour de 2007)	Prévision pour 2010	Écart 2010/ année de référence	Prévision pour 2020	Écart 2020/année de référence
SO_2	47 459	54 959	64 349	17,09 %	74 344	35,27 %
NO_x	93 699	73 974	83 130	12,38 %	91 253	23,36 %
TPM	10 348	7 129	8 344	17,04 %	9 640	35,22 %
PM_{10}	8 157	6 844	8 010	17,04 %	9 255	35,23 %
$PM_{2,5}$	6 854	6 296	7 369	17,04 %	8 514	35,23 %
CO	3 092	6 165	7 154	16,04 %	8 212	33,20 %
HC	2 843	2 520	2 933	16,39 %	3 376	33,97 %
CO_2	3 298 991	3 620 092	4 212 740	16,37 %	4 841 468	33,74 %

Le tableau 2 présente des prévisions d’émissions, dans le cas où la région EC/CL serait désignée zone SECA. Une telle désignation aurait des répercussions importantes sur les émissions de SO_x et de particules, soit des réductions d’environ 29 % et 21 %, respectivement, en 2010, comparativement à l’année de référence. Certes, les réductions d’émissions seraient atténuées par la croissance prévue de l’activité maritime, mais même en 2020, les réductions de SO_x et de particules atteindraient environ 18 % et 9 %, respectivement, par rapport aux niveaux de 2002

Tableau 2 : Mise à jour de l’inventaire des émissions et des prévisions SECA (émissions exprimées en tonnes)

Émission	Année de référence 2002 (Étude de 2006)	Année de référence 2002 (Mise à jour de 2007)	Prévision pour 2010 (SECA)	Écart 2010/ année de référence	Prévision pour 2020 (SECA)t	2020 Écart 2020/année de référence
SO_2	47 459	54 959	39 080	-28,89 %	44 939	-18,23 %
NO_x	93 699	73 974	83 130	12,38 %	91 253	23,36 %
TPM	10 348	7 1297	5 658	-20,63 %	6 511	-8,67 %
PM_{10}	8 157	6 844	5 431	-20,65 %	6 251	-8,67 %
$PM_{2.5}$	6 854	6 296	4 997	-20,63 %	5 750	-8,67 %
CO	3 092	6 165	7 154	16,05 %	8 212	33,21 %
HC	2 843	2 520	2 933	16,40 %	3 376	34,00 %
CO_2	3 298 991	3 620 092	4 212 740	16,37 %	4 841 468	33,74 %

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GLOSSARY

BC	British Columbia
CARB	California Air Resource Board
CCG	Canadian Coast Guard
CO	Carbon monoxide
CO_2	Carbon dioxide
CSA	Canadian Shipowners Association
cST	Centistoke
DWT	Deadweight Tons
EC/GL	Eastern Canada and Great Lakes
EPA	Environmental Protection Agency (U.S.)
HC	Hydrocarbons
HFO	Heavy Fuel Oil
IAPP	International Air Pollution Prevention (IMO Certificate)
ICST	International Classification of Ships by Type
IFO	Intermediate Fuel Oil
IMO	International Maritime Organization
INNAV	CCG Information System on Marine Navigation
MCR	Maximum Continuous Rating (for engine load in kW)
MDO	Marine Diesel Oil
MGO	Marine Gas Oil
Mt	Metric Ton
NOx	Oxides of nitrogen
POLA	Port of Los Angeles
PM	Particulate Matter
$PM_{2.5}$	Particulate Matter less than 2.5 microns
PM_{10}	Particulate Matter less than 10 microns
ppm	Parts per million
rpm	Revolutions per minute
TDC	Transportation Development Centre
TPM	Total Particulate Matter
SECA	Sulphur Emission Control Area
SFC	Shipping Federation of Canada
SO_2	Sulphur dioxide
SOW	Statement of Work
SOx	Oxides of sulphur
USEPA	United States Environmental Protection Agency
WME	Weir Marine Engineering

1. INTRODUCTION

Canada, as a member of the International Maritime Organization (IMO) and a signatory of the Montreal Protocol, is committed to reduce emissions that contribute to global warming. Emissions from all forms of transportation, including aviation, passenger vehicles, trucks, rail transport and marine vessels contribute to global warming; therefore, it is important for governments to fully understand the emissions characteristics from these activities so that appropriate strategies can be developed to effect emissions reductions. This report presents work that was completed by Weir Marine Engineering (WME) for the Transportation Development Centre (TDC) of Transport Canada to better understand the contribution of marine shipping to air emissions within the Eastern Canada and Great Lakes (EC/GL) region.

TDC had mandated an earlier study on the contribution of marine transportation to the overall emissions inventory within the EC/GL geographical region. The study, completed in 2006 by Levelton Consultants Ltd. [1], resulted in an air emissions inventory and forecast that was based on marine activity data from the Canadian Coast Guard (CCG) INNAV database, generic marine vessel profiles that had been developed primarily on the West Coast of North America, and emission factors from a number of previous studies. Emissions calculations were facilitated using the National Emission Inventory Tool for the Commercial Marine Sector [2], a Microsoft Access database application that had been originally developed for Environment Canada, and subsequently customized for the EC/GL. Version 1.2 of the "Tool" was provided to WME at the start of the current project. This included two independent copies of the Tool: one included fuel quality parameters to forecast emissions based on current fuel sulphur limits, and the other included fuel quality parameters to forecast emissions if the EC/GL region were to be designated a Sulphur Emission Control Area (SECA) by the IMO [3]. While ships are operating in a designated SECA, they are limited to using fuel with a maximum sulphur content of 1.5%, or they must use an exhaust cleaning system or other proven technological means to achieve a maximum emission of oxides of sulphur (SOx) of 6.0 g SOx/kW h or less.

The 2006 study recognized that the emissions inventory for the EC/GL should be further validated, and would most likely be improved, through surveys and measurements that would provide vessel profiles and emission factors specific to the nature of the vessels and marine activity in the region. The work reported here followed from those recommendations and included the following tasks:

- Conducting vessel surveys and site visits;
- Updating the economic cargo growth forecast for the EC/GL;
- Modifying the Marine Emissions Inventory Tool application;
- Updating vessel profiles used in the Tool as appropriate for the EC/GL;
- Updating emission factors as appropriate for the vessel and engine profiles applicable to the EC/GL;
- Developing a revised emissions inventory and forecast;
- Updating the SECA forecast that would project the potential benefits of designating the EC/GL as a SECA; and
- Measuring emissions on active vessels in the EC/GL and comparing these measurements with the emission factors used in the Tool.

2. VESSEL SURVEYS AND SITE VISITS

The concentration of an air contaminant from a main or auxiliary engine in a specific mode of operation is calculated as the product of the engine's maximum continuous power (MCR in kW), load factor for the mode of operation, the emission factor for the specific contaminant (g/kW-hr) and the time in mode (hr). In order to achieve an accurate emissions inventory, it is important that the Tool contains engine profiles (maximum power and load factors by mode of operation) that are as representative as possible for the marine vessels operating in the area of interest. The Tool also requires fuel quality information because the emission factors for some air contaminants vary according to the fuel used. The overall objective of the vessel surveys and site visits was to collect data for the marine vessels operating in the EC/GL and update as required the engine profiles for the different modes of operation (underway, manoeuvring, and alongside) and fuel quality information used in the Tool. The information that was required according to the TDC Statement of Work (SOW) included:

- Type and power of main engines;
- Type and power of auxiliary engines;
- Fuel quality and sulphur content used in main and auxiliary engines while underway, manoeuvring, and alongside (also referred to as hotelling);
- Underway and manoeuvring speeds; and
- Duration of operation of auxiliary engines per port call.

In addition to the above requirements, WME extended the survey to include some boiler information. The Tool did not include emissions from boilers, which was raised as a weakness by certain stakeholders and identified as a significant contribution to air emissions by the B.C. Chamber of Shipping survey on the West Coast [4].

2.1 Survey Form Template

WME consulted with SENES Consultants Ltd., TDC, Environment Canada, and key stakeholders in the EC/GL region to develop a template for the collection of data. This included meetings with the Canadian Shipowners Association (CSA), the CSA Environmental Committee, the Shipping Federation of Canada, and Les Armateurs de St-Laurent. WME also reviewed the approach and data template that had been used in similar recent surveys by the California Air Resource Board (CARB) and British Columbia Chamber of Shipping. An English and French copy of the survey form developed by WME is included in Appendix A.

2.2 Survey Participants

Fifty-four organizations were requested to complete the questionnaire and to arrange on-site vessel surveys where appropriate. The organizations contacted are summarized in Table 2-1.

Table 2-1: Organizations Contacted by WME to Participate in the Marine Vessel Survey

Shipping Federation of Canada (FSC) Members	
ACL	Mathers Marine agency
Anglo-Eastern Ship Management	McLean Kennedy
Atship Services	Montreal Marine Services
China Ocean Shipping	Montship
China Shipping	Montship Maritime Inc.
Echo Freight	MSC (Mediterranean Shipping)
F.K. Warren	Navitrans Shipping
Fednav International	OOCL (Canada)
Furncan Marine	Protos Shipping
Gresco Ltd	Robert Reford
Hapag-Lloyd Canada	Seabridge Shipping
Inchcape Shipping HFX	Senator Lines
Inchcape Shipping Services MTL	Wallenius Wilhelmsen
Maersk Lines	Zim integrated Shipping

Table 2-1 (cont.)

Canadian Shipowners Association (CSA) Members	
Algoma Central Corporation	Petro-nav (Desgagnes)
Canada Steamship Line	Rigel Shipping Canada
Group Desgagnes	Seaway Marine Transport
Oceanex	Upper Lakes Group

Other Stakeholders	
Atlantic Pilotage Authority	Pilots Association (Bas-St-Laurent)
Beaver Marine	Pilots Association (Central)
Canadian National	Port of Montreal
Canadian Navy	Rowan Companies
Great Lakes Pilots Authority	Secunda Marine Services
Halifax port authority	St-John's port authority
HRM transit (Ferry)	V.Ships (Canada)
Les Armateurs de St-Laurent	Verreault Navigation
Laurentian Pilotage Authority	Wappen Reederei

2.3 Survey Validation

Onboard vessel surveys were arranged to ensure that the survey forms were well-understood, to verify that data collected were valid, and to obtain more detailed information. The onboard surveys were arranged in advance, normally through the vessel agent. In order to maximize the number of surveys done, WME maintained a flexible 24/7 schedule to have the best opportunities for vessel visits. Whenever possible, multiple visits were completed in the same day when vessels were in the same proximity. However, it was rare to conduct more than two visits in one day because of travel times and vessel availability. For vessels transiting the Montreal area, visits were usually conducted by boarding the vessel at one lock, meeting with the Chief Engineer during a portion of the transit, and disembarking at an upstream or downstream lock. Overall, significant effort was required for the onboard data collection.

Thirty-two onboard surveys were conducted, including surveys in the Ports of Montreal and Halifax, and extended ride-along surveys onboard a container vessel during a 54-hour transit between Montreal, Quebec, and St John's, Newfoundland, and on a ferry during a transit between North Sydney, Nova Scotia, and Port aux Basques, Newfoundland. The ride-along surveys were conducted in conjunction with measuring main engine exhaust emissions. The results of the exhaust emissions measurements are reported in Section 7 of this report.

2.4 Data Organization

A stand-alone MS-Access database was developed by WME to organize the data and facilitate its analysis to determine average characteristics by vessel class. Stakeholders were very concerned about the public release of their information, so a copy of the survey database without vessel identifiers was provided to TDC under separate cover. The key fields in the complete database are summarized below.

2.4.1 Vessel Information

General information about each vessel was requested, including Name, Vessel Class, IMO Number, Year of Build, DWT, and Country Flag. Information regarding the Maximum Cruise Speed and Typical Cargo were also requested. All of this information is important to allow for the exact identification of a vessel. This was also useful in identifying the INNAV vessel class that each vessel belonged to, since not many people who filled out the forms were familiar with the correct INNAV vessel class of their own vessel.

2.4.2 Operating Profile

The type of information requested included the types of fuel used, the grade and location of last fuelling, fuel consumption and sulphur content of last fuel used. During onboard surveys, copies of the last bunker delivery note were obtained if available.

2.4.3 Boiler Information

Boiler information included fuel type, average fuel consumption and percentage of time that the boilers were used.

2.4.4 Engine Information

For each engine on a vessel, the following information was requested:

- Engine Use (propulsion or auxiliary);
- Engine Make;
- Engine Model;
- Year of Build of Engine;
- Engine Type (2-stroke, 4-stroke, gas turbine);
- Rated Power (MCR);
- rpm at MCR; and
- Percent time of use during each mode of vessel operation.

Information regarding the fuel quality normally used at sea, while manouevring and while hotelling was also requested.

2.5 Survey Results

In consultation with the CSA, it was agreed that member companies and their representatives on the CSA Environmental Committee would provide completed survey forms for their vessels. This was very successful and a 100% completion rate was achieved for the Canadian Great Lakes domestic fleet. The full participation of the Canadian Great Lakes domestic fleet is considered a significant success of the project because a key objective was to address marine industry concerns that the emissions from the 2006 inventory did not represent domestic ships and ship operating profiles.

In all, 167 completed survey forms were returned to WME. This included 83 vessels from the Canadian domestic fleet and 84 foreign flagged vessels. The data from the questionnaires and onboard vessel surveys are summarized in the following sections by vessel class according to the data requirements for the Tool and the SOW for this project. Where appropriate, values that were reported in the 2006 TDC study are also shown to facilitate comparison and discussion. WME was supported by SENES Consultants Ltd. who was subcontracted to conduct an independent analysis of the survey data. Key conclusions from the SENES review are included in the following sections. The full SENES Report is provided in Appendix B.

2.6 Vessel Classes

There are several different organizations that assign standardized Vessel Classes to commercial marine vessels for statistical and tracking purposes. They include the CCG two-digit alphanumeric INNAV Vessel Classes, Lloyds Register Vessel Classes, and a Transport Canada System used for tracking commodities by Vessel Class. The initial Marine Tool developed for Environment Canada was based on the Lloyds Register System that uses a one-digit alphanumeric code for general Vessel Class, and a two-digit alphanumeric sub-class. The 2006 TDC study and version 1.2 of the Tool used 24 of the two-digit alphanumeric INNAV Vessel Classes, and WME was required to use these same INNAV vessel classes for this study.

Regardless of the system used to assign the Vessel Class, however, it can be difficult to assign a definitive class because many vessels carry multiple cargos. Very few of the people who completed the surveys were able to provide their known INNAV Vessel Class, so an assignment had to be made based on the vessel characteristics and “usual” cargo. The distribution of completed surveys by INNAV Vessel Class is shown in Table 2-2. In addition to the 24 Vessel Classes used in the Tool, survey forms were returned and have been included in the database for two Tugs (Class HT) and one Cable Ship (Class SC).

Table 2-2: Vessel Classes Surveyed

INNAV Vessel Class	# Surveys
HT – Tugs	2 (not included in Tool)
HO – Tugs Ocean	0
MA – Merchant Auto	0
MB – Merchant Bulk:	63
MC – Merchant Container	32
MF - Merchant Ferry	5
MG – Merchant General	6
MH – Merchant RO/RO	11
MM – Merchant (Dry)	7
MO- Merchant Ore	0
MP – Merchant Passenger	1
MR – Merchant Reefer	0
MS – Merchant Coastal	0
SC – Cable Ship	1 (not included in Tool)
TC – Merchant Crude	3
TG – Merchant Gasoline	3
TL – Merchant Chemical	13
TM – Merchant Molasses	0
TO – Merchant Ore/Bulk/Oil	0
TQ – Merchant Liquefied Gas	0
TS – Merchant Super Tanker	0
TT – Merchant (Tanker)	17
TU – Merchant ULCC	0
TV – Merchant VLCC	0
WR – Warship – General	0
WS – Warship Surface	3
TOTAL SURVEYS	167

The current survey (total of onboard and mail-in) has captured data from 14 classes as summarized in Table 2-2. Within the 167 survey responses, Merchant Bulk (MB), Merchant Container (MC) and Tankers (of all classes) are relatively well represented. There are 10 different tanker classes within the 24 INNAV vessel classes used in the Tool. Limited but reasonable representation was achieved for Merchant RoRo (MH), Merchant Dry (MM) and Merchant General (MG). For the remaining vessel classes there were insufficient data to establish robust engine profiles. However, the first three ship classes noted above make up a large fraction of the total activity in eastern Canada. The 2006 TDC Inventory report shows that 67% of the total commercial marine activity captured within the INNAV system relates to just three vessel categories: 31% for MB, 21% for MC and 15% for Merchant Tanker (TT).[1] This strongly implies that greater attention should be applied to characterizing these three vessel classes. The next three

[1] As determined by total CO_2 emissions, which directly relate to fuel consumption.

vessel classes in terms of significance are Merchant Ferry (MF), MG and Merchant Passenger (MP) (7%, 7% and 6% of the total activity, respectively).

2.7 Type and Power Rating of Main Engines by Vessel Class

Version 1.2 of the Tool and the 2006 inventory assumed that all main diesel engines, except for tugs and ferries, are 2-stroke engines. However, main diesel engines may be either 2-stroke or 4-stroke engines, which have different emissions characteristics. For each vessel class, the survey identified the proportion of each main engine type. Main engines were identified as four major engine types: 2-stroke, 4-stroke, steam and gas turbine. Table 2-3 shows the Vessel Classes surveyed and their associated engine types.

Table 2-3: Main Engine Type per Vessel Class

INNAV Vessel Class	# Surveys	2-Stroke	4-Stroke	Steam	Gas Turbine
HT – Tugs	2	-	2	-	-
HO – Tugs Ocean	0	-	-	-	-
MA – Merchant Auto	0	-	-	-	-
MB – Merchant Bulk	63	44	14	5	-
MC – Merchant Container	32	31	1	-	-
MF – Merchant Ferry	5	1	4	-	-
MG – Merchant General	6	2	4	-	-
MH – Merchant RO/RO	11	5	6	-	-
MM – Merchant (Dry)	7	4	3	-	-
MO – Merchant Ore	0	-	-	-	-
MP – Merchant Passenger	1	-	1	-	-
MR – Merchant Reefer	0	-	-	-	-
MS – Merchant Coastal	0	-	-	-	-
SC – Cable Ship	1	-	1	-	-
TC – Merchant Crude	3	3	-	-	-
TG – Merchant Gasoline	3	2	1	-	-
TL – Merchant Chemical	13	13	-	-	-
TM – Merchant Molasses	0	-	-	-	-
TO – Merchant Ore/Bulk/Oil	0	-	-	-	-
TQ – Merchant Liquefied Gas	0	-	-	-	-
TS – Merchant Super Tanker	0	-	-	-	-
TT – Merchant (Tanker)	17	14	3	-	-
TU – Merchant ULCC	0	-	-	-	-
TV – Merchant VLCC	0	-	-	-	-
WR – Warship – General	0	-	-	-	-
WS – Warship Surface	3	-	1	-	2
TOTAL NUMBER OF VESSELS	167	119	41	5	2

In Table 2-4, diesel engine types have been further categorized according to the engine speed (rpm):

- Low Speed: up to 300 rpm
- Medium Speed: 300 to 1,000 rpm
- High Speed: greater than 1,000 rpm

Table 2-4: Type and Power Rating of Main Engines by Vessel Class

INNAV Vessel Class	Typical Main Engine Type	Avg. Total Power Rating from Survey (kW)	2006 Study Avg. Total Power Rating (kW)
HT – Tugs	High speed 4-stroke diesel	654	-
HO – Tugs Ocean	-	-	6,275
MA – Merchant Auto	-	-	10,530
MB – Merchant Bulk	Low speed 2-stroke diesel	6,977	7,931
MC – Merchant Container	Low speed 2-stroke diesel	31,113	23,988
MF – Merchant Ferry	4 stroke diesel	2,557	-
MG – Merchant General	Med speed 4-stroke diesel	3,504	5,728
MH – Merchant RO/RO	Low speed 2-stroke or Med speed 4-stroke diesel	13,990	11,251
MM – Merchant (Dry)	Low speed 2-stroke or Med speed 4-stroke diesel	7,512	1,607
MO – Merchant Ore	-	-	12,022
MP – Merchant Passenger	Med speed 2-stroke diesel	1,500	18,351
MR – Merchant Reefer	-	-	5,700
MS – Merchant Coastal	-	-	7,170
SC – Cable Ship	Med speed 4-stroke diesel	3,000	-
TC – Merchant Crude	Low speed 2-stroke diesel	12,639	13,461
TG – Merchant Gasoline	Low speed 2-stroke diesel	8,298	10,171
TL – Merchant Chemical	Low speed 2-stroke diesel	7,033	6,942
TM – Merchant Molasses	-	-	6,417
TO – Merchant Ore/Bulk/Oil	-	-	10,940
TQ – Merchant Liquefied Gas	-	-	13,068
TS – Merchant Super Tanker	-	-	20,477
TT – Merchant (Tanker)	Low speed 2-stroke diesel	8,280	9,353
TU – Merchant ULCC	-	-	26,778
TV – Merchant VLCC	-	-	21,594
WR – Warship – General	-	-	-
WS – Warship Surface	Low speed 4-stroke or Gas Turbine	45,682	-

-: Information not provided

2.8 Type and Power Rating of Auxiliary Engines by Vessel Class

Although the INNAV database, which is accessed in the Tool, allows ‘lookup’ of main engine size directly, this database (or any other current vessel movement database) does not have comprehensive auxiliary engine information (the Lloyds database has auxiliary engine information for only a small fraction of vessels). Studies of auxiliary engine use by class of vessel have been used in the past to determine profiles of auxiliary engine size, load factor and fuel use. Early studies showed that there is great variability in auxiliary use between different classes of ships and even within one class of ship. However, a reasonably consistent approach has been followed in recent years, which makes use of predictive equations (regression relations based on survey work) or ratios that establish estimated auxiliary engine power based on vessel DWT or main engine power. There are different ways of making use of such relations within an inventory. The Tool uses a set of ratios that relate total installed auxiliary power to the main engine size of a particular vessel, and these ratios differ by class of vessel. The ratios in Version 1.2 of the Tool were determined by previous work in California and therefore relate to ships that operate in California waters. A significant goal of this project was to either confirm the appropriateness of these ratios for ships in eastern Canada, or to replace them with ratios that are more representative.

The data for auxiliary engines is summarized in Table 2-5. The data are summarized as total average auxiliary power per Vessel Class, and are compared to the total average auxiliary power from the 2006 Inventory for the same Vessel Classes. Most vessels have 3 or 4 auxiliary engines. The survey results database does include the specific data for the individual engines that can be viewed for detailed analysis.

Table 2-5: Type and Power Rating of Auxiliary Engines by Vessel Class

INNAV Vessel Class	Typical Aux Engine Type	Avg Total Aux Power From Survey (kW)	2006 Study Avg Total Aux Power (kW)
HT – Tugs	High speed 2-stroke diesel and 4-stroke diesel	67	-
HO – Tugs Ocean	-	-	784
MA – Merchant Auto	-	-	2,001
MB – Merchant Bulk	High speed and low speed 4-stroke diesel	2,016	1,166
MC – Merchant Container	Med speed 4-stroke diesel	5,633	4,462
MF – Merchant Ferry	High speed 4-stroke diesel	1,158	-
MG – Merchant General	Med or high speed 4-stroke diesel	471	1,088
MH – Merchant RO/RO	Med speed 4-stroke diesel	5,221	5,108
MM – Merchant (Dry)	Med or high speed 4-stroke diesel	1,701	236
MO – Merchant Ore	-	-	1,767
MP – Merchant Passenger	High speed 4-stroke diesel	1,238	5,102
MR – Merchant Reefer	-	-	775
MS – Merchant Coastal	-	-	1,362
SC – Cable Ship	Med speed 4-stroke diesel	5,500	-
TC – Merchant Crude	Med or high speed 4-stroke diesel	2,843	2,840
TG – Merchant Gasoline	Med or high speed 4-stroke diesel	2,005	2,146
TL – Merchant Chemical	Med or high speed 4-stroke diesel	2,278	1,465
TM – Merchant Molasses	-	-	1,354
TO – Merchant Ore/Bulk/Oil	-	-	2,308
TQ – Merchant Liquified Gas	-	-	2,757
TS – Merchant Super Tanker	-	-	4,321
TT – Merchant (Tanker)	Med or high speed 4-stroke diesel	2,297	1,973
TU – Merchant ULCC	-	-	5,650
TV – Merchant VLCC	-	-	4,556
WR – Warship – General	-	-	1,777
WS – Warship Surface	High speed 4-stroke diesel or gas turbine	3,314	1,777

- : Information not provided

2.9 Load Factors and Effective Auxiliary Power for Auxiliary Engines by Vessel Class

The surveys were used to determine total and effective engine power values for auxiliary engines. Total power is simply the sum of maximum (MCR) engine power for all installed auxiliary engines. Effective power is the sum of maximum power times the load factor for each engine. If a ship had two engines of 700 kW each, and one was used at berth with a load factor of 0.50 and the other was not used at all, the effective power determined for berthing would be 350 kW, and the effective load factor, which the Tool requires, would be 0.25.

Table 2-6 summarizes the survey data on auxiliary engine use by Vessel Class. The survey was expanded to include several different phases of vessel operation to determine if there are significant differences in engine parameters during hotelling (while loading and unloading), manoeuvring, at half-ahead speed, and normal cruising speed.

Table 2-6: Average Auxiliary Engine Load Factors by Vessel Class

INNAV Vessel Class	% MCR Ballasted – Cruising	% MCR Loaded – Cruising	% MCR Ballasted – Half-ahead	% MCR Loaded – Cruising	% MCR Manoeuvring	% MCR Unloading / Hotelling	% MCR Loading / Hotelling	% Time Ballasted – Cruising	% Time Loaded – Cruising	% Time Ballasted – Half-ahead	% Time Ballasted – Half-ahead	% Time Manoeuvring	% Time Unloading / Hotelling	% Time Loading / Hotelling
HT – Tugs	80	80	40	40	80	-	-	50	50	50	50	50	-	-
MB – Merchant Bulk	15	19	15	17	28	44	31	30	36	41	47	65	65	58
MC – Merchant Container	10	15	10	12	28	16	18	21	24	29	32	57	35	37
MF – Merchant Ferry	60	60	-	-	80	50	50	100	100	-	-	100	100	100
MG – Merchant General	29	37	29	33	49	58	37	40	50	40	45	83	91	55
MH – Merchant RO/RO	11	13	6	9	32	25	25	21	29	19	26	68	39	39
MM – Merchant (Dry)	9	9	4	4	48	31	36	22	22	13	13	78	44	56
MP – Merchant Passenger	0	25	0	25	38	10	10	0	50	0	50	100	25	25
SC – Cable Ship	-	-	-	-	-	-	-	-	-	-	-	-	100	100
TC – Merchant Crude	16	22	0	0	35	16	16	30	33	14	14	60	38	38
TG – Merchant Gasoline	34	34	26	26	38	39	33	44	44	29	29	67	56	44
TL – Merchant Chemical	13	21	4	4	39	33	26	32	36	26	26	66	51	38
TT – Merchant (Tanker)	25	24	14	14	37	26	18	41	42	23	23	70	51	40
WS – Warship Surface	20	28	20	20	23	0	5	33	43	33	33	43	0	8

-: Information not provided

Most vessels have at least three diesel generators to generate power throughout the ship. Only one diesel generator is usually required to operate at about 30 to 40% load under normal sailing conditions; however, two generators are generally used in restricted water for safety purposes. Vessels equipped with bow thrusters will require two out of three, or three out of four generators for berthing. Where a shaft generator is installed, it would normally be sufficient to supply all power requirements while at sea. While alongside, vessels will normally require their generators for hotel services, and to operate pumps, cranes, etc. to support unloading and loading activities unless shore power is available. This makes the average data for auxiliary engines more difficult to interpret than for main engines because the variability is much greater from one vessel to another.

2.9.1 Merchant Bulk Vessels

Based on simple averages from the survey responses, 0.29 is suggested for the installed auxiliary power to main engine power ratio (although this ratio is not very representative for an individual ship), with 0.21, 0.31 and 0.42 for effective load factors for underway, manoeuvring and berthing, respectively. The berthing ratio is an average of the ratios determined for loading (0.34) and unloading (0.49).

2.9.2 Merchant Container Vessels

Based on the survey response averages, Tool parameters of 0.17 for the ratio of installed auxiliary power to main engine power, and 0.21, 0.33 and 0.20 for effective load factors for underway, manoeuvring and berthing, respectively, are recommended.

2.9.3 Tankers

Based on the survey responses, tankers were separated into two distinct groups: TT and Other Tankers. Based on the survey response averages for TT, Tool parameters of 0.29 for the ratio of installed auxiliary power to main engine power, and 0.30, 0.37 and 0.24 for effective auxiliary load factors for underway, manoeuvring and berthing, respectively, are recommended. The berthing load factor is an average representative of both loading (0.18) and unloading (0.30) activities.

The survey responses grouped as “Other Tanker” include the INNAV categories of Merchant Gasoline (TG), Merchant Chemical (TL) and Merchant Crude (TC) (although TC was not well represented). The three TC surveys were not complete so they were not used to determine the auxiliary engine ratios. The general cargoes stated for the TG and TL ships were petroleum products and “chemicals”. The following parameters are recommended for use in the Tool for the TG, TL, and TC ship classes: 0.28 for ratio of installed auxiliary power to main engine power, and 0.20, 0.36 and 0.30 for effective auxiliary load factors for underway, manoeuvring and berthing, respectively. The berthing value is an average representation of loading (0.25) and unloading (0.35).

The Merchant Molasses (TM) and Merchant Ore/Bulk/Oil (TO) tanker classes were not represented in the survey questionnaires, partly due to relatively few vessel visits over a typical year. The 2002/2003 INNAV records show that the average main engine size for these two ship classes (5,985 kW and 11,180 kW, respectively) are reasonably close to the TL and TG average main engine sizes (4,732 kW and 9,605 kW, respectively). Therefore, the same auxiliary parameters as noted above are recommended for these additional ship categories. These parameters can also be used for Merchant Super Tankers (TS) and Merchant Liquified Gas (TQ), since there are very few visits by these vessels in a year (24 and 3, respectively, in 2002/2003).

2.9.4 Merchant RoRo Vessels

Most of the surveyed vessels that could be considered RoRo vessels were categorized as MM, MH, MC or a combination of two or more of these categories. The questionnaire responses specified cargo loads consisting of paper, newsprint, containers, cars, trailers or simply “RoRo”. Based on the survey data the following parameters are recommended for use in the Tool for the MH ship class: 0.33 for ratio of installed auxiliary power to main engine power, and 0.20, 0.37 and 0.27 for effective auxiliary load factors for underway, manoeuvring and berthing, respectively. There was no difference found between loading and unloading auxiliary power demand.

2.9.5 Merchant General and Merchant Coastal

The following parameters are recommended for use in the Tool for the MG class vessels: 0.15 for ratio of installed auxiliary power to main engine power, and 0.38, 0.52 and 0.42 for effective auxiliary load factors for underway, manoeuvring and berthing, respectively. The berthing factor is an average representative of loading (0.34) and unloading (0.50).

Merchant Coastal (MS) ships were not represented in the returned surveys. The previous version of the Tool relied on the assumption that this class of ship is similar in auxiliary profile to MG. This assumption appears to be consistent with what was assumed in the Port of Los Angeles (POLA) work. At this time, the same parameters used for MG are recommended for MS ships.

2.9.6 Warships

Warships active in eastern Canada are either from the Iroquois or the Halifax class, with the Halifax class being dominant (12 of these vessels are currently active and split between the east and west coasts). One survey response was gathered for each class. The recommended ratios for Warship – General (WR) and Warship – Surface (WS) are 0.17 for main to auxiliary engine ratio, 0.34 for underway and manoeuvring load factors and 0 for berthing. Canadian warships use shoreside power while at berth. The 2002/2003 filtered INNAV records showed very few warship transits that were included in the Inventory (nine unique voyages).

2.9.7 Other Vessel Classes

Little to no information was obtained for the Merchant Auto (MA), Merchant Ore (MO), MP, MF, Tugs Ocean (HO) and Merchant Reefer (MR) ship classes. MO ships were assumed to have similar characteristics to MB ships, consistent with the previous assumption used in the Tool.

Consistent with changes made to the specific vessel classes discussed above, the existing manoeuvring load factors in the Tool were considered too high for MA and MR ships. Therefore, the manoeuvring load factors were set to be equal to the higher of the existing POLA underway and berthing load factors (which was berthing load factor in both cases).

Five questionnaire responses were received for Merchant Ferry (MF) ships and two for Ocean Tugs (HO). However, in both cases, the responses were not deemed adequate for determining a profile to represent the entire ship class. One questionnaire was collected for MP ships. Therefore, the existing auxiliary engine parameters (including manoeuvring load factor) are recommended for these three ship classes at this time.

2.10 Typical Fuel Quality per Vessel Class

Typical fuel quality per Vessel Class is shown in Table 2-7. Distillate fuels include Marine Gas Oil (MGO), Intermediate Fuel Oil (IFO) and Marine Diesel Oil (MDO), while residual fuels include Heavy Fuel Oil (HFO).

Table 2-7: Fuel Quality per Vessel Class

INNAV Vessel Class	# Vessels Surveyed	Propulsion Engines		Auxiliary Engines		
		Distillate	Residual	Distillate	Residual	Both
HT – Tugs	2	2	0	2	0	0
HO – Tugs Ocean	0	-	-	-	-	-
MA – Merchant Auto	0	-	-	-	-	-
MB – Merchant Bulk	63	7	56	45	11	4
MC – Merchant Container	32	0	32	11	19	2
MF – Merchant Ferry	5	2	3	2	1	0
MG – Merchant General	6	3	3	5	1	0
MH – Merchant RO/RO	11	0	11	6	4	1
MM – Merchant (Dry)	7	0	7	3	3	1
MO – Merchant Ore	0	-	-	-	-	-
MP – Merchant Passenger	1	1	0	1	0	0
MR – Merchant Reefer	0	-	-	-	-	-
MS – Merchant Coastal	0	-	-	-	-	-
SC – Cable Ship	1	1	0	1	0	0
TC – Merchant Crude	3	0	3	0	1	2
TG – Merchant Gasoline	3	1	2	1	1	1
TL – Merchant Chemical	13	1	12	4	5	4
TM – Merchant Molasses	0	-	-	-	-	-
TO – Merchant Ore/Bulk/Oil	0	-	-	-	-	-
TQ – Merchant Liquified Gas	0	-	-	-	-	-
TS – Merchant Super Tanker	0	-	-	-	-	-
TT – Merchant (Tanker)	17	3	14	8	5	4
TU – Merchant ULCC	0	-	-	-	-	-
TV – Merchant VLCC	0	-	-	-	-	-
WR – Warship – General	0	-	-	-	-	-
WS – Warship Surface	3	3	0	3	0	0
ALL VESSELS	167	24	143	92	51	19

- : Information not provided

Main engine fuel quality per Vessel Class, on a domestic/foreign vessel basis, is shown in Table 2-8.

Table 2-8: Main Engine Fuel Quality per Vessel Class (Domestic vs. Foreign)

INNAV Vessel Class	# Vessels Surveyed	Domestic		Foreign	
		Distillate	Residual	Distillate	Residual
HT – Tugs	2	2	0	0	0
HO – Tugs Ocean	-	-	-	-	-
MA – Merchant Auto	-	-	-	-	-
MB – Merchant Bulk	63	6	46	1	10
MC – Merchant Container	32	0	1	1	30
MF – Merchant Ferry	5	2	3	0	0
MG – Merchant General	6	2	2	1	1
MH – Merchant RO/RO	11	0	4	0	7
MM – Merchant (Dry)	7	0	0	0	7
MO – Merchant Ore	-	-	-	-	-
MP – Merchant Passenger	1	1	0	0	0
MR – Merchant Reefer	-	-	-	-	-
MS – Merchant Coastal	-	-	-	-	-
SC – Cable Ship	1	0	0	1	0
TC – Merchant Crude	3	0	0	0	3
TG – Merchant Gasoline	3	1	0	0	2
TL – Merchant Chemical	13	0	1	1	11

Table 2-8 (cont.)

INNAV Vessel Class	# Vessels Surveyed	Domestic		Foreign	
		Distillate	Residual	Distillate	Residual
TM – Merchant Molasses	-	-	-	-	-
TO – Merchant Ore/Bulk/Oil	-	-	-	-	-
TQ – Merchant Liquified Gas	-	-	-	-	-
TS – Merchant Super Tanker	-	-	-	-	-
TT – Merchant (Tanker)	17	0	9	3	5
TU – Merchant ULCC	-	-	-	-	-
TV – Merchant VLCC	-	-	-	-	-
WR – Warship – General	-	-	-	-	-
WS – Warship Surface	3	3	0	0	0
ALL VESSELS	167	17	66	8	76

-: Information not provided

2.11 Fuel Sulphur Content and Fuel Consumption

2.11.1 Fuel Sulphur

Much thought and consultation was required to develop appropriate terminology for the survey form to collect data regarding fuel characteristics. A variety of fuel types are used by the commercial marine industry and different nomenclature may be used for describing similar marine fuels depending on their source. Respondents were asked to classify their fuel used as: Distillate (Light) or Residual (Heavy), and indicate the specific fuel grade, location and sulphur content of the last bunker delivery. When conducting onboard surveys, copies of bunker delivery notes for the last bunker delivery were obtained whenever possible.

A light distillate fuel (MGO, MDO) with low sulphur content (< 0.5%) is used by approximately 50% of the vessels for auxiliary diesel generators and in some cases for the propulsion engine only if operating in a SECA environment. An intermediate fuel (IFO grade 180 cSt), 1-2% sulphur content, is used by a few vessels or blended with light distillate for generator use but the rest of the fleet (approx 50%) will use a heavy fuel oil (IFO/HFO grade 380 cSt) as the preferred type of fuel for the propulsion engine, diesel generators and auxiliary boilers. Steam vessels will use a HFO grade 500 cSt as their fuel for the main boilers. Only one steam vessel was surveyed.

In general it was found that foreign vessels that operate only partly in Canadian waters purchase as little fuel as possible in Canada, and in some cases are able to completely avoid the Canadian marine fuel market. This was at first believed to be because Canadian marine fuel has lower sulphur content and is sold at a higher price than some other sources of marine fuels. However, analysis of the data collected did not confirm this.

For vessels that operate 90% or more of their time in Canadian waters, average fuel sulphur levels were reported to be 0.53% Sulphur for light (distillate) type fuels, and 2.53% Sulphur for heavy (residual) type fuels. For vessels operating less than 90% of their time in Canadian waters, average fuel sulphur levels were reported to be 0.77% for light (distillate) type fuels, and 2.5% for heavy (residual) type fuels.

The data was then looked at to see if there was a difference between vessels with and without an IMO International Air Pollution Prevention (IAPP) certificate. For vessels claiming to have an IAPP certificate, average fuel sulphur levels were reported to be 0.69% for light (distillate) type fuels, and 2.45% for heavy (residual) type fuels. For vessels without an IAPP certificate, average fuel sulphur levels were reported to be 0.61% for light (distillate) type fuels, and 2.21% for heavy (residual) type fuels, indicating no significant difference.

There was no apparent difference in fuel sulphur based on area of operation (e.g. international or domestic), or based on vessel status with respect to IMO IAPP certification. Except for very regional operations, such as passenger ferries, tugs and other harbour vessels, it cannot be assumed that a vessel will be using fuel that was embarked in any particular area. Based on the limited data from this survey, it is recommended that available worldwide averages for fuel sulphur by fuel type be used for the emissions inventory and forecast.

Based on all surveys from this study, for commercial marine vessels average sulphur for light (distillate) marine fuels was 0.66% and average sulphur for residual marine fuels was 2.42%, for vessels operating in the EC/GL region. It is important to note that the assumptions for fuel sulphur that were used in the 2006 study have not been changed in the Tool and for the inventory calculations presented in this report. As described in section 4 of this report, it would be straightforward to use the revised Tool to calculate the impact of changing the fuel sulphur assumptions.

Naval vessels use only one grade of fuel procured to a Canadian General Standards Board Specification. Information obtained from the Department of National Defence indicates that fuel sulphur for naval fuels in 2006 was less than 0.2%, and often was within the limit for ultra-low sulphur fuel at less than 15 parts per million (ppm) sulphur. New sulphur limits for marine diesel in Canada came into effect in June 2007, which limit sulphur content to 500 ppm maximum. This change can be expected to impact the emissions from vessels that operate exclusively in Canadian waters and procure fuel in the domestic marine fuel market. The survey data on fuel sulphur content is summarized in Table 2-9.

Table 2-9: Fuel Sulphur Content by Vessel Class

INNAV Vessel Class	Distillate		Residual	
	Range of Sulphur Content (%)	Avg. Sulphur Content (%)	Range of Sulphur Content (%)	Avg. Sulphur Content (%)
HT – Tugs	-	-	-	-
HO – Tugs Ocean	-	-	-	-
MA – Merchant Auto	-	-	-	-
MB – Merchant Bulk	0.1 – 3	1.2	1.36 – 4.5	3.6
MC – Merchant Container	0.0094 – 4.09	0.9	1.5 – 4.5	2.5
MF – Merchant Ferry	0.2	0.2	-	-
MG – Merchant General	0.2	0.2	2.2 – 4.5	3.7
MH – Merchant RO/RO	0.0019 – 1.5	0.3	1.45 – 4.5	2.3
MM – Merchant (Dry)	0.19 – 1.74	0.8	1.95 – 3.18	2.6
MO – Merchant Ore	-	-	-	-
MP – Merchant Passenger	N/A	N/A	N/A	N/A
MR – Merchant Reefer	-	-	-	-
MS – Merchant Coastal	-	-	-	-
SC – Cable Ship	-	-	-	-
TC – Merchant Crude	0.32 – 0.5	1.3	2 – 3.29	2.8
TG – Merchant Gasoline	0.06 – 0.14	0.1	1.38 – 2.62	2.0
TL – Merchant Chemical	0.0001 – 2.49	0.5	0.8 – 3.73	2.1
TM – Merchant Molasses	-	-	-	-
TO – Merchant Ore/Bulk/Oil	-	-	-	-
TQ – Merchant Liquified Gas	-	-	-	-
TS – Merchant Super Tanker	-	-	-	-
TT – Merchant (Tanker)	0.0005 – 4.5	0.5	0.65 – 4.15	2.1
TU – Merchant ULCC	-	-	-	-
TV – Merchant VLCC	-	-	-	-
WR – Warship – General	-	-	-	-
WS – Warship Surface	0.05	0.05	-	-
ALL VESSELS	0.0019 – 4.5	0.8	0.65 – 4.5	2.8

-: Information not provided

2.11.2 Fuel Consumption

The survey form requested that respondents indicate the average fuel consumption in metric tonnes per day for both light (distillate) fuels and heavy (residual) fuels. It was interesting to note that where both a vessel and its Company provided separate survey data, the number provided by the vessels for fuel consumption per day was often considerably different than figures offered by their company. There was also very wide variety in the fuel consumptions reported within one vessel class, and many survey forms were incomplete for fuel consumption unless the survey was completed by WME through an on-site vessel visit. The survey data for fuel consumption is available in the database, although it is not used directly in the Tool for emissions calculations. Due to the high variability in the data reported, and the implications of fuel switching, the fuel consumption data is not considered very useful. The average fuel consumption reported by vessel class is shown in Table 2-10.

Table 2-10: Average Fuel Consumption by Vessel Class

INNAV Vessel Class	Reported Light Fuel Consumption (Tonne/day)	Reported Residual Fuel Consumption (Tonne/day)
HT – Tugs	2.4	0
HO – Tugs Ocean	-	-
MA – Merchant Auto	-	-
MB – Merchant Bulk	4.3	19.1
MC – Merchant Container	8.0	124.7
MF – Merchant Ferry	6.0	0
MG – Merchant General	6.6	4.9
MH – Merchant RO/RO	2.9	44.6
MM – Merchant (Dry)	1.8	27.6
MO – Merchant Ore	-	-
MP – Merchant Passenger	10	0
MR – Merchant Reefer	-	-
MS – Merchant Coastal	-	-
SC – Cable Ship	-	-
TC – Merchant Crude	2.1	51
TG – Merchant Gasoline	16	-
TL – Merchant Chemical	1.2	23.9
TM – Merchant Molasses	-	-
TO – Merchant Ore/Bulk/Oil	-	-
TQ – Merchant Liquified Gas	-	-
TS – Merchant Super Tanker	-	-
TT – Merchant (Tanker)	1.8	25.3
TU – Merchant ULCC	-	-
TV – Merchant VLCC	-	-
WR – Warship – General	-	-
WS – Warship Surface:	-	-

-: Information not provided

2.12 Load Factors of Main Engines by Vessel Class

Table 2-11 summarizes the survey data on main engine use by Vessel Class. The survey was expanded to include several different phases of vessel operation to determine if there are significant differences in engine parameters during hotelling (while loading and unloading), manoeuvring, at half-ahead speed, and normal cruising speed. It should be noted that although there is an inherent assumption in the Tool and in the data presented that main engines are not used while alongside, there was some evidence from the survey data that a shaft generator in combination with a main engine may be used to provide electrical power alongside. One respondent for a Tanker (Class TT) stated this directly on the survey form. This seems, however, to be fairly rare and is not expected to have any appreciable impact on the overall emissions estimates.

Table 2-11: Average Main Engine Load Factors by Vessel Class

Vessel Class	% MCR Ballasted – Cruising	% MCR Loaded – Cruising	% MCR Ballasted – Half-ahead	% MCR Loaded – Half-ahead	% MCR Manoeuvring	% MCR Unloading	% MCR Loading	% Time Ballasted – Cruising	% Time Loaded – Cruising	% Time Ballasted – Half-ahead	% Time Loaded – Half-ahead	% Time Manoeuvring	% Time Unloading	% Time Loading
HT – Tugs	80	80	40	40	90	0	0	50	50	50	50	50	0	0
MB – Merchant Bulk	78	81	37	41	32	3	0	92	95	88	91	90	4	0
MC – Merchant Container	74	80	41	37	39	1	1	100	100	100	100	100	3	3
MF – Merchant Ferry	80	81	-	-	80	0	0	100	100	100	100	100	0	0
MG – Merchant General	70	78	52	57	50	0	0	100	100	100	100	100	0	0
MH – Merchant RO/RO	81	78	35	45	36	0	0	85	100	83	100	100	0	0
MM – Merchant (Dry)	86	86	59	59	58	4	3	100	100	100	100	100	1.5	1.5
MP – Merchant Passenger	-	35	-	20	20	0	4	100	100	100	100	100	0	0
SC – Cable Ship	-	-	-	-	-	-	-	-	-	-	-	-	100	100
TC – Merchant Crude	88	83	-	30	35	0	0	100	100	100	100	100	0	0
TG – Merchant Gasoline	95	84	80	80	53	0	0	100	100	100	100	100	0	0
TL – Merchant Chemical	82	85	55	55	64	0	0	100	100	100	100	100	0	0
TT – Merchant (Tanker)	81	82	49	51	40	4	3	100	100	100	100	100	6	6
WS – Warship Surface	-	82	30	30	18	0	0	0	50	50	50	67	0	0

-: Information not provided

2.13 Underway and Manoeuvring Speeds by Vessel Class

The cruising (underway) speed of the majority of commercial vessels is their most economical speed, which is often at or less than two knots below the vessel maximum speed. At the cruising speed, a main engine should generally be at 85-90% of MCR to achieve the greatest fuel economy. The survey results found that the normal cruising speed can vary from 12 to 24 knots depending on vessel class and size. In ballast condition, a vessel may gain 0.5 to 1 knot if applicable. The survey also asked vessels to report their half ahead speed and corresponding % MCR. The intent was to gain an appreciation of the potential impact on emissions of vessel operation at intermediate speeds, as might be the case in restricted waters. It was found, however, that the use of intermediate engine loads is quite limited other than for manoeuvring for some vessels. Table 2-12 presents the underway and half-ahead speeds by Vessel Class. The manoeuvring speed is very variable, and the estimate in the 2006 Study of 5 kts is considered a reasonable estimation. It should be noted, however, that with an assumption of 5 kts, the reported load factors for propulsion engines during manoeuvring are high compared to other studies.

When one compares the normal cruising speeds assumed in the 2006 study (shown for comparison in Table 2-12) with the findings of this study, there is generally good agreement for most vessel classes.
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Table 2-12: Vessel Speeds by Mode

Vessel Class	Max Cruise Speed	Normal Cruise Speed Ballast	Normal Cruise Speed Loaded	Normal Half Ahead Speed Ballast	Normal Half Speed Loaded	2006 Study Cruise Speed
HT – Tugs	10.0	10.0	10.0	5.0	5.0	10.2
MB – Merchant Bulk	12.6	12.6	12.2	7.9	7.6	13.6
MC – Merchant Container	22.1	21.6	20.6	12	11.3	18.9
MF – Merchant Ferry	11.2	14	9	12	10.5	15.0
MG – Merchant General	12.2	12.5	11.9	8.3	7.4	13.3
MH – Merchant RO/RO	16.8	16.3	16.1	11.2	10.8	16.5
MM – Merchant (Dry)	14.4	14.4	13.6	11.0	10	13.6
MP – Merchant Passenger	12.5	-	12	-	8	20.0
SC – Cable Ship	14	-	12	-	-	-
TC – Merchant Crude	15.1	15	14.3	8.9	7.5	13.4
TG – Merchant Gasoline	14.7	13.8	12.1	10.3	9.6	16.1
TL – Merchant Chemical	14.1	13.9	13.5	10.3	9.4	13.6
TT – Merchant (Tanker)	14.5	13.7	13.6	9.8	9.4	12.5
WS – Warship Surface:	24.7	15	14	10	10	10.4

-: Information not provided

2.14 Duration of Operation of Auxiliary Engines by Vessel Class

The 2006 Inventory assumed that all vessel classes use separate auxiliary diesel engines for electrical power at all times. Through anecdotal information received during site visits, or through the comments field on the survey form it was found that 60% of the Tankers, and 22% of both the Merchant Bulk and Merchant Container ships surveyed use shaft generators while underway. This would indicate that the assumptions for auxiliary engine use in the 2006 Inventory may overestimate emissions.

The relative impact of auxiliary engine emissions would be greatest while alongside because either the auxiliary engines are not operating while underway, or because the contribution to overall emissions from the auxiliary engines would be small relative to propulsion engine emissions while underway. Table 2-13 presents the data for average port time for loading and unloading, which would dictate the time that auxiliary engines would be operated while alongside. It can be difficult to interpret and estimate an average port time per vessel class because some vessels will unload and load in a single port, while (and perhaps more often) other vessels will unload in one port and transit to another port to take on cargo. Loading and unloading times may be significantly different for vessels of the same class.

Table 2-13: Average Port Time for Loading and Unloading

INNAV Vessel Class	Port Time Unloading (hr)	Port Time Loading (hr)	Avg Port Time from 2006 Study (hr)
HT – Tugs	-	-	64.1
MA – Merchant Auto	-	-	10.0
MB – Merchant Bulk	21	18	59.4
MC – Merchant Container	24	21	38.4
MF – Merchant Ferry	0.6	0.7	1.0
MG – Merchant General	72	43	57.2
MH – Merchant RO/RO	40	39	44.2
MM – Merchant (Dry)	33	62	3.9
MO – Merchant Ore	-	-	27.9
MP – Merchant Passenger	36	36	40.5
MR – Merchant Reefer	-	-	56.2
MS – Merchant Coastal	-	-	47.7
SC – Cable Ship	48	-	N/A
TC – Merchant Crude	28	30	35.2
TG – Merchant Gasoline	26	18	27.3
TL – Merchant Chemical	29	24	33.2
TM – Merchant Molasses	-	-	55.4
TO – Merchant Ore/Bulk/Oil	-	-	77.0
TQ – Merchant Liquified Gas	-	-	54.7
TS – Merchant Super Tanker	-	-	37.4
TT – Merchant (Tanker)	46	24	37.9
TU – Merchant ULCC	-	-	33.0
TV – Merchant VLCC	-	-	45.2
WR – Warship – General	-	-	71.8
WS – Warship Surface	-	-	48.5

-: Information not provided

2.15 Auxiliary and Exhaust Boilers

Many vessels have an exhaust boiler that is used for heating purposes when the main engine is operating to eliminate the requirement of an auxiliary boiler at sea. A smaller percentage of vessels use a composite boiler (exhaust boiler complimented by an auxiliary boiler). The boilers in vessels not equipped that way can burn between 0.5 – 1 Mt of fuel per day. If the cargo, such as petroleum product, is heated during transport then the auxiliary boiler can burn up to 14 Mt per day depending on the requirement. Table 2-14 provides the survey data for average boiler fuel consumption and the percent time used for those Vessel Classes that reported boiler use. Although there was a considerable degree of variability in reported boiler use and associated fuel consumption, the data for merchant bulk was fairly consistent and the average boiler fuel consumption rate for merchant bulk ships in the EC/GL region was found to be a close match to the bulk carrier ships characterized as part of the B.C. Chamber of Shipping Inventory and Puget Sound Inventory [5].

From anecdotal information collected during the on-site surveys or through the comments field on the survey form it was reported that 44% of the Merchant Container, 33% of the Tankers and 11% of the Merchant Bulk ships surveyed use exhaust gas recirculation for hot water while underway.

Table 2-14: Boiler Use by Vessel Class

Vessel Class	% Vessels with Boilers Reported	% Boilers using Distillate	% Boilers using Residual	Average Fuel Daily Fuel Consumption (Mt/day)	Percent (%) Time Boiler Used
MB – Merchant Bulk	65	73	27	1.5	58
MC – Merchant Container	34	20	80	2.9	37
MG – Merchant General	50	67	33	1.5	52
MH – Merchant RO/RO	91	30	70	1.5	43
MM – Merchant (Dry)	86	50	50	1.0	47
TC – Merchant Crude	67	0	100	15	25
TG – Merchant Gasoline	33	100	0	1.6	100
TL – Merchant Chemical	46	0	100	1.4	43
TT – Merchant (Tanker)	82	0	100	5.4	55
WS – Warship Surface	67	100	0	0.2	100
ALL VESSELS	58	46	54	2.6	54

2.16 Estimation of Main and Auxiliary Engines Compliant with IMO NOx Emission Limits

The vessel survey database and an extract from the CCG database for the period covering 2004 through 2006 were evaluated to estimate the proportion of vessels operating in the EC/GL region that can currently be expected to meet MARPOL 73/78 NOx limits for ships built in 2000 or later. The INNAV data included information for 5,149 ships, of which 356 had ‘0’ indicated for the year of build. Of the remaining 4,793 records, 28% of the ships have a reported year of build of 2000 or later. It was noted that 116 ships were reported to have been build before 1950, making them more than 60 years old. It is suspected that the INNAV data may contain records for inactive ships, which, if they were removed from the dataset, would increase the percentage of the remaining vessels with a build date of 2000 or later.

When the same analysis was applied to the data from the WME vessel surveys, it was found that of the 167 surveys, 29% of ships had a reported build date of 2000 or later. If one separates out the 83 Canadian Flagged ships, only four ships, or 5% have a build date of 2000 or later. The oldest Canadian ship surveyed was built in the 1950s, with 60% of the vessels surveyed being newer than 1980.

There was good agreement between the most recent extract of INNAV data and the WME survey database for the overall proportion of ships operating in the EC/GL region that have a year of build of 2000 or greater. Based on this, approximately 25 to 30% of ships operating in the EC/GL region can be assumed to comply with the MARPOL 73/78 NOx emissions requirements.

3.0 ECONOMIC GROWTH FACTORS UPDATE

3.1 Methodology

The port authorities of twelve major ports in the EC/GL region were contacted by WME, and asked to provide their cargo forecasts in terms of tonnage of commodities transported or number of ship visits. These ports included for example the ports of Montreal, Halifax, St. John’s, St. John, Quebec, Sarnia and Windsor. The typical response from most of these ports indicated that no forecast data was available, but only historical data to year 2005 on aggregate tonnage of commodities transported. Some port authorities suggested applying an annual growth rate between 1% and 2% as a rough estimate of future marine traffic. This was based on projections included in port business plans.

In addition to the port authorities, WME contacted the Canadian Coast Guard (CCG), Statistics Canada, and the Great Lakes St. Lawrence Seaway Study. However, no forecast from these organizations was available. Furthermore, discussion with the CSA and the Shipping Federation of Canada indicated that although some member companies might have developed a forecast for their share of marine traffic in the EC/GL region, they would be reluctant to release such estimates. In any event, such forecasts would be fragmented and would not provide representative data on the EC/GL region as a whole.

The only comprehensive marine traffic forecast available was from the Transport Canada Surface and Marine Statistics and Forecasts Branch. These relevant and useful data files and statistics on marine traffic were received in the form of MS Excel files and pivot tables. The data covered, for example, the “Marine Traffic Flows” by major commodities for the years 1990 to 2002, and the forecast to year 2020 by tonnage of each commodity; historical data for years 2003 and 2004 on “Marine Traffic Flows” by major commodities; and types of commodities carried by Transport Canada vessel class in the years 2000 to 2004.

The data received was reviewed by WME and its interpretation was discussed with Transport Canada Surface and Marine Statistics and Forecasts Branch. The commodity forecast predicts the tonnage of each of the major commodities expected to be transported in years 2010 and 2020, and is based on historical data up to the year 2002. The forecast had not been updated since it was originally developed.

However, the historical data for years 2003 and 2004 on the same major commodities was also available, and could be used to update the commodities forecast. The data provided by Transport Canada on commodities carried by vessel classes in years 2000 to 2004 covered the 44 different vessel classes recognized by Transport Canada. It should be noted that the only commodities forecast available from Transport Canada covers all Canadian regions. No forecast specific for the EC/GL region was developed; however, Transport Canada indicated that some of the pivot tables could be manipulated to provide historical data specific for the EC/GL region.

The steps followed to update the economic cargo growth factors based on the data received from Transport Canada are summarized as follows.

The historical data on the actual tonnage of major commodities transported in years 2003 and 2004 was compared to the tonnage that had been forecasted for these years (see Table 3-1). For approximately 87% of all commodities, similar trends were observed for both years, i.e. for both years the original forecast was either overestimated or underestimated in comparison to the historical data. For the remaining commodities, the forecast for one year was overestimated while being underestimated for the other year.

i. To capture these variations while avoiding any skewed data, which might have been due to temporary conditions, it was decided to use the average of the two years (2003 and 2004) to calculate a correction factor for each commodity. The correction factor represents the percent difference between the historical and the forecasted tonnage transported for each commodity (see Table 3-1).

ii. The correction factor was then applied to the original forecast for years 2010 and 2020 provided by Transport Canada, to calculate a corrected commodity forecast for these years (see Table 3-2). This is based on the assumptions that the factors that affected the years 2003 and 2004 will persist to year 2020, and that all other factors previously used to develop the forecast for years 2010 and 2020 remain unchanged.

iii. The ratio of each commodity carried in the EC/GL region (average of 2003 and 2004 data) compared to the data for all of Canada was calculated (column 7 of Table 3-2). This ratio was used to calculate the Corrected Forecast of each commodity for EC/GL for 2010 and 2020 (columns 8 and 9).

iv. A growth factor for each commodity for year 2010 was then calculated based on the corrected commodity forecast for that year in comparison to the average historical data for years 2003 and 2004 (see Table 3-3). Each of these growth factors, which could be more or less than 1.00, indicating an increase or a decrease in tonnage of commodity transported, represents the percent difference between the average tonnage of the commodity transported in years 2003 and 2004, and the corrected forecast for the year 2010 for that commodity. A growth factor for each commodity for year 2020 was calculated in a similar fashion (see Table 3-3).

v. These growth factors were then applied to the data files provided by Transport Canada on the different commodities transported in years 2003 and 2004. The Transport Canada data was divided into 44 vessel classes. The vessel classes used by Transport Canada are based on the International Classification of Ships by Type (ICST), which was developed by an ad hoc advisory group on Maritime Statistics in 1994.

vi. The outcome presented the projected tonnage of each of the major commodities transported by each of the ICST vessel classes for years 2010 and 2020. The total tonnage expected to be transported by each of the 44 ICST vessel classes for each of years 2010 and 2020 was then calculated by adding up the projected tonnage of each commodity transported by each vessel class (see Table 3-4).

vii. The 24 INNAV vessel classes (INNAV Gen-Type) were matched-up with the 44 ICST vessel classes (see Table 3-5). Thus, the projected total tonnage transported by each of the INNAV vessel classes in years 2010 and 2020 was calculated (see Table 3-6). The total tonnage transported by each of the INNAV vessel classes in year 2002 was also calculated in a similar fashion (see Table 3-6).

viii. An updated economic cargo growth factor for each class of marine vessels, using the INNAV vessel classes, was calculated by comparing the projected total tonnage to be transported in years 2010 and 2020 by each of the INNAV vessel classes to that transported in the base year 2002 (see Table 3-6).

3.2 Results

The updated economic growth factors for the EC/GL region are provided in Table 3-6.

3.2.1 Historical versus Original Forecasted Tonnage for Years 2003 and 2004 for Canada

By comparing the originally forecasted tonnage to the historical tonnage of the major commodities, as shown in Table 3-1, the original forecast for 24 commodities was underestimated. Ten of these commodities were grossly underestimated by more than 25%, such as plastics and rubber products which were underestimated by 66%, alcoholic and non-alcoholic beverages which were underestimated by a factor of 2, and parts and accessories for motor vehicles which were underestimated by a factor of approximately 32 times. Twenty-two other commodities were overestimated. On average, the forecasted tonnage for all the major commodities combined was underestimated by 4.3%.

3.2.2 Vessel Classes

The data provided by Transport Canada on marine traffic is based on the major commodities transported by each of the 44 Transport Canada vessel classes. In order to determine the economic cargo growth factors for each of the 24 INNAV vessel classes, and since no recognized correlation between these vessel classes had been established, an assignment had to be made to correlate the Transport Canada and INNAV vessel classes. However, it is often difficult to assign a definitive class since many vessels carry multiple cargos. Therefore, any assignment would be based on the “usual” cargo transported by each vessel class. Table 3-5 provides the allocation of the 44 Transport Canada vessel classes to the 24 INNAV vessel classes, which is based on the similarity of transported cargos.

3.2.3 Growth Factors for Passenger Carriers and Warships

Based on the data provided by Transport Canada and as indicated in Table 3-4, some vessel classes carry a combination of cargo and passengers. For example; in year 2002 the Transport Canada vessel class Ro-Ro Passenger carried 820 Mt (of animal feed and products), in year 2003 it carried 6,409 Mt (of meat, fish, seafood, articles of base metal, etc.), and in year 2004 it carried a total of 18,857 Mt (of meat, fish, seafood, autos and other equipment, articles of base metals among other commodities). The manipulation of the tonnage of cargo associated with this class of vessels resulted in a growth factor of 16.983 / 17.468 for years 2010 / 2020 for the Merchant Ferry INNAV vessel class (see Tables 3-5 and 3-6). While these factors are applicable to the cargo portion of the Merchant Ferries activities, it does not reflect the passenger related activities of this vessel class. Therefore, it is unrealistic to expect that the Merchant Ferries total activities to grow by such factors.

Another example of vessels carrying both cargo and passengers is the Cruise vessel class. According to Transport Canada data, in 2002 this class carried 1,611 Mt (of autos and other equipment). In years 2003 and 2004, there was no cargo carried on this class of vessels. This resulted in a growth factor of 0.00 for the Merchant Passenger INNAV vessel class (see Tables 3-5 and 3-6). Although such factors are correctly projected for the cargo portion of the Merchant Passenger activities, it is unrealistic to extend them to cover the passenger-related activities of this vessel class.

Since the forecast and historical data provided by Transport Canada, which are the only available data, focussed on the major commodities transported by different vessel classes, and do not address the transport of passengers, the calculated growth factors for the vessel classes that carry only passengers or a combination of cargo and passengers, should be assigned a growth factor of 1.00. Similarly, since the Transport Canada data does not address the activities associated with the INNAV vessel classes identified as WR and WS, a growth factor of 1.00 should be assigned to these classes for years 2010 and 2020.

3.2.4 Assumptions and Factors Affecting the Accuracy of Results

Throughout the process of manipulating the data to calculate the updated economic cargo growth factors, the results of the calculations were verified to ensure that no data was unintentionally dropped from the calculations. For example, the total tonnage of all major commodities was repeatedly verified throughout the process. This was of particular importance when allocating the projected tonnage of major commodities to the different ICST vessel classes (see Tables 3-3 and 3-4). The maximum deviation ever found was 0.15%, which is mainly due to rounding of large numbers.

With the somewhat arbitrary nature of vessel class assignment due to the lack of an established correlation between the ICST vessel classes and the INNAV vessel classes, different assignments would generate different economic cargo growth factors. It is important that a consistent correlation of different vessel classes be established and agreed upon by the various stakeholders.

Table 3-1: Original Forecast versus Historical Tonnage of Major Commodities for Years 2003 and 2004

Major Commodity	Original Transport Canada Forecast for Years			Historical Data for Years			Correction Factor
	2003	2004	Average	2003	2004	Average	
Alcoholic and Non-Alcoholic Beverages	79,815	90,634	85,225	248,073	272,476	260,274	3.0539741
Animal Feed and Products	926,897	919,084	922,990	534,560	771,864	653,212	0.7077127
Articles of Base Metal	771,426	799,611	785,519	767,132	955,476	861,304	1.0964778
Autos and Other Equipment	588,973	602,121	595,547	505,877	445,343	475,610	0.7986105
Basic Chemicals	10,555,112	10,668,581	10,611,846	10,104,731	10,232,193	10,168,462	0.958218
Canola	3,552,355	3,913,432	3,732,893	3,237,601	3,081,366	3,159,484	0.84639
Cement	4,550,594	4,555,666	4,553,130	4,383,143	4,814,746	4,598,945	1.0100622
Coal	50,795,389	51,448,275	51,121,832	48,526,960	45,498,069	47,012,515	0.9196172
Containerized	27,177,443	28,004,321	27,590,882	28,711,747	31,787,089	30,249,418	1.0963556
Crude Petroleum	61,835,409	61,260,046	61,547,727	75,826,251	78,141,176	76,983,714	1.250797
Electronic, Electrical Equipment and Office Equipment	177,783	172,388	175,086	184,365	200,704	192,534	1.0996587
Fertilizers	1,117,064	1,141,639	1,129,351	1,400,654	1,164,034	1,282,344	1.1354695
Fuel Oils	15,100,993	14,986,747	15,043,870	17,095,502	16,552,865	16,824,183	1.1183414
Gasoline and Aviation Turbine Fuel	15,400,119	15,788,193	15,594,156	15,145,450	15,175,367	15,160,408	0.9721852
Gypsum	8,060,858	8,144,824	8,102,841	7,359,926	8,196,823	7,778,375	0.9599565
Iron and Steel – Primary and Semi-Finished	3,989,683	3,803,250	3,896,466	2,701,546	3,374,107	3,037,826	0.7796362
Iron Ore and Concentrates	40,537,265	41,319,923	40,928,594	41,920,847	38,073,177	39,997,012	0.9772388
Live Animals	2,936	3,192	3,064	2,187	2,327	2,257	0.7366785
Logs and Other Wood in the Rough	6,972,792	7,126,091	7,049,441	7,275,006	6,703,801	6,989,404	0.9914834
Lpgs and Other Refined Petroleum & Coal Products	4,848,037	5,054,827	4,951,432	7,146,551	6,959,247	7,052,899	1.4244159
Lumber	2,531,554	2,402,006	2,466,780	1,876,873	2,097,268	1,987,070	0.805532
Machinery	148,548	155,272	151,910	228,806	191,687	210,247	1.3840242
Meat, Fish, Seafood	188,160	198,430	193,295	607,928	647,991	627,959	3.2487044
Mixed Loads or Unidentified Freight or Cargo	403,317	396,597	399,957	549,518	525,656	537,587	1.3441113
Newsprint	3,134,348	3,176,124	3,155,236	3,006,841	2,528,551	2,767,696	0.8771756
Non-Ferrous Metals – Primary and Semi-Finished	691,140	678,610	684,875	789,315	906,405	847,860	1.2379769

Table 3-1 (cont.)

Major Commodity	Original Transport Canada Forecast for Years			Historical Data for Years			Correction Factor
	2003	2004	Average	2003	2004	Average	
Other Agricultural Products	5,081,867	5,178,930	5,130,398	3,329,663	3,600,581	3,465,122	0.6754099
Other Cereal Grains	2,416,664	2,714,641	2,565,652	1,873,220	2,350,409	2,111,814	0.82311
Other Chemical Products & Preparations	36,035	39,806	37,920	28,691	33,474	31,082	0.8196733
Other Manufactured and Miscellaneous Goods	48,281	48,395	48,338	22,843	12,931	17,887	0.3700324
Other Metallic Ores and Concentrates	8,979,054	9,073,536	9,026,295	8,188,026	7,755,962	7,971,994	0.8831967
Other Non-Metallic Mineral Products	416,472	460,687	438,579	992,746	1,348,713	1,170,729	2.6693673
Other Non-Metallic Minerals	2,630,509	2,537,992	2,584,251	2,551,796	2,974,555	2,763,175	1.0692366
Other Wood Products (Plywood, Veneer, Etc)	164,444	161,584	163,014	74,358	93,587	83,972	0.5151239
Paper and Paperboard	415,679	394,695	405,187	266,015	258,960	262,487	0.6478177
Parts and Accessories For Motor Vehicles	435	476	455	19,425	11,093	15,259	33.499936
Plastic and Rubber Products	35,752	41,231	38,492	61,999	65,998	63,999	1.6626612
Potash	4,959,322	4,853,248	4,906,285	5,965,505	7,262,742	6,614,124	1.348092
Prepared Foods	2,374,276	2,375,109	2,374,693	2,395,893	2,731,955	2,563,924	1.0796868
Salt	8,357,124	8,220,713	8,288,918	8,835,444	9,378,865	9,107,155	1.0987145
Stone, Sand, Gravel and Crushed Stone	20,124,292	20,948,330	20,536,311	21,394,567	23,596,003	22,495,285	1.0953907
Sulphur	4,823,823	5,091,915	4,957,869	5,630,865	6,453,568	6,042,217	1.2187125
Waste and Scrap	3,427,653	3,497,036	3,462,345	3,773,531	4,262,881	4,018,206	1.1605448
Wheat	17,543,874	19,780,056	18,661,965	15,436,525	18,276,085	16,856,305	0.9032438
Wood Chips	8,701,346	8,860,114	8,780,730	8,896,076	8,877,334	8,886,705	1.0120691
Wood Pulp	5,729,926	5,703,827	5,716,876	5,061,510	4,786,043	4,923,776	0.8612704
Total	360,404,841	366,792,204	363,598,522	374,936,088	383,431,547	379,183,816	-

Note 1: All tonnage reported in metric tons.
Note 2: Correction Factor = 1 + [(Historical Data – Forecast Data) / Forecast Data]

Table 3-2: Corrected Commodity Forecast for Years 2010 and 2020 (Eastern Canada)

Major Commodity	Original Forecast for Years (Canada)		Correction Factor	Corrected Forecast for Years (Canada)		Ratio of Eastern Canada/ Canada	Corrected Forecast for Years (Eastern Canada)	
	2010	2020		2010	2020		2010	2020
Alcoholic and Non-Alcoholic Beverages	110,696	110,011	3.0539741	338,064	335,969	0.991938523	335,339	333,261
Animal Feed and Products	857,902	849,346	0.7077127	607,148	601,093	0.38979107	236,661	234,301
Articles of Base Metal	814,977	839,724	1.0964778	893,604	920,739	0.591672192	528,721	544,776
Autos and Other Equipment	640,668	728,275	0.7986105	511,644	581,608	0.228141224	116,727	132,689
Basic Chemicals	11,117,695	11,997,455	0.958218	10,653,175	11,496,178	0.677929317	7,222,100	7,793,596
Canola	3,777,844	4,050,107	0.84639	3,197,529	3,427,971	0.139263977	445,301	477,393
Cement	4,770,411	5,107,033	1.0100622	4,818,412	5,158,421	0.836359398	4,029,924	4,314,294
Coal	52,212,107	54,130,585	0.9196172	48,015,151	49,779,416	0.466655052	22,406,513	23,229,816
Containerized	33,504,469	45,298,953	1.0963556	36,732,813	49,663,761	0.530246318	19,477,439	26,334,026
Crude Petroleum	62,639,468	65,152,939	1.250797	78,349,260	81,493,101	0.991411199	77,676,334	80,793,173
Electronic, Electrical Equipment and Office Equipment	166,652	167,000	1.0996587	183,260	183,644	0.982540892	180,060	180,438
Fertilizers	1,120,807	1,120,877	1.1354695	1,272,642	1,272,722	0.671423897	854,482	854,536
Fuel Oils	15,944,657	17,203,944	1.1183414	17,831,570	19,239,883	0.90758531	16,183,671	17,461,835
Gasoline and Aviation Turbine Fuel	16,673,390	17,848,208	0.9721852	16,209,624	17,351,764	0.933032161	15,124,101	16,189,754
Gypsum	8,396,789	8,948,229	0.9599565	8,060,551	8,589,911	0.965214042	7,780,157	8,291,103
Iron and Steel – Primary and Semi-Finished	3,919,989	4,166,277	0.7796362	3,056,166	3,248,180	0.794788136	2,429,004	2,581,615
Iron Ore and Concentrates	42,464,776	46,617,712	0.9772388	41,498,228	45,556,639	0.997506602	41,394,756	45,443,048
Live Animals	3,118	3,127	0.7366785	2,297	2,304	0.149410454	343	344
Logs and Other Wood in the Rough	7,947,022	9,459,304	0.9914834	7,879,340	9,378,743	0.015008134	118,254	140,757
Lpgs and Other Refined Petroleum & Coal Products	5,334,679	5,313,982	1.4244159	7,598,802	7,569,321	0.872184649	6,627,558	6,601,846
Lumber	2,375,743	2,378,340	0.805532	1,913,737	1,915,829	0.10445043	199,891	200,109
Machinery	161,455	190,602	1.3840242	223,457	263,798	0.558261143	124,747	147,268
Meat, Fish, Seafood	250,256	251,163	3.2487044	813,008	815,955	0.178328713	144,983	145,508
Mixed Loads or Unidentified Freight or Cargo	395,909	396,456	1.3441113	532,146	532,881	0.990437663	527,057	527,785
Newsprint	3,190,834	3,281,491	0.8771756	2,798,921	2,878,444	0.602238253	1,685,617	1,733,509
Non-Ferrous Metals – Primary and Semi-Finished	682,303	699,438	1.2379769	844,675	865,888	0.716935719	605,578	620,786
Other Agricultural Products	5,613,448	6,659,407	0.6754099	3,791,379	4,497,829	0.791947178	3,002,572	3,562,043
Other Cereal Grains	2,610,978	2,660,221	0.82311	2,149,122	2,189,655	0.641553979	1,378,778	1,404,782
Other Chemical Products & Preparations	43,640	43,149	0.8196733	35,771	35,368	0.301315906	10,778	10,657
Other Manufactured and Miscellaneous Goods	47,472	47,486	0.3700324	17,566	17,571	0.724203085	12,721	12,725
Other Metallic Ores and Concentrates	9,309,345	9,973,590	0.8831967	8,221,983	8,808,642	0.839132865	6,899,336	7,391,621
Other Non-Metallic Mineral Products	548,992	547,473	2.6693673	1,465,462	1,461,406	0.851903417	1,248,432	1,244,977
Other Non-Metallic Minerals	2,703,440	2,731,960	1.0692366	2,890,617	2,921,112	0.93731445	2,709,417	2,738,000
Other Wood Products (Plywood, Veneer, Etc)	161,526	161,920	0.5151239	83,206	83,409	0.309257149	25,732	25,795
Paper and Paperboard	387,104	386,786	0.6478177	250,773	250,567	0.397008195	99,559	99,477
Parts and Accessories For Motor Vehicles	416	415	33.499936	13,929	13,902	0.35474842	4,941	4,932
Plastic and Rubber Products	43,268	42,877	1.6626612	71,939	71,290	0.853244946	61,382	60,828
Potash	4,886,798	4,893,760	1.348092	6,587,853	6,597,239	0.239407409	1,577,181	1,579,428
Prepared Foods	2,460,984	2,668,566	1.0796868	2,657,092	2,881,215	0.648976107	1,724,389	1,869,840
Salt	8,565,341	8,964,670	1.0987145	9,410,864	9,849,612	0.943029653	8,874,724	9,288,476
Stone, Sand, Gravel and Crushed Stone	21,838,566	23,554,109	1.0953907	23,921,763	25,800,953	0.706365498	16,897,508	18,224,903

Table 3-2 (cont.)

Major Commodity	Original Forecast for Years (Canada)		Correction Factor	Corrected Forecast for Years (Canada)		Ratio of Eastern Canada/ Canada	Corrected Forecast for Years (Eastern Canada)	
	2010	2020		2010	2020		2010	2020
Sulphur	5,408,023	5,972,928	1.2187125	6,590,826	7,279,282	0.01059207	69,810	77,103
Waste and Scrap	3,720,654	4,215,807	1.1605448	4,317,985	4,892,633	0.78463315	3,388,034	3,838,922
Wheat	20,120,264	21,353,805	0.9032438	18,173,504	19,287,693	0.554996399	10,086,229	10,704,600
Wood Chips	9,259,217	9,888,919	1.0120691	9,370,967	10,008,269	0.023967615	224,600	239,874
Wood Pulp	5,743,104	6,567,049	0.8612704	4,946,365	5,656,005	0.168176499	831,862	951,207
TOTAL	382,947,196	417,645,475	-	399,804,190	435,727,815	-	285,583,305	308,637,755

Table 3-3: Growth Factors of Commodity Forecast for Years 2010 and 2020 Relative to Historical Data for Years 2003 and 2004 (EC/GL)

Major Commodity	Historical Average for Years 2003 and 2004 (Eastern Canada)	Corrected Forecast for Years (Eastern Canada)		Growth Factors (Relative to Years 03 and 04) for Years	
		2010	2020	2010	2020
Alcoholic and Non-Alcoholic Beverages	259,279	335,339	333,261	1.293351	1.285336
Animal Feed and Products	249,883	236,661	234,301	0.947087	0.937642
Articles of Base Metal	460,032	528,721	544,776	1.149313	1.184213
Autos and Other Equipment	95,764	116,727	132,689	1.218904	1.385581
Basic Chemicals	7,074,203	7,222,100	7,793,596	1.020906	1.101692
Canola	476,403	445,301	477,393	0.934714	1.002078
Cement	3,776,396	4,029,924	4,314,294	1.067135	1.142437
Coal	21,812,309	22,406,513	23,229,816	1.027242	1.064987
Containerized	15,136,716	19,477,439	26,334,026	1.286768	1.739745
Crude Petroleum	76,277,236	77,676,334	80,793,173	1.018342	1.059204
Electronic, Electrical Equipment and Office Equipment	188,970	180,060	180,438	0.952852	0.954849
Fertilizers	859,200	854,482	854,536	0.994509	0.994572
Fuel Oils	15,225,460	16,183,671	17,461,835	1.062935	1.146884
Gasoline and Aviation Turbine Fuel	14,268,847	15,124,101	16,189,754	1.059939	1.134622
Gypsum	7,548,055	7,780,157	8,291,103	1.03075	1.098442
Iron and Steel – Primary and Semi-Finished	2,426,475	2,429,004	2,581,615	1.001042	1.063936
Iron Ore and Concentrates	39,753,051	41,394,756	45,443,048	1.041298	1.143134
Live Animals	45	343	344	7.626574	7.649815
Logs and Other Wood in the Rough	140,206	118,254	140,757	0.843432	1.003933
Lpgs and Other Refined Petroleum & Coal Products	6,104,103	6,627,558	6,601,846	1.085755	1.081542
Lumber	153,240	199,891	200,109	1.304429	1.305855
Machinery	123,048	124,747	147,268	1.013811	1.196835
Meat, Fish, Seafood	74,657	144,983	145,508	1.941984	1.949023
Mixed Loads or Unidentified Freight or Cargo	535,099	527,057	527,785	0.984972	0.986332
Newsprint	1,615,487	1,685,617	1,733,509	1.043411	1.073057
Non-Ferrous Metals – Primary and Semi-Finished	620,788	605,578	620,786	0.975498	0.999997
Other Agricultural Products	2,836,888	3,002,572	3,562,043	1.058403	1.255616
Other Cereal Grains	1,283,083	1,378,778	1,404,782	1.074582	1.094849
Other Chemical Products & Preparations	8,700	10,778	10,657	1.238893	1.224936
Other Manufactured and Miscellaneous Goods	16,206	12,721	12,725	0.784978	0.785201
Other Metallic Ores and Concentrates	6,849,679	6,899,336	7,391,621	1.00725	1.079119
Other Non-Metallic Mineral Products	1,040,462	1,248,432	1,244,977	1.199882	1.196561
Other Non-Metallic Minerals	2,636,329	2,709,417	2,738,000	1.027723	1.038566
Other Wood Products (Plywood, Veneer, Etc)	4,607	25,732	25,795	5.585424	5.599051
Paper and Paperboard	87,515	99,559	99,477	1.137621	1.136687

Table 3-3 (cont.)

Major Commodity	Historical Average for Years 2003 and 2004 (Eastern Canada)	Corrected Forecast for Years (Eastern Canada)		Growth Factors (Relative to Years 03 and 04) for Years	
		2010	2020	2010	2020
Parts and Accessories For Motor Vehicles	436	4,941	4,932	11.33324	11.31127
Plastic and Rubber Products	55,175	61,382	60,828	1.112489	1.102453
Potash	1,380,284	1,577,181	1,579,428	1.142649	1.144277
Prepared Foods	1,616,221	1,724,389	1,869,840	1.066927	1.156921
Salt	8,657,700	8,874,724	9,288,476	1.025067	1.072857
Stone, Sand, Gravel and Crushed Stone	15,534,944	16,897,508	18,224,903	1.08771	1.173155
Sulphur	64,753	69,810	77,103	1.078104	1.19072
Waste and Scrap	3,071,803	3,388,034	3,838,922	1.102946	1.249729
Wheat	10,211,052	10,086,229	10,704,600	0.987776	1.048335
Wood Chips	193,289	224,600	239,874	1.161989	1.241014
Wood Pulp	837,973	831,862	951,207	0.992708	1.135129
Total	271,642,050	285,583,305	308,637,755	-	-

Note 1: All tonnage reported in metric tons.

Note 2: Growth Factor For 2010 = 1 + [(Corrected Forecast For 2010 – Historical Average For 2003 and 2004) / Historical Average For 2003 and 2004)]

Note 3: Growth Factor For 2020 = 1 + [(Corrected Forecast For 2020 – Historical Average For 2003 and 2004) / Historical Average For 2003 and 2004)]

Table 3-4: Projected Total Tonnage for Years 2010 and 2020 by ICST Vessel Class (EC/GL)

ICST Vessel Code	ICST Vessel Class	Historical Total Tonnage for Year 2002	Historical Average Total Tonnage for Years 2003 and 2004	Projected Total Tonnage for Years		Notes
				2010	2020	
1,100	Oil Tanker	27,039,075	32,197,076	32,866,559	34,223,833	
1,110	Crude Oil Tanker	33,406,977	45,676,361	46,671,833	48,658,583	
1,120	Crude/products Tanker	12,038,390	12,359,089	13,044,147	13,875,268	
1,130	Oil Products Tanker	9,162,751	9,130,192	9,675,787	10,354,824	
1,140	Oil/chemical Tanker	4,743,435	5,513,913	5,831,584	6,216,141	
1,200	Chemical Tanker	2,266,035	2,613,875	2,741,764	2,935,406	
1,300	Liquefied Gas Carrier	0	0	0	0	1
1,310	Lpg Carrier	68,450	121,680	129,401	136,758	
2,100	Bulk Oil Carrier	126,191	206,353	212,396	225,800	
2,110	Ore/Bulk/Oil	2,143,212	3,120,560	3,221,984	3,433,162	
2,120	Ore/oil	280,255	0	0	0	1
2,200	Bulk Carrier	25,411,271	27,455,606	28,560,906	30,869,491	
2,210	Ore Carrier	1,886,668	1,987,403	2,006,653	2,153,294	
2,220	Bulk/container Carrier	483,796	243,227	250,907	266,134	
2,290	Other Bulk Carrier	103,530,523	104,110,583	108,444,316	115,784,066	
3,100	Container	12,454,791	13,678,988	17,591,419	23,770,613	
3,200	Specialized Carrier	778,270	699,580	822,058	1,238,601	
3,210	Barge Carrier	0	18	20	23	1
3,240	Livestock Carrier	0	0	0	0	1
3,250	Vehicle Carrier	712,080	679,786	863,384	1,459,014	
3,290	Other Specialized Carrier	689,888	593,629	621,303	644,672	
3,300	General Cargo	1,402,135	1,806,813	1,890,586	2,025,718	
3,310	Reefer	66,126	95,489	137,672	146,954	
3,320	Ro-ro Passenger	820	9,469	12,838	13,066	
3,330	Ro-ro Container	0	0	0	0	1
3,340	Other Ro-ro Cargo	1,645,259	1,639,728	1,759,784	1,935,972	
3,350	General Cargo / Passenger	0	8,760	8,738	9,589	
3,360	General Cargo / Container	17,275	8,705	9,029	10,224	
3,370	General Cargo / Single Deck	1,793,505	1,550,774	1,640,529	1,780,625	
3,380	General Cargo / Multi Deck	878,903	850,373	903,233	972,108	
3,400	Dry Cargo Barge	4,025,128	4,703,977	4,966,479	5,288,866	
3,500	Passenger	0	0	0	0	1
3,510	Cruise	0	0	0	0	1
4,100	Fish Processing and Catching	4,114	6,121	11,863	11,909	
4,110	Fish Processing	0	0	0	0	1
4,120	Fish Catching	0	145,709	148,541	154,489	
4,200	Offshore Production and Support	82,674	53,978	63,562	63,852	
4,210	Offshore Drilling and Exploration	0	0	0	0	1
4,220	Offshore Support	209,168	305,295	359,828	362,398	
4,900	Tug	116,848	67,007	74,251	86,313	
4,910	Tug	0	0	0	0	1
4,920	Research Survey	0	0	0	0	1
4,930	Dredger	0	0	0	0	1
4,990	Other Not Elsewhere Indicated	0	1,931	1,888	1,989	2
TOTAL		**247,464,013**	**271,642,048**	**285,545,242**	**309,109,755**	4

Note 1: No data was indicated in the pivot tables provided by Transport Canada; therefore, considered nil.
Note 2: This Vessel Class includes icebreakers, cable ships, etc.
Note 3: All tonnage reported in metric tons.
Note 4: In comparison to Table 3-3, the projected total tonnage for year 2010 in Table 3-4 differs by 0.013%. The projected total tonnage for year 2020 differs by 0.15%.

Table 3-5: Canadian Coast Guard Vessel Class (INNAV) Correlation to Transport Canada Vessel Class

INNAV General Class		Similar ICST Vessel Classes		Notes
Code	Name	Code	Name	
HO	Tugs Ocean	4900 – 4910	Tug, Tug	
MA	Merchant Auto	3250	Vehicle Carrier	
MB	Merchant Bulk	2200 – 2220 – 2290	Bulk Carrier + Bulk / Container Carrier + Other Bulk carrier	
MC	Merchant Container	3100	Container	
MF	Merchant Ferry	3320	Ro-Ro Passenger	
MG	Merchant General	3300 – 3350 -3360 – 3370 – 3380 – 3200 – 3210 – 3290 – 4990 – 4920 – 3240	General Cargo + General Cargo / Passenger + General Cargo / Container + General Cargo Single Deck + General Cargo Multi-Deck + Specialized Carrier + Barge Carrier + Other Specialized Carrier + Other Not elsewhere included (icebreaker, cable ships, etc.) + Research Survey + Livestock Carrier	
MH	Merchant RO/RO	3340	Other Ro-Ro Cargo	
MM	Merchant (Dry)	3400	Dry cargo barge	
MO	Merchant Ore	2210 – 2120	Ore Carrier + Ore / oil Carrier	
MP	Merchant Passenger	3500 – 3510	Passenger + Cruise	
MR	Merchant Reefer	3310	Reefer	
MS	Merchant Coastal	4100 – 4110 – 4120 – 4210 – 4200 – 4220	Fish Processing and Catching + Fish Processing + Fish Catching + Offshore Drilling and Exploration + Offshore Production + Offshore Support	
TC	Merchant Crude	1110 – 2100	Crude Oil Tanker + Bulk Oil Carrier	1
TG	Merchant Gasoline	1130	Oil Products Tanker	
TL	Merchant Chemical	1200 – 1140	Chemical tanker + Oil / Chemical Tanker	2
TM	Merchant Molasses	1200	Chemical Tanker	2
TO	Merchant Ore/Bulk/Oil	2110	Ore / Bulk / Oil	
TQ	Merchant Liquefied Gas	1300 – 1310	Liquefied Gas Carrier + Lpg Carrier	
TS	Merchant Super Tanker	1100	Oil Tanker	
TT	Merchant (Tanker)	1120	Crude / Products Tanker	
TU	Merchant ULCC	1110	Crude Oil Tanker	1, 3
TV	Merchant VLCC	1110	Crude Oil Tanker	1, 3
WR	Warship – General	None	None	
WS	Warship – Surface	None	None	

Note 1: Crude Oil Tanker Tonnage to be divided equally among the three INNAV vessel classes.
Note 2: Chemical Tanker tonnage to be divided equally between the two INNAV vessel classes.
Note 3: ULCC (Ultra Large Crude Carrier), VLCC (Very Large Crude Carrier).

Table 3-6: Updated Economic Cargo Growth Factors for Years 2010 and 2020 Relative to Year 2002 by Canadian Coast Guard Vessel Classes (INNAV) (EC/GL)

INNAV General Class		Historical Total Tonnage for Year 2002	Projected Total Tonnage for Years		Updated Economic Cargo Growth Factors for Years		Notes
Code	Name		2010	2020	2010*	2020**	
HO	Tugs Ocean	116,848	74,251	86,313	0.635	0.739	
MA	Merchant Auto	712,080	863,384	1,459,014	1.212	2.049	
MB	Merchant Bulk	129,425,590	137,256,129	146,919,691	1.061	1.135	
MC	Merchant Container	12,454,791	17,591,419	23,770,613	1.412	1.909	
MF	Merchant Ferry	820	12,838	13,066	15.656	15.934	1
MG	Merchant General	5,559,976	5,897,384	6,683,549	1.061	1.202	
MH	Merchant RO/RO	1,645,259	1,759,784	1,935,972	1.070	1.177	
MM	Merchant (Dry)	4,025,128	4,966,479	5,288,866	1.234	1.314	
MO	Merchant Ore	2,166,923	2,006,653	2,153,294	0.926	0.994	
MP	Merchant Passenger	0	0	0	0.000	0.000	1
MR	Merchant Reefer	66,126	137,672	146,954	2.082	2.222	
MS	Merchant Coastal	295,956	583,794	592,648	1.973	2.002	
TC	Merchant Crude	11,261,850	15,769,674	16,445,328	1.400	1.460	
TG	Merchant Gasoline	9,162,751	9,675,787	10,354,824	1.056	1.130	
TL	Merchant Chemical	5,876,453	7,202,466	7,683,844	1.226	1.308	
TM	Merchant Molasses	1,133,018	1,370,882	1,467,703	1.210	1.295	
TO	Merchant Ore/Bulk/Oil	2,143,212	3,221,984	3,433,162	1.503	1.602	
TQ	Merchant Liquefied Gas	68,450	129,401	136,758	1.890	1.998	
TS	Merchant Super Tanker	27,039,075	32,866,559	34,223,833	1.216	1.266	
TT	Merchant (Tanker)	12,038,390	13,044,147	13,875,268	1.084	1.153	
TU	Merchant ULCC	11,135,659	15,557,278	16,219,528	1.397	1.457	2
TV	Merchant VLCC	11,135,659	15,557,278	16,219,528	1.397	1.457	2
WR	Warship – General	-	-	-	-	-	3
WS	Warship – Surface	-	-	-	-	-	3
All Vessel Classes		247,464,014	285,545,243	309,109,756			

All tonnage reported in metric tons.

Note 1: Use Growth Factors of 1.00, as discussed in subsection 3.3.3 of the report.
Note 2: ULCC (Ultra Large Crude Carrier), VLCC (Very Large Crude Carrier)
Note 3: No data was available on this vessel class. Use Growth Factors of 1.00, as discussed in the report.
*Updated Economic Cargo Growth Factor For Year 2010 = 1+ [(Projected Total Tonnage For year 2010 – Historical Total Tonnage For Year 2002) / Historical Total Tonnage For Year 2002]
** Updated Economic Cargo Growth Factor For Year 2020 = 1+ [(Projected Total Tonnage For year 2020 – Historical Total Tonnage For Year 2002) / Historical Total Tonnage For Year 2002]

Table 3-7: Comparison of Updated Economic Cargo Growth Factors for Canada and the EC/GL Region

INNAV Vessel Class		Original Economic Cargo Growth Factors for Years		Updated Economic Cargo Growth Factors for Years (Canada)		Economic Cargo Growth Factors for Years (EC/GL)	
Code	Vessel Class	2010	2020	2010	2020	2010	2020
HO	Tugs Ocean	1.09	1.29	1.010	1.200	0.635	0.739
MA	Merchant Auto	1.15	1.20	1.043	1.251	1.212	2.049
MB	Merchant Bulk	1.11	1.18	1.084	1.155	1.061	1.135
MC	Merchant Container	1.29	1.74	1.411	1.896	1.412	1.909
MF	Merchant Ferry	1.00	1.00	1.00	1.00	1.00	1.00
MG	Merchant General	1.12	1.22	1.042	1.147	1.061	1.202
MH	Merchant RO/RO	1.06	1.14	1.029	1.128	1.070	1.177
MM	Merchant (Dry)	1.11	1.18	1.147	1.244	1.234	1.314
MO	Merchant Ore	1.14	1.22	0.952	1.021	0.926	0.994
MP	Merchant Passenger	1.00	1.00	1.00	1.00	1.00	1.00
MR	Merchant Reefer	1.16	1.34	1.722	1.859	2.082	2.222
MS	Merchant Coastal	1.12	1.22	1.939	1.968	1.973	2.002
TC	Merchant Crude	1.06	1.11	1.393	1.452	1.400	1.460
TG	Merchant Gasoline	1.05	1.11	1.051	1.128	1.056	1.130
TL	Merchant Chemical	1.06	1.14	1.169	1.250	1.226	1.308
TM	Merchant Molasses	1.05	1.11	1.150	1.235	1.210	1.295
TO	Merchant Ore/Bulk/Oil	1.06	1.11	1.813	1.933	1.503	1.602
TQ	Merchant Liquefied Gas	1.02	1.08	1.306	1.331	1.890	1.998
TS	Merchant Super Tanker	1.06	1.11	1.207	1.258	1.216	1.266
TT	Merchant (Tanker)	1.05	1.11	1.106	1.178	1.084	1.153
TU	Merchant ULCC	1.06	1.11	1.396	1.455	1.397	1.457
TV	Merchant VLCC	1.06	1.11	1.396	1.455	1.397	1.457
WR	Warship – General	1.00	1.00	1.00	1.00	1.00	1.00
WS	Warship – Surface	1.00	1.00	1.00	1.00	1.00	1.00
All Vessel Classes		1.09	1.20	1.157	1.261	1.153	1.249

4. MARINE EMISSIONS INVENTORY TOOL MODIFICATIONS

The Marine Emissions Inventory Tool was originally developed for Environment Canada in 2005 to support a national marine emissions inventory. It is an MS Access database application that contains a number of routines that calculate emissions based on commercial marine vessel activity. This includes domestic and internationally flagged vessels used for:

- international and domestic freight and passenger transport;
- workboats in Canadian waters; and
- defence and regulatory activities by the Canadian government.

The Marine Tool was designed to estimate emissions of the following air contaminants:

- suspended particulate matter (total particulate matter, PM10 and PM2.5);
- oxides of nitrogen (NOx);
- sulphur dioxide (SO_2);
- volatile organic compounds (VOCs);
- total hydrocarbons (HC);
- carbon monoxide (CO);
- ammonia (NH_3);
- carbon dioxide (CO_2);

Emission estimates can be resolved to the following level of detail:

- Vessel Class level;
- operating mode level (underway, manoeuvring, dockside);
- temporally at a monthly and annual level; and
- spatially – regional (user-defined), provincial/territorial or national level.

Complete details of the original Tool can be found in the User's Manual National Emission Inventory Tool for the Commercial Marine Sector [2].

In the 2006 Transport Canada study, the Tool was modified to use specifically the INNAV ship activity data for the EC/GL region and provide a regional emissions inventory that could be resolved into 16 areas within the EC/GL. The data could also be manipulated to allow further resolution of emissions into 4 km x 4 km sections within each area for input into regional air quality dispersion models. The Tool version as a result of that work was the starting point from which the Tool has been further developed in support of the work reported here.

As part of the 2007 update, SENES Consultants Ltd. has updated the Tool to Version 2.2. This V2.2 Tool update has provided additional functionality and flexibility, and it includes new user interfaces and output formatting as well as an updated User's Guide. In support of the new features contained within the Tool, several user interface screens have been added in order to facilitate entry of data and scenario testing. The screens are generally self-explanatory, but help information is available through the updated User's Guide that is accessed through the application Main Menu screen. The following sections provide an overview of the most significant changes in version 2.2. The updated User's Guide was provided under separate cover and is embedded with the Tool to provide on-line help. It should be noted that the updated manual remains at version 2.1 as the software changes from versions 2.1 to 2.2 did not require any changes to the User's Guide. Version 2.2 was developed and provided to Transport Canada and Environment Canada very late in the project to fulfill a new request from Environment Canada. Some of the figures used to illustrate the Tool in the following sections also indicate Version 2.1.

4.1 Main Menu Screen

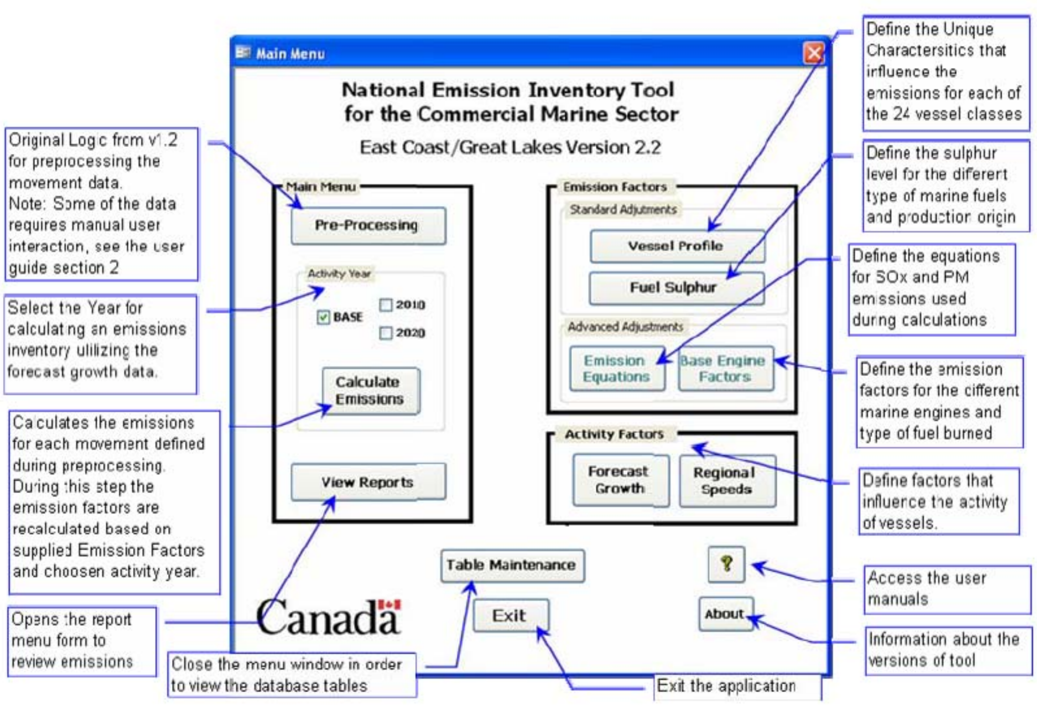
The main menu screen provides the user access to many of the common functionalities of the Tool for calculating emissions. Similar to previous versions, the inventory calculations are separated into three main categories: pre-processing, calculation, and reporting. As can be seen in Figure 4-1, additional detail and functionality have been added to the Emission Factors and Activity Factors within the main menu. Within the emissions grouping there are standard adjustments and advanced adjustments. The standard adjustments influence vessel engine characteristics by class of vessel and define the marine fuel characteristics (primarily the sulphur content). These tables should be considered by any user of the Tool before any inventory calculations are commenced.

The advanced adjustments influence the emission factors that are used to produce air contaminant emission estimates. Emission factors must be defined for all marine engine/boiler and fuel configurations that are represented in the standard adjustments tables. In addition, emission profiles are defined for the air contaminants that strongly relate to the level of sulphur in fuel (PM and SOx). Changes do not necessarily have to be made to these tables and should only be considered by advanced users of the Tool. The advanced adjustments are included partly for the sake of transparency in emissions methodology, but also to reflect the fact that improvements in both emissions data and understanding are occurring each year and major or minor adjustments may be appropriate in the future.

The Marine Tool also allows the user to adjust certain aspects of the activity. The forecast growth is used to support forecasting for the years 2010 and 2020 by defining expected activity growth by Vessel Class. Certain waterways in Eastern Canada have reduced speed restrictions that limit the top speed of the vessel while cruising within these zones. The Tool allows the user to define the speed limits by region and month (to allow for seasonal impacts on vessel movement, such as ice flows).

Figure 4-1 provides an overview of the appearance and function of the updated Tool.

Figure 4-1 – Main Menu: Welcome Screen



The new version of the Tool approaches forecast development differently than the previous version, in both Tool operation and estimation methodology. Fundamentally, two sources of change impact the future emission levels: activity level and fuel/engine technology changes. As discussed previously, the standard and advanced emission factor adjustments allow for changes in technology and fuel standards. Within the Activity Factors block, the forecast growth and regional speed forms allow for adjustments that impact activity. The Tool calculates forecast scenarios by the user selecting which year (BASE, 2010, or 2020) is of interest prior to the calculate emissions step. Based on which year the user has selected, the Tool will use that year's stated activity growth factors during the calculations. The Tool records which year has been represented and during the reporting stage opens the appropriate excel sheet for that year.

This forecast technique provides the user with flexibility to capture realistic changes that could impact future emissions. With Version 2.2 (and 2.1), the Tool should be thought of a single scenario emissions calculator. When running future scenarios, the user should examine both the activity growth for a forecast year and the expected engine and fuel technologies. In order to help the user keep track of the different scenarios, the reporting structure allows the user to save the excel sheets with any naming convention for future reference.

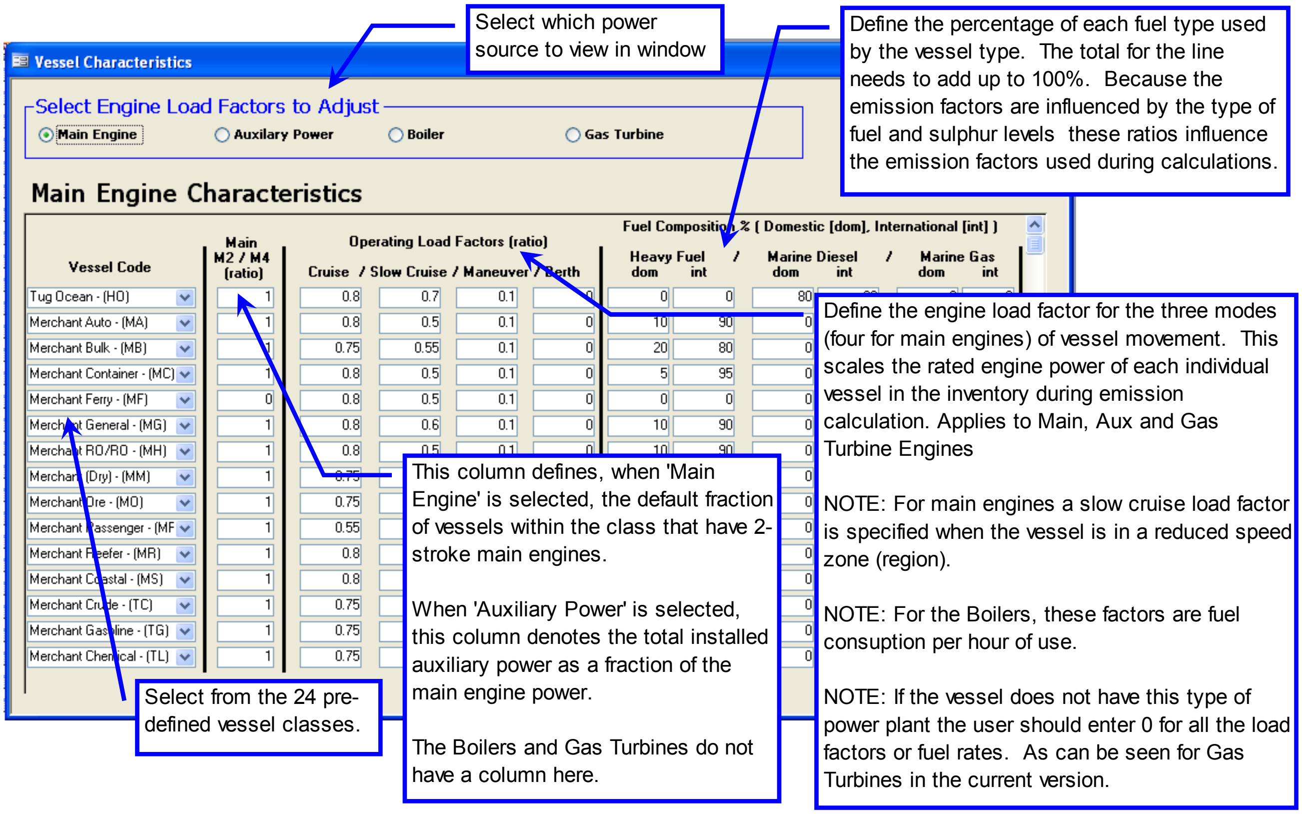
4.2 Vessel Profile

The Vessel Profile entry form (Figure 4-2) is used to provide data for each of the current 24 pre-defined Vessel Classes. The information is separated by type of engine (Main, Auxiliary, Boiler and Gas Turbine) with specifics entered for each of the 24 classes.

Common to all four engine types is the description of average fleet fuel composition and activity level for four operational modes, Cruise, Slow Cruise, Manoeuvring and Berthing (Versions 2.1 and 2.2 include the slow-cruise as a mode of operation, which was not included in previous versions). Because the fuel sulphur level and emission factors are influenced by the type of fuel used, this form allows the user some control over the emissions profile for each Vessel Class. The three types of marine fuel defined within the Tool are:

- Heavy Fuel Oil (HFO)
- Marine Diesel Oil (MDO)
- Marine Gas Oil (MGO)

Figure 4-2 – Vessel Profile: Entry Form



4.3. Main Engine

In addition to fuel composition, the engine load factors and main M2/M4 ratios need to be defined (previous versions of the Tool assumed that all main engines were two-stroke engines). The engine load factor represents the fraction of maximum continuous power (MCR) used in each of the four activity modes and therefore must lie between 0.0 and 1.0. A load factor of 0 indicates that the main engine is not used during the activity mode. For example, at berth main engines are typically not used.

The slow cruise load factor is used in conjunction with the reduced speed zones defined by region and month within the activity factors of the tool. This reduced load factor is used only if the vessel is operating in a reduced speed zone and represents a harmonized load factor for all the reduced speed zones (current data does not support separate load factors for small differences in vessel speed).

The M2/M4 ratio represents the ratio of 2-stroke and 4-stroke main engine types as an average for an entire Vessel Class. For example, tugboats receive ‘0’ since main engines are all 4-stroke. The average ratios by ship class are the default values if the specific engine type is not included with the INNAV data for a particular vessel. This version of the Tool supports emission estimates for both 2-stroke and 4-stroke marine engine types if that level of detail is available following pre processing. The issue of whether or not the main engine type identifier is present for a specific vessel in the INNAV data has not been investigated.

4.4 Auxiliary Engines

In addition to fuel composition, the engine load factors and auxiliary to main power ratio need to be defined. The engine load factor should lie between 0.0 and 1.0, indicating the fraction of maximum engine power used on average for the three activity modes (for auxiliary engines there are assumed to be no differences between cruise and slow cruise load factors). A load factor of 0 indicates that the auxiliary engine is not used during a particular mode.

The Auxiliary/Main ratio represents an average for the entire Vessel Class so that the magnitude of the total installed auxiliary power can be estimated for each vessel in the fleet. This ratio is used in conjunction with the engine load factors to determine the effective auxiliary power used in each of the three modes. Therefore, although most ships have two or more installed auxiliary engines, only one effective auxiliary power value is used in the emission calculations. This simplification can be made since auxiliary engines on a particular vessel are almost always of the same type and therefore have the same emission characteristics.

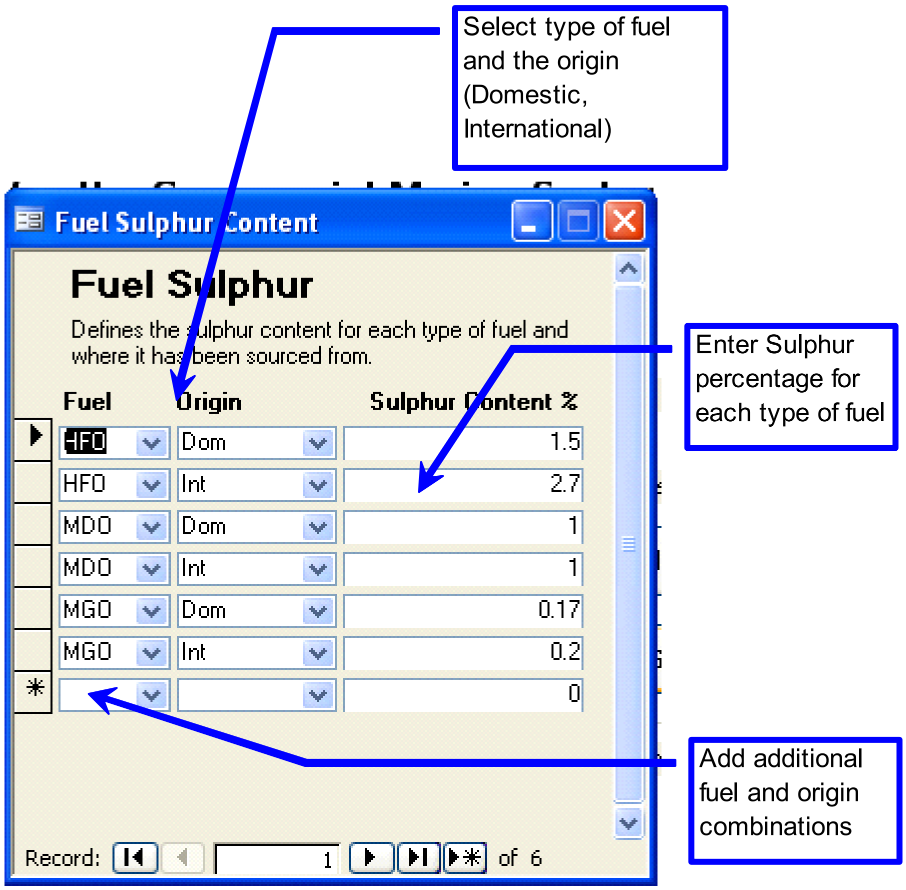
4.5 Boiler Emissions

In addition to fuel composition, the boiler fuel consumption (tonnes/hour) needs to be defined for each mode of activity. This constitutes a difference from the fields needed for engine emission estimates. A fuel consumption rate of 0 indicates that the boiler is not used during a particular mode; for example Ocean Tugs have a 0 for all three modes, as current experience indicates these vessels do not have boilers.

4.6 Fuel Sulphur

The Fuel Sulphur Content form shown in Figure 4-3 is relatively straightforward and allows the user to change the sulphur content of the three different marine fuels, further categorized by source region (domestic or international). Although this form and functionality is new for Versions 2.1 and 2.2, the fuel characteristics were defined for v1.2 and were used in the previous 2006 inventory.

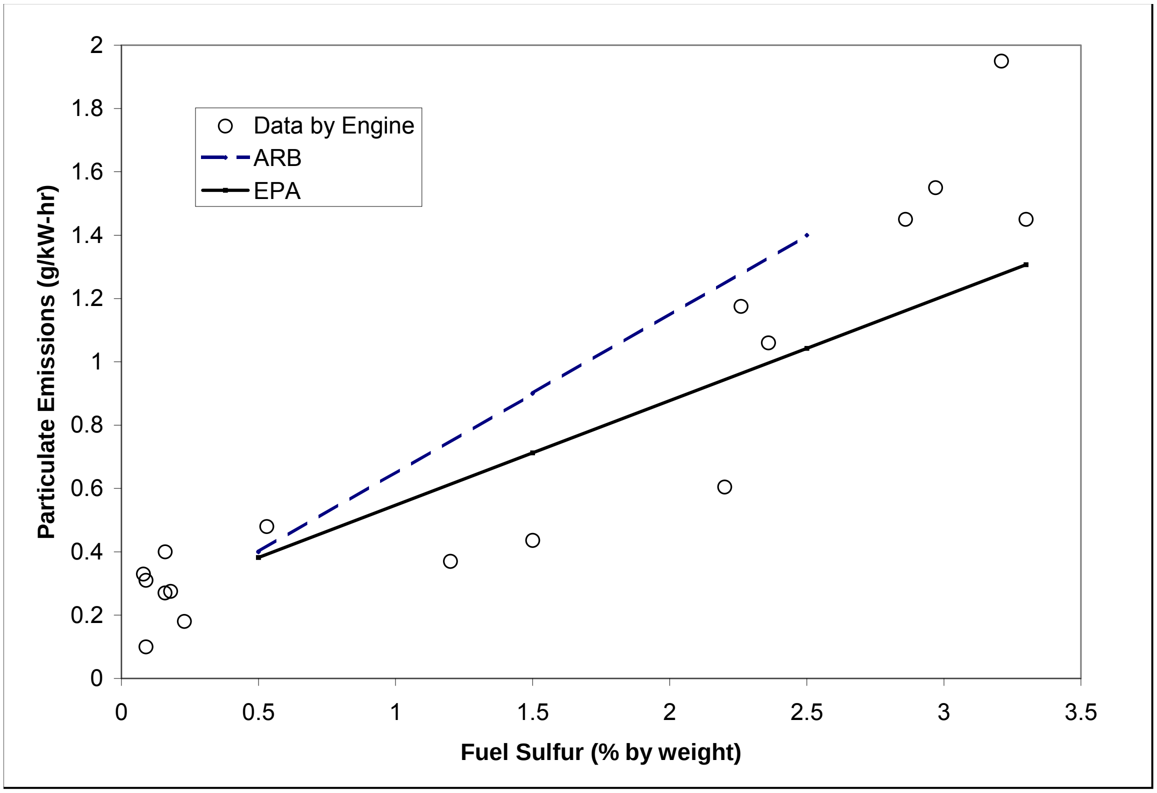
Figure 4-3 – Fuel Sulphur Content



4.7 Emission Equations

Recent marine emissions studies have indicated a linear relationship between fuel sulphur content and engine particulate emissions. Figure 4-4 shows a simple plot of PM emissions data in g/kWh and corresponding sulphur content of marine diesel. Due to a lack of specific emissions data, the data points correspond to a number of different marine emissions testing programs and are representative of both medium speed (4-stroke) and slow speed (2-stroke) marine engines. Two regression lines are shown: the solid line is representative of analysis conducted for the U.S. EPA and the dashed line is representative of analysis conducted by the California Air Resources Board (CARB). The difference in regression lines is a result of data points being included or excluded in the regression. The user may change these coefficients to match either the EPA or CARB profile, or potentially a different profile that may be developed in the future. Any deviation from a linear assumption would require slight modification to the Tool coding. Further discussion is provided in Appendix B.

Figure 4-4 – PM Emission Profiles

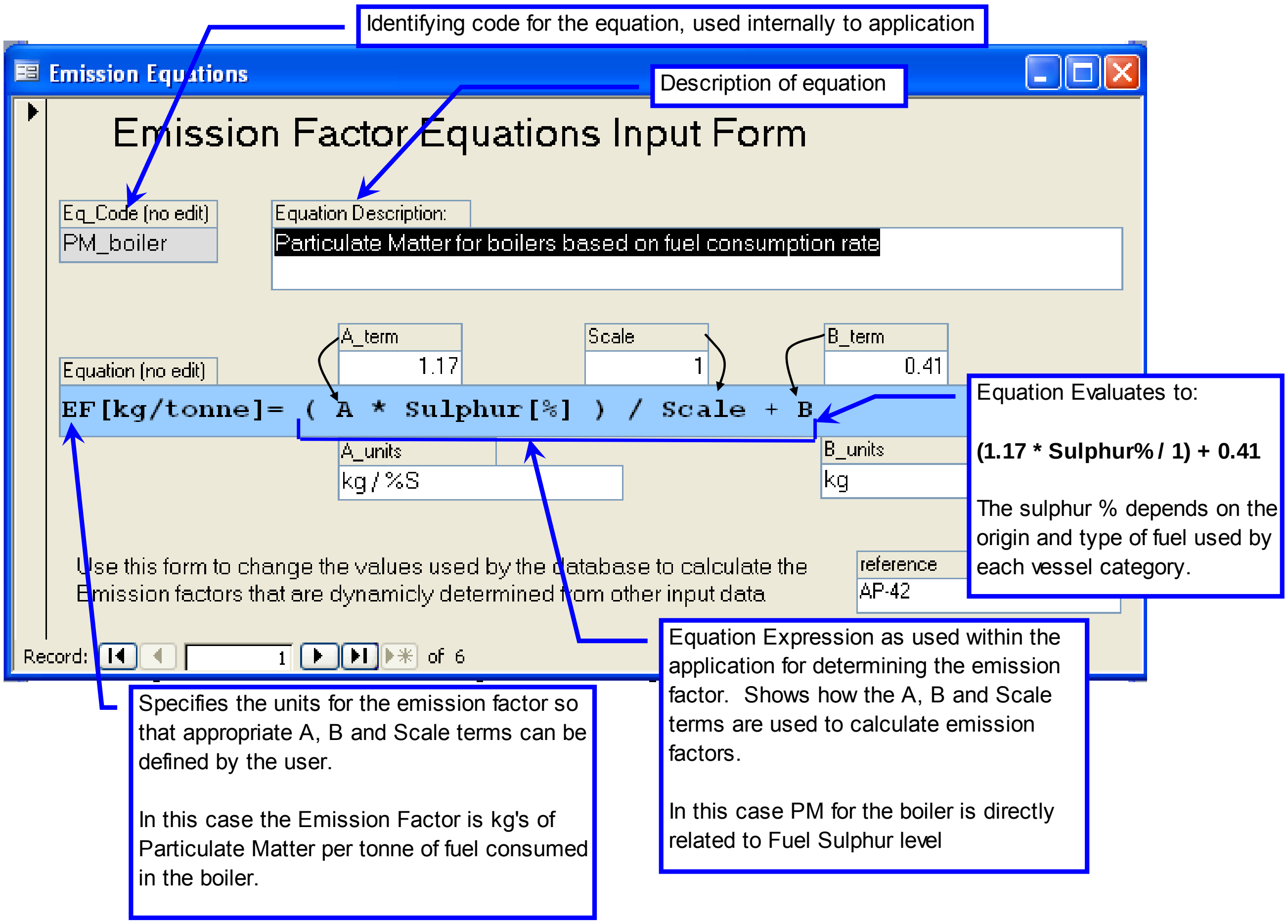


The establishment of sulphur dependent emission equations is achieved through the Emission Equations form (Figure 4-5) and is considered an advanced adjustment for users with experience in marine engine fuels and emission rates. This interface application currently has six equations available that the user can modify:

- PM_boiler – Total Particulate Matter equation for Boilers;
- PM_engine – Total Particulate Matter equation for Main and Auxiliary engines;
- SO2_boiler – Sulphur emission equation for Boilers;
- SO2_engine – Sulphur emission equation for Main and Auxiliary engines;
- PM10 – Ratio of PM_{10} to total PM for Main, Auxiliary and Boiler sources; and
- PM25 – Ratio of $PM_{2.5}$ to PM_{10} for Main, Auxiliary and Boiler sources.

Both the SO_2 and PM – Ratio equations (the latter 4) are simple ratios, but are expressed with the same structure as a linear regression equation for consistency within the Tool. For this reason, the B_term shown in Figure 4-5 is zero in all four cases.

Figure 4-5 – Emission Equation

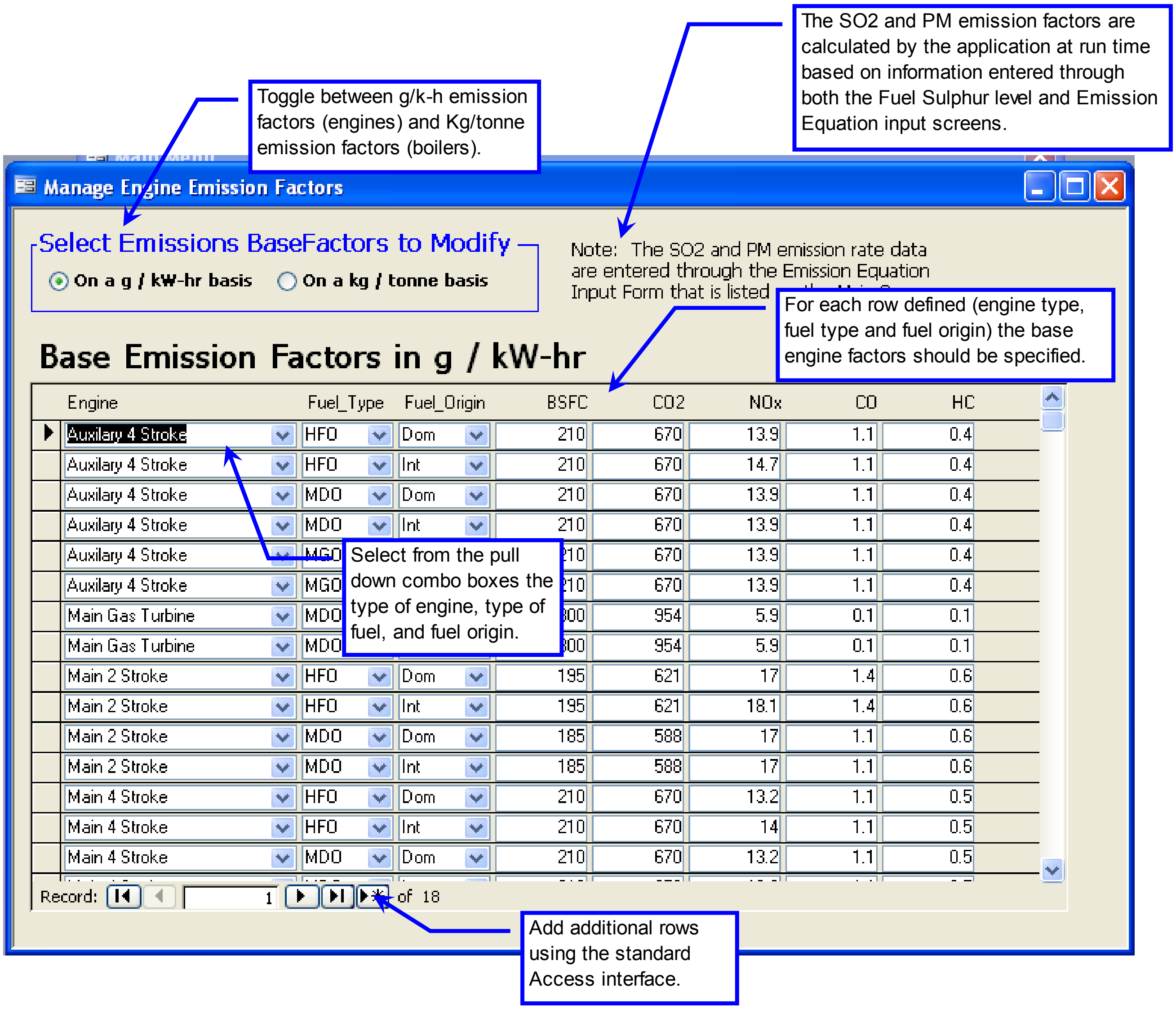


The equations as displayed in the blue box directly show how the equation is implemented in the underlying code. It is up to the user to ensure that the A, B and Scale terms are the correct units and value for the emission factor of concern. The A and B 'units' boxes are present for the user's information only and help to prevent conversion and unit scale errors.

4.8 Base Engine Emission Factors

Marine engine emissions are influenced by the type of engine and the quality of fuel used during operation. At this time, both fuel quality and fuel consumption rate influence boiler emissions. The new base engine emission factors form (Figure 4-6) allows the user to specify the emissions by engine type, fuel type and fuel origin. As noted on the screen, the emission factors for SO_2 and PM are calculated at run time based on other inputs from the user (fuel sulphur level). As with the new emission equations form, this screen is considered an advanced adjustment assuming the user has previous knowledge of emission rates for marine engines.

Figure 4-6 – Base Engine Factors

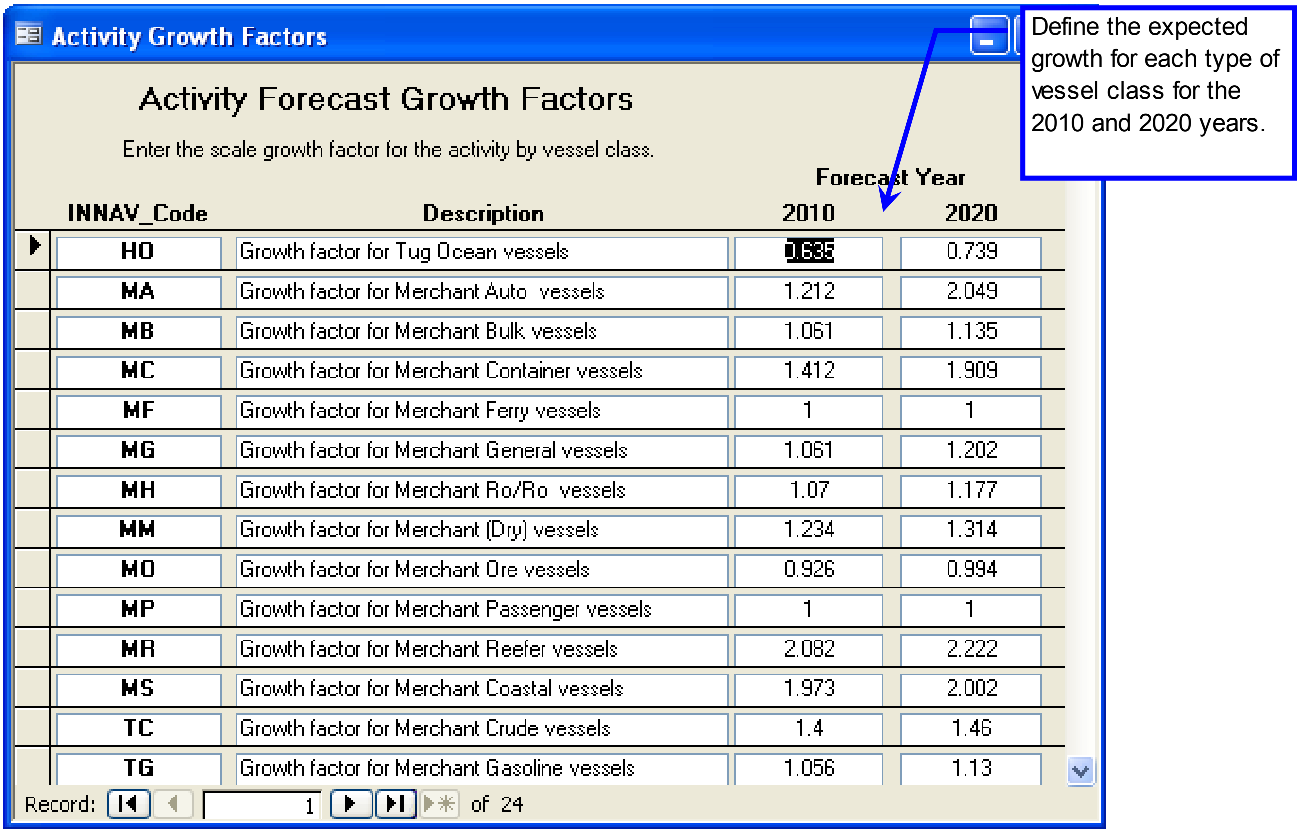


In a similar fashion to the vessel profile entry form, the user selects between two options to enter data. In the current version of the Tool, engine emission factors are expressed on an energy basis (g/kWh) whereas boiler rates are expressed on a fuel consumption rate basis (kg/tonne). On each row the user selects the engine, fuel type and fuel origin for defining the emission factors. Within each form the Engine pull down box is filtered to present only reciprocating engines on the g/kWh form and boilers for the kg/tonne form.

4.9 Activity Growth Factors

The user enters the activity forecasts through a new form that identifies growth by vessel category and the two predefined years 2010 and 2020 as seen in Figure 4-7. The growth factors are interpreted as a simple scaling of the existing activity (voyage) data in the input activity table.

Figure 4-7 – Forecast Growth Factors



Activity Growth Factors

Activity Forecast Growth Factors

Enter the scale growth factor for the activity by vessel class.

INNAV_Code	Description	Forecast Year 2010	Forecast Year 2020
HO	Growth factor for Tug Ocean vessels	0.635	0.739
MA	Growth factor for Merchant Auto vessels	1.212	2.049
MB	Growth factor for Merchant Bulk vessels	1.061	1.135
MC	Growth factor for Merchant Container vessels	1.412	1.909
MF	Growth factor for Merchant Ferry vessels	1	1
MG	Growth factor for Merchant General vessels	1.061	1.202
MH	Growth factor for Merchant Ro/Ro vessels	1.07	1.177
MM	Growth factor for Merchant (Dry) vessels	1.234	1.314
MO	Growth factor for Merchant Ore vessels	0.926	0.994
MP	Growth factor for Merchant Passenger vessels	1	1
MR	Growth factor for Merchant Reefer vessels	2.082	2.222
MS	Growth factor for Merchant Coastal vessels	1.973	2.002
TC	Growth factor for Merchant Crude vessels	1.4	1.46
TG	Growth factor for Merchant Gasoline vessels	1.056	1.13

Record: 1 of 24

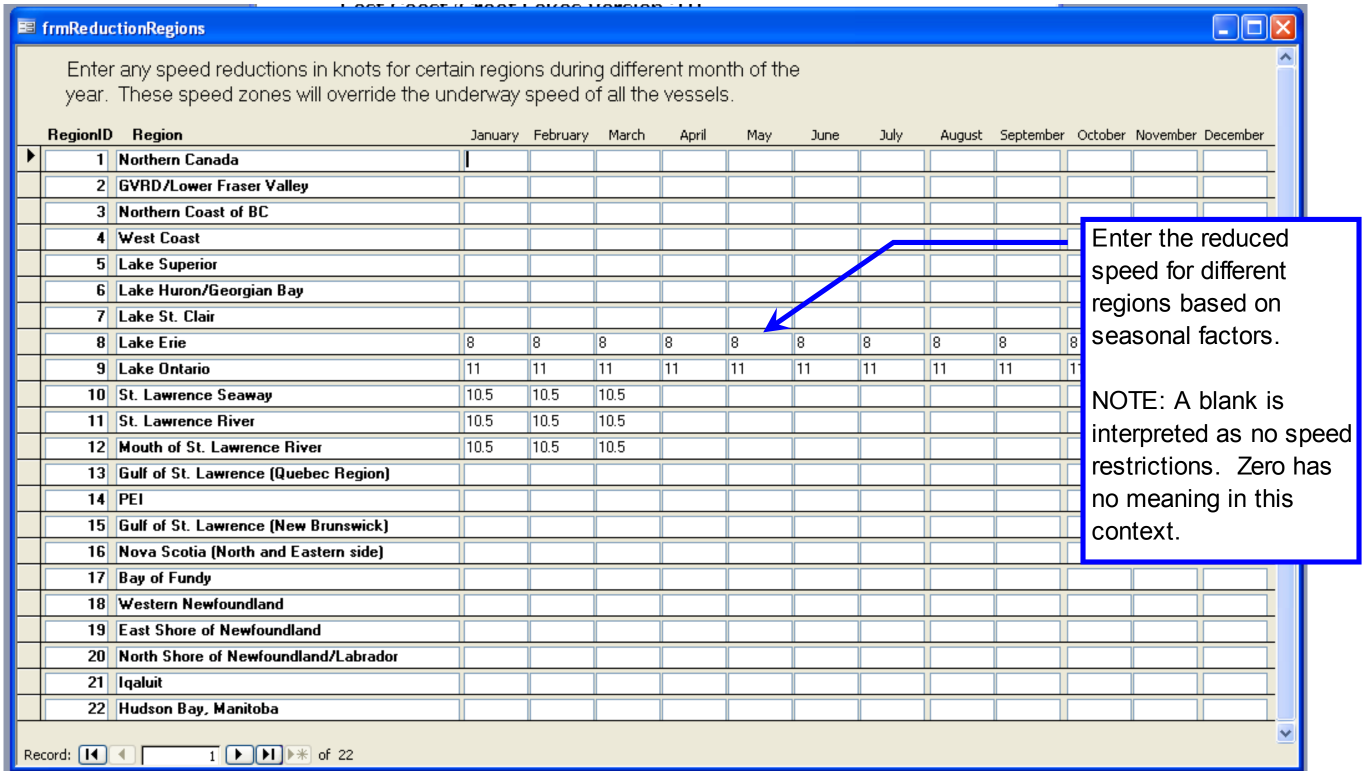
Define the expected growth for each type of vessel class for the 2010 and 2020 years.

4.10 Speed Reduction Zones

The user enters the reduced speeds for certain regions and certain times of the year in a simple form as shown in Figure 4-8 (the user should leave the field blank if there is no speed restriction for a particular region).

The speeds influence the emission calculations by assuming emissions are ‘on’ for a longer period. Specifically, a speed entry for a region enacts both a revised time of transit calculation (using the speed input) and the ‘slow cruise’ engine load factor (no load changes are enacted for auxiliary engines or boilers). Whether or not a region speed limit increases or decreases main engine emissions from the full underway assumption depends on the slow cruise load factors entered in the vessel characteristics table.

Figure 4-8 – Reduced Speed Zones



RegionID	Region	January	February	March	April	May	June	July	August	September	October	November	December
1	Northern Canada												
2	GVRD/Lower Fraser Valley												
3	Northern Coast of BC												
4	West Coast												
5	Lake Superior												
6	Lake Huron/Georgian Bay												
7	Lake St. Clair												
8	Lake Erie	8	8	8	8	8	8	8	8	8	8		
9	Lake Ontario	11	11	11	11	11	11	11	11	11	11		
10	St. Lawrence Seaway	10.5	10.5	10.5									
11	St. Lawrence River	10.5	10.5	10.5									
12	Mouth of St. Lawrence River	10.5	10.5	10.5									
13	Gulf of St. Lawrence (Quebec Region)												
14	PEI												
15	Gulf of St. Lawrence (New Brunswick)												
16	Nova Scotia (North and Eastern side)												
17	Bay of Fundy												
18	Western Newfoundland												
19	East Shore of Newfoundland												
20	North Shore of Newfoundland/Labrador												
21	Iqaluit												
22	Hudson Bay, Manitoba												

4.11 Emission Calculation

The emission calculation process within the Tool has been modified to support the additional criteria provided by the new user forms, but follows the basic methodology from the earlier Tool version. When the user selects the calculate emissions button along with the desired year from the main menu, the emissions are calculated on a per vessel movement basis and are driven by the data contained within the Vessel Summary table (which is generated during the pre-processing) and the speed reduction zones criteria.

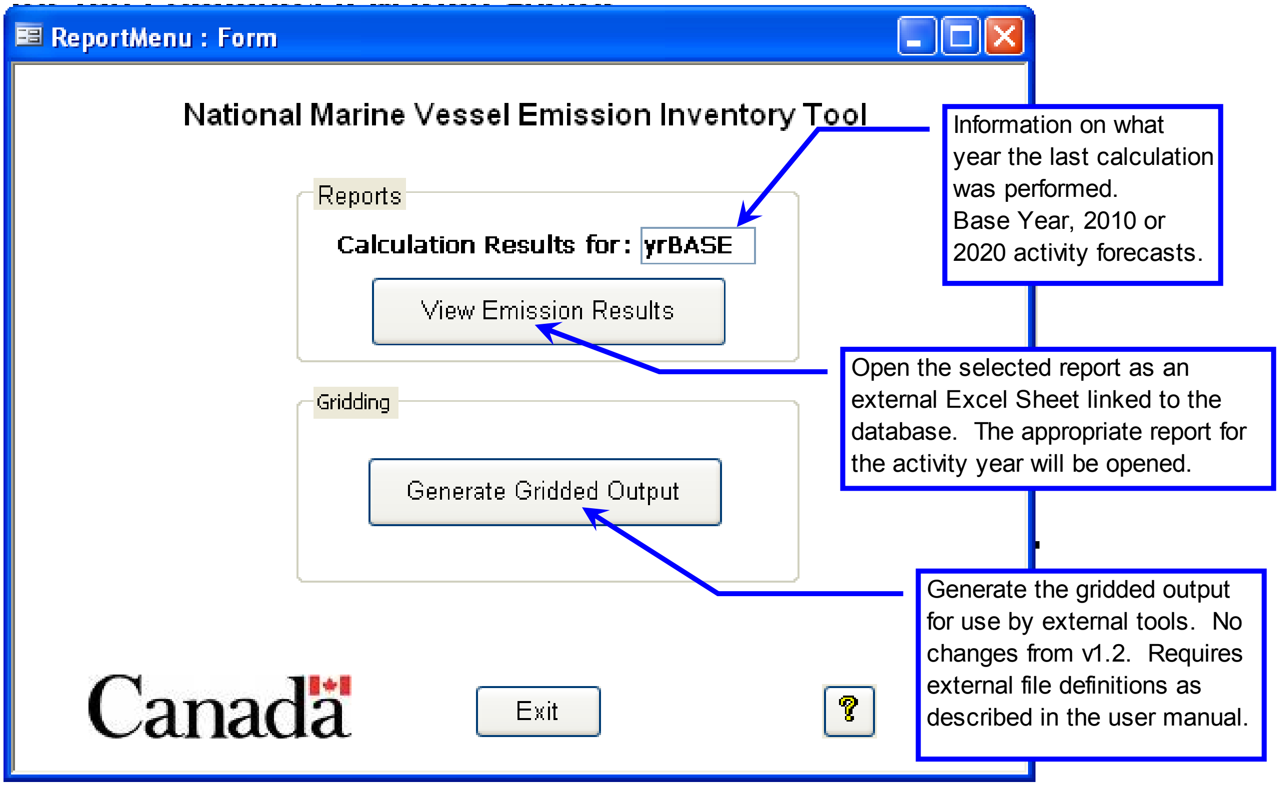
The emission factors that are used during the emission calculations are dynamically generated from all data provided by the user through the Emission Definition forms before the emissions are calculated for each vessel. This step is automatic and the user can be certain that the latest changes to the emission factors/equations will be incorporated in the new emissions totals.

4.12 Report Menu

The report menu is changed from the previous version, as shown in Figure 4-9. The uncertainty calculations and old forecasting methodology have been removed from the Tool and this menu reflects that change. The user can view reports in an excel pivot table format and also generate gridding data for external processing, as with the previous Tool version. In order to help the user keep track of forecast scenarios the tool records and displays the last set of calculations that the tool performed.

For both the base year emissions and forecast report the excel pivot reports are provided as external files that are linked to the marine database Tool. The excel reports for the base year and the forecast years are essentially identical except for titles and page set up.

Figure 4-9 – Reporting Menu

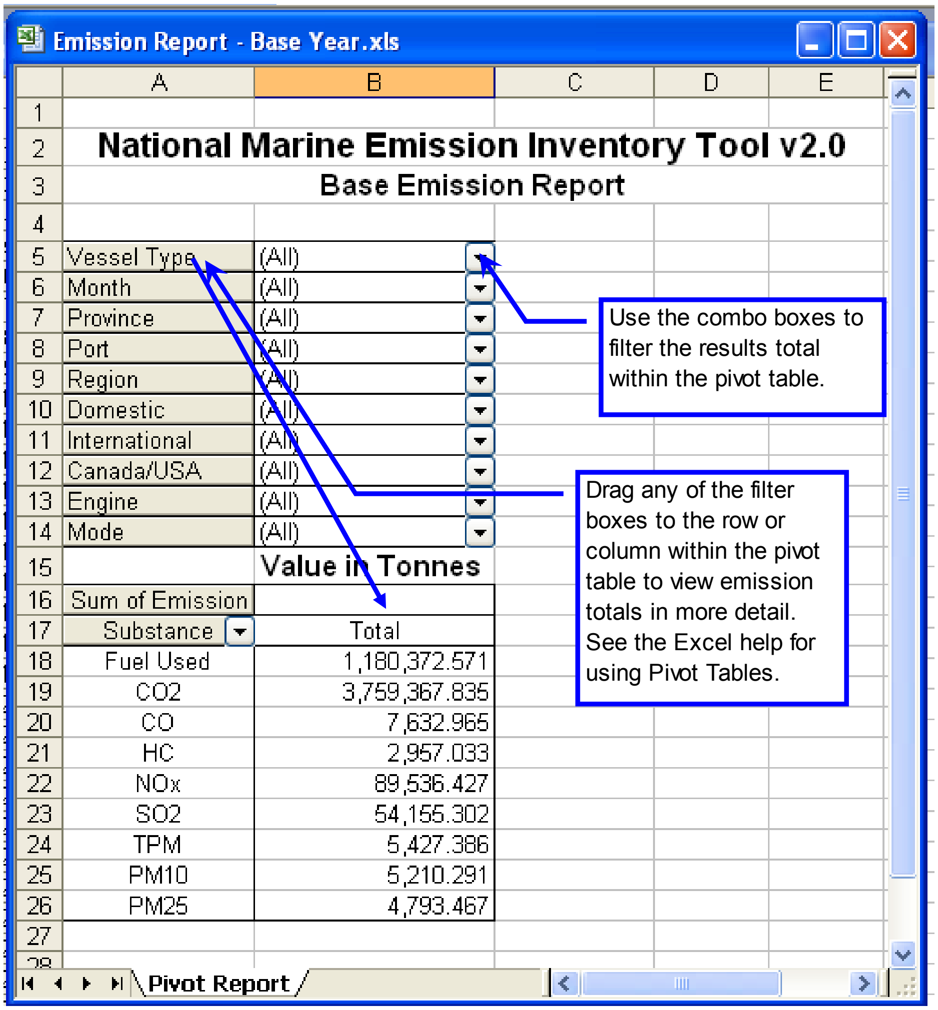


4.13 Emissions Reporting

The base emissions are reported through an externally linked Excel pivot table report (see Figure 4-10). The pivot table is a useful way to view and filter the emissions results data. The updated version of the Tool includes adding:

- fuel consumption (Fuel Used) totals;
- filtering by Engine (main, auxiliary and boilers); and
- filtering by Mode of activity (underway, manoeuvring, berthing).

Figure 4-10 – Emissions Report



5. EMISSION FACTORS

5.1 Proposed Emission Factors

The emission factors in Table 5.1 represent the air contaminants that were inventoried as part of the 2006 Inventory. Emissions result from both main (propulsion) engine use and auxiliary engine use. Main engines tend to be 2-stroke engines that use HFO, while auxiliary engines are primarily 4-stroke engines that use either HFO or MDO. However, there are a considerable number of vessels operating in EC/GL that have 4-stroke propulsion engines. In general, these ships are smaller and primarily of the bulk carrier or RoRo type. As discussed later in this Section, the emission factors for PM and SOx are relative to the specific sulphur content of fuel.

Table 5-1
Baseline Emission Factors for Inventory Development*

Engine Type	Fuel Type	Sulphur content (%)	Fuel Cons (g/kWh)	CAC Emission Factors in g/kWh								
				CO2	NOx	SO2	CO	HC	VOC	TPM	PM10	PM25
auxiliary 4 str all activity	HFO	2.7	210	670	14.7	11.1	1.1	0.4	0.4	1.11	1.07	0.98
	HFO	1.5	210	670	13.9	6.2	1.1	0.4	0.4	0.71	0.68	0.63
	MDO	1	210	670	13.9	4.13	1.1	0.4	0.4	0.55	0.53	0.49
	MDO	0.2	210	670	13.9	0.8	1.1	0.4	0.4	0.28	0.27	0.25
	MDO	0.1	210	670	13.9	0.4	1.1	0.4	0.4	0.25	0.24	0.22
main 2 str underway	HFO	2.7	195	621	18.1	10.3	1.4	0.6	0.6	1.05	1.01	0.93
	HFO	1.5	195	621	17	5.7	1.4	0.6	0.6	0.68	0.65	0.60
main 4str underway	HFO	2.7	210	670	14	11.1	1.1	0.5	0.5	1.11	1.07	0.98
	HFO	1.5	210	670	13.2	6.2	1.1	0.5	0.5	0.71	0.68	0.63
	MDO	1	210	670	13.2	4.13	1.1	0.5	0.5	0.55	0.53	0.49
	MDO	0.2	210	670	13.2	0.8	1.1	0.5	0.5	0.28	0.27	0.25
	MDO	0.1	210	670	13.2	0.4	1.1	0.5	0.5	0.25	0.24	0.22

*The emission factors that are substantially different from the original factors used are highlighted in red.

The baseline factors above were used to develop specific emission factors for each class of ship used in the inventory. In effect, slight differences in ship class emission factors relate to either engine type or to fuels used. For example, Merchant Ferry ships do not use HFO and therefore the SO_2 and PM emission factors in particular are lower compared to other ship classes.

The questionnaire responses suggest that one half of the fuel consumed by auxiliary engines in EC/GL is MDO (as opposed to HFO). Therefore, the original assumption of 25% MDO use in auxiliary engines was changed to 35% MDO use, with the remaining portion HFO. At this time it was decided that a conservative factor should be used (rather than a higher percentage such as 50%). However, the Tool user can change this assumption if desired.

5.2 Revision to SOx Emission Factors

The California Air Resources Board (CARB) has proposed an SOx emission equation calculated based on the sulphur content of the fuel being used. The equation is shown below:

$$EF_{SOx}(g/kWh) = 4.2(S) \tag{1}$$

Where S = sulphur content of fuel in %.

5.3 Revision to PM Emission Factors

CARB has expressed an alternate analysis of PM emissions data that indicates higher PM emission factors for both MDO and HFO [6]. Through discussions with the U.S. EPA, Environment Canada has decided to support use of the higher CARB PM emission rates in the current inventory for EC/GL. This is consistent with actions taken by Environment Canada on the west coast.

The Inventory summaries presented in this report relate to this new version of the Tool (V2.2) that makes use of a PM-Sulphur emissions equation consistent with CARB. The PM-Sulphur equation can be expressed as follows:

$$EF_{PM}(g/kWh) = 0.4653(S) + 0.25 \qquad (2)$$

Where S = sulphur content of fuel in %.

Although CARB did not express their analysis in this direct form, the resultant equation is consistent with their findings/opinion that a linear relationship is reasonable to assume at this time, with a recommended emission factor of 1.5 g/kWh for 2.7% S and 1.0 g/kWh for 1.5% S fuel. This effectively 'scales up' the linear profile used to determine the PM emission factors in Table 5-1. The CARB recommendation does not address specific PM_{10} and $PM_{2.5}$ emission factors. Version 2.2 of the Tool has applied a ratio of 0.96 and 0.92 for PM_{10} to total PM and $PM_{2.5}$ to PM_{10}, respectively. In general, this is consistent with assumptions applied in past marine emissions inventories, although some variation in appropriate ratios has been noted. At least one recent marine PM study indicates that total PM emission rates could in fact be much higher than PM_{10} emission rates when high sulphur fuel is consumed.

6. REVISED INVENTORY AND SECA FORECAST

6.1 2002/2003 Baseline

The revised emissions inventory totals calculated using the updated Tool with the same fuel sulphur assumptions as in the 2006 study are summarized in Table 6-1. The table provides total emissions of commercial marine traffic in the EC/GL, and includes emissions from main engines, auxiliary engines and boilers. The original 2006 Inventory data are provided for information purposes.

Table 6-1: 2002/2003 Base Year Inventory Totals

Air Contaminant	TOTAL EMISSIONS (tonnes/year)							
	All Activity		Underway		Berthing		Manoeuvring	
	2006 Study	Revised	2006 Study	Revised	2006 Study	Revised	2006 Study	Revised
SO_2	47,459	54,959	42,897	47,181	4,304	7,445	259	332
NOx	93,700	73,974	86,161	64,622	7,025	8,899	514	453
TPM	10,348	7,129	9,741	6,243	563	844	44.1	42
PM_{10}	8,157	6,844	7,651	5,993	470	811	36	40
$PM_{2.5}$	6,855	6,296	6,401	5,514	423	746	31	37
CO	3,093	6,165	2,605	5,230	438	894	50	40
HC	2,843	2,520	2,620	2,254	195	251	29	14
CO_2	3,298,992	3,620,092	2,924,988	3,029,367	346,731	566,509	27,272	24,216

The updated baseline inventory, developed using version 2.2 of the Tool and its updated parameters, is higher for CO, SO_2 and CO_2, but lower for all other air contaminants.

6.2 Forecast

The original forecasts completed for the TDC Inventory in 2006 accounted for future changes to domestic marine fuel (MDO) as well as minor changes to NOx emission rates due to the application of IMO Marpol Annex VI for post 2000 vessels. Version 1.2 of the Tool and the 2006 inventory assumed that 2% of vessels would be replaced annually. No changes were made to these assumptions for the 2010 and 2020 forecasts shown here. However, it should be noted that these forecasts are very simplistic, and do not account for expected improvements in engine efficiency and (more importantly) realistic reductions in emission rates. Already there has been clear indication that newer (or retrofitted) ships have achieved significant reductions in NOx and PM emission rates.

The forecast inventories also require activity growth factors by class of vessel. WME developed a revised set of growth factors for the 2002 INNAV activity, as discussed in Section 3. These factors were used in the Tool, along with the revised emission factors. Table 6-2 provides the forecast Inventory totals as well as the 2002 baseline for comparison.

Table 6-2: Baseline and Forecast Emissions for Eastern Canada and the Great Lakes

Air Contaminant	Total Emissions (tonnes)				
	2002	**2010**	***% Change***	**2020**	***% Change***
SO_2	54,959	64,349	*17.1*	74,344	*35.3*
NOx	73,974	83,130	*12.4*	91,253	*23.4*
TPM	7,129	8,344	*17.0*	9,640	*35.2*
PM_{10}	6,844	8,010	*17.0*	9,255	*35.2*
$PM_{2.5}$	6,296	7,369	*17.0*	8,514	*35.2*
CO	6,165	7,154	*16.0*	8,212	*33.2*
HC	2,520	2,933	*16.4*	3,376	*34.0*
CO_2	3,620,092	4,212,740	*16.4*	4,841,468	*33.7*

6.3 SECA Forecast

With the new version of the Tool, achieving a SECA forecast is relatively simple, as changes to fuel sulphur entered in the Tool are directly used to update emission factors. International heavy fuel oil sulphur content was changed from 2.7% to 1.5% for the SECA forecast. Domestic marine diesel sulphur content was set at 300 ppm for the 2010 and 2020 forecasts, consistent with Environment Canada regulations implemented in 2007 and the original assumptions applied in the earlier 2006 TDC Inventory forecasts. The reduction in PM emission rates follows from the PM-Sulphur equation discussed in Section 4. A SECA emissions inventory for EC/GL is shown in Table 6-3, along with the baseline inventory for 2002 for comparison.

Table 6-3: Baseline and SECA Forecast Emissions for Eastern Canada and the Great Lakes

Air Contaminant	Total Emissions (tonnes)				
	2002	2010	*% Change*	2020	*% Change*
SO_2	54,959	39,080	*-28.9*	44,939	*-18.2*
NOx	73,974	83,130	*12.4*	91,253	*23.4*
TPM	7,129	5,658	*-20.6*	6,511	*-8.7*
PM_{10}	6,844	5,431	*-20.6*	6,251	*-8.7*
$PM_{2.5}$	6,296	4,997	*-20.6*	5,750	*-8.7*
CO	6,165	7,154	*16.0*	8,212	*33.2*
HC	2,520	2,933	*16.4*	3,376	*34.0*
CO_2	3,620,092	4,212,740	*16.4*	4,841,468	*33.7*

The comparison of forecasted SECA and non-SECA emissions is provided in Table 6-4. The implementation of a SECA along the east coast of North America would be expected to result in major reductions of SO_2 and PM in the EC/GL region.

Table 6-4: Comparison of Forecasted SECA and Non-SECA Emissions

Air Contaminant	TOTAL EMISSIONS (tonnes)					
	2010	2010 SECA	% Difference	2020	2020 SECA	% Difference
SO_2	64,349	39,080	-39	74,344	44,939	-40
NOx	83,130	83,130	0	91,253	91,253	0
TPM	8,344	5,658	-32	9,640	6,511	-32
PM_{10}	8,010	5,431	-32	9,255	6,251	-32
$PM_{2.5}$	7,369	4,997	-32	8,514	5,750	-32
CO	7,154	7,154	0	8,212	8,212	0
HC	2,933	2,933	0	3,376	3,376	0
CO_2	4,212,740	4,212,740	0	4,841,468	4,841,468	0

7. MEASUREMENT OF EXHAUST EMISSIONS FROM VARIOUS COMMERCIAL VESSELS

7.1 Introduction

Exhaust emissions measurements were recorded from three vessels to help characterize emissions from commercial marine vessels operating in the EC/GL region. One of the vessels was a container ship which was tested during a regular transit between Montreal, Quebec, and St. John's, Newfoundland, in February 2007. The second vessel was a ferry which was tested during a return transit between North Sydney, Nova Scotia, and Port aux Basques, Newfoundland, in November 2007. The third vessel was a tanker which was tested during a transit between Montreal, Quebec, and Oakville, Ontario, in April 2008.

7.2 Scope of Work

The scope of work for the three vessels was similar, and is summarized below:

- Preliminary site visits were conducted on each vessel to discuss the trial requirements with ships' staff and conduct a survey of the main engine uptakes.
- All of the test equipment was calibrated prior to installation on board the vessels, and the calibration was verified prior to the on-site tests.
- Exhaust measurements were recorded during the transits.
- Fuel samples were taken from the test vessels during the emission measurements and were analyzed to obtain fuel parameters.
- Post-trial verification of the instrumentation and an analysis of the results was carried out.

7.3 Emissions Measurements

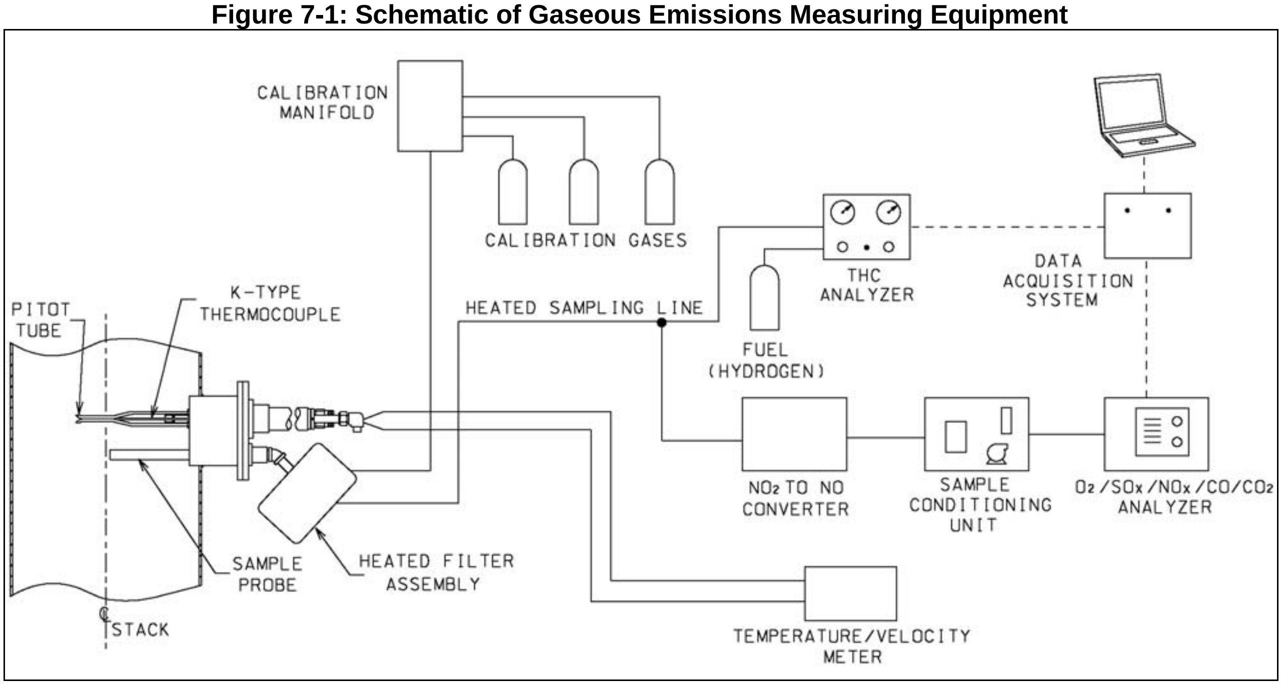
7.3.1 Gaseous Emissions

The WME continuous emission monitoring system (CEMS) consists the following:

- O_2/SOx/NOx/CO/CO_2 analyzer (Horiba model PG-250 Portable Multi-Gas Analyzer);
- External NO_2 to NO converter (Horiba);
- Total hydrocarbon analyzer (J.U.M. Engineering Model 3-2 Portable THC Analyzer);
- Gas sample conditioning unit (custom made);
- Temperature/velocity meter (Delta Profile Velocity Meter);
- Sample probe;
- Heated filter assembly; and
- Heated sampling line.

The CEMS meets the requirements of the ISO 8178-2:1996 *Reciprocating Internal Combustion Engines – Exhaust Emissions Measurement Part 2: Measurement of Gaseous and Particulate Exhaust Emissions at Site* Standard. A schematic of the equipment set-up is provided in Figure 7-1.

Figure 7-1: Schematic of Gaseous Emissions Measuring Equipment



Certified primary calibration gas standards with an accuracy of +- 1% were used to calibrate the exhaust gas emission instrumentation. At the completion of each trial, the exhaust gas emission instrumentation was verified using the calibration gas standards and all results were within +- 5%.

Data is collected using an IOTech DataShuttle high-resolution data acquisition system, Laptop computer and Dasylab 32 version 5.6 data acquisition system software. Results are recorded every 60 seconds and each data point is based on the average of 60 readings, which are taken at one second intervals.

All gaseous emissions data is calculated on a wet basis and corrected to 15% oxygen. The trial data are converted from parts per million by volume (ppm_v) or percent, to g/kWh in accordance with ISO 8178-2:1996.

7.3.2 Particulate Matter

Two different methods have been used to determine particulate matter (PM) emissions.

ISO 9096:2003 - The first method involved using the method described in ISO 9096:2003 *Stationary Source Emissions – Manual Determination of Mass Concentration of Particulate Matter*. This method includes the use of a Thermo Anderson Model M9096 Portable Particulate Sampling System attached to the CEMS discussed earlier.

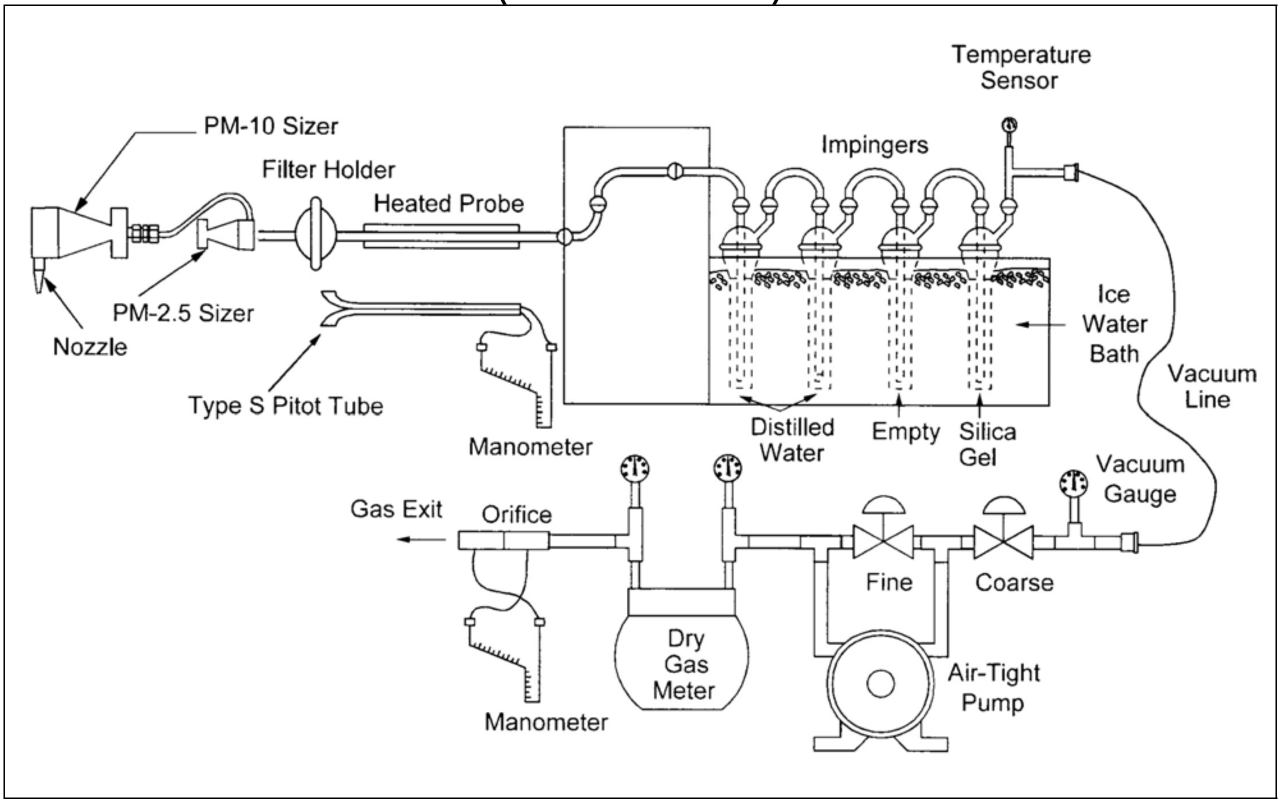
A sample stream of the gas is extracted isokinetically through the sampling train for a measured period of time, and with a controlled flow rate and a known volume. The PM entrained in the gas sample is separated by a pre-weighed plane filter, which is then dried and re-weighed. The increase in weight of the filter is attributed to particulates collected from the sample gas, which allows for the calculation of the particulate concentration. The filter paper used during the test had a nominal 2.5-micron pore size. PM measurements for each portion of the transit were based on a single sample. Typical sampling time for PM is approximately 30 minutes. PM is calculated on a dry basis and corrected to 15% oxygen.

USEPA Method 201A - Sampling of PM can also be done based on USEPA Method 201A: *Determination of PM10 Emissions (Constant Sampling Rate Procedure Modified with PM 2.5).* This method uses a combination of cyclones and a filter to determine the PM emissions equal to or less than aerodynamic diameters of nominally 10 microns (PM_{10}) and 2.5 microns ($PM_{2.5}$).

For this method, the $PM_{10/2.5}$ sampling train consists of a sampling probe, a cyclone assembly and impinger assembly. The sampling probe consists of a stainless steel nozzle attached to two in-stack constant sampling rate (CSR) cyclones in series. The CRS cyclones separate PM into PM_{10} and PM $_{2.5}$. A 47 mm diameter quartz fine in-stack filter is located down-flow of the CRS cyclones for the collection of $PM_{2.5}$. The filter is a 99.99% efficient 2.1 micron filter which effectively captures all measurable particles ≤ 2.5 microns in diameter. The opposite end of the sampling probe is connected to an impinger assembly. The impingers, cooled by ice water, are temperature monitored. The dried gas is then drawn through a leak-free pump and exited through a dry gas meter equipped with a low-pressure-drop orifice used for flow indication.

A schematic drawing of the Method 201A instrumentation set-up is provided in Figure 7-2.

Figure 7-2: Schematic of Particulate Matter Emissions Instrumentation Set-up (USEPA Method 201A)



The $PM_{10/2.5}$ particulate samples (in-stack filter and the $PM_{10/2.5}$ acetone rinses) are submitted for gravimetric determination. Gravimetric analysis involves measuring the weight gain on the in-stack particulate filter and the residue left over in the $PM_{10/2.5}$ acetone rinses. The total weight gains of the in-stack filter and the $PM_{10/2.5}$ acetone rinses are used to calculate $PM_{10/2.5}$ emission data.

7.4 Merchant Container Vessel

7.4.1 Description of Merchant Container Vessel

A description of the Merchant Container vessel is summarized in Table 7-1.

Table 7-1: Merchant Container and Engine Specifications

INNAV Vessel Class	Merchant Container
Year of Build	2005
Gross Tonnage	14,639
Dead Weight	14,528 tonnes
Maximum Cruising Speed	19.5 knots
Engine Manufacturer	MAN B&W
Main Engine Description	Model No. 8L 58/64
Stroke	4
Fuel Quality	HFO 380
Number of Cylinders	8
MCR and Speed	11,120 kW at 428 rpm

7.4.2 Test Fuel Properties

A sample of the fuel was taken from the Merchant Container vessel during the emission measurements and was analyzed to obtain the fuel properties, as shown in Table 7-2.

Table 7-2: Test Fuel Properties – Merchant Container

Fuel Property	Merchant Container
	HFO
Density, corrected to 15^{o} C (g/ml)	0.9859
Carbon, mass (%)	86.7
Hydrogen, mass (%)	10.78
Sulphur, mass (%)	1.90
Nitrogen, mass (%)	< 0.5
Oxygen, mass (%)	0.90
Flash Point (^{o} C)	72.2
Kinematic Viscosity (cSt) @ 40^{o} C	698.77
Kinematic Viscosity (cSt) @ 50^{o} C	341.90

7.4.3 Operating Profiles during Emissions Measurements

Gaseous emissions were measured per subsection 7.3.1, and PM emissions were measured using the ISO 9096:2003 method.

Emission measurements were taken from the container vessel main engine at the power levels and corresponding operating profiles listed in Table 7-3. Gaseous and particulate emissions were measured continuously during the transit. Due to the winter/ice conditions in the St. Lawrence River, there was a speed limit of 10 kn between Montreal and Three Rivers. Vessel speed during this leg of the journey ranged between 8 and 10 kn.

Table 7-3: Merchant Container Operating Profile during Exhaust Measurements

Journey Segment/ Vessel Activity	Engine Load (kW)	Engine Load (% MCR)	Avg. Vessel Speed (kn)	Avg. Ground Speed (kn-GPS Data)	Time (minutes)
Manoeuvring out of Montreal	3616	33	N/A	N/A	40
Underway: Montreal to Three Rivers	4744	43	8.6	10.5	350
Underway: Three Rivers to Quebec City	9093	82	15.0	17.0	210
Underway: Quebec City to St. John's	10220	92	19.0	20.0	2615
Manoeuvring into St. John's	3616	33	N/A	N/A	60

N/A: Not available.

7.4.4 Results from Merchant Container Vessel

Exhaust gas emission results are provided in Table 7-4. For engine loads at 4744, 9093 and 10220 kW, data was collected under steady state conditions. For the manoeuvring portions of the transit, date engine load varies; the load and results shown represent the mathematical average of the data recorded during the manoeuvring portions of the transit. The exhaust emissions time weighted average (TWA) for each leg of the journey was also calculated.

Table 7-4: Measured Exhaust Emissions in g/kWh from Merchant Container Vessel

Exhaust Gas Emissions	Load (kW)					TWA (g/kWh)
	3616	4744	9093	10220	3616	
NOx (g/kWh)	8.6	8.7	11.9	13.2	9.4	12.4
SOx (g/kWh)	3.9	4.6	5.0	5.6	5.5	5.1
CO (g/kWh)	0.5	0.6	0.4	0.4	0.5	0.4
CO_2 (g/kWh)	411.0	471.0	523.3	559.3	517.3	545.0
NMHC (G/kWh)	N/A	N/A	N/A	0.8	0.9	0.8
O_2 (g/kWh)	1378.0	1349.0	1297.6	1256.8	1317.6	1272.0
PM (g/kWh)	0.84	0.55	0.23	0.17	N/A	0.27

N/A: Not Available.

7.5 Merchant Ferry Vessel

7.5.1 Description of Merchant Ferry

A description of the Merchant Ferry is summarized in Table 7-5.

Table 7-5: Merchant Ferry and Engine Specifications

INNAV Vessel Class	Merchant Ferry
Year of Build	1989
Gross Tonnage	27,614
Dead Weight	4,513 tonnes
Maximum Cruising Speed	22 knots
Engine Manufacturer	MAK
Main Engine Description	8M552
Stroke	4
Fuel Quality	MGO and IFO
Number of Cylinders	8
MCR and Speed	5,150 kW at 500 rpm

7.5.2 Test Fuel Properties

Fuel samples were taken from the Merchant Ferry during the emission measurements and were analyzed to obtain the fuel properties, as provided in Table 7-6. It should be noted that the Merchant Ferry carries two types of fuel on board. The MGO is generally used while alongside and during manoeuvring activities in port, while the IFO is generally used while underway. The IFO fuel used by the ferry was a blend of 90% bunker and 10% MGO.

Table 7-6: Test Fuel Properties – Merchant Ferry

Fuel Property	Merchant Ferry	
	MGO	IFO
Density, corrected to $15^{o}C$ (g/ml)	0.8502	0.9761
Carbon, mass (%)	N/A	N/A
Hydrogen, mass (%)	N/A	N/A
Sulphur, mass (%)	<0.2	1.61
Nitrogen, mass (%)	N/A	N/A
Oxygen, mass (%)	N/A	N/A
Flash Point (^{o}C)	75.2	111.5
Kinematic Viscosity (cSt) @ $40^{o}C$	3.1	331.4
Kinematic Viscosity (cSt) @ $50^{o}C$	N/A	N/A

N/A: Not available.

7.5.3 Operating Profile during Measurements

Gaseous emissions were measured as described in subsection 7.3.1. Gaseous emissions measurements were taken from the Merchant Ferry No. 1 main engine at the power levels and corresponding vessel operating profiles listed in Table 7-7. No measurements were taken during manoeuvring activities out of North Sydney. The first four hours of underway measurements took place while running on MGO fuel, although normally, MGO is used only while alongside and during manoeuvring. After 4 hours, the fuel was switched to IFO fuel. Emission measurements during this changeover took 25 minutes. After the 25 minute changeover, it is assumed that the engine was running entirely on IFO fuel.

PM was measured using the USEPA Method 201A. Three separate particulate emission measurements were taken during the return transit from Port aux Basques to North Sydney. The protocol used for particulate emission measurement requires steady state conditions during the measurements. Each particulate emission measurement was taken during steady state conditions over a time period ranging from 48 minutes to 60 minutes, at an engine load of 4378 kW (85% of MCR) using IFO fuel.

Table 7-7: Merchant Ferry Operating Profile during Gaseous Exhaust Measurements

Journey Segment/ Vessel Activity	Engine Load (kW)	Engine Load (% MCR)	Fuel Quality	Time (minutes)
Underway (first four hours)	4378	85	MGO	240
Underway (Changeover from MGO to IFO fuel)	4378	85	MGO-IFO Changeover	25
Underway	4378	85	IFO	60
Underway	3863	75	IFO	25
Manoeuvring (minimum engine load recorded)	1339	26	MGO	35
Manoeuvring (maximum engine load recorded)	4378	85	MGO	

7.5.4 Results from Merchant Ferry

Gaseous exhaust emission results are provided in Table 7-8. Results are based on the average readings for each leg of the transit. For engine loads while underway, data was collected under steady state conditions.

For the manoeuvring portions of the transit, the data was not collected under steady state conditions because the engine load varied during this activity. Consequently, the results shown represent the minimum, maximum and mathematical average of the data recorded during the manoeuvring portions of the transit. The engine load could not be measured during manoeuvring; therefore, the minimum and maximum values were provided by the vessel crew. For this reason, no average engine load during manoeuvring is available.

Particulate exhaust emission results are provided in Table 7-9. Three tests were taken during the transit from Port aux Basques to North Sydney. These tests were each taken under steady state conditions, while the vessel was underway. The average emission results provided are the mathematical average of the three tests.

Table 7-8: Measured Gaseous Exhaust Emissions in g/kWh from Merchant Ferry

Vessel Activity	Fuel Quality	Engine Load (%)	NOx (g/kWh)	SOx (g/kWh)	CO (g/kWh)	CO_2 g/kWh)	NM THC (g/kWh)	O_2 (g/kWh)
Underway	MGO	85	14.72	0.14	1.48	697.09	0.92	3318.09
Underway	IFO	75	17.48	9.82	1.72	775.91	1.03	3446.58
Underway	MGO-IFO Changeover	85	17.72	6.03	1.73	759.08	0.94	3373.65
Underway	IFO	85	19.22	10.13	1.87	818.12	1.09	3555.82
Manoeuvring (minimum engine load)	MGO	26	30.8	3.31	4.19	1536.3	1.89	7478.2
Manoeuvring (maximum engine load)	MGO	85	9.42	1.01	1.28	469.93	0.58	2287.45
Manoeuvring (average throughout test)	MGO	N/A	20.11	2.16	2.74	1003.12	1.24	4882.83

N/A: Not available.

Table 7-9: Measured Particulate Exhaust Emissions in g/kWh from Merchant Ferry

Vessel Activity	Fuel Quality	Engine Load (kW)	Particulate Concentration (mg/dsm^3)		Particulate Emission Rate (kg/h)		Particulate Emissions (g/kWh)	
			$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}	$PM_{2.5}$	PM_{10}
Underway	IFO	4377.5	29.4	31.2	0.744	0.790	0.17	0.18
Underway	IFO	4377.5	33.8	36.5	0.810	0.875	0.19	0.20
Underway	IFO	4377.5	36.3	40.9	0.859	0.968	0.20	0.22
AVERAGE	**-**	**4377.5**	**33.1**	**36.2**	**0.804**	**0.877**	**0.18**	**0.20**

7.6 Merchant Tanker Vessel

7.6.1 Description of Merchant Tanker

A description of the Merchant Tanker is provided in Table 7-10.

TABLE 7-10: Merchant Tanker and Engine Specifications

INNAV Vessel Class	Merchant Tanker
Gross Tonnage	8,848
Main Engine Description	6S42MC Mark VI
Manufacturer	MAN B&W
Stroke	2
Quality of Fuel Used	Marine Bunker Fuel Oil
Number of Cylinders	6
MCR and Speed	6,150 kW at 210 rpm

7.6.2 Test Fuel Properties

A sample of the fuel was taken from the Merchant Tanker vessel during the emission measurements and was analyzed to obtain the fuel properties, as shown in Table 7-11.

TABLE 7-11: Test Fuel Properties – Merchant Tanker

Fuel Property	Marine Bunker Fuel Oil
Density, corrected to 15 °C (g/mL)	0.9716
Sulphur, mass (%)	0.75
Flash point (°C)	78.35
Kinematic Viscosity (cSt) @ 40ºC	569.1

7.6.3 Operating Profile during Measurements

Gaseous emissions were measured as described in subsection 7.3.1. Gaseous emission measurements were taken from the test vessel main engine at the power levels and corresponding vessel operating profiles listed in Table 7-12. The total transit time from Montreal to Oakville was approximately 41 hours (23 April, 4:00am to 24 April, 9:00pm). Gaseous emissions were measured over a period of 28 hours.

Table 7-12: Merchant Tanker Operating Profile During Gaseous Exhaust Measurements

Vessel Activity and Approximate Time when Activity Started	Engine Load (kW)	Engine Load (%)	Time at Specified Engine Load (minutes)
Alongside at dock (Engine start-up at 04:00, 23 April).	615	10	60
Alongside - while waiting its turn to pass through one of the Seaway locks (09:00, 23 April).	738	12	35
Underway – after passing through a few locks, the vessel picked up some speed since this part of the Seaway was wide (10:40, 23 April).	2706	44	20
Underway – the vessel passed through a few more locks and then the Seaway opened up enough for the ship to go to full power. There was also no traffic and it was some distance to the next lock (13:25, 23 April).	5105	83	35
Underway - due to the narrowing of the Seaway, the vessel had to sail at a very low speed (14:20, 23 April).	738	12	40
Underway – the Seaway widened and the vessel was able to pick up some speed (15:45, 23 April).	2399	39	20
Underway – due to lack of traffic and the width of the Seaway, vessel speed increased (16:15, 23 April).	4121	67	15
Underway – due to lack of traffic and the width of the Seaway, the vessel was able to sail faster.	4182	68	25
Underway – As the Seaway started to narrow again the vessel had to decrease its speed (18:30, 23 April).	2091	34	20
Underway – the Seaway started to widen again and the vessel was able to increase its speed (19:00, 23 April).	3321	54	30
Alongside – Due to traffic on the next lock approach, the vessel was docked (21:20, 23 April).	738	12	20
Underway – the vessel increased speed after moving through lock (00:15, 24 April).	1476	24	25
Underway – the vessel decreased speed due to the narrowing of the Seaway (01:05, 24 April).	1169	19	30

Table 7-12 (cont.)

Vessel Activity and Approximate Time when Activity Started	Engine Load (kW)	Engine Load (%)	Time at Specified Engine Load (minutes)
Underway – the Seaway widened extensively at this point so the vessel was able to increase speed (02:55, 24 April).	4428	72	40
Underway – the vessel decreased speed due to narrowing of Seaway (04:15, 24 April).	2768	45	40
Underway – the vessel decreased speed further due to narrowing of the Seaway (05:15, 24 April).	1968	32	75

PM was measured using the USEPA Method 201A. Three separate particulate emission measurements were taken. The protocol used for particulate emission measurement requires steady state conditions during the measurements. Each particulate emission measurement was taken during steady state conditions over a time period of 60 minutes, at an engine load of 5104.5 kW (83% of MCR).

7.6.4 Results from Merchant Tanker

Gaseous exhaust emission results are provided in Table 7-13.

Table 7-13: Measured Gaseous Exhaust Emissions in g/kWh from Merchant Tanker

Vessel Activity	Engine Load (%)	NOx (g/kWh)	SOx (g/kWh)	CO (g/kWh)	CO_2 (g/kWh)	NM THC (g/kWh)	O_2 (g/kWh)
Alongside	10	12.43	8.73	7.63	1280.39	0.84	5648.89
Alongside	12	11.64	7.66	6.22	1106.66	0.79	4732.04
Underway	44	13.44	4.31	3.14	672.02	0.47	2356.4
Underway	83	13.29	3.98	2.47	605.26	0.21	1831.87
Underway	12	11.22	7.44	6.09	1080.66	0.63	4592.49
Underway	39	12.83	4.32	2.76	671.09	0.27	2376.12
Underway	67	12.35	4.02	2.93	597.6	0.22	1837.84
Underway	68	12.4	3.79	2.4	590.85	0.2	1815.51
Underway	34	13.53	4.6	3.02	732.07	0.29	2754.73
Underway	54	12.03	4.09	3.09	617.53	0.23	1964.54
Alongside	12	11.94	7.78	6.9	1182.62	0.65	4867.22
Underway	24	9.79	4.4	3.4	747.13	0.34	2764.53
Underway	19	9.95	5.6	4.59	879.8	0.56	3348.94
Underway	72	12.58	3.75	2.34	593	0.19	1798.2
Underway	45	14.25	4.47	2.94	724.22	0.31	2399.97
Underway	32	9.32	3.6	2.7	599.61	0.31	2175.15

Particulate exhaust emission results are provided in Table 7-14. The average emission results provided are the mathematical average of the three tests.

Table 7-14: Measured Particulate Exhaust Emissions in g/kWh from Merchant Tanker

Vessel Activity	Engine Load (kW)	Particulate Concentration (mg/dsm^3)		Particulate Emission Rate (kg/h)		Particulate Emissions (g/kWh)	
		PM2.5	PM10	PM2.5	PM10	PM2.5	PM10
Underway	5104.5	15.7	20.7	0.461	0.572	0.09	0.11
Underway	5104.5	14.5	18.2	0.398	0.499	0.08	0.10
Underway	5104.5	16.0	21.8	0.439	0.598	0.09	0.12
AVERAGE	**-**	**15.4**	**20.2**	**0.433**	**0.556**	**0.09**	**0.11**

7.7 Discussion of Results

7.7.1 IMO Compliance

IMO ship pollution rules are contained in the *International Convention on the Prevention of Pollution from Ships*, known as MARPOL 73/78. On 27 September 1997, the MARPOL Convention was amended by the "1997 Protocol", which includes Annex VI titled *Regulations for the Prevention of Air Pollution from Ships*. MARPOL Annex VI sets limits on NOx and SOx emissions from ships exhausts, and prohibits deliberate emissions of ozone depleting substances.

7.7.2 NOx Emissions

NOx emission limits are set for diesel engines manufactured after 2000, which range from 9.8 to 17.0 g/kWh depending on the engine maximum operating speed, as shown in Table 7-15.

Table 7-15: MARPOL Annex VI NOx Emissions Limits

Engine Speed (n, rpm)	NOx, g/kWh
n<130 rpm	17.0
130 rpm<- n <2000 rpm	45.0 x $n^{(-0.2)}$
n >= rpm	9.8

The IMO NOx limit for the Merchant Container vessel is 13.4 g/kWh, which is based on the maximum engine speed of 428 rpm (per Table 7-1). The measured NOx emissions from the Merchant Container ranged from 8.6 to 13.2 g/kWh, with a calculated TWA of 12.4 g/kWh. The NOx emissions measured never exceeded the IMO limit of 13.4 g/kWh.

These IMO limits do not apply to the Merchant Ferry vessel, since the engine tested was built in 1989; however, if these limits did apply, the NOx limit for this engine (500 rpm per Table 7-5) would be 12.98 g/kWh. The measured underway NOx emissions from the Merchant Ferry ranged from 14.72 g/kWh (MGO fuel at 85% engine load) to 19.22 g/kWh (IFO fuel at 85% engine load). NOx emissions during manoeuvring were found to range from 9.42 (MGO fuel at 85% engine load) to 30.8 (MGO fuel at 26% engine load).

The IMO limits also do not apply to the Merchant Tanker, since the engine tested was built in 1999. However, if theses limits did apply the NOx limit for this engine (210 rpm per Table 10) would be 15.44 g/kWh. The measured underway NOx emissions from the test vessel main engine ranged from 9.32 g/kWh (underway at 32% engine load) to 14.25 g/kWh (underway at 45% engine load). NOx emissions while alongside were found to range from 11.64 g/kWh (alongside at 12% engine load) to 12.43 g/kWh (alongside at 10% engine load). The measured NOx concentrations did not exceed the IMO limit during the 28 hours of testing.

7.7.3 SOx Emissions

The IMO limits for sulphur in marine fuels are 4.5% by weight, and 1.5% by weight for ships operating within a SECA. Alternatively, exhaust gas cleaning systems can be used to reduce the total SOx emissions to a maximum of 6.0 g/kWh within a SECA.

The sulphur content of the fuel used on the Merchant Container vessel was 1.9% by weight, and the measured SOx exhaust emissions ranged from 3.9 to 5.6 g/kWh.

With respect to the Merchant Ferry, underway SOx emissions were measured as 0.14 g/kWh, using MGO fuel with a sulphur content < 0.02%. SOx emissions using the IFO fuel (sulphur content of 1.6%) were found to range from 6.03 g/kWh to 10.13 g/kWh. The lower SOx measurement was obtained during the MGO-IFO changeover at 85% engine load, whereas the higher SOx measurement was obtained using IFO fuel at 85% engine load. During manoeuvring, SOx measurements were found to range from 1.02 g/kWh to 3.31 g/kWh, with the mathematical average of all measurements being 2.16 g/kWh. The type of fuel used during manoeuvring was MGO (sulphur content < 0.02%).

Using Marine Bunker fuel oil with sulphur content 0.75%, measured underway SOx emissions from the Merchant Tanker were found to range between 3.6 g/kWh (32% engine load) and 7.44 g/kWh (12% engine load). While alongside, SOx measurements were found to range from 7.78 g/kWh (12% engine load) to 8.73 g/kWh (10% engine load).

7.7.4 PM Emissions

There are currently no regulatory limits for PM emissions from ships.

Measured PM emissions from the Merchant Container ranged from 0.17 to 0.84 g/kWh, and were obtained by using a nominal 2.5-micron filter. These results are not comparable to $PM_{2.5}$ emission factor, and are provided for information purposes only.

With respect to the Merchant Ferry, $PM_{2.5}$ emissions were found to range from 0.17 g/kWh to 0.20 g/kWh, with an average of 0.18 g/kWh during the 8-hour return transit from Port aux Basques to North Sydney. PM_{10} emissions were found to range from 0.18 g/kWh to 0.22 g/kWh, with an average of 0.20 g/kWh. These results were obtained while using IFO fuel (sulphur content of 1.61%).

With respect to the Merchant Tanker, $PM_{2.5}$ emissions were found to be 0.09 g/kWh, on average, while PM_{10} emissions were found to be 0.11 g/kWh, on average.

8. COMPARISON OF MEASURED EMISSIONS WITH EMISSION FACTORS

8.1 Gaseous Emissions

8.1.1 Merchant Container Vessel

Results from the MC vessel discussed in the previous section are compared to the proposed emission factors, as shown in Table 8-1.

Table 8-1: Comparison of Measured Gaseous Emissions from Merchant Container with Proposed Emission Factors (Underway)

Parameter	Measured Emissions for MERCHANT CONTAINER 4-Stroke MAIN ENGINE Sulphur = 1.9% 42%>Load>93% MCR (g/kWh)	Proposed Emission Factors 4-Stroke MAIN ENGINE Sulphur = 1.9% Load >20%MCR (g/kWh)	Notes
NOx	8.8 to 13.2	13.2	1
SOx	4.6 to 5.6	8.0	2
CO	0.4 to 0.6	1.1	1
CO_2	469.6 to 559.0	670	1
NM THC	0.8	0.5	1

Note 1: Value from Table 5.1.
Note 2: Calculated using eqn. 1, subsection 5.2.

The measured emissions from the Merchant Container were found to be generally lower than the proposed Emission Factors in the Tool, except for NM THC results, which were found to be slightly higher.

8.1.2 Merchant Ferry Vessel

Results from the Merchant Ferry discussed in the previous section are compared to the proposed Emission Factors, as shown in Table 8-2.

Table 8-2: Comparison of Measured Gaseous Emissions from Merchant Ferry with Proposed Emission Factors (Underway)

Parameter	Measured Emissions for MERCHANT FERRY 4-Stroke MAIN ENGINE Sulphur = 1.61% Load = 75% (g/kWh)	Measured Emissions for MERCHANT FERRY 4-Stroke MAIN ENGINE Sulphur = 1.61% Load = 85% (g/kWh)	Proposed Emission Factors 4-Stroke MAIN ENGINE Sulphur = 1.61% Load >20%MCR (g/kWh)	Notes
NOx	17.48	19.22	13.2	1
SOx	9.82	10.13	6.76	2
CO	1.72	1.87	1.1	1
CO_2	775.91	818.12	670	1
NM THC	1.03	1.09	0.5	1

Note 1: Value from Table 5.1.
Note 2: Calculated using eqn. 1, subsection 5.2.

In general, the measured emissions from the ferry were found to be higher than the proposed Emission Factors. Higher emissions were measured at 85% load compared to those at 75% load.

8.1.3 Merchant Tanker Vessel

Results from the Merchant Tanker compared to the proposed Emission Factors are shown in Table 8-3. Table 8-3 shows emissions for engine loads greater than 20% MCR.

Table 8-3: Comparison of Measured Gaseous Emissions from Merchant Tanker with Proposed Emission Factors (Engine Load =>20%)

Parameter	**Measured Emissions for MERCHANT TANKER** 2-Stroke MAIN ENGINE Sulphur = 0.75% Load =>20% (g/kWh)	**Proposed Emission Factors** 2-Stroke MAIN ENGINE Sulphur = 0.75% Load =>20% (g/kWh)	**Notes**
NOx	9.32 - 14.25	17	1
SOx	3.6 – 4.47	3.15	2
CO	2.34 – 3.4	1.4	1
CO_2	590.85 – 747.13	621	1
NM THC	0.19 – 0.47	0.6	1

Note 1: Value from Table 5.1.
Note 2: Calculated using eqn. 1, subsection 5.2.

The measured emissions from the tanker were found to be lower than the proposed Emission Factors for NOx and NM THC. The measured emissions were found to be higher than the proposed Emission Factors for SOx and CO. The CO_2 Emission Factor was within the measured range of CO_2 emissions.

It is engineering common knowledge that engines are not as efficient at low engine loads. For this reason, Emission Factors should be adjusted upwards to account for higher emissions at dock. Table 8-4 provides measured emissions from the Merchant Tanker at engine loads less than 20% MCR, and compares them with the proposed emission factors adjusted for low loads. The low load adjustment factors are provided in Table 10 of Appendix B.

Table 8-4: Comparison of Measured Gaseous Emissions from Merchant Tanker with Proposed Emission Factors (Engine Load <20%)

Parameter	Measured Emissions for MERCHANT TANKER 2-Stroke MAIN ENGINE Sulphur = 0.75% Load = 10% (g/kWh)	Proposed Emission Factor 2-Stroke MAIN ENGINE Sulphur = 0.75% Load = 10% (g/kWh)	Measured Emissions for MERCHANT TANKER 2-Stroke MAIN ENGINE Sulphur = 0.75% Load = 12% (g/kWh)	Proposed Emission Factor 2-Stroke MAIN ENGINE Sulphur = 0.75% Load = 12% (g/kWh)	Measured Emissions for MERCHANT TANKER 2-Stroke MAIN ENGINE Sulphur = 0.75% Load = 19% (g/kWh)	Proposed Emission Factor 2-Stroke MAIN ENGINE Sulphur = 0.75% Load = 19% (g/kWh)	Notes
NOx	12.43	20.74	11.22-11.94	19.38	9.95	17.2	1
SOx	8.73	3.94	7.44-7.78	3.69	5.6	3.18	2
CO	7.63	2.8	6.09-6.9	2.3	4.59	1.5	1
CO_2	1280.39	776.3	1080.66-1182.62	726.6	879.8	627.2	1
NM THC	0.84	1.7	0.63-0.79	1.3	0.56	0.7	1

Note 1: Value from Table 5.1 multiplied by the low load adjustment factor.
Note 2: Calculated using eqn. 1, subsection 5.2 multiplied by the low load adjustment factor.

The measured emissions from the tanker were found to be lower than the proposed Emission Factors for NOx and NM THC. The measured emissions were found to be higher than the proposed Emission Factors for SOx, CO and CO_2.

8.2 Particulate Emissions

As stated in subsection 7.7.4, the PM results from the Merchant Container vessel are not comparable to the $PM_{2.5}$ emission factors, and are provided for information purposes only.

Table 8-5 shows the measured PM emissions from the Merchant Ferry compared to the Proposed Emission Factors, based on a fuel sulphur content of 1.6%.

Table 8-5: Comparison of Measured Particulate Emissions from Merchant Ferry with Proposed Emission Factors (Underway)

Parameter	Measured Emissions from MERCHANT FERRY (g/kWh)	Proposed Emission Factor* Fuel Sulphur = 1.6% (g/kWh)
$PM_{2.5}$	0.18	0.88
PM_{10}	0.20	0.95

* Calculated using eqn. 2, subsection 5.3.

The measured $PM_{2.5}$ and PM_{10} emissions were found to be much lower than those calculated using the CARB assumptions discussed in Section 4.7.

Table 8-6 shows the measured PM emissions from the Merchant Tanker compared to the Proposed Emission Factors, based on a fuel sulphur content of 0.75%.

Table 8-6: Comparison of Measured Particulate Emissions from Merchant Tanker with Proposed Emission Factors (Underway)

Parameter	Measured Emissions from MERCHANT FERRY (g/kWh)	Proposed Emission Factor* Fuel Sulphur = 0.75% (g/kWh)
$PM_{2.5}$	0.09	0.53
PM_{10}	0.11	0.58

* Calculated using eqn. 2, subsection 5.3.

8.3 Other Recent Emission Testing Results

There have been two other recent emissions measurements on ships conducted on behalf of Transport Canada that have been compared to the emission factors in the Tool.

8.3.1 MV *Cabot*

Emissions measurements were carried out on board the MV *Cabot*, a Merchant RoRo vessel, in March 2004 and March 2005 by the TDC in collaboration with Environment Canada's Emissions Research and Measurement Division (References 7 and 8). The emission measurements took place during transits between Montreal, Quebec, and St. John's, Newfoundland. Details of the emissions measurement program are provided in References 8 and 9. The reports describe the field-testing of a water injection system (WIS) to reduce oxides of nitrogen (NOx) emissions. Emissions measurements were taken at various load settings (e.g. 20, 47, 50 and 75 percent engine load), and for a range of water injection volumes. The engine was operated on both MDO and IFO fuel. The IFO is used approximately 98% of the time, while the MDO is used for manoeuvring and when near port. Samples of the fuel showed that the IFO had a sulphur content of 1.3% and the MDO had a sulphur content of 0.394%.

Tables 8-7 and 8-8 show the baseline emissions measured, that is with no water injection, at indicated engine loads.

Table 8-7: MV *Cabot* – Comparison of Measured Emissions with Proposed Emission Factors (MDO Fuel = 0.394% Sulphur))

Parameter	**Measured Emissions for MV *CABOT*** (g/kWh) 4-Stroke MAIN ENGINE Sulphur = 0.394% Load = 20% **2004**	**Measured Emissions for MV *CABOT*** (g/kWh) 4-Stroke MAIN ENGINE Sulphur = 0.394% Load = 20% **2005**	**Measured Emissions for MV *CABOT*** (g/kWh) 4-Stroke MAIN ENGINE Sulphur = 0.394% Load = 47% **2004**	**Measured Emissions for MV *CABOT*** (g/kWh) 4-Stroke MAIN ENGINE Sulphur = 0.394% Load = 47% **2005**	**Proposed Emission Factors** (g/kWh) 4-Stroke MAIN ENGINE Sulphur = 0.394% Load =>20%	Notes
NOx	29.6	31.9	21.9	20.4	13.2	1
PM	0.34	0.44	0.19	0.15	0.43	2

Note 1: Value from Table 5.1.
Note 2: Calculated using eqn. 2, subsection 5.3.

The measured NOx was found to be significantly higher than the Proposed Emission Factor. The measured PM was found to be generally lower than the Proposed Emission Factor. Both NOx and PM decreased with increasing engine load.

Table 8-8: MV *Cabot* – Comparison of Measured Emissions with Proposed Emission Factors (IFO Fuel = 1.3% Sulphur))

Parameter	**Measured Emissions for MV CABOT** (g/kWh) 4-Stroke MAIN ENGINE Sulphur = 1.3% Load = 50% **2004**	**Measured Emissions for MV CABOT** (g/kWh) 4-Stroke MAIN ENGINE Sulphur = 1.3% Load = 50% **2005**	**Measured Emissions for MV CABOT** (g/kWh) 4-Stroke MAIN ENGINE Sulphur = 1.3% Load = 70% **2004**	**Measured Emissions for MV CABOT** (g/kWh) 4-Stroke MAIN ENGINE Sulphur = 1.3% Load = 70% **2005**	**Proposed Emission Factors** (g/kWh) 4-Stroke MAIN ENGINE Sulphur = 1.3% Load =>20%	**Notes**
NOx	24.9	20.4	17.0	18.8	13.2	1
PM	0.34	0.26	0.19	0.32	0.85	2

Note 1: Value from Table 5.1.
Note 2: Calculated using eqn. 2, subsection 5.3.

The measured NOx was found to be higher than the Proposed Emission Factor. The measured PM was found to be significantly lower than the Proposed Emission Factor. NOx was found to decrease with increased engine load. PM emissions did not necessarily decrease with increased engine load.

8.3.2 *Camille Marcoux*

Emission measurements were carried on board the *Camille Marcoux*, a Passenger and Vehicular Ferry, in March 2007 during a regular transit between Matane and Godbout, Quebec. Details of the emissions measurement program are provided in the report prepared by Weir [9]. Results obtained from the test are compared with the proposed emission factors in Table 8-9.

Table 8-9: *Camille Marcoux* – Comparison of Measured Emissions with Proposed Emission Factors (Underway)

Parameter	**Measured Emissions for *CAMILLE MARCOUX*** 4-stroke No. 1 MAIN ENGINE Sulphur = 0.0081% Load = 80% (g/kWh)	**Measured Emissions for *CAMILLE MARCOUX*** 4-stroke No. 4 MAIN ENGINE Sulphur = 0.0081% Load = 80% (g/kWh)	**Proposed Emission Factors** 4-Stroke MAIN ENGINE Sulphur = 0.0081% Load >20%MCR (g/kWh)	**Notes**
NOx	12.5	11.6	13.2	1
SOx	0.2	0.1	0.03	2
CO	1.9	1.7	1.1	1
CO_2	871.0	886.4	670	1
NM THC	1.7	2.0	0.5	1
PM	0.20	0.10	0.25	3

Note 1: Value from Table 5.1.
Note 2: Calculated using egn. 1, subsection 5.2
Note 3: Calculated using eqn. 2, subsection 5.3.

There is reasonable agreement between the proposed emission factors and the measurements taken on the underway Passenger and Vehicular Ferry (80% load). The measured values for SOx, CO_2, NM THC and CO were higher than the proposed emission factors. Both NOx and PM were slightly below the respective proposed emission factors.

9. CONCLUSIONS

The survey was successful in addressing the previously expressed concerns of the Canadian domestic shipping industry by achieving 100% participation of the Canadian Great Lakes commercial fleet. This allowed the parameters in the Marine Emissions Inventory Tool to be updated to reflect the ships and operating profiles applicable to the EC/GL region.

Based on the updated Tool and its parameters, an updated emissions inventory was developed for the base year (2002) and projected for 2010 and 2020. Projections were developed to predict future emissions with and without a SECA designation for the region. Overall, the revised baseline inventory and forecasts indicate that the 2006 study based on vessel profiles from the West Coast of North America had somewhat over-estimated marine emissions (depending on specific air contaminant considered). However, the SECA forecasts from this 2007 update are consistent in general with the 2006 study in that they indicate a significant reduction in PM and SOx emissions should the EC/GL region be designated a SECA.

During development of the baseline inventory and forecasts which were the primary objectives of the project, the following key findings were also identified:

The format of the ship activity data required for the Tool, does not match exactly any existing ship movement database and makes it very difficult to update the Tool parameters and resulting forecasts as new information becomes available. The future use of the Tool could be much more efficient if the Tool database was modified to accept data directly from the desired ship activity database (e.g. INNAV).

The required comprehensive data for forecasting activity growth is only available from the Transport Canada Surface and Marine Statistics and Forecasts Branch. Unfortunately this data is not in a format that is compatible with forecasting activity growth based on INNAV vessel classes, nor is it directly compatible with the Marine Emissions Inventory Tool. The future use of the Tool could be much more efficient if the Tool was updated to include a module to accept commodity forecast data and calculate activity forecasts based on the INNAV vessel classes.

There is significant variability in auxiliary engine size and use that limits the accuracy of emissions estimates on an individual ship-by-ship basis. The average engine profiles and emission factors used in the Tool for the aggregate data should not be used to estimate emissions or set reduction targets for an individual vessel.

The Tool does not currently differentiate between loading and unloading activities for use of auxiliary engines while alongside. The survey data indicated significant differences in unloading versus loading auxiliary engine use for all tanker classes. In the case of crude oil tankers, for example, unloading requires a significant amount of energy for both heating of the crude and operating pumps.

Some ship classes have a significant proportion of ships with 4-stroke main engines. Since 4-stroke diesel engines have lower NOx emissions compared to 2-stroke engines, earlier inventory efforts may have over-estimated total NOx emissions in the EC/GL region.

The use of shaft generators in place of an auxiliary generator to generate power while underway is significant for the ships surveyed in the EC/GL region. In particular, shaft generator use was significant for Merchant Bulk and Merchant Container vessels. The Tool currently does not account for the use of shaft generators and subsequent reduction in emissions. This may lead to an overestimation of emissions in the underway and manoeuvring modes of operation.

Emissions from auxiliary boilers are an important component of overall emissions from marine activities that was previously not included in the 2006 inventory. However, the high variability in the reported boiler usage profiles by vessel class and boiler fuel consumption indicates that further work is required to validate and improve the boiler assumptions that have been included in Version 2.2 of the Tool.

10. RECOMMENDATIONS

It is recommended that the Marine Emissions Inventory Tool be revised to accept marine activity data directly in the INNAV format and commodity data directly from the Transport Canada Surface and Marine Statistics and Forecasts Branch so that forecasts can be updated on a regular basis as new information becomes available. In addition, the conclusions presented in Section 9 should be considered in a future update to the Tool.

11. REFERENCES

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8. Radloff .E., Gautier C., Diesel Engine NOx Reduction Using Charge Air Water Injection, ASME 2005 Fall Technical Conference September 11-14, 2005 – Ottawa, Canada.
9. Weir Canada Inc., Measurement of Exhaust Gas Emissions from the Main Engines On Board MV *Camille Marcoux*, July 24, 2008.

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Appendix A

Weir Marine Engineering Commercial Marine Vessel Survey

SURVEY OF COMMERCIAL MARINE VESSELS
EASTERN CANADA AND GREAT LAKES REGION

Transport Canada / Transports Canada

Weir Marine Engineering is conducting a survey on behalf of Transport Canada to estimate typical operational profiles of marine vessels in the Eastern Canada and Great Lakes Region. Information collected will be consolidated by Weir Marine Engineering to provide summary data based on vessel type and geographic area. Information on specific vessels will not be released to any Government Department or other third party and will not appear in any report released to the public.

VESSEL INFORMATION

Vessel Name:		Lloyds/IMO No.:	Year of Build:	Country Flag:
Vessel Type (INNAV Code if known):	IMO IAPP Certificate: Yes ☐ No ☐	Deadweight tonnage:	Maximum Cruise Speed: kts	Typical Cargo:

OPERATING PROFILE

Date this survey is completed:	yyyy mm dd	Port where this survey is completed:		
% of Operations in the Eastern Canada & Great Lakes Region:	%	**Marine Fuel Types Used:**	**Distillate (Light)** ▼	**Residual (Heavy)** ▼
Average Time per Port visit:	Unloading ► hrs	Grade:		
	Loading ► hrs			
Normal Cruising Speed:	Ballast ► kts			
	Loaded ► kts	Location of last Fuelling:		
Normal Half Ahead Speed:	Ballast ► kts	% Sulphur of last fuelling:	%	%
	Loaded ► kts	Average Fuel Consumption:	tons / day	tons / day

ADDITIONAL COMMENTS

BOILER(S)

Fuel Type:	
Avg Fuel Consumption:	tons / day
% of Time Used:	

Would you like to receive a copy of the survey results? ***YES*** ☐ ***NO*** ☐ **If Yes, Please provide Contact Information:**

Name:	Title:
Organization:	
Street Address:	City:
Country:	Postal Code:
Email:	Send paper copy by regular mail: ☐ Send electronic copy by email: ☐

PLEASE RETURN COMPLETED FORMS: BY MAIL: ***MR. MIKE DAVIES***
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SURVEY OF COMMERCIAL MARINE VESSELS
EASTERN CANADA AND GREAT LAKES REGION

Transport Canada | Transports Canada

VESSEL NAME	

Please use additional survey sheets for vessels with more than 6 engines

ENGINE INFORMATION (FOR ALL PROPULSION & AUXILIARY POWER INCLUDING DIESEL-GENERATOR SETS)

Engine No.:	Engine 1▼		Engine 2▼		Engine 3▼		Engine 4▼		Engine 5▼		Engine 6▼	
Engine Use:	Propulsion ☐ Auxiliary Power ☐		Propulsion ☐ Auxiliary Power ☐		Propulsion ☐ Auxiliary Power ☐		Propulsion ☐ Auxiliary Power ☐		Propulsion ☐ Auxiliary Power ☐		Propulsion ☐ Auxiliary Power ☐	
Engine Make:												
Engine Model:												
Year of Engine:												
Engine Type:	Gas Turbine ☐ 2 Stroke Diesel ☐ 4 Stroke Diesel ☐		Gas Turbine ☐ 2 Stroke Diesel ☐ 4 Stroke Diesel ☐		Gas Turbine ☐ 2 Stroke Diesel ☐ 4 Stroke Diesel ☐		Gas Turbine ☐ 2 Stroke Diesel ☐ 4 Stroke Diesel ☐		Gas Turbine ☐ 2 Stroke Diesel ☐ 4 Stroke Diesel ☐		Gas Turbine ☐ 2 Stroke Diesel ☐ 4 Stroke Diesel ☐	
Rated Power (MCR):	kW ☐ Hp ☐		kW ☐ Hp ☐		kW ☐ Hp ☐		kW ☐ Hp ☐		kW ☐ Hp ☐		kW ☐ Hp ☐	
RPM at MCR:												
Fuel Type Normally Used:	Distillate	Residual	Distillate	Residual	Distillate	Residual	Distillate	Residual	Distillate	Residual	Distillate	Residual
At sea ►	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Manoeuvring ►	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Hotelling ►	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Load as % of MCR and % of Time used: (See examples below)	**Load ▼**	**Time ▼**	**Load ▼**	**Time ▼**	**Load ▼**	**Time ▼**	**Load ▼**	**Time ▼**	**Load ▼**	**Time ▼**	**Load ▼**	**Time ▼**
At sea (Ballast) ►	%	%	%	%	%	%	%	%	%	%	%	%
At sea (Loaded) ►	%	%	%	%	%	%	%	%	%	%	%	%
Half Ahead (Ballast) ►	%	%	%	%	%	%	%	%	%	%	%	%
Half Ahead (Loaded) ►	%	%	%	%	%	%	%	%	%	%	%	%
Manoeuvring ►	%	%	%	%	%	%	%	%	%	%	%	%
Hotelling (Unloading) ►	%	%	%	%	%	%	%	%	%	%	%	%
Hotelling (Loading) ►	%	%	%	%	%	%	%	%	%	%	%	%
EXAMPLE No. 1 ►	*80 %*	*50 %*	*80 %*	*50 %*	*◄ Represents 2 engines that normally operate one at a time (each operating at 50% of the time) at 80% load*							
EXAMPLE No. 2 ►	*Represents 3 engines that normally share the total load and run continuously ► 100% of the time at the same load (3 x 60%)*						*60 %*	*100 %*	*60 %*	*100 %*	*60 %*	*100 %*
Procedures or systems to reduce emissions												

ENQUÊTE STATISTIQUE SUR LES NAVIRES DE LA MARINE MARCHANDE
RÉGION EST DU CANADA ET DES GRANDS LACS

Transports Canada | Transport Canada

Génie maritime Weir effectue une enquête statistique pour le compte de *Transports Canada* dans le but de déterminer le profil opérationnel type des navires de la région de l'Est du Canada et des Grands Lacs. Génie maritime Weir compilera l'information recueillie et fournira un sommaire des données en fonction du type de navire et de la région géographique. L'information relative à des navires particuliers ne sera pas dévoilée à aucun service gouvernemental et n'apparaitra pas dans aucun rapport destiné au public.

INFORMATION SUR LE NAVIRE

Nom du navire:		No. de Lloyds/IMO:	Année de construction:	Pavillon:
Type de navire (code INNAV si connu):	Certificat IMO IAPP: Oui ☐ Non ☐	Tonnage de port en lourd:	Vitesse de croisière maximale: nds	Cargaison type:

PROFIL OPÉRATIONNEL

Date à laquelle l'enquête est complétée:	aaaa mm jj	Port dans lequel l'enquête est complétée:			
% des opérations dans la région de l'Est du Canada et des Grands Lacs:	%	**Types de carburants de navire utilisés:**		**Distillat (Léger)** ▼	**Résiduel (Lourd)** ▼
Durée moyenne de la visite dans ce port:	Déchargement ► hres	Grade:			
	Chargement ► hres				
Vitesse de croisière normale:	Ballast ► nds				
	Chargé ► nds	Lieu du dernier ravitaillement:			
Vitesse avant demi moyenne:	Ballast ► nds	% en souffre du dernier ravitaillement:		%	%
	Chargé ► nds	Consommation moyenne de carburant::		tonnes / jour	tonnes / jour

COMMENTAIRES ADDITIONNELS

CHAUDIÈRE(S)

Type de carburant:	
Consommation moyenne:	tonnes / jour
% du temps utilisé:	

Aimeriez-vous recevoir les résultats de l'enquête statistique? ***OUI*** ☐ ***NON*** ☐ **Si oui, prière de fournir l'information ci-dessous:**

Nom:	Titre:
Organisme:	
Adresse:	Ville:
Pays:	Code postal:
Courriel:	Envoyez une copie papier par Poste Canada: ☐ Envoyez une copie électronique par courriel: ☐

PRIÈRE DE RETOURNER LES FORMULAIRES COMPLÉTÉS: PAR LA POSTE À :

M. MIKE DAVIES
WEIR MARINE ENGINEERING
8600 ST-PATRICK STREET
LASALLE, QUEBEC, CANADA H8N 1V1

PAR TÉLÉCOPIEUR AU : **(514) 366-8475**
ou
PAR COURRIEL: mdavies@weiramericas.com

Pour obtenir plus d'information sur cette enquête statistique, prière de communiquer avec M. Mike Davies, Génie maritime Weir au (514) 366-4310, poste 318, ou par courriel à: mdavies@weiramericas.com

Transports Canada | Transport Canada

ENQUÊTE STATISTIQUE SUR LES NAVIRES DE LA MARINE MARCHANDE
RÉGION EST DU CANADA ET DES GRANDS LACS

NOM DU NAVIRE	

Si votre navire a plus de 6 moteurs, s.v.p. utiliser une autre fiche

INFORMATION RELATIVE AU MOTEUR (POUR TOUT MOTEUR DE PROPULSION OU MOTEUR AUXILIAIRE, Y COMPRIS LE GROUPE ÉLECTROGÈNE DIESEL)

No. du moteur:	Moteur 1▼		Moteur 2▼		Moteur 3▼		Moteur 4▼		Moteur 5▼		Moteur 6▼	
Utilisation du moteur:	Propulsion ☐ Auxiliaire ☐		Propulsion ☐ Auxiliaire ☐		Propulsion ☐ Auxiliaire ☐		Propulsion ☐ Auxiliaire ☐		Propulsion ☐ Auxiliaire ☐		Propulsion ☐ Auxiliaire ☐	
Marque du moteur:												
Modèle du moteur:												
Année du moteur:												
Type de moteur:	Turbine à gaz ☐ Diesel 2 temps ☐ Diesel 4 temps ☐		Turbine à gaz ☐ Diesel 2 temps ☐ Diesel 4 temps ☐		Turbine à gaz ☐ Diesel 2 temps ☐ Diesel 4 temps ☐		Turbine à gaz ☐ Diesel 2 temps ☐ Diesel 4 temps ☐		Turbine à gaz ☐ Diesel 2 temps ☐ Diesel 4 temps ☐		Turbine à gaz ☐ Diesel 2 temps ☐ Diesel 4 temps ☐	
Puissance nominale (Régime de puissance continu (RPC)):	kW ☐ CV ☐		kW ☐ CV ☐		kW ☐ CV ☐		kW ☐ CV ☐		kW ☐ CV ☐		kW ☐ CV ☐	
R/min au RPC:												
Type de carburant normalement utilisé:	Distillat	Résiduel	Distillat	Résiduel	Distillat	Résiduel	Distillat	Résiduel	Distillat	Résiduel	Distillat	Résiduel
En mer ▶	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Lors d'une manoeuvre ▶	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
À quai ▶	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
% de la charge du RPC et % du temps utilisé: (voir exemples ci-dessous)	**Charge** ▼	**Temps** ▼	**Charge** ▼	**Temps** ▼	**Charge** ▼	**Temps** ▼	**Charge** ▼	**Temps** ▼	**Charge** ▼	**Temps** ▼	**Charge** ▼	**Temps** ▼
En mer (ballast) ▶	%	%	%	%	%	%	%	%	%	%	%	%
En mer (chargé) ▶	%	%	%	%	%	%	%	%	%	%	%	%
Avant demi (ballast) ▶	%	%	%	%	%	%	%	%	%	%	%	%
Avant demi (chargé) ▶	%	%	%	%	%	%	%	%	%	%	%	%
Lors d'une manoeuvre ▶	%	%	%	%	%	%	%	%	%	%	%	%
À quai (déchargement) ▶	%	%	%	%	%	%	%	%	%	%	%	%
À quai (chargement) ▶	%	%	%	%	%	%	%	%	%	%	%	%
EXEMPLE no. 1 ▶	*80 %*	*50 %*	*80 %*	*50 %*	*◄ représente 2 moteurs qui fonctionneraient normalement en alternance (chacun à 50% du temps) et à 80% chargé*							
EXEMPLE no. 2 ▶	*représente 3 moteurs qui se partageraient normalement la charge et fonctionneraient en continu(100% du temps et à la même charge (3 X 60%))* ▶						*60 %*	*100 %*	*60 %*	*100 %*	*60 %*	*100 %*
Procédures ou systèmes visant à réduire les émissions												

Pour obtenir plus d'information sur cette enquête statistique, prière de communiquer avec M. Mike Davies,Génie maritime Weir au (514) 366-4310, poste 318, ou par courriel à: mdavies@weiramericas.com

Appendix B

Marine Emission Factors, Engine Profiles and SECA Forecast

Marine Emission Factors, Engine Profiles and SECA Forecast

Prepared for:
Weir Marine Engineering
In support of:
Transport Development Centre
Transport Canada
Contract No. T8200-055529/001/MTB

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GLOSSARY OF ACRONYMS

AE	Auxilliary Engine
CAC	Common Air Contaminants
CH_4	Methane
CO	Carbon monoxide
CO_2	Carbon dioxide
CoS	B.C. Chamber of Shipping
DFO	Diesel Fuel Oil
DWT	Dead Weight Tonnage
EC	Environment Canada
GHG	Greenhouse gases
HC	Hydrocarbons
HFO	Heavy Fuel Oil, or bunker oil
INNAV	Information System on Marine Navigation
LFV	Lower Fraser Valley in British Columbia
LMIU	Lloyds Maritime Intelligence Unit
MDO	Marine Diesel Oil
NH_3	Ammonia
ME	Main Engine
NO_x	Nitrogen oxides
N_2O	Nitric oxide
PM	Same as TPM
PM_{10}	Inhalable particulate matter (mean aerodynamic diameter less than 10 µm)
$PM_{2.5}$	Respirable particulate matter (mean aerodynamic diameter less than 2.5 µm)
POLA	Port of Los Angeles
rpm	revolutions per minute (designating engine ‘speed’)
SECA	Sulphur Emission Control Area
SO_x	Sulphur oxides
TDC	Transportation Development Centre (Transport Canada)
TPM	Total suspended Particulate Matter (mean aerodynamic diameter less than 30µm)
U.S. EPA	United States Environmental Protection Agency
VOC	Volatile organic compounds
WME	Weir Marine Engineering

EXECUTIVE SUMMARY

This report provides a set of engine 'profiles' for main and auxilliary engine use by commercial marine vessels operating in eastern Canada. The engine profiles were determined by assessing information collected by Weir Marine Engineering (WME) through ship survey questionnaires received from January to September of 2007, as part of a marine emissions study for the Transport Development Centre (TDC) of Transport Canada[1]. In addition, a review of marine diesel engine emission rates was conducted. Both of these initiatives were used to update an existing Environment Canada (EC) Marine Emissions Tool ('Tool') that allows estimation of a marine emissions inventory using an MS Access database application. The Tool update was used to revise a previous marine vessel emissions inventory for eastern Canada and the Great Lakes ('TDC Inventory'), completed in 2006. A total of 167 questionnaire returns were available for analysis.

The surveys were facilitated through the cooperation of the Canadian Shipowners Association. The survey responses were found to illuminate important operating characteristics that should be considered in future marine vessel emissions inventory development in Canada. Some of these characteristics suggest different average operational conditions for vessels operating in eastern Canada to those previously assessed for vessels in California waters. This was an important consideration of the study described here, since the earlier 2006 TDC Inventory had to rely on engine profiles representative of ships visiting terminals at the Port of Los Angeles (POLA). The engine profiles allow a reasonable estimate of ship auxilliary engine power (and associated emissions) based on available surrogate information (main engine power).

The analysis of the WME survey questionnaires indicates the revised parameters shown in Table ES-1 should be utilized in the current version of the Tool (Version 2.2) for eastern Canada. The Tool was updated to Version 2.2 during the course of this work to support a main engine type (2-stroke versus 4-stroke) field. The *4-stroke ratio* parameter in Table ES-1 is a new feature of the updated Tool that replaces the previous (inherent) assumptions for engine type for propulsion engines. Due to limited representation of several vessel classes at this time (in particular, Merchant Ferry and Merchant Passenger), some of the existing parameters in the Tool should remain unchanged (as indicated in Table ES-1).

[1] Contract No. T8200-055529/001/MTB

Table ES-1
Original and Revised Auxilliary Engine (AE) Ratios in the Marine Tool

INNAV Vessel Class	INNAV Code	AE power		Underway		Manoeuvre		Berth		*4-stroke ratio*
Merchant Auto	MA	0.19	0.19	0.13	0.13	0.67	0.24	0.24	0.24	0.24
Merchant (Dry)	MM	0.15	0.33	0.17	0.20	0.45	0.37	0.22	0.27	0.47
Merchant Bulk	MB	0.15	0.29	0.17	0.21	0.45	0.31	0.22	0.42	0.24
Merchant Ore	MO	0.15	0.29	0.17	0.21	0.45	0.31	0.22	0.42	0.24
Merchant Container	MC	0.19	0.17	0.13	0.21	0.50	0.33	0.17	0.20	0.04
Merchant Coastal	MS	0.19	0.15	0.17	0.38	0.45	0.52	0.22	0.42	0.57
Merchant General	MG	0.19	0.15	0.17	0.38	0.45	0.52	0.22	0.42	0.57
Merchant Passenger	MP	0.27	0.27	0.17	0.17	0.45	0.45	0.22	0.22	0.00
Merchant Ferry	MF	0.13	0.13	0.17	0.17	0.45	0.45	0.22	0.22	1.00
Tugs, Ocean	HO	0.13	0.13	0.17	0.17	0.45	0.45	0.22	0.22	1.00
Merchant Ro/Ro	MH	0.45	0.33	0.15	0.20	0.45	0.37	0.20	0.27	0.47
Merchant Reefer	MR	0.14	0.14	0.20	0.20	0.67	0.34	0.34	0.34	0.24
Merchant (Tanker)	TT	0.21	0.29	0.13	0.30	0.45	0.37	0.67	0.24	0.14
Merchant Chemical	TL	0.21	0.28	0.13	0.20	0.45	0.36	0.67	0.30	0.13
Merchant Crude	TC	0.21	0.19	0.13	0.24	0.45	0.33	0.67	0.26	0.00
Merchant Gasoline	TG	0.21	0.28	0.13	0.20	0.45	0.36	0.67	0.30	0.13
Merchant Liquified Gas	TQ	0.21	0.25	0.13	0.23	0.45	0.37	0.67	0.33	0.13
Merchant Molasses	TM	0.21	0.28	0.13	0.20	0.45	0.36	0.67	0.30	0.13
Merchant Ore/Bulk/Oil	TO	0.21	0.28	0.13	0.20	0.45	0.36	0.67	0.30	0.13
Merchant Super Tanker	TS	0.21	0.28	0.13	0.20	0.45	0.36	0.67	0.30	0.13
Merchant ULCC	TU	0.21	0.19	0.13	0.24	0.45	0.33	0.67	0.26	0.00
Merchant VLCC	TV	0.21	0.19	0.13	0.24	0.45	0.33	0.67	0.26	0.00
Warship, General	WR	0.19	0.17	0.17	0.34	0.45	0.34	0.22	0.00	0.00
Warship, Surface	WS	0.19	0.17	0.17	0.34	0.45	0.34	0.22	0.00	0.00

Original ratios used in Tool
Revised ratios for Tool (V2.2)

The Tool and Inventory are structured to use 24 separate vessel classes (INNAV classes); yet commercial marine engine emissions in eastern Canada and the Great Lakes are dominated by a small subset of the 24 classes. Merchant Bulk and Merchant Container ships were well represented from the survey questionnaires, but further survey collection is recommended for Merchant Passenger/Merchant Ferry and Tankers. There are significant differences in auxilliary demand while berthing between the different types of tankers represented in the Tool and TDC Inventory. Of the 36 tanker ship surveys collected, virtually no representation was gained for crude oil tankers (TC, TU and TV). It was also found that use of shaft generators tends to confound the estimation of effective auxilliary power demand in different activity modes. In addition, the surveys indicated that there may be a sizeable number of Merchant Bulk ships still operating with steam turbine engines (5 of 63 returned questionnaires). These ships were over 40 years old. No other ship class indicated steam turbine use.

In addition to the effect of the revised engine profiles, the updated emission factors also significantly influenced the Inventory totals for some air contaminants. Table ES-2 provides a summary of the revised Emission Inventory for Eastern Canada and the Great Lakes (EC/GL) region, including forecasts to 2010 and 2020. No changes were made to the original vessel activities (voyages) and spatial allocations from the base year. The forecasts required use of updated growth factors by class of vessel, which were determined by Weir Marine Engineering. The growth factors account for expected changes in cargo shipments and associated ship movements.

Table ES-2
Revised Baseline and Forecast Inventory Totals (tonnes) for Eastern Canada/Great Lakes*

Air Contaminant	Total Emissions (tonnes)				
	2002	2010	*% Change*	2020	*% Change*
SO_2	54,959	64,349	*17.1%*	74,344	*35.3%*
NO_x	73,974	83,130	*12.4%*	91,253	*23.4%*
TPM	7,129	8,344	*17.0%*	9,640	*35.2%*
PM_{10}	6,844	8,010	*17.0%*	9,255	*35.2%*
$PM_{2.5}$	6,296	7,369	*17.0%*	8,514	*35.2%*
CO	6,165	7,154	*16.0%*	8,212	*33.2%*
HC	2,520	2,933	*16.4%*	3,376	*34.0%*
CO_2	3,620,092	4,212,740	*16.4%*	4,841,468	*33.7%*

* As extracted from the updated Tool pivot table reports

The Tool update completed by SENES also included the addition of accounting for boiler emissions. Earlier marine inventories (including the 2006 TDC Inventory) assumed boiler emissions were negligible. The B.C. Marine Emissions Inventory completed in 2007 by the B.C. Chamber of Shipping (CoS) clearly showed that ocean going vessel boiler emissions are not negligible, particularly during berthing activity. The CoS boiler fuel consumption rates and emission factors were adapted for use in the Tool for EC/GL. In the context of the EC/GL Inventory, the boiler fuel consumption rates in the Tool should be considered to have a relatively high degree of uncertainty.

The forecasts in Table ES-2 assume that marine engine emission rates (in g/kWh) will remain the same in future years, with the exception of NO_x emission rates. No changes were made to the assumptions in the original version of the Tool (and 2006 TDC Inventory) that make use of a 2% vessel replacement factor per year, with newer vessels assumed to have lower NO_x emission rates (due to the Marpol Annex VI NO_x Technical Code). In addition, no changes were made to the original assumptions relating to use of lower sulphur marine distillate that will be available in future years. It should be noted that the forecasts assume that there will be no improvements to freight efficiency (amount of fuel consumed per tonne of goods shipped) or to emission rates of other air contaminants and therefore should be interpreted with caution.

Table ES-3 provides revised forecasts using the same framework and additionally accounting for a SECA scenario with a sulphur in fuel limitation of 1.5% by mass. The forecast levels of SO_2 are significantly lower than the baseline level, as are particulate matter emissions (to a lesser degree).

Table ES-3
Revised Baseline and SECA Forecast Inventory Totals (tonnes) for Eastern Canada/Great Lakes*

Air Contaminant	Total Emissions (tonnes)				
	2002	**2010**	*% Change*	**2020**	*% Change*
SO_2	54,959	39,080	*-28.9%*	44,939	*-18.2%*
NO_x	73,974	83,130	*12.4%*	91,253	*23.4%*
TPM	7,129	5,658	*-20.6%*	6,511	*-8.7%*
PM_{10}	6,844	5,431	*-20.6%*	6,251	*-8.7%*
$PM_{2.5}$	6,296	4,997	*-20.6%*	5,750	*-8.7%*
CO	6,165	7,154	*16.0%*	8,212	*33.2%*
HC	2,520	2,933	*16.4%*	3,376	*34.0%*
CO_2	3,620,092	4,212,740	*16.4%*	4,841,468	*33.7%*

*Assumes sulphur content of marine fuel is limited to 1.5% for 2010 and 2020.

The collection and analysis of survey questionnaires and review of activity based marine engine emission factors facilitated an update to the EC marine emissions Tool and 2006 TDC Inventory for eastern Canada and the Great Lakes. The significant implications of the work can be summarised as follows:

- Further work should be considered to improve some of the auxilliary engine profiles developed as part of this project;
- There is significant variability in the installed auxilliary engine power and use that limits the accuracy of emissions estimates on a ship-by-ship basis, and also reduces the applicability of an emissions profile to commonly used classes of vessel. This issue is exacerbated for some ship classes in eastern Canada due to varying cargoes (and hence INNAV classification);
- Some INNAV ship classes have a large fraction with 4-stroke main engine(s). Since 4-stroke diesel engines have lower NO_x emission rates, earlier inventory efforts may have over-estimated total NOx emissions in eastern Canada;
- The use of shaft generators and exhaust gas boilers confounds the characterisation of auxilliary and boiler usage profiles from ships and this issue should be explored further;
- Although there remains considerable uncertainty associated with PM emissions from ships, the current understanding of this issue implies that there would be a greater PM

benefit associated with establishment of a SECA zone than earlier work had suggested; and,

- Further PM emissions research for use of bunker oil in large marine diesel engines is needed before a satisfactory level of understanding is achieved.

1.0 INTRODUCTION

1.1 BACKGROUND

Commercial marine vessel air contaminant emissions result from use of ship main engine(s), auxilliary engines and boilers. Auxilliary engines tend to be used for generation of electrical power for pumps, thrusters, loading/unloading equipment and lighting. Boilers are used for fuel heating and hot water production. Engine emissions are typically calculated on the basis of engine power in kW, engine load factor (percentage of maximum power in different marine activities) and emission rates in grams of pollutant per unit of energy developed (g/kWh). Each of these three factors can have an associated uncertainty, potentially resulting in significant uncertainty for the engine emission estimates. This is particularly the case for auxilliary engines.

While at sea (underway), main engine emissions are an order of magnitude higher than auxilliary and boiler emissions. While at dock or at berth, main engines are not used by commercial ships, although some (tankers in particular) may use their main engines at berth for operation of a shaft generator for electrical power needs. Due to the length of stay while at berth, total emissions due to ship auxilliary and boiler use can be substantial, and surpass in magnitude the total main engine emissions while in and near harbour areas. This has resulted in greater international attention applied to characterizing ship auxilliary and boiler use during the last several years.

Ship movement data (port of origin, port of destination, etc.) include specific ship identification, which allows main engine power rating to be determined accurately. In many cases, auxilliary engine power rating and load factor cannot be established directly, due to lack of such data in available records. Therefore, ships must be ordered into several different classes, each associated with an auxilliary engine 'profile'. A ship class profile allows estimation of auxilliary power use while underway, manoeuvring and at berth through empirical means based on available ship data (usually main engine power or deadweight tonnage). In the same way, boiler use profiles have recently been established and used in very recent marine emission inventories (for example, the 2005/2006 marine emissions inventory for B.C. completed by the B.C. Chamber of Shipping (CoS))[2].

Ship class profiles for auxilliary engine can be determined by a survey program. A questionnaire is constructed and ships arriving to port are asked to respond to specific questions relating to installed auxilliary power and usage patterns. The questionnaire can be administered by interview (for example, during a ship visit) or can be completed independently and returned as either hard copy or electronic format. Depending on the level of resources available for a

[2] B.C. Chamber of Shipping, 2007. 2005/2006 B.C. Ocean-Going Vessel Emissions Inventory. Available from http://chamber-of-shipping.com

particular marine emissions inventory, these profiles can be locally developed or a broad assumption can be made that profiles developed elsewhere relate reasonably well to the ships that frequent marine terminals in the region of interest.

The auxilliary engine operating profiles developed from past inventory efforts are not representative of ships with non-typical usage patterns. For example, since the majority of all ships generate ship's service power by running 1 or more 4-stroke auxilliary diesel engines, all ship class profiles assume auxilliary power is derived from 4-stroke diesels. In reality, a fraction of ships generate auxilliary power by use of shaft generators (and therefore the auxilliary power imposes an additional load on 2-stroke propulsion engines). Some (older) ships may generate auxilliary power from steam turbines. The improper characterization of these ships is considered to contribute to the overall uncertainty of the marine emissions inventory, which currently is high when compared to the uncertainty of emission inventories for land based transportation.

1.2 TDC Marine Emissions Inventory for Eastern Canada

The purpose of this assessment and report is to provide an analysis of marine vessel survey questionnaires ('WME surveys') collected for the Transport Development Centre (TDC) of Transport Canada as part of a larger project to assess marine vessel emissions in eastern Canada and the Great Lakes (EC/GL). The assessment and resulting ship auxilliary engine profiles facilitate an update to the existing profiles within an MS Access based marine emissions tool (Tool) that was previously developed for Environment Canada and used to complete a marine air contaminant emissions inventory for EC/GL (activity year 2002/2003) in a project that was completed by TDC in 2006[3].

The 2006 Marine Emission Inventory Study: Eastern Canada and Great Lakes (hereafter referred to as '2006 TDC Inventory') acknowledged that the auxilliary engine emission profiles assumed for the inventory should be re-assessed at a later date if possible. The profiles assumed for the 2006 TDC Inventory were taken from inventory work completed on the west coast of North America (California).

A review of marine activity based emission factors was also completed as part of this project. ENVIRON Environmental Consulting completed a review of marine emission factors for SENES, which is provided in Appendix B. The updated profiles and emission factor information was then used to complete a revised marine emissions inventory and SECA forecast.[4]

[3] Levelton, Maritime Innovation and James Corbett, 2006. *Marine Emission Inventory Study: Eastern Canada and Great Lakes*. Prepared for Transport Canada.
[4] SENES and Weir completed an update of the Tool software as part of a separate contract. This update included additional coding to incorporate boiler emissions.

There are several simplifications inherent to the version of the Tool that was used to produce the 2006 TDC Inventory. These simplifications were reasonable at the time and were made to achieve an annual marine emissions inventory within the resources made available for the project. The assumptions were consistent with other recent marine inventories produced elsewhere.

The previous version of the Tool applied the following assumptions:

Main Engine(s):

- Assumption that all engines are 2-stroke diesels (with the exception tugs and ferries);
- Constant load factors assumed for vessels when underway;
- Constant load factors assumed for vessels when manoeuvring;
- Consistent use of one fuel and sulphur content in all modes (no fuel switching);
- Main engine(s) not used while berthing.

Auxilliary Engines:

- Assumption that all engines are 4-stroke diesels;
- Installed engine power (which relates to all engines combined) is estimated as a fraction of ship main engine power (depending on vessel class);
- Effective load factor for the installed engine power rating is estimated from results of surveys conducted elsewhere (Port of Los Angeles);
- Constant load factor assumed in each of three modes: underway, manoeuvring and at berth;
- Consistent use of one fuel and sulphur content in all modes (no fuel switching).

Boilers:

- Boiler emissions assumed negligible.

The updates completed for the Tool in its present form (V2.2) include accounting for both 2-stroke and 4-stroke main engines, revision of auxilliary engine use profiles (from WME survey information), revision of emission calculations to directly use sulphur content of fuel for SO_x and PM emissions, and an expansion of the emission calculations to include boilers. This report and analysis primarily deals with the survey information and update of auxilliary engine profiles.

The Tool uses detailed activity data contained in the Canadian Coast Guard INNAV system. INNAV contains vessel movements as well as individual ship characteristics such as deadweight tonnage (DWT) and main (propulsion) engine maximum power rating. INNAV does not contain information on ship auxilliary engines. For this reason, assumptions regarding both installed auxilliary engine power and use (load factor) must be applied. The previous version of the Tool used auxilliary engine profiles obtained from a study that was completed for the Port of Los Angeles (POLA)[5]. Whether or not these profiles are representative of ships that operate in eastern Canada was to be assessed as part of this project.

In addition to auxilliary engine parameters, the WME survey data include information on main engine type (2-stroke, 4-stroke or turbine) and boiler fuel consumption. The engine type information was used to establish the fleet fraction of main engines that are 4-stroke diesels (remainder assumed to be 2-stroke diesels) for each vessel class. Boiler fuel consumption information from the surveys was not consistent, with many responses left blank and many of the completed responses contradictory. This suggests that boiler use may be more difficult to characterize. These and other issues are discussed in greater detail in the following sections.

[5] Starcrest LLC, 2005. Port of Los Angeles Baseline Air Emissions Inventory – 2001. Prepared for the Port of Los Angeles (POLA), July 2005. Available from POLA by request.

2.0 SURVEY QUESTIONNAIRES

A copy of the survey questionnaire used to collect the information presented in this report is provided in Appendix A. At the time of a draft report completed in March 2007, 86 completed questionnaires had been collected, either through direct interviews (35) or through email. Since that time, additional responses were collected through email such that 167 responses were considered for this final analysis.

In the case of questionnaires collected by direct interview, each field was discussed before assigning a value. For questionnaires that were sent through email, ship deadweight tonnage (DWT) and main engine power were checked by WME against an INNAV database representing vessel movements in eastern Canada for 2004-2006. Other fields could not be checked.

The survey questionnaires were used to determine total and effective engine power for auxilliary engines. Total power is simply the sum of the maximum continuous engine rating (MCR) for all installed auxilliary engines. Effective power is the sum of MCR multiplied by the load factor for each engine used in a particular activity (at berth, manoeuvre, underway). If a ship had two engines of power 700 kW each, and one was used at berth with a load factor of 0.50 and the other was not used at all, the effective power determined for berthing would be 350 kW, and an effective load factor (which the Tool requires) would be 0.25.

In the case where zero was indicated for effective auxilliary power, the ship entry was not included in the ship class average determination. In some cases, the reason for the zero response was the use of a shaft generator. In other cases, the responder may not have known an appropriate answer to state. The issue of how to properly account for emissions due to use of shaft generators is not straightforward, and is discussed in the following sections.

Additional information was requested in the survey questionnaires, subject to a design criterion that the survey be limited to two pages in length. Since questionnaire response was voluntary, and response error could increase with a longer survey form, limiting the survey length was considered prudent. Boiler information included in the survey returns was not adequate to establish reasonable boiler fuel consumption profiles. This was primarily due to a relatively high degree of variability in boiler use. Part of this variability is due to different boiler usage patterns for an individual ship in each of the activity modes. In effect, once all the survey forms were collected it was clear that questions relating to boiler use would have to be more focussed to achieve reasonable guidance. Merchant Bulk ships were the exception and reasonable consistency was found in the survey responses for these ships. The average boiler fuel consumption rate for Merchant Bulk ships in eastern Canada was found to be a close match to the ‘bulk carrier’ ships characterized as part of the CoS and Puget Sound inventory efforts.

Within the 167 survey responses, Merchant Bulk, Merchant Container and Tankers (of all types) are relatively well represented. There are ten different tanker classes within the 24 INNAV vessel classes used. Limited, but reasonable representation was achieved for Merchant RoRo, Merchant (Dry) and Merchant General. There is inadequate representation of other vessel classes to establish robust auxilliary engine profiles. However, the first three ship classes noted above make up a large fraction (approximately 70% by total fuel consumption) of the total ship activity in eastern Canada[6].

TDC requested that the ship classifications in the Tool and Inventory follow the two-digit alphanumeric INNAV vessel types (for the earlier 2006 Inventory). It was often difficult to assign a definitive INNAV type for the surveyed ships because many vessels carry multiple cargos in eastern Canada. Very few of those who completed the survey questionnaires were able to provide their known Transport Canada or INNAV vessel type, so an assignment had to be made by WME based on the vessel characteristics and "usual" cargo.

[6] Based on annual CO_2 emissions from the 2002/2003 TDC emissions inventory.

3.0 SHIP ENGINE PROFILES

Two recent marine vessel survey (and resulting emission inventory) initiatives serve as useful comparisons to the average vessel characteristics determined from the WME survey questionnaires. One is the POLA work (2001 activity year), which provides the basis for the original auxilliary engine profiles in the Tool, and the other is the 2005/2006 B.C. Ocean-going Vessel Emissions Inventory completed by the B.C. Chamber of Shipping (CoS) in 2007 (CoS Inventory). Each of these studies has allowed for improvements to the current understanding of marine vessel emissions and the development of methodologies to construct marine vessel emission inventories.

Although the INNAV database, which is accessed in the Tool, allows ‘lookup’ of main engine power rating directly, this database does not have auxilliary engine information[7]. Studies of auxilliary engine use by vessel class have been used in the past to determine profiles of auxilliary engine power, load factor and fuel use. Early studies showed that there is great variability in auxilliary use between different classes of ship and even within one class of ship. However, a reasonably consistent approach has been followed in recent years, which makes use of predictive equations (regression relations based on survey work) or ratios that establish estimated auxilliary engine power based on vessel DWT or main engine power. There are different ways of making use of such relations within an inventory. The Tool uses a set of ratios that relate total installed auxilliary power to the main engine power rating of a particular vessel, and these ratios differ by class of vessel. The ratios were determined by previous work in California and therefore relate to ships that operate in California waters. A significant goal of this project was to either confirm the appropriateness of these ratios for ships in eastern Canada, or to replace them with ratios that are more representative. Table 3.1 shows the POLA average main engine power rating , average total installed auxilliary power and load factors for auxilliary engine use while underway, manoeuvring and berthing (as described in the POLA 2001 inventory report).

[7] The Lloyds database has auxilliary engine information for a small fraction of the vessels within.

Table 3.1
POLA Average Auxilliary Power rating and Load Factors (Inventory of 2001 Activity)*

Ship Category or Class	Average Main Engine Power (kW)	Average Installed Aux Power (kW)	Auxilliary Load Factor		
			underway	manoeuvring	berthing
Auto Carrier	10,683	2,027	0.13	0.67	0.24
Bulk Carrier	7,954	1,169	0.17	0.45	0.22
Container Ship	30,885	5,746	0.13	0.50	0.17
Cruise Ship	39,563	11,000	0.80	0.80	0.64
General Cargo	9,331	1,777	0.17	0.45	0.22
Misc/Merchant Ferry	6,252	1,680	0.17	0.45	0.22
Tugs, Ocean	2,000	250	0.17	0.45	0.22
RoRo	10,993	4,992	0.15	0.45	0.20
Reefer	9,567	1,300	0.20	0.67	0.34
Tanker	9,409	1,985	0.13	0.45	0.67

*See www.portoflosangeles.org for a copy of the report

Table 3.2 shows the 24 different vessel classes in the Tool and how the auxilliary engine and emission characteristics relate to the POLA profiles. In Version 1 of the Tool, 10 different INNAV ship classes are represented with the same 'Tanker' profiles, whereas 3 classes are represented as 'Bulk Carrier' type and just 1 as 'Container Ship' type. This matching was completed as part of the 2006 TDC Inventory and is evident within the Table structure of the Tool.

The 2006 TDC Inventory report shows that 67% of the total commercial marine activity captured within the INNAV system relates to just three vessel classes: 31% for Merchant Bulk, 21% for Merchant Container and 15% for Merchant Tanker[8]. This strongly implies that greater attention should be applied to characterizing these three vessel classes. The next three vessel classes in terms of significance are Merchant Ferry, Merchant General and Merchant Passenger (7%, 7% and 6% of the total activity respectively).

[8] As determined by total CO_2 emissions, which directly relate to fuel consumption.

Table 3.2
INNAV Vessels and Relation to POLA Engine Profiles in the Tool*

INNAV Vessel Class	INNAV Code	Associated POLA Vessel Class
Merchant Auto	MA	Auto Carrier
Merchant (Dry)	MM	Bulk Carrier
Merchant Bulk	MB	Bulk Carrier
Merchant Ore	MO	Bulk Carrier
Merchant Container	MC	Container Ship
Merchant Coastal	MS	General Cargo
Merchant General	MG	General Cargo
Merchant Passenger	MP	Misc/Merchant Ferry
Merchant Ferry	MF	Misc/Merchant Ferry
Tugs, Ocean	HO	Tugs, Ocean
Merchant Ro/Ro	MH	RoRo
Merchant Reefer	MR	Reefer
Merchant (Tanker)	MT	Tanker
Merchant Chemical	TL	Tanker
Merchant Crude	TC	Tanker
Merchant Gasoline	TG	Tanker
Merchant Liquified Gas	TQ	Tanker
Merchant Molasses	TM	Tanker
Merchant Ore/Bulk/Oil	TO	Tanker
Merchant Super Tanker	TS	Tanker
Merchant ULCC	TU	Tanker
Merchant VLCC	TV	Tanker
Warship, General	WR	n/a
Warship, Surface	WS	n/a

*This mapping relates to the earlier version of the Tool, before update.

3.1 EFFECTIVE AUXILLIARY ENGINE POWER IN THREE ACTIVITY MODES

The main determinant of auxilliary engine emissions is the effective auxilliary power, or effective auxilliary demand used while in a particular mode of activity. This value incorporates the number of engines in operation and load factor for each into one measure. The implication here is that operating two 1000 kW engines, each at 20% load, is equivalent to operating one of the engines at 40% load. In reality, there would be different emissions for the two scenarios, but current emission testing data does not allow for such a distinction to be made. Common operating practice is to operate the minimum number of auxilliary engines (often one engine) within the most efficient load range (50 - 85% load).

There are sufficient completed surveys from the current work to make a meaningful comparison of effective auxilliary engine power for 4 of the ship classes described in the POLA inventory

(2001 activity year) study, the CoS inventory study and the WME survey summary. This comparison is shown in Table 3.3. A general expectation in marine inventory development has been that a higher main engine (ME) power rating should relate to higher effective auxilliary demand. Therefore, average ME rating is included in Table 3.3. Average installed auxilliary engine (AE) power is also included.

The WME survey effective auxilliary power values shown in Table 3.3 should not be considered final recommended values to use in inventory development, but are shown here to serve as an initial comparison. Further development is provided in the following sections.

Table 3.3
Average Main Engine (ME) and Auxilliary Engine Power for Three Marine Studies

Ship Class	Data Origin	Average ME Power (kW)	Average Total AE Power (kW)	Effective Auxilliary Power (kW)		
				underway	manoeuvre	berth
MB	POLA Average	7,954	1,169	199	526	257
	CoS Average	8,113		520	n/a	405
	WME Survey Average	**7,010**	**2,046**	**450**	**634**	**807**
MC	POLA Average	30,885	5,746	747	2,873	977
	CoS Average	32,251		1,348	n/a	1,234
	WME Survey Average	**31,113**	**5,401**	**1,134**	**1,782**	**1,080**
Tanker	POLA Average	9,409	1,985	258	893	1,330
	CoS Average	7,677		638	n/a	509
	WME Survey Average	**8,194**	**2,502**	**626**	**901**	**676**
MH RoRo	POLA Average	10,993	4,992	749	2,246	998
	CoS Average*	9,072		655	n/a	866
	WME Survey Average	**11,325**	**3,750**	**601**	**1,073**	**806**

*these values actually represent a 'general cargo' category, which included RoRo.

Table 3.3 shows both similarities and differences for the ships surveyed as part of this work and those characterized in the POLA work. The auxilliary characteristics from the WME survey are more similar to those determined in the CoS work than the POLA work. The POLA manoeuvring values are representative of the short duration procedures near berth that can require substantially more auxilliary power (for example, for use of bow thrusters). In contrast, manoeuvring in the Tool represents the last several kilometres of travel before establishing berth (which is consistent with the definition of manoeuvring for CoS)[9]. Therefore, higher POLA manoeuvring auxiliary engine demand should be expected in some cases. The CoS work assumed manoeuvring auxilliary demand was near equivalent to underway demand (the survey for the CoS study did not specifically address manoeuvring).

[9] Although many terminal locations are characterized in the Tool as requiring 2 – 4 km of 'manoeuvring' travel to berth, some terminals are characterized with 20 km or more of manoeuvring distance.

Table 3.3 indicates that Merchant Bulk (MB) ships in eastern Canada, which were very well represented in the survey returns, are different on average to those that visit both POLA and B.C. marine terminals. In particular, the MB ships in eastern Canada operate at a relatively high auxilliary power at berth. A recent update to the POLA inventory was completed for activity year 2005.[10] This inventory report showed a substantial difference (increase) in bulk carrier auxilliary engine power demand at berth that better matches the averages determined for CoS and the WME surveys. However, effective auxilliary power at berth (now 285 kW) remains substantially lower than that determined for Merchant Bulk ships in EC/GL.

Tanker responses on average were similar to the CoS averages, although the average power demand at berth was somewhat higher. Tanker survey responses were separated out into a Merchant Tanker (TT) category and an Other Tanker category for this project. It was evident that the survey returns had minimal representation of crude oil tankers (TC, TU and TV INNAV classes). The (2001 inventory year) POLA average auxilliary demand for tankers at berth is surprisingly high. The 2005 POLA inventory contradicts this value and established effective auxilliary power at berth of less than 1,000 kW (even for the large VLCC and ULCC crude oil tankers). Therefore, it appears likely that the tanker auxilliary profiles adopted in the earlier version of the Tool were not representative of tanker vessels visiting west coast ports or ports in eastern Canada.

The WME auxilliary power demand at berth is an average of the higher and lower demands reported for unloading and loading, respectively. For some ships classes, there is not a significant difference. Significant differences in auxilliary power demand in unloading versus loading modes were noted for all tanker classes surveyed. For the case of crude oil tankers, unloading requires a significant amount of energy for both heating of the crude and operating pumps.

3.2 USE OF MAIN ENGINE POWER FOR AUXILLIARY DEMAND

An important indication from the WME questionnaires for tanker, bulk (MB) and container (MC) ships is that a significant percentage do not use auxilliary engines while underway, and instead make use of shaft generators. A shaft generator extracts energy from the main engines to produce electricity that would otherwise be generated from the auxilliary diesel engine(s). It is likely that the 2001 activity year POLA analysis accounted for this effect (this however could not be confirmed from the POLA report) and this is the reason for a lower average value reported while underway for MB, MC and tankers, as shown in Table 3.3.

[10] Starcrest LLC, 2007. Port of Los Angeles Inventory of Air Emissions 2005. Prepared for the Port of Los Angeles (POLA), September 2007.

Aside from specific information on auxilliary engine rating and operation the WME surveys provided the following characteristics:

Tankers (derived from 10 ships that provided anecdotal information):

- 33% of ships use exhaust gas recirculation (instead of boilers) to produce hot water while underway;
- 60% of ships use shaft generators while at sea;
- 10% use shaft generators while at berth.

Merchant Bulk (derived from 9 ships that provided anecdotal information):

- 11% of ships use exhaust gas recirculation for hot water while underway;
- 22% of ships use shaft generators while underway.

Merchant Container (derived from 9 ships that provided anecdotal information):

- 44% of ships use exhaust gas recirculation for hot water while underway;
- 22% of ships use shaft generators while underway.

The information presented above was obtained from 18 direct interviews (vessel visits) during which WME recorded operational details from a representative and an additional 10 surveys that provided information in the ‘Additional Comments’ fields. The trends should not be considered robust, but instead they indicate that there are confounding factors when creating average auxilliary profiles for the three ship classes. This is especially the case if remaining consistent with the 2006 TDC Inventory approach, which assumed all ships use separate diesel auxilliary engines for electrical power at all times.

Reducing the effective auxilliary engine use for a particular ship class due to use of shaft generators requires an accompanying increase to main engine load to supply energy to the shaft generator(s) (in particular during manoeuvring and berthing). Sufficient data to support such an approach were not available. Instead, those ships indicating use of a shaft generator(s) in a particular mode of activity were removed from the analysis used to produce the auxilliary engine profiles. This includes survey responses that had auxilliary load factor fields blank. A blank response may indicate shaft generator use (and therefore zero load on an auxilliary engine), but could also indicate uncertainty regarding an appropriate value to enter.

It should be noted that most of the variation described above relates to underway activity. In this mode, emissions due to auxilliary engine use are relatively low when compared to main engine emissions. A similar argument can be made for boiler use. Therefore, although a potential over-estimate of auxilliary emissions during underway activity exists within the current methodology employed in the Tool, this effect would be rather small in the context of total ship emissions.

3.3 INSTALLED AUXILLIARY ENGINE POWER

A ratio is used in the Tool to estimate the total installed auxilliary engine power as a function of main engine power. Use of such ratios represents an intermediate step in determining effective auxilliary demand (kW) in different modes of activity.

The POLA report states that the Lloyds database was used to determine ratios between main engine (ME) power and total installed auxilliary engine (AE) power. Most vessels in the Lloyds database contain no information on auxilliary engines. Therefore, AE information was likely gained during numerous vessel boardings (ride-alongs). Assuming the ratios are representative of ships that visit POLA, they may not be appropriate for ships visiting eastern Canadian ports.

Table 3.4 shows a comparison of the average ratio of total auxiliary engine power to main engine power (AE Ratio) from the WME surveys to that determined for the POLA inventory. Similar ratios were not determined in the CoS work, although the ratios could be determined from the CoS database of survey responses at a future time.

Table 3.4
Average Ratio of Installed Auxilliary Engine Power to Main Engine Power by Vessel Class

Ship Category or Class	Average Main Engine Power (kW)	Average Installed Aux Power (kW)	POLA AE Ratio	WME AE Ratio
Auto Carrier	10,683	2,027	0.190	***N/A***
Bulk Carrier	7,954	1,169	0.147	***0.290***
Container Ship	30,885	5,746	0.186	***0.170***
Cruise Ship	39,563	11,000	0.278	***N/A***
General Cargo	9,331	1,777	0.190	***N/A***
Misc/Merchant Ferry	6,252	1,680	0.269	***N/A***
Tugs, Ocean	2,000	250	0.125	***N/A***
RoRo	10,993	4,992	0.454	***0.330***
Reefer	9,567	1,300	0.136	***N/A***
Tanker	9,409	1,985	0.211	***0.310***

Note: N/A = not available for this comparison

The WME survey ratios are provided for 4 vessel classes only. Other classes are omitted due to insufficient survey returns and/or difficulty matching an appropriate classification from the POLA work. It is interesting to note that the WME surveyed vessels report a good match to the POLA average ratio ***only*** for container ships. However, other studies have noted significant differences in auxilliary engine rating for Tankers frequenting a specific region or harbour area. Also worth noting, the 'Tanker' class is rather broad and includes crude (oil), refined petroleum products, chemical and other sub-classes. It appears likely that the distribution of tankers operating in eastern Canada is quite different from those operating in California in 2001. However, as previously noted, the 2005 POLA inventory does not support the POLA tanker and bulk carrier average auxilliary engine power rating noted in Table 3.4. The average installed auxilliary engine power determined for POLA 2005 is 2,850 kW and approximately 2,500 kW for bulk carriers and tankers respectively (actual average for a tanker class could not easily be determined from the report). Figure 3.1 provides an aggregate view of the relationship between main engine power and installed auxilliary engine power for those ship classes with multiple WME survey returns (12 or greater).

Figure 3.1
Relationship Between Main and Auxilliary Engine Power for WME Survey Questionnaire Responses

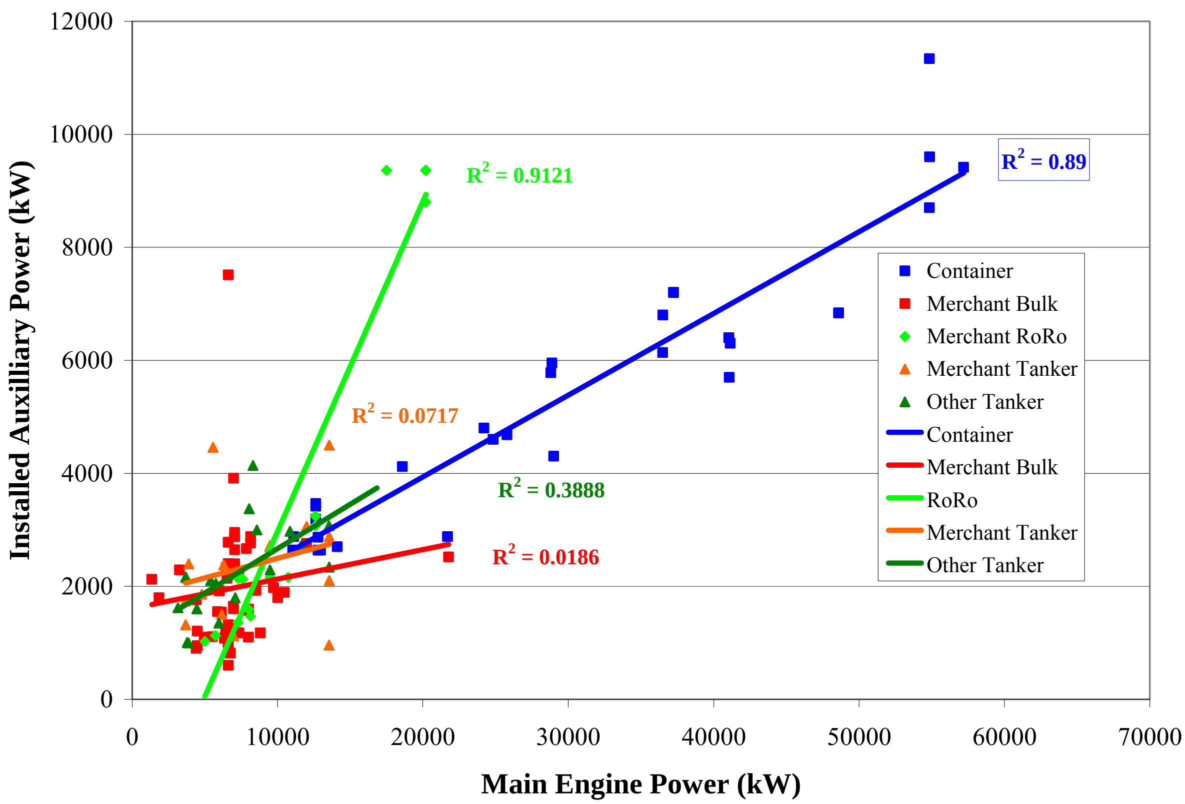


Figure 3.1 illustrates the difficulty in establishing average ratios for a particular class of vessel (in this case, auxilliary to main engine power ratio). The survey data are colour-coded for Merchant Container, Merchant Bulk, Merchant RoRo, Merchant Tanker and Other Tanker categories. A clear (linear) relationship exists for container ships; the linear regression line shown in the Figure has a reported 'R^2' value of 0.89. The R-squared parameter is a measure of

how well the data points match an assumption of linearity. In essence, the 'ratio' method of estimating auxilliary engine power assumes a linear relationship in the data and constructing a regression line (with an associated R-squared value) tests this assumption. The assumption is shown to be reasonable for container ships, potentially reasonable for RoRo ships and not reasonable for Merchant Bulk and Tankers (due to the significant spread of data points).

For both Merchant Bulk and Tanker ships, there appears to be considerable variability in installed auxilliary engine power, likely due to different cargoes and loading/unloading requirements. The complete lack of relationship between main engine and installed auxilliary engine power for Merchant Bulk indicates there may be two or more distinct groups within this class of vessel; potentially self-loaders and those without self loading capability. This also may relate to ships that serve the Great Lakes and those that frequent oceanic trips. The good agreement for MC ships is likely due to consistency in loading/unloading patterns with few self-loaders among the group.

The plotted data for RoRo ships produces a regression line with a high R-squared value. However, it is not clear that these data represent a consistent pattern associated with one ship class. Instead, it appears that there is a substantial difference in auxilliary engine power requirements for larger vessels with higher installed main engine power (approximately 18,000 – 20,000 kW) than for the smaller vessels . This issue is investigated further in Section 3.4.5.

There are ten different tanker vessel classes within the 24 classes of INNAV ships. It was difficult to clearly place a tanker within one INNAV tanker class, since it was evident that many of the tankers surveyed fit several of the INNAV tanker designations. The exception was the TT (Merchant Tanker) sub - class , which had 17 responses that clearly indicated this specific tanker designation. Therefore, both 'TT' and 'Other Tanker' classes were carried through the analyses in Section 3.3. The establishment of average auxilliary engine power ratio and applicability for tankers is not simplistic, since a sizeable fraction use shaft generators (which was apparent from comments in several returned questionnaires). In addition, auxilliary power demand was shown to be significantly higher during unloading compared to loading (likely due to the use of cargo pumps during unloading), which was not the case for other ships surveyed (exception Merchant Bulk).

3.4 AUXILLIARY ENGINE PROFILES FOR EASTERN CANADA

To serve as indication for differences in auxilliary engine profiles determined from the WME surveys to those from the POLA and CoS inventories, average power and DWT values were determined from the INNAV records in the Tool and compared to POLA and CoS values where possible. The 2002/2003 INNAV records in the Tool are post-filtered such that many ships that register within the INNAV system, yet do not make a stop at a Canadian port, are not included.

All non-entries (blanks) and zero entries for auxilliary engine use (load factor) were removed from the analyses shown here. As previously indicated, it was not clear what these responses meant in real terms – in some cases they likely represented a 'don't know' and in others they represented non use of engines. As one survey responder indicated, 'engine info is difficult to answer due to many variables'. For the cases where the engines are not used, the blank or zero would be due to operation of shaft generators. This assumption was supported by the fact that many more zero or blank entries occurred for underway activity – when it would be expected that shaft generator engagement would be highest. However, in a few cases a shaft generator could be used while berthing also (with the implication that main engines would run at berth). One tanker response (TT) stated this directly.

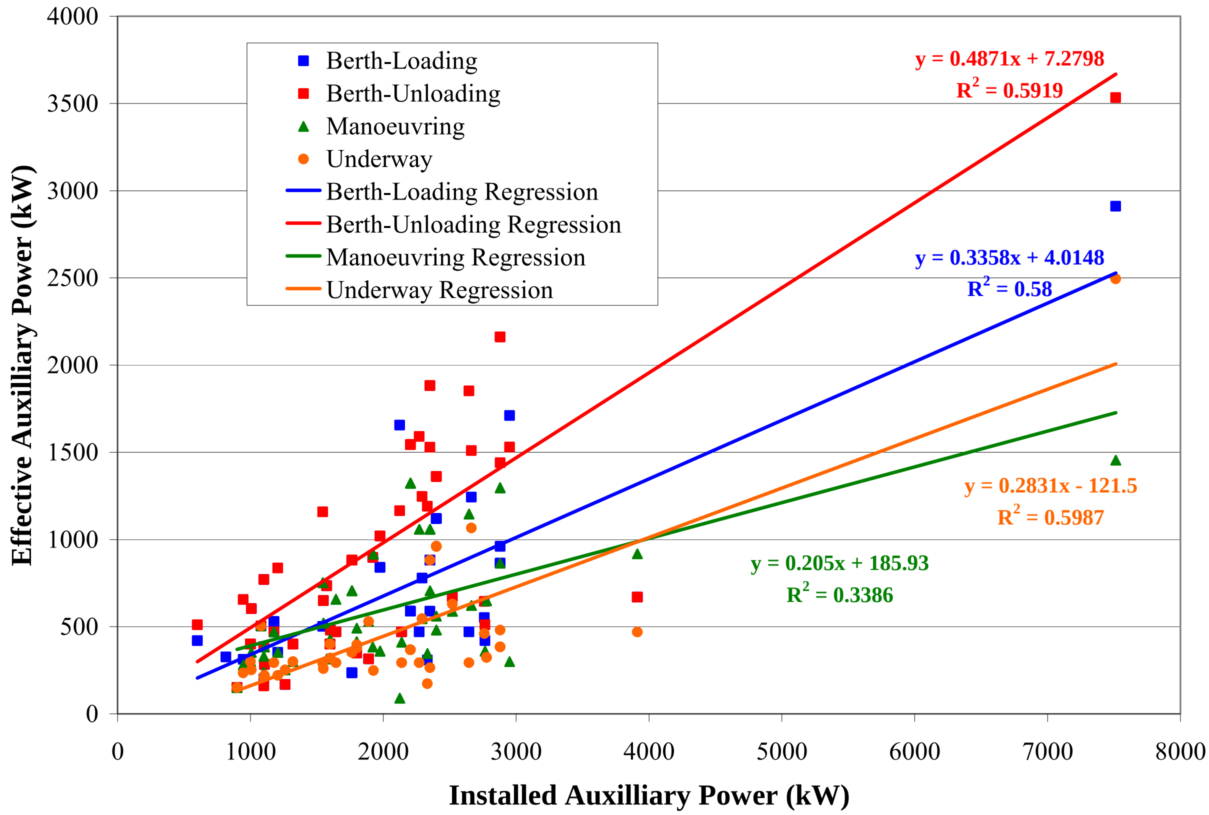
The fraction of ships with 4-stroke propulsion engines (as opposed to 2-stroke main engines) was also established for each of the INNAV vessel classes, based on the survey response averages. This particular field in the survey form ('Engine Type') had very few missing or non valid responses. There were five Merchant Bulk ships built in the 1960s that reported steam turbine propulsion systems. No other ship classes reported steam turbines

3.4.1 Revised Engine Profile for Merchant Bulk Ships

Merchant Bulk ships captured within the 2002/2003 INNAV movements that make up the TDC Inventory have an average DWT of 34,784 which is much lower than the average recorded in the CoS Inventory (59,000 for those described as 'Bulk Carrier'). This average is not available for the POLA ships. The average main engine power for the INNAV vessels was 6,904 kW whereas the average for the CoS Inventory was 8,100 kW. Therefore, in an aggregate sense, the bulk carriers that travel B.C. waters are different to the Merchant Bulk ships frequenting eastern Canadian ports.

Figure 3.2 shows a plot of effective auxiliary engine power against installed auxilliary engine power, based on 63 survey responses flagged as Merchant Bulk. Linear regressions were plotted to validate the use of a ratio in the Tool. Of the 63 survey responses, there were 4 missing or zero entries for loading/unloading at berth and 15 zero or missing entries for auxilliary engine operation underway. The linear regression lines show that the assumption of a linear relationship between effective auxilliary power and installed auxilliary power is reasonable for each activity mode, although relatively weak for manoeuvring.

Figure 3.2
Effective Auxilliary Power for Merchant Bulk Ships



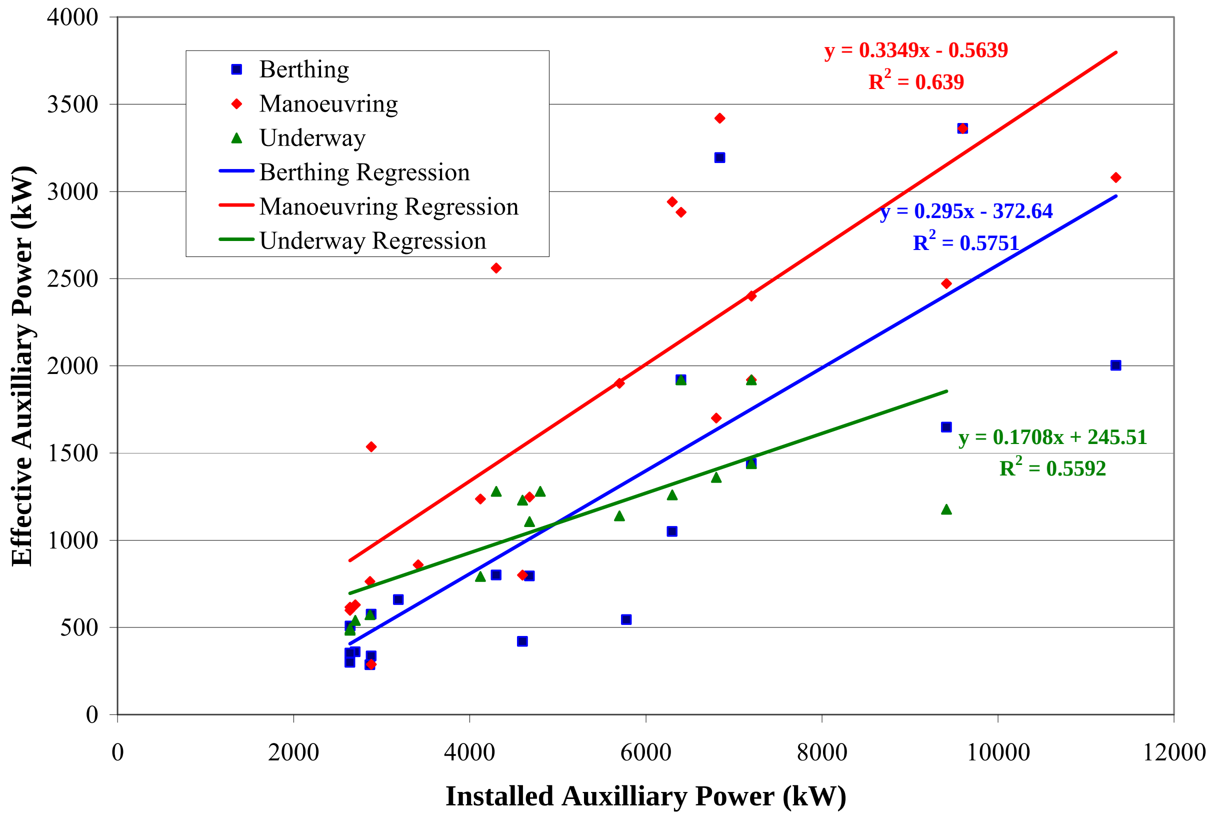
Based on simple averages from the WME survey responses, 0.29 is suggested for installed auxilliary power to main engine power ratio (although this ratio is not very representative for an individual ship, as displayed in Figure 3.1), with 0.21, 0.31 and 0.42 for effective load factors for underway, manoeuvring and berthing, respectively. The 'at berth' ratio is an average of the ratios determined for loading (0.34) and unloading (0.49). A ship class ratio of 0.24 is recommended to represent the ships with 4-stroke main engines. As previously mentioned, five reponses (out of 63 total) indicated steam turbine propulsion systems. The Tool does not account for emissions from steam turbines. Therefore these returns were omitted from the determination of ship class averages.

3.4.2 Revised Engine Profile for Merchant Container Ships

Thirty two returned questionnaires were used for the generation of auxilliary engine ratios for the MC ships. The 2002/2003 (filtered) INNAV database shows that Merchant Container vessels had an average main engine power of approximately 19,838 kW, with a maximum of 47,963 kW. This relates to the WME survey average of approximately 31,113 kW and maximum of 57,200 kW. This implies that the MC vessels have increased their power requirements, which is consistent with trends found elsewhere (e.g., Port of Vancouver).

Up to half of the questionnaires indicated zero or null response for auxilliary engine use for each of the activity modes (including berthing). In some cases, these responses likely relate to use of shaft generators. The zero/blank indications for dockside activity (approximately 1/3 of the vessel responses) are puzzling, since it is unlikely that the container ships would run main engines to operate shaft generators while at berth. The survey-derived data plots shown in Figure 3.3 do not include the 'zero' responses. There were no significant differences in loading versus unloading auxilliary engine operation; therefore the one plot and regression ('Berth') is representative of both activities.

Figure 3.3
Effective Auxilliary Power for Merchant Container Ships



Similar to the case with Merchant Bulk ships, an assumption of a linear relationship between installed auxilliary engine power and effective auxilliary power in the different activity modes appears reasonable for Merchant Container ships.

Based on the questionnaire response averages, Tool parameters of 0.17 for ratio of installed auxilliary power to main engine power, and 0.21, 0.33 and 0.20 for effective load factors for underway, manoeuvring and at berth , respectively are recommended. A ratio of 0.04 is suggested for fraction of ships with 4-stroke main engines. Further investigation of shaft generator use by this class of vessel should be considered.

3.4.3 Revised Engine Profile for Tankers

Based on the survey responses, tankers were separated into two distinct groups: Merchant Tankers and Other Tankers. This distinction led to small improvements for the auxilliary power regression lines (when compared to treating all tankers as one group). For the 36 survey responses categorized as tankers, 6 reported use of a shaft generator as general comments. One of these ships (a Merchant Tanker) reported use of the shaft generator at all times (including berthing).

Many of the Merchant Tankers report carrying oil or oil products (furnace oil, bunker oil, diesel etc). There were three returned questionnaires within the Merchant Crude (TC) category, although in each case these responses had missing entries for auxilliary engine operation while loading and unloading at berth. This may be due to variable use of auxilliary power at berth, with the estimation of an average load factor presenting a difficulty for the ship engineer filling in the questionnaire. There were no Very Large Crude Carrier (TV) or Ultra Large Crude Carrier (TU) ships included in the Weir survey responses.

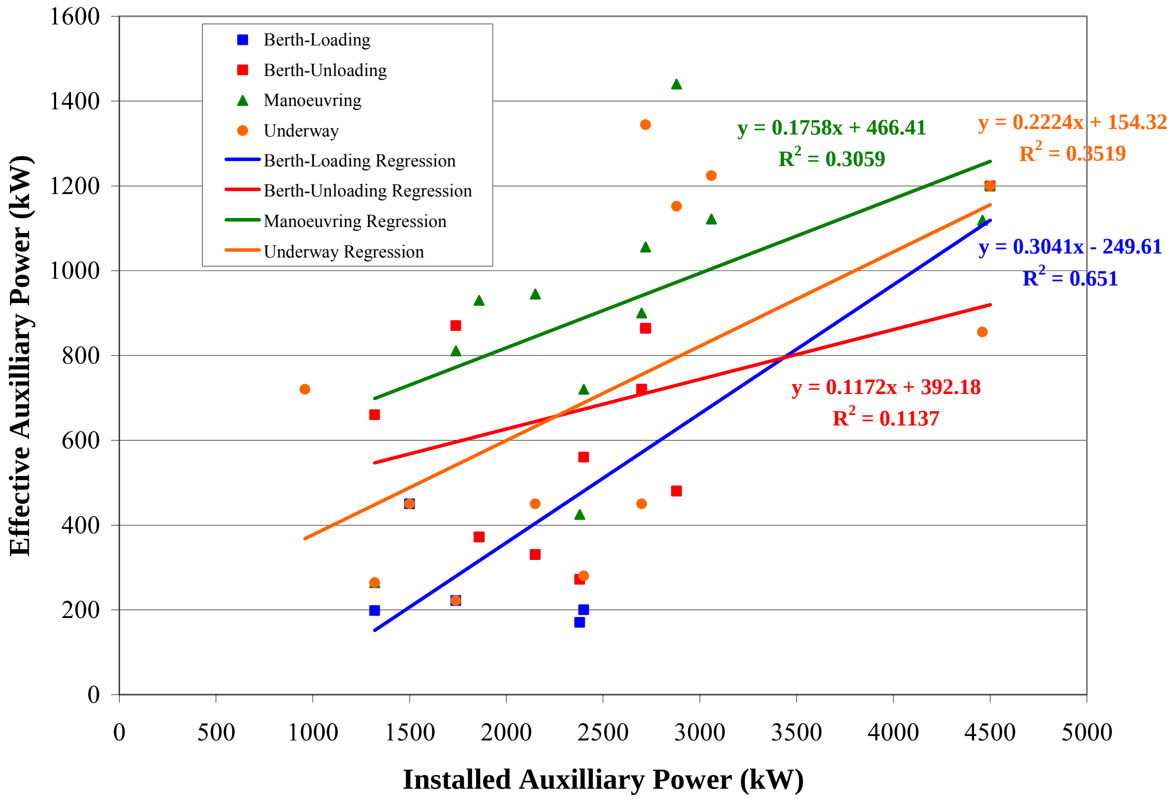
3.4.3.1 Merchant Tankers

Merchant Tankers are the largest group of tankers that visit EC/GL ports. Figure 3.4 shows a plot of effective auxilliary engine power demand for Merchant Tankers while underway, manoeuvring and at berth , and the respective linear regression lines for each activity. Berthing demand was separated into unloading (higher demand) and loading (lower demand). A large degree of variability is evident during unloading activity. A weak linear relationship was found between installed auxilliary power and effective auxilliary power used while underway and manoeuvring.

As was indicated in Table 3.3, the Merchant Tankers surveyed in the EC/GL region are equipped with smaller main engines than those vessels that visit California ports. It is likely therefore that the vessels surveyed are also smaller in deadweight tonnage. The Merchant Crude ships in the 2002/2003 filtered INNAV database have an average and maximum main engine power of 13,455 kW and 25,839 kW respectively, compared to 6,537 kW and 27,539 kW for Merchant Tankers.

Although some of the MB, MC and MH ships in eastern Canada use shaft generators (or steam turbines) for auxilliary power needs, the issue may be more significant for tankers. To remain consistent with the current framework of the Tool, and to allow time for further study of this issue, all auxilliary power for tankers is assumed to be derived from 4-stroke auxilliary diesel engines, as is the case for the other ship classes. No reliable estimate can be made at this time for the percentage of Merchant Tankers or Other Tankers that use shaft generators (and how they use the generators).

Figure 3.4
Effective Auxilliary Power for Merchant Tankers (TT)



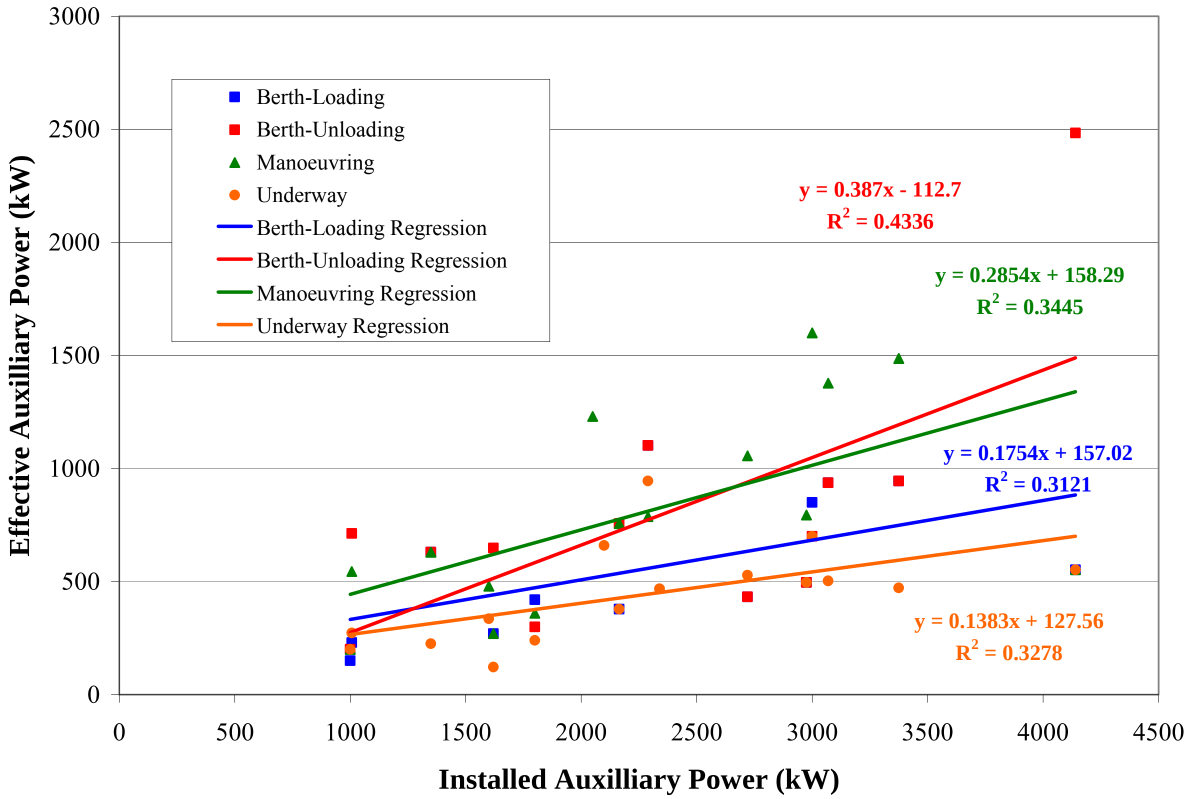
Based on the questionnaire response averages, Tool parameters of 0.29 for the ratio of installed auxilliary power to main engine power, and 0.30, 0.37 and 0.24 for effective auxilliary load factors for underway, manoeuvring and berthing, respectively are recommended. The berthing load factor is an average representative of both loading (0.18) and unloading (0.30) activities. A ratio of 0.14 is suggested for the fraction of TT ships with 4-stroke main engines.

3.4.3.2 Other Tankers

The survey responses grouped as 'Other Tanker' include the INNAV categories of TG, TL and TC (although TC was not well represented as stated earlier). The three TC entries were not used to determine the auxilliary engine ratios. The general cargoes stated for the TG and TL ships were petroleum products and 'chemicals'.

Figure 3.5 indicates that for the Other Tankers group, the survey-derived data suggest a rather weak linear relationship between total installed auxilliary power and effective auxilliary demand while underway, manoeuvring and loading.

Figure 3.5
Effective Auxilliary Power for Other Tankers (TL and TG)



The following parameters are recommended for use in the Tool for the TG and TL ship classes: 0.28 for ratio of installed auxilliary power to main engine power, and 0.20, 0.36 and 0.30 for effective auxilliary load factors for underway, manoeuvring and berthing, respectively. The berthing value is an average representation of loading (0.25) and unloading (0.35). A ratio of 0.13 is suggested for fraction of ships with 4-stroke main engines.

The TM and TO tanker classes were not represented in the survey questionnaires, partly due to relatively few vessel visits over a typical year. The 2002/2003 INNAV records show that the average main engine power rating for these two ship classes (5,985 kW and 11,180 kW respectively) are reasonably close to the TL and TG average main engine power (4,732 kW and 9,605 kW respectively). Therefore the same auxilliary parameters as noted above are recommended for these additional ship classes. These parameters can also be used for Merchant Super Tankers (TS) and Merchant Liquefied Gas (TQ), since there are very few visits by these vessels in a year (24 and 3 respectively in 2002/2003).

TC, TU and TV tanker classes all relate to crude oil transport, with relatively large average main engine power rating when compared to other tanker classes. It is recommended that these three tanker groups continue to be represented by POLA crude oil tanker ratios until better information is gained. This includes the assumption that all main engines are 2-stroke diesels (consistent with the POLA characterization). The updated (2005 activity year) POLA ratios for 'Aframax' class tankers should be used[11], with 0.19, 0.24, 0.33 and 0.26 for AE power, underway, manoeuvre and berth ratios respectively.

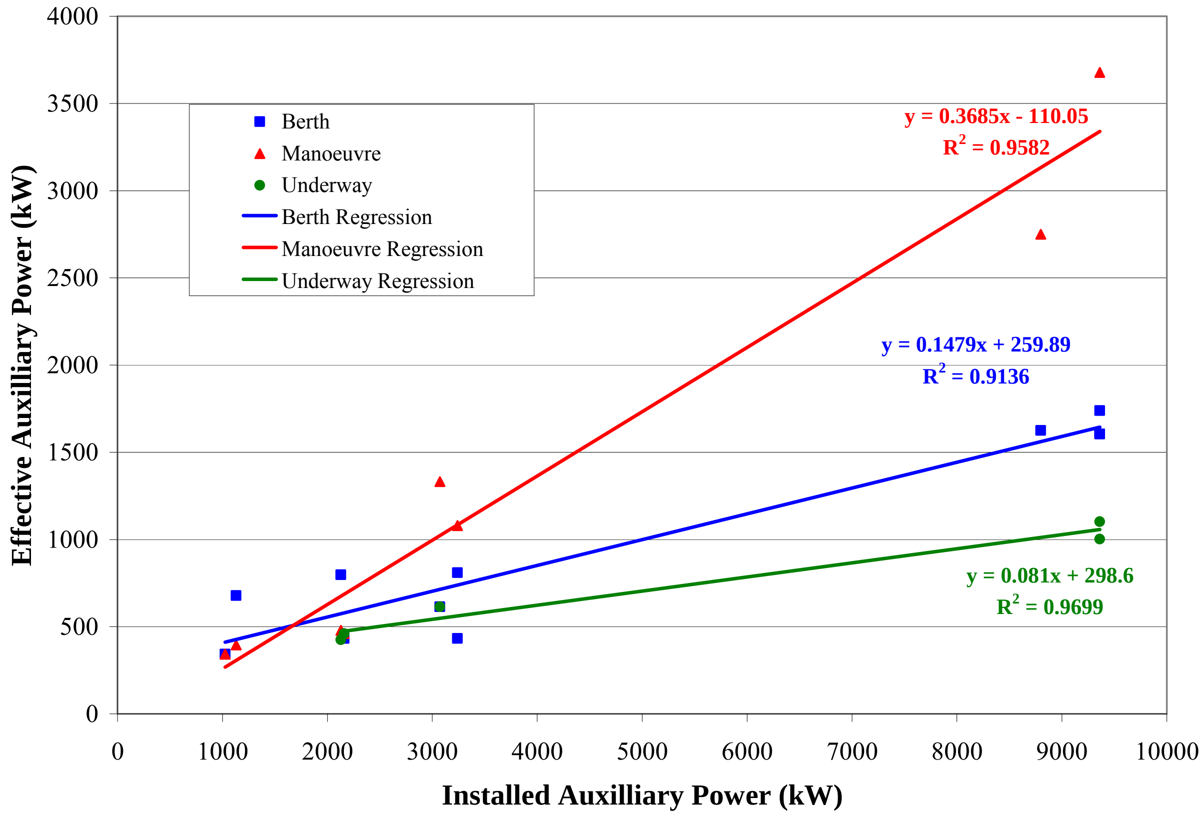
3.4.4 Revised Engine Profile for Merchant RoRo Vessels

Most of the surveyed vessels that could be considered RoRo vessels were classified as MM, MH, MC or a combination of two or more of these categories. The questionnaire responses specified cargo loads consisting of paper, newsprint, containers, cars, trailers or simply 'RoRo'. The 2002/2003 filtered INNAV records show just 3 unique voyages by MM ships and additionally show that MM ships have relatively low main engine power requirements (983 – 2,230 kW). Of the responses that were categorized to include the MM designation, none had main engines within this power range. Therefore, to remain consistent with the INNAV activity records, all survey responses initially designated as MM or MH were considered to be MH. There were 18 of these responses. Only one of these responses did not include 'MH' within the *INNAV CODE* response field on the survey form.

The data plots for Merchant RoRo vessels shown in Figure 3.6 are highly linear, although this is exaggerated due to the large gap between ships with relatively low total installed auxilliary power and those with relatively high installed power. For the four surveyed RoRo vessels with high installed auxilliary power (~ 9,000 kW), each was additionally classed on the questionnaire as 'MC', indicating merchant container vessel.. Only one of the remaining 13 responses included the extra MC designation and it had a total installed auxilliary power of only 2,160 kW.

[11] the 2005 POLA report did not include average main engine power for ULCC or VLCC tankers and the Aframax class represents moderately large crude oil tankers.

Figure 3.6
Effective Auxilliary Power for RoRo Vessels



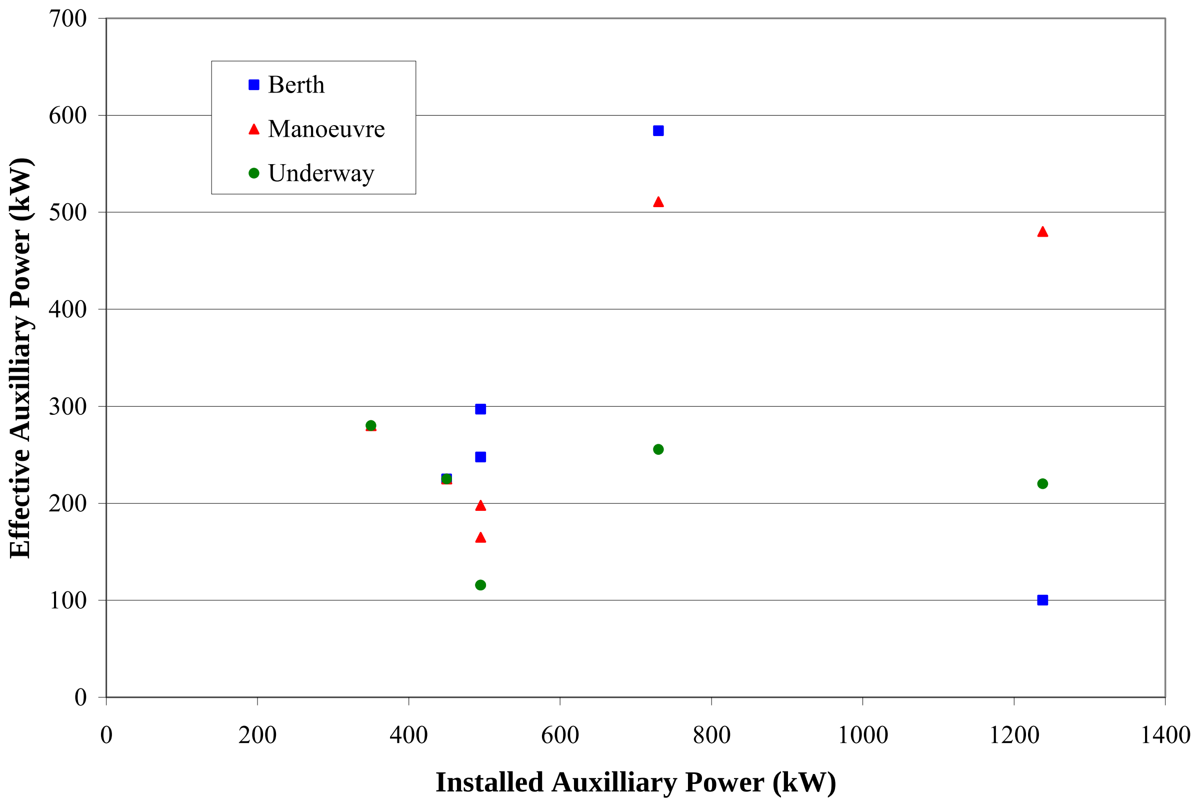
The following parameters are recommended for use in the Tool for the MH ship class: 0.33 for ratio of installed auxilliary power to main engine power, and 0.20, 0.37 and 0.27 for effective auxilliary load factors for underway, manoeuvring and berthing, respectively. There was no difference found between loading and unloading auxilliary power demand. A ratio of 0.47 is recommended for fraction of ships with 4-stroke main engines.

The ratios above are also suggested for MM vessels, due to lack of information (and relative insignificance) for this ship type.

3.4.5 Revised Engine Load Profile for Merchant General (MG) and Merchant Coastal (MS) Vessels

The 2002/2003 filtered INNAV database shows 2,418 unique voyages of Merchant General (MG) ships, with an average and maximum main engine power rating of 5,772 kW and 25,053 kW respectively. There is limited representation of this vessel class within the WME survey responses, as only six completed questionnaires were identified as MG. Ship cargoes were reported to be dry bulk, wood chip or 'general'. Figure 3.7 shows a plot of the survey-derived data for Merchant General ships.

Figure 3.7
Effective Auxilliary Power for Merchant General/Merchant Coastal Vessels*



*Regressions not shown due to insufficient data points.

The following parameters are recommended for use in the Tool for the MG ship class: 0.15 for ratio of installed auxilliary power to main engine power, and 0.38, 0.52 and 0.42 for effective auxilliary load factors for underway, manoeuvring and berthing, respectively. The berthing factor is an average representative of loading (0.34) and unloading (0.50). A ratio of 0.57 is suggested for fraction of ships with 4-stroke main engines.

Merchant Coastal ships were not represented in the returned WME surveys. The previous version of the Tool relied on the assumption that this class of ship had a similar auxilliary engine load profile to Merchant General. This assumption appears to be consistent with what was assumed in the POLA work. At this time, the same parameters used for Merchant General are recommended for Merchant Coastal ships.

3.4.6 Revised Engine Load Profiles for Warships (WR, WS)

Warships active in eastern Canada are either from the Iroquois or the Halifax class, with the Halifax class being dominant (12 of these vessels are currently active and split between the east and west coasts). One survey response was gathered for each class. The recommended ratios for WR and WS are 0.17 for main to auxilliary engine ratio, 0.34 for underway and manoeuvring load factors and 0 for berthing. Canadian warships use shoreside power (electrification) while at berth. The 2002/2003 filtered INNAV records showed very few warship visits to eastern Canadian ports (nine unique voyages).

3.4.7 Revised Engine Profiles for Other Vessel Classes

Little to no information was obtained for the MA, MO, MP, MF, HO and MR ship classes. Merchant Ore (MO) ships were assumed to have similar characteristics to Merchant Bulk ships, consistent with the previous assumption used in the Tool.

Consistent with changes made to the specific vessel classes discussed in Sections 3.4.1 – 3.4.5, the existing manoeuvring load factors in the Tool were considered too high for MA and MR ships. Therefore, the manoeuvring load factors were set to be equal to the higher of the existing (POLA) underway and berthing load factors (which was berthing load factor in both cases). In addition, the Merchant Bulk ratio of 0.24 for fraction of ships with 4-stroke main engines was used.

Five questionnaire responses were received for Merchant Ferry (MF) ships and two for Ocean Tugs (HO). However, in both cases, the responses were not deemed adequate for determining a profile to represent the entire ship class. One questionnaire was collected for Merchant Passenger (MP) ships. Therefore, the existing auxilliary engine profile (including manoeuvring load factor) are recommended for these three ship classes at this time. An assumption of 1.0 for fraction of ships with 4-stroke main engines is recommended for HO and MF, and 0.0 for MP. This is roughly consistent with the assumptions used in the earlier version of the Tool. Since MP and MF vessels account for 13% of the inventory activity by fuel consumption, it is recommended that further study be conducted for these ship types.

4.0 MARINE ENGINE EMISSION FACTORS

A review of marine emissions testing data and generation of a set of recommended marine engine activity based emission factors (EFs) were completed by ENVIRON and are presented in Appendix B. As part of the 2006 TDC Inventory, a brief review of recent marine emissions and inventory studies was completed and used to establish a set of activity based emission factors. Most of the emission factors recommended for the marine inventory were consistent with past and ongoing initiatives elsewhere, with the exception of particulate matter (PM) emission rates.

There remains a considerable level of uncertainty associated with PM emission rates for large marine diesel propulsion engines using fuel high in sulphur content (commonly termed heavy fuel oil – HFO). Other fuels that are used by commercial marine vessels are marine diesel oil, also known as marine distillate (MDO) and marine gas oil (MGO). In addition, ocean going vessels utilize a blend of HFO and MDO commonly refer to intermediate fuel oil (IFO) which has a lower sulphur content than HFO. A set of baseline EFs was developed from the ENVIRON recommendations, and this is shown in Table 4.1. Those factors that significantly differ from the original set of factors used in the 2006 TDC Inventory are highlighted in red.

Table 4.1
Baseline Emission Factors for Inventory Development*

Engine Type	Fuel Quality	Sulphur content (%)	Fuel Cons (g/kWh)	CAC Emission Factors in g/kWh								
				CO2	NOx	SO2	CO	HC	VOC	TPM	PM10	PM25
auxilliary 4 str all activity	HFO	2.7	210	670	14.7	11.1	1.1	0.4	0.4	1.11	1.07	0.98
	HFO/IFO	1.5	210	670	13.9	6.2	1.1	0.4	0.4	0.71	0.68	0.63
	MDO	1	210	670	13.9	4.13	1.1	0.4	0.4	0.55	0.53	0.49
	MDO	0.2	210	670	13.9	0.8	1.1	0.4	0.4	0.28	0.27	0.25
	MDO	0.1	210	670	13.9	0.4	1.1	0.4	0.4	0.25	0.24	0.22
main 2 str underway	HFO	2.7	195	621	18.1	10.3	1.4	0.6	0.6	1.05	1.01	0.93
	HFO/IFO	1.5	195	621	17	5.7	1.4	0.6	0.6	0.68	0.65	0.60
main 4str underway	HFO	2.7	210	670	14	11.1	1.1	0.5	0.5	1.11	1.07	0.98
	HFO/IFO	1.5	210	670	13.2	6.2	1.1	0.5	0.5	0.71	0.68	0.63
	MDO	1	210	670	13.2	4.13	1.1	0.5	0.5	0.55	0.53	0.49
	MDO	0.2	210	670	13.2	0.8	1.1	0.5	0.5	0.28	0.27	0.25
	MDO	0.1	210	670	13.2	0.4	1.1	0.5	0.5	0.25	0.24	0.22

*The emission factors that are substantially different from the original factors used are highlighted in red.

The emission factors in Table 4.1 represent the air contaminants that were inventoried as part of the original TDC Inventory. Emissions are produced by both main (propulsion) engine and auxilliary engine operation. Main engines tend to be both 2-stroke and 4-stroke engines that use HFO or IFO, while auxilliary engines are primarily 4-stroke engines that use HFO, IFO or MDO. There are a considerable number of vessels operating in EC/GL that have 4-stroke propulsion engines. In general, these ships are smaller and are primarily engaged as bulk carriers or RoRo vessels. The PM emission factors directly relate to a specific sulphur content of fuel to allow both use of PM emission factors that match regional fuel characteristics and specific projections (such as a SECA inventory).

The main engine PM emission factors are substantially lower than those used in the earlier version of the Tool (and 2006 TDC Inventory). The CO emission factors for main engines are also highlighted, since they are much higher than the original EFs used (0.5 g/kWh). The 2006 TDC Inventory report states that the 0.5 g/kWh EF was sourced from the Entec report. However, the Entec work has very little discussion of CO emissions. The 1.4 g/kWh matches that currently recommended by both the U.S. EPA and the California Air Resources Board (CARB). It should be recognized that CO emission rates have not been a primary focus of past marine engine emission tests, since CO emissions from ships are not high relative to other industrial and community sources.

Application of manoeuvring EFs for main engines at low load (i.e., load factor less than 0.20) also presents a difficulty in marine emission inventory development. It is expected that EFs increase at low load for marine 2-stroke propulsion engines, but this expectation is based on the behaviour of smaller 4-stroke diesel engines using distillate fuel. It has been common practice to apply scaling factors to the ME underway EFs to account for the expected increase in energy based emission rates. It is not clear that the scaling factors that have recently been used in marine emission inventories apply to propulsion engines. Adding to the complexity of this issue, it is also not clear what average ME load factors should be used during 'manoeuvring', since vessels not only travel at different speeds, but also may cycle their engines on and off while continuing under momentum. In practice, use of a lower load factor (i.e., 5% ME load) is somewhat countered by the use of a higher EF. The implication is that a harmonized, simplistic characterization may be the most appropriate representation to use for manoeuvring activity at this time.

Development of an expanded set of emission factors that relate to different ME load factors while manoeuvring would not provide increased accuracy of the emissions inventory, yet would add significant complexity. Therefore, a minimum ME load for manoeuvring was established as 0.10 for all ship classes. Any ship class with an original ME load factor for manoeuvring lower than 0.10 was subsequently increased. A set of ME manoeuvring emission factors was developed assuming a consistent ME load factor of 0.10.

Adjustments to the baseline and manoeuvring emission factors to achieve specific EFs for each vessel class were accomplished with the same fuel assumptions applied in the original 2006 TDC Inventory. There was one exception; the survey questionnaires clearly indicated greater use of MDO in auxilliary engines than that applied in California. In fact, the questionnaire responses suggest that one half of the fuel consumed by auxilliary engines is MDO (as opposed to HFO or IFO). Therefore the original assumption of 25% MDO use in auxilliary engines was changed to 35% MDO use, with the remaining portion HFO. At this time it was decided that a conservative factor should be used (rather than a higher percentage such as 50%). To serve as example, Figure 4.2 provides the full set of ME underway emission factors developed for the 24 vessel classes. Notable differences in SO_2 and PM are evident for those ship classes that do not use HFO (e.g., Merchant Ferry). Other emission factors can be viewed in the updated version of the Tool.

Table 4.2
Main Engine Emission Factors for 24 INNAV Vessel Classes

INNAV Vessel Class	INNAV Code	Fuel Origin (%)		Emission Factors in g/kWh								
		Domestic	International	CO2	NOx	SO2	CO	HC	VOC	TPM	PM10	PM25
Merchant Auto	MA	10	90	621	18.0	9.9	1.4	0.6	0.6	1.02	0.98	0.90
Merchant (Dry)	MM	0	100	621	18.1	10.3	1.4	0.6	0.6	1.05	1.01	0.93
Merchant Bulk	MB	20	80	621	17.9	9.5	1.4	0.6	0.6	0.99	0.95	0.87
Merchant Ore	MO	20	80	621	17.9	9.5	1.4	0.6	0.6	0.99	0.95	0.87
Merchant Container	MC	5	95	621	18.0	10.1	1.4	0.6	0.6	1.03	0.99	0.91
Merchant Coastal	MS	45	55	621	17.6	8.6	1.4	0.6	0.6	0.91	0.87	0.80
Merchant General	MG	10	90	621	18.0	9.9	1.4	0.6	0.6	1.02	0.98	0.90
Merchant Passenger	MP	55	45	621	17.5	8.2	1.4	0.6	0.6	0.88	0.84	0.78
Merchant Ferry	MF	100	0	670	13.2	0.7	1.1	0.5	0.5	0.27	0.26	0.24
Tugs, Ocean	HO	80	20	670	13.2	4.1	1.1	0.5	0.5	0.55	0.53	0.49
Merchant Ro/Ro	MH	10	90	621	18.0	9.9	1.4	0.6	0.6	1.02	0.98	0.90
Merchant Reefer	MR	0	100	621	18.1	10.3	1.4	0.6	0.6	1.05	1.01	0.93
Merchant (Tanker)	TT	25	75	621	17.8	9.3	1.4	0.6	0.6	0.97	0.93	0.86
Merchant Chemical	TL	5	95	621	18.0	10.1	1.4	0.6	0.6	1.03	0.99	0.91
Merchant Crude	TC	20	80	621	17.9	9.5	1.4	0.6	0.6	0.99	0.95	0.87
Merchant Gasoline	TG	0	100	621	18.1	10.3	1.4	0.6	0.6	1.05	1.01	0.93
Merchant Liquified Gas	TQ	40	60	621	17.7	8.8	1.4	0.6	0.6	0.93	0.89	0.82
Merchant Molasses	TM	0	100	621	18.1	10.3	1.4	0.6	0.6	1.05	1.01	0.93
Merchant Ore/Bulk/Oil	TO	5	95	621	18.0	10.1	1.4	0.6	0.6	1.03	0.99	0.91
Merchant Super Tanker	TS	0	100	621	18.1	10.3	1.4	0.6	0.6	1.05	1.01	0.93
Merchant ULCC	TU	0	100	621	18.1	10.3	1.4	0.6	0.6	1.05	1.01	0.93
Merchant VLCC	TV	0	100	621	18.1	10.3	1.4	0.6	0.6	1.05	1.01	0.93
Warship, General	WR	100	0	670	13.2	1.0	1.1	0.5	0.5	0.30	0.29	0.26
Warship, Surface	WS	100	0	670	13.2	1.0	1.1	0.5	0.5	0.30	0.29	0.26

4.1 REVISION TO PM EMISSION FACTORS

As discussed in Appendix B, the California Air Resources Board (CARB) has expressed an alternate analysis of PM emissions data that indicates higher PM emission factors for both MDO and HFO. Through discussions with the U.S. EPA, Environment Canada has decided to support use of the higher CARB PM emission rates in the current inventory for EC/GL. This is consistent with actions taken by EC on the west coast.

In a separate contract for TDC, WME and SENES were tasked with a further update of the Tool, to support the direct consideration of sulphur content of fuel for the specific energy based emission factors for PM and SO_x. The Inventory summaries presented in this report relate to this new version of the Tool (V2.2) that makes use of a PM-Sulphur emissions equation consistent with the CARB analysis discussed in Appendix B. The changes for SO_x emissions relate primarily to user control with the Tool and do not significantly change the effective SO_x emission factors indicated in Table 4.2.

The PM-Sulphur equation can be expressed as follows:

$$EF(g/kWh) = 0.4653(S) + 0.25$$

Where S = sulphur content of fuel in %.

Although CARB did not express their analysis in this direct form[12], the resultant equation is consistent with their findings/opinion that a linear relationship is reasonable to assume at this time, with a recommended emission factor of 1.5 g/kWh for 2.7% S and 1.0 g/kWh for 1.5% S fuel. This effectively 'scales up' the linear profile used by SENES (stated in Appendix B) to determine the PM emission factors in Table 4.2. The CARB recommendation does not address specific PM_{10} and $PM_{2.5}$ emission factors. SENES has applied a ratio of 0.96 and 0.92 for PM_{10} to total PM and $PM_{2.5}$ to PM_{10} respectively. In general, this is consistent with assumptions applied in past marine emissions inventories, although some variation in appropriate ratios has been noted. At least one recent marine PM study indicates that total PM emission rates could in fact be much higher than PM_{10} emission rates when high sulphur fuel is consumed. Clearly, further investigation is necessary, and the PM emission factors in the Tool (V2.2), although representative of current understanding, have considerable uncertainty.

[12] Todd Sax and Andrew Alexis, CARB 2007. *A Critical Review of Ocean-Going Vessel Particulate Matter Emission Factors*. November 9, 2007. Available from the CARB website.

4.2 BOILER EMISSIONS

The Tool update described above also incorporated boiler emissions. SENES did not conduct a thorough review of boiler emission rates (since this was not part of the contracted work), but instead provided a set of emission factors and fuel consumption rates based on the CoS inventory for B.C. as interim guidance. No discussion of these rates is provided in this report. It was found that boiler fuel consumption reported by respondents in the WME survey questionnaires were somewhat contradictory and not clear enough to use for profile development in several cases. For Merchant Bulk and Merchant Container ships (which had a large number of questionnaire returns), the average boiler fuel consumption rates were similar to those found in the CoS work. However, several questionnaire returns indicated that boiler use does not occur 100% of the time. It was not clear from the responses whether or not the fuel consumption rates specified included the effect of intermittent use.

The questionnaires did not request boiler usage information in different modes of activity. Therefore, consistent with the CoS work, SENES assumed boilers were used while underway. Some ships clearly use exhaust gas recirculation and therefore do not run boilers while main engines are operating (for most of the time at least). Therefore, the assumption of underway boiler use of approximately the same magnitude of berthing boiler use is likely a conservative assumption. At least one recent marine inventory in the U.S. has claimed that boiler use during underway activity is negligible. However, this assumption may apply to certain ships (for example, container ships) and not necessarily all ships. The CoS surveys requested boiler fuel consumption specifically during underway (and other) activity, resulting in non-zero rates for all classes of vessel surveyed. Further investigation of ship boiler use in EC/GL is suggested.

5.0 REVISED INVENTORY AND FORECAST PROJECTIONS

A number of pivot table exports were made from the updated Tool to highlight the revised emission inventory totals. The tables relate to total emissions of commercial marine traffic in EC/GL, from main engines, auxilliary engines and boilers.

Table 5.1
Revised 2002/2003 Inventory Totals – All Activity (tonnes/year)

Air Contaminant	Total Emissions (tonnes)
SO_2	54,959
NO_x	73,974
TPM	7,129
PM_{10}	6,844
$PM_{2.5}$	6,296
CO	6,165
HC	2,520
CO_2	3,620,092

Table 5.2
Revised 2002/2003 Inventory Totals – Underway (tonnes/year)

Air Contaminant	Total Emissions (tonnes)
SO_2	47,181
NO_x	64,622
TPM	6,243
PM_{10}	5,993
$PM_{2.5}$	5,514
CO	5,230
HC	2,254
CO_2	3,029,367

Table 5.3
Revised 2002/2003 Inventory Totals – Berthing (tonnes/year)

Air Contaminant	Total Emissions (tonnes)
SO_2	7,445
NO_x	8,899
TPM	844
PM_{10}	811
$PM_{2.5}$	746
CO	894
HC	251
CO_2	566,509

Table 5.4
Revised 2002/2003 Inventory Totals – Manoeuvring (tonnes/year)

Air Contaminant	Total Emissions (tonnes)
SO_2	332
NO_x	453
TPM	42
PM_{10}	40
$PM_{2.5}$	37
CO	40
HC	14
CO_2	24,216

The original forecasts completed for the TDC Inventory in 2006 accounted for future changes to domestic marine fuel (MDO) as well as minor changes to NO_x emission rates (in line with IMO Marpol Annex VI for post 2000 vessels) as newer ships become part of the active fleet. SENES did not make changes to these projected differences for the 2010 and 2020 forecasts shown here. However, it should be noted that these forecasts are simplistic, and do not account for expected improvements in engine efficiency and (more importantly) realistic reductions in emission rates. Already there has been clear indication that newer (or retrofitted) ships have achieved significant reductions in NO_x and PM emission rates. Recent marine emissions inventories completed for POLA and the Port of Seattle include use of lower PM and NOx emission factors for ships with installed emission controls[13].

[13] For example, see the *Puget Sound Maritime Air Emissions Inventory, April 2007.* Available from the Port of Seattle website.

With the new version of the Tool, achieving a SECA forecast is relatively simple, as changes to fuel sulphur entered to the Tool are directly used to update emission factors. International heavy fuel oil sulphur content was changed from 2.7% to 1.5% for the SECA forecast. Domestic marine diesel sulphur content was set at 300 ppm for the 2010 and 2020 forecasts, consistent with Environment Canada regulations implemented in 2007 and the original assumptions applied in the earlier 2006 TDC Inventory forecasts. The reduction in PM emission rates follow the PM-Sulphur equation shown in Section 4.1. A SECA emissions inventory for EC/GL is shown in Table 5.5.

Table 5.5
SECA Inventory for Eastern Canada and the Great Lakes
(Based on 2002/2003 Activity Year)

Air Contaminant	Total Emissions (tonnes)
SO_2	33,604
NO_x	73,974
TPM	4,861
PM_{10}	4,666
$PM_{2.5}$	4,293
CO	6,165
HC	2,520
CO_2	3,620,092

The forecast inventories also require economic growth factors (increase in commodities shipped) by class of vessel. WME developed a revised set of growth factors for the 2002/2003 INNAV vessel classes as shown in Table 5.6. These growth factors were used in the Tool, along with the revised emission factors and fuel assumptions.

Table 5.6: 2010/2020 Economic Growth Factors

INNAV General Class		Historical Total Tonnage For Year 2002	Projected Total Tonnage For Years		Updated Economic Cargo Growth Factors For Years		Notes
Code	Name		2010	2020	2010	2020	
HO	Tugs Ocean	116,848	74,251	86,313	0.635	0.739	
MA	Merchant Auto	712,080	863,384	1,459,014	1.212	2.049	
MB	Merchant Bulk	129,425,590	137,256,129	146,919,691	1.061	1.135	
MC	Merchant Container	12,454,791	17,591,419	23,770,613	1.412	1.909	
MF	Merchant Ferry	820	12,838	13,066	15.656	15.934	Note 1
MG	Merchant General	5,559,976	5,897,384	6,683,549	1.061	1.202	
MH	Merchant RO/RO	1,645,259	1,759,784	1,935,972	1.070	1.177	
MM	Merchant (Dry)	4,025,128	4,966,479	5,288,866	1.234	1.314	
MO	Merchant Ore	2,166,923	2,006,653	2,153,294	0.926	0.994	
MP	Merchant Passenger	0	0	0	0.000	0.000	Note 1
MR	Merchant Reefer	66,126	137,672	146,954	2.082	2.222	
MS	Merchant Coastal	295,956	583,794	592,648	1.973	2.002	
TC	Merchant Crude	11,261,850	15,769,674	16,445,328	1.400	1.460	
TG	Merchant Gasoline	9,162,751	9,675,787	10,354,824	1.056	1.130	
TL	Merchant Chemical	5,876,453	7,202,466	7,683,844	1.226	1.308	
TM	Merchant Molasses	1,133,018	1,370,882	1,467,703	1.210	1.295	
TO	Merchant Ore/Bulk/Oil	2,143,212	3,221,984	3,433,162	1.503	1.602	
TQ	Merchant Liquefied Gas	68,450	129,401	136,758	1.890	1.998	
TS	Merchant Super Tanker	27,039,075	32,866,559	34,223,833	1.216	1.266	
TT	Merchant (Tanker)	12,038,390	13,044,147	13,875,268	1.084	1.153	
TU	Merchant ULCC	11,135,659	15,557,278	16,219,528	1.397	1.457	
TV	Merchant VLCC	11,135,659	15,557,278	16,219,528	1.397	1.457	
WR	Warship - General	-	-	-	-	-	Note 2
WS	Warship - Surface	-	-	-	-	-	Note 2
All Vessel Types		247,464,014	285,545,243	309,109,756			

Note 1: Use Growth Factors of 1.00, as discussed in the report.
Note 2: No data was available on this vessel type. Use Growth Factors of 1.00, as discussed in the Weir report.
Note 3: Updated Economic Cargo Growth Factor For Year 2010 = 1+ [(Projected Total Tonnage For year 2010 – Historical Total Tonnage For Year 2002) / Historical Total Tonnage For Year 2002]
Note 4: Updated Economic Cargo Growth Factor For Year 2020 = 1+ [(Projected Total Tonnage For year 2020 – Historical Total Tonnage For Year 2002) / Historical Total Tonnage For Year 2002]

Table 5.7 provides the baseline and forecast Inventory totals. Table 5.8 provides the same baseline with alternate forecasts, assuming that a SECA zone will be established on the east coast of North America. The future SECA inventories apply the same limit of 1.5% sulphur for heavy fuel oil that was applied in the base year SECA forecast.

Table 5.7
Baseline and Forecast Emissions for Eastern Canada and the Great Lakes

Air Contaminant	Total Emissions (tonnes)				
	2002	**2010**	*% Change*	**2020**	*% Change*
SO_2	54,959	64,349	*17.1%*	74,344	*35.3%*
NO_x	73,974	83,130	*12.4%*	91,253	*23.4%*
TPM	7,129	8,344	*17.0%*	9,640	*35.2%*
PM_{10}	6,844	8,010	*17.0%*	9,255	*35.2%*
$PM_{2.5}$	6,296	7,369	*17.0%*	8,514	*35.2%*
CO	6,165	7,154	*16.0%*	8,212	*33.2%*
HC	2,520	2,933	*16.4%*	3,376	*34.0%*
CO_2	3,620,092	4,212,740	*16.4%*	4,841,468	*33.7%*

Table 5.8
Baseline and SECA Forecast Emissions for Eastern Canada and the Great Lakes

Air Contaminant	Total Emissions (tonnes)				
	2002	**2010**	*% Change*	**2020**	*% Change*
SO_2	54,959	39,080	*-28.9%*	44,939	*-18.2%*
NO_x	73,974	83,130	*12.4%*	91,253	*23.4%*
TPM	7,129	5,658	*-20.6%*	6,511	*-8.7%*
PM_{10}	6,844	5,431	*-20.6%*	6,251	*-8.7%*
$PM_{2.5}$	6,296	4,997	*-20.6%*	5,750	*-8.7%*
CO	6,165	7,154	*16.0%*	8,212	*33.2%*
HC	2,520	2,933	*16.4%*	3,376	*34.0%*
CO_2	3,620,092	4,212,740	*16.4%*	4,841,468	*33.7%*

APPENDIX A: SURVEY QUESTIONNAIRE

SURVEY OF COMMERCIAL MARINE VESSELS
EASTERN CANADA AND GREAT LAKES REGION

Excellent Engineering Solutions WEIR SERVICES

Transport Canada Transports Canada

Weir Marine Engineering is conducting a survey on behalf of Transport Canada to estimate typical operational profiles of marine vessels in the Eastern Canada and Great Lakes Region. Information collected will be consolidated by Weir Marine Engineering to provide summary data based on vessel type and geographic area. Information on specific vessels will not be released to any Government Department or other third party and will not appear in any report released to the public.

VESSEL INFORMATION

Vessel Name:		Lloyds/IMO No.:	Year of Build:	Country Flag:
Vessel Type (INNAV Code if known):	IMO IAPP Certificate: Yes ☐ No ☐	Deadweight tonnage:	Maximum Cruise Speed: kts	Typical Cargo:

OPERATING PROFILE

Date this survey is completed:	yyyy mm dd		Port where this survey is completed:		
% of Operations in the Eastern Canada & Great Lakes Region:	%		**Marine Fuel Types Used:**	**Distillate (Light)** ▼	**Residual (Heavy)** ▼
Average Time per Port visit:	Unloading ►	hrs	Grade:		
	Loading ►	hrs			
Normal Cruising Speed:	Ballast ►	kts			
	Loaded ►	kts	Location of last Fuelling:		
Normal Half Ahead Speed:	Ballast ►	kts	% Sulphur of last fuelling:	%	%
	Loaded ►	kts	Average Fuel Consumption:	tons / day	tons / day

ADDITIONAL COMMENTS

BOILER(S)

Fuel Type:	
Avg Fuel Consumption:	tons / day
% of Time Used:	

Would you like to receive a copy of the survey results? ***YES*** ☐ ***NO*** ☐ **If Yes, Please provide Contact Information:**

Name:	Title:
Organization:	
Street Address:	City:
Country:	Postal Code:
Email:	Send paper copy by regular mail: ☐ Send electronic copy by email: ☐

PLEASE RETURN COMPLETED FORMS: BY MAIL: ***MR. MIKE DAVIES***
WEIR MARINE ENGINEERING
8600 ST-PATRICK STREET
LASALLE, QUEBEC, CANADA H8N 1V1

FAX: **(514) 366-8475**
or
EMAIL: mdavies@weiramericas.com

For more information on this study, contact Mr. Mike Davies, Weir Marine Engineering at (514) 366-4310 ext 318, or email: mdavies@weiramericas.com

Transport Canada Transports Canada

SURVEY OF COMMERCIAL MARINE VESSELS
EASTERN CANADA AND GREAT LAKES REGION

VESSEL NAME	

Please use additional survey sheets for vessels with more than 6 engines

ENGINE INFORMATION (FOR ALL PROPULSION & AUXILIARY POWER INCLUDING DIESEL-GENERATOR SETS)

Engine No.:	Engine 1▼	Engine 2▼	Engine 3▼	Engine 4▼	Engine 5▼	Engine 6▼
Engine Use:	Propulsion ☐ Auxiliary Power ☐	Propulsion ☐ Auxiliary Power ☐	Propulsion ☐ Auxiliary Power ☐	Propulsion ☐ Auxiliary Power ☐	Propulsion ☐ Auxiliary Power ☐	Propulsion ☐ Auxiliary Power ☐
Engine Make:						
Engine Model:						
Year of Engine:						
Engine Type:	Gas Turbine ☐ 2 Stroke Diesel ☐ 4 Stroke Diesel ☐	Gas Turbine ☐ 2 Stroke Diesel ☐ 4 Stroke Diesel ☐	Gas Turbine ☐ 2 Stroke Diesel ☐ 4 Stroke Diesel ☐	Gas Turbine ☐ 2 Stroke Diesel ☐ 4 Stroke Diesel ☐	Gas Turbine ☐ 2 Stroke Diesel ☐ 4 Stroke Diesel ☐	Gas Turbine ☐ 2 Stroke Diesel ☐ 4 Stroke Diesel ☐
Rated Power (MCR):	kW ☐ Hp ☐	kW ☐ Hp ☐	kW ☐ Hp ☐	kW ☐ Hp ☐	kW ☐ Hp ☐	kW ☐ Hp ☐
RPM at MCR:						

Fuel Type Normally Used:	Distillate	Residual	Distillate	Residual	Distillate	Residual	Distillate	Residual	Distillate	Residual	Distillate	Residual
At sea ►	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Manoeuvring ►	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Hotelling ►	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐	☐
Load as % of MCR and % of Time used: (See examples below)	**Load ▼**	**Time ▼**	**Load ▼**	**Time ▼**	**Load ▼**	**Time ▼**	**Load ▼**	**Time ▼**	**Load ▼**	**Time ▼**	**Load ▼**	**Time ▼**
At sea (Ballast) ►	%	%	%	%	%	%	%	%	%	%	%	%
At sea (Loaded) ►	%	%	%	%	%	%	%	%	%	%	%	%
Half Ahead (Ballast) ►	%	%	%	%	%	%	%	%	%	%	%	%
Half Ahead (Loaded) ►	%	%	%	%	%	%	%	%	%	%	%	%
Manoeuvring ►	%	%	%	%	%	%	%	%	%	%	%	%
Hotelling (Unloading) ►	%	%	%	%	%	%	%	%	%	%	%	%
Hotelling (Loading) ►	%	%	%	%	%	%	%	%	%	%	%	%
EXAMPLE No. 1 ►	*80 %*	*50 %*	*80 %*	*50 %*	*◄ Represents 2 engines that normally operate one at a time (each operating at 50% of the time) at 80% load*							
EXAMPLE No. 2 ►	*Represents 3 engines that normally share the total load and run continuously ► 100% of the time at the same load (3 x 60%)*						*60 %*	*100 %*	*60 %*	*100 %*	*60 %*	*100 %*
Procedures or systems to reduce emissions												

APPENDIX B: EMISSION FACTOR REVIEW (ENVIRON)

ENVIRON

MEMORANDUM

To: Bryan McEwen, SENES

From: Christian Lindhjem

Date: March 23, 2007

Subject: Marine Engine Emission Factors

The purpose of this report is to recommend the most appropriate, and consistent with other international efforts, emission factors to use in Canadian marine vessel emissions estimates. It outlines the emission factors commonly used to describe marine engine emissions and discusses the uncertainty and considerations associated with the estimates used to date.

In the U.S., determination of the emission factors recommended for use to estimate emissions from any source category usually falls to the regulating authority to decide on the basis of the best information available. European agencies have used a variety of sources for estimates depending on the country or the selected study.

The U.S. EPA and the California Air Resources Board (ARB) have investigated emission rates and have had recommendations for about 15 years that continue to evolve. In that time, little data have been publicly available from which to base estimates, and what are available are potentially conflicting. At the time of this writing (March 7, 2007), no clear decision from either regulatory agency has been made. ARB has expressed its intent to produce a 'white paper' discussing its rationale for marine engine emission factors. The emission factors discussed here are the most frequently used and largely appear in the EPA estimates used to date.

The remainder of this document discusses the following topics:

- Commercial Engine Types
- Emissions Standards
- Emission Testing Considerations
- Hydrocarbon (THC), Carbon Monoxide (CO), Nitrogen Oxides (NOx), Sulfur Dioxide (SO2), and Carbon Dioxide (CO2) Emission Factor Estimates
- Particulate Emission Factors
- Low Load Adjustment Factors

Commercial Engine Types

Engines used in commercial marine activity primarily use the diesel engine cycle. However, some older freight vessels and older and tactical military vessels use steam boilers and gas turbines.

Marine diesel engines have historically been grouped into slow, medium, and high-speed engines representing the rated speed ranges in engine revolutions per minute (rpm), outlined below in Table 1 with typical stroke type. The speed ratings shown below are conventional interpretations rather than clear categorizations of engine design. The slow-speed engines typically have a much longer stroke than bore diameter approaching a ratio of 3:1 but always greater than 2:1. This provides an opportunity for high compression ratios and a clearly unique design. The medium speed engines stroke to bore ratio is nearly always less than 2:1 and usually less than 1.5:1. There is no clear distinction between medium-speed and high-speed engines, but medium-speed engines are designed with larger bores and higher power ratings.

Table 1. Historic marine engine categories.

Speed Category	Engine RPM	Engine Stroke Type
Slow	< 250 RPM	2
Medium	250 – 1,400 RPM	4 (occasional 2-stroke engines)
High	> 1,400 RPM	4

The United State Environmental Protection Agency (EPA) has defined three categories of engines by the cylinder size (stroke times the bore cross-section area), as shown in Table 2. The EPA's primary purpose in defining the engine types in this manner was to distinguish the engine makers and typical design characteristics. Category 1 engines are similar to most nonroad engines, and Category 2 engines are most similar to very large (e.g., mining) nonroad and locomotive engines. Category 3 engines are unique to ocean-going vessel (OGV) and stationary engines. Nearly all slow-speed and some medium-speed engines are found in Category 3, the largest grouping. The primary use of Category 3 engines is for propulsion on larger, deep draft, OGV, but these engines are also used on some vessels on the Great Lakes. Occasionally, medium-speed Category 3 engines are found in use as auxiliary engines on ships with large electric loads, such as cruise ships and ships carrying refrigerated cargo. Category 1 and 2 engines are used in a wide variety of marine applications both as propulsion and auxiliary engines and can be either medium or high-speed engines.

Table 2. U.S. EPA marine engine categories.

Engine Category	Displacement (l/cylinder)
Category 1	< 5.0
Category 2	5.0 < disp. < 30
Category 3	>30

Emissions Standards

The emissions standards in Table 3 do not result in much emissions reduction. Emission standards for NOx have been instituted under international standards starting with model year 2000. The EPA has finalized more stringent emissions standards that will result in emission reductions from U.S flagged commercial marine vessels. These standards are shown in Table 4. However, the data in this report are intended to produce a revised marine emissions inventory to be used as a baseline for the year 2002/2003. This means that only two model years would be affected by the international emission standards, accounting for a small portion of the fleet. It is also uncertain how much NOx emission reduction the international standard will provide when fully implemented.

Table 3. MARPOL international NOx emission standard for engine built after 1/1/2000.

Rated Engine Speed	NOx Emission Standard
<130 rpm	17.0 g/kW-hr
130 rpm <= Engine Speed < 2,000 rpm	$45 * n^{-0.2}$ g/kW-hr
▲ 2,000 rpm	9.8 g/kW-hr

Table 4. EPA primary exhaust emissions standards for US flagged vessels (g/kW-hr). EPA (1999)

Power	Liters/cylinder	Model Year	THC + NOx g/kW-hr	CO g/kW-hr	PM g/kW-hr
Power < 37 kW	And disp. <0.9	2005	7.5	5.0	0.40
All Power Levels	0.9 < disp. < 1.2	2004	7.2	5.0	0.30
All Power Levels	1.2 < disp. < 2.5	2004	7.2	5.0	0.20
All Power Levels	2.5 < disp. < 5.0	2007	7.2	5.0	0.20
All Power Levels	5.0 < disp. < 15	2007	7.8	5.0	0.27
Power <3300 kW	15 < disp. < 20	2007	8.7	5.0	0.50
Power >3300 kW	15 < disp. < 20	2007	9.8	5.0	0.50
All Power Levels	20 < disp. < 25	2007	9.8	5.0	0.50
All Power Levels	25 < disp. < 30	2007	11.0	5.0	0.50

The EPA (http://www.epa.gov/otaq/locomotv.htm#regs) recently proposed additional more stringent standards that will take effect with the 2009 model year and be phased in through the 2018 model year. The phase-in schedule for the different engine types is quite complicated, but by the 2017 model year, all new engines (installed in US vessels) with power ratings greater than 600 kW will meet emissions standards of 1.8 g/kW-hr for NOx and less than 0.06 g/kW-hr PM.

Emission Testing Considerations

The emission testing of mobile sources has developed over many years with some specifications unique to diesel engines in general. This testing requires special equipment to produce consistent results from test to test and engine to engine.

Load Measurements

The actual load of the engine is usually measured at the flywheel using piezo-electric or other technology. However, this may be difficult for in-situ testing on-board a vessel. An alternative technique for auxiliary engines is to determine the electrical generation of the engine under given engine loads. Another method is to use the engine manufacturer's engine map, which provides an estimate of the engine output as a function of the fueling rate. However, if the engine is not operating according to manufacturer's specifications, this load measurement may be erroneous. Therefore, measuring the actual kilowatt engine output is a source of uncertainty to consider when reviewing emission factor reports.

Total Hydrocarbon (THC)

The primary requirement for measuring hydrocarbon emissions is the use of a heated flame ionization detector on a diluted heated sample. Other methods typically produce measurements that are biased low either because the heavier hydrocarbons are condensed on the sampling lines or are not measured at all (e.g., infrared).

Nitrogen Oxides (NOx)

The method for measuring NOx uses a chemiluminescence method that reduces the water interference found with most other measurement methods.

Temperature and humidity corrections are applied to the measured amount to correct for ambient conditions to a standard set of reference laboratory conditions. The typical diesel NOx correction factors are shown in the equations here. Another more complicated correction is available when an intercooled turbocharger is used in the engine design. The effect of the ambient condition corrections on NOx with typical engine parameters is shown in Figures 1 and 2.

$$\text{NOx-actual} = \text{KNOx} * \text{NOx-reference} \quad (1)$$

$$\text{KNOx} = 1 + A\,(H - 10.71) + B\,(T - 25) \quad (2)$$

Where T = ambient temperature, ^{o}C
H = ambient humidity, g H2O/kg of dry air
$A = 0.309\,(\text{Mass}_{fuel}/\text{Mass}_{dry\ air}) - 0.0266$
$B = -0.209\,(\text{Mass}_{fuel}/\text{Mass}_{dry\ air}) + 0.00954$

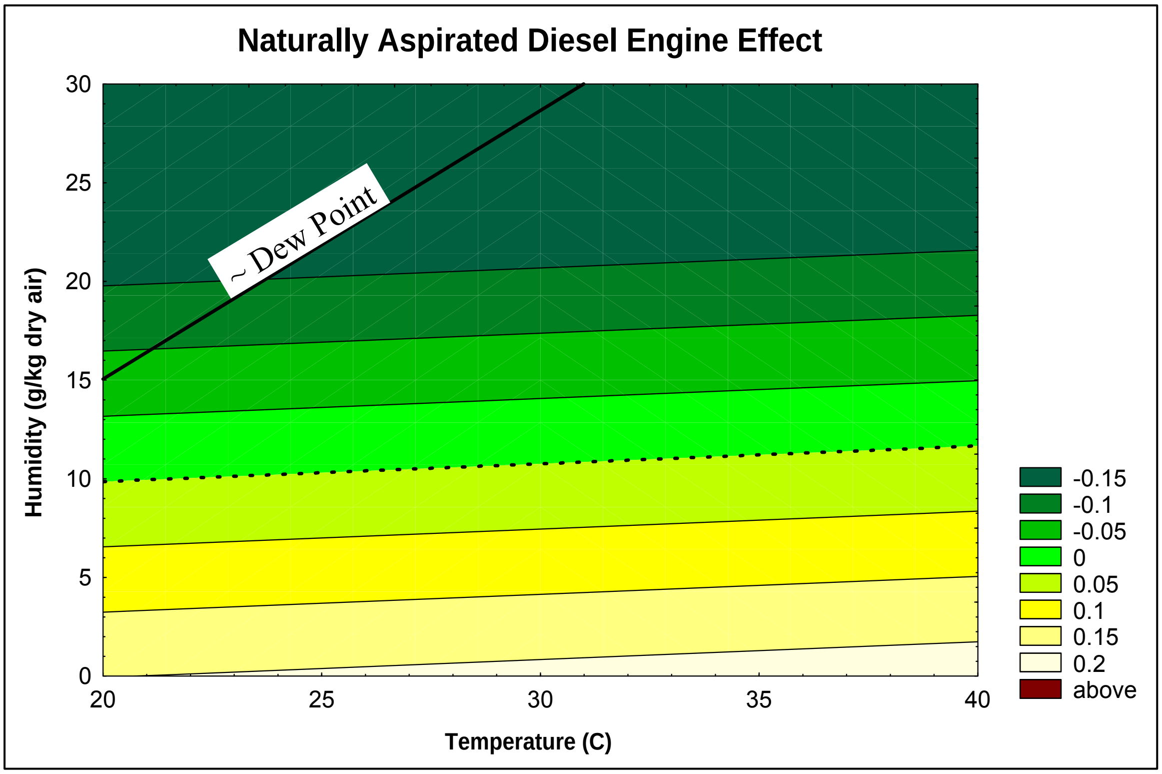


Figure 1. NOx adjustment (fractional change, 1 - KNOx) from equation 3. (Dotted line is no adjustment or KNOx =1)

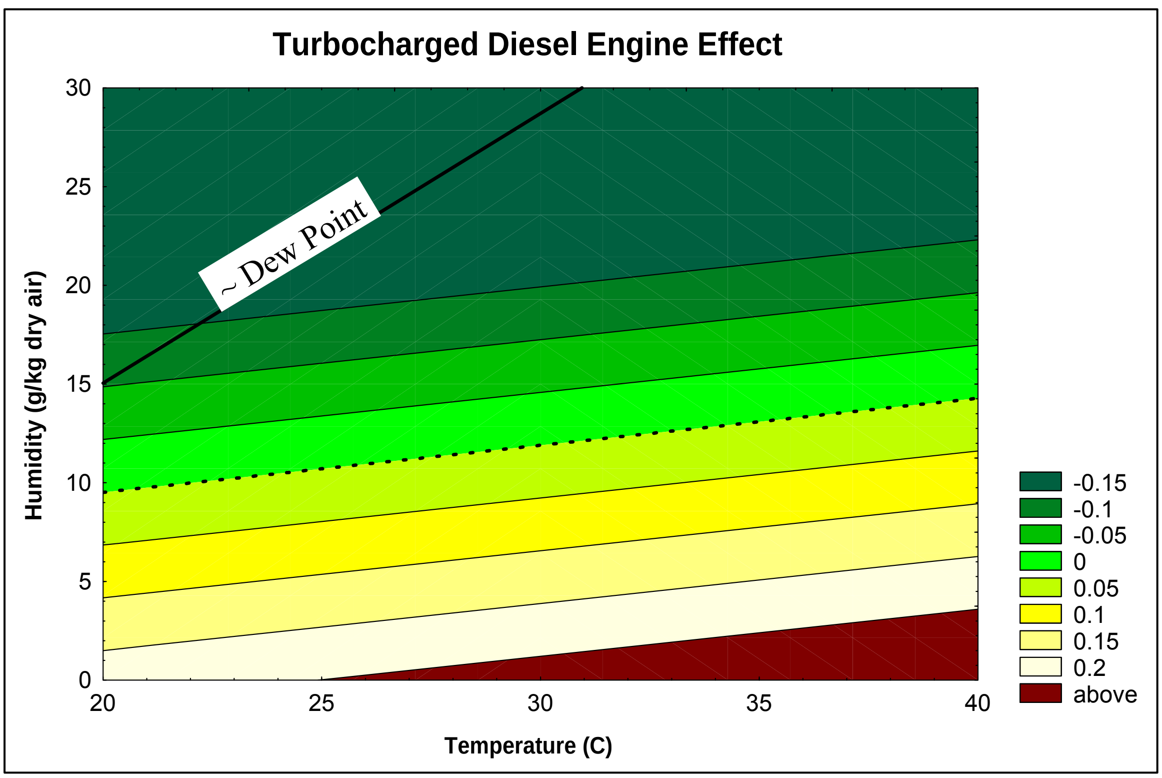


Figure 2. NOx adjustment (fractional change, 1 - KNOx) from equation 4. (Dotted line is no adjustment or KNOx =1)

Field measurements need to be corrected for ambient conditions to provide a consistent basis from which to compare emission results from various studies.

Particulate Matter Collection

Particulate matter (PM) emissions from mobile source diesel engines are difficult to measure and require special sampling systems and handling requirements that differ significantly from those used most often used for stationary sources. With large marine engines using high sulfur (greater than 0.5% sulfur) fuel, the particulate measured includes a large amount of sulfate most probably in the form of hydrated sulfuric acid. The sulfuric acid forms because a fraction of the fuel sulfur converts directly to sulfur trioxide (SO3), which rapidly absorbs water to a level of hydration not carefully characterized to date. The remaining particulate contains elemental carbon (black carbon soot), organic carbon consisting of unburned or partially burned fuel and engine oil, and metals from the fuel or engine wear.

The measurement of mobile source exhaust emissions seeks to identify the amount and form of the particulate emission as it emerges from the tailpipe. The particulate may rapidly change form (size or composition) in the immediate downwind plume or more slowly in the ambient air. Any atmospheric transformation would be the subject for air quality modeling or plume characteristic studies. To measure the particulate as it emerges from the tailpipe requires a special system to 'fix' the particulate by rapidly cooling the exhaust so it can be filtered. Maeda (2004) and Miller (2007) have described the method (ISO 8178-1 dilution filtering) generally accepted for use in measuring PM mobile sources. A portion of the exhaust stream is diluted with clean air in order that the entire mixture is below 52Cd prior to filtering. By convention, the filters then need to be conditioned (typically for 12 to 24 hours) at room temperature (22C) and 45% relative humidity (9.5C dewpoint) prior to weighing. The level of hydration of sulfate particulate is determined under the conditions dictated by those required in the weighing room.

Diesel particulate, including hydrate sulfuric acid, can be collected on the walls of sampling trains, so test-to-test variability must be considered when conducting particulate sampling. A good practice is to condition the sampling train by running the sample through for a period prior to beginning actual filtering. Another method described by Miller (2007) is to reduce the length (surface area) of sampling train.

The ISO emission measurement protocols also include a humidity adjustment, though it is less apparent that temperature and humidity affect diesel particulate formation than they do with NOx emissions.

Hydrocarbon (THC), Carbon Monoxide (CO), Nitrogen Oxides (NOx), Sulfur Dioxide (SO2), and Carbon Dioxide (CO2) Emission Factor Estimates

The generally accepted emission factors for most criteria pollutants for smaller marine engines has been outlined by the EPA (1999) , shown in Table 5, and for larger marine engines by ICF (2006) primarily using ENTEC (2002)/IVL (2004) estimates, shown in Table 6. These emission factors, however, do not distinguish between large (Category 3) medium-speed engines and smaller medium-speed engines. The larger Category 3 medium-speed engines are typically rated as speeds below 750 rpm. There is evidence to suggest that these larger engines have higher NOx emissions than the smaller engines (ENVIRON, 2002), but alternative emission factors for these engine types have not been generally accepted for use in emission inventories. The emissions for the larger engines, provided in Table 6, as summarized by ICF (2006) were primarily taken from the ENTEC (2002) estimates that were (self) reported to rely on a large database of marine emission tests. Where ICF did not report emission results, such as NOx for medium-speed Category 3 engines using lower sulfur fuels, consistent ENTEC (2002) estimates were added.

Table 5. Baseline emission factors for category 1 (typically high and smaller medium speed) marine engines (taken from Table 5-3, EPA 1999).

Power Range [kW]	HC [g/kW-hr]	CO [g/kW-hr]	NOx [g/kW-hr]
37-75	0.27	2.0	11
75-130	0.27	1.7	10
130-225	0.27	1.5	10
225-450	0.27	1.5	10
450-560	0.27	1.5	10
560-1000	0.27	1.5	10
1000+	0.27	2.5	13

Table 6. Emission factors for Category 2 and 3 engines, g/kWh. (ICF, 2006)

<table>
<tr><th>Cat.</th><th>Speed</th><th>Sulfur</th><th>HC</th><th>CO</th><th>NOx</th><th>SO_2</th><th>CO_2</th><th>BSFC</th></tr>
<tr><td rowspan="5">3</td><td rowspan="2">SSD</td><td>2.7%</td><td>0.6</td><td>1.4</td><td>18.1</td><td>10.3</td><td>621</td><td rowspan="2">195</td></tr>
<tr><td>2.5%</td><td>0.6</td><td>1.4</td><td>18.1</td><td>9.5</td><td>621</td></tr>
<tr><td rowspan="3">MSD</td><td>2.7%</td><td>0.5</td><td>1.1</td><td>14.0</td><td>11.1</td><td>670</td><td rowspan="3">210</td></tr>
<tr><td>2.5%</td><td>0.5</td><td>1.1</td><td>14.0</td><td>10.3</td><td>670</td></tr>
<tr><td>1.5%</td><td>0.5</td><td>1.1</td><td>13.2</td><td>6.2</td><td>670</td></tr>
<tr><td rowspan="3">2</td><td rowspan="3">MSD</td><td>2.5%</td><td>0.5</td><td>1.1</td><td>14.7</td><td>10.3</td><td>670</td><td rowspan="3">210</td></tr>
<tr><td>1.5%</td><td>0.5</td><td>1.1</td><td>13.9</td><td>6.2</td><td>670</td></tr>
<tr><td>0.3%</td><td>0.5</td><td>1.1</td><td>13.9</td><td>1.2</td><td>670</td></tr>
<tr><td>Steam</td><td>Steam</td><td>2.7%</td><td>0.1</td><td>0.2</td><td>2.1</td><td>16.1</td><td>972</td><td>305</td></tr>
<tr><td>Gas Turbine</td><td>Turbine[1]</td><td>0.07%</td><td>0.08</td><td>0.09</td><td>6.0</td><td>0.4</td><td>944</td><td>296</td></tr>
</table>

1 – Cooper (2001) used in EPA inventories

Carbon dioxide (CO2) was calculated from the brake specific fuel consumption (BSFC) (also referred to as the specific fuel oil consumption (SFOC)). The fuel consumption weight was converted from fuel carbon (molecular weight of 13.8 assuming 1.8 hydrogen atoms per carbon atom, U.S. Code of Federal Regulations) to CO2 (molecular weight of 44). Sulfur dioxide was also calculated from the fuel consumption using the weight fraction of sulfur (accounting for the 2.247% of sulfur directly converted to particulate) and molecular weight of SO2. Category 1 engines (in Table 5) would have the same CO2 and SO2 emission rates as other medium-speed engines in Table 6.

Particulate Emission Factors

Particulate matter emission factors are currently under intense debate primarily because of the dearth of emissions data. The difficulty in determining an appropriate emission factor for baseline conditions is complicated by the need for also projecting the effect of fuel sulfur regulations and their effect on particulates of lower sulfur fuels. Fuel sulfur partially converts to sulfuric acid, and heavier fuels with higher fuel sulfur content may, in addition, produce higher rates of unburned or partially burned fuel or oil emitted as organic carbon and collected as particulate. Heavier fuels and higher sulfur levels are known to produce higher particulate emission rates, but there is only a minimal set of emissions data available for precisely determining emission rates using high sulfur fuels.

The debate over particulate emission factors as it stands in March, 2007, is characterized here.

California Air Resources Board (ARB)

ARB has provided emission factor estimates for all common air contaminant (CAC) emissions including particulate (PM), as shown in Table 7. (ARB (2005a), ARB (2005b), ARB (2006)). The criteria pollutants other than PM are similar to those the EPA has used (Table 6). The particulate emission rates are somewhat different than any other reported estimates (ICF, 2006; ENTEC, 2002; or IVL, 2004) and are a primary source of confusion.

Table 7. ARB (2006) emission factors, g/kW-hr for marine engines

Engine Type	Fuel Type	HC	CO	NOx	PM	SO_2	CO2
Slow Speed	HFO (2.5% sulfur)	0.6	1.4	18.1	1.5	10.5	620
Medium Speed	HFO (2.5%)	0.5	1.1	14	1.5	11.5	677
Medium Speed	HFO (2.5%)	0.4	1.1	14.7	1.5	11.1	722
Medium Speed	Distillate (0.5%)	0.4	1.1	13.9	0.38	2.1	690
Medium Speed	Distillate (0.1%)	0.4	1.1	13.9	0.25	0.4	690

ARB (2007) has issued a review of available data that concluded that the particulate emission factor for residual fuels at 2.5% sulfur would be 1.4 g/kW-hr or close to their original estimate, shown in Table 7. If an emission factor at an intermediate level of sulfur (1.5%) is required, then 0.9 g/kW-hr should be used. These estimates, using 210 g/kW-hr fuel consumption linearly extended down to 0.5% sulfur, are shown in Figure 3, below.

U.S. Environmental Protection Agency (EPA)

For work performed for EPA, ENVIRON (2002) developed a particulate emission factor and sulfur relationship relying on Lloyds (1995) data, shown in Figure 3. As ENVIRON noted at the time, the functional form of the sulfur effect on PM was confusing because it showed a nonlinear relationship and was considerably higher than typical when using the historic relationship between sulfur and particulate described by EPA (2004).

<u>ENVIRON (2002) Estimate</u>
PM EF (kg/tonne) (at 3% sulfur) = 0.9016 x EXP(0.7238 x 3.0)

Though not explicitly stated in the Lloyds (1995) report, the data used to create the ENVIRON (2002) relationship likely used smaller higher speed 4-stroke engines (Lloyds provided only the vessel type but not the engine models, and listed these vessels as tugs, which predominately use medium or high speed engines) for the two data points in Figure 3 with low sulfur fuels. The upper range sulfur data were taken from larger 2-stroke engines (Lloyds lists these ships as tanker or general cargo vessels, and so most likely used larger propulsion engines) affecting the apparent empirical relationship between sulfur and particulate. For instance, the base emission factor (at low sulfur) for the larger engines may have been higher than tug engines, so the sulfur PM relationship estimated may have been perturbed by the choice of engines in the data set.

The EPA (2004) PM adjustment for fuel sulfur content, shown in the equation below, provides a basic relationship between sulfur and PM emissions. Combined with an estimated base emission rate (0.25 g/kW-hr typical for diesel engines running low sulfur fuels), the sulfur relationship has been used to calculate the particulate emissions factors in Tables 2-8 and 2-10 of ICF (2006) that were used for EPA marine vessel emissions modeling. The effect of fuel sulfur on particulate was developed from tests that measured the mass of particulate as a function of sulfur level on nonroad engines using fuel sulfur levels up to 0.5% mass by volume. In the equation below, the conversion factor of 2.247% was determined using the assumed level of hydration expressed (7H2O:H2SO4) and therefore may not represent actual conversion rates or level of hydration.

SPM adj = BSFC x 7.0 x 0.02247 x 0.01 x (soxfuel)

Where
soxfuel = % sulfur in fuel greater than 0.1%
BSFC = Brake Specific Fuel Consumption = 210 g/kW-hr for 4-stroke engines, for example

PM (g/kW-hr) = 0.25 (PM at 0.1% sulfur) + SPM adj

Since the time of these evaluations, a few studies have been conducted to measure particulate at various sulfur levels to add to the Lloyds (1995) study. These data include Maeda (2004), Cooper (2003), Miller (2007), Wright (1997), and Fleischer (1998), and are included in Figure 3. The ARB method relies more heavily on the Lloyds results while the EPA approach (to date) represents the bulk of the available data.

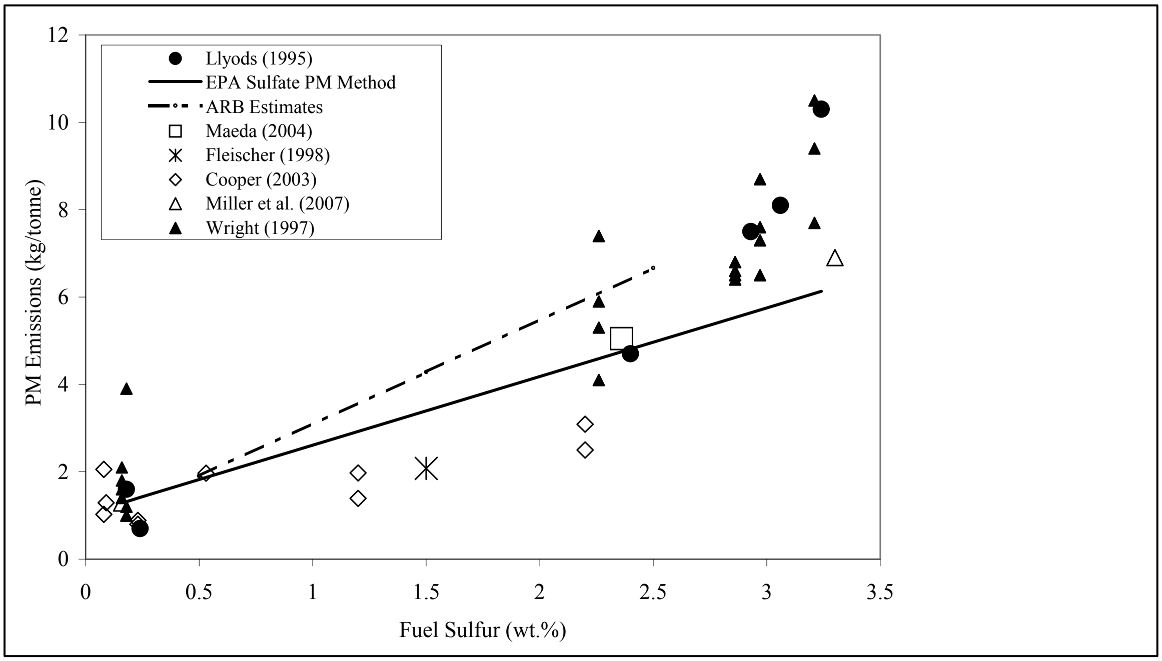


Figure 3. PM emission rate data compared with ARB and EPA estimates.

Because the exhaust mixture is filtered, all PM sizes are collected at once. Therefore, separate studies need to be undertaken to determine the size proportions. The many types of measurements required for size determination have not been well defined yet or compared side by side, so there is no clear estimate of the weight fraction by size. For purposes of analysis, ICF (2007) has been recommending to the EPA that 0.96 of PM is PM10 and 0.92 of PM10 is PM2.5. By contrast, the EPA NONROAD model for smaller diesel engines uses 1.00 for PM10 and 0.97 for PM2.5 factors to convert total PM to smaller sizes. (http://www.epa.gov/otaq/models/nonrdmdl/nonrdmdl2004/420p04009.pdf)

There is less debate over the particulate emission rates for smaller engines that typically use a distillate fuel with sulfur levels below 0.5%, averaging about 0.3%, shown in Table 8. The particulate emission factor of 0.3 g/kW-hr is approximately the same as that for medium speed engines at the same sulfur level.

Table 8. PM emission factors for category 1 (typically high and smaller medium speed) marine engines (taken from Table 5-3, EPA 1999).

Power Range [kW]	PM [g/kW-hr]
37-75	0.90
75-130	0.40
130-225	0.40
225-450	0.30
450-560	0.30
560-1000	0.30
1000+	0.30

Low Load Adjustment Factors

Low load adjustment factors have been used to adjust emission rates for engines operating at reduced load during maneuvering and other reduced speed modes. The generally used adjustment factors for low load conditions (CoS 2007, Starcrest 2004 and ICF 2006), shown in Table 9, were derived from a report by EEA (2000).

Table 9. Emission factor adjustment factors at low loads. (ICF, 2006)

Load	NOx	CO	HC	PM	SO_2
1%	11.47	20.00	89.44	19.17	1.00
2%	4.63	10.00	31.62	7.29	1.00
3%	2.92	6.67	17.21	4.33	1.00
4%	2.21	5.00	11.18	3.09	1.00
5%	1.83	4.00	8.00	2.44	1.00
6%	1.60	3.33	6.09	2.04	1.00
7%	1.45	2.86	4.83	1.79	1.00
8%	1.35	2.50	3.95	1.61	1.00
9%	1.27	2.22	3.31	1.48	1.00
10%	1.22	2.00	2.83	1.38	1.00
11%	1.17	1.82	2.45	1.30	1.00
12%	1.14	1.67	2.15	1.24	1.00
13%	1.11	1.54	1.91	1.19	1.00
14%	1.08	1.43	1.71	1.15	1.00
15%	1.06	1.33	1.54	1.11	1.00
16%	1.05	1.25	1.40	1.08	1.00
17%	1.03	1.18	1.28	1.06	1.00
18%	1.02	1.11	1.17	1.04	1.00
19%	1.01	1.05	1.08	1.02	1.00
20%	1.00	1.00	1.00	1.00	1.00

The EEA report relied on limited data from the Lloyds (1995) and ETC (1997) as the basis for the analysis. The analysis relied on data from engines typically well under 8,000 kW and this power level may have been a result of multiple engines. The data was only representative of smaller Category 1, 2, or perhaps in rare cases Category 3, and all were medium-speed engines. For particulate load adjustment factors, it is clear that EEA relied on data for engines burning low sulfur fuel because high load conditions resulted in PM emission rates averaging less than 0.3 g/kW-hr. Surprisingly, slow speed engines used for propulsion engines on most large ships are most subject to low load conditions during maneuvering modes compared with auxiliary engines that are more comparable to the engines used in the EEA analysis. Therefore, the load adjustment factors in Table 9 are not justified for slow speed engines or engines using high sulfur fuels. The low load adjustments in Table 6 are uniquely unsuited to the situation where the adjustment factors are most often used to adjust emissions.

Emission factor adjustments for low load conditions, therefore, are largely unknown for larger marine engines, yet it is engineering common knowledge that engines are not as efficient at low loads. Emission factors should be adjusted upwards to account for higher emissions near dock, but without clear data only a supposition of the likely effect is available at this time. The EPA has suggested in public comments that while maneuvering modes might average 2% load (Starcrest, 2005) on the propulsion engine, this is a result of true engine loads of 10% for a portion of time. Captains typically demand short bursts of power followed by no load idle conditions.

ICF (2006) (or Starcrest (2005) which formed the basis for ICF adjustments) misinterpreted the EEA, 2000, estimates for SO2, so revised figures are provided here using the fuel consumption (same as CO2) adjustment factors. The EEA adjustment for CO2 is actually 1.25 at 20% load, but has been normalized to 1 at 20% load in Table 10 to put it on the same basis as the other emission adjustments.

Table 10. Emission factor adjustment factors at low loads. (ICF, 2006 and EEA, 2000)

Load	NOx	CO	HC	PM	SO_2 (fuel)	CO_2 (normalized)
2%	4.63	10.00	31.62	7.29	3.28	3.28
3%	2.92	6.67	17.21	4.33	2.44	2.44
4%	2.21	5.00	11.18	3.09	2.01	2.01
5%	1.83	4.00	8.00	2.44	1.76	1.76
6%	1.60	3.33	6.09	2.04	1.59	1.59
7%	1.45	2.86	4.83	1.79	1.47	1.47
8%	1.35	2.50	3.95	1.61	1.38	1.38
9%	1.27	2.22	3.31	1.48	1.31	1.31
10%	1.22	2.00	2.83	1.38	1.25	1.25
11%	1.17	1.82	2.45	1.30	1.21	1.21
12%	1.14	1.67	2.15	1.24	1.17	1.17
13%	1.11	1.54	1.91	1.19	1.14	1.14
14%	1.08	1.43	1.71	1.15	1.11	1.11
15%	1.06	1.33	1.54	1.11	1.08	1.08
16%	1.05	1.25	1.40	1.08	1.06	1.06
17%	1.03	1.18	1.28	1.06	1.04	1.04
18%	1.02	1.11	1.17	1.04	1.03	1.03
19%	1.01	1.05	1.08	1.02	1.01	1.01
20%	1.00	1.00	1.00	1.00	1.00	1.00

Conclusion

Much work remains to be accomplished before everyone will be satisfied that emissions from marine engines are well understood. However, based on the weight of data available, the EPA summarized emission factors appear to be the most justified. These are summarized in Table 11, below.

Table 11. Recommended full load (>20%) emission factors for marine engines, g/kWh.

Cat.	Speed	Sulfur	HC	CO	NOx	PM	SO_2	CO_2	BSFC
3	SSD	2.7%	0.6	1.4	18.1	1.05	10.3	621	195
		1.5%	0.6	1.4	17.0	0.68	5.7	621	
		0.2%	0.6	1.4	17.0	0.28	0.8	621	
		0.1%	0.6	1.4	17.0	0.25	0.4	621	
	MSD	2.7%	0.5	1.1	14.0	1.11	11.1	670	210
		1.5%	0.5	1.1	13.2	0.71	6.2	670	
		0.2%	0.5	1.1	13.2	0.28	0.8	670	
		0.1%	0.5	1.1	13.2	0.25	0.4	670	
2	MSD	2.7%	0.4	1.1	14.7	1.11	11.1	670	210
		1.5%	0.4	1.1	13.9	0.71	6.2	670	
		0.2%	0.4	1.1	13.9	0.28	0.8	670	
		0.1%	0.4	1.1	13.9	0.25	0.4	670	
1 < 1MW	MSD	0.3%	0.27	2.5	13	0.30	1.2	670	210
1 > 1MW	MSD	0.3%	0.27	2.5	10	0.30	1.2	670	210
Steam Boiler	Steam	2.7%	0.1	0.2	2.1	1.50	16.1	972	305
		1.5%	0.1	0.2	2.1	0.92	8.9	972	
		0.2%	0.1	0.2	2.1	0.30	1.2	972	
		0.1%	0.1	0.2	2.1	0.25	0.6	972	
Gas Turbine	Turbine[1]	0.07%	0.08	0.09	6.0	0.007	0.4	944	296

1 – Cooper (2001) used in EPA inventories

Open Issues

Emission factor measurements are currently being conducted as part of this project, however, the data gathering has yet to be finalized to be used in this analysis.

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