2010 NATIONAL MARINE EMISSIONS INVENTORY FOR CANADA

FINAL REPORT

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APPENDICES

EXECUTIVE SUMMARY

SNC-Lavalin Inc., Environment Division (SLE), in partnership with ClearSky Engineering Inc. (ClearSky) was contracted by Environment Canada (EC) to complete a national marine emissions inventory for the 2010 calendar year. The inventory includes all commercial marine vessel classes tracked by the Canadian Coast Guard (CG) within Canada's territorial waters, as well as smaller commercial craft such as ferries, tugboats and fishing vessels. All coastal areas as well as inland rivers and lakes are included in the inventory.

The basis for the inventory is movement data as logged in the Information System on Marine Navigation (INNAV) for eastern Canada and the Arctic and the Vessel Traffic Operator Support System (VTOSS) for the west coast through CG Vessel Traffic Services (VTS). INNAV data for 2010 is representative of all ocean going vessel (OGV) movements whereas data gaps exist in the 2010 VTOSS data set. Identifying and filling data gaps is part of the project scope. SLE used Pacific Pilotage Authority movement data as well as port-level data to supplement VTOSS as needed.

A project advisory committee (PAC) was formed by EC in late 2009, consisting of approximately 30 representatives from both foreign and domestic shipping associations as well as Canadian ports, provincial and regional governments and other governmental agencies. The PAC worked with EC to develop the statement of work for the project and additionally provided access to supporting data to better characterize the OGV movements.

Canada's Marine Emissions Inventory Tool (MEIT) was updated to Version 4.0 to support development of the inventory following current best practice methods. An activity-based methodology was used with emissions calculated on a voyage by voyage basis, based on times in mode (underway, anchor, berth). The methodology was developed and applied to eastern Canada and adjusted as necessary to account for lower resolution data in the Arctic and data gaps on the West Coast.

MEIT V4.0 evaluates each 'segment' of a voyage for vessel speed and implied load on the main engines. This procedure replaces a previous origin-destination approach where vessels were assumed to travel at their typical cruising speeds at all times (with some exceptions in speed restricted areas), along pre-defined routes.

Figure ES- 1: Sample Voyage Segments

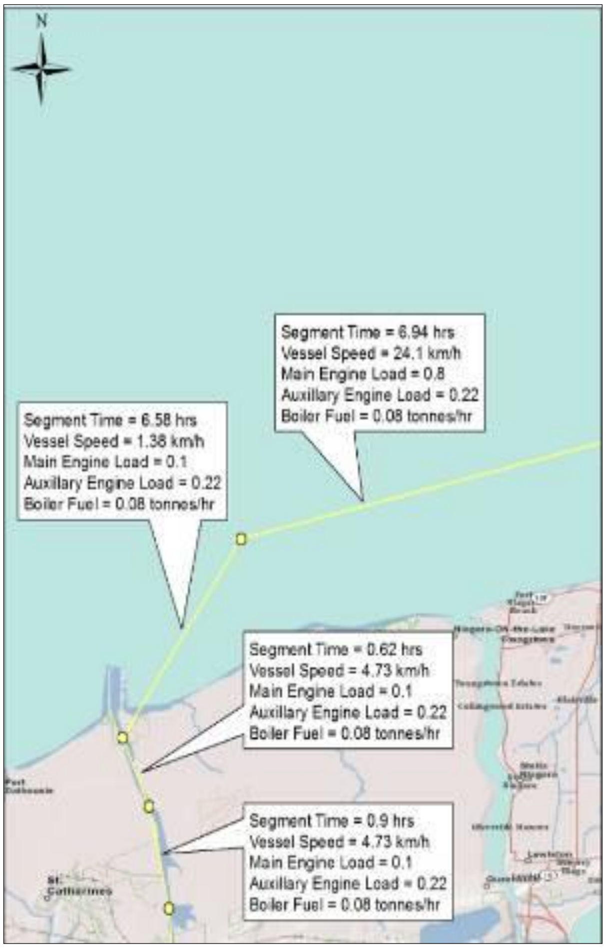


Figure ES-1 shows the general method used to estimate OGV emissions. In this case, a Merchant Bulk ship is captured in the model travelling through the Welland Canal and into Lake Ontario. The vessel's engine use and emissions are evaluated at every segment of its journey by use of the model-estimated speed (for main engine load) and ship class averages for auxiliary engine load and boiler fuel consumption.

MEIT has look up tables to identify installed ship engine power when possible and to estimate these levels from statistical data when not. Additional information was required for the calculations. The following criteria were established from different data sources, including previous vessel survey programs:

- Fuel sulphur levels, as well as origin of fuels (domestic versus international);
- Average auxiliary engine use (load) while at berth and anchor; and
- Average boiler fuel consumption.

CG vessel tracking is not fully representative of smaller vessel classes and short-term movements in and near harbour areas for tug boats and barges. Movement summaries for ferries, tugboats and fishing vessels were developed based on independent investigations involving identification of scheduling data, focused stakeholder requests and consideration of complementary data sources. Although these vessels tend to be much smaller than the OGVs, their activities are significant to the inventory as a whole.

The National Marine Emissions Inventory for 2010 is presented in Tables ES-1, to ES-4 for Canada (all regions), Eastern Canada / Great Lakes, Western Canada and Canada's Arctic respectively. Emissions were estimated for Criteria Air Contaminants (CACs), greenhouse gases (GHGs) and select air toxics (not shown in the tables). Allocation of the full inventory to the general vessel classes is presented in Figure ES-5 for select air contaminants of interest.

Table ES-1: 2010 Marine Emissions Estimates for Canada (All Regions)

	Air Contaminant	Emissions by Mode of Activity (tonnes)			
		Underway	Berthing	Anchoring	Total
Criteria Air Contaminants (CACs)	NO_x	180,549	10,264	3,124	**193,938**
	SO_x	91,396	7,942	2,839	**102,177**
	CO	15,897	1,198	349	**17,444**
	VOC	10,359	5,287	89	**15,736**
	PM	12,950	907	312	**14,170**
	PM_{10}	12,432	871	300	**13,603**
	$PM_{2.5}$	11,438	801	276	**12,515**
	NH_3	221	3	0	**224**
GHGs	CO_2	7,681,089	770,871	223,556	**8,675,517**
	CH_4	98	34	9	**141**
	N_2O	203	20	6	**228**

Table ES-2: 2010 Emissions Estimates for the East Coast / Great Lakes

	Air Contaminant	Emissions by Mode of Activity (tonnes)			
		Underway	Berthing	Anchoring	Total
Criteria Air Contaminants (CACs)	NO_x	105,480	6,962	1,766	**114,208**
	SO_x	52,019	5,202	1,438	**58,659**
	CO	9,564	844	199	**10,608**
	VOC	7,406	4,905	50	**12,362**
	PM	7,424	595	160	**8,179**
	PM_{10}	7,127	572	153	**7,852**
	$PM_{2.5}$	6,557	526	141	**7,224**
	NH_3	126	2	0	**128**
GHGs	CO_2	4,552,708	545,797	128,005	**5,226,511**
	CH_4	63	26	5	**94**
	N_2O	120	14	3	**137**

Table ES-3: 2010 Emissions Estimates for Western Canada

	Air Contaminant	Emissions by Mode of Activity (tonnes)			
		Underway	Berthing	Anchoring	Total
Criteria Air Contaminants (CACs)	NO_x	71,213	3,066	1,348	**75,628**
	SO_x	38,001	2,549	1,391	**41,940**
	CO	6,014	327	148	**6,489**
	VOC	2,813	375	39	**3,227**
	PM	5,311	291	151	**5,753**
	PM_{10}	5,099	279	145	**5,523**
	$PM_{2.5}$	4,691	257	134	**5,081**
	NH_3	90	1	0	**91**
GHGs	CO_2	2,948,286	208,120	94,681	**3,251,087**
	CH_4	33	7	4	**44**
	N_2O	78	5	2	**86**

Table ES-4: 2010 Emissions Estimates for Canada's Arctic*

	Air Contaminant	Emissions by Mode of Activity (tonnes)			
		Underway	Berthing	Anchoring	Total
Criteria Air Contaminants (CACs)	NO_x	3,856	236	10	**4,103**
	SO_x	1,376	192	10	**1,579**
	CO	319	26	1	**347**
	VOC	140	7	0	**147**
	PM	216	21	1	**238**
	PM_{10}	207	21	1	**229**
	$PM_{2.5}$	190	19	1	**210**
	NH_3	5	0	0	**5**
GHGs	CO_2	180,095	16,954	870	**197,919**
	CH_4	2	1	0	**3**
	N_2O	5	0	0	**5**

*Note: Canada's Arctic marine emissions have recently been updated in a separate Arctic study completed for Transport Canada. The values shown in Table ES-4 should not be used for other purposes.

Figure ES-2: 2010 Emissions (All Regions) by Air Contaminant

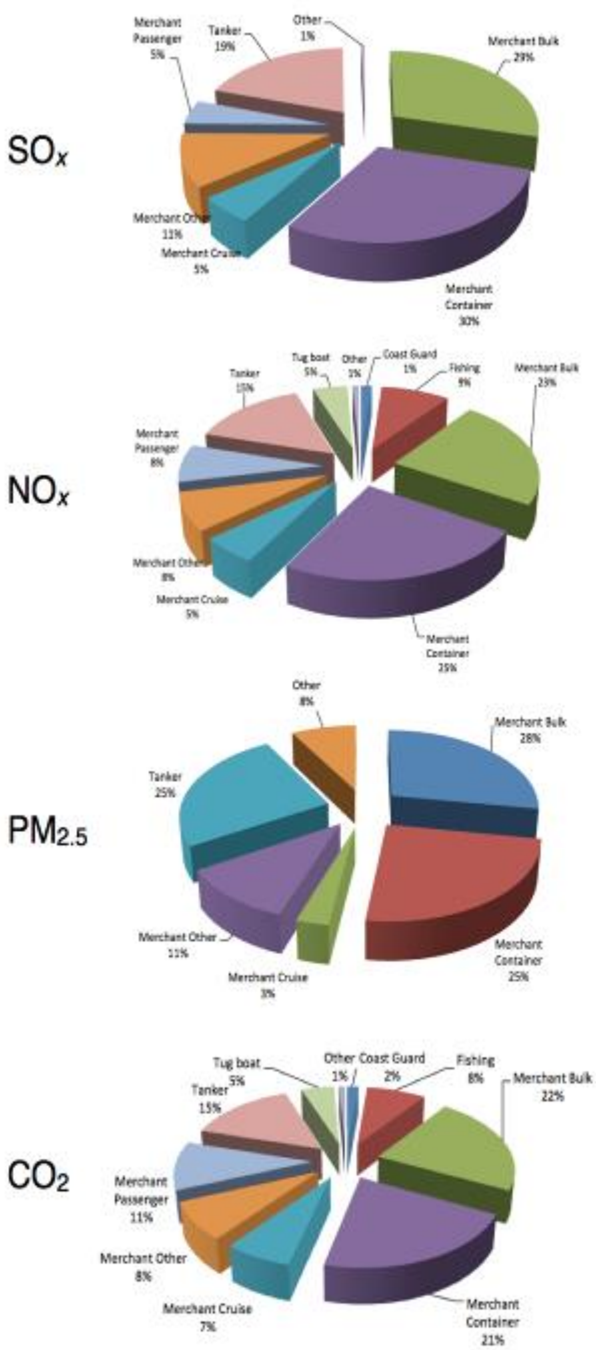


Figure ES-2 shows that three OGV classes are responsible for approximately three quarters of the CAC emissions in Canada (as shown by sulphur oxides (SO_x), nitrogen oxides (NO_x) and suspended particulate matter (PM). Domestic marine traffic, including fishing vessels, tug boats and ferries (Merchant Passenger) become more significant for greenhouse gas emissions, as indicated by carbon dioxide (CO_2) emissions. Domestic traffic consumes lower sulphur fuel compared to the international OGV classes.

The general methods used in the 2010 inventory were first pioneered by the BC Chamber of Shipping in 2006 for development of the 2005/2006 BC Ocean Going Vessel Emissions Inventory and were later used in the Transport Canada 2002 – 2007 Arctic Emissions Inventory (with some adjustment). The 2010 emissions estimates for the OGV classes were found to be similar in magnitude to those determined in the previous studies, when accounting for the larger geographical boundary on the west coast compared to that used previously.

The total emissions estimates are higher on both coasts due to a greater accounting of the smaller vessel classes, including tug boats, ferries and fishing vessels that were not fully characterized previously. However, some of the difference is due to adjustments in accounting methods.

Inventory Backcasts and Forecasts

Emissions backcasts and forecasts were developed for Canada in 5 year increments from 1980 to 2030, including an additional backcast to 1987. The forecasts account for ship rollover (scrappage), all identifiable ship engine emission and fuel standards, as well as changes to the baseline activity. The 2010 annual engine hours by ship class were scaled with historic commodity data (backcasts) and commodity projections (forecasts) and these annual hours were used with revised emission rates based on the engine emission and fuel standards.

The International Maritime Organization (IMO) International Convention on the Prevention of Pollution from Ships (MARPOL) includes definition of an Emissions Control Area (ECA) that member countries can propose and establish for sensitive regions. A North American ECA has been adopted by IMO member states and will become effective in August 2012. For this reason, beginning in 2015, all of the inventory forecasts were subject to a 0.1% sulphur limit to the fuels used. Canada's Arctic is not included in the ECA.

As of March 2012, MARPOL Annex VI has a chapter 4 that has regulations on energy efficiency for ships through the Energy Efficiency Design Index (EEDI) for new ships built after 2013 and Ship Energy Efficiency Management Plan (SEEMP) requirements for all ships. These regulations target reduction of emissions on a tonne-mile basis, through improved ship design (EEDI) and improved operational efficiency (SEEMP). The regulations ramp up to a 30% reduction in fuel consumption by 2025. EEDI may be understood by consider the following simplified formula:

$$\text{EEDI} = \frac{\text{CO}_2\ \text{Emissions}}{\text{Transport Work}}$$

Although EEDI implies improvement through ship design, SEEMP requires operational changes such as reduced cruise speeds and higher frequency of maintenance. Both programs are expected to achieve the same numerical results of lower fuel consumption and emissions per tonne-mile. IMO has completed modelling of the potential CO_2 emissions reductions due to EEDI and SEEMP with a 'low' scenario (30% SEEMP uptake within the international fleet) and a 'high' scenario (60% uptake). SLE followed the same approach for 'high' and 'low' scenario forecasts for the national inventory.

Tables ES-5 and ES-6 present the national inventory backcasts and forecasts for the 'high' and 'low' scenarios, respectively.

Table ES-5: Marine Emissions Inventory Backcast and Forecast for Canada – 'High' IMO Scenario

Inventory Year	Criteria Air Contaminants (CACs)								Greenhouse Gases (GHGs)		
	NO_x	SO_x	CO	HC	PM	PM_{10}	PM_{25}	NH_3	CO_2	CH_4	N_2O
1980	105,393	57,813	9,563	9,717	8,054	7,732	7,113	120	4,741,242	76	124
1985	105,527	57,878	9,578	9,722	8,063	7,740	7,121	120	4,750,517	76	124
1990	136,080	77,919	12,233	11,293	10,678	10,250	9,430	153	6,075,833	100	159
1995	155,469	91,531	13,904	10,088	12,459	11,961	11,004	175	6,960,038	113	182
2000	179,877	105,876	15,967	12,459	14,415	13,838	12,731	207	8,021,887	127	210
2005	205,215	122,247	18,251	17,741	16,587	15,924	14,650	237	9,142,818	146	240
2010	193,938	102,177	17,444	15,736	14,170	13,603	12,515	224	8,675,517	141	228
2015	217,463	6,809	19,971	17,091	4,413	4,236	3,898	257	9,941,513	162	262
2020	193,874	5,536	20,027	17,351	4,293	4,121	3,791	258	10,001,093	164	263
2025	157,128	5,409	19,711	17,528	4,226	4,057	3,733	253	9,890,454	164	260
2030	129,650	5,618	20,451	18,152	4,385	4,210	3,873	263	10,267,141	171	270

Table ES-6: Marine Emissions Inventory Backcast and Forecast for Canada – 'Low' IMO Scenario

Inventory Year	Criteria Air Contaminants (CACs)								Greenhouse Gases (GHGs)		
	NO_x	SO_x	CO	HC	PM	PM_{10}	PM_{25}	NH_3	CO_2	CH_4	N_2O
1980	105,393	57,813	9,563	9,717	8,054	7,732	7,113	120	4,741,242	76	124
1985	105,527	57,878	9,578	9,722	8,063	7,740	7,121	120	4,750,517	76	124
1990	136,080	77,919	12,233	11,293	10,678	10,250	9,430	153	6,075,833	100	159
1995	155,469	91,531	13,904	10,088	12,459	11,961	11,004	175	6,960,038	113	182
2000	179,877	105,876	15,967	12,459	14,415	13,838	12,731	207	8,021,887	127	210
2005	205,215	122,247	18,251	17,741	16,587	15,924	14,650	237	9,142,818	146	240
2010	193,938	102,177	17,444	15,736	14,170	13,603	12,515	224	8,675,517	141	228
2015	221,203	6,928	20,296	17,228	4,484	4,305	3,960	262	10,091,773	164	266
2020	200,120	5,710	20,579	17,584	4,410	4,234	3,895	265	10,256,117	168	270
2025	162,446	5,565	20,196	17,731	4,331	4,157	3,825	260	10,118,828	168	266
2030	132,827	5,713	20,736	18,272	4,448	4,270	3,928	267	10,405,182	173	274

The inventory forecasts show that an increase in emissions is expected by 2015, with the exception of SO_x and PM, which are expected to drop due to the implementation of the North American ECA. Other IMO regulations are shown to have a lowering effect on emissions after 2015, particularly for NO_x.

The 2010 Canadian marine emissions inventory was developed by accessing data and information from the Canadian Coast Guard, Canadian government (Environment Canada, Transport Canada), Canadian ports and a number of shipping agencies and associations active in Canada. This information allowed development of a sophisticated inventory model to account for actions such as fuel switching, slow steaming and use of shoreside power. The Canadian Coast Guard INNAV data used for eastern Canada and the Arctic was found to be highly useful and consistent with other dependable sources of ship movement data such as port ship call records. The Canadian Coast Guard VTOSS data was found to be inferior to INNAV for purposes of marine inventory development. For this reason, the emission estimates for the west coast are considered to have higher uncertainty than estimates for the east coast. The INNAV system is now being used by the Coast Guard on the west coast (as of 2011) and will be available for future marine emission studies.

MEIT 4.0 constitutes an update to Canada's marine emissions model that effectively accounts for ship characteristic and movement data now available. Suggested actions for future improvements to MEIT and Canada's national marine emissions inventory include the following:

- Further investigation into fishing vessel activity;
- Further evaluation of the relationship between ship speed (as determined through analysis of Coast Guard INNAV data) and main engine load for ocean going vessels; and,
- Evaluation of the west coast inventory by acquiring and using 2011 INNAV data in MEIT V4.0.

TABLE OF ACRONYMS

AE	Auxiliary engine
BC CoS	BC Chamber of Shipping
CACs	criteria air contaminants
CH_4	methane
CO	carbon monoxide
CO_2	carbon dioxide
DPM	diesel particulate matter
CO_2e	carbon dioxide equivalent
ECA	Emission Control Area
EEDI	Energy Efficiency Design Index
EF	emission factor
EI	Emissions Inventory
EPA	U.S. Environmental Protection Agency
GHGs	greenhouse gases
GWP	Global Warming Potential
HC	hydrocarbons
HFO	Heavy Fuel Oil, also referred to as residual oil
hp	horsepower
IMO	International Maritime Organization
INNAV	Information System on Marine Navigation (Canadian Coast Guard)
IPCC	Intergovernmental Panel on Climate Change
kW	Kilowatt
ME	Main engine
MEIT	Marine Emissions Inventory Tool
MCR	Maximum Continuous Rating (engines)
MDO	marine diesel oil, also referred to as marine distillate
N_2O	dinitrogen monoxide, also referred to as nitrous oxide
NO_x	oxides of nitrogen
OD	Origin - destination
OGV	Ocean Going Vessel
PM	suspended particulate matter
PM_{10}, $PM_{2.5}$	suspended particulate matter of diameter 10 (2.5) microns or less
ppm	parts per million (used to identify sulphur level in diesel fuel)
SEEMP	Ship Energy Efficiency Management Plan

TABLE OF ACRONYMS (Cont'd)

SO_2	sulfur dioxide
SO_x	oxides of sulfur
TEU	twenty foot equivalent unit
tonne	Metric tonne = 1,000 kg
VTOSS	Vessel Traffic Operator Support System

1. INTRODUCTION

SNC-Lavalin Inc., Environment Division (SLE), in partnership with ClearSky Engineering Inc. (ClearSky) was contracted to complete a national marine emissions inventory for the 2010 calendar year. The inventory includes all commercial marine vessel classes tracked by the Canadian Coast Guard (CG) within Canada's territorial waters, as well as smaller commercial craft such as ferries, tugboats and fishing vessels that are not fully represented in the CG movement data. All coastal areas as well as inland rivers and lakes are included in the inventory.

Environment Canada compiles emissions inventories (EIs) for different sectors of activity and for different sets of air contaminants in support of strategic environmental initiatives. The International Maritime Organization (IMO) International Convention on the Prevention of Pollution from Ships (MARPOL) includes definition of an Emissions Control Area (ECA) that member countries can propose and establish for sensitive regions. A North American ECA has been adopted by IMO member states and will become effective in August 2012. This marine inventory will set an effective baseline with which emission reductions can be monitored over time. It is expected that the national inventory will be re-assessed in 2015.

Canada has a 'Marine Emissions Inventory Tool' (MEIT) that has been developed and supported by the Canadian government since a 2002 marine inventory was completed for the Great Lakes and east coast of Canada (work completed in 2006). Since this time there has been a history of investigations and developments to improve the model as understanding of ship emissions data as well as Canadian ship movements has increased. MEIT V3.5 was used as a starting point for this project, with the expectation that the model would be updated (to V4.0) with additional information and support from the project stakeholders, which include several active shipowners associations.

In 2010, CG movement data was available from the CG Information System on Marine Navigation (INNAV) and the Vessel Traffic Operation Support System (VTOSS). 2010 INNAV data is representative of Ocean Going Vessel (OGV) movements in eastern Canada (including the Great Lakes) as well as Canada's Arctic. VTOSS is representative of movements off the coast of British Columbia. As the INNAV system is now supported in all coastal areas of Canada (2011), MEIT updates were developed reflective of INNAV structure and data quality. 2010 VTOSS data were formatted to mimic the INNAV structure to the degree possible.

A map of Canada's territorial waters is shown in Figure 1.1.

Figure 1-1: Canada's Territorial Waters

1.1 Scope of Work

The scope of work for the 2010 national marine emissions inventory includes a number of criteria based on previous marine assessments completed in Canada as well as new criteria supportive of the federal government's current programs and initiatives.

1.1.1 Boundaries

The geographical boundaries for the national inventory include Canada's territorial waters as well as all inland rivers and lakes with significant commercial marine activity. Canada's territorial waters extend 200 nautical miles offshore, with the exception of a portion of eastern Canada where a shared boundary exists between Canada and Greenland. Operational boundaries for the inventory include all commercial marine vessels, with emissions distinguished by:

- Domestic and international voyages;
- Class of vessel (e.g., Merchant Container, Merchant Bulk);
- Type of engine (propulsion, auxiliary) as well as boilers;
- Engine size (installed capacity in kW as well as cylinder size in litres);
- Modes of activity, including underway, berthing and anchoring;
- Type of emission (exhaust and fugitive); and
- Fuel type (distillate and residual oils)

Underway activity is defined to be all ship movements, regardless of speed. Berth activity occurs when a ship is stationary at any identifiable berth location in Canada (e.g., terminal, wharf or wharf section). Anchor activity occurs at all other times when a ship is stationary.

1.1.2 Air Contaminants

The 2010 inventory includes numerous air contaminants of interest to Canadian government. Criteria Air Contaminants (CACs), also referred to as 'Common Air Contaminants' by some Canadian jurisdictions, have known effects on either human health or the environment. They are typically included in most large scale inventory efforts in Canada. GHG emissions play a role in climate change and therefore are also typically included in emissions accounting.

Air toxic emission estimates are more uncertain and tend to be characterized by use of speciation profiles. The list of air toxics included in the inventory are those supported by the U.S. EPA for marine engines in their 2008 National Emission Inventory (NEI).

The following air contaminant species are characterized in the 2010 inventory:

Criteria Air Contaminants (CACs):

- Nitrogen oxides (NO_x), sulphur oxides (SO_x), carbon monoxide (CO), volatile organic compounds (VOC), particulate matter (PM, as total PM, PM_{10} and $PM_{2.5}$, as well as elemental, organic and sulphate fractions) and ammonia (NH_3).

Greenhouse Gases (GHGs):

- Carbon dioxide (CO_2), methane (CH_4) and nitrous oxide (N_2O), as well as equivalent carbon dioxide amounts (eCO_2).

Air Toxics:

- 9 different metals, including lead, mercury and chromium;
- 13 different 'Hazardous Air Pollutants' (HAPs), including benzene, toluene and formaldehyde;
- 16 Polycyclic Aromatic Hydrocarbons (PAHs);
- Combined dioxins; and
- Polychlorinated biphenyls

Additional reporting on air contaminants includes the following definitions:

- Diesel particulate matter (DPM) as PM due to combustion of diesel;

1.1.3 Emission Scenarios

The 2010 inventory includes backcasts and forecasts from 1980 to 2030 in five year increments. Additionally, a backcast for 1987 is included for NOx only.

1.1.4 Temporal and Spatial Resolution

Temporal resolution of the 2010 inventory includes emissions by hour, day and month over the year. Spatial resolution includes emissions allocated to region of Canada (by province as well as many regional areas defined in MEIT from past work) and to a 1km by 1km polar-stereographic grid true at 60N latitude.

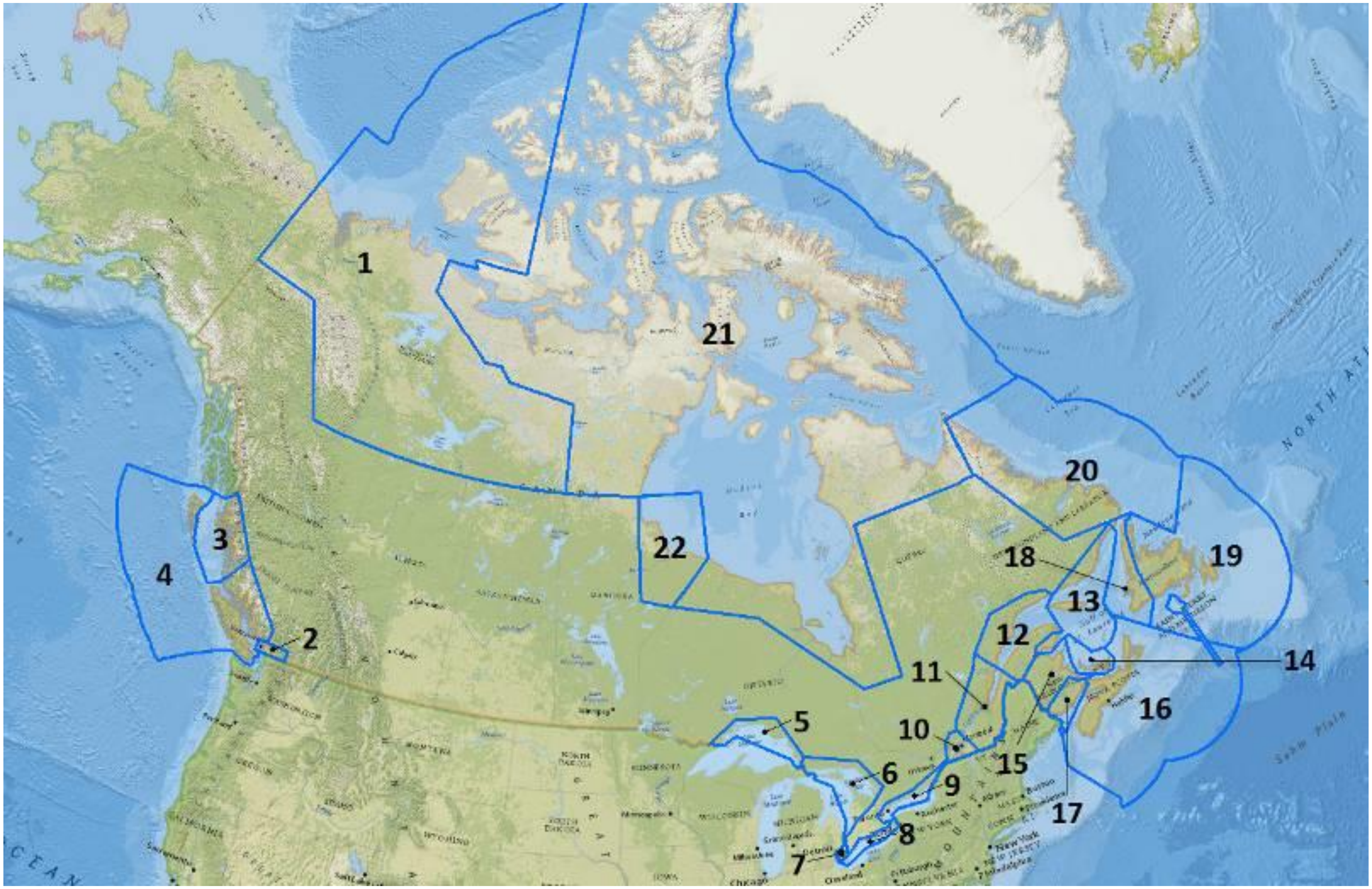
Specific Regions identified in MEIT are identified below and displayed in Figure 1.2.

The regional areas in the model are defined as follows:

1. **Northern Canada:** western boundary is between the Northwest Territories and Nunavut. The eastern boundary is the border between Northwest Territories and the Yukon Territory. Primary port: Tuktoyaktuk, NWT.
2. **Greater Vancouver Regional District/Lower Fraser Valley:** This region encompasses the area within the jurisdiction of Metro Vancouver. Primary Port: Port Metro Vancouver.
3. **Northern Coast of BC:** Boundary on the western side is the eastern side of Haida Gwaii (formerly the Queen Charlotte Islands) extending north to the international boundary and south to the northern tip of Vancouver Island. Primary Port: Prince Rupert.
4. **West Coast:** Entire West Coast following the 200 nautical mile limit, but excludes regions 2 and 3. Primary Port: Victoria.
5. **Lake Superior:** Includes the entire lake with the eastern boundary being the western side of Sault Ste. Marie. Sault Ste. Marie is not in this region. Primary Port: Thunder Bay.
6. **Lake Huron/Georgian Bay:** Starting at the western side of Sault Ste. Marie this region includes all of Lake Huron and Georgian Bay and extends to the northern end of Sarnia. Sarnia is not included in this region. The eastern side of this region is the Straits of Mackinac separating Mackinaw City and St. Ignace. Primary Port: Sault Ste. Marie.
7. **Lake St. Clair:** Region starts at the northern side of Sarnia and stretches to the southern side of Windsor. Both Sarnia and Windsor are included in this region. Primary Port: Sarnia.
8. **Lake Erie:** Region starts at the southern side of Windsor and includes Lake Erie and the Welland Canal. The eastern boundary is the point where the Welland Canal enters into Lake Ontario. Primary Port: Nanticoke.
9. **Lake Ontario:** Region includes Lake Ontario from the start of the Welland Canal to the Quebec border. Primary Port: Hamilton.
10. **St. Lawrence Seaway:** Region includes the area from the Quebec border to Contrecoeur, Quebec. This area includes the entire port of Montreal. Primary Port: Montreal.
11. **St. Lawrence River:** Region includes the area from Contrecoeur to Les Escoumins.
12. **Mouth of St. Lawrence River:** Regionextends from Les Escoumins/Trois-Pistoles to the western tip of Anticosti Island. Eastern border is formed by extending a line from Havre-St. Pierre to the eastern tip of Anticosti Island (Port Menier) and then down to the Cape of Gaspe. Primary Port: Sept Iles.

13. **Gulf of St. Lawrence (Quebec Region):** Western boundary of this region is the line between Havre-St. Pierre/Eastern tip of Anticosti/Gaspe. Northern/Eastern boundary is the Quebec/Newfoundland border. Southern boundary is the Quebec border running from Dalhousie (NB) to the Madeleine Islands. Primary Port: Havre St. Pierre.
14. **PEI:** Boundary is the provincial waters around PEI. Primary Port: Charlottetown.
15. **Gulf of St. Lawrence (New Brunswick) Region:** Northern boundary extends from Dalhousie to the point where provincial boundary meets the provincial boundary of PEI and Quebec. South-eastern boundary is the provincial boundary between PEI and NB. Primary Port: Dalhousie.
16. **Nova Scotia (North and Eastern side) Region:** Northwestern boundary extends to the provincial boundary between PEI/NB/Nova Scotia, around the tip of Cape Breton Island. The eastern boundary is the 200 nautical mile limit. The southern limit is the international border and the western limit will be the provincial boundary extending out of the Bay of Fundy to the international boundary. Primary Port: Halifax
17. **Bay of Fundy (New Brunswick) Region:** This region includes the western portion of the Bay of Fundy from the provincial border to the international boundary. Primary Port: Saint John.
18. **Western Newfoundland Region:** The western boundary for this region is the provincial border between Newfoundland and Quebec. The Northern boundary is the line running between Red Bay and the tip of Newfoundland. The southern boundary is the line running over the northern tip of Cape Breton Island and the eastern boundary is the line running from Burgeo (NF) to the Nova Scotia Border. Primary Port: Corner Brook.
19. **East Shore of Newfoundland Region:** This region is bounded in the south west by the line from Burgeo (NF) to the Nova Scotia Border, in the south by the Nova Scotia Provincial Boundary, in the east by the 200 nautical mile border and in the north west by the line extending from Fogo to the 200 mile limit. Primary Port St. John’s.
20. **North Shore of Newfoundland/Labrador Region:** This region is bounded in the north by the line running northeast from the Labrador/Quebec border to the 200 nautical mile limit, and south by the line running northeast from Fogo to the 200 mile limit. The eastern boundary is the 200 mile limit. Primary Port: Happy Valley Goose Bay.
21. **Iqaluit Region:** The southern boundary is the line connecting the Labrador/ Quebec border with Nuuk, Greenland. The eastern border is the border between NWT and Nunavut. Primary Port: Iqaluit.
22. **Hudson Bay, Manitoba Region:** The northern boundary is the border between Manitoba and Nunavut extending eastwards. The western boundary is the Ontario/Manitoba border extended northward. Primary port: Churchill, MN.

Figure 1-2: MEIT Regions for the 2010 National Marine Inventory



1.2 Project Stakeholders

The shipping industry has had a much greater role in marine EI development since 2005, beginning with the 2005/2006 B.C. Chamber of Shipping (BC CoS) inventory for the west coast that included an extensive voluntary survey program involving ships that visited the B.C. ports. Similarly, an east coast vessel survey program was conducted for Transport Canada in 2007. At a meeting of the Canadian Marine Advisory Council in November 2009, interested members were asked to sit on a project advisory committee (PAC) for the 2010 national marine inventory. Approximately 30 people volunteered, consisting of representatives from both foreign and domestic shipping associations as well as several representatives from Canadian ports, provincial and regional governments and other governmental agencies. The PAC worked with EC to shape the statement of work for the project and additionally provided access to supporting data.

1.3

2. PREVIOUS CANADIAN STUDIES OF MARINE EMISSIONS

The history of marine emission models in Canada is relatively young. Unlike other mobile based emissions sources, much of the shipping sector is international in origin. As such, there have been a limited number of emissions testing programs suitable for model development. Before approximately 1999, marine EIs were largely 'top down' efforts based on estimated fuel sales. Emission estimates were developed from the amount of fuel estimated to have been consumed in Canadian waters. The uncertainty in fuel data compounded the difficulty in developing accurate inventories. Since 1999, a 'bottom up' approach has been favoured, utilizing energy-based emission rates and ship voyage data. Several significant marine vessel emissions testing or quantification studies can be identified over the last decade or so that have been referenced in Canadian model development, including:

- Lloyd's Register of Shipping, 1999: Marine Exhaust Emissions Quantification Study – Mediterranean Sea;
- US EPA, 2000: Analysis of Commercial Marine Vessels Emissions and Fuel Consumption Data (prepared by Sierra Research and Energy and Environmental Analysis, Inc);
- Entec UK Ltd., 2002: Quantification of Emissions from Ships Associated with Ship Movements Between Ports in the European Community;
- Swedish Methodology for Environmental Data (SMED), 2004: Methodology for Calculating Emissions from Ships; and
- California Air Resources Board (CARB), 2007: A Critical Review of Ocean-Going Vessel Particulate Emission Factors.

2.1 Background: Canadian Marine Emissions Models

2.1.1 The Marine Emissions Inventory Tool (MEIT)

The MEIT originated in 2005, leveraging the current understanding of ship exhaust emission rates and an activity-based structure following international best practices. The developmental history of MEIT is shown in Table 1.1.

Table 2-1: MEIT History

Model Versions	Model Features
Version 1.0, September 2005 (Levelton Consultants Ltd.)	Framework of model developed; MS Access database platform; Lloyd's movement data used to elaborate vessel activities; and Entec 2002 energy based emission factors employed.
Version 1.2, March 2006 (Levelton Consultants Ltd.)	Vessel movement data structure modified to accept Canadian INNAV data; Ship profiles established based on California studies; and Inventory completed for Eastern Canada / Great Lakes.
Version 2.1, March 2007 (SENES Consultants Ltd.)	New ship profiles developed based on eastern Canadian survey data; Recalculation of inventory for Eastern Canada / Great Lakes.
Version 2.2, March 2008 (SENES Consultants Ltd.)	User inputs for fuel sulphur; Fuel consumption calculations; Reduced speed regions facilitated; Characterization of ship boilers; Emission factor equations for PM*.
Version 2.5, June 2008 (ClearSky Engineering, Levelton Consultants Ltd.)	Full GHG characterization; Vessel routing for West Coast of Canada; Engine characterization by EPA categories.
Version 3.0, December 2008 (ClearSky Engineering)	SQL Server platform; Multi-user, network capabilities.
Version 3.5, March 2010 (ClearSky Engineering)	Fleet turnover assumptions for forecasts; Fuel based emission rates to complement activity based rates; Revised cruise ship method (based on BC CoS method, 2006)**; Ammonia (NH3) added to contaminants; Anchoring mode added.

Notes: *PM = suspended particulate matter
** BC CoS = BC Chamber of Shipping

All versions of MEIT noted in Table 1-1 rely on an Origin – Destination (OD) approach whereby vessel underway activity is simulated by identifying distances attributable to unique OD pairs. By estimating the distance of a voyage and assuming a characteristic cruising speed, an estimated time of travel can be determined. This approach, consistent with similar studies in the U.S. and other regions, was used for the previous marine emissions inventories developed for eastern Canada and the Great Lakes.

2.1.2 Other Canadian Marine Models

A unique marine emissions model was developed in 2006 by the B.C. Chamber of Shipping (BC CoS). This model was constructed around the CG VTOSS data, which contains voyage position/time data points approximately every five minutes. Contrary to MEIT and an OD approach, each voyage point was assessed with its prior point to evaluate the ship speed. The ship speed was used to calculate the expected engine load and emissions were tabulated each five minute interval. This model, requiring significant development time and effort, showcased that additional information could be extracted from the CG data records to illuminate ship activities such as anchoring and bunkering.

In addition to the MEIT developmental work noted in Table 1.1, MEIT V2.2 was modified to support development of a Canadian Arctic Marine Inventory (Arctic Model) in 2008[1]. This model applied a similar (but simplified) method to the BC CoS model whereby underway transit time is determined directly from the CG data points and not from route characteristics. Some of the developments in this model, notably its fleet turnover scheme, provided the rationale for some of the MEIT V3.5 updates. Fleet turnover assumptions are used to develop inventory forecasts that include the expected effects of newer ships that (for some pollutants) have lower emission rates. The Arctic Model and analysis showed that, in some cases, vessel movements cannot be properly characterized with an OD approach. In Canada's north, a ship voyage (e.g., Merchant General ship) may originate from one community, include a number of community stops to deliver or pickup supplies and return to the same community of origin. The methodological approach used in the BC CoS Model and the Arctic Model was further investigated for the MEIT update to V4.0.

2.1.3 General Calculation Method

A commonality in most if not all of the Canadian marine emissions studies since 2000 is an activity-based calculation method that is widely accepted as current best practice for marine EIs. The calculation method can be expressed with the following equation[2]:

$$E = ME * LF * T * EF_{act} + AE * LF * T * EF_{act} + BO * T * EF_{fuel} \quad (1)$$

Each of the variables in equation (1) is identified in Table 2-2.

1 SENES Consultants Ltd., 2008. Canadian Arctic Marine Assessment, 2002 – 2050. Completed for Transport Canada.
2 The inclusion of boilers did not occur until the 2005/2006 BC Inventory completed by the CoS.

Table 2-2: Ship Emission Parameters

Parameter	Description
E	Emissions
ME	Main Engine capacity (maximum continuous rating or MCR) in kW
AE	Auxiliary Engine capacity in kW
LF	Load Factor (on engines, fraction from 0 to 1)
EFact	Emission Factor – activity based factors in g/kWh
EFfuel	Emission Factor – fuel based factors in kg/tonne fuel
BO	Boiler fuel consumption rate in tonnes/hr
T	Time (hours)

Emissions are a result of main engine(s), auxiliary engine(s) and boiler use over the duration of a voyage. EI accuracy depends on how well time measures can be extracted from the movement data and how well the engine parameters are characterized. Load factors on the engines differ by mode of activity and therefore application of equation (1) changes for the different modes of ship activity that can be resolved in the movement data used to develop a marine EI. Underway, manoeuvring and berthing are commonly characterized in marine EIs. Higher resolution inventories additionally account for slow speed underway and anchoring.

Key considerations for marine EIs include the set of emission factors (EFs) used to represent the vessels and the set of assumptions used to characterize engine use. Engine use assumptions are commonly referred to as ‘ship profiles’ that differ by the type and class of vessel.

2.2 Previous Emission Inventory Estimates

Marine exhaust emissions are dominated by the main engine emissions. However, while berthing the main engines are not operating and therefore auxiliary engines and boilers are the primary sources. Auxiliary engine (AE) and boiler activities are set based on ship class ‘profiles’ that have been developed through previous shipper survey efforts in Canada. Main engine (ME) activities relate to ship speed and therefore a marine emissions inventory must include estimates or assumptions regarding ship speed and the corresponding ME load.

All recent examples of Canadian marine emission inventories use the Propeller Law as a basis to estimate ME loads. The Propeller Law states that the total shaft power of a ship is directly related to the cube of the ship speed. This can be expressed as follows:

$$P = K\left(\frac{V}{V_{max}}\right)^3 \qquad (2)$$

Where:

P = Shaft Power, K = a constant, V = speed at any time, V_{max} = maximum cruise speed

This relation is not always constant over the full range of speed for a vessel, but the equation is appropriate for most applications[3].

The Propeller Law may be applied in a static sense, by assuming ships travel a set speed at all times, thereby assuming one engine load for all underway (or manoeuvring) activities. Conversely, the Propeller Law may be applied in a dynamic sense, by estimating ship speed on a voyage by voyage basis and setting the ME load accordingly. Both approaches have been previously used in Canada.

2.2.1 Eastern Canada and the Great Lakes

The MEIT was used to develop an OD based marine EI for eastern Canada in 2005, for the 2002 calendar year. This EI was completed before any significant shipper survey work had been completed in Canada and therefore ship profile assumptions were applied in the inventory based on studies completed in the U.S. (notably, for the port of LA/Long Beach[4]). INNAV data was used to establish the number of OGV voyages in the region, representing ships of 400 gross tonnes (GT) or greater (smaller commercial vessels were not represented, with the exception of ferries). Voyage distances were determined based on measurements on navigational charts along known shipping routes. Average cruise speeds were determined based on marine engineering judgment.

The vessel cruise speeds and associated loads noted in Table 2-3 were developed during the 2002 eastern Canadian marine inventory, based on experience from marine engineers.

Table 2-3: 2002 Eastern Canada / Great Lakes Marine Inventory Vessel Assumptions (Example)

Ship Class	Cruise Speed (knots)	ME Load Factor (% of MCR)
Ocean Tug	10.2	0.75
Merchant Auto	19.8	0.80
Merchant Bulk	13.6	0.75
Merchant Container	18.9	0.80
Merchant General	13.3	0.80
Merchant Ro/Ro	16.5	0.80
Merchant Passenger	20.0	0.55
Merchant Chemical	13.6	0.75

3 Molland, A. F., 2008. The Maritime Engineering Reference Book: A Guide to Ship Design, Construction and Operation.

4 Starcrest, 2005. Port of Los Angeles Baseline Air Emissions Inventory – 2001. Prepared for the Port of Los Angeles.

Merchant Ore/Bulk	11.8	0.75
Merchant Liquefied Gas	13.6	0.75
Merchant Super Tanker	13.8	0.75

As noted in Table 2-3, Merchant Passenger ships were characterized with a lower ME load (0.55) with the expectation that cruise ships tend not to use their full engine capacity when cruising.

As first acknowledged in MEIT V2.2, reduced speed zones and associated ME loads are necessary for those regions of Canada where ships do not travel at full underway speeds. Eastern Canada is allocated to a number of regions as shown in Figure 1.2. Several of these regions were characterized with lower average cruise speeds and ME loads with some variation by month of year to account for ice hazards. Additionally, a voluntary speed reduction zone was established in 2000 on the St. Lawrence River between Montreal and Sorel to reduce shoreline erosion caused by ship wake. The compliance rate has been favourable to the recommended speed reduction to 10 knots for ships transiting upriver and 14 knots for downriver travel. The speed limits shown in Table 2-4, which apply to both upriver and downriver movements, were applied to each vessel to re-determine the underway engine loads by region; faster vessels were associated with lower engine loads (these ME loads are not shown here).

Table 2-4: Speed Restriction (knots) in St. Lawrence Regions

RegionID	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec
8	11	11	11	11	11	11	11	11	11	11	11	11
9	11	11	11	11	11	11	11	11	11	11	11	11
10	9	9	9	9	9	9	9	9	9	9	9	9
11	11	11	11	13	13	13	13	13	13	13	13	13
12	12	12	12	14	14	14	14	14	14	14	14	14

Table 2-5 provides a summary of the 2002 inventory results, identifying the significant vessel classes in terms of activity (hours in berthing and underway modes) and CO_2 emissions.

Table 2-5: 2002 Marine Inventory for Eastern Canada and the Great Lakes*

Vessel Class	Total Trips	Total Engine Hours	CO_2 Emissions (tonnes)			
			Berthing Emissions	Manoeuvring Emissions	Underway Emissions	Total Emissions
Ocean Tug	920	57,547	4,965	292	14,312	19,569
Merchant Auto	129	2,909	218	112	11,906	12,236
Merchant Bulk	12,715	671,629	64,343	5,003	926,872	996,218

Merchant Container	2,867	139,334	26,998	4,051	672,561	703,610

Table 2-5 (Cont'd): 2002 Marine Inventory for Eastern Canada and the Great Lakes*

Vessel Class	Total Trips	Total Engine Hours	CO_2 Emissions (tonnes)			
			Berthing Emissions	Manoeuvring Emissions	Underway Emissions	Total Emissions
Merchant General	2,672	160,142	15,040	886	203,265	219,191
Merchant Ro/Ro	698	39,740	24,782	844	78,918	104,545
Merchant Passenger	2,543	105,563	73,126	3,054	128,929	205,109
Merchant Ore/Bulk	119	8,703	6,646	106	14,899	21,652
Merchant Chemical	867	50,297	10,126	453	60,244	70,823
Tanker	6,073	319,349	117,286	9,229	759,832	886,347
TOTAL	**29,603**	**1,555,210**	**343,529**	**24,031**	**2,871,740**	**3,239,299**

* Vessel classes as per the inventory report

The largest contributions to the inventory were found to be from Merchant Bulk, Merchant Container and Merchant Tanker vessel classes. For the EI totals, 88.7% relates to underway activity, 10.6% to berthing and the remainder (0.7%) to manoeuvring.

2.2.2 Western Canada

Following a 'best practices' review of marine EIs published in 2005[5], the BC Chamber of Shipping with support from EC, developed an activity-based, high resolution OGV marine EI for the West Coast (British Columbia)[6]. This inventory is based on the 3 – 5 minute CG VTOSS data points, which provide the basis for high resolution route development, including times spent awaiting a pilot, times at anchor and times at berth. Compared to the 2002 inventory for eastern Canada, it can be viewed as a 'time-in-mode' activity approach.

5 SENES Consultants Ltd., 2004. Review of Methods Used in Calculating Marine Vessel Emission Inventories. Prepared for Environment Canada, September.

6 BC Chamber of Shipping, 2007. 2005 – 2006 BC Ocean Going Vessel Emissions Inventory. Prepared by the BC Chamber of Shipping, January.

The inventory was the first of its kind internationally, providing insight into vessel activities and emissions that were previously 'hidden in the data'. Rather than the use of assumptions for vessel speed, speeds were established each interval based on the spatial locations of the previous and current call-in points. A comprehensive ship survey effort was used to support the inventory, with approximately 70% of all vessels that visited BC ports during the year providing engine and boiler use information. This survey effort is by far the most representative program of its kind that has ever been supported in Canada.

Implied vessel speed was used to estimate the expected engine load on propulsion engines, following application of the Propeller Law. Use of the equation in theory allows application of a wide range of propulsion engine loads within a marine EI. An example set of calculated engine loads is shown in Table 2-6 for a container vessel with 40,000 kW engine (maximum continuous rating – MCR) and maximum cruise speed of 25 knots.

Table 2-6: Example Calculation of Engine Loads for a Fictitious Container Vessel (40 MW MCR)

Vessel Speed (knots)	Estimated Engine Power Used (kW)	Estimated Engine Load (unitless)
25	40,000	1.00
24	35,400	0.88
23	31,150	0.78
21	23,700	0.59
20	20,500	0.51
18	15,000	0.37
16	10,500	0.26
14	7,000	0.18
10	2,600	0.07
7	880	0.02

Table 2-6 provides a justification for widespread use of 0.80 for underway engine loads in the past, acknowledging that most vessels tend to cruise near their maximum speed when possible. Full use of the Propeller Law, as was initially attempted in the BC CoS inventory, can lead to a practical obstacle. At times a ship may be accelerating or may be influenced by tidal forces and at these times Propeller Law estimates of engine load are not valid[7]. Additionally, there may be small errors in CG positional data that could lead to errors in estimated vessel speed.

For these reasons, the BC CoS methodology binned the estimated engine loads according to relatively simple criteria that can be expressed as follows:

[7] Other reasons noted in the CoS report include winds, cargo load and engine make/model.

- 0.80 when the estimated speed is approximately 65% of the maximum speed or higher;
- 0.40 when the estimated speed is less than 65% but more than 45% of the maximum speed; and
- 0.03 when the estimated speed is less than 45% of the maximum speed.

These three bins relate to full underway, slow cruise and manoeuvre. Use of just two underway cruise loads was based on information provided by some of the ship captains that visited BC ports[8]; ships tend to use their propulsion engines under high load (e.g., 0.80) unless limited by formal speed restrictions.

A summary of the BC CoS EI is provided in Table 2-7.

Table 2-7: 2005/2006 BC Ocean-Going Vessel Emissions Inventory*

Vessel Class	Total Engine Hours	CO2 Emissions (tonnes)
Bulk Vessel	195,000	272,407
Containership	49,536	341,964
Cruise Ship	26,952	414,983
General Cargo	86,232	149,494
Motor Vehicle Carrier	12,432	35,223
Tanker	28,056	51,290
Misc	17,520	12,722
Inventory Total	**415,728**	**1,278,084**

*Vessel classes as per the BC CoS inventory report.

The inventory total for BC during the year (in this case, April 1, 2005 to March 31, 2006) for CO_2 is 1,278,084 tonnes. Of this amount, 77.0% relates to underway activity, 16.5% to berthing, 4.4% to manoeuvring and 2.1% to anchoring.

2.2.3 Arctic

A marine activity and emissions inventory was developed for Canada's Arctic in 2008, for activities during the calendar years 2002 – 2007. Forecasts were included for 2020 and 2050. This inventory was based on CG INNAV data, as was the 2002 eastern Canada inventory, but utilized a modified time-in-mode approach similar to the 2005/2006 BC CoS inventory. Unlike eastern and western Canada, most of the marine traffic in the Arctic is domestic in origin.

[8] 'Half ahead' was typically related to an engine load of approximately 40%. The low engine load applied for manoeuvring speeds was verified through a vessel 'ride-along' program.

The methods employed for the inventory were based on the time stamps of the vessel calls to the CG INNAV system[9]. At the time, vessels active in Canadian waters were expected to call in at least every 24 hours and when a change in mode was experienced (e.g., anchor and berth). Given the relatively coarse resolution in the data, the following assumptions were applied for propulsion engine loads:

- Engine loads of 0.80 for all activity flagged as 'underway' in the CG data records, with some exceptions;
- Engine loads of 0.0 for all activity flagged as 'anchor' and 'berthing' in the CG data records; and
- No characterization of manoeuvring.

Investigation was conducted to establish reasonable underway engine loads for those vessel classes that were thought to be different than the general cargo carrying vessels in terms of engine use characteristics. For example, an average underway load of 0.25 for CG ice breaker ships was used, based on fuel consumption data made available to the study authors.

Ship class profiles from MEIT and the BC CoS were further developed based on Lloyd's Seaweb data. This allowed additional engine criteria such as engine revolutions per minute (rpm) to be expressed. A summary of the Arctic EI is presented in Table 2-8.

Table 2-8: Arctic Marine Inventory for 2007

Ship Class	CO2 Emissions (tonnes)
Coast Guard	41,674
Fishing	19,799
Tugboat	21,999
Merchant Bulk	17,732
Merchant General	24,490
Merchant Passenger	15,812
Research	1,416
Special Purpose	24,136
Tanker	25,339
ARCTIC TOTAL	**192,397**

[9] The data actually originates from the CG NORDREG system, which is considered to be included within the INNAV system. At the time of the work, NORDREG participation was voluntary for ships in the Arctic, although ship participation was considered by the CG to be nearly 100% for OGVs.

Table 2-8 shows that although Canada's Arctic is vast, the level of shipping activity within this area is far lower than other areas of Canada. Additionally, Canadian Coast Guard movements are a very significant portion of the total activity levels, which is not the case for west and east coasts of Canada.

3. 2010 ESTIMATION METHODS

As with recent Canadian marine emissions inventories, the 2010 national inventory is an activity based inventory (ABI). An ABI links between activity based emission factors (e.g., grams emission per kWh of energy used) and activity measures that provide estimates of engine/boiler use.

The 2010 inventory benefits from two high quality datasets:

- CG movement data (INNAV, VTOSS[10]) representative of all commercial marine vessels over 200 gross tonnes active in Canadian waters; and
- Lloyds Seaweb data for vessel characteristics.

These two datasets provide identification of most of the vessels in Canadian waters, including engine capacities as well as additional characteristics such as cylinder size, fuel tanks and cargo capacities. While Lloyds Seaweb includes virtually all of the large commercial vessels active in Canada in 2010 and approximately 250 different fields per vessel, many of its fields of interest for this project are unpopulated for vessels. For this reason, the ships represented in the 2010 inventory are individually characterized to the degree possible, with default parameterizations by ship class used to fill out the activity profiles, as required.

Additional survey information was provided for the project from project stakeholders. The data made available and accessed as part of this project allowed an update of the MEIT to V4.0. MEIT V4.0 is highlighted in this chapter. Further information on MEIT and the 2010 inventory methods is provided in Appendix A.

3.1 CG Data Structure

Every conceptual model must adhere to the limitations of the data sets employed. There are strict rules employed within the CG vessel traffic management systems (INNAV, VTOSS) and by the CG staff receiving information from vessels operating within, or about to enter, Canadian territorial waters. Based on discussions with CG staff[11], the following limitations of the CG data were noted:

- Tug boats ≤20 m in length overall (LOA) do not report their movements.
- Fishing vessels <24 m in LOA do not report their movements.

[10] VTOSS data for 2010, as acquired from the CG for the project, is incomplete for the 2010 calendar year.

[11] A tour of the CG Marine Communications Traffic Services (MCTS) center in Vancouver was conducted by Martin Jenner (Officer in Charge) on September 15th 2011 and follow up questions were addressed by Ian Wade, Regional Program Specialist on December 2 2011.

- Short movements (e.g., harbour tug) tend not to be recorded in the CG data (even when the tug LOA may be ≥20 m) due to the considerable time required on the part of the VTS officer and the short duration of the movement.
- Vessels about to enter Canadian waters are required to provide a 24 hour advance notice of arrival to the CG. These notices may be used to establish a data point at the extent of Canada's territorial waters.

As further evaluated in Chapter 4, there are exceptions to the points noted above. In particular, vessels that are not required to call in to the CG do so on occasion. For example, there are records for fishing vessels less than 24 m LOA in the INNAV and VTOSS records.

Both vessel tracking systems (INNAV, VTOSS) are hierarchical. The best or preferred source of data is radar, followed by Automatic Identification System (AIS) reports and dead reckoning (DR) reports. Radar installations exist in some but not all coastal areas and where they do exist the radar data only become available as ships near land (approximately 50 nautical miles). There are many AIS receivers on both coasts and the effective reception range extends out to approximately 100 nautical miles in ideal situations. However, there were problems noted with AIS processing in 2010 and therefore the successful use of AIS was low in some areas (example, Prince Rupert). Use of AIS in the CG tracking systems is still relatively new and becoming more effective each year.

There are differences in the reporting of barge movements in INNAV and VTOSS. In the west, VTOSS represents a barge movement as a tug boat movement (annotated to acknowledge a barge is being towed). In the east, INNAV represents a barge movement as two separate movements – one for the barge and one for the tug boat. As identified by the CG, when a tug boat less than 20m LOA is pulling a barge it is required to call in to the CG since the effective length is greater than 20m. However, if the tug leaves the barge at a destination, it may drop below 20m LOA and therefore not report during its return trip. This issue may be of greater importance in the west (notably, in southern B.C.) since there are a large number of barge movements each year. It should be expected that the VTOSS and INNAV data do not fully represent all tug boat movements.

Importantly, the INNAV system in the east is internally consistent. When a vessel is identified by the CG it is tracked with the same unique identifier for its entire journey. In contrast, there are six MCTS zones in the west and a ship is 'handed off' from one zone to another as its voyage progresses. Only the ship name is held common upon handoff and therefore the same vessel can be identified differently if a mis-spelling or mis-identification occurs. Given the internal consistency of the INNAV system, data corrections occur as better data become available (e.g., when a ship nears the coast and either AIS or radar is received). No such corrections occur in VTOSS and therefore erroneous data remain in the data set. Pacific Region implemented INNAV in January 2011 so vessel movement data is now consistent across Canada.

3.2 Ship Classes

Previous marine EIs in eastern Canada have largely been based on the CG INNAV vessel classes, which are similar to those used in VTOSS. Table 3-1 provides a listing of the INNAV vessel classes, as well as the general vessel classes used to organize the 2010 inventory. Some of the specific vessel classes used by the CG are lumped together since they are treated identically in the model (e.g., Special Purpose classes, some of which had zero, 1 or 2 active vessels in 2010).

The general classes were chosen by SLE to organize the reporting as well as for development of ship class profiles.. For example, MB, MC and MW are included within the INNAV 'Merchant' class but have relatively high levels of activity, and therefore were included as separate categories in the general vessel classes for reporting purposes. The MW class was populated by SLE to consist of large diesel-electric cruise ships only, since the original INNAV MP class contains both smaller passenger ships as well as the cruise ships. The engine and emissions profile for these two types of ships are greatly different.

Table 3-1: INNAV Commercial Ship Classes and Symbols for the 2010 EI

General Vessel Class	INNAV Class	INNAV Class Name
Barge	BW	Barge Self-Propelled
	BD, BH, BO, BP, BT, BG	All other types (towed barges)
Coast Guard	CI	Coast Guard Icebreaker
	CF, CL, CH, CP, CR, CS, CT	All other types
DFO	DS	DFO Fishing Surveillance Vessel
Fishing	FF	Factory Ship
	FG	Other Fishing VSL (Open Boat)
	FL	Longliner
	FV	Fishing Vessel
	FC	Crab Boat
	FD	Dragger (Scallop, Clam, etc.)
	FO	Groundfish Boat (Open Boat)
	FP	Fishery Patrol
	FT	Trawler

Table 3-1 (Cont'd): INNAV Commercial Ship Classes and Symbols

General Vessel Class	INNAV Class	INNAV Class Name
Merchant Bulk	MB	Merchant Bulk
Merchant Container	MC	Merchant Container
Merchant Cruise	MW	Cruise
Merchant Other	MA	Merchant Auto
	MG	Merchant General
	MQ	Merchant Rail/Trailer Ferry
	MH	Merchant RO/RO
	ML	Merchant Lash
	MM	Merchant Dry
	MO	Merchant Ore
	MR	Merchant Reefer
	MS	Merchant Coastal
Merchant Passenger	MF	Merchant Ferry
	MP	Merchant Passenger
Special Purpose	SB, SF, SN, SP, SV, SY, SC, SD, SR, SS, ST	Many types
Tanker	TG	Merchant Gasoline
	TL	Merchant Chemical
	TQ	Merchant Liquefied Gas
	TV	Merchant VLCC
	TC	Merchant Crude
	TO	Merchant Ore/Bulk/Oil
	TS	Merchant Super Tanker
	TT	Merchant (Tanker)
	TU	Merchant ULCC
Tug Boat	HO	Tug Ocean
	HS	Tug Supply
	HT	Tug General
	HW	Tugs Workboat
	HF	Tug Fire
	HH	Tug Harbour
War	WR	Warship - General
	WS	Warship Surface
	WU	Warship Undersea

3.3 Emission Factors

Equation (1) noted in Chapter 2 requires a set of energy based emission factors for main and auxiliary engines and fuel based emission factors for boilers. Emission factors have largely been identified by Environment Canada through previous Canadian studies and related investigations (exception air toxics). Tables 3-3 and 3-4 provide identification of the base emission factors used in MEIT V4.0, which are consistent with the previous version of MEIT (V3.5).

In comparison to diesel engines installed in land-based equipment, emission factors for commercial marine vessels continue to be drawn from a limited dataset due to the costs and complexities involved with on-board emission testing of these large engines. The original version of MEIT developed in 2005 was populated with emission factors sourced from European studies, primarily Entec 2002 (see Section 1.1). Entec analyzed emissions data from propulsion engines and data from two research programs, Lloyd's Register Engineering Services in 1995 and IVL Swedish Environmental Research Institute in 2002.

The current set of emission factors were reviewed during a project conducted for Transport Canada in 2007[12]. These emission factors were largely sourced from a study prepared for the EPA in 2006[13], referencing the Entec 2002 study and therefore the rates may not fully represent current fleets with newer vessels. The main difference from the original emission factors used in MEIT is a move away from composite emission factors (based on an assumed distribution of engines for vessels) to specific factors appropriate for engine size (EPA category), speed (rpm) and fuel type. Table 3-2 provides a definition for the EPA engine classification scheme.

Table 3-2: EPA Engine Categories

Engine Category	Displacement (litres/cyl)	Typical Use
C1	< 7	Harbour Vessels
C2	7 ≤ X < 30	Auxiliary Engines in OGVs
C3	≥ 30	Main Engines in OGVs

As evaluated for the US EPA in 2000[14] 'low load' adjustment factors should be used for marine engines at reduced load movements such as manoeuvring. This issue was investigated for Transport Canada in 2008[15], supporting use of the same factors. The recommended adjustment rates by air contaminant are shown in Table 3-5 for ME load of 0.1. These values are used to scale up the emission factors regardless of engine and fuel type.

[12] Weir Marine Engineering, 2008. 2007 Marine Emission Inventory and Forecast Study, Final Draft. Prepared for the Transportation Development Centre of Transport Canada, in partnership with SENES Consultants Ltd.

[13] ICF Consulting, 2006. Current Methodologies and Best Practices in Preparing Port Emission Inventories. Prepared for the U.S. EPA Office of Policy, Economics and Innovation, Sector Strategies Program.

[14] Energy and Environmental Analysis Inc., 2000. Analysis of Commercial Marine Vessels Emissions and Fuel Consumption Data. Prepared for the US EPA under contract to Sierra Research. EPA420-R-00-002, February.

[15] Weir, 2008. 2007 Marine Emission Inventory and Forecast Study, Final Draft. Prepared for the Transportation Development Centre of Transport Canada, in partnership with SENES Consultants Ltd.

Table 3-3: Current MEIT Activity Based Emission Factors (g/kWh) by Engine Classification*

Engine	Cat.	Fuel	BSFC	NOx (dom/int)	CO	HC	NH3	CO2	CH4	N2O	CO2e
Main 2-stroke	C3	HFO	195	17/18.1	1.4	0.6	0.021	621	0.006	0.017	627.431
		MDO	185	17	1.1	0.6	0.02	588	0.006	0.017	594.515
Main 4-stroke		HFO	210	13.2/14.0	1.1	0.5	0.023	670	0.004	0.017	676.431
		MDO	210	13.2	1.1	0.5	0.022	670	0.004	0.017	676.515
Auxiliary 4-stroke	C2	HFO	210	13.9/14.7	1.1	0.4	0.001	670	0.004	0.017	676.431
		MDO	210	13.9	1.1	0.4	0.001	670	0.004	0.017	676.515

*Note: HFO – heavy fuel oil, MDO – marine distillate oil
NO_x values are shown for domestic (dom) and international (int) fuel by purchase location. Domestic HFO fuel is lower in sulphur content on average.

Table 3-4: Boiler Emission Factors (kg/tonne fuel)

Fuel	NOx	CO	HC	NH3	CO2	CH4	N2O	CO2e
HFO,MDO	12.3	4.6	0.38	0.006	3188	0.29	0.081	3219

Table 3-5: Low Load (ME load 0.1) Scale Factors for All Emission Factors (unitless)

Fuel	NOx	CO	HC	PM	NH3	CO2	CH4	N2O	CO2e
1.0	1.22	2.00	2.83	1.38	1.0	1.0	1.0	1.0	1.0

The International Maritime Organization (IMO) International Convention on the Prevention of Pollution from Ships, known as MARPOL 73/78 includes Annex VI titled "Regulations for the Prevention of Air Pollution from Ships". MARPOL Annex VI sets limits on NOx and SOx emissions from ship exhausts as shown in Table 3-6. SO_x emissions are limited by fuel standards (maximum sulphur content). For the 2010 inventory, the Tier 1 NO_x standards were applied to every vessel built in 2000 or later (e.g., the NO_x emission rates were used instead of the rates shown in Table 3-3). The low load scaling factors in Table 3-5 were applied to all vessels, regardless of age.

Table 3-6: IMO NO_x and SO_x Limits

Standard	Engine RPM 'n'	NOx Emission LImit (g/kWh)	Fuel Standard (max. sulphur content)	Year	Relevance
Tier 1	n < 130	17.0	n/a	2000	Applies to all vessels constructed during or after this year
	n = 130-2000	$45*n^{-0.2}$			
	n > 2000	9.8			
SO_x /FUEL	n/a	n/a	1.00%	2010	Only applies to ECA areas
Tier 2	n < 130	14.4	n/a	2011	Applies to all vessels constructed during or after this year
	n = 130-2000	$44*n^{-0.23}$			
	n > 2000	7.7			
SO_x /FUEL	n/a	n/a	0.10%	2015	Only applies to ECA areas
Tier 3	n < 130	3.4	n/a	2016	Only applies to vessels operating in ECA areas
	n = 130-2000	$9*n^{-0.2}$			
	n > 2000	1.96			
SO_x /FUEL	n/a	n/a	0.50%	2020	Applies to all areas, pending a 2018 fuel availability review.

The forecast inventories are subject to the IMO limits in Table 3-6, depending on the year of the forecast inventory. As previously noted, an ECA will be established on the east and west coasts of Canada in 2012 and therefore all forecast inventories assume the ECA standards. In addition, the forecasts are subject to Canada's regulations for domestic marine distillate, as noted below.

Environment Canada regulates the sulphur content of marine diesel through its *Sulphur in Diesel Fuel Regulations*[16]. While marine diesel sales to 'Non-large Vessels' is limited to 15 ppm (0.0015%) sulphur by 2014, sales to 'Large Vessels (Marine Diesel)'is limited to 1,000 ppm (0.1%) which is above the current estimated average sulphur content of marine diesel sold in Canada. A fuels study report completed by BMT in 2008 shows that marine diesel is available as 100% distillate (often labeled marine gas oil or

[16] See http://www.ec.gc.ca/energie-energy/default.asp?lang=En&n=7A8F92ED-1

MGO) or a 'heavier distillate that sometimes contains a portion of residual oil' (commonly referred to as marine diesel oil or MDO)[17]. It is expected that, in some regions of Canada, both MGO and MDO are not readily available for purchase and for these situations it is more likely that MGO is available rather than MDO[18]. Heavy Fuel Oil (HFO) is not subject to the fuel regulations noted above. The forecasts assume the following distinction for domestic marine distillate use in 2015 and beyond:

- MDO sulphur content for ocean going vessels will not change (e.g., average sulphur content of 500 ppm)
- MDO sulphur content for the smaller classes of vessel (fishing, ferries, tugboats) will decrease to 15 ppm (e.g., these vessels will consumed MGO exclusively)

3.3.1 SO_x and PM Emissions Equations

Both SO_x and PM emissions are known to vary with fuel sulphur content. As such, MEIT has accounted for SO_x and PM emissions in a dynamic manner since V2.2. Each equation assumes a linear relationship with fuel sulphur content as follows:

SO_x:

Engines: EF (g/kWh) = 4.2(S) (3)

Boilers: EF (kg/tonne) = 20.0(S) (4)

PM:

Engines: (g/kWh) = 0.4653(S) + 0.25 (5)

Boilers: (kg/tonne) = 1.17(S) + 0.41 (6)

where S = sulphur content of fuel in %.

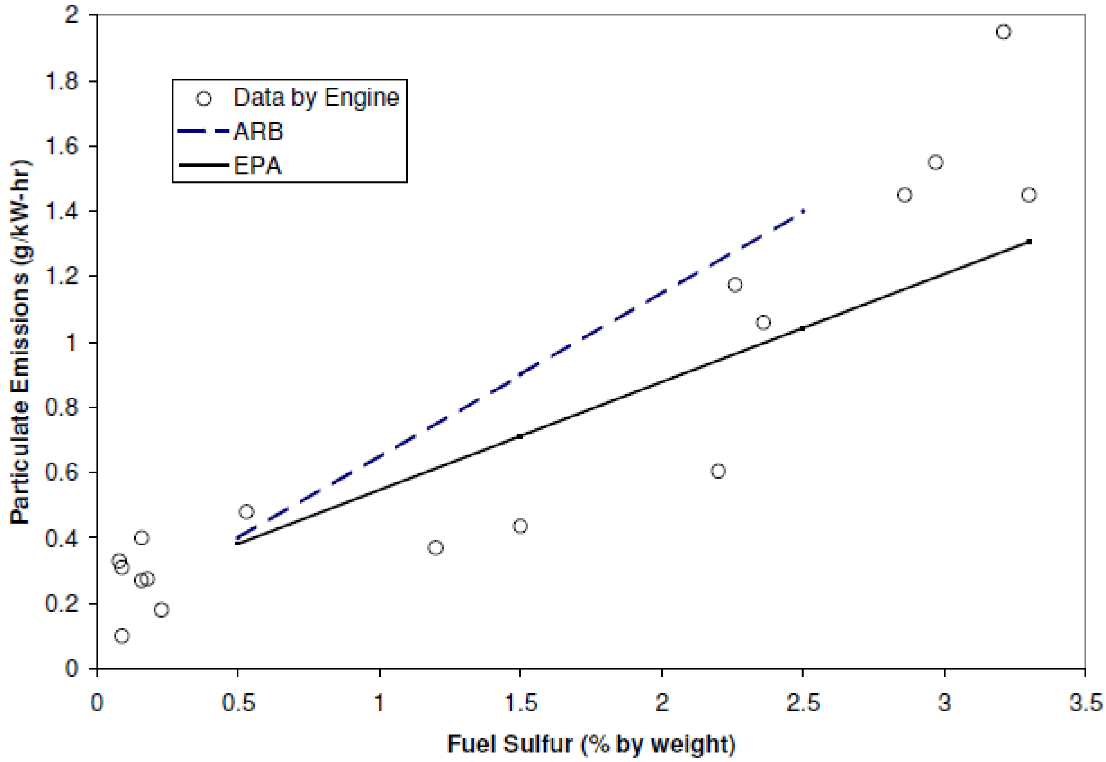
Ratios of 0.96 and 0.92 are applied for PM_{10} to total PM and $PM_{2.5}$ to $PM_{10,}$ respectively. While the SO_x expressions are based on an assumption of total oxidation of the fuel sulphur to SO_2 in the atmosphere, the PM expressions are based on previous PM emissions tests at different sulphur levels. The boiler PM equation originates from the EPA[19] and the engine PM equation is a result of the California Air Resources Board (CARB) analysis of past emissions data as shown in Figure 3.1.

[17] BMT Technologies Ltd., 2008. Update on Availability, Quality and Quantity of Marine Fuels in Canada

[18] 2007 fuel sales data from the BMT Report shows that a greater amount of MGO was sold over MDO for Canada as a whole.

[19] EPA AP-42 Compilation of Emission Factors, Chapter 1. See http://www.epa.gov/ttnchie1/ap42/

Figure 3-1: PM Emission Rates (g/kWh) by Fuel Sulphur Content*



* The CARB analysis ('ARB' in the figure above) is a re-analysis of the data, rejecting several data points that were included in the prior EPA regression analysis. Additional detail can be found in Weir, 2008.

Changes to the emission rates for the forecast inventories are discussed in greater detail in Chapter 8.

3.3.2 Fugitive Emissions

Estimates of fugitive VOC emissions were calculated in the 2010 inventory which required development of an entirely new mechanism in the MEIT model. VOC emissions escape from the tanks of fuel carrying ships during transit and also during loading and unloading activities. It should be noted that landside inventory efforts (e.g., Metro Vancouver's inventory for the LFV) may include loading/unloading VOC emissions but would not include marine transit emissions.

The fugitive emission calculations require an estimate of the type and amount of fuel carried in the ships that visit Canadian ports. Since the CG data does not contain cargo tonnages, estimates were achieved by assuming most of a vessel DWT is comprised of fuel cargo, for the appropriate ship classes. More specifically, the equations used to estimate the fugitive emissions are defined below.

Transit:

$$E\ (mg) = DWT * LF * TF * EF_{transit} \quad (7)$$

Load/Unload:

$$E\ (mg) = DWT * LF * EF_{load} \quad (8)$$

Where:

E = emissions

DWT = deadweight tonnage

LF = load factor (assumed to be 0.9 currently)

TF = transit factor (assumed to be 0.5 currently)

$EF_{transit}$ = transit emission rate

EF_{load} = loading/unloading emission rate

The emission rates for fugitive VOC emissions were taken from the EPA , as defined in Table 3-7[20].

Table 3-7: Fugitive VOC Emission Rates

Vessel Class	Transit Emission Rate (mg/week/litre)	Load/Unload Emission Rate (mg/litre)
Crude Oil Tanker	150	73
Distillate Oil Tanker	0.54	0.55
Gasoline Tanker	320	215
LNG Tanker	0.0	0.0

Currently, the model assumes LNG vapours are captured and used as fuel for the vessel engines. As noted above, the load factor (LF) is less than 1.0 since DWT accounts for the mass of engine fuel as well as crew and supplies on board. The transit factor (TF) assumes that the cargo is carried one way only (e.g., the return leg of a voyage is done under ballast). These factors should be investigated in the future.

3.3.3 Toxic Emissions

Toxic emission estimates were achieved in the inventories by use of speciation profiles. A speciation profile is used to separate VOC and PM emission estimates into their expected constituents. The Speciation profiles used for the national inventory were obtained from the EPA[21] and are shown in Table 3-8.

[20] These rates are published in the US EPA AP-42 Compilation of emission factors, Chapter 5.2

[21] These profiles were taken from the EPA's U.S. National Emissions Inventory for 2008, available from http://www.epa.gov/ttnchie1/net/2008inventory.html

Table 3-8: Air Toxic Speciation Profiles

Air Toxic	Group	Speciation Basis	Speciation Ratio (Cat 1 and 2 engines)	Speciation Ratio (Cat 3 engines)
Dioxin	Dioxins/Furans	PM10	0.000000005	4.37E-10
Ethyl Benzene	HAP	VOC	0.00125	0.00125
Styrene	HAP	VOC	0.00131	0.00131
Acrolein	HAP	VOC	0.00219	0.00219
Toluene	HAP	VOC	0.002	0.002
n-Hexane	HAP	VOC	0.00344	0.00344
Hexachlorobenzene	HAP	PM10	0.00000004	3.5E-09
Propionaldehyde	HAP	VOC	0.00381	0.00381
Xylene	HAP	VOC	0.003	0.003
Formaldehyde	HAP	VOC	0.0935	0.00157
2,2,4-Trimethylpentane	HAP	VOC	0.00025	0.00025
Benzene	HAP	VOC	0.0127	0.0000098
Acetaldehyde	HAP	VOC	0.0464	0.000229
Phosphorous	HAP	PM10	0.00179	0.00179
Chromium (Cr3+)	Metals	PM10	0.000033	0.000127
Chromium (Cr6+)	Metals	PM10	0.000017	0.0000653
Lead	Metals	PM10	0.00015	0.000014
Manganese	Metals	PM10	0.00000128	0.0000573
Mercury	Metals	PM10	0.00000005	0.000000271
Nickel	Metals	PM10	0.001	0.00325
Arsenic	Metals	PM10	0.00003	0.0000874
Beryllium	Metals	PM10	0.000000546	0.000000546
Cadmium	Metals	PM10	0.00000515	0.0000226
Cobalt	Metals	PM10	0.0000594	0.0000594
Selenium	Metals	PM10	5.15E-08	0.00000191
Anthracene	PAH	PM25	0.0000231	0.000000525
Pyrene	PAH	PM25	0.0000244	0.000000553
Benzo(g,h,i)perylene	PAH	PM25	0.00000563	0.000000128
Indeno(1,2,3,c,d)pyrene	PAH	PM10	0.00001	0.000000874
Benzo(b)fluoranthene	PAH	PM10	0.00001	0.000000874
Fluoranthene	PAH	PM25	0.0000138	0.000000312

Table 3-8 (Cont'd): Air Toxic Speciation Profiles

Air Toxic	Group	Speciation Basis	Speciation Ratio (Cat 1 and 2 engines)	Speciation Ratio (Cat 3 engines)
Benzo(k)fluoranthene	PAH	PM10	0.000005	0.000000437
Acenaphthylene	PAH	PM25	0.0000231	0.000000525
Chrysene	PAH	PM25	0.00000438	9.93E-08
Benzo(a)pyrene	PAH	PM10	0.000005	0.000000437
Benz(a)anthracene	PAH	PM25	0.000025	0.000000567
Acenaphthene	PAH	PM25	0.000015	0.00000034
Phenanthrene	PAH	PM25	0.000035	0.000000794
Fluorene	PAH	PM25	0.0000306	0.000000695
Naphthalene	PAH	PM25	0.000876	0.0000199
Polychlorinated Biphenyls	PCBs	PM10	0.0000005	4.37E-08

3.4 Ship Characterization by Vessel Class

Similar to the 2005/2006 B.C. inventory completed by the BC CoS, MEIT V4.0 determines ship speed and Main engine (ME) load for each voyage segment. The applied procedure is identical for each OGV vessel class with the exception of cruise ships. The smaller commercial ship classes (tug boats, ferries, fishing vessels) are characterized in a more simplistic nature, due to lack of consistent data in the CG records (some of the activity for these vessel classes must be simulated based on surrogate data).

A number of specific voyages in 2010 were assessed to determine how well a voyage could be characterized based on its segment attributes. An example voyage is presented in Figure 3.2. In this example, the average speed for an auto carrier (MA) from Halifax to Montreal was just 8 knots, considerably lower than the typical cruise speed expected for an MA vessel. Additionally, significant anchoring time is noted near Halifax as well as near Rimouski. This voyage may be an example of excess scheduling time, with the ship company electing to save fuel by lowering speed.

The example voyage also shows that the vessel route can be established reasonably well, with the exception of segments that are separated by an extended period of time (one segment is shown to cross over land).

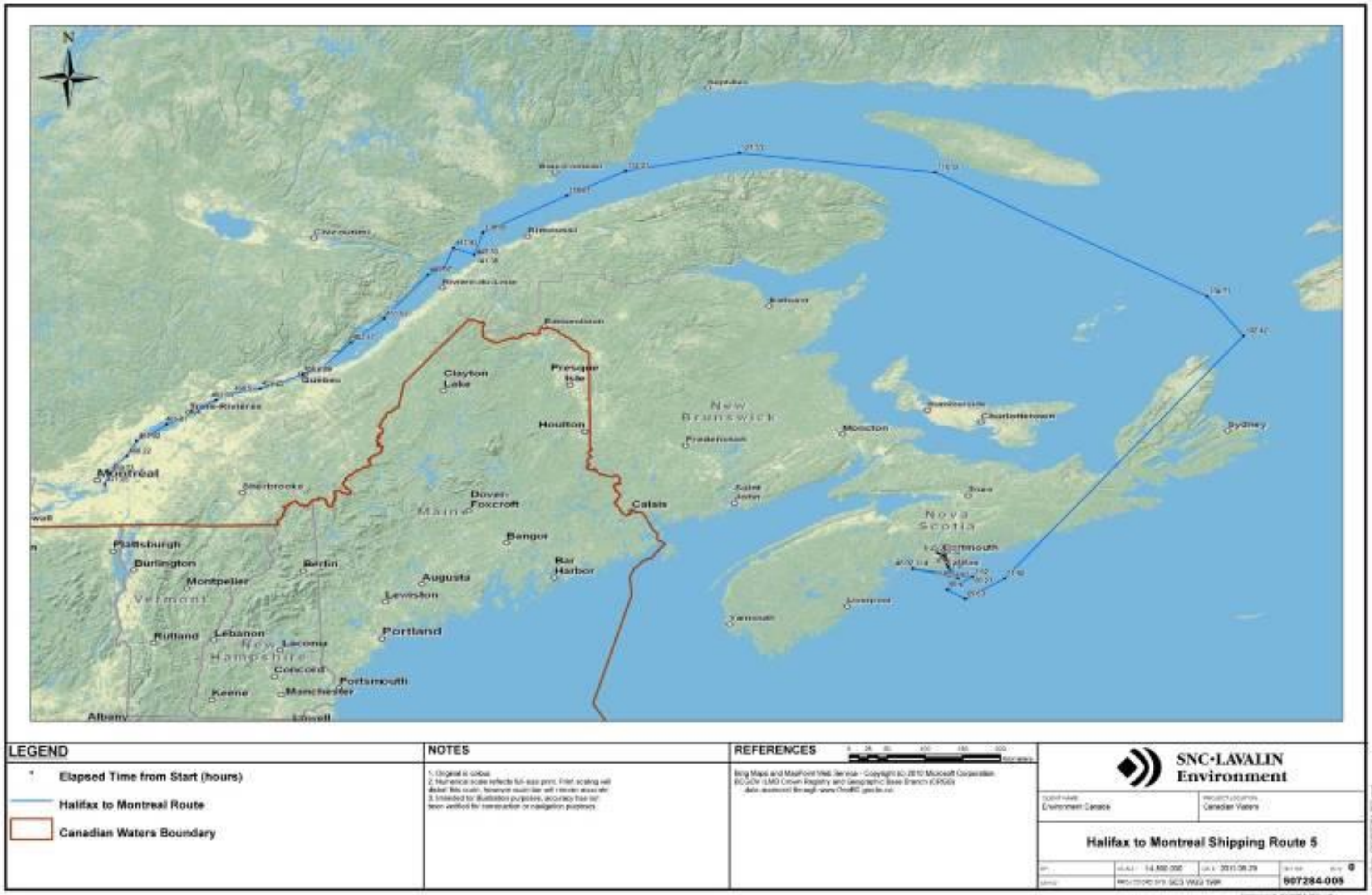
As illustrated in Figure 3-3, ME load can be estimated from the ship speed at any time, assuming that the CG data points are reasonably accurate in space and time. Auxiliary engine (AE) load as well as boiler use is not expected to vary unless the activity mode changes (e.g., from underway activity to berthing). In this case the Merchant Bulk ship travels slowly through the Welland Canal and MEIT characterizes its

ME load at one tenth of the maximum rating of the ship's engines until it enters Lake Ontario and speeds up (with a final ME load of 0.8).

Generalized assumptions are appropriate for AEs and boilers, since their use does not significantly change with vessel speed, other than for the short periods required for manoeuvring to and from berth. AE and boiler assumptions are implemented within ship profiles, which differ by ship class and (to some degree) by region of Canada. Ship class profiles are identified for eastern Canada, the Arctic and the West Coast in Appendix A.

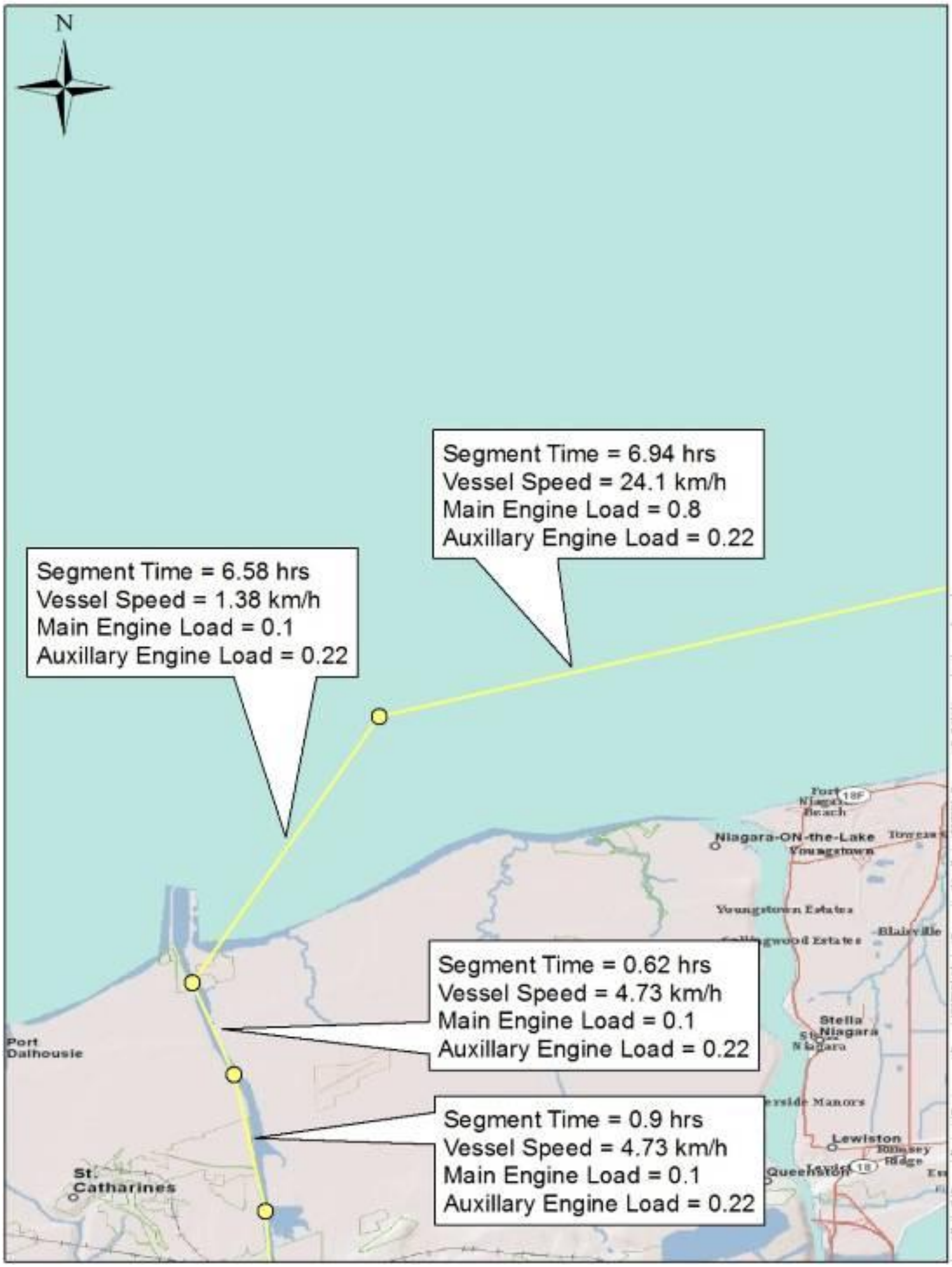
Accurate emission estimates for SO_x, PM and (to a lesser degree) NO_x require definition of fuel sulphur content. Fuel sulphur levels are also defined as part of the vessel class profiles in Appendix A and are summarized in the following section.

Figure 3-2: Example Voyage, MA Vessel from Halifax to Montreal



Notes: Elapsed time (in hours) from the start of voyage is indicated by each INNAV data point shown.

Figure 3-3: Example Vessel Characterization in Eastern Canada (Merchant Bulk Ship through the Welland Canal)



3.4.1 Fuel Sulphur Levels by Ship Class

Commercial ships generally use either distillate, with relatively low sulphur content or residual oil with relatively high sulphur content. Intermediate fuels are also used, which are a blend of distillate and residual oil. Fuel is sourced both domestically and internationally and therefore specific assumptions are required for the different vessel classes. These assumptions are based on Canadian fuel standards or survey data.

The following fuel definitions were used in the 2010 inventory:

- Marine distillate (MDO), domestic origin, 0.05% sulphur;
- Marine distillate (MDO), international origin, 1.0% sulphur;
- Residual fuel (HFO), domestic origin, 1.5% sulphur; and
- Residual fuel (HFO), international origin, 2.6% sulphur.

The international MDO sulphur level is based on Canadian surveys across Canada[22]. The domestic MDO and HFO level derives from a Canadian fuels availability study completed in 2008[23] and the international HFO sulphur level is based on an assessment of international fuels from the IMO in 2009[24].

Each vessel class was assigned an allocation for fuels used in the main engine(s), auxiliary engines and boilers as fractions derived from the sources noted above. Further details on fuel allocations are provided in Appendix A. The resultant fuel sulphur levels used in the emission calculations are summarized by engine type and ship class in Table 3-9 (eastern Canada and the Arctic) and Table 3-10 (West Coast). As further elaborated in Appendix A, the West Coast sulphur levels were established directly from survey data (a comprehensive survey data set from the BC CoS 2005/2006 inventory assessment and a smaller 2010 survey data set provided to SLE by the BC CoS during this project[25]).

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[22] 2007 surveys completed for Transport Canada for eastern Canada implied 0.77% sulphur for vessels operating 'less than 90% of the time in Canadian waters'. The application of 1.0% as an average is consistent with previous marine inventories for eastern Canada.

[23] BMT Technologies Ltd., 2008. Update on Availability, Quality and Quantity of Marine Fuels in Canada.

[24] IMO Marine Environmental Protection Committee, 2010. Prevention of Air Pollution from Ships, Sulphur Monitoring for 2009. Available from http://www.rina.org.uk/hres/mepc%2061_5.pdf

[25] The 2010 surveys collected by the CoS number approximately 300. These surveys were used to update the Merchant Bulk and Merchant Container fuel definitions only, since the other vessel classes did not have sufficient representation.

Table 3-9: Fuel Sulphur Allocations by Vessel Class and Source, Eastern Canada and Arctic

General Class	Specific Class	Source	Sulphur Level (%)
Coast Guard	All	AE	0.05
		ME	0.05
		BO	0.05
Fishing	All	AE	0.05
		ME	0.05
		BO	N/A
Merchant Bulk	MB	AE	1.90
		ME	2.38
		BO	1.90
Merchant Container	MC	AE	2.00
		ME	2.55
		BO	2.00
Merchant Cruise	MW	AE	1.50
		ME	1.50
		BO	1.50
Merchant Other	MA, MG, MH	AE	1.97
		ME	2.49
		BO	1.97
	MM	AE	2.04
		ME	2.60
		BO	2.04
	MO	AE	1.90
		ME	2.38
		BO	1.97
	MQ	AE	1.97
		ME	2.49
		BO	1.97
	MR	AE	2.04
		ME	2.60
		BO	2.60
	MS	AE	1.72
		ME	2.11
		BO	1.72

Table 3-9 (Cont'd): Calculated Fuel Sulphur Levels by Vessel Class and Engine Type, Eastern Canada and Arctic

General Class	Specific Class	Source	Sulphur Level (%)
Merchant Passenger	MF	AE	0.05
		ME	0.05
		BO	0.05
Tanker	MP	AE	1.65
		ME	2.00
		BO	1.65
	TC	AE	1.90
		ME	2.38
		BO	1.90
	TG, TM, TS, TU, TV	AE	2.04
		ME	2.60
		BO	2.04
	TL, TO	AE	2.00
		ME	2.55
		BO	2.00
	TQ	AE	1.75
		ME	2.16
		BO	1.75
	TT	AE	1.86
		ME	2.33
		BO	1.86
Tug Boat	Ocean	AE	0.24
		ME	0.24
		BO	0.24
	All other	AE	0.05
		ME	0.05
		BO	0.05
War	All	AE	0.05
		ME	0.05
		BO	0.05

Table 3-10: Calculated Fuel Sulphur Levels by Vessel Class and Engine Type, West Coast

General Class	Specific Class	Source	Sulphur Level (%)
Coast Guard	All	AE	0.05
		ME	0.05
		BO	0.05
Fishing	All	AE	0.05
		ME	0.05
		BO	0.05
Merchant Bulk	MB	AE	2.30
		ME	2.50
		BO	2.36
Merchant Container	MC	AE	1.90
		ME	2.57
		BO	1.90
Merchant Cruise	MW	AE	n/a
		ME	1.44
		BO	1.32
Merchant Other	MA	AE	2.04
		ME	2.69
		BO	2.38
	MH	AE	1.70
		ME	2.42
		BO	1.55
Tanker	TT	AE	2.88
		ME	2.97
		BO	3.37
	TL	AE	2.43
		ME	2.58
		BO	2.44
	TU, TV	AE	0.93
		ME	1.35
		BO	1.35
Tug Boat	All	AE	0.05
		ME	0.05
		BO	0.05
War	All	AE	0.05
		ME	0.05

		BO	0.05

3.4.1.1 Fuel Sulphur Adjustments

Adjustments were made to the assumed fuel sulphur levels by ship class for Port Metro Vancouver (PMV). PMV has a 'differentiated harbour dues' program that rewards shippers that use lower sulphur fuels. This program is configured to track vessel berthing activity within three categories as follows:

- Gold: Use of diesel with sulphur level of 0.5% or lower;
- Silver: Use of diesel with sulphur level between 0.5% and 1.0%;
- Bronze: Use of diesel with sulphur level between 1.0% and 2.0%.

3.4.2 Additional Characteristics

Additional vessel and engine characteristics are required for either the MEIT emission calculations or to link vessels with existing and future emission standards. These characteristics are either identified through vessel look up tables in the model or are established from vessel class profiles. The necessary characteristics include the following:

Engine criteria:

- installed power rating (kW);
- type (2-stroke or 4-stroke);
- cylinder size (for EPA engine category);
- operating rpm; and
- average load while underway and at anchor/berth (auxiliary engines only).

Boiler criteria:

- Average boiler fuel consumption while underway and at anchor/berth.

These characteristics are identified by vessel class in Appendix A.

3.5 Shoreside Power

During 2010, the only port with shoreside power capability for vessels was Port Metro Vancouver, at their Canada Place cruise terminal. PMV provided SLE with the total amount of hours cruise vessels were connected to shoreside power during the year, and the vessels that had capability to use the infrastructure. Use of shoreside power was accounted for in the model as follows:

- For those vessels capable of 'plugging in', the total hours connected to power were subtracted from the total berth hours equally across all of the annual calls to the terminal;
- The estimated dockside power requirements for the affected vessels (following the methods described in this report) were used to estimate the total electrical consumption over the year; and,
- The average BC Hydro emission intensity value of 25.0 g CO_2e/kWh was applied for the electricity used and included in the marine inventory.

The shoreside power assumption was held constant for the forecast years, meaning that no expectation that a greater percentage of cruise ships will use dockside electrification was applied. No shoreside power use was assumed for any of the backcast years.

3.6 CG Data Assumptions and Corrections

There are both spatial and temporal errors in the CG INNAV data. SLE implemented a processing system to identify and remove the errors as required, characterizing voyages or voyage segments in a default manner where necessary, based on route distance estimates and assumptions for average vessel speed. A larger number of processing steps were required for the VTOSS data as this dataset contains a great deal of data points that are either incorrect spatially or cause difficulty in processing voyage summaries.

3.6.1 East Coast and Arctic

INNAV data was processed to refine voyages to trips with an identifiable origin and destination. The INNAV data is structured in this manner, with virtually every trip in the data tagged with a unique identifier. Many of the unique trips include a stop at a Canadian berth. There are some exceptions; notably a trip for a ferry can include several individual legs that stop at a berth location.

The non-underway data points are associated with locations such as Wharf, Wharf Section, berth or anchor. Those that were not clearly classified in the INNAV data as a berthing stop were classified in MEIT as anchor.

For the primary commercial ship classes, the following assumptions were applied:

- The elapsed time between a 'berth' data point and a subsequent 'underway' data point was considered berthing with auxiliary engine use (following the ship class profiles). The same procedure was applied to anchoring activity;
- Berthing activity that extended beyond two weeks was considered dry dock activity with no engine use;

- Manoeuvring activity is included in the INNAV 'underway' data points. This activity is appropriately characterized within the propulsion engine load factor determination scheme described in Section 3.3; and
- INNAV data at the limits of Canada's territorial waters are suspect. Any data point within 20 km of Canada's demarcation was removed from the dataset, replaced with a fabricated data point based on the vessel's heading and speed. The vessel's heading and speed is determined from data points within Canada's waters.

Figure 3.4 shows that the INNAV trips that include a Canadian port origin and/or destination also include data points at the berth locations. Although there may be some exceptions, most of the INNAV trips are expected to include all time associated with manoeuvring. For this reason, no unique 'manoeuvring' activity definition is formally applied in MEIT V4.0, unlike previous versions of the model. As noted in Appendix A, slow speed movements would be expected to correspond to a propulsion engine load of 0.1 or 0.25. With this approach, each trip summary will include a portion of time that corresponds to manoeuvring.

Figure 3-4: Illustration of Origin / Destination Points in the INNAV Data

Figure 3.5 identifies an issue that may occur near Canada's eastern demarcation and other areas beyond radar and AIS range. As previously noted, vessels are required to send an advanced notice of arrival to the CG before entering Canadian waters. This information may be used to establish one or more data points near Canada's territorial water boundary that have either positional or temporal errors (or both). Although SLE effectively removed any data point within 20km of Canada's boundary, some voyages such as the one in this example have errors that remain. For this voyage, the vessel is represented in the model near St. Pierre – Miquelon at 82 hours into its journey (as represented by SLE) and then leaves Canadian waters and again travels west to end up west of St. Pierre – Miquelon at hour 113. The 'bad' data point in this case is likely the one outside of Canadian waters at hour 82.

Data filtering methods were determined and applied to the INNAV trip and segment data in a consistent fashion to identify and correct errors such as the one noted above. Full trips were removed if one or more of the following criteria were met:

- Trip arrival is before departure;
- Trip is too short (elapsed time less than 0.1 hours); and
- Trip is too long (elapsed time greater than one month, with exceptions).

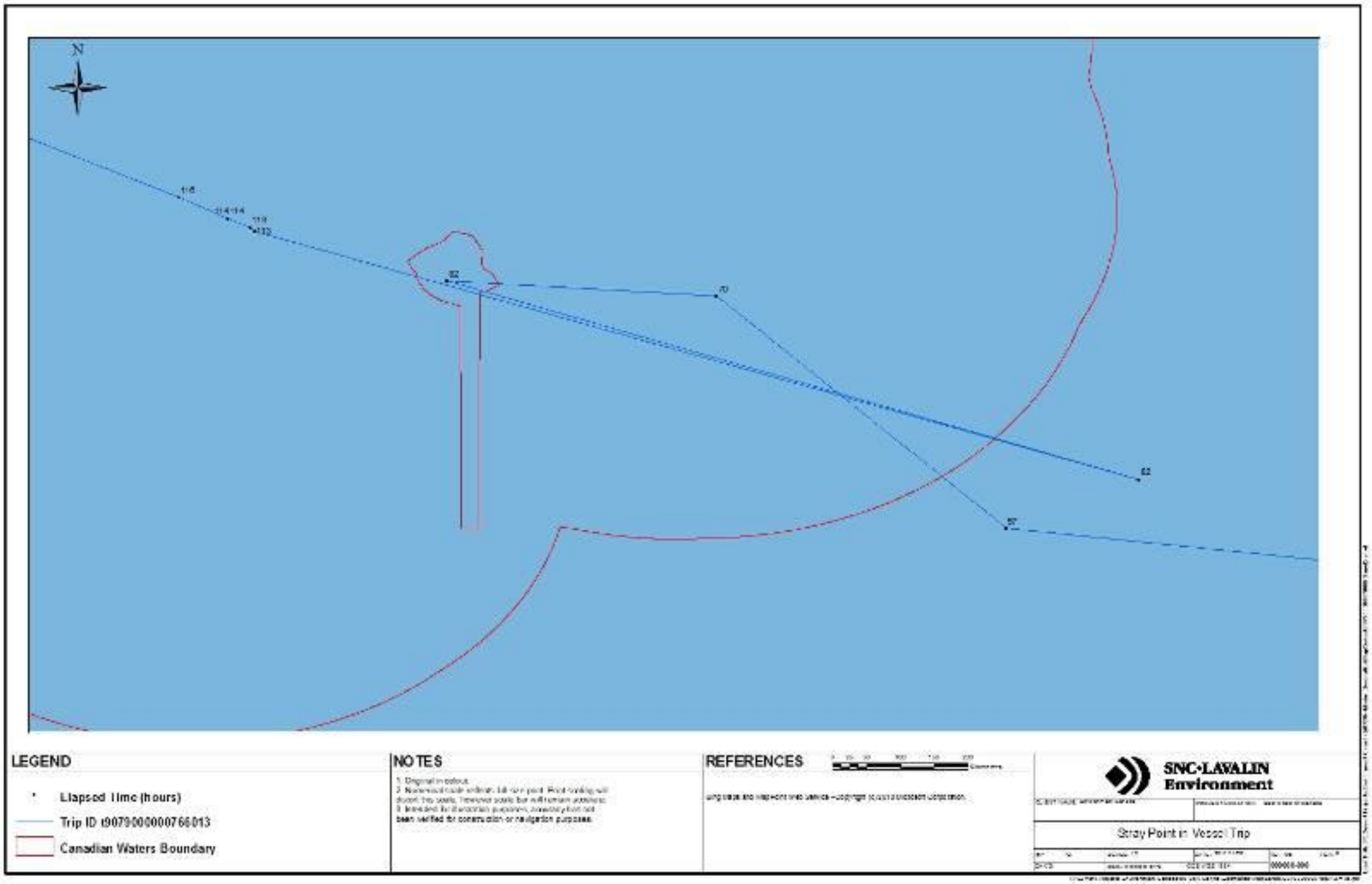
Following the trip filtering above, trip segments or data points were removed if one or more of the following criteria were met:

- Berthing / anchoring trip segments outside of Canadian waters;
- Trip segment has no starting point or destination (this may occur at start and end of calendar year); and
- Trip segments with no travel distance within Canadian waters.

An additional filter was used to evaluate how many segments like the problematic ones shown in Figure 3.5 may exist. This filter simply identified the segments and associated engine hours where vessels were determined to be travelling at 200% or more of their stated cruise speeds. Application of this filter identified approximately 1% of the total inventory underway hours and 4% of the total inventory distance travelled. Ultimately this filter was not employed in the inventory since there would be no systematic way to correct the voyages that have problematic segments of this nature. Also, MEIT limits ME engine load to 0.8, meaning there is no significant danger that higher-than-actual emissions would be allocated to a particular vessel with the problematic data[26]. However, estimated voyage distances in MEIT clearly do have error and spatial gridding of the MEIT totals will be subject to these errors, which would be more likely to occur in open water than near harbours.

[26] It is expected that errors of this nature occur in open water where vessels would typically be travelling at or near their cruise speeds with relatively high main engine loads.

Figure 3-5: Illustration of Positional Error in CG Data Points



The net effect of the filtering methods is identified in Table 3-11 in terms of engine hours removed from the inventory data set. The CG and DFO vessels were not subject to all of the filtering, as noted in the table. This is due to differences in their voyage characteristics from those of the OGV classes (very long trips in Canadian waters are possible).

Table 3-11: Trip / Segment Rejects (Hours in Canadian Waters)

Trip Reject Reason	Coast Guard	DFO	Merchant Bulk	Merchant Container	Merchant Other	Special Purpose	Tanker	Total
Trip Arrival Before Departure	473	304	2,973	22	1,483	147	117	**5,519**
Trip Too Short	943	662	167	0	2,731	2,409	344	**7,256**
Sum of Underway Segments too short	0		1		0	2	0	**3**
Canadian Water portion too short	1		2	0	0	45	0	**49**
Canadian Water Trip Time should not be larger than 744 hours (1 Month)	n/a	5,462	9,538	1,185	7,753	n/a	26,801	**50,739**
Berth/Anchor Outside Canadian Waters	-		546	100	4,538	7,796	207	**13,187**

Table 3-11 shows that the most significant filter applied to the INNAV data is for trip length greater than one month. This filter removes approximately 5% of the total underway engine hours from the eastern inventory. However, it is expected that these hours are incorrect, since cargo ship voyages in Canadian waters should extend several days and not a month or more.

3.6.2 West Coast

Preliminary assessment of the CG VTOSS data for Canada's west coast showed that significant errors exist in the data. Most importantly, the VTOSS data for November and December of 2010 were incomplete, missing many voyages that were known to have occurred. In addition, some voyages in the data set are missing specific movements such as an anchor to berth movement. For this reason, a summary dataset was required to ensure that all OGV movements during the year would be represented.

Through the Project Steering Committee, SLE accessed the 2010 summary records from the Pacific Pilotage Authority for 2010. The Pilots provide navigational aid for all of B.C.'s coastal areas, including the Fraser River. The Pacific Pilot data used for the inventory includes the following information for each individual 'Move':

- Identification of vessel;
- Move origin and destination; and,
- Move origin and destination date/times.

In total, approximately 11,500 'Moves' are defined in the 2010 data. A Move occurs between two identified location points; location points consist of pilot stations, anchorages and berths. Within a single voyage, several Moves may occur.

SLE conducted a test of the Pilot data by comparing the records with data obtained from Port Metro Vancouver for anchor and berth periods during 2010 within their jurisdiction. This test was favourable for both number of stops by ship type as well as total time at anchor and berth. Agreement within 1% was determined (this data is not shown here, but may be available upon request).

The Pilot data was used to construct trips for every vessel that made a stop at a B.C. berth and/or anchorage during the year. Each trip entails the movements from a pilot station into harbour and back to a pilot station, accounting for all anchor and berth periods. For each trip, a search was completed through the VTOSS data to collect data points that could be used to interpolate between the pilot data points and to extrapolate to/from the pilot station to the boundary of Canada's territorial waters. For any trip without identifiable VTOSS data, SLE assigned a route based on the typical traffic patterns. Figures 3-6 and 3-7 illustrate the method for trips to Port Metro Vancouver and Port of Prince Rupert, respectively.

Figure 3-6: Constructed Trips Using Pacific Pilot Data – MB to Port Metro Vancouver

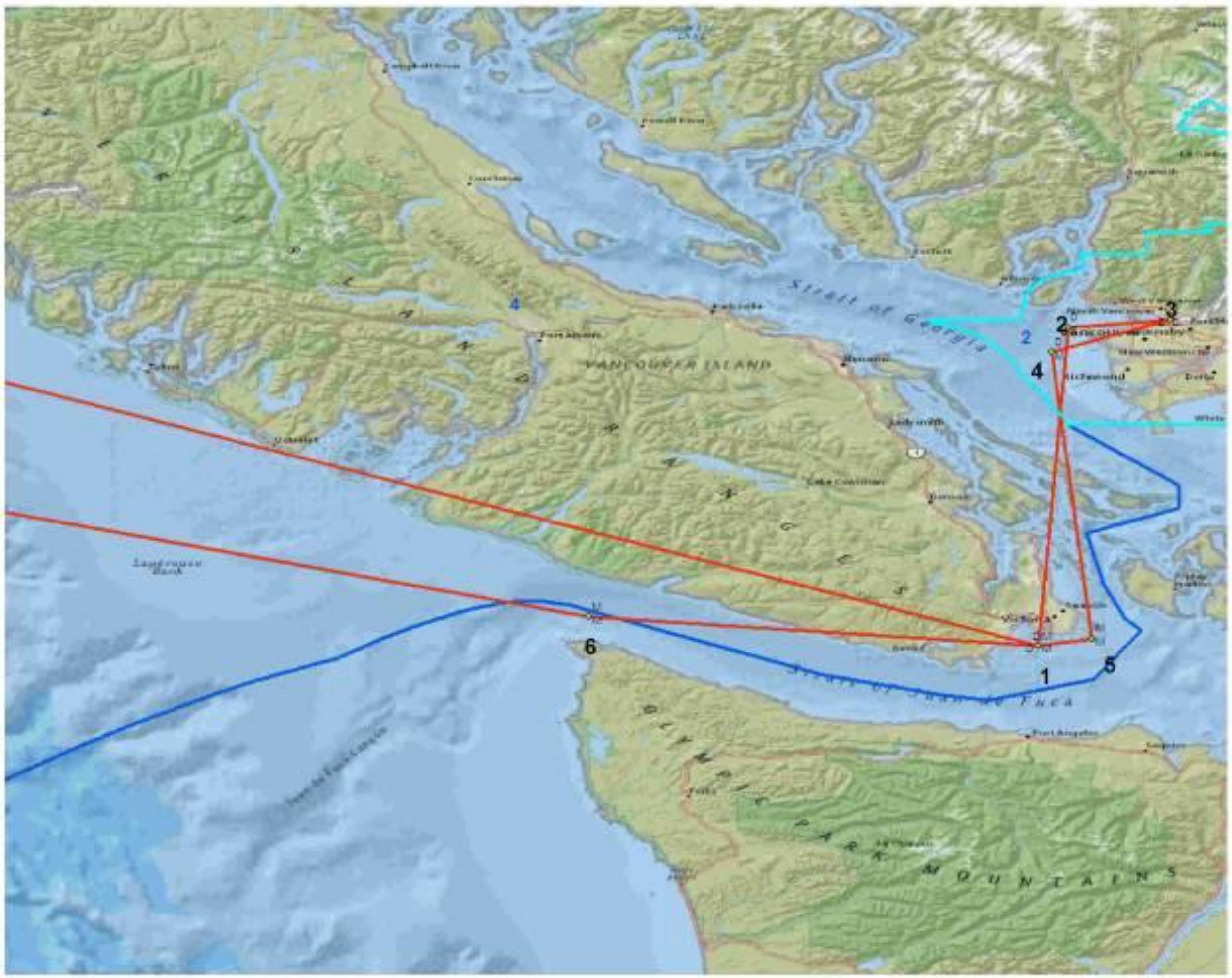


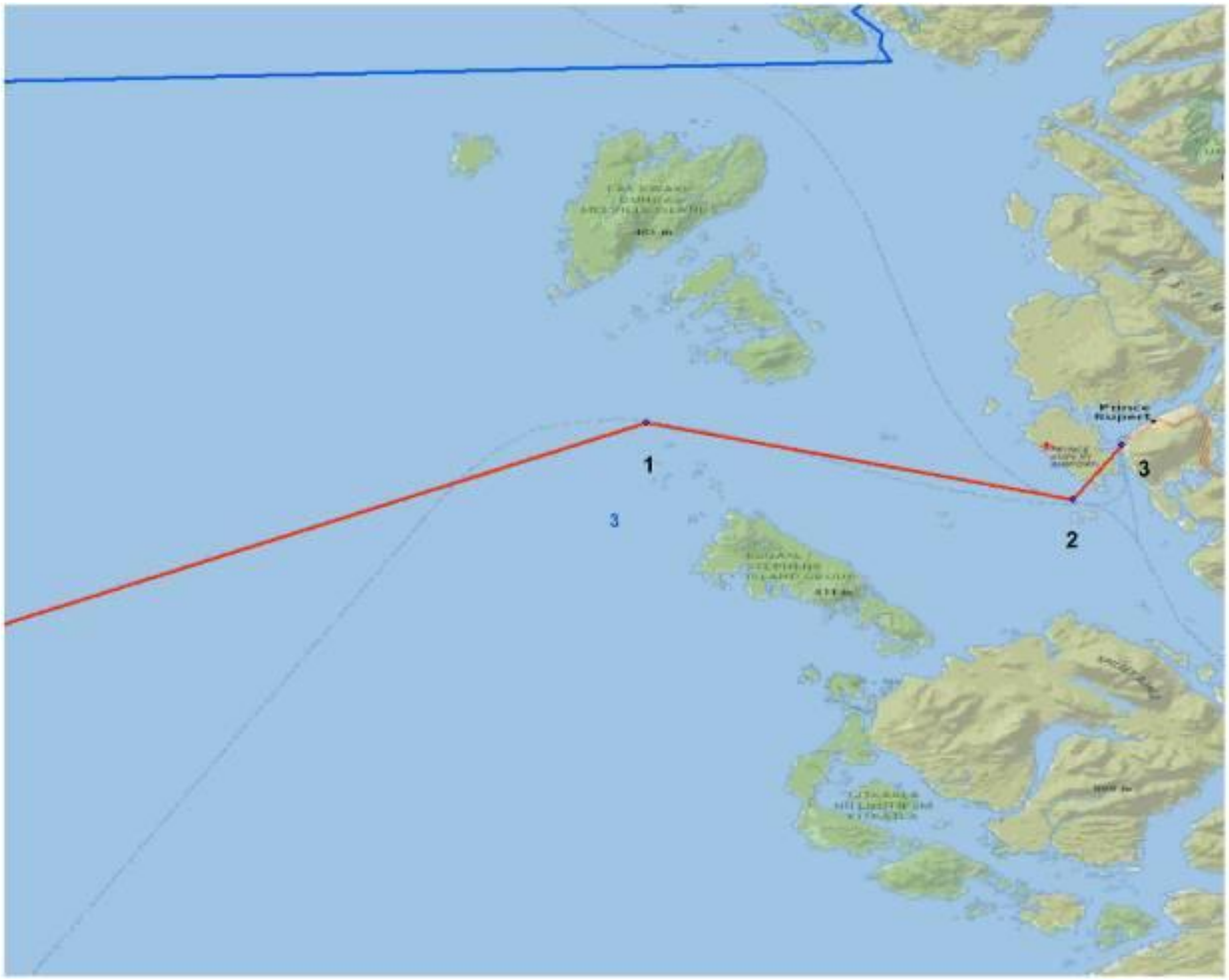
Figure 3-6 shows a Merchant Bulk trip to and from Pacific Coast Terminals. Pilot data was used to establish the times of travel from the Brochie Pilot Station (1) to the terminal (3) and back to Brochie (1). The processing steps taken in the model to complete the trips within Canada's waters were as follows:

- Search for intermediate VTOSS data points that could be used, insert these points (date/time and position) into the trip record – points 4, 5 and 6 were inserted (as well as additional points west that are not shown in the figure);
- Force an intermediate data point (date/time and position) between Brochie and the terminal at the entrance to the PMV harbour if one does not exist in the trip record – point 2 was inserted; and,
- Extend the trip to the edge of Canada's territorial waters assuming full underway speed.

Figure 3-7 shows a Merchant Container trip to Fairview Terminal. Pilot data was used to establish the time of travel between the Triple Island Pilot Station (1) and Fairview Terminal (3). The processing steps taken in the model to complete the trip within Canada's waters were as follows:

- Search for intermediate VTOSS data points that could be used, insert these points (dat/time and position) into the trip record – no data found;
- Force an intermediate data point (date/time and position) between Triple Island and Fairview at the entrance to the Rupert harbour if one does not exist in the trip record – point 2 was inserted; and,
- Extend the trip to the edge of Canada's territorial waters assuming full underway speed.

Figure 3-7: Constructed Trips Using Pacific Pilot Data – MC to Port of Prince Rupert



The Pilot data can be used to determine total transit time from point to point in MEIT. A corresponding average vessel speed can be determined by dividing the distance of travel by elapsed time. For those trips that do not have intermediate VTOSS data points between a pilot station and a berth, the implied vessel speed would be too high for the harbour movements. For this reason, intermediate points were inserted to the trips to force the harbour speeds to the lower speeds expected. The model was programmed to estimate the distance from the harbour entrance (roughly positioned by SLE) to the berth in question and an associated travel time assuming a speed of 5 knots was applied. This time was used to establish the intermediate data point. In effect, this procedure forced the model to apply a low speed main engine load (0.10) for all harbour movements without associated VTOSS data. Any trip that occurs entirely within a harbour area (e.g., does not involve a pilot station data point) was not altered.

Intermediate 'harbour' data points were established in the model for the ports of Metro Vancouver, Prince Rupert, Nanaimo and Alberni. Both a Burrard Inlet and a Fraser River intermediate point were applied for Port Metro Vancouver, given the considerable geographical spread of the terminals.

4. 2010 ACTIVITY DATA

A number of statistical summaries from the INNAV and VTOSS data are provided in this chapter to showcase the 2010 vessel movements and to evaluate surrogate methods to account for vessel activity that is not fully represented in the CG data.

4.1 Vessels in Canadian Waters

Table 4-1 provides a summary of the commercial vessels that were active in Canadian waters in 2010, according to the CG records. The vessel classes are categorized by minimum, average and maximum DWT and vessel age.

Table 4-1: Active Commercial Vessels in Canadian Waters, 2010*

General Vessel Class	Vessel Type	Count	Year			DWT		
			MIN	AVG	MAX	MIN	AVG	MAX
Coast Guard	CI	18	1969	1984	2006	1,159	2,292	4,640
	Other	127	1959	1989	2009	184	1,321	7,500
DFO	All	16	1968	1982	2002	53	621	1,442
Fishing	FC	26	1944	1983	2003	N/A	N/A	N/A
	FF	47	1938	1975	2003	500	2,553	19,286
	FL	20	1942	1974	2001	N/A	N/A	N/A
	FT	65	1966	1980	2004	94	900	2,040
	Other	462	1938	1977	2010	78	696	4,975
Merchant Bulk	MB	1954	1929	2000	2010	1,891	62,922	207,960
Merchant Container	MC	475	1971	2000	2010	1,259	57,015	116,440
Merchant Cruise	MW	24	1987	2000	2008	2,248	8,476	19,189
Merchant Other	MA	33	1983	2002	2010	10,546	21,900	39,516
	MG	448	1959	1999	2010	61	19,867	157,991
	MH	186	1971	1996	2010	580	17,368	51,648
	MM	31	1945	1987	2009	4,222	29,208	180,201
	MR	18	1975	1990	2007	2,500	7,779	13,879
	Other	21	1943	1980	2010	1,200	47,036	227,183
Merchant Passenger	MF	116	1951	1980	2009	20	1,929	55,000
	MP	141	1923	1985	2009	49	4,852	14,601

Table 4-1 (Cont'd): Active Commercial Vessels in Canadian Waters, 2010*

General Vessel Class	Vessel Type	Count	Year			DWT		
			MIN	AVG	MAX	MIN	AVG	MAX
Special Purpose	All	127	1904	1981	2010	4	6,316	97,000
Tanker	TC	201	1991	2004	2010	13,754	143,496	321,300
	TL	267	1980	2005	2010	6,285	32,665	68,467
	TM	50	1982	2006	2010	11,283	46,903	110,531
	TS	114	1976	2002	2010	30,990	85,437	193,049
	Other	254	1963	2002	2010	835	77,094	318,000
Tug Boat	HH	45	1903	1971	2010	66	191	435
	HO	24	1963	1990	2008	137	1,289	4,393
	HS	28	1962	1986	2010	100	2,499	6,128
	Other	767	1903	1975	2010	10	1,737	128,826
War	WR, WS	114	1960	1991	2009	804	15,320	40,532
COMBINED		**6,223**	**1903**	**1995**	**2010**	**4**	**44,533**	**321,300**

*Note: Several classes were removed / amalgamated from the CG data, such as barges and pleasure craft (yachts).

4.2 Activity by Region

Summaries are presented in this section for trip activity characteristics including number of trips, distance travelled, times in mode, vessel speed and estimated load on propulsion engines.

4.2.1 Eastern Canada / Great Lakes

Table 4-2 provides a summary of the 2010 INNAV vessel activity in eastern Canada by general vessel class, not including ferries, tugboats and fishing vessels. These vessel classes are not fully represented in the INNAV data as discussed in the following sections. Summaries are provided for the number of trips in the year, total travel distance in Canadian waters, and total time spent in underway, berth and anchor modes.

Table 4-2: 2010 Eastern Canada Activity Hours by Mode*

General Vessel Class	Trips	Total Distance (nautical miles)	Total Anchor (h)	Total Berth (h)	Total Underway (h)
Coast Guard	2,811	242,923	2,646	170,859	71,543
DFO	521	119,128	5,707	34,773	25,723
Merchant Bulk	11,494	3,264,599	69,267	208,793	314,103
Merchant Container	2,483	1,439,256	2,923	38,296	102,897
Merchant Cruise	477	156,485	60	4,277	11,149
Merchant Other	3,649	1,527,984	12,337	93,589	134,554
Special Purpose	4,652	140,545	15,089	169,837	57,752
Tanker	6,862	2,491,006	60,396	155,419	226,832
Grand Total	**33,019**	**9,381,926**	**168,426**	**875,843**	**944,553**

*Berthing hours for CG and DFO ships may include time the vessels are idle with no crew on board.

The activity hours noted in Table 4-2 can be compared to the activity hours by vessel class determined in the 2002 inventory for eastern Canada (Table 2-5). Greater underway time is noted in Table 4-2 for those vessel classes that can be directly compared (e.g., Merchant Bulk, Merchant Container) although the identified number of trips in 2010 is lower than 2002 for some vessel classes, including Merchant Bulk and Merchant Container.

Table 4-3 provides a summary of the average vessel speeds in the different regions of eastern Canada. As noted in Chapter 3, the vessel speeds are used to estimate the load on the main engines.

Table 4-3: Average Vessel Speeds in Regions of Eastern Canada (Speed Shown as a Percentage of Vessel Maximum Cruise Speed)

Region	Merchant Bulk	Merchant Container	Merchant Other	Merchant Passenger	Tanker	Weighted Average
5	83.5		89.9	84.2	91.0	84.4
6	58.4	90.0	65.2	65.3	46.6	57.0
7	58.6	49.8	56.6	65.6	68.5	59.2
8	40.2	37.1	37.2	35.6	43.1	40.1
9	59.5	65.6	65.0	65.1	71.0	62.0
10	48.8	45.7	49.7	63.6	51.0	53.1
11	77.7	65.0	79.8	68.5	79.2	75.2
12	77.9	77.4	81.0	80.3	85.6	80.0
13	88.9	81.4	86.6	69.9	86.6	84.3
14	75.0		77.6	63.9	86.8	71.3
15	75.8	100.0	74.6		77.3	75.9
16	77.7	59.2	72.0	72.8	77.7	71.9
17	58.6	61.2	77.0	76.5	63.2	70.9
18	75.5	68.7	77.1	71.3	77.9	73.0
19	84.9	76.6	83.3	70.0	73.2	75.4
20	83.6	67.4	81.5	66.6	81.1	76.7
Average	**65.7**	**63.7**	**71.7**	**70.9**	**73.5**	**69.0**

The estimated speeds were used to bin the vessel engine loads according to the methodology described in Appendix A. Table 4-4 shows a breakdown of the ME loads by elapsed time for 2010, by general vessel class.

Table 4-4: Distribution of ME Load Factor by General Vessel Class*

Vessel Class	Total Underway Time (h)	Underway Hours by Load Factor Bins			
		0.1	0.25	0.4	0.8
Coast Guard	71,543	3,514	5,664	55,728	6,638
DFO	25,723	1,955	4,742	16,661	2,364
Merchant Bulk	314,103	61,992	44,497	69,614	137,999
Merchant Container	102,897	30,219	29,131	12,711	30,835
Merchant Other	134,554	29,130	17,603	22,944	64,877
Special Purpose	57,752	2,024	3,871	46,617	5,240
Tanker	226,832	37,067	28,708	46,888	114,170
Grand Total	**933,404**	**165,902**	**134,217**	**271,163**	**362,122**

*Merchant Cruise is not included in this table.

Table 4-4 shows that some vessel classes are characterized with full underway engine load (0.80) during much of the underway time while other classes spend a large portion of time at lower engine loads.

Cruise Ship underway activity was characterized in a dynamic manner, to account for a greater degree of variability in the transit speeds employed by region of Canada and time of day. Table 4-5 provides a summary of the estimated cruise ship engine loads by region of eastern Canada by allocating the calculated power levels to several categories, including ‘berth’ (base load), ‘low’ (less than 25% of maximum), ‘mid’ (25 – 50% of maximum) and ‘high’ (above 50% of maximum). These categories are used here for reporting purposes only. As described in Appendix A, any engine load from the ‘base load’ (estimated power level while at berth and anchor) to a load factor of 0.8 is possible in the methodology for cruise ships, based on the vessel speed.

To serve as example, cruise ship activity in Region 10 (Montreal) is shown to be dominated by berthing activity (521 hours in 2010). Transit activity in this Region is brief and tends to occur with ‘mid’ engine load use. Conversely, activity in Region 12 is dominated by ‘mid’ and ‘high’ engine load use with little berthing activity.

Table 4-5: Cruise Ship Hours by Mode

Region	Time (hours) by Mode			
	Berth	Low	Mid	High
10	521	22	56	7
11	1,114	182	620	252
12	72	40	384	567
13		26	237	308
14	409	119	328	118
16	1,406	1,389	2,504	2,861
17	682	80	189	171
18	33	27	39	75
19	101	5	108	312
20			55	38
Grand Total	**4,337**	**1,891**	**4,519**	**4,709**

4.2.1.1 Fishing Vessels

Fishing vessels are not fully represented in the INNAV data. As evaluated in the previous Arctic inventory assessment for Transport Canada[27], some of the active fishing vessels in Canada cannot be identified in the INNAV records, potentially due to their small size, while some vessels are identified but may not have their movements detailed to a similar level of the larger commercial vessel classes[28]. Fisheries and Oceans Canada (DFO) and the CG were contacted for available fishing vessel activities and the available statistics published by these two organizations were analyzed. The number of active fishing vessels in each eastern province in 2010 is summarized in Table 4-6. The data were mapped to the applicable INNAV regions as noted.

[27] SENES Consultants Ltd., 2008. Arctic Marine Vessel Activity and Emissions Inventory. Prepared for Transport Canada.

[28] In some cases, fishing vessels are noted to be at sea, but their position/time data are not updated on a frequent basis.

Table 4-6: Active Fishing Vessels in Each Province/Region in Eastern Canada in 2010

Province	DFO Region	INNAV Region	Number of Vessels by Length Overall (LOA)					
			< 35'	35 – 44'11''	45' – 64'11''	65' - 99'11''	>= 100'	Total
Nova Scotia	SCOTIA-FUNDY	16-17	1,678	1,759	122	17	27	3,603
	GULF	16-14	194	513	19	1	0	727
New Brunswick	SCOTIA-FUNDY	16-17	149	300	37	7	2	495
	GULF	16-14	589	1,123	97	23	3	1,835
PEI	GULF	14	71	1,238	22	1	1	1,333
Quebec	QUEBEC	12-13	630	502	185	11	2	1,330
NFLD	NEWFOUNDLAND	20	6,780	602	465	14	23	7,884
		TOTAL	**10,091**	**6,037**	**947**	**74**	**58**	**17,207**

Of the several types of fishing vessels captured in INNAV, 'Fishing Vessels' (FV) is assumed to be representative of the vessels identified in Table 4-6. Other INNAV fishing classes are less populated and tend to be made up of larger vessels.

Active fishing (FV) vessels in the INNAV system are identified in Table 4-7 with an identical breakdown of LOA to that used in Table 4-6. The annual hours of FV activity in the INNAV data by vessel size category and region of Canada are shown in Table 4-8.

Table 4-7: Active FV Vessels in INNAV for Eastern Canada / Great Lakes

Vessel Counts in INNAV	Number of Vessels by Length Overall (LOA)						
	< 35'	35 – 44'11''	45' – 64'11''	65' - 99'11''	>= 100'	Unknown	Grand Total
Fishing Vessel	11	42	64	36	41	7	201

Table 4-8: Annual Hours of FV Class Underway Activity in INNAV for Eastern Canada / Great Lakes

Region	Annual Activity Hours by Length Overall (LOA)						
	< 35'	35 – 44'11''	45' – 64'11''	65' -99'11''	>= 100'	Unknown	Grand Total
6			3,254	14,111			17,365
7			10	735			745
8			4,506	10,786			15,292
11	0	2,663				1	2,664
12		793	135	243			1,171
13					232		232

Table 4-8 (Cont'd): Annual Hours of FV Class Underway Activity in INNAV for Eastern Canada/ Great Lakes

Region	Annual Activity Hours by Length Overall (LOA)						
	< 35'	35 – 44'11"	45' – 64'11"	65' - 99'11"	>= 100'	Unknown	Grand Total
16	1,857	15,749	49,458	42,135	33,514	2	142,715
17	2,540	43,626	32,590	6,902	6,123		91,781
18		13,697	128,854	25,910	20,855		189,316
19	11,793	7,774	8,020	8,787	48,800	8,170	93,344
20			1	26	21,843		21,871
21				1,182	30,317	3,582	35,081
Combined	**16,191**	**84,301**	**226,829**	**110,819**	**161,685**	**11,755**	**611,578**

The INNAV data was used to determine the average annual amount of underway activity per vessel for the vessels less than 100 feet in overall length. As noted in Section 3.1, vessels with LOA greater than 24m (77') are expected to be fully represented in the CG records. The vessel group averages were applied to the number of active vessels noted in Table 4-6 to simulate additional trips within the model. A revised annual estimate for fishing vessel activity in eastern Canada is shown in Table 4-9.

Table 4-9: Total Estimated Fishing Vessel Activity in Eastern Canada / Great Lakes for 2010

Region	Annual Activity Hours by Length Overall (LOA)						
	< 35'	35'-44'11"	45'-64'11"	65'-99'11"	> 100'	Unknown	Total
6			3,254	14,111			17,365
7			10	735			745
8			4,506	10,786			15,292
11	0	2,663				1	2,664
12	518,175	450,545	302,290	17,022			1,288,032
13	518,175	450,545	302,290	17,023	232		1,288,265
14	760,813	3,690,520	261,440	40,235			4,753,008
16	2,146,725	3,316,263	449,300	74,280	33,514	2	6,020,084
17	1,502,707	1,847,953	259,806	37,140	6,123		3,653,729
18		13,697	128,854	25,910	20,855		189,316
19	11,793	7,774	8,020	8,787	48,800	8,170	93,344
20	11,153,100	1,080,590	1,519,620	43,330	21,843		13,818,484
21				1,182	30,317	3,582	35,081

Grand Total	**16,611,489**	**10,860,549**	**3,239,391**	**290,543**	**161,685**	**11,755**	**31,175,410**

All of the simulated FV trips were associated with slow speeds and use of an ME load factor of 0.1. This reflects the assumption that most of the time the FV ships are at sea they are trawling.

No data were available to estimate the additional fishing activity that may occur in the Great Lakes. The fishing activity in Regions 6, 7 and 8 shown in Table 4-9 relates to unscaled INNAV movement data. Fishing activity levels in the Great Lakes should be investigated at a future time.

4.2.1.2 Ferries

INNAV data do not represent all ferry movements in eastern Canada. To determine an aggregate estimate of the ferry activity levels in eastern Canada, an independent investigation of ferry movements was conducted as part of the project work. The organizations providing ferries services in each region of eastern Canada are listed in Table 4-10. Vessel movement data was obtained from their online data resources (schedules, reports) and through phone calls.

Table 4-10: Information Resources used for Each Province/Region in Eastern Canada / Great Lakes

Newfoundland, Labrador	◆ http://www.tw.gov.nl.ca/ferryservices/index.html ◆ http://www.labradorferry.ca ◆ http://www.coastofbays.nl.ca
Ontario	◆ http://www.mto.gov.on.ca/english/traveller/ferry/index.shtml ◆ http://www.spmtours.com/dayandvacation.html ◆ http://www.chicheemaun.com/chi/english/schedule_fares.html ◆ http://www.chicheemaun.com/jii/english/schedule_fares.html
New Brunswick	◆ http://www.gnb.ca/0113/ferries/ferries-e.asp ◆ http://new-brunswick.net/new-brunswick/ferry.html ◆ http://www.coastaltransport.ca/generalinformation.htm
Nova-Scotia	◆ http://www.municipalities.com/islandscap/ferries2.htm ◆ http://www.marine-atlantic.ca/eng/annual-ferry-schedule.asp ◆ http://foundlocally.com/stjohns/trans/Trans-Ferries.htm ◆ http://gov.ns.ca/tran/hottopics/ferries.asp ◆ http://www.tancookislandtourism.ca/
Quebec	◆ http://www.traversiers.gouv.qc.ca/en/index.php ◆ http://www.ctma.ca/traversier-madeleine/index_ang.cfm ◆ http://www.inter-rives.qc.ca/ ◆ http://traverserdl.com/english/home ◆ http://www.relaisnordik.com/en/home/24.cfm ◆ http://www.navettesmaritimes.com/en/route.html ◆ http://www.bonjourquebec.com/qc-en/tourist-services-directory/ferry/
All Regions	◆ http://wwwapps.tc.gc.ca/Saf-Sec-Sur/4/vrqs-srib/m.aspx?lang=e

No estimates were consistently available for the amount of time spent using auxiliary engines while berthing / awaiting passengers (or the size of auxiliary engines employed). In some cases, ferries use shore electrification facilities for required power when docked. For this reason, no use of auxiliary engines was assumed for ferries while berthed. The scheduling – derived total estimated underway hours by general area of eastern Canada is shown in Table 4-11.

Table 4-11: Total Schedule-derived Ferry Activity in Eastern Canada by General Area*

Regions	Total Underway (hr)
New Brunswick	49,670
Great Lakes	21,840
Newfoundland and Labrador	30,840
Nova Scotia	32,641
Quebec	37,673
Total	**172,663**

Total Ferry activity in the INNAV data is summarized in Table 4-12. Many, but not all of the ferries identified through the scheduling data, can be found in the INNAV records. Conversely, activity not identified through the available scheduling records can be found in INNAV. The ferry vessels found in the scheduling data appear in both the Merchant Ferry (MF) and Merchant Passenger (MP) INNAV classes. INNAV ferry activity by region of eastern Canada is shown in Table 4-13.

Table 4-12: Total INNAV Ferry Activity in 2010, Eastern Canada, By Ferry Type

Vessel Class	Trips	Total Distance (knots)	Total Underway Time (h)	Total Berth Time (h)	Total Anchor Time (h)
MF	9,691	558,241	47,020	174,949	467
MP	4,935	137,956	18,287	167,744	2,301
TOTAL	**14,626**	**696,197**	**65,307**	**342,693**	**2,767**

Table 4-13: Total INNAV Ferry Activity in Eastern Canada*

Region (trip start)	Trips	Total Distance (knots)	Total Underway Time (hours)	Total Berth Time (hours)	Total Anchor Time (hours)
0	277	5,938	597	2,294	11
5	2	154	15	23	-
6	48	2,392	317	3,619	-
7	14	378	56	12,946	-
8	3	178	30	739	0
9	124	3,926	612	23,727	0
10	2,144	29,138	4,474	37,639	33
11	2,193	62,294	6,732	131,508	338
12	2,973	107,112	8,852	21,177	2
13	532	71,502	7,607	17,317	116
14	306	26,573	1,788	761	7
16	1,600	136,934	10,144	25,691	3
17	1,188	74,711	6,594	21,496	-
18	1,390	103,981	8,730	8,742	2,254
19	1,705	41,328	4,098	34,234	-
20	127	29,657	4,661	780	4
Grand Total	**14,626**	**696,197**	**65,307**	**342,693**	**2,767**

* Region 0 corresponds to activity that begins outside of Canada and crosses the border (e.g., a voyage segment crosses the international border).

To complete an estimate for all ferry activities in eastern Canada, an activity matching approach was used on a vessel by vessel basis as follows:

- For a vessel identified in INNAV, all of its activities were included in the inventory.
  - If this vessel was also identified through scheduling records and the scheduled activity data was greater than the INNAV data, the INNAV data (hours) was scaled up to match.
- For a vessel identified in the scheduling data that was not identified in INNAV, all of its activity was included in the inventory, with a simulated route based on its origin and destination.

- The vessel engine criteria was based on the stated passenger and car capacity, matched to similar vessels in the INNAV data.

Table 4-14 provides the total estimated ferry activity for eastern Canada characterized in the 2010 inventory.

Table 4-14: Total Estimated Ferry Activity by INNAV Region of Eastern Canada*

Region (trip start)	Total Distance (knots)	Total Underway Time (hours)	Total Berth Time (hours)	Total Anchor Time (hours)
0	26,313	4,963		
1	1,876	311		102
5	515	121	23	
6	22,854	2,144	9,373	
7	8,837	843	16,738	
8	10,732	1,134	4,059	
9	92,909	18,133	23,695	19
10	58,736	9,842	63,300	27
11	128,620	21,994	180,535	505
12	127,073	10,244	25,145	3
13	73,693	8,890	19,718	139
14	43,196	3,931	7,985	
16	306,226	31,064	52,392	10
17	278,534	45,246	65,406	
18	137,443	11,223	8,283	6,802
19	265,006	30,256	69,779	
20	39,972	5,940	809	4
21	37,166	5,369	519	21
22	654	56	39	1
Total	**1,660,355**	**211,703**	**547,799**	**7,634**

* Region 0 corresponds to activity that begins outside of Canada and crosses the border (e.g., a voyage segment crosses the international border).

4.2.1.3 Tug Boats

Tug boat activity includes barges and tow boats as well as harbour assist movements for vessels coming into and leaving a berth. All 2010 INNAV tug boat activity for 2010 is listed in Table 4-15.

Table 4-15: 2010 INNAV Tugboat Activity in Eastern Canada by Specific Vessel Class

Vessel Class	Trips	Total Distance (km)	Total Underway Time (h)	Total Berth Time (h)	Total Anchor Time (h)
HF	373	7,264	840	8,349	2
HH	5,033	142,162	13,435	202,362	1,327
HO	2,349	170,849	10,738	94,088	2,026
HS	1,786	576,299	29,885	140,828	9,397
HT	9,211	775,620	65,886	416,310	7,158
HW	223	8,147	931	57,583	0
TOTAL	**18,975**	**1,680,342**	**121,715**	**919,520**	**19,909**

Harbour assist movements (HH) are related to the OGV calls to port during the year. However, it is likely that the 'Tug General' class in INNAV (HT) also contains vessels that, at least some of the time, conduct harbour assist movements. Conversely, HH vessels may perform duties beyond harbour assist movements, such as helping vessels through locks in the St. Lawrence Seaway. Preliminary investigations on the INNAV tug boat activity near Canadian port areas indicate that the harbour assist movements are under-represented. In the cases of Montreal and Halifax, these activities have previously been determined through local emission inventory investigations[29]. This finding is not unexpected, given the understanding of tug boat representation in the CG records as noted in Section 3.1.

As applied in several past port and terminal inventories, a reasonable assumption can be applied whereby approximately three hours of tug boat assist is required for each OGV visit to berth. Table 4-16 provides an estimate of additional tugboat assist activity by INNAV region of eastern Canada, broken down by OGV vessel class.

[29] See the Port of Montreal inventory report at http://www.tc.gc.ca/media/documents/quebec-eng/rapport_emission_mtl_e.pdf. The Halifax work has not yet been published (as of November 2011).

Table 4-16: Estimate of Additional Tugboat Assist Underway Activity (hours) by OGV Vessel Class and Region of Eastern Canada

OGV Class	Estimated Hours of HH Tug Boat Activity by Region of Eastern Canada																Total
	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	
MA												207					207
MB	909	3,027	2,472	897	3,183	1,056	3,129	3,255	141	57	162	738	150	162	36	36	19,467
MC		3	6		9	1,215	33	21				2,109	813	123	435	120	4,887
MG	66	75	108	6	147	759	852	396	24	18	96	435	141	159	429	9	4,194
MH	3	3			3	243	123	24	6			300	3	57	159		1,056
MO								63									63
MQ								2,181									2,181
MR										3			27	3	27		60
MS															3		3
TC						90	237	3				540	288		288		1,446
TG						3	12										15
TL	9	249	6	69	234	1,038	885	204	66	81	48	375	726	60	321	30	4,566
TO						24	66	48						3	9		168
TQ												3	72				75
TS												3					3
TT	60	609	15	201	468	1,626	726	210	39	9	33	1,590	585	144	954	117	7,560
TU												3					3
TV												9	3		3		15
Total	**1,047**	**3,966**	**2,607**	**1,173**	**4,044**	**6,054**	**6,063**	**6,405**	**276**	**168**	**339**	**6,312**	**2,808**	**711**	**2,664**	**312**	**45,969**

It was found that HH activity in the INNAV data varies greatly by port region. In some areas the INNAV data is far lower than that implied in Table 4-16. In other regions, such as Region 10 (Montreal), the estimates in Table 4-16 are only moderately higher. It was assumed that the tug boat assist movements for the ports are not represented in the INNAV records and the significant amount of INNAV HH (and HT) activity that occurs near ports such as Montreal is due to movements of a different nature. This assumption is reasonable, since in many cases the HH INNAV movements extend far beyond the port areas, which would not be expected for OGV assist movements. No independent estimate could be made for other potential tug boat movements that may not be fully represented in INNAV, such as additional work boat activities. Based on an understanding of how barge movements are viewed by the CG (as noted in Section 3.1), all tug boat activities associated with barge movements are expected to be represented in INNAV. However, 'return' tug boat trips for smaller tugs that may deliver a barge to a destination and return unladen may be under represented. The total estimated tug boat activity in eastern Canada for 2010 is provided in Table 4-17.

Table 4-17: Total Estimated Tug Boat Activity for 2010, Eastern Canada

Region	Annual Estimated Tug Boat Underway Hours by Class						
	HF	HH	HO	HS	HT	HW	Grand Total
5		1,047			106		1,153
6		3,971		0	1,153		5,124
7		2,841	4	14	1,034		3,894
8	3	1,227	88	355	11,069	201	12,944
9		4,315	16	571	7,277	107	12,286
10		11,023	158	278	5,032	274	16,764
11		12,951	1,021	482	10,210	766	25,429
12		6,958	1,007	759	8,502	261	17,486
13		471	310	1,052	2,886	676	5,396
14		451	1	1	1,530		1,983
15		450	275	32	329		1,086
16	425	9,972	5,006	6,277	12,458		34,139
17		3,681	1,321		5,478	394	10,875
18		1,125	130	110	1,055	8	2,428
19	607	4,908	4,321	23,186	2,297		35,320
20		709	155	647	2,151		3,662
Grand Total	**1,036**	**66,102**	**13,814**	**33,766**	**72,568**	**2,686**	**189,971**

4.2.2 Arctic

Independent investigations of the smaller vessel classes within the Arctic could not be completed during the project. However, an Arctic emissions inventory and forecast project will be conducted by Transport Canada in 2012, which will include small vessel investigations. For this reason the Arctic summaries should be considered inclusive of all OGV classes but representation of fishing and tug boat activity may not be complete.

Total Arctic activity is shown in Table 4-18 by mode of activity.

Table 4-18: 2010 Arctic Activity Summary by Mode

General Vessel Class	Annual Number of Trips	Total Anchor Time (hours)	Total Berth Time (hours)	Total Underway Time (hours)
Coast Guard	15	0	2,431	9,712
Fishing	46	0	25	30,842
INNAV Test	8	0	93	1,522
Merchant Bulk	18	17	4,933	3,455
Merchant Other	204	499	9,847	8,878
Merchant Passenger	51	124	558	5,153
Special Purpose	5	1	26	1,456
Tanker	137	402	8,301	6,941
Tug Boat	297	498	10,898	13,380
Grand Total	**781**	**1,541**	**37,112**	**81,338**

4.2.3 Western Canada

Table 4-19 provides a summary of the 2010 activity in western Canada by general vessel class, not including ferries, tugboats and fishing vessels. Summaries are provided for the total travel distance in Canadian waters and total time spent in underway, berth and anchor modes.

Table 4-19: 2010 Western Canada Activity Hours by Mode

General Vessel Class	Total Distance (nautical miles)	Total Anchor (h)	Total Berth (h)	Total Underway (h)
Coast Guard	137,611	1,093	168	39,612
Merchant Bulk	1,567,949	132,103	134,188	142,704
Merchant Container	803,273	714	32,818	45,990
Merchant Cruise	399,920		4,759	23,440
Merchant Other	485,818	6,225	27,549	38,509
Special Purpose	34,748	113	577	7,750
Tanker	305,818	10,082	16,091	27,551
Other	127,660	923	435	21,812
Grand Total	**3,862,796**	**151,252**	**216,584**	**347,368**

The activity hours noted in Table 4-19 cannot be directly compared to the previous estimate completed for BC shown in Table 2-5, since the inventory boundaries are different (the 2010 boundary extends 200 nautical miles whereas the 2005/6 inventory extends 50 nautical miles from shore). However, berthing and anchoring activity for the two inventories are comparable. Total berthing hours for the two inventories are very similar, whereas total anchoring hours in 2010 were 30% higher than 2005/6. It is expected that some of this increase in anchoring may have been due to remaining effects of the global economic slowdown and excess scheduling time for some of the ships (notably, Merchant Bulk ships).

Table 4-20 shows the distribution of estimated main engine loads attributed to each of the main OGV classes, not including cruise ships. As discussed in Appendix A, only three underway main engine load bins were used for the west due to lower data quality (compared to eastern Canada / Great Lakes).

Table 4-20: Distribution of Main Engine Loads by Vessel Class*

Vessel Class	Total Underway Time (h)	Underway Hours by Load Factor Bins		
		0.1	0.4	0.8
Merchant Bulk	142,704	19,165	23,676	99,864
Container	45,990	7,668	5,994	32,329
Merchant Other	38,509	6,807	5,070	26,632
Tanker	27,551	5,382	3,648	18,522
Other	21,812	9,846	6,481	5,485
Total	**276,567**	**48,867**	**44,869**	**182,832**

*Merchant Cruise is not included in this table.

Cruise Ship underway activity is shown in Table 4-21 as a summary of the estimated cruise ship engine loads by region of western Canada. Similar to the data for eastern Canada, the calculated power levels were binned to several categories, including 'berth' (base load), 'low' (less than 25% of maximum), 'mid' (25 – 50% of maximum) and 'high' (above 50% of maximum). These categories are used here for reporting purposes only. As described in Appendix A, any engine load from the 'base load' (estimated power level while at berth and anchor) to a load factor of 0.8 is possible, based on the vessel speed. For vessels with installed gas turbines, the maximum load factor on engines is limited to 0.5 (i.e., 50% of the total installed engine capacity, including the gas turbines).

Table 4-21: Cruise Ship Hours by Mode, Western Canada

Region	Time (hours) by Mode			
	Berth	Low	Mid	High
2	3,352	192	308	25
3	124	865	1,572	4,005
4	1,282	1,511	5,262	9,701
Grand Total	**4,759**	**2,568**	**7,141**	**13,731**

4.2.3.1 Fishing Vessels

Total fishing vessel activity in the VTOSS records by type of vessel is shown in Table 4-22.

Table 4-22: VTOSS Fishing Vessel Activity for 2010

Fishing Vessel	VTOSS Code	Annual Hours of Activity
Crab Boat	FC	624
Factory Ship	FF	2,936
Fishery Patrol	FP	58
Fishing Vessel	FV	31,597
Fishing Vessels (Generic)	F	1,418
Longliner	FL	1,625
Seiner	FN	96
Trawler	FT	8,196

Given that the fishing vessels tend to be smaller than the other classes of fishing vessels, it was expected that the VTOSS activity for some of the fishing vessel classes would be under-represented, similar to the case for eastern Canada. Table 4-23 provides a breakdown of the fishing vessel classes by size (LOA). The annual hours of activity by vessel size grouping and region in the VTOSS data is presented in Table 4-24.

Table 4-23: VTOSS Fishing Vessel Size Distribution

Vessel Counts in INNAV	Number of Vessels by Length Overall (LOA) (metres)						
	< 10	10 - 15	16 - 20	20 - 30	>30	Unknown	Grand Total
Dragger (Scallop, Clam etc)	0	0	0	2	11	2	15
Factory Ship	0	0	0	1	34	0	35
Fishery Patrol	0	0	0	0	1	0	1
Fishing Vessel	2	14	34	152	93	47	342
Fishing Vessels (Generic)	5	97	50	30	77	9	268
Longliner	0	0	0	6	11	0	17
Shrimp Boat	0	0	0	0	1	2	3
Trawler	0	0	1	19	19	1	40

Table 4-24: Annual Hours of FV Class Underway Activity in VTOSS for Western Canada

Region	Annual Activity Hours by Length Overall (LOA) (metres)						
	< 10	10 - 15	16 - 20	20 - 30	>30	Unknown	Grand Total
2	5	34	108	1,119	489	71	1,826
3	0	0	59	3,367	3,116	173	6,715
4	7	51	492	17,858	14,965	2,767	36,140
Total	**12**	**85**	**659**	**22,344**	**18,570**	**3,011**	**44,681**

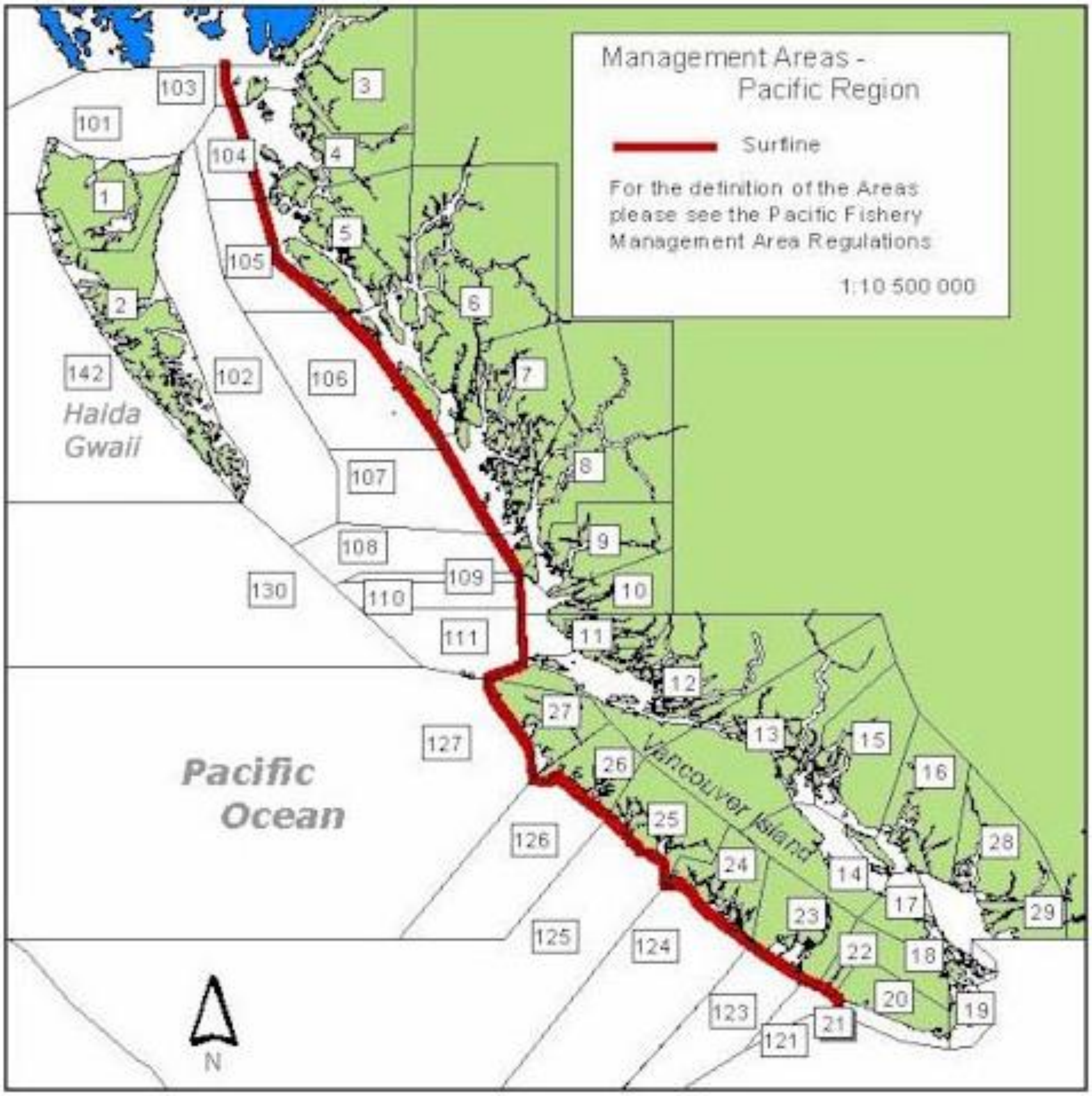
As expected, very little activity is present in the VTOSS data for the smaller vessels. Additionally, these smaller vessels tend to be in the F and FV (Generic Fishing and Fishing Vessel class respectively). The amount of activity for each vessel (hours noted in VTOSS) is small and on the order of 100 hours for the year. This differs considerably from the INNAV data in eastern Canada where much higher activity levels were found on average for the fishing vessels represented. Further analysis of the VTOSS data shows that the included activity corresponds to full underway travel and not the slower movements that may be associated with fishing within the fishing grounds. This was corroborated with the Coast Guard[30].

To complete an independent estimate of fishing vessel activity, the Department of Fisheries and Oceans Canada (DFO) Licensed Fishing Vessel Directory for the Pacific Region[31] was evaluated which yielded 4 766 ship records. The information available includes the Vessel Registration Number, Vessel name, LOA (m), Contact Owner, License and Area. The licenses were regrouped by management area as identified in Figure 4-1 and Table 4-25.

30 Personal communication with Ian Wade, Regional Program Specialist, MCTS Pacific Region. Fishing vessels tend to report during travel, but not during activity within the fishing grounds.

31 http://www-ops2.pac.dfo-mpo.gc.ca/ops/vrndirectory/VRNdirSelect.cfm

Figure 4-1: Pacific Fishery Management Areas for the British Columbia Coast[32]



[32] http://www.pac.dfo-mpo.gc.ca/fm-gp/maps-cartes/areas-secteurs/index-eng.htm

Table 4-25: License Area Descriptions for the Pacific Region

License Area	Description
CRAB AREA A	Areas 1, 2, 101 to 110, 130 and 142
CRAB AREA B	Areas 3 to 10
CRAB AREA E	Areas 20 to 27, 121 and 123 to 127
CRAB AREA G	Areas 11, 12, 13, 15 and 111
CRAB AREA H	Areas 14, 16 to 19 and Subarea 29-5
CRAB AREA I	Areas 28 and 29 excluding Subareas 29-5 and 29-8
CRAB AREA J	Subarea 29-8
GEODUCK AREA G	Areas 12 through 19, and 29.
GEODUCK AREA G	Areas 12, 14, 16, 17 and 29
GEODUCK AREA N	Areas 1 through 10 and related offshore areas.
GEODUCK AREA N	Areas 6 to 10
GEODUCK AREA W	Areas 20, 23, 24, 25, 26, 27 and related offshore areas.
HERRING SEINE GULF	Areas 14 to 18
HERRING SEINE PRINCE RUPERT	Area 5
RED SEA URCHIN AREA N	Areas 1 through 10, 101, 105, 106, 109 & 142
RED SEA URCHIN AREA S	Areas 11 through 29 & 123
ROCKFISH AREA INSIDE	Areas 13 to 19, and 28 and 29, and Subareas 12-1 to 12-13, 12-15 to 12-48 and Subareas 20-4 to 20 -7
ROCKFISH AREA OUTSIDE	Areas 1 to 11, 21, 23 to 27, 101 to 111, 121, 123 to 127, 130 and 142 and Subareas 12-14, and 20-1 to 20-3
SALMON AREA A SEINE	Areas 1 to 10, Subarea 101-7
SALMON AREA B SEINE	Areas 11 to 29 and 121
SALMON AREA C GILL NET	Areas 1 to 10, Subarea 101-7
SALMON AREA D GILL NET	Areas 11 to 15 and 23 to 27
SALMON AREA E GILL NET	Areas 16 to 22, 28, 29 and 121
SALMON AREA F TROLL	Areas 1 to 10, 101 to 110, 130 and 142
SALMON AREA G TROLL	Areas 11, 20 to 27, 111, 121, 123 to 127 and Subareas 12-5 to 12-16
SALMON AREA H TROLL	Areas 12 to 19, 28 and 29
SEA CUCUMBER AREA C	Portions of Areas 7, 8, 9 and 10

Table 4-25 (Cont'd): License Area Descriptions for the Pacific Region

License Area	Description
SEA CUCUMBER AREA G	Portions of Areas 12 and 13
SEA CUCUMBER AREA P	Subareas 4-3, 5-1, 5-2, 5-4, 5-5, 5-7, 5-11 to 5-24, 6-2, 6-3, 6-5 to 6-12, 6-14 to 6-16 and 6-26 to 6-28
SEA CUCUMBER AREA P	Portions of Areas 3, 4, 5 and 6
SEA CUCUMBER AREA W	Portions of Area 24

The total number of commercial fishing licenses as well as the average vessel LOA for the defined license areas is shown in Table 4-26.

Table 4-26: License Area Descriptions for the Pacific Region

License Area	Number of fishing licenses	Average vessel overall length (m)
CRAB AREA A	52	13.2
CRAB AREA B	11	9.5
CRAB AREA E	26	8
CRAB AREA G	16	9.2
CRAB AREA H	37	7.6
CRAB AREA I	50	9.4
CRAB AREA J	18	7.1
GEODUCK AREA G	6	10.9
GEODUCK AREA N	40	11.5
GEODUCK AREA W	9	12
HERRING SEINE GULF	238	21.2
HERRING SEINE PRINCE RUPERT	10	21.9
RED SEA URCHIN AREA N	17	9.8
RED SEA URCHIN AREA S	22	10.1
ROCKFISH AREA INSIDE	64	9.8
ROCKFISH AREA OUTSIDE	187	13
SALMON AREA A SEINE	92	19.2
SALMON AREA B SEINE	151	19.8
SALMON AREA C GILL NET	506	10.7

SALMON AREA D GILL NET	331	10.7

Table 4-26 (Cont'd): License Area Descriptions for the Pacific Region

License Area	Number of fishing licenses	Average vessel overall length (m)
SALMON AREA E GILL NET	336	10.4
SALMON AREA F TROLL	265	13.2
SALMON AREA G TROLL	158	12.9
SALMON AREA H TROLL	75	12.1
SEA CUCUMBER AREA C	32	9.8
SEA CUCUMBER AREA G	17	10.6
SEA CUCUMBER AREA P	33	10.1
SEA CUCUMBER AREA W	2	7.3
Other	1965	13.4

The following steps were taken to complete an independent estimate of the additional small vessel (F and FV) activity not represented in the CG records:

- Each License Area was assumed to have the number of active fishing vessels noted in Table 4-26, with the exception of License Areas with average LOA over 18.0 m where half of the vessels noted were assumed active and not represented in VTOSS;
- The licenses that could not be matched to a License Area ('Other') were ignored;
- The average annual activity hours per vessel from the 20m – 30m LOA F and FV vessels in VTOSS were ascribed to each active vessel (approximately 100 hours for the year for each vessel);
- Each active fishing vessel was assumed to have a main engine power rating equal to the average rating of all F and FV vessels in VTOSS within the 10m – 20m LOA range;
- Full underway engine use with a main engine load of 0.8 was applied for all estimated hours; and,
- An additional 2 months of fishing activity (with main engine load of 0.1) was added for all active vessels noted in Table 4-26 that could be associated with a License Area.

The total estimated fishing vessel activity for the west coast of Canada is provided in Table 4-27.

Table 4-27: Total Estimated Fishing Vessel Activity in Western Canada

Vessel Class	Region 2	Region 3	Region 4	Total
Dragger (Scallop, Clam etc.)	8	0	90	98
Factory Ship	23	408	1,953	2,383
Fishery Patrol	4	25	631	660
Fishing Vessel	292,581	203,161	3,915,158	4,409,900
Fishing Vessels (Generic)	85	700	2,482	3,267
Longliner	0	40	160	201
Seiner	7	0	14	20
Shrimp Boat	5	0	4	9
Trawler	84	92	1,577	1,754

4.2.3.2 Ferries

British Columbia Ferry Services Inc. (B.C. Ferries) operates all major vehicle and passenger ferries off of the coast of B.C. Additional ferries are operated inland by the province (as well as ferries operated in other western provinces). BC Ferries provided SLE with aggregate fuel consumption records for the year, representative of the activities on its 28 different routes. Each route and its approximate distance are identified in Table 4-28.

Table 4-28: BC Ferries Routes

Routes	Distance (in Nautical Miles)
01 - Tsawwassen - Swartz Bay	24
02 - Horseshoe Bay - Nanaimo	30
03 - Horseshoe Bay - Langdale	10
04 - Swartz Bay - Fulford Harbour	5
05 - Swartz Bay - Gulf Islands	28
06 - Vesuvius Bay - Crofton	3
07 - Saltery Bay - Earls Cove	10
08 - Horseshoe Bay - Snug Cove	3
09 - Tsawwassen - Gulf Islands	22
10 - Bear Cove - Bella Bella - Prince Rupert	274

11 - Prince Rupert - Skidegate	93
12 - Mill Bay - Brentwood	3

Table 4-28 (Cont'd): BC Ferries Routes

Routes	Distance (in Nautical Miles)
13 - Langdale - Gambier Island - Keats Island	7
17 - Comox - Powell River	17
18 - Texada Island - Powell River	5
19 - Gabriola Island - Nanaimo Harbour	4
20 - Thetis Island - Kuper Island - Chemainus	10
21 - Denman Island - Buckley Bay	1
22 - Hornby Island - Denman Island	1
23 - Quadra Island - Campbell River	2
24 - Cortes Island - Quadra Island	6
25 - Alert Bay - Sointula - Port Mcneill	20
26 - Skidegate - Alliford Bay	4
30 - Nanaimo - Tsawwassen	38
40 - Bear Cove – Mid Coast	450

A representative ferry that would likely be used on each route was identified and characterized from the BC Ferries fleet. It was assumed that all fuel is consumed in the main engines, due to lack of information on auxiliary engines that may be used on the ferries. The total activity estimates for BC Ferries are provided in Table 4-29 by region of western Canada.

Table 4-29: BC Ferries Activity Estimates (Engine Hours) by Region of Western Canada

Vessel Class	Region			Total
	2	3	4	
Merchant Ferry	14,509	4,763	58,193	77,466

4.2.3.3 Tug Boats

Tug boat activity includes barges and tow boats as well as harbour assist movements for vessels coming into and leaving a berth. All 2010 VTOSS tug boat activity for 2010 is listed in Table 4-30.

Table 4-30: 2010 VTOSS Tugboat Activity in Western Canada by Specific Vessel Class

Region	Annual Tug Boat Underway Hours by Class						
	General Tug	Harbour Tug	Ocean Tug	Supply Tug	Other Tug	Workboat	Grand Total
2	65,326	14	178	31	7,729		73,278
3	28,115				2,707		30,823
4	143,968	15	27	101	12,441	309	156,860
Total	**237,409**	**29**	**205**	**132**	**22,877**	**309**	**260,961**

Table 4-30 shows that VTOSS contains a great deal of HT (General Tug) activity, which is associated with barge movements[33]. Given the very low HH (Harbour Tug) activity, SLE assumes that none of the tugboat assist movements are represented in VTOSS. Similar to procedures taken for eastern Canada, a simple estimate of the total tugboat assist activity was made, assuming an average of 3 hours of HH use per OGV visit to berth. This estimate is shown in Table 4-31 by region of western Canada.

Table 4-31: Estimate of Tugboat Assist Activity*

OGV Class	Estimated Hours of HH Tug Boat Activity by Region of Western Canada			
	2	3	4	Total
MA	255		6	261
MB	5,043	744	747	6,534
MC	2,181	297	15	2,493
MG	1,188	93	300	1,581
MH	165		36	201
MM	3			3
MO	12			12
TC	144	3		147
TG	3			3
TL	723	78		801
TM	39			39
TO	30			30
TQ	6			6
TS	3			3
TT	285	18	6	309

33 SLE was informed by the Coast Guard that all barge movements should be represented in VTOSS data, since LOA is calculated from the tugboat and barge in combination, making all tug-barge combinations greater than the 24m reporting threshold. However, if a tugboat deposits its barge it may or may not report an unladen journey (e.g., back to berth).

TV	3	3		6

* These estimates are made by assuming an average of 3 hours of assist activity is required for each ship call to berth.

Tugboat activity data was supplied to SLE from Seaspan Marine Corporation. Seaspan is the largest tugboat operator in southern B.C. This information was supplied by tugboat type and hours of activity by region over the year. The Seaspan data was compared to the VTOSS data to evaluate the representativeness of the Coast Guard records (the Seaspan data is not shown here). The Seaspan activity hours in 2010 constitute less than half of the VTOSS HT activity for the year, which supports the expectation that VTOSS captures the majority of the tugboat towing activity in southern B.C. Further evaluation of tugboat movement data was considered beyond the scope of this project. The total estimated tugboat hours of activity for western Canada are shown in Table 4-32.

Table 4-32: Total Estimated Tug Boat Activity for 2010, Western Canada

Region	Annual Estimated Tug Boat Underway Hours by Class						
	General Tug	Harbour Tug	Ocean Tug	Supply Tug	Other Tug	Workboat	Grand Total
2	65,326	14	344	31	18,855		84,570
3	28,115				4,069		32,185
4	143,968	15	660	101	16,949	309	162,001
Grand Total	**237,409**	**29**	**1,004**	**132**	**39,873**	**309**	**278,756**

4.2.4 Additional Activity (Inland Lakes)

Table 4-34 provides information for additional ferry activity, mostly comprised of inland ferry movements. For each route, annual engine hours were calculated by multiplying the number of trips per year by the estimated one-way trip time. In a similar way, the total distance for each route is calculated by multiplying the number of trips per year by the estimated one-way trip distance. The number of trips per year was taken from available ferry schedules. Where a ferry did not have a fixed daily schedule, the number of one-way trips per year was estimated using the assumptions noted in Table 4-33, over an assumed 12 hour day. Where a trip distance was not found in the public schedules, GIS mapping was used to obtain an estimate.

Table 4-33: Ferry Trip Assumptions for Inland Routes

Estimated One-Way Trip Time t (mins)	Time Between One-Way Trips Regardless of Direction (mins)
$t < 5$	20
$5 \leq t < 10$	25
$10 \leq t < 20$	30

20 ≤ t	40

Table 4-34: Additional Ferry Activity by Province/Region

Province/Region	Number of Inland Routes	Annual Engine Hours	Total Distance (km)
Alberta	7	4,265	32,300
British Columbia	16	44,079	334,043
Manitoba	8	6,972	67,956
Saskatchewan	13	14,300	132,577
Northwest Territories	5	3,770	52,575
Yukon	2	1,333	19,506
Total	**51**	**74,721**	**638,960**

Table 4-35 identifies the information resources used to obtain the additional ferry information.

Table 4-35: Information Resources used for Each Province/Region in Western Canada

British Columbia	http://www.th.gov.bc.ca/marine/ferry_schedules.htm
Alberta	http://www.transportation.alberta.ca/1965.htm
Saskatchewan	http://www.highways.gov.sk.ca/ferry/ http://www.saskparks.com/riverhurst_ferry.htm
Manitoba	http://www.gov.mb.ca/mit/namo/schedule.html http://ldwhite68.tripod.com/ferries/ferry2mb.htm
Northwest Territories	http://www.dot.gov.nt.ca/_live/pages/wpPages/ferries.aspx#Lafferty http://www.dot.gov.nt.ca/_live/pages/wpPages/Open_Close_Dates_Ferries.aspx
Yukon	http://www.hpw.gov.yk.ca/trans/maintenance/george_black_ferry_stats.html http://www.511yukon.ca/textreport.html

4.3 Port-Level Data Investigations

Canadian Port Authorities, in some cases with the participation of Transport Canada, have recently been conducting port-level emission inventories. These inventories account for berthing and harbour movements of the commercial vessels that come to port in a calendar year. Since the vessel movements are determined directly from port ship call records, this presents an opportunity to evaluate the larger scale INNAV movement data with an independent dataset.

The port-level inventories are primarily concerned with berthing (and in some cases anchoring) activities and emissions. Two comparisons are made in this section for the ports of Montreal and Halifax with the 2010 INNAV data. Number of vessel calls by type, as well as average vessel anchoring and berthing times are evaluated.

4.3.1 Port of Montreal

Table 4-36 shows a comparison of the 2010 INNAV and Port of Montreal datasets. Several assumptions were made to match the Port of Montreal vessel classifications with the INNAV classifications. The 2010 INNAV records did not show substantial 'Tanker General' calls to the port. Similarly, the 2007 port records did not show substantial 'Merchant Chemical' calls to the port. This may be due to different classification schemes within the two datasets.

The following matching for vessel classes was assumed:

- 'Container' in the port records are Merchant Container in INNAV records;
- 'Tanker' in the port records are Merchant Tanker in INNAV records;
- 'Bulk Carrier' in the port records are Merchant Bulk in INNAV records;
- 'Tanker General' in the port records are Merchant Chemical in INNAV records; and
- 'Merchant General' in the port records are Merchant General in INNAV records.

Table 4-36: Data Comparison for Port of Montreal

Vessel Class	Year	Annual Visits	Berth Time/Visit	% Diff	Notes
Container	**2010**	**378**	**57**	**5%**	
	2007	464	54		
Tanker	**2010**	**454**	**47**	**51%**	Several vessels had long stays in 2010 (up to 15 days)
	2007	427	32		
Bulk Carrier	**2010**	**205**	**89**	**22%**	
	2007	273	73		
Tanker General	**2010**	**306**	**34**	**7%**	May be an imperfect match of vessel types
	2007	507	32		
Merchant General	**2010**	**152**	**43**	**-57%**	Few long stays were noted in 2010; several long stay occurred in 2007 (up to 15days)
	2007	83	100		

Both datasets showed no formal anchoring activity. This is logical, since ships that visit this port tend to use empty berths while waiting their allotted berth spot to load/unload[34]. In this sense the INNAV records agree, showing no formal anchoring at this port.

The number of ship calls for the year is lower in 2010 than 2007; however this is expected due to the economic downturn that began in 2008. Average berthing times per visit ('Berth Time/Visit') are a very good match for Container vessels and Tanker General and a good match for Bulk Carriers. Considerable difference is apparent for Tankers and Merchant General. As documented in the Port Montreal report, some of the vessels to the port can stay for very long periods. Vessels that have extended stays may significantly affect the average berth time per visit.

The INNAV records appear to be a good match to port level data at the Port of Montreal.

4.3.2 Port of Halifax

The Port of Halifax completed a port-level emissions inventory for the 2009 activity year that has not been published. A summary of the port visits in 2010 was completed to visualize the implications of the INNAV data at another leading Canadian port. This summary is shown in Table 4-37 for the major ship classes that visited the port in 2010.

Table 4-37: Data Summary for Port of Halifax

Vessel Class	Activity	Annual Visits	Time/Visit	Notes
Container	**Berth**	**694**	**13**	
	Anchor	0	0	
Tanker	**Berth**	**430**	**30**	Significant Anchoring
	Anchor	152	16	
Bulk Carrier	**Berth**	**37**	**155**	Several vessels stayed up to 24 days at berth
	Anchor	51	119	
Merchant RoRo	**Berth**	**91**	**30**	Anchor periods can be long
	Anchor	13	92	
Passenger	**Berth**	**129**	**10**	Good match to expectations
	Anchor	0	0	

[34] See the Port of Montreal Emissions Inventory for 2007, http://www.tc.gc.ca/media/documents/quebec-eng/rapport_emission_mtl_e.pdf.

The summary shows some interesting characteristics that can be verified with the port at a future time. Container berthing periods at this port are much shorter than those at the Port of Montreal and Bulk Carrier periods are much longer (although there are fewer Bulk Carrier calls). Passenger visits to the port relate to cruise ships. Based on published data for several other ports, 10 hours is the expected length of call for cruise ships.

Unlike Montreal, the Port of Halifax has a significant amount of anchoring activity that is flagged as such in the INNAV records. Consistent with expectations, Container ships do not anchor as they tend to be on tighter schedules than other classes of ship. As with Montreal, some vessels stay for extended periods at berth (Bulk Carriers in particular). Extended periods at anchor are also evident.

The INNAV berth and anchor implications for the Port of Halifax are reasonable and can be further evaluated by knowledgeable port staff. The summary shows that the INNAV data can include a significant amount of anchor activity for a particular port.

5. 2010 EMISSION ESTIMATES

5.1 Canada

The 2010 marine emission estimates for all of Canada are provided in Table 5-1. These estimates are re-expressed by vessel class in Table 5-2.

Table 5-1: 2010 Emissions Estimates for Canada by Activity Mode (tonnes)

Air Contaminant	Underway	Berthing	Anchoring	Total
NO_x	180,549	10,264	3,124	**193,938**
SO_x	91,396	7,942	2,839	**102,177**
CO	15,897	1,198	349	**17,444**
VOC	10,359	5,287	89	**15,736**
PM	12,950	907	312	**14,170**
PM_{10}	12,432	871	300	**13,603**
$PM_{2.5}$	11,438	801	276	**12,515**
NH_3	221	3	0	**224**
CO_2	7,681,089	770,871	223,556	**8,675,517**
CH_4	98	34	9	**141**
N_2O	203	20	6	**228**

Table 5-2: Total Emission Estimates for 2010 by Vessel Class (tonnes)

Vessel Class	Criteria Air Contaminants (CACs)								Greenhouse Gases (GHGs)		
	NOx	SO_x	CO	HC	PM	PM10	PM25	NH3	CO2	CH4	N2O
Coast Guard	2,746	43	224	98	56	53	49	3	136,117	1	3
Fishing	17,126	224	1,883	1,098	359	344	317	18	714,380	4	18
Merchant Bulk	45,892	30,370	4,070	1,623	3,946	3,788	3,485	48	1,991,140	38	53
Merchant Container	47,434	30,196	3,993	1,671	4,015	3,855	3,546	52	1,845,818	26	50
Merchant Cruise	10,466	5,235	921	406	768	737	678	19	563,529	5	14
Merchant Other	15,433	11,073	1,361	545	1,438	1,381	1,270	17	722,739	12	19
Merchant Passenger	15,020	4,937	1,506	572	806	774	712	21	916,972	23	23
Special Purpose	978	15	79	35	19	19	17	1	47,248	0	1
Tanker	29,519	19,893	2,673	9,339	2,577	2,474	2,276	31	1,308,443	27	35
Tug boat	8,773	183	685	325	176	169	155	13	403,505	3	11
War	552	9	50	24	10	10	9	1	25,626	1	1
Total	**193,938**	**102,177**	**17,444**	**15,736**	**14,170**	**13,603**	**12,515**	**224**	**8,675,517**	**141**	**228**

5.2 Eastern Canada and the Great Lakes

Table 5-3 provides the total 2010 emissions estimates by activity mode for eastern Canada / Great Lakes in 2010. The inventory is additionally presented by general vessel class and by region of eastern Canada in Tables 5-4 and 5-5.

Table 5-3: 2010 Emissions Estimates for Eastern Canada / Great Lakes by Activity Mode (tonnes)

Air Contaminant	Underway	Berthing	Anchoring	Total
NO_x	105,480	6,962	1,766	**114,208**
SO_x	52,019	5,202	1,438	**58,659**
CO	9,564	844	199	**10,608**
VOC	7,406	4,905	50	**12,362**
PM	7,424	595	160	**8,179**
PM_{10}	7,127	572	153	**7,852**
$PM_{2.5}$	6,557	526	141	**7,224**
NH_3	126	2	0	**128**
CO_2	4,552,708	545,797	128,005	**5,226,511**
CH_4	63	26	5	**94**
N_2O	120	14	3	**137**

The inventory is significantly higher than previous estimates (exception SO_x and PM), largely due to additional vessel activities previously omitted (fishing vessels, tug boats) as well as a more thorough accounting of harbour related activities. SO_x and PM estimates for 2010 are similar to the 2002 estimates, largely due to a small reduction in fuel sulphur levels at the international level and a very significant reduction for marine distillate sold domestically. Differences in methodologies also must be considered when comparing the two estimates.

Table 5-4: Total Emission Estimates for 2010 by Vessel Class, Eastern Canada / Great Lakes (tonnes)

Vessel Class	Criteria Air Contaminants (CACs)								Greenhouse Gases (GHGs)		
	NOx	SO_x	CO	HC	PM	PM_{10}	PM_{25}	NH_3	CO_2	CH_4	N_2O
Coast Guard	1,780	28	145	63	36	35	32	2	88,093	1	2
Fishing	12,657	173	1,515	898	282	271	249	13	549,920	3	14
Merchant Bulk	27,489	17,714	2,450	987	2,329	2,236	2,057	29	1,204,277	23	32
Merchant Container	22,296	14,407	1,882	778	1,903	1,827	1,681	24	896,429	14	24
Merchant Cruise	3,197	1,820	293	124	250	240	220	6	180,570	3	5
Merchant Other	9,321	6,876	836	333	890	854	786	11	462,914	8	12
Merchant Passenger	6,670	854	748	247	206	197	182	8	463,995	17	12
Special Purpose	877	14	71	30	18	17	16	1	43,085	0	1
Tanker	25,335	16,655	2,302	8,731	2,171	2,084	1,917	27	1,123,092	23	30
Tug Boat	4,429	116	350	164	92	89	81	6	207,095	1	5
Other	157	2	15	7	3	3	3	0	7,040	0	0
Total	**114,208**	**58,659**	**10,608**	**12,362**	**8,179**	**7,852**	**7,224**	**128**	**5,226,511**	**94**	**137**

Table 5-5: Total Emission Estimates for 2010 by Region of Eastern Canada / Great Lakes (tonnes)*

Region	Criteria Air Contaminants (CACs)								Greenhouse Gases (GHGs)		
	NOx	SO_x	CO	HC	PM	PM_{10}	PM_{25}	NH_3	CO_2	CH_4	N_2O
0	603	134	69	29	26	25	23	1	40,384	2	1
5	632	444	62	24	57	55	51	1	33,787	1	1
6	803	486	82	31	62	60	55	1	46,786	1	1
7	729	447	67	26	59	56	52	1	38,356	1	1
8	3,326	2,028	305	131	276	265	244	4	157,689	3	4
9	2,405	1,494	234	88	195	187	172	2	129,314	3	3
10	3,007	2,158	320	230	262	252	232	2	183,454	7	5
11	10,838	6,707	990	1,342	878	843	775	11	527,345	12	14
12	13,166	7,745	1,163	669	1,038	996	917	15	584,792	10	15
13	10,124	5,777	874	498	787	755	695	12	421,621	6	11
14	2,472	205	287	163	72	69	64	3	112,178	1	3
15	110	78	11	4	10	9	8	0	6,174	0	0
16	34,814	18,248	3,145	4,984	2,550	2,448	2,253	40	1,512,683	23	40
17	3,469	1,041	393	1,355	170	163	150	3	190,374	5	5
18	3,525	1,730	316	184	246	236	218	4	165,698	3	4
19	16,837	8,607	1,476	2,152	1,203	1,155	1,063	19	752,324	12	20
20	7,350	1,331	816	452	288	276	254	8	323,552	3	8
Total	**114,208**	**58,659**	**10,608**	**12,362**	**8,179**	**7,852**	**7,224**	**128**	**5,226,511**	**94**	**137**

*Region 0 represents vessel movements (segments) that cross over Canada's territorial waters demarcation. Only the portion that falls within Canada are 'counted'.

5.3 Arctic

Table 5-6 provides the total 2010 emissions estimates by activity mode for Canada's Arctic. The inventory is additionally presented by general vessel class and by region of eastern Canada in Tables 5-7 and 5-8.

Table 5-6: 2010 Emissions Estimates for Canada's Arctic by Activity Mode (tonnes)*

Air Contaminant	Underway	Berthing	Anchoring	Total
NO_x	3,856	236	10	**4,103**
SO_x	1,376	192	10	**1,579**
CO	319	26	1	**347**
VOC	140	7	0	**147**
PM	216	21	1	**238**
PM_{10}	207	21	1	**229**
$PM_{2.5}$	190	19	1	**210**
NH_3	5	0	0	**5**
CO_2	180,095	16,954	870	**197,919**
CH_4	2	1	0	**3**
N_2O	5	0	0	**5**

*Note: Canada's Arctic marine emissions have recently been updated in a separate Arctic study completed for Transport Canada. The values shown in Table ES-4 should not be used for other purposes[35]

[35] This report has not yet been released. Further information may be available from Ernst Radloff, Transport Canada, Transportation Development Centre Ottawa ON.

Table 5-7: Total Emission Estimates for 2010 by Vessel Class, Canada's Arctic (tonnes)*

Vessel Class	Criteria Air Contaminants (CACs)								Greenhouse Gases (GHGs)		
	NOx	SO_x	CO	HC	PM	PM10	PM25	NH3	CO2	CH4	N2O
Coast Guard	615	10	51	22	13	12	11	1	30,951	0	1
Fishing	721	11	59	27	15	14	13	1	35,115	0	1
Merchant Bulk	418	265	37	14	34	33	30	0	17,680	0	0
Merchant Other	728	560	65	25	72	69	63	1	37,880	1	1
Merchant Passenger	483	197	40	16	29	27	25	1	20,409	0	1
Special Purpose	38	1	3	1	1	1	1	0	1,913	0	0
Tanker	672	526	61	24	67	64	59	1	36,255	1	1
Tug boat	429	9	31	16	8	8	7	1	17,715	0	0
Total	**4,103**	**1,579**	**347**	**147**	**238**	**229**	**210**	**5**	**197,919**	**3**	**5**

*Note: Canada's Arctic marine emissions have recently been updated in a separate Arctic study completed for Transport Canada. The values shown in Table ES-4 should not be used for other purposes

Table 5-8: Total Emission Estimates for 2010 by Region of Canada's Arctic (tonnes)*

Region	Criteria Air Contaminants (CACs)								Greenhouse Gases (GHGs)		
	NOx	SOx	CO	HC	PM	PM_{10}	PM_{25}	NH_3	CO_2	CH_4	N_2O
1	477	26	37	17	11	11	10	1	21,412	0	1
21	3,475	1,457	296	125	215	206	190	5	168,771	2	4
22	150	95	14	5	12	12	11	0	7,735	0	0
TOTAL	**4,103**	**1,579**	**347**	**147**	**238**	**229**	**210**	**5**	**197,919**	**3**	**5**

*Note: Canada's Arctic marine emissions have recently been updated in a separate Arctic study completed for Transport Canada. The values shown in Table ES-4 should not be used for other purposes

5.4 West Coast

Table 5-9 provides the total 2010 emissions estimates by activity mode for the west coast. The inventory is additionally presented by general vessel class and by region of western Canada in Tables 5-10 and 5-11.

Table 5-9: 2010 Emissions Estimates for Canada's West Coast by Activity Mode (tonnes)

Air Contaminant	Underway	Berthing	Anchoring	Total
NO_x	71,213	3,066	1,348	**75,628**
SO_x	38,001	2,549	1,391	**41,940**
CO	6,014	327	148	**6,489**
VOC	2,813	375	39	**3,227**
PM	5,311	291	151	**5,753**
PM_{10}	5,099	279	145	**5,523**
$PM_{2.5}$	4,691	257	134	**5,081**
NH_3	90	1	0	**91**
CO_2	2,948,286	208,120	94,681	**3,251,087**
CH_4	33	7	4	**44**
N_2O	78	5	2	**86**

As with eastern Canada, the inventory is significantly higher than previous estimates due to additional vessel activities previously omitted (fishing vessels, tug boats, ferries) but also to a much larger geographical boundary (200 nautical miles from shore, as compared to 50 nautical miles for the 2005/6 inventory).

Table 5-10: Total Emission Estimates for 2010 by Vessel Class, Canada's West Coast (tonnes)

Vessel Class	Criteria Air Contaminants (CACs)								Greenhouse Gases (GHGs)		
	NOx	SO_x	CO	HC	PM	PM10	PM25	NH3	CO2	CH4	N2O
Coast Guard	352	5	28	13	7	7	6	0	17,073	0	0
Fishing	3,748	41	308	173	62	59	55	3	129,344	1	3
Merchant Bulk	17,985	12,391	1,583	621	1,582	1,519	1,398	18	769,182	15	21
Merchant Container	25,138	15,789	2,110	894	2,112	2,028	1,865	28	949,390	12	26
Merchant Cruise	7,269	3,416	628	283	518	497	457	13	382,960	3	10
Merchant Other	5,384	3,636	460	187	477	458	421	5	221,945	3	6
Merchant Passenger	7,867	3,886	718	309	572	550	506	13	432,568	5	11
Special Purpose	63	1	5	3	1	1	1	0	2,250	0	0
Tanker	3,512	2,712	311	584	339	325	299	4	149,095	3	4
Tug boat	3,915	58	303	145	75	72	67	6	178,694	1	5
War	396	6	35	16	7	7	6	0	18,586	1	1
Total	**75,628**	**41,940**	**6,489**	**3,227**	**5,753**	**5,523**	**5,081**	**91**	**3,251,087**	**44**	**86**

Table 5-11: Total Emission Estimates for 2010 by Region of Canada's West Coast (tonnes)

Region	Criteria Air Contaminants (CACs)								Greenhouse Gases (GHGs)		
	NOx	SOx	CO	HC	PM	PM10	PM25	NH3	CO2	CH4	N2O
2	8,133	4,681	766	590	603	579	533	7	438,859	11	11
3	5,651	2,778	498	225	402	386	355	8	278,722	3	7
4	61,844	34,481	5,225	2,412	4,748	4,558	4,194	76	2,533,506	30	67
TOTAL	**75,628**	**41,940**	**6,489**	**3,227**	**5,753**	**5,523**	**5,081**	**91**	**3,251,087**	**44**	**86**

6. SENSITIVITY ANALYSIS

Since the MEIT estimation methodologies were updated for Version 4.0, a sensitivity analysis was conducted to determine the potential impact of the revised methods on the inventory estimates. Although many updates were accomplished, most of the revisions do not have a major impact on the inventory estimates as a whole. The methodology changes that have the potential to significantly affect the inventory outcomes are the following:

- Determination of vessel main engine load from ship speed for most of the large commercial vessel classes;
- Revised engine load calculation scheme for cruise ships, loosely based on a previous method employed by the BC Chamber of Shipping;
- Estimation of manoeuvring, berthing and anchoring emissions directly from the CG records (e.g., not from assumed vessel and port profiles); and,
- Simulation of additional tug boat, ferry and fishing vessel activity using surrogate information.

The impact of these changes is more significant for eastern Canada and therefore the sensitivity tests focus on eastern Canada and not the west. The first three changes noted above were evaluated with alternative estimation schemes through use of a previous version of MEIT (V3.5). No alternative estimates could be made for tug boat, ferry and fishing vessels.

6.1 Main Engines: Alternative Estimates

The MEIT V3.5 framework was used to develop an alternate estimate of underway emissions for the main OGV vessel classes. This alternate estimate allows comparison of a distance-based estimate (V3.5) with a time-based estimate (V4.0).

As previously noted, MEIT V3.5 applies an origin – destination (OD) approach where time of travel is calculated from the distance of the voyage and the assumed voyage speed. The distance of each trip and the percentage of the distance in each region transited is another key input for the OD approach. The distances in eastern Canada were measured along shipping lanes on navigational charts for domestic trips and to the expected entry and exit points along Canada's waterway boundaries for the international trips.

A comparison was conducted for the entire eastern Canada / Great Lakes inventory by re-calculating the vessel underway CO_2 emissions for several significant OGV classes with MEIT V3.5. This approach applies a higher average ME load factor to that used in the 2010 inventory, but over a shorter period of time. MEIT V3.5 does not have defined distances for every OD pair found in the 2010 INNAV records for Eastern Canada. For this reason, the MEIT V4.0 distance estimates (made by linearly connecting the INNAV voyage points) were used instead.

The two inventory estimates are shown in Table 6-1 by OGV vessel class.

Table 6-1: Comparison of Underway Emission Estimates, MEIT V4.0 versus MEIT V3.5

Vessel Class	Underway CO_2 Emission Estimates (tonnes)	
	MEIT V4.0 (Speed-based Approach)	MEIT V3.5 (OD Approach)
Merchant Bulk	1,026,735	925,712
Merchant Container	839,046	924,006
Merchant Cruise	152,514	305,382
Merchant Other	394,528	384,792
Tanker	942,166	896,073
Total	**3,354,989**	**3,435,965**

The Comparison in Table 6-1 implies that for the inventory as a whole, the revised ME emission methodology itself does not cause a large difference (comparisons for the other air contaminants would be similar on a percent difference basis), assuming reasonably correct distance estimates. However, a significant difference is noted for Merchant Cruise and Merchant Container classes. These differences are likely caused by the 2010 voyage speeds (and implied engine loads) being substantially lower than the assumed voyage speeds and engine loads applied in the older model. The much higher cruise emissions in MEIT V3.5 are caused in part by vessels that have gas turbine as well as diesel engines (the V3.5 methodology for cruise vessels, as applied here, uses the total installed engine capacity).

There have been clear indications in the public media that the large container ship lines have been evaluating and using lower vessel speeds during the last several years[36]. The average container ship speeds, as estimated through the INNAV analysis completed for the 2010 inventory, imply that international container ships that visited Canadian ports in 2010 travelled at slower speeds than were used in previous years. The comparison in Table 6-1 shows that a savings in fuel consumption (and emissions) likely occurred as a result.

[36] For example, gCaptain, an online news website for the maritime sector has been reporting on lower containership speeds. See http://gcaptain.com/maersk?32053

To further evaluate differences in the underway estimation scheme, containership emissions by region of Eastern Canada were extracted from MEIT V3.5 and MEIT V4.0. These emission estimates are displayed in Table 6-2.

Table 6-2: Comparison of MC Underway Emission Estimates, MEIT V4.0 versus MEIT V3.5, by Region of Eastern Canada

Region	MC Underway CO2 Emission Estimates (tonnes)	
	MEIT V4.0 (Speed-based Approach)	MEIT V3.5 (OD Approach)
5	7	6
6	23	18
7	37	23
8	364	260
9	270	205
10	10,246	16,498
11	96,770	123,603
12	105,239	112,182
13	95,402	98,252
14	96	112
15	96	109
16	315,182	363,432
17	1,995	1,928
18	33,101	36,866
19	155,679	142,390
20	24,540	28,124
Total	**839,046**	**924,006**

Table 4-3 shows that Merchant Container ships were found to travel at just 65% and 59% of their maximum vessel cruise speeds in Regions 11 and 16, respectively. Table 6-2 shows that there is a significant decrease in the estimated containership emissions with MEIT V4.0, even with the longer voyage times accounted for.

6.2 Berthing Emissions: Alternative Estimates

Another key element of the OD approach is the use of port profiles to assign berth times and manoeuvring distances by vessel type for each port. Average berth times by port and vessel class were determined for the 2002 inventory by averaging the duration between vessel arrival and departure for concurrent trip segments. Vessel manoeuvring distance estimates for port approaches were developed based on the experience of master mariners and their knowledge of port boundary locations where speed reductions were required. Manoeuvring was assumed to occur at 5 knots. An example of the port profile information is shown in Table 6-3 for Merchant Containers at a select number of port regions. As indicated, average berthing periods were assumed to be the same at the different Canadian ports.

Table 6-3: 'Activity Profile' Table Excerpt from MEIT V3.5

GEN_TYPE	Port	DistanceManeuvering	AvgDocksideHours
MC	ABY	3.7	38.4
MC	AG4	3.7	38.4
MC	AGC	3.7	38.4
MC	AGW	3.7	38.4
MC	AKP	3.7	38.4
MC	AKU	3.7	38.4
MC	ALC	3.7	38.4
MC	AMR	3.7	38.4
MC	APK	3.7	38.4
MC	AQB	3.7	38.4

A comparison of berthing CO_2 emissions from the two different methods is shown in Table 6-4.

Table 6-4: Comparison of Berthing Emissions for East Coast / Great Lakes: MEIT V4.0 Versus MEIT V3.5

Vessel Class	Berthing CO_2 Emission Estimates (tonnes)	
	MEIT V4.0	MEIT V3.5
Merchant Bulk	132,123	241,801
Merchant Container	52,425	84,271
Merchant Cruise	27,657	11,016
Merchant Other	57,960	75,783
Tanker	116,508	120,157
Total	**386,672**	**533,029**

This comparison shows that berthing emission estimates are generally reduced with MEIT V4.0, with the exception of cruise ships. This is due to berthing times from the INNAV data being lower than those previously assumed through the ship class profiles for several ports (e.g., Halifax). The higher cruise ship berthing emissions are largely caused by the revised engine load methodology and not greater berth time. The revised engine load methodology for cruise ships implies a greater base load on average for vessels while docked.

It should be noted that the 2010 inventory berthing emissions as a whole (MEIT V4.0) are higher than those included in the 2002 inventory (shown in Table 2-5). Boiler emissions were not included in the 2002 inventory. Differences in AE loads at berth were also different for some vessel classes (Merchant Bulk in particular). The addition of boiler emissions at berth is of greater significance for CO_2 compared to other air contaminants (NO_x and PM in particular).

7. BACKCAST AND FORECAST INVENTORIES

Forecasts are achieved by scaling the activity level (e.g., ship movements) and the emission rates separately. While the total level of shipping activity may increase, it is expected that emissions from ships will decrease for each unit of energy used (for some of the air contaminants). The future emission and fuel standards by year are expressed in Chapter 3. Applying the future emission rates requires determination of ship replacement (rollover).

In addition to future emission rate improvements on a g/kWh basis, the ship Energy Efficiency Design Index (EEDI) has been adopted by the IMO Marine Environment Protection Committee (MEPC) as a measure of the CO_2 emission performance of ships. A ship's EEDI value is calculated on characteristics of the ship at build, incorporating parameters including ship capacity, engine power and fuel consumption. As currently drafted, the EEDI will result in a reduction of CO_2 emissions. However, it will also reduce emissions of the CACs.

Backcasts also require assumption of ship replacement, although no distinction can be made for emission rates for vessels built before 2000. The backcasts are subject to historical fuel criteria, which affect emission rates of SO_x and PM. The backcast fuel assumptions applied in the model that are different than the 2010 fuel characteristics are as follows:

- Domestic MDO had a sulphur content of 1.0% S for 2005 and all prior years;
- Domestic HFO had an average sulphur content of 1.7% for 2005 and all prior years;
- International HFO had an average sulphur content of 2.7% for 2005 and all prior years

The backcast fuel assumptions are simplistic, due to lack of information that can be traced back to 1980. The international HFO value relates to IMO literature[37] for 2000 and 2005, domestic HFO and MDO to the previous inventory completed for eastern Canada[38]. It is possible that the average sulphur levels were significantly different than these values during 1980-1995.

7.1 MARPOL Annex VI Energy Efficiency Regulations

MARPOL Annex VI now has a chapter 4 as of March 2012 that stipulates regulations on energy efficiency for ships through EEDI (new ships built after 2013) and Ship Energy Efficiency Management Plan (SEEMP)

[37] IMO Marine Environmental Protection Committee, 2010. Prevention of Air Pollution from Ships, Sulphur Monitoring for 2009. Available from http://www.rina.org.uk/hres/mepc%2061_5.pdf.

[38] Levelton Consultants Ltd., 2006. Marine Emission Inventory Study: Eastern Canada and Great Lakes. Prepared for Transportation Development Centre of Transport Canada.

requirements for all ships. An example of a SEEMP component is to set a maximum operational cruise speed below the design speed to save fuel. Other components may be careful route selection to avoid inclement weather and more frequent maintenance actions on propellers or engines.

EEDI may be easily understood by consider the following simplified formula:

$$\mathrm{EEDI} = \frac{\mathrm{CO_2\ Emissions}}{\mathrm{Transport\ Work}}$$

CO_2 emissions are calculated from combustion of fuel, including propulsion and auxiliary engines and boilers. Table 7-1 provides the IMO EEDI reduction percentages and related criteria by vessel type, size (DWT) and year of implementation.

Table 7-1: Reduction Factors (as Percentages) for the EEDI Relative to the EEDI Reference Value

Ship Type	Size	Phase 0 (Jan 2013)	Phase 1 (Jan 2015)	Phase 2 (Jan 2020)	Phase 3 (Jan 2025)
Bulk Carrier	≥20,000 DWT	0	10	20	30
	10,000–20,000 DWT	N/A*	0–10**	0–20**	0–30**
Gas Carrier	≥10,000 DWT	0	10	20	30
	2,000–10,000 DWT	N/A*	0–10**	0–20**	0–30**
Tanker	≥20,000 DWT	0	10	20	30
	4,000–20,000 DWT	N/A*	0–10**	0–20**	0–30**
Container Ship	≥15,000 DWT	0	10	20	30
	10,000–15,000 DWT	N/A*	0–10**	0–20**	0–30**
General Cargo Ships	≥15,000 DWT	0	10	15	30
	3,000–15,000 DWT	N/A*	0–10**	0–15**	0–30**
Refrigerated Cargo Carriers	≥5,000 DWT	0	10	15	30
	3,000–5,000 DWT	N/A*	0–10**	0–15**	0–30**
Combination Carriers	≥20,000 DWT	0	10	20	30
	4,000–20,000 DWT	N/A*	0–10**	0–20**	0–30**

* No required EEDI applies.

** Reduction factor to be linearly interpolated between the two values dependent upon vessel size; the lower value of the reduction factor is to be applied to the smaller ship size.

As noted, 2015 is the first year the efficiency standards will be mandatory. However, the standards do not apply to all ship classes (the largest cargo vessels are targeted) and capacities (DWT). Additionally, an exemption clause is present for developing countries and it is not clear what percentage of the international fleet may opt out. The expectation is that compliance will be 100% for new ships and less than 100% for existing ships (through SEEMP). It is also important to note that these standards are relative to the average efficiency of ships built between 1999 and 2009[39].

The IMO modelling of the potential CO_2 emissions reductions due to SEEMP includes a 'low' scenario with 30% uptake and a 'high' scenario with 60% uptake from the international fleet. Their modelling includes determination of a baseline for the ship classes noted in Table 7-1. The forecasts for the Canadian national inventory must relate to the 2010 baseline and as such simplifications are required to incorporate the new IMO efficiency regulations. Application of these regulations within the inventory forecasts was accomplished through 'low' and 'high' forecast scenarios with the following approach:

- Only the ship classes noted in Table 7-1 are affected, for both EEDI and SEEMP regulations;
- EEDI are applied according to the schedule, for new ships introduced to the fleet. Ship rollover is identified in Section 7.2;
- For effected ships, the EEDI percent reductions are applied as reductions to the total ship underway fuel consumption and emissions from all sources (main and auxilliary engines, boilers) as determined in the 2010 Canadian marine inventory;
- For the remaining fleet without EEDI requirements, the 'low' scenario assumes 30% of the fleet will achieve the EEDI percent reductions as reductions to the underway fuel consumption and emissions measures as determined in the 2010 Canadian marine inventory.
- For the remaining fleet without EEDI requirements, the 'high' scenario assumes 60% of the fleet will achieve the EEDI percent reductions as reductions to the underway fuel consumption and emissions measures as determined in the 2010 Canadian marine inventory.

The necessary assumption that the 2010 inventory is a suitable baseline with which to apply the IMO efficiency standards is an inherent uncertainty in the approach. It is expected that, to some degree, efficiency gains are already included in the 2010 inventory, for at least the containership class of vessel.

7.2 Ship Rollover Assumptions

The existing fleet of ships serving Canada's ports is identified in Table 4-1 by age distribution. The information includes those vessels represented in the Coast Guard data, meaning that some classes, fishing vessels and tugboats in particular, are not well represented.

[39] See: http://www.imo.org/mediacentre/hottopics/ghg/documents/report%20assessment%20of%20imo%20mandated%20energy%20efficiency%20measures%20for%20international%20shipping.pdf for a discussion of this topic, as well as simulations of emission reduction scenarios that may result.

In future years, the distribution of vessels in Canada will be newer on average than the 2010 distribution. The simulation of the age distribution of future vessel fleets can practically be achieved using one of three different methods (each of which has been used previously in Canada[40]): 1) A set annual replacement rate (% of fleet) is applied with the oldest vessels being replaced as time advances; 2) A scrappage age is set and when a vessel is projected to meet this age it is immediately replaced with a new vessel of that year; and 3) the relative age distribution of the fleet is preserved.

Ship rollover was set in the model based on the third option identified above. One desirable feature of method #3 is that, when applied separately for each ship class, those ship classes that currently are experiencing a growth in usage with a more frequent introduction of newer vessels remain with this trend in the future. For example, new (and larger) container ships are being introduced more frequently than bulk carrier ships and this trend should be expected to continue in the future with the current Canadian projections of containerized trade.

This rollover assumption methodology effectively means that if 10% of vessels in 2010 were built during 2008 to 2010 then 10% of simulated vessels in 2015 are assumed to have been built from 2013 to 2015. For the backcasts, this same approach was used, moving the relative age distribution back in time. It should be noted that this approach is much more reasonable for a large shipping fleet and therefore the backcasts/forecasts have greater relevance at larger regional scales.

7.3 Activity Assumptions

Growth rates by vessel class and forecast year are identified in Tables 7-2 and 7.3 for eastern and western Canada respectively. The Arctic growth rates were assumed to be identical to those for eastern Canada, due to lack of alternative information. These rates were set based on commodity data in past years (backcasts) and projections for the future years (forecasts). A combined approach was used to utilize the best sources of information available. Commodity forecasts from Transport Canada were last developed prior to the economic downturn in 2008 and therefore their representativeness is suspect. Data was requested from several of Canada’s largest ports (Metro Vancouver and Prince Rupert in the west, Montreal and Halifax in the east) to supplement the Transport Canada data. Not one of these ports were willing to provide commodity forecasts beyond 2015. Additionally, historical cruise data was available from the Northwest and Canada Cruise Association (NWCCA).

[40] MEIT V3.5 has rollover method #1, set at 2%/year. The 2002-2007 Arctic Inventory applied method #2 with a scrappage age of 25 years, based on a clear expectation (in 2007) that most of the current vessels would be replaced by 2025. Many of the active vessels in 2007 were of age 40 years or more, suggesting that a great deal of the existing fleet would be replaced in the near future. Recent Canadian port inventories have applied method #3 to the landside sources such as cargo handling equipment and trucks.

The growth rates are relative to the commodity throughputs experienced in 2010 and are used to linearly scale the ship activity (hours of engine use) for the backcast and forecast years. A rate greater than 1.0 causes an increase in ship engine hours and a rate less than 1.0 a decrease. The following steps were taken to develop the rates shown in Tables 7-2 and 7-3:

- Transport Canada commodity data for 1985 – 2005 was used to develop the backcast rates by specific vessel class. The mapping of the commodities to the vessel classes is identical to that previously used by Transport Canada, as expressed in the 2007 marine inventory report for eastern Canada[41];
- The growth rates for 1985 - 1990 for many of the vessel classes were set based on the aggregate annual commodity levels since much less detail was available in the TC commodity data for these years;
- 1980 rates were set equal to the 1985 rates, due to lack of available data;
- Forecast rates were developed by assuming the rate of increase for the previous Transport Canada commodity forecasts expressed in Weir, 2008 between 2010 and 2020 could be extended to represent 2015 – 2030; and,
- the backcast and forecast rates identified above were replaced if better data could be sourced from either the major ports or the NWCCA. Specifically, the following replacements were made:
  - Merchant Bulk and Merchant Container growth rates were set based on port 'dry bulk' and 'containerized (TEU)' data for 1995 – 2005 and port forecasts for 2015; and
  - Merchant Cruise growth rates were set based on NWCCA passenger data back to 1980 and port forecasts for 2015.

In general, the historical NWCCA and port data agrees with the historical Transport Canada data reasonably well, with the exception of autos and containerized goods. It was assumed that the port data in TEU would provide a better basis for growth rates than the Transport Canada data in tonnes, since container ship capacity is more commonly expressed in TEUs. The Transport Canada forecast rates were not considered ideal and therefore the 2015 Merchant Auto, Merchant Bulk, Merchant Container and Merchant Cruise growth rates were set based on the commodity/passenger projections from the ports. In some cases these projections are much higher than the Transport Canada forecast rates and in those cases the 2015 rates were held constant in the future years until the Transport Canada growth rates exceeded them (which never occurred for Merchant Bulk).

[41] Weir Marine Engineering, 2008. 2007 Marine Emissions Inventory and Forecast Study. Prepared for Transportation Development Centre, Transport Canada.

In all cases, exceptions were made for fishing vessels (F) and Merchant Ferry (MF) vessels. Fishing levels were held constant for all years, due to lack of data and MF levels were set based on the recent national population trend from Statistics Canada (6.3% increase (decrease) each five year period).

Table 7-2: Growth Rates by Vessel Class (Eastern Canada)

Ship Class	1980	1985	1987	1990	1995	2000	2005	2010	2015	2020	2025	2030
F	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
HO	0.66	0.66	0.71	0.72	0.77	0.91	1.09	1.00	1.05	1.10	1.16	1.21
MA	0.66	0.66	0.71	0.72	0.77	0.91	1.09	1.00	1.18	1.18	1.18	1.19
MB	0.54	0.54	0.56	0.87	0.95	1.14	1.15	1.00	1.34	1.34	1.34	1.34
MC	0.48	0.48	0.56	0.62	0.63	0.88	1.02	1.00	1.27	1.50	1.75	1.99
MF	0.69	0.71	0.74	0.78	0.83	0.88	0.94	1.00	1.06	1.13	1.20	1.28
MG	0.66	0.66	0.71	0.72	0.77	0.91	1.09	1.00	1.06	1.14	1.21	1.28
MH	0.66	0.66	0.71	0.72	1.86	1.43	1.54	1.00	1.06	1.11	1.16	1.21
MM	0.66	0.66	0.71	0.72	0.62	0.68	1.04	1.00	1.06	1.08	1.12	1.16
MO	0.66	0.66	0.71	0.72	0.77	0.91	1.09	1.00	1.06	1.07	1.10	1.14
MR	0.66	0.66	0.71	0.72	4.97	3.28	1.26	1.00	1.06	1.14	1.21	1.28
MS	0.66	0.66	0.71	0.72	0.34	0.09	0.90	1.00	1.06	1.03	1.04	1.06
MW	0.10	0.10	0.14	0.18	0.19	0.49	0.62	1.00	1.37	1.37	1.37	1.37
TC	0.66	0.66	0.71	0.72	0.50	0.72	1.25	1.00	1.04	1.07	1.11	1.15
TG	0.66	0.66	0.71	0.72	2.77	2.32	2.56	1.00	1.04	1.08	1.12	1.16
TL	0.66	0.66	0.71	0.72	0.20	0.28	0.48	1.00	1.04	1.09	1.13	1.17
TM	0.66	0.66	0.71	0.72	0.43	0.62	0.62	1.00	1.05	1.10	1.15	1.20
TO	0.66	0.66	0.71	0.72	3.65	1.97	1.06	1.00	1.05	1.11	1.16	1.22
TQ	0.66	0.66	0.71	0.72	0.04	0.04	0.03	1.00	1.03	1.05	1.08	1.10
TT	0.66	0.66	0.71	0.72	0.66	0.69	1.57	1.00	1.03	1.07	1.10	1.14
TU	0.66	0.66	0.71	0.72	0.73	0.42	1.13	1.00	1.03	1.06	1.09	1.12
TV	0.66	0.66	0.71	0.72	0.73	0.42	1.13	1.00	1.03	1.06	1.09	1.12

Table 7-3: Growth Rates by Vessel Class (Western Canada)

Ship Class	1980	1985	1987	1990	1995	2000	2005	2010	2015	2020	2025	2030
F	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00
HO	0.72	0.72	0.84	0.79	0.52	0.91	1.47	1.00	1.05	1.10	1.16	1.21
MA	0.72	0.72	0.84	0.79	0.44	0.84	1.19	1.00	1.18	1.21	1.31	1.42
MB	0.23	0.23	0.31	0.82	0.95	0.92	0.84	1.00	1.29	1.29	1.29	1.29
MC	0.08	0.08	0.11	0.13	0.19	0.43	0.75	1.00	1.39	1.49	1.73	1.97
MF	0.74	0.74	0.76	0.78	0.83	0.88	0.94	1.00	1.06	1.13	1.20	1.28
MG	0.72	0.72	0.84	0.79	3.74	2.84	2.20	1.00	1.05	1.11	1.16	1.21
MH	0.72	0.72	0.84	0.79	0.52	2.07	0.66	1.00	1.05	1.10	1.15	1.20
MM	0.72	0.72	0.84	0.79	1.27	1.43	1.58	1.00	1.05	1.10	1.15	1.19
MO	0.72	0.72	0.84	0.79	0.99	1.91	0.24	1.00	1.03	1.07	1.10	1.14
MR	0.72	0.72	0.84	0.79	0.84	0.86	0.90	1.00	1.07	1.14	1.21	1.27
MS	0.72	0.72	0.84	0.79	0.84	0.86	0.90	1.00	1.01	1.03	1.04	1.06
MW	0.42	0.42	0.50	0.61	0.94	1.66	1.59	1.00	1.25	1.25	1.25	1.25
TC	0.72	0.72	0.84	0.79	0.30	0.08	0.37	1.00	1.03	1.06	1.09	1.12
TG	0.72	0.72	0.84	0.79	0.27	0.29	0.15	1.00	1.04	1.08	1.12	1.15
TL	0.72	0.72	0.84	0.79	0.84	0.77	0.64	1.00	1.04	1.08	1.12	1.16
TM	0.72	0.72	0.84	0.79	1.22	2.14	1.55	1.00	1.04	1.09	1.13	1.17
TO	0.72	0.72	0.84	0.79	0.83	0.17	0.98	1.00	1.06	1.12	1.18	1.24
TQ	0.72	0.72	0.84	0.79	0.84	0.86	0.90	1.00	1.01	1.03	1.04	1.05
TT	0.72	0.72	0.84	0.79	0.11	0.11	0.70	1.00	1.03	1.05	1.08	1.10
TU	0.72	0.72	0.84	0.79	0.31	0.07	0.38	1.00	1.04	1.07	1.11	1.14
TV	0.72	0.72	0.84	0.79	0.31	0.07	0.38	1.00	1.03	1.06	1.09	1.12

7.4 Backcast / Forecast Inventories

The backcast and forecast marine inventories for Canada are provided in Tables 7-4a and 7-4b. The forecast inventories are subject to the IMO 'high' (7-1) and 'low' (7-2) SEEMP assumptions for the years 2015-2030. The backcast and baseline (2010) estimates are the same for both scenarios.

As noted in Tables 7-2 and 7-3, ship traffic to all areas of Canada is expected to increase. Both the high and low scenarios in Tables 7-4a and 7-4b show an increase in fuel consumption and GHG emissions. Estimates for the CACs vary: any contaminant that has an association with fuel sulphur level is shown to decrease by 2015 (SO_x and PM) due to the North American ECA, whereas contaminants with little to no association with fuel sulphur are shown to rise. NO_x emissions decrease substantially by 2030, due to lower emission rates associated with newer vessels introduced to the fleet.

The forecasts are re-examined by ship class and major region of Canada for 2015 in Tables 7-5 to 7-7.

Table 7-4a: All Backcasts and Forecasts for Canada – 'High' IMO Scenario Forecast

Inventory Year	Criteria Air Contaminants (CACs)								Greenhouse Gases (GHGs)		
	NOx	SO_x	CO	HC	PM	PM10	PM25	NH3	CO2	CH4	N2O
1980	105,393	57,813	9,563	9,717	8,054	7,732	7,113	120	4,741,242	76	124
1985	105,527	57,878	9,578	9,722	8,063	7,740	7,121	120	4,750,517	76	124
1987	115,024	63,888	10,392	10,503	8,857	8,503	7,823	131	5,165,414	83	135
1990	136,080	77,919	12,233	11,293	10,678	10,250	9,430	153	6,075,833	100	159
1995	155,469	91,531	13,904	10,088	12,459	11,961	11,004	175	6,960,038	113	182
2000	179,877	105,876	15,967	12,459	14,415	13,838	12,731	207	8,021,887	127	210
2005	205,215	122,247	18,251	17,741	16,587	15,924	14,650	237	9,142,818	146	240
2010	193,938	102,177	17,444	15,736	14,170	13,603	12,515	224	8,675,517	141	228
2015	217,463	6,809	19,971	17,091	4,413	4,236	3,898	257	9,941,513	162	262
2020	193,874	5,536	20,027	17,351	4,293	4,121	3,791	258	10,001,093	164	263
2025	157,128	5,409	19,711	17,528	4,226	4,057	3,733	253	9,890,454	164	260
2030	129,650	5,618	20,451	18,152	4,385	4,210	3,873	263	10,267,141	171	270

Table 7-4b: All Backcasts and Forecasts for Canada – 'Low' IMO Scenario Forecast

Inventory Year	Criteria Air Contaminants (CACs)								Greenhouse Gases (GHGs)		
	NOx	SO_x	CO	HC	PM	PM10	PM25	NH3	CO2	CH4	N2O
1980	105,393	57,813	9,563	9,717	8,054	7,732	7,113	120	4,741,242	76	124
1985	105,527	57,878	9,578	9,722	8,063	7,740	7,121	120	4,750,517	76	124
1987	115,024	63,888	10,392	10,503	8,857	8,503	7,823	131	5,165,414	83	135
1990	136,080	77,919	12,233	11,293	10,678	10,250	9,430	153	6,075,833	100	159
1995	155,469	91,531	13,904	10,088	12,459	11,961	11,004	175	6,960,038	113	182
2000	179,877	105,876	15,967	12,459	14,415	13,838	12,731	207	8,021,887	127	210
2005	205,215	122,247	18,251	17,741	16,587	15,924	14,650	237	9,142,818	146	240
2010	193,938	102,177	17,444	15,736	14,170	13,603	12,515	224	8,675,517	141	228
2015	221,203	6,928	20,296	17,228	4,484	4,305	3,960	262	10,091,773	164	266
2020	200,120	5,710	20,579	17,584	4,410	4,234	3,895	265	10,256,117	168	270
2025	162,446	5,565	20,196	17,731	4,331	4,157	3,825	260	10,118,828	168	266
2030	132,827	5,713	20,736	18,272	4,448	4,270	3,928	267	10,405,182	173	274

Table 7-5a: 2015 Forecast by Vessel Class (Eastern Canada / Great Lakes) – 'High' IMO Scenario

Vessel Class	Criteria Air Contaminants (CACs)								Greenhouse Gases (GHGs)		
	NOx	SO_x	CO	HC	PM	PM_{10}	PM_{25}	NH_3	CO_2	CH_4	N_2O
Coast Guard	1,780	28	145	63	36	35	32	2	88,093	1	2
Fishing	12,657	5	1,515	898	259	249	229	13	549,920	3	14
Merchant Bulk	33,715	1,009	3,110	1,250	662	635	585	37	1,531,921	29	41
Merchant Container	26,146	711	2,257	931	483	463	426	29	1,076,283	17	29
Merchant Cruise	4,207	155	401	169	103	99	91	8	247,380	4	6
Merchant Other	9,296	313	869	345	201	193	178	11	480,922	9	12
Merchant Passenger	7,044	64	793	262	147	141	129	9	491,834	19	13
Special Purpose	877	14	71	30	18	17	16	1	43,085	0	1
Tanker	24,330	752	2,338	9,054	490	470	433	27	1,141,798	23	30
Tug boat	4,650	18	368	173	85	82	75	7	217,450	1	6
War	156	2	15	7	3	3	3	0	7,040	0	0
Total	**124,858**	**3,071**	**11,881**	**13,182**	**2,486**	**2,386**	**2,196**	**144**	**5,875,727**	**106**	**154**

Table 7-5b: 2015 Forecast by Vessel Class (Eastern Canada / Great Lakes) – 'Low' IMO Scenario

Vessel Class	Criteria Air Contaminants (CACs)								Greenhouse Gases (GHGs)		
	NOx	SO_x	CO	HC	PM	PM10	PM25	NH3	CO2	CH4	N2O
Coast Guard	1,780	28	145	63	36	35	32	2	88,093	1	2
Fishing	12,657	5	1,515	898	259	249	229	13	549,920	3	14
Merchant Bulk	34,625	1,034	3,191	1,284	679	652	600	38	1,570,491	30	42
Merchant Container	26,928	732	2,323	959	497	477	439	30	1,107,209	17	30
Merchant Cruise	4,207	155	401	169	103	99	91	8	247,380	4	6
Merchant Other	9,409	316	879	350	204	196	180	11	486,426	9	13
Merchant Passenger	7,044	64	793	262	147	141	129	9	491,834	19	13
Special Purpose	877	14	71	30	18	17	16	1	43,085	0	1
Tanker	24,577	759	2,360	9,063	495	475	437	27	1,152,278	24	31
Tug boat	4,650	18	368	173	85	82	75	7	217,450	1	6
War	156	2	15	7	3	3	3	0	7,040	0	0
Total	**126,910**	**3,128**	**12,062**	**13,259**	**2,525**	**2,424**	**2,230**	**146**	**5,961,207**	**107**	**156**

Table 7-6a: 2015 Forecast by Vessel Class (Western Canada) – 'High' IMO Scenario

Vessel Class	Criteria Air Contaminants (CACs)								Greenhouse Gases (GHGs)		
	NOx	SO_x	CO	HC	PM	PM10	PM25	NH3	CO2	CH4	N2O
Coast Guard	352	5	28	13	7	7	6	0	17,073	0	0
Fishing	3,748	1	308	173	57	55	50	3	129,344	1	3
Merchant Bulk	21,289	622	1,934	757	407	390	359	22	943,097	19	25
Merchant Container	32,494	834	2,763	1,169	579	556	511	37	1,244,147	16	34
Merchant Cruise	8,959	300	785	353	210	202	186	16	478,699	3	12
Merchant Other	5,446	151	473	192	102	98	90	5	228,524	3	6
Merchant Passenger	8,067	64	761	327	170	164	151	13	458,522	6	12
Special Purpose	63	1	5	3	1	1	1	0	2,250	0	0
Tanker	3,502	101	318	600	66	63	58	4	152,558	3	4
Tug boat	4,111	3	318	152	73	70	64	6	187,629	1	5
War	396	6	35	16	7	7	6	0	18,586	1	1
Total	**88,427**	**2,088**	**7,729**	**3,755**	**1,679**	**1,612**	**1,483**	**108**	**3,860,429**	**53**	**102**

Table 7-6b: 2015 Forecast by Vessel Class (Western Canada) – 'Low' IMO Scenario

Vessel Class	Criteria Air Contaminants (CACs)								Greenhouse Gases (GHGs)		
	NOx	SO_x	CO	HC	PM	PM10	PM25	NH3	CO2	CH4	N2O
Coast Guard	352	5	28	13	7	7	6	0	17,073	0	0
Fishing	3,748	1	308	173	57	55	50	3	129,344	1	3
Merchant Bulk	21,844	637	1,983	777	417	400	368	22	965,176	19	26
Merchant Container	33,478	859	2,845	1,204	596	572	527	38	1,280,750	16	35
Merchant Cruise	8,959	300	785	353	210	202	186	16	478,699	3	12
Merchant Other	5,545	153	481	195	104	100	92	5	232,428	3	6
Merchant Passenger	8,067	64	761	327	170	164	151	13	458,522	6	12
Special Purpose	63	1	5	3	1	1	1	0	2,250	0	0
Tanker	3,526	101	320	601	67	64	59	4	153,478	3	4
Tug boat	4,111	3	318	152	73	70	64	6	187,629	1	5
War	396	6	35	16	7	7	6	0	18,586	1	1
Total	**90,089**	**2,130**	**7,870**	**3,815**	**1,709**	**1,640**	**1,509**	**110**	**3,923,936**	**54**	**104**

Table 7-7a: 2015 Forecast by Vessel Class (Arctic) – 'High' IMO Scenario[42]

Vessel Class	Criteria Air Contaminants (CACs)								Greenhouse Gases (GHGs)		
	NOx	SO_x	CO	HC	PM	PM10	PM25	NH3	CO2	CH4	N2O
Coast Guard	615	10	51	22	13	12	11	1	30,951	0	1
Fishing	721	0	59	27	13	13	12	1	35,115	0	1
Merchant Bulk	466	321	44	17	42	40	37	1	21,492	0	1
Merchant Other	699	567	66	26	73	70	64	1	38,464	1	1
Merchant Passenger	511	209	43	17	30	29	27	1	21,634	0	1
Special Purpose	38	1	3	1	1	1	1	0	1,913	0	0
Tanker	678	539	62	25	69	66	61	1	37,187	1	1
Tug boat	450	4	33	16	8	8	7	1	18,601	0	1
Total	**4,178**	**1,651**	**361**	**153**	**248**	**238**	**219**	**6**	**205,357**	**3**	**5**

[42] Canada's Arctic marine emissions have recently been updated in a separate Arctic study completed for Transport Canada. The values shown in Table ES-4 should not be used for other purposes. Further information may be available from Ernst Radloff, Transport Canada, Transportation Development Centre, Ottawa ON.

Table 7-7b: 2015 Forecast by Vessel Class (Arctic) – 'Low' IMO Scenario[42]

Vessel Class	Criteria Air Contaminants (CACs)								Greenhouse Gases (GHGs)		
	NOx	SO_x	CO	HC	PM	PM10	PM25	NH3	CO2	CH4	N2O
Coast Guard	615	10	51	22	13	12	11	1	30,951	0	1
Fishing	721	0	59	27	13	13	12	1	35,115	0	1
Merchant Bulk	476	327	45	18	43	41	38	1	21,933	0	1
Merchant Other	711	575	67	26	74	71	65	1	39,037	1	1
Merchant Passenger	511	209	43	17	30	29	27	1	21,634	0	1
Special Purpose	38	1	3	1	1	1	1	0	1,913	0	0
Tanker	683	543	63	25	69	67	61	1	37,447	1	1
Tug boat	450	4	33	16	8	8	7	1	18,601	0	1
Total	**4,205**	**1,670**	**363**	**154**	**251**	**241**	**221**	**6**	**206,630**	**3**	**5**

8. CONCLUSION

The 2010 Canadian marine emissions inventory was developed by accessing vessel movement data and associated information from the Canadian Coast Guard, Canadian government (Environment Canada, Transport Canada), Canadian ports and a number of shipping agencies and associations active in Canada. This information allowed development of a detailed inventory model that accounts for actions such as fuel switching, slow steaming and use of shoreside power. MEIT 4.0 constitutes an update to Canada's marine emissions model that effectively accounts for ship characteristic and movement data now available.

The Canadian Coast Guard INNAV data used for eastern Canada and the Arctic was found to be highly useful and consistent with other dependable sources of ship movement data such as port ship call records. The Canadian Coast Guard VTOSS data was found to be inferior to INNAV for purposes of marine inventory development. For this reason, the emission estimates for the west coast are considered to have higher uncertainty than estimates for the east coast. However, the ship activity data for the west coast was improved by using information from the Pacific Pilotage Authority as well as Port Metro Vancouver to enhance the simulation of vessel movements near port areas. The INNAV system has recently been adopted by the Coast Guard for the west coast (as of 2011) and will be available for future marine emission studies.

MEIT 4.0 constitutes an update to Canada's marine emissions model that effectively accounts for ship characteristic and movement data now available. Suggested actions for future improvements to MEIT and Canada's national marine emissions inventory include the following:

- Further investigation into fishing vessel and tugboat activity;
- Further evaluation of the relationship between ship speed (as determined through analysis of Coast Guard INNAV data) and main engine load for ocean going vessels; and,
- Evaluation of the west coast inventory by acquiring and using 2011 INNAV data in MEIT V4.0.

APPENDIX A: MEIT V4.0 UPDATES

PROPULSION ENGINE LOADS

Propulsion or ME loads can be determined by the estimated vessel speed in relation to its maximum cruise speed through the Propeller Law, as noted in Chapter 2. The Propeller Law has been used in several past marine inventories as the basis for setting the expected ME load based on vessel speeds in different modes (full underway, reduced speed, manoeuvring).

MEIT V4.0 was updated to apply a time-in-mode approach to estimate ship ME load in the emission calculations for each ‘segment’ of a trip. This constitutes a change in methodology that is aligned with the BC Chamber of Shipping inventory approach used in the 2005/2006 BC OGV inventory. A trip segment is the elapsed time and distance travelled between two CG call-in points.

Propulsion engine loads can also be characterized with a simple OD approach, similar to that used in the previous versions of MEIT. This approach was also used in the 2010 inventory as a key quality analysis step (outlined in Chapter 7).

East Coast / Great Lakes

OGVs (not including cruise ships)

INNAV vessel data points include both position and time. Theoretically, both distance and elapsed voyage time can be determined from the data for each ship transiting through Canadian waters. INNAV includes unique trip identifiers which allow the related data points to be strung together into an articulated trip.

Each INNAV trip was evaluated for its segments. Distance is determined simply by assuming a linear path (meaning that there is always some error with this measure, particularly when the data points are further separated in time and along narrower waterways), and speed is determined by dividing this distance by the elapsed time between data points. Model speed therefore is a reasonable determination of the ship speed at any given time, but uncertainties should be expected, more so in regions that do not have radar or AIS reception. The INNAV trip segments were screened with set criteria to remove problematic data points. Some segments were removed simply because they are outside of Canadian waters (and the portion inside of Canadian waters was kept).

An analysis of vessel speeds is shown in Table A-1 for several of the major shipping classes included in INNAV, focusing on different generalized regions of eastern Canada (see Figure 1.2). The table shows the average calculated speed of the vessel classes by dividing the estimated underway distance by the elapsed time according to the INNAV data. The number of trips during the year, as logged in INNAV, is also shown.

As should be expected, the average speeds are higher in the open water regions (defined in this exercise to be 18, 19, 20) and lower along the St. Lawrence River (10, 11, 12) and Great Lakes (5, 6, 7, 8, 9) regions. The 'trip average' speeds are inclusive of all regions and not just those noted in the three generalized areas.

Table A-1: Average Vessel Speeds by General Region of Eastern Canada*

Vessel Class	2010 Trips	Average Speed (knots)			
		Open Water	St. Lawrence	Great Lakes	Trip Average
Coast Guard	2,687	5.5	8.7	7.5	6.2
Merchant Bulk	11,112	10.0	8.7	7.3	9.8
Merchant Container	2,433	12.7	13.1	8.6	13.5
Merchant Cruise	490	15.0	11.5	N/A	14.5
Merchant General	3,642	11.1	10.1	8.0	11.2
Merchant Passenger	14,675	10.9	7.9	7.2	10.5
Special Purpose	4,518	8.6	5.7	5.7	7.0
Tanker	6,600	10.9	9.7	7.2	10.7
Tug Boat	18,975	9.3	5.7	5.6	7.5
Total	**72,166**	**10.3**	**8.9**	**7.1**	**9.9**

* Note: Coast Guard vessels are used for ice breaking activity at times and therefore the vessels speeds in Open Water may be inclusive of ice breaking activities. The fishing vessels tend not to be active in the St. Lawrence (those captured in INNAV). Merchant Cruise ships are not active in the Great Lakes.

These average speeds are inclusive of all activity flagged as 'underway' in the INNAV system. This means that short term movements into and out of berth locations (e.g., manoeuvring) are included, as well as slow speed movements near locks and through canals.

Several important features can be noted in Table A-1:

- The average speeds calculated from the INNAV data are lower than the vessel maximum cruise speeds in all cases (the average maximum cruise speeds by vessel class are not shown).

- The average speeds for regions within the St. Lawrence River and the Great Lakes are lower than speeds in regions further east (exception, Merchant Container[43]).

For each trip segment, the implied vessel speed and ME load was estimated in MEIT. Although the Propeller Law was used as the basis for the ME load estimates, the possible load values were restricted to 0.00, 0.10, 0.25, 0.40, and 0.80 to force the calculations to adhere to reasonable load assumptions (e.g., similar to restrictions used in the previous BC CoS inventory). Table A-2 provides a definition of the ME load assignments.

Table A-2: Main Engine Load Estimates for MEIT V4.0

Vessel Speed as a Percentage of Maximum Cruise Speed	Implied ME Load Range via Propeller Law	Assigned ME load
≥ 80%	0.51 – 1.00	0.80
60% ≤ x < 80%	0.22 – 0.51	0.40
30% ≤ x <60%	0.03 – 0.22	0.25
≤ 30%	0.00 – 0.03	0.10
0	0.0	0

The lower load bins 0.10 and 0.25 differ from those applied in the BC CoS work (which used 0.03, 0.40 and 0.80). The additional bin of 0.25 was added to reflect the lower speed waterways through the St. Lawrence and Great Lakes and the understanding that ships at times are choosing to travel at speeds substantially lower than their normal cruising speeds. For both the 0.10 and 0.25 load bins, the assigned load is greater than the upper end of the range implied by the Propeller Law. This decision was made to account for the influence of tides as well as small errors in either position or time associated with INNAV points that are close to each other (near port areas). In addition, there is considerable uncertainty associated with marine engine emission rates at loads below 0.10. As noted in previous marine inventories, loads below 0.20 should be associated with higher emission rates on a g/kWh basis[44]. Application of a lower engine load than 0.10 would logically be associated with higher emission rates in the model. This level of complexity in MEIT cannot be supported with movement data resolvable through the INNAV data points. For this reason, the 0.1 load factor bin is the lowest engine load asignment (aside from zero) in MEIT V4.0. As shown in Table 3-5, a scaled set of emission rates were used for ME load 0.1 to acknowledge the different engine combustion conditions expected.

43 Few container vessels are active on the Great Lakes.

44 Energy and Environmental Analysis Inc., 2000. Analysis of Commercial Marine Vessels Emissions and Fuel Consumption Data. Prepared for the US EPA, EPA 420-R-00-002.

Exceptions to the rules noted in Table A-2 were applied to cruise ships, as described in the following section. Additional exceptions were applied to some of the fishing vessel, tug boat and ferry movements, as described in the main body of this report.

Figures A-1 and A-2 provide an illustration of the ME load factor assignment for portions of two different OGV trips in eastern Canada. The first trip (Merchant Container leaving Halifax) is characterized in the model as follows:

- an initial segment of 0.22 hours at 0.1 load factor;
- a second segment of 0.30 hours at 0.25 load factor;
- a third segment of 0.07 hours (4 minutes) at 0.8 load factor;
- a fourth segment of 0.20 hours at 0.1 load factor; and,
- a fifth segment of 0.12 hours at 0.4 load factor.

The third and fourth segments imply there is a small error in either position or time for at least one of the INNAV points, since it's highly unlikely the vessel would increase its speed and then immediately slow just 10 or 20 minutes later. In reality, the vessel likely continued at a similar speed and engine load as used during the second segment. Over the third and fourth segments combined, a weighted average engine load value of 0.28 can be calculated, which is nearly equivalent to the engine load assumption applied in the second segment. The fifth segment has an associated load of 0.4, which appears reasonable for the location.

In the second example a Merchant Bulk ship can be seen leaving the Windsor ON area heading to Michigan. In this example the INNAV data points are further spread in both distance and time, compared to the previous example. This portion of the trip is characterized in the model with an ME load of 0.40 for over 4 hours, followed by an ME load assignment of 0.8 for the next 8-9 hours.

The two figures illustrate that greater error may result when the INNAV data points are close together in space and time. However, these errors are not likely to be significant over longer averaging periods.

Figure A-1: ME Load Factor Assignment Example for a Merchant Container Ship

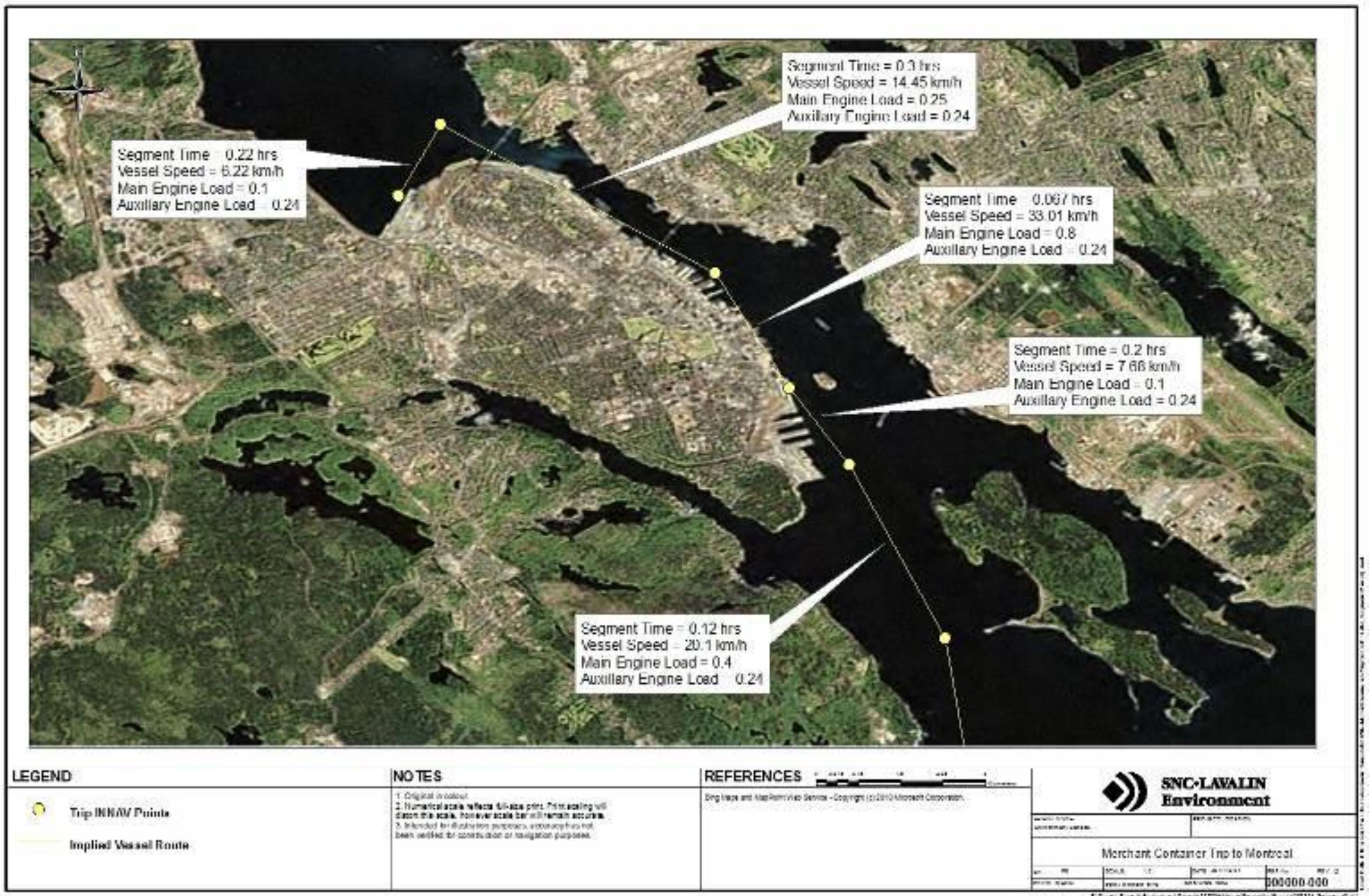
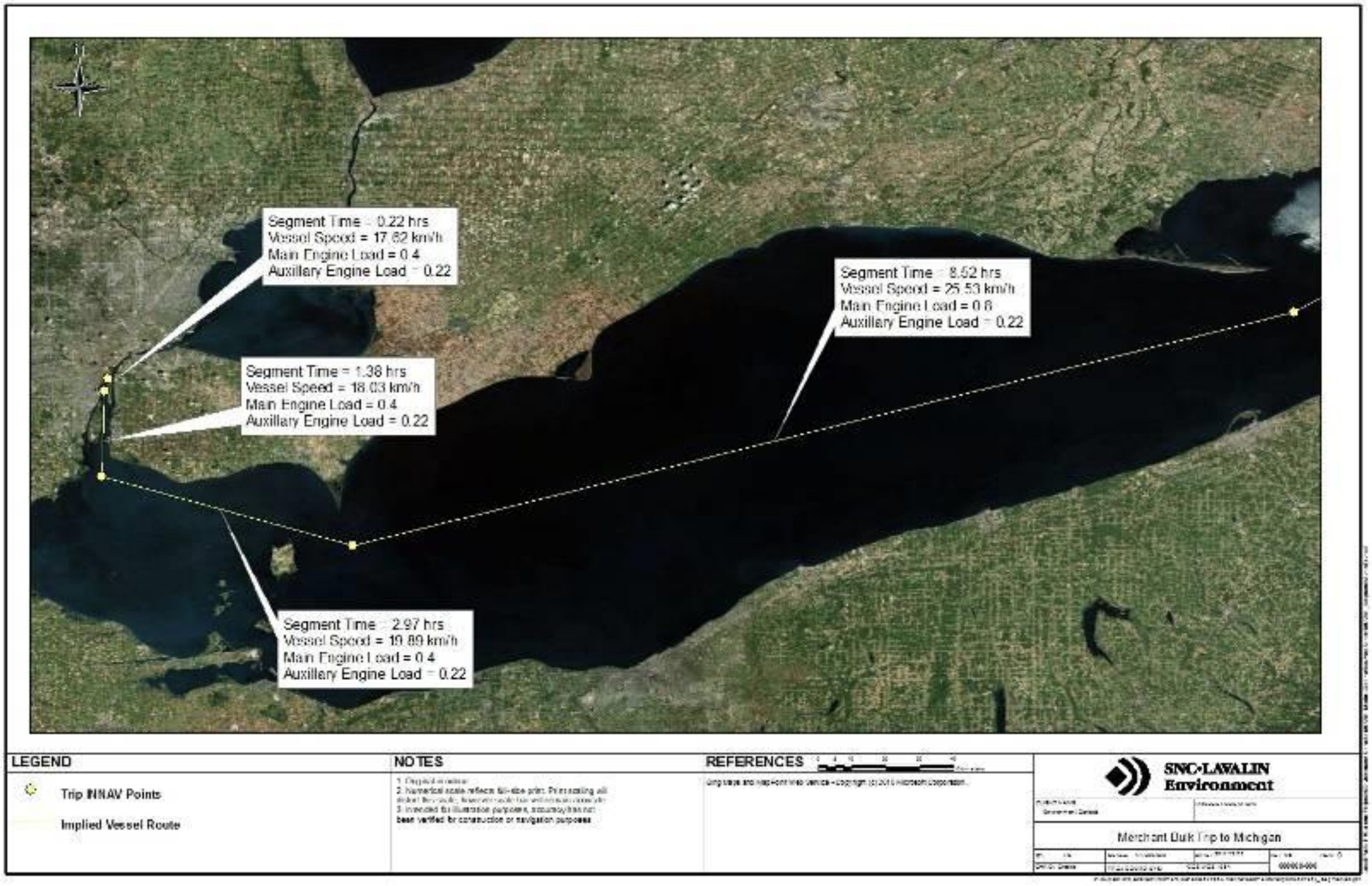


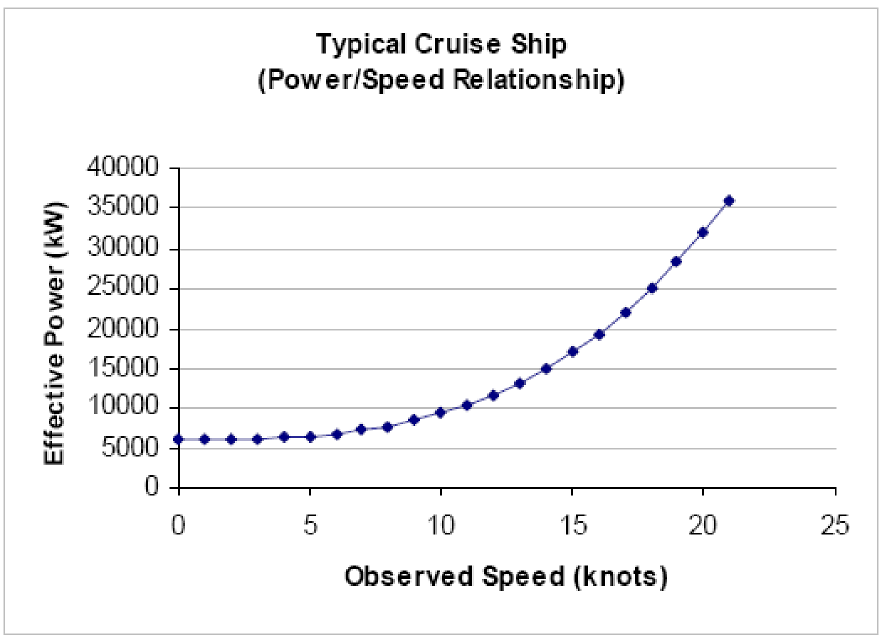
Figure A-2: ME Load Factor Assignment Example for a Bulk Carrier



Cruise Ships

An emission calculation method specific to cruise ships was developed based on the unique operating characteristics of these vessels. Cruise ships use multiple diesel-electric drives for load balancing enabling ship engineers to closely match generated power to demand. For this reason, cruise ships cannot be represented with separate main and auxiliary engines, similar to the other OGV classes. Additionally, cruise ships are bound by different time constraints than cargo vessels and therefore may spend a greater portion of time at speeds well below maximum. The BC Chamber of Shipping reported in their 2005-2006 Emission Inventory that cruise ship speeds can be used to estimate the total engine power through the Propeller Law once the base engine load is established. Cruise ships require a significant base engine load for onboard electrification at all times. The Chamber of Shipping published a typical cruise ship profile based on survey data collected from 31 vessels, as shown in Figure A-3.

Figure A-3: Typical Cruise Ship Power/Speed Profile



Building on the work done by the BC CoS, this profile was implemented in the previous version of the MEIT to estimate the effective power for the underway portion of cruise ship trips based on the average underway speed. This method was further refined in MEIT V4.0 to suit a wider range of cruise ship speeds.

A revised cubic function was developed during the project to match the BC CoS profile, while accounting for a variable base load by size of ship. This function is identified below:

$$P\ (kW) = a(3.1012x^3) + a(2.0282x^2) + a(18.636x) + \text{Base Load}\ (kW) \qquad (7)$$

where:

a = vertical scale factor based on installed engine power
x = underway speed (knots)

Equation 7 is solved for 'a' for each cruise ship in INNAV by looking up 80% of its installed power (P) and maximum cruise speed (assigned to 'x').

The Base Load represents the minimum power the vessel requires while not moving (e.g., at berth or anchor). This value cannot be determined directly from INNAV data or any other data source. The Base Load was estimated on a ship by ship basis according to an equation developed by Poplawski *et al* in 2010[45]. This equation is shown below:

$$\text{Berth Power}\ (kW) = (1 - \text{monthvar})(5143 + (P - 1250)2.857) \qquad (8)$$

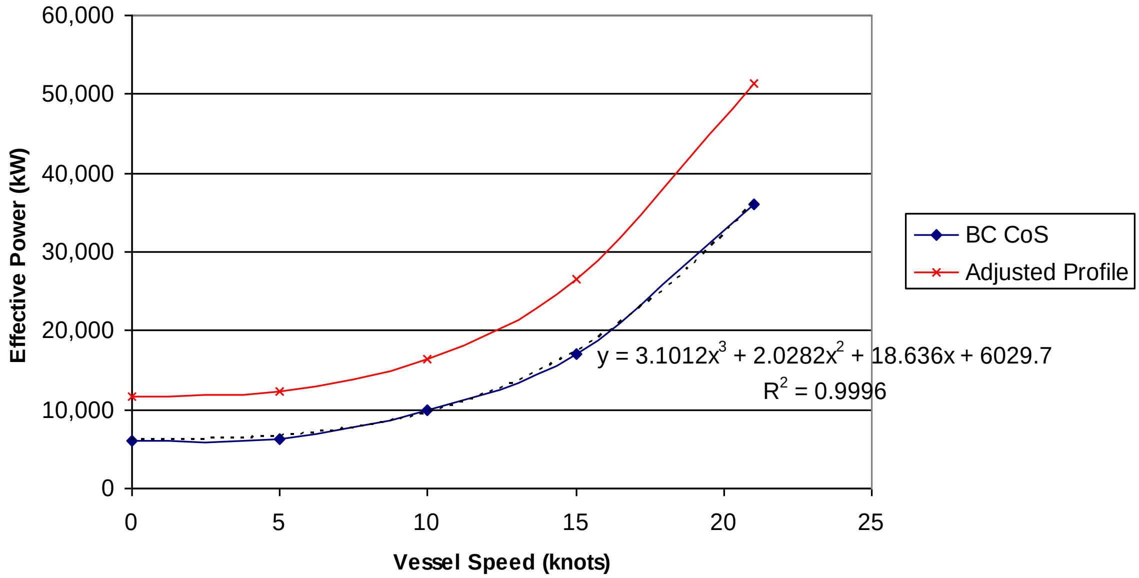
Where: P = passenger capacity

monthvar = Factor to account for variability in energy consumption during cooler months when air conditioning demands would be low (assumed to be zero for this study, due to lack of supporting information).

As an example, Figure A-4 illustrates the adjusted profile developed in MEIT V4.0 for a large cruise ship with a passenger capacity of 3,500 and 64,000 kW maximum engine power, with the original BC CoS profile (which is representative of a smaller vessel).

[45] Poplawski, K., Setton, E., McEwen, B., Hrebenyk, D., Graham, M and P. Keller, 2011. *Impact of Cruise Ship Emissions in Victoria, BC, Canada*. Atmospheric Environment **45** (2011) 824 – 833.

Figure A-4: Adjusted Cruise Ship Profile for MEIT V4.0



An adjusted profile was developed for each cruise ship in the 2010 INNAV data set and the effective power was solved for every trip segment based on the vessel speed estimates. This differs from the ME load factor assignment for the other major vessel classes since any load from 0.0 to 1.0 is possible. The vessel speed for a particular cruise ship will vary significantly during a trip depending on the trip itinerary which typically includes a number of port calls and slower-speed sightseeing segments. In some cases cruise ships will increase speed at night to the next destination and slow down during day time hours for sightseeing.

Arctic

INNAV data points are less frequent for a given voyage in the Arctic compared to eastern Canada. A simple investigation of voyages in the Arctic shows that vessel speed cannot be reliably estimated with the methods used for eastern Canada. Both speed and distance estimates through MEIT V4.0 are highly suspect given the distance and time between consecutive INNAV data points for a particular voyage. This same conclusion was determined in a previous Arctic EI completed in 2008[46].

Similar to the 2008 inventory, a simplified approach to estimating propulsion engine loads was employed for the Arctic. All activities flagged as underway for a particular vessel class in the INNAV data,

46 SENES Consultants Ltd., 2008. Canadian Arctic Marine Assessment, 2002 – 2050. Completed for Transport Canada.

for any voyage with either the origin or the destination (or both) within the defined Arctic regions (1, 21 and 22) were associated with the same ME load. These loads are identified in Table A-3 for the active vessel classes in the Arctic. Additional information related to these engine loads is discussed in the Arctic EI report.

Table A-3: Underway ME Loads for the Arctic by Vessel Class*

General Vessel Class	Specific Classes	Main Engine Load Factor
Coast Guard	CI	0.25
Fishing	FF, FV, FT	0.50
Merchant Bulk	MB	0.75
Merchant Cruise	MW	0.55
Merchant Other	MO	0.80
Merchant Passenger	MP	0.8
Special Purpose	SR, SS, SV	0.75
Tanker	TT, TL, TO	0.75

*Note: Canada's Arctic marine emissions have recently been updated in a separate Arctic study completed for Transport Canada. The values shown in Table A-3 should not be used for other purposes. Further information may be available from Ernst Radloff, Transport Canada, Transportation Development Centre, Ottawa ON.

West Coast

As noted in Chapter 4, SLE was provided the 2010 Pacific Pilot data that has a record of all movements to anchorage and berth during the year. This data set was used to develop trip data throughout the west coast, linking with the VTOSS data where possible. Since many of the voyage legs were constructed by assuming vessel speeds, a simplified scheme was used for estimating main engine load in the model. This scheme assigns one of three possible underway main engine loads, consistent with those used for the 2005/2006 BC Marine Inventory completed by the B.C. Chamber of Shipping[47], as defined in Table A-4.

Table A-4: Main Engine Load Estimates for MEIT V4.0

Vessel Speed as a Percentage of Maximum Cruise Speed	Implied ME Load Range via Propeller Law	Assigned ME load
≥ 80%	0.51 – 1.00	0.80
60% ≤ x < 80%	0.21 – 0.50	0.40
≤ 60%	0.00 – 0.20	0.10

47 The only exception is the low engine load setting of 0.1. The CoS used a main engine load of 0.03 for the same speed range.

0	0.0	0

AUXILLIARY ENGINE AND BOILER PROFILES

Generalized assumptions are appropriate for ship auxiliary engines (AEs) and boilers since their usage patterns do not significantly change with vessel speed, other than for the short periods required for manoeuvring to and from berth. AE and boiler assumptions are implemented within ship profiles, as identified in this section.

A number of ship criteria are needed to support ship emission calculations, as identified in Table A-5. For this project, SLE was able to utilize CG data (INNAV and VTOSS), Lloyd's Seaweb data and stakeholder survey data to refine the MEIT V3.5 ship profiles. Table A-5 identifies how these three sources are used to obtain the necessary ship criteria. No entries are shown for Main Engine – Engine Load since this is dynamically determined in MEIT V4.0 by ship speed.

Table A-5: Ship Criteria Data Source for Emission Calculations

Data Source	Vessel		Main Engine							Aux Engines							Boiler	
	Cruise Speed	DWT	Power Rating	Engine Type	Engine RPM	Engine Displacement	Engine Load	Fuel Type	Fuel Sulphur	Power Rating	Engine Type	Engine RPM	Engine Displacement	Engine Load	Fuel Type	Fuel Sulphur	Fuel Type	Fuel Cons/hr
CG	x	x	x															
Sea Web	x	x	x	x	x	x		x		x	x	x	x		x		x	
Survey			x	x				x	x	x	x	x		x	x	x	x	x

Notes: DWT = deadweight tonnage

Loads on auxiliary engines can only be practically determined from ship survey efforts since these loads have no relation to ship speed and instead depend on factors such as number of crew (or passengers in the case of ferries and cruise ships) and onboard pumps and other cargo handling equipment. There are a number of other engine and ship details necessary to support the general emission calculation (1) or to separate activities and emissions into categories of interest (such as EPA engine category). New data made available for this project was used to test and refine the existing ship profiles, as required.

Two large-scale survey efforts were completed by the BC Chamber of Shipping (BC CoS) in 2005/2006[48] for the West Coast of Canada and by Transport Canada (TC) in 2007[49] for eastern Canada. The profiles developed in the TC work are those used in MEIT V3.5. Updates to these profiles were accomplished through a number of information sources, including:

- BC Chamber of Shipping survey data from the 2005/6 work as well as additional Chamber surveys collected during 2010;
- Lloyd Seaweb data based on vessels active in Canadian waters in 2010; and,
- 2010 vessel survey data provided by other project partners, including Fednav Limited, Canadian Shipowners Association and the Northwest and Canada Cruise Association.

There are differences in ship characteristics for ships active in western Canada versus those active in eastern Canada and the Arctic. For this reason, ship profiles are identified for the east and west separately.

Eastern Canada / Great Lakes

Installed Auxiliary Capacity (AE)

Lloyd ship data was used to establish new profile regression equations to predict installed AE capacity. The Lloyd data include AE information (number and capacity of engines) on approximately 10% – 20% of vessels in the CG database. For the high activity vessel classes in 2010, regression equations were developed for AE based on deadweight tonnage (DWT) and main engine capacity (ME). Both DWT and ME are available from the INNAV dataset for virtually every active vessel tracked.

Example regressions are provided for container vessels (MC) in Figures A-5 and A-6. Regression equations for the other ship classes are shown in Appendix B.

[48] BC Chamber of Shipping, 2007. 2005 – 2006 BC Ocean Going Vessel Emissions Inventory. Prepared by the BC Chamber of Shipping, January

[49] Weir Marine Engineering, 2008. 2007 Marine Emission Inventory and Forecast Study, Final Draft. Prepared for the Transportation Development Centre of Transport Canada, in partnership with SENES Consultants Ltd.

Figure A-5: MC Auxiliary Capacity (AE) versus Deadweight Tonnage (DWT) Regression

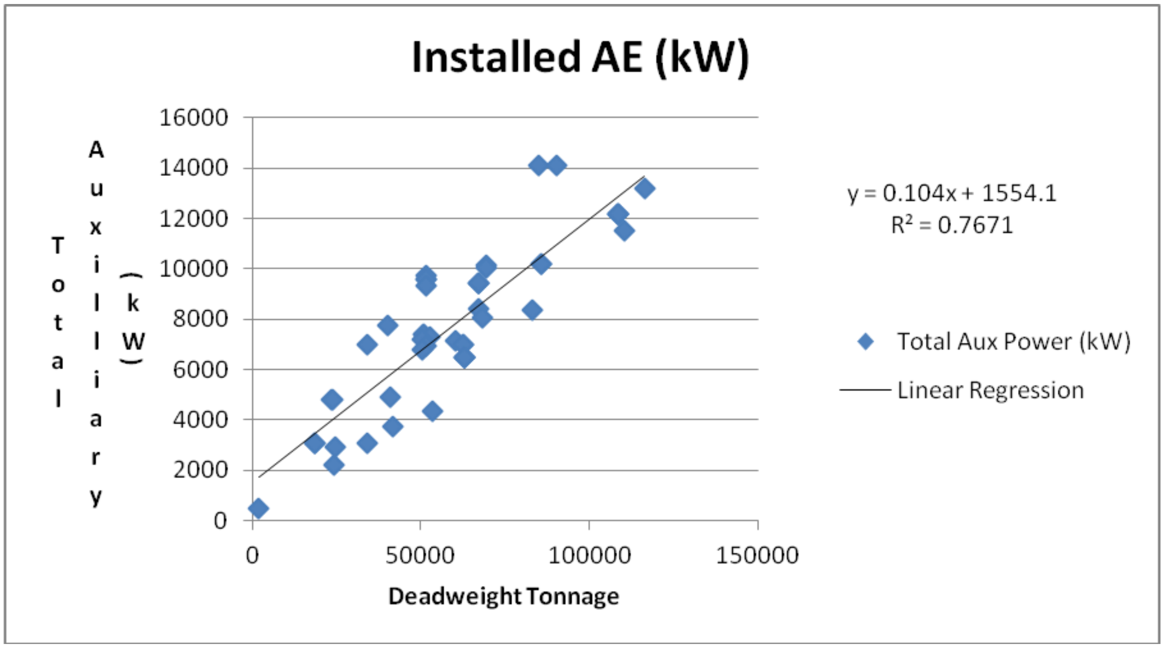
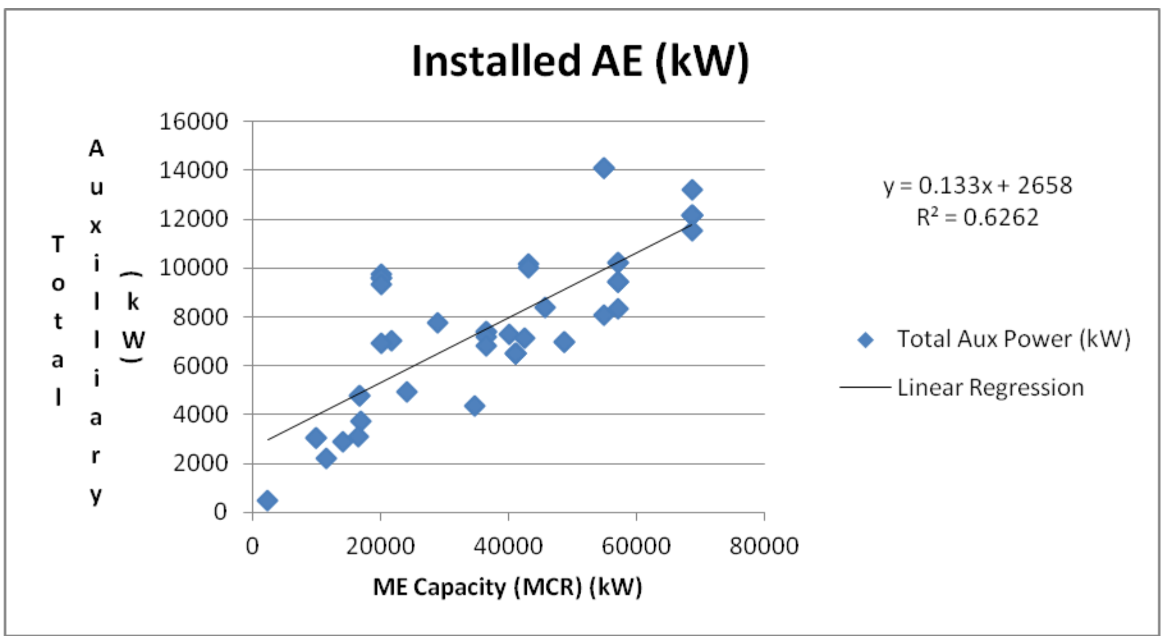


Figure A-6: MC Auxiliary Capacity (AE) versus Main Engine Capacity (ME) Regression



For each vessel class, the MEIT calculation module determines the AE capacity with the following hierarchy:

- Lookup of specific AE data for the vessel (exists for 10 – 20% of ships 200 GT or greater); if this is not found, continue,
- Select regression equation with the best agreement (highest R^2 value) to predict the installed AE capacity. For example, in the case of MC, the regression equation based on DWT was selected in the MEITV4.0.

Auxiliary Engine Load Factor

Based on previous survey data collected in Canada, auxiliary engine use varies somewhat by mode of activity. MEIT sets a unique ratio for the AE load (fraction of installed auxiliary capacity) by vessel class and mode of activity. Some of the INNAV ship classes are not uniquely characterized due to lack of representation in the survey programs. For these cases, the ratios are set from a similar ship class with better representation.

The ratios used for the 2010 inventory are shown in Table A-6.

Table A-6: Auxiliary Engine Load Factors, Eastern Canadian Regions

GENERAL CLASS	SPECIFIC CLASS (CODE)	AE LOAD FACTORS		
		UNDERWAY	ANCHOR	BERTH
Coast Guard	CI	0.10	0.10	0.0
	All other	0.17	0.22	0.22
Fishing	FF	0.50	0.50	0.0
	All other	0.20	0.20	0.0
Merchant Bulk	MB	0.21	0.28	0.29
Merchant Container	MC	0.21	0.20	0.20
Merchant Cruise	MW	n/a	n/a	n/a
Merchant Other	MM, MH	0.20	0.27	0.27
	MA	0.13	0.24	0.24
	MO	0.21	0.42	0.42
	MS, MG	0.38	0.42	0.42
	MR	0.20	0.34	0.34
Tanker	TL, TG, TM, TO, TS	0.2	0.3	0.3
	TQ	0.23	0.33	0.33
	TT	0.3	0.24	0.24
	TC, TU, TV	0.24	0.26	0.26
Tug Boat	Ocean	0.17	0.22	0.22

	Other	0.00	0.00	0.00
War	All	0.34	0.00	0.00

The AE factors Table A-6 are used with the vessel installed AE capacity determined from either Sea web data or the ship class regression equations. Cruise ships are not represented in Table A-6 since a unique estimation approach to estimate engine load was employed, as previously identified.

Boiler Fuel Consumption

Ship boilers are used to provide hot water and to warm residual oil fuels (reduce viscosity) before use. Boilers tend to be used by all of the OGV vessel classes while at berth and at anchor. During underway travel some ships have exhaust gas economizers to capture waste heat and do not require boiler use. Boiler fuel consumption rates used for 2010 by mode are shown in Table A-7.

Table A-7: Boiler Fuel Consumption by Vessel Class

General Class	Specific Class	Underway (tonnes/hr)	Berth (tonnes/hour)
Coast Guard	CI	0.00	0.00
Fishing	FV	0.10	0.0
	All other	0.0	0.0
Merchant Bulk	MB	0.08	0.08
Merchant Container	MC	0.14	0.18
Merchant Cruise	MW	0.36	0.35
Merchant Other	MA, MR	0.10	0.11
	All others	0.08	0.08
	TU, TV	0.10	0.92
Tanker	All others	0.10	0.11
Tug Boat	All	0.00	0.00
War	All	0.10	0.00

The boiler rates shown in Table A-7 were taken from MEIT V3.5 and are largely based from survey programs on the West Coast (BC CoS, 2005/2006). As noted, some vessel classes are considered to have negligible boiler use (Coast Guard, Tug boats) and others have lower boiler use while underway compared to berth. Boiler use has not been extensively studied and therefore these rates may have higher uncertainty compared to other profile parameters in MEIT. Boiler use while at anchor is considered to be the same as at berth.

Fuel Sulphur Levels

The following fuel definitions were used in the 2010 inventory:

- Marine distillate (MDO), domestic origin, 0.05% sulphur;
- Marine distillate (MDO), international origin, 1.0% sulphur;
- Residual fuel (HFO), domestic origin, 1.5% sulphur; and
- Residual fuel (HFO), international origin, 2.6% sulphur.

As noted above, vessel classes that use domestic MDO were assigned sulphur levels of 0.05%, based on a previous study of Canadian marine fuels[50]. Each vessel class was assigned an allocation for fuels used in the main engine(s), auxiliary engines and boilers as fractions derived from the sources noted above. An example is shown in Table A-8 for percent HFO and MDO for fuel used in MEs. The resultant fuel sulphur levels used in the emission calculations are summarized by engine type and ship class in Table A-9.

Table A-8: Allocation of Fuels by Ship Class and Engine Type (Main Engines)

General Vessel Class	Type	Fuel Source for MEs (%)			
		HFO Dom	HFO Int	MDO Dom	DMO Int
Coast Guard	C	0	0	100	0
Fishing	All	0	0	100	0
Merchant Bulk	MB	20	80	0	0
Merchant Container	MC	5	95	0	0
Cruise	MW	100	0	0	0
Merchant Other	MA, MG, MH, MQ,	10	90	0	0
	MM	0	100	0	0
	MO	20	80	0	0
	MS	45	55	0	0
Merchant Ferry	MF	0	0	100	0
Merchant Passenger	MP	100	0	0	0
Tanker	TC	20	80	0	0
	TG, TM, TS, TU, TV	0	100	0	0

50 BMT Technologies Ltd., 2008. Update on Availability, Quality and Quantity of Marine Fuels in Canada

	TL, TO	5	95	0	0
	TQ	40	60	0	0
	TT	25	75	0	0
Tug	H	0	0	100	0
	HO	0	0	80	20
Warship	WR	0	0	100	0
	WS	0	0	100	0

Table A-9: Calculated Fuel Sulphur Levels by Vessel Class and Engine Type

General Class	Specific Class	Source	Sulphur Level (%)
Coast Guard	All	AE	0.05
		ME	0.05
		BO	0.05
Fishing	All	AE	0.05
		ME	0.05
		BO	N/A
Merchant Bulk	MB	AE	1.90
		ME	2.38
		BO	1.90
Merchant Container	MC	AE	2.00
		ME	2.55
		BO	2.00
Merchant Cruise	MW	AE	1.50
		ME	1.50
		BO	1.50
Merchant Other	MA, MG, MH	AE	1.97
		ME	2.49
		BO	1.97
	MM	AE	2.04
		ME	2.60
		BO	2.04
	MO	AE	1.90
		ME	2.38
		BO	1.97
	MQ	AE	1.97
		ME	2.49
		BO	1.97
	MR	AE	2.04
		ME	2.60

		BO	2.60
	MS	AE	1.72
		ME	2.11
		BO	1.72

Table A-9 (Cont'd): Calculated Fuel Sulphur Levels by Vessel Class and Engine Type

General Class	Specific Class	Source	Sulphur Level (%)
Merchant Passenger	MF	AE	0.05
		ME	0.05
		BO	0.05
Tanker	MP	AE	1.65
		ME	2.00
		BO	1.65
	TC	AE	1.90
		ME	2.38
		BO	1.90
	TG, TM, TS, TU, TV	AE	2.04
		ME	2.60
		BO	2.04
	TL, TO	AE	2.00
		ME	2.55
		BO	2.00
	TQ	AE	1.75
		ME	2.16
		BO	1.75
	TT	AE	1.86
		ME	2.33
		BO	1.86
Tug Boat	Ocean	AE	0.24
		ME	0.24
		BO	0.24
	All other	AE	0.05
		ME	0.05
		BO	0.05
War	All	AE	0.05
		ME	0.05
		BO	0.05

Additional Profile Criteria

Additional profile characteristics are required to link each vessel with appropriate emission rates. These characteristics are defined in Table A-10. The 'Default Engine Assumptions' in the table are used as follows:

- ME Type: a default ME engine parameter when the vessel-specific value cannot be obtained from the model lookup table. In some cases this value allows a blending of emission rates from available 2-stroke and 4-stroke emissions data. This default is rarely used.
- ME RPM: default rpm setting when the vessel-specific value cannot be obtained from the model lookup table. In some cases this value is used to select a specific emissions rate (NO_x) that is dependent on rpm.
- ME (AE) EPA Class: a default value when engine displacement cannot be determined from the model lookup table. This value is used for inventory forecasts to link engines with emissions limits.
- AE Type: a default value used to establish the AE engine type. Currently all AEs are assumed to be 4-stroke when the values cannot be determined from the model lookup table.
- AE RPM: default rpm setting for AEs. Currently set at 1000 rpm due to lack of available data by ship class.

Table A-10: Additional Ship Class Profile Criteria

Ship Classification		Default Engine Assumptions					
General Vessel Class	Specific Class	ME Type (% 4-stroke)	ME RPM	ME EPA Class	AE Type (% 4-stroke)	AE RPM	AE EPA Class
Coast Guard	All	1.00	861	2	1	1000	2
Fishing	All	1.00	1000	2	1	1000	2
Merchant Bulk	MB	0.24	164	3	1	1000	2
Merchant Container	MC	0.04	165	3	1	1000	2
Cruise	MW	1.00	690	3	1	1000	3
Merchant Other	MA	0.24	107	3	1	1000	2
	MG	0.57	444	3	1	1000	2
	MH	0.47	458	3	1	1000	2
	MM	0.47	267	3	1	1000	2
	MO	0.24	86	3	1	1000	2
	MQ	0.57	100	3	1	1000	2
	MR	0.24	358	3	1	1000	2
	MS	0.57	1800	2	1	1000	2

Table A-10 (Cont'd): Additional Ship Class Profile Criteria

Ship Classification		Default Engine Assumptions					
Specific Class	Class Code	ME Type (% M4)	ME RPM	ME EPA Class	AE Type (% A4)	AE RPM	AE EPA Class
Merchant Ferry	MF	1.00	994	3	1	1000	2
Merchant Passenger	MP	0.00	822	3	1	1000	2
Tanker	TC	0.00	98	3	1	1000	2
	TG	0.13	500	3	1	1000	2
	TL	0.13	181	3	1	1000	2
	TM	0.13	149	3	1	1000	2
	TO	0.13	124	3	1	1000	2
	TQ	0.13	170	3	1	1000	2
	TS	0.13	91	3	1	1000	2
Tanker	TT	0.14	166	3	1	1000	2
	TU	0.00	84	3	1	1000	2
	TV	0.00	76	3	1	1000	2
Tug	All	1.00	1100	2	1	2000	1
Warship	WR	0.00	520	3	1	1000	2
	WS	0.00	1150	2	1	1000	2

Arctic

There has been no survey work conducted for vessels that frequent the Arctic. As such, the vessel characteristics used for Eastern Canada / Great Lakes was used for vessels in Canada's Arctic. An exception was made for 'cruise ships' that are active in the north, which resemble typical cargo ships with separate propulsion and auxiliary engines. These ships were treated as MP ships in MEIT. As noted in the main body of this report, a separate study is currently being conducted for 2010 ship emissions in the Arctic by Transport Canada.

Western Canada

AE Capacity and Loads

The same regressions developed for the eastern Canadian inventory were used for installed AE capacity for OGV vessels active on the West Coast in 2010. These regressions are provided in Appendix B.

AE loads for vessels on the West Coast were established by the BC CoS in 2005 / 2006 in a slightly different way than that employed in MEIT for the Eastern Canada / Great Lakes. Rather than a single ratio that is applied to the total installed AE capacity, the BC CoS identified the number of auxiliary engines used by mode of activity and the average load on those engines. This was largely achieved through evaluation of the numerous vessel surveys obtained. This same approach could not be used for the 2010 inventory, since vessel surveys were not available for most of the vessels in 2010. For this reason, the same model structure and load factors used for vessels in eastern Canada were used for the West Coast. The load factors for Merchant Bulk and Merchant Container were updated with BC CoS surveys collected for 2010 (other vessel classes did not have sufficient representation).

Table A-11: 2010 AE Loads by Vessel Class for the West Coast

General Class	Specific Class (code)	AE Load Factors		
		Underway	Anchor	Berth
Coast Guard	CI	0.10	0.10	0.00
	All other	0.17	0.22	0.22
Fishing	FF	0.50	0.50	0.00
	All other	0.20	0.20	0.00
Merchant Bulk*	MB	0.30	0.28	0.29
Merchant Container*	MC	0.15	0.15	0.15
Merchant Cruise	MW	n/a	n/a	n/a
Merchant Other	MM, MH	0.20	0.27	0.27
	MA	0.13	0.24	0.24
	MO	0.21	0.42	0.42
	MS, MG	0.38	0.42	0.42
	MR	0.20	0.34	0.34
Tanker	TL, TG, TM, TO, TS	0.20	0.30	0.30
	TQ	0.23	0.33	0.33
	TT	0.30	0.24	0.24
	TC, TU, TV	0.24	0.26	0.26
Tug Boat	Ocean	0.17	0.22	0.22
	Other	0.00	0.00	0.00
War	All	0.34	0.00	0.00

*Updated with 2010 survey data

Boiler Fuel Consumption

The same boiler fuel consumption rates used for Eastern Canada / Great Lakes were used for the west coast, since most of the MEIT boiler rates originated from the BC CoS survey data. The rates were updated for Merchant Bulk and Merchant Container ships since these vessel classes had sufficient representation in the 2010 surveys (however, the updated rates are virtually identical to the rates determined in 2005/2006). The 2010 boiler fuel consumption rates are shown in Table A-12.

Table A-12: 2010 Boiler Fuel Consumption Rates

General Class	Specific Class	Underway (tonnes/hr)	Berth (tonnes/hour)
Coast Guard	CI	0.00	0.00
Fishing	FV	0.10	0.00
	All other	0.00	0.00
Merchant Bulk*	MB	0.08	0.08
Merchant Container*	MC	0.14	0.19
Merchant Cruise	MW	0.36	0.35
Merchant Other	MA, MR	0.10	0.11
	All others	0.08	0.08
Tanker	TU, TV	0.10	0.92
	All others	0.10	0.11
Tug Boat	All	0.00	0.00
War	All	0.10	0.00

* Updated with 2010 survey data.

Fuel Sulphur Levels

Fuel sulphur levels for the West Coast were assigned directly to the container and bulk ship classes from surveys collected by the BC CoS during 2010. For all other OGV vessel classes, the average sulphur levels from the 2005/2006 inventory report were used[51]. Vessel classes that use domestic MDO were assigned sulphur levels of 0.05%, based on a previous study of Canadian marine fuels[52].

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[51] BC Chamber of Shipping, 2007. 2005 – 2006 BC Ocean Going Vessel Emissions Inventory. Prepared by the BC Chamber of Shipping, January.

[52] BMT Technologies Ltd., 2008. Update on Availability, Quality and Quantity of Marine Fuels in Canada

Table A-13: Fuel Sulphur Levels by Ship Class for the West Coast

General Class	Specific Class	Source	Sulphur Level (%)
Coast Guard	All	AE	0.05
		ME	0.05
		BO	0.05
Fishing	All	AE	0.05
		ME	0.05
		BO	0.05
Merchant Bulk	MB	AE	2.30
		ME	2.50
		BO	2.36
Merchant Container	MC	AE	1.90
		ME	2.57
		BO	1.90
Merchant Cruise	MW	AE	n/a
		ME	1.44
		BO	1.32
Merchant Other	MA	AE	2.04
		ME	2.69
		BO	2.38
	MH	AE	1.70
		ME	2.42
		BO	1.55
Tanker	TT	AE	2.97
		ME	2.97
		BO	3.37
	TL	AE	2.43
		ME	2.58
		BO	2.44
	TU, TV	AE	0.93
		ME	1.35
		BO	1.35
Tug Boat	All	AE	0.05
		ME	0.05
		BO	0.05
War	All	AE	0.05
		ME	0.05

		BO	0.05

APPENDIX B: SHIP CLASS REGRESSION EQUATIONS

As indicated in Appendix A, Lloyd ship data was used to establish new profile regression equations to predict installed auxiliary engine (AE) capacity. The Lloyd data include AE information (number and capacity of engines) on approximately 10% – 20% of vessels in the CG database. For the high activity vessel classes in 2010, regression equations were developed for AE based on deadweight tonnage (DWT) and main engine capacity (ME). Both DWT and ME are available from the INNAV dataset for virtually every active vessel tracked.

Figures B-1 to B-20 show the regression equations for the high activity ship classes, following the INNAV vessel class codes specified in Table 2-2.

Figure B-1: MC Auxiliary Capacity (AE) versus Main Engine Capacity Regression

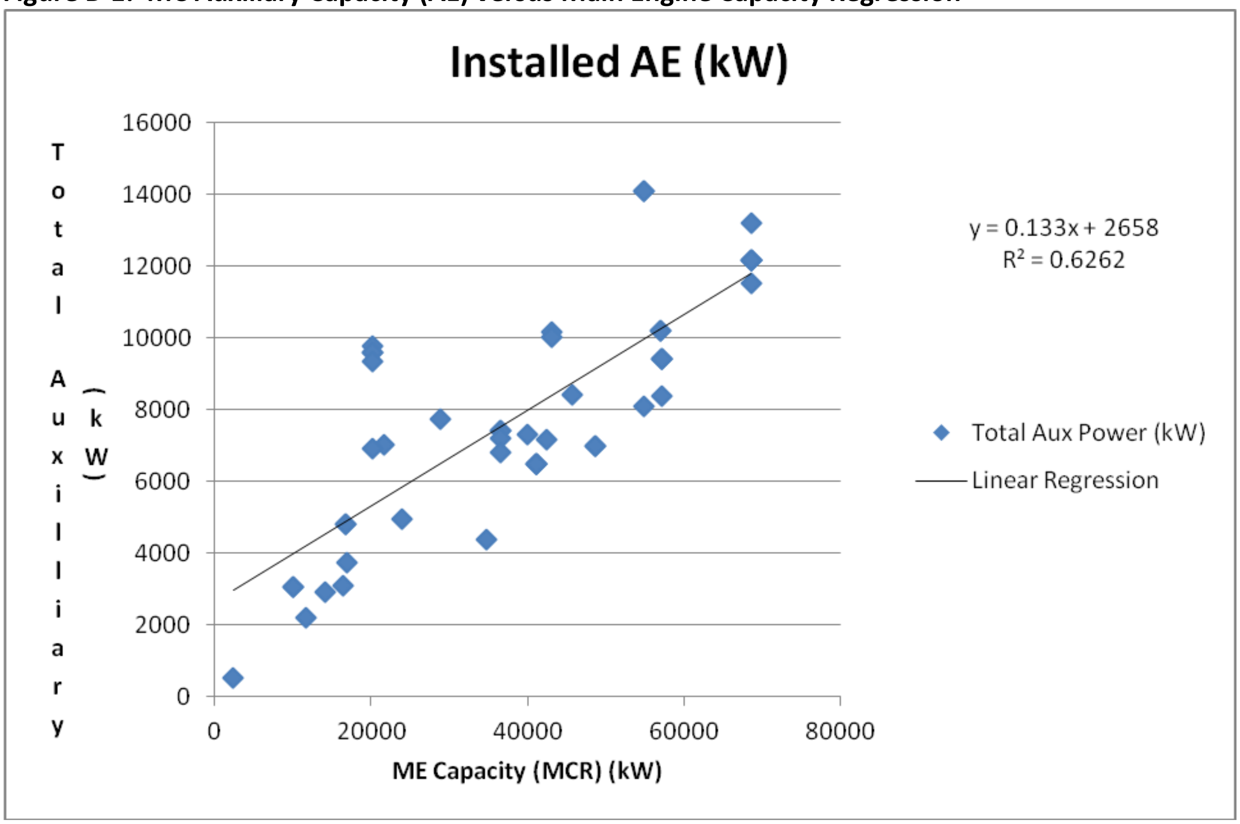


Figure B-2: MC Auxiliary Capacity (AE) versus Deadweight Tonnage (DWT) Regression

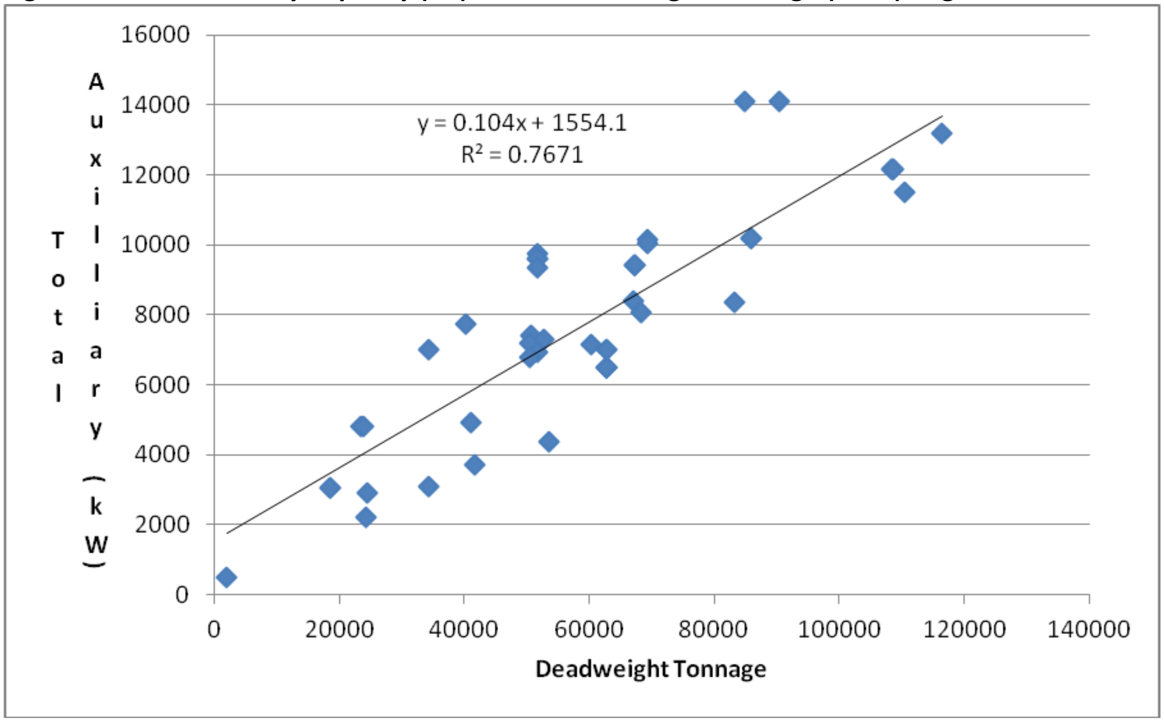


Figure B-3: MC Auxiliary Capacity (AE) versus Main Engine Capacity Regression

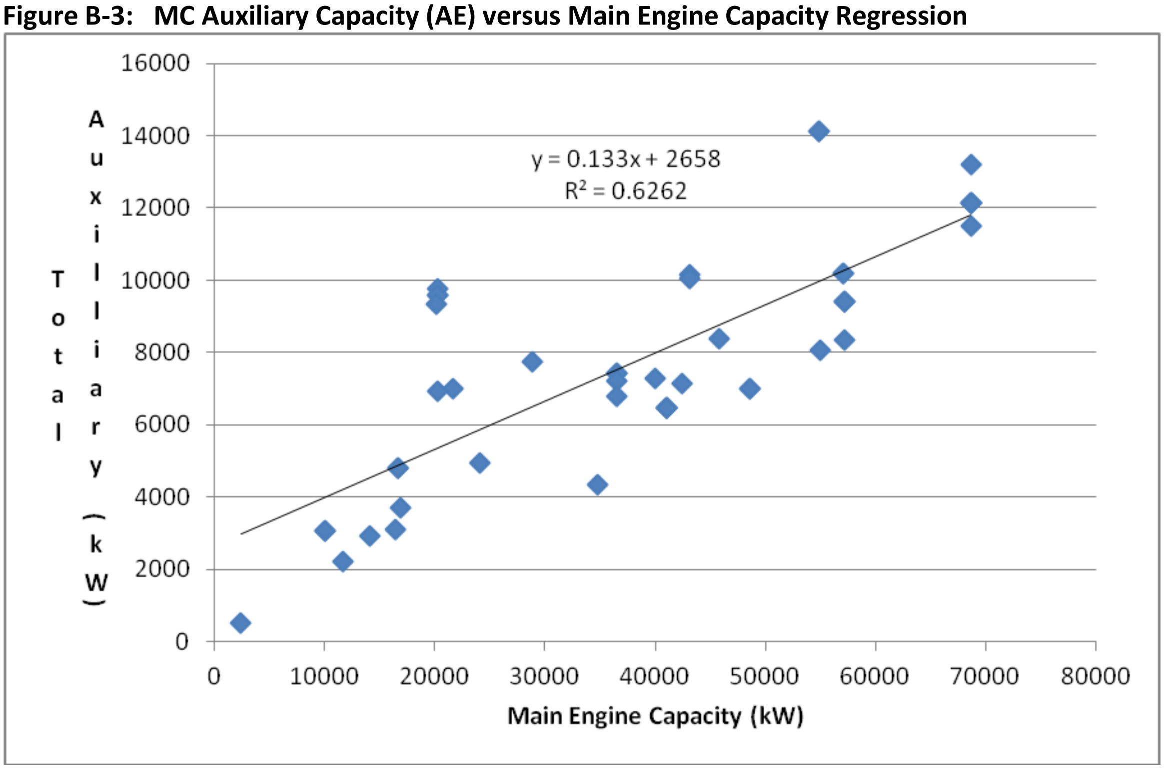


Figure B-4: MB Auxiliary Capacity (AE) versus Deadweight Tonnage (DWT) Regression

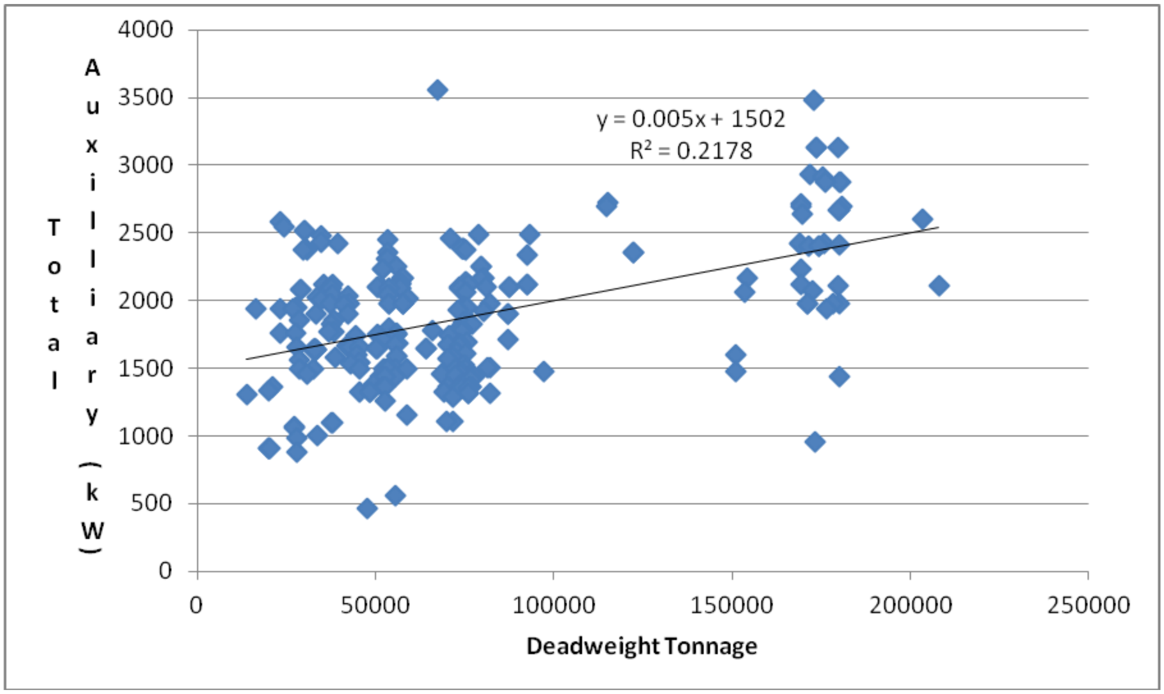


Figure B-5: MB Auxiliary Capacity (AE) versus Main Engine Capacity Regression

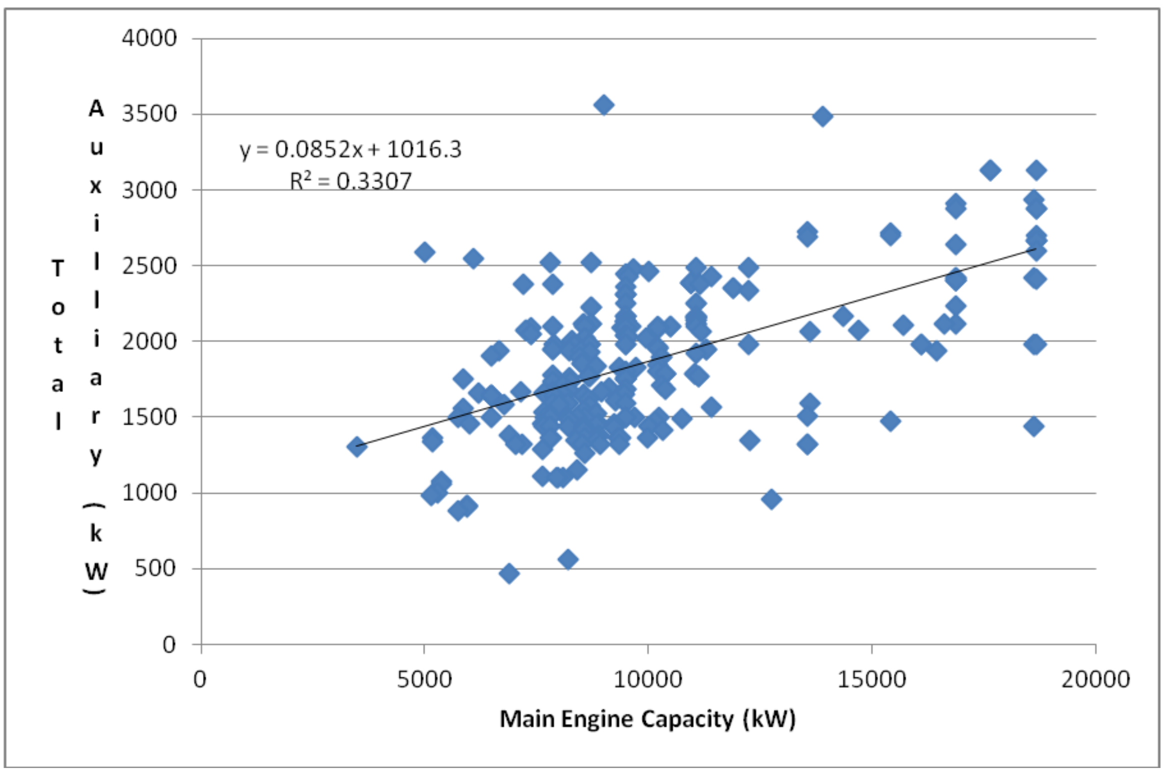


Figure B-6: MA and MH Auxiliary Capacity (AE) versus Deadweight Tonnage (DWT) Regression

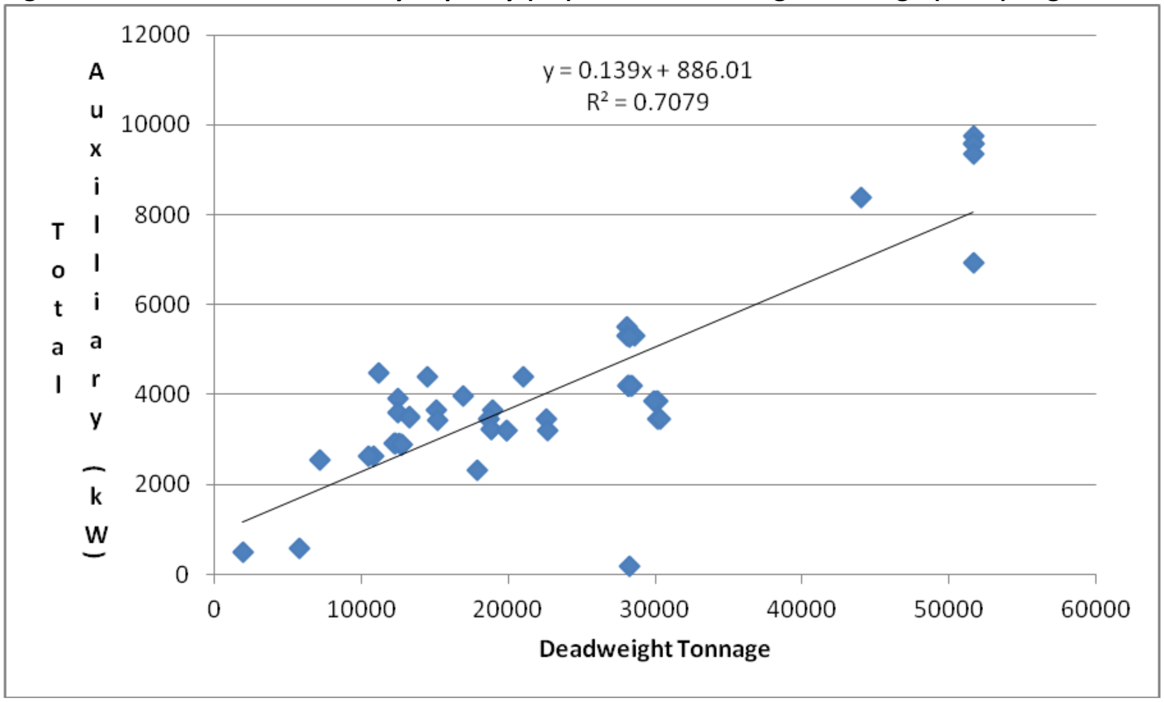


Figure B-7: MA and MH Auxiliary Capacity (AE) versus Main Engine Capacity Regression

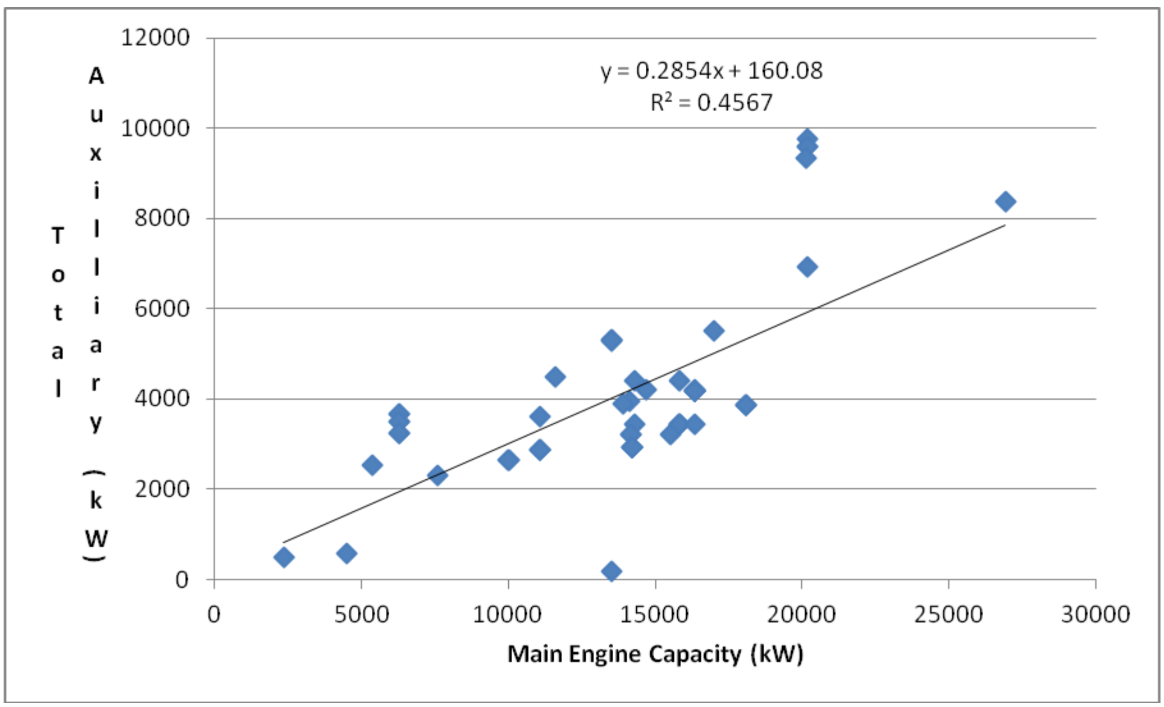


Figure B-8: MF and MP Auxiliary Capacity (AE) versus Deadweight Tonnage (DWT) Regression

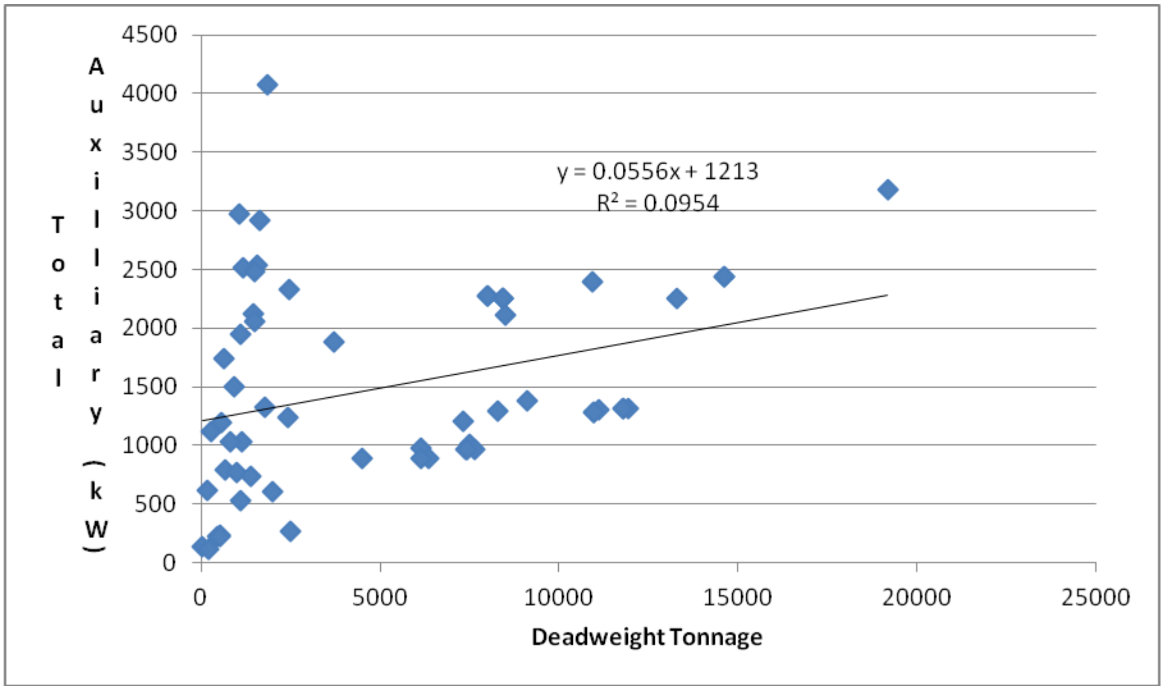


Figure B-9: MF and MP Auxiliary Capacity (AE) versus Main Engine Capacity Regression

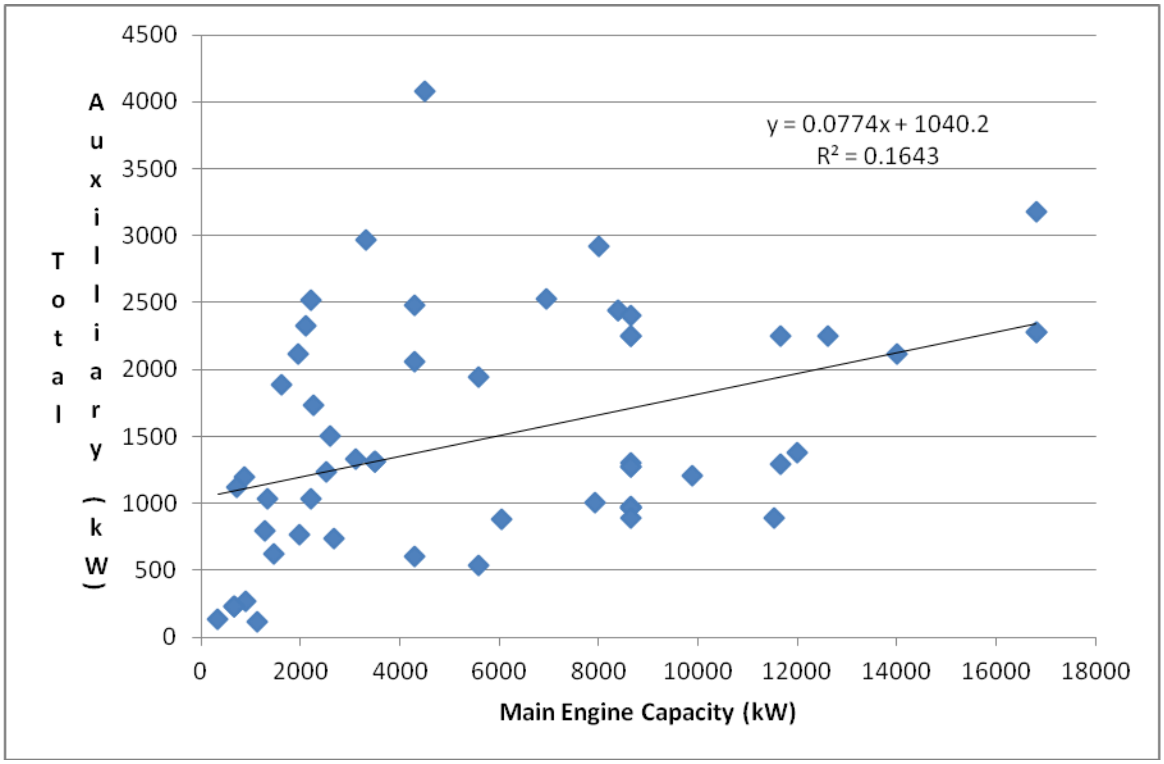


Figure B-10: MG Auxiliary Capacity (AE) versus Deadweight Tonnage (DWT) Regression

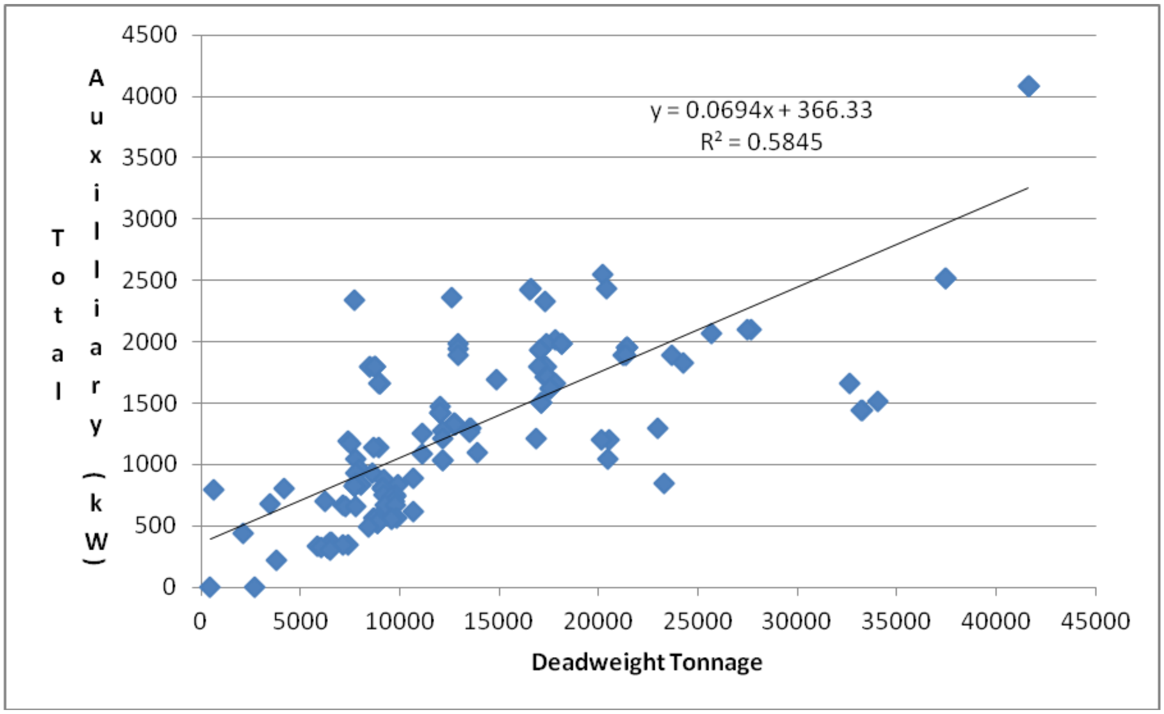


Figure B-11: MG Auxiliary Capacity (AE) versus Main Engine Capacity Regression

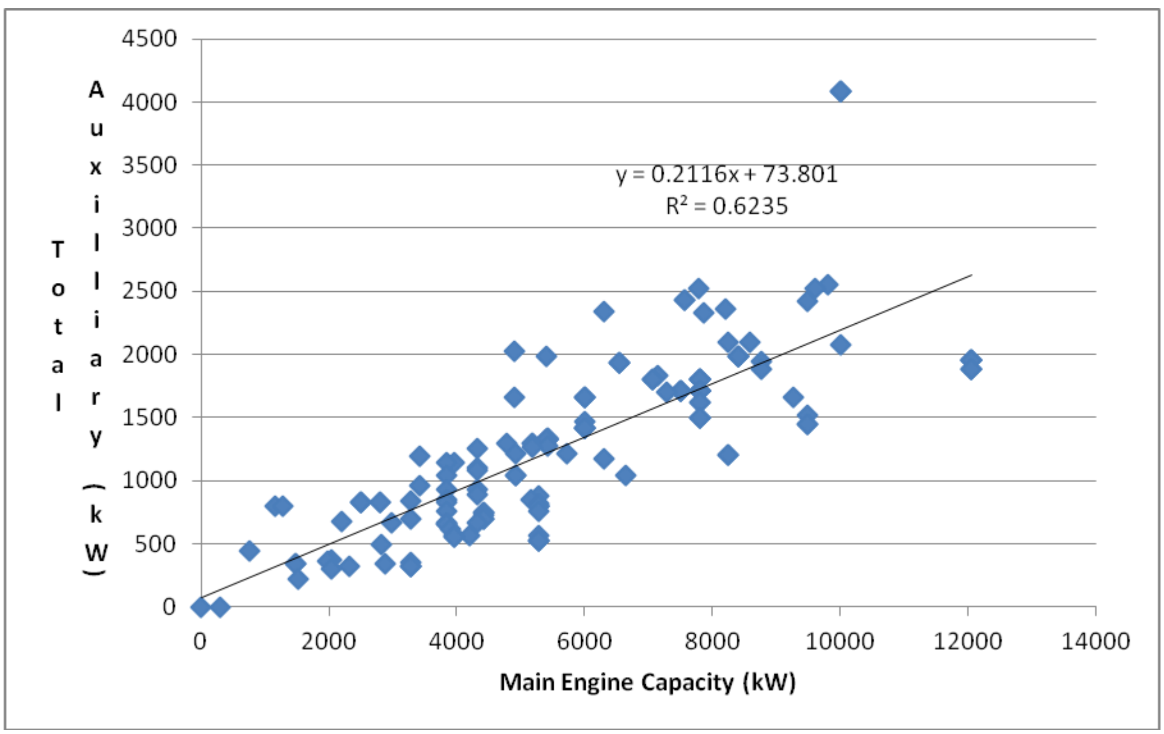


Figure B-12: MM Auxiliary Capacity (AE) versus Deadweight Tonnage (DWT) Regression

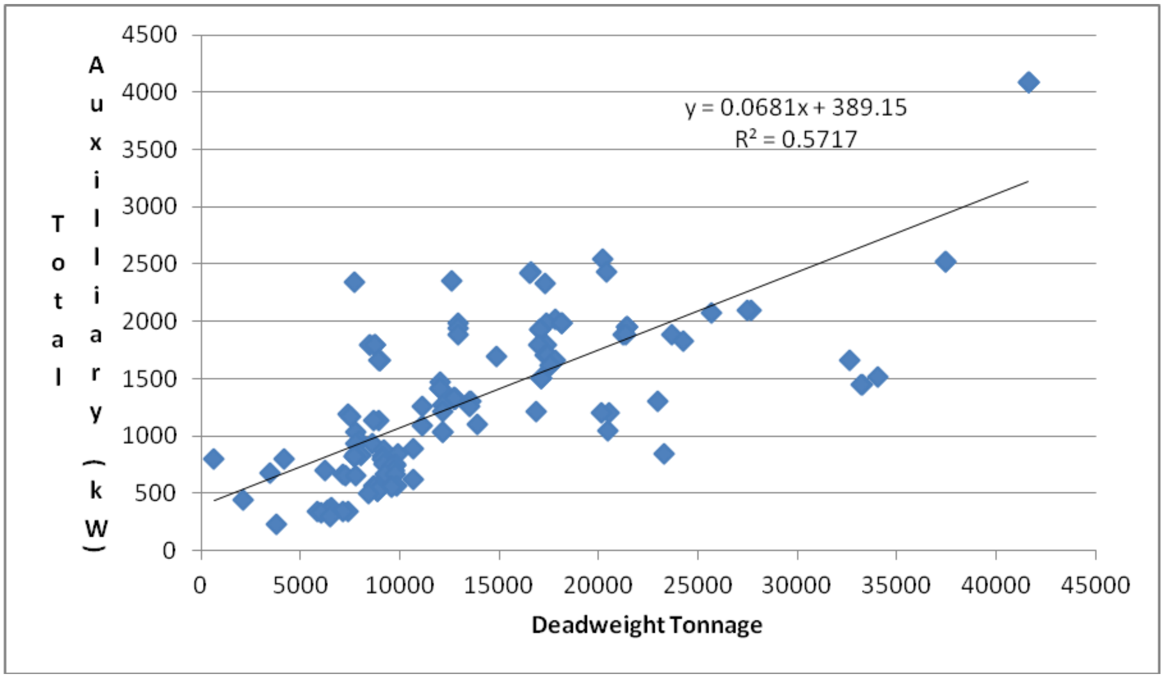


Figure B-13: MM Auxiliary Capacity (AE) versus Main Engine Capacity Regression

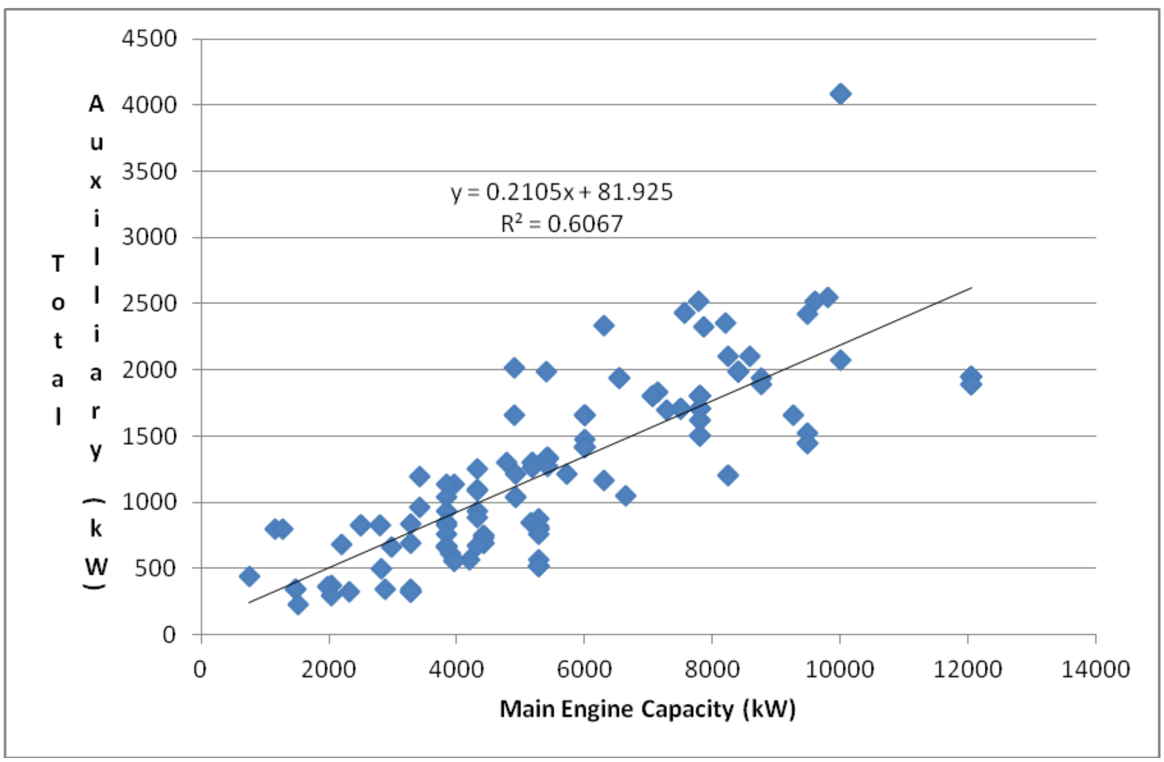


Figure B-14: TC, TG, TO, TS, TU and TV Auxiliary Capacity (AE) versus Deadweight Tonnage (DWT) Regression

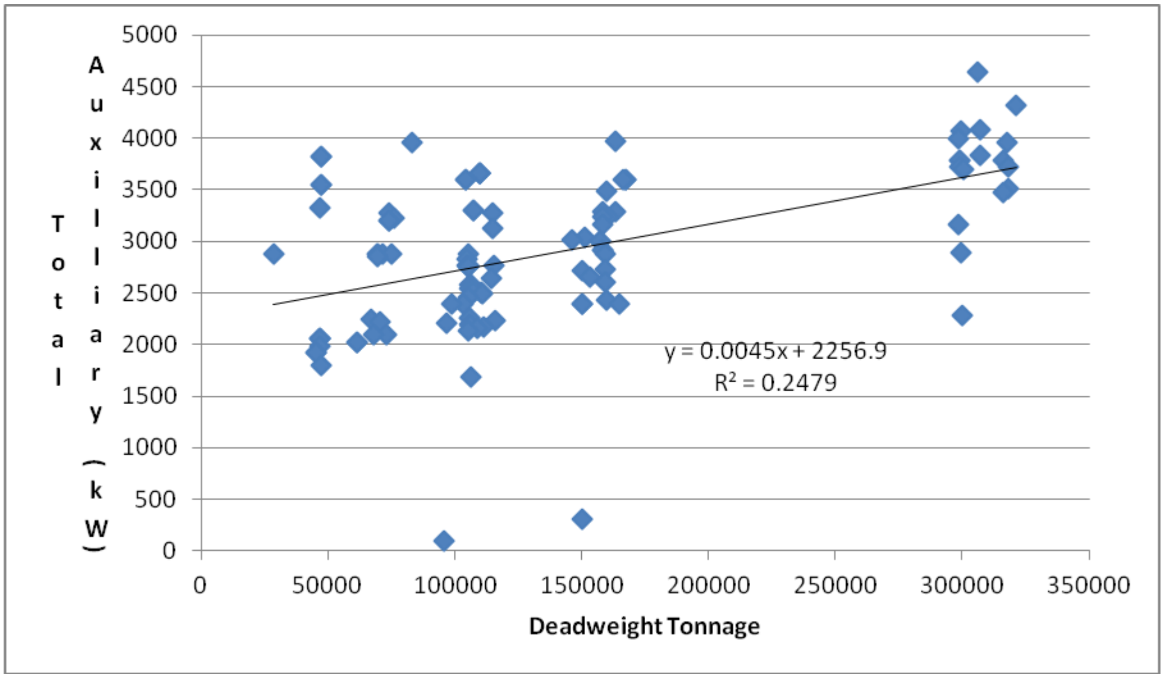


Figure B-15: TC, TG, TO, TS, TU and TV Auxiliary Capacity (AE) versus Main Engine Capacity Regression

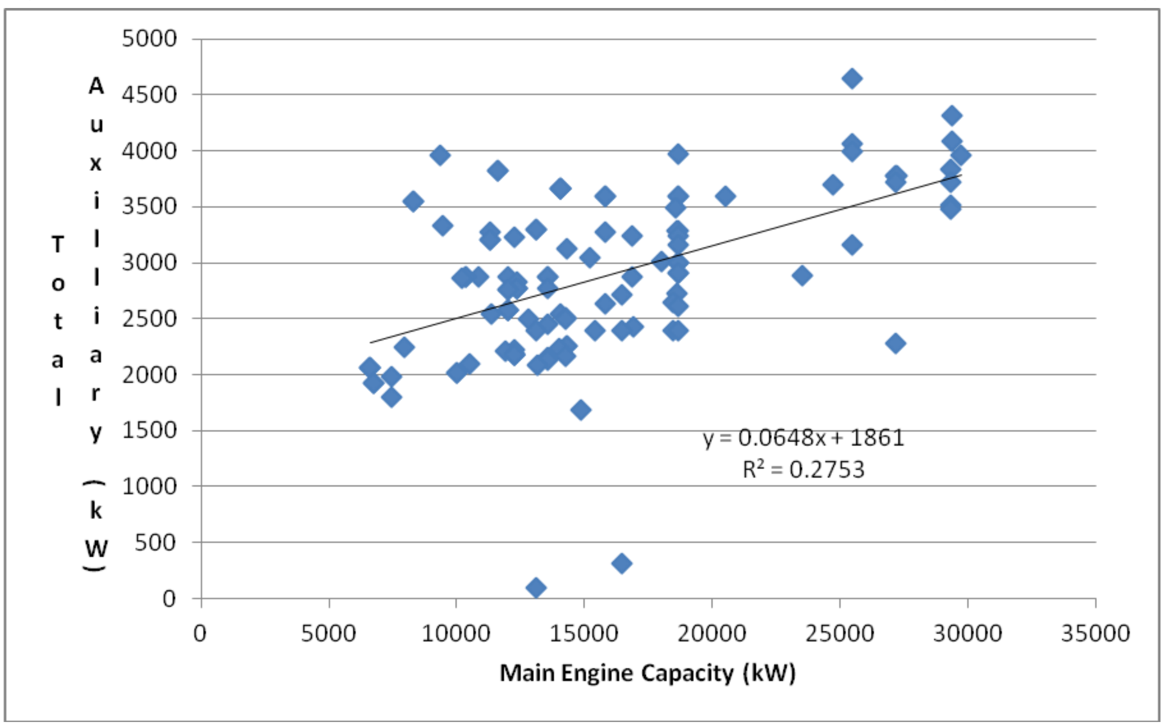


Figure B-16: TL Auxiliary Capacity (AE) versus Deadweight Tonnage (DWT) Regression

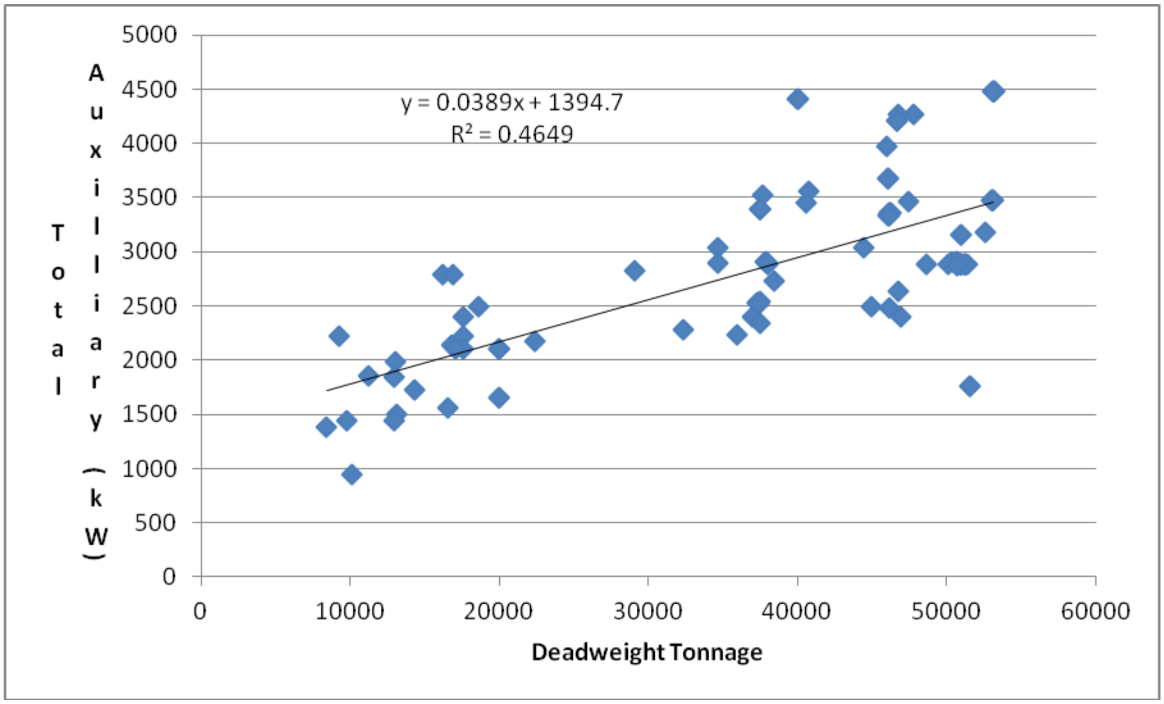


Figure B-17: TL Auxiliary Capacity (AE) versus Main Engine Capacity Regression

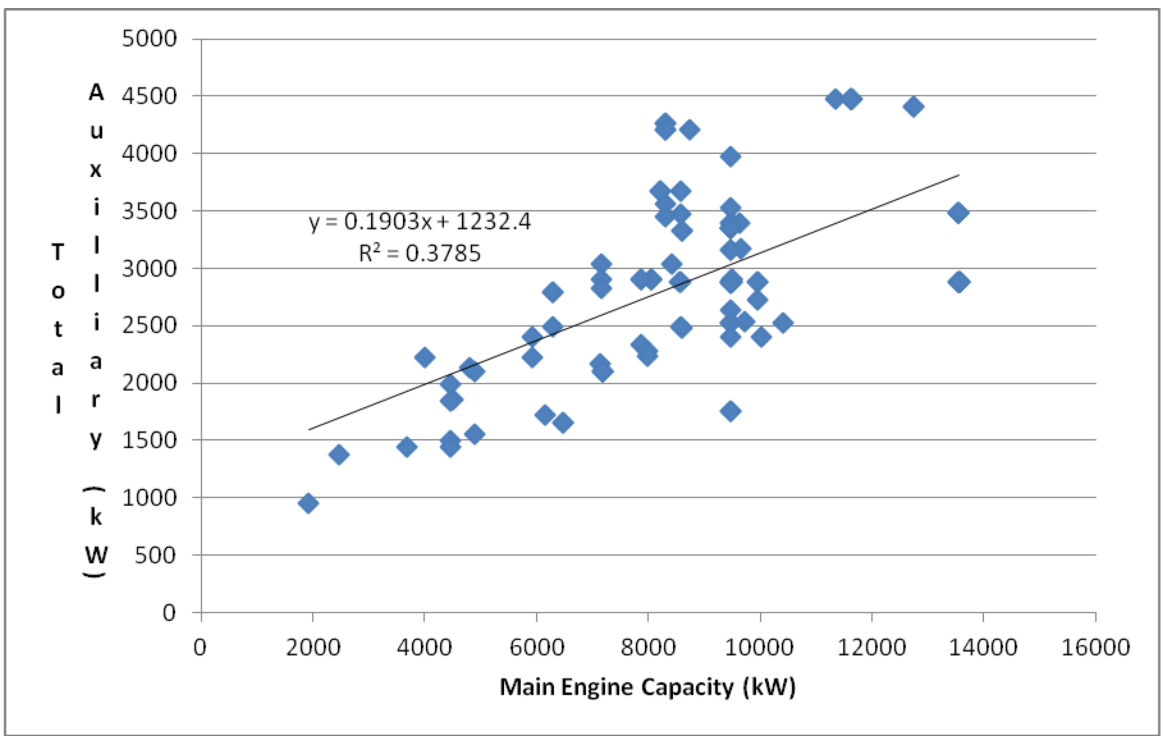


Figure B-18: Merchant Class Combined Auxiliary Capacity (AE) versus Deadweight Tonnage (DWT) Regression

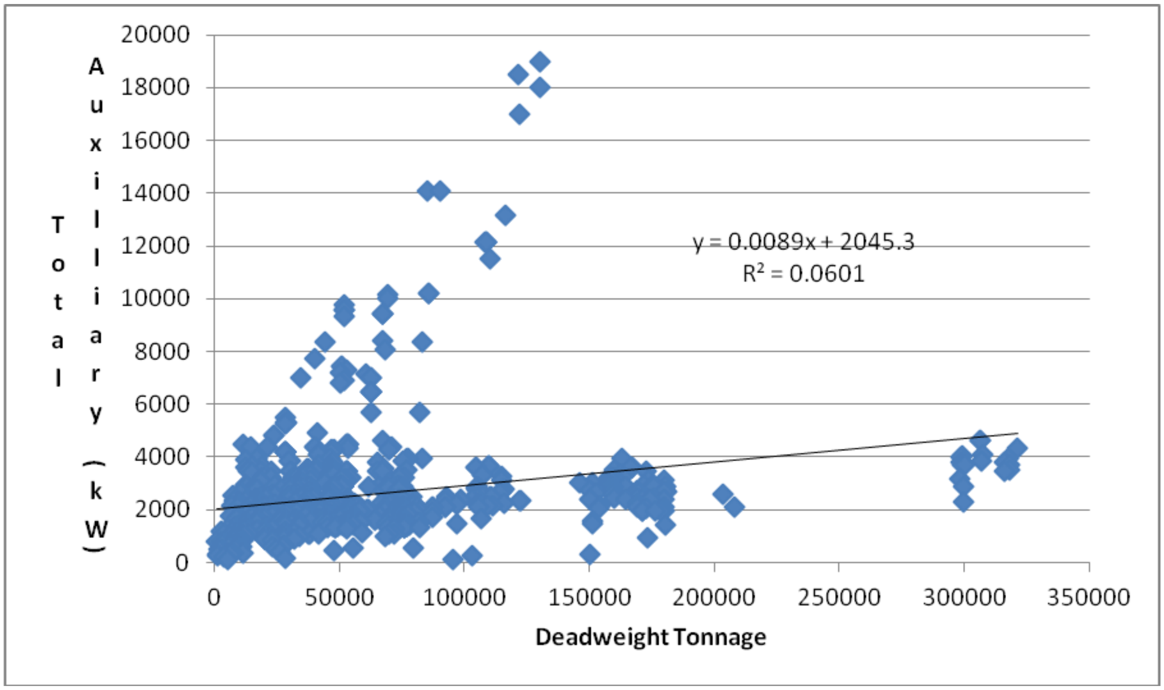


Figure B-19: Merchant Class Combined Auxiliary Capacity (AE) versus Main Engine Capacity Regression

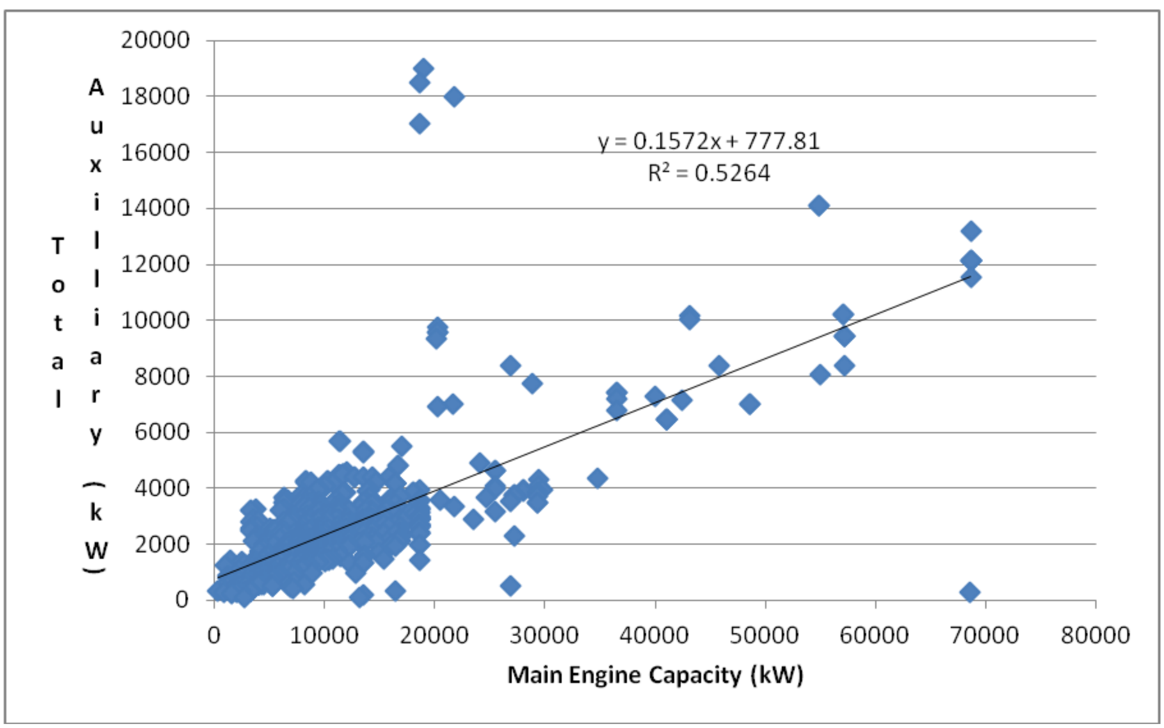


Figure B-20: TT Auxiliary Capacity (AE) versus Deadweight Tonnage (DWT) Regression

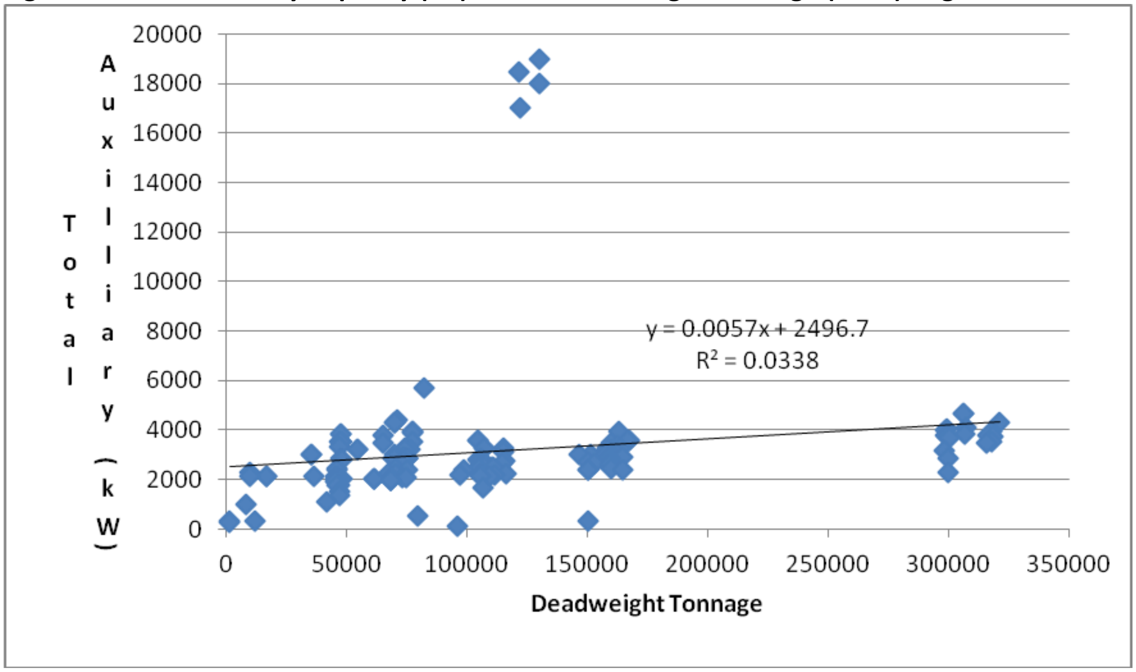
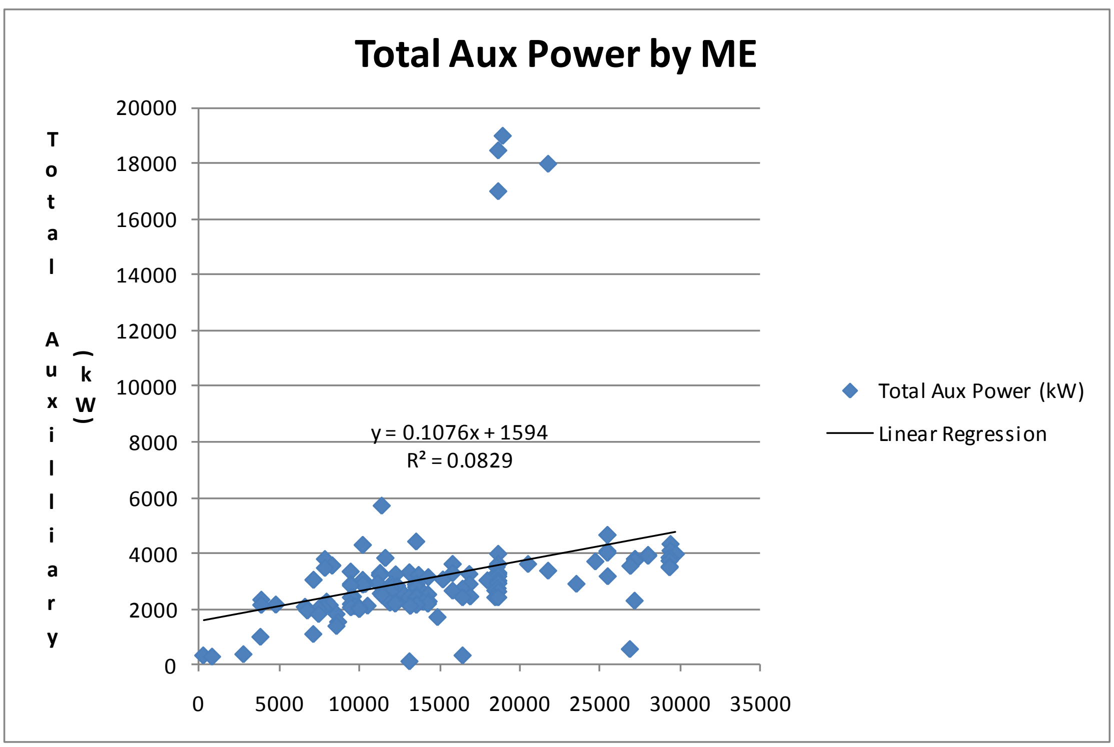


Figure B-21: TT Auxiliary Capacity (AE) versus Main Engine Capacity Regression



APPENDIX C: ADDITIONAL DATA

Innocent Passage

Determination of innocent passage was made by identifying all OGVs that were active in Canadian waters during 2010 but did not make a stop at a Canadian berth. This procedure could not be accomplished for western Canada due to problems found in the CG VTOSS data (no innocent passage was included in the west inventory). The hours within Canadian waters and the corresponding emission estimates by vessel class for eastern Canada and the Arctic are provided in Table C-1.

Domestic and International Voyages

The Canadian inventory for eastern Canada and the Arctic is categorized to domestic and international voyages by activity hours in Table C-2 and emissions in Table C-3. International voyages are shown by U.S. voyages and Other International voyages. Any ship that spent time outside of Canada during 2010 was considered an international ship and its voyages classified as international. This means, for example, that all of the moves (and hours in Canadian waters) associated with a container ship originating from Europe are considered international, even if a specific voyage for this ship (as defined in the CG INNAV data) begins and ends entirely within Canada (this may occur for an international ship that makes several stops within Canada before departing). As with Innocent Passage, western Canada is not represented.

Elemental Carbon, Organic Carbon and Sulphates

Total $PM_{2.5}$ estimates in the inventory were allocated to their estimated EC, OC and sulphates portions by use of simple ratios. The ratios used were developed from previous tests done by Agrawal *et al* [53]. These ratios are described below by source type and in the order EC, OC, Sulphates:

Marine engines, HFO:	5	15	80
Marine engines, MDO:	34	43	23
Boilers, HFO:	8	2	90

[53] Agrawal, H., W.A. Welch, J.W. Miller and D.R. Cockert, 2008. Emission Measurements from a Crude Oil Tanker at Sea. Environ Sci Technol., 2008 Oct1; 42(19): 7098-103.

These estimates are provided in TableC-4. There has been recent interest and study in elemental carbon (black carbon) amounts from marine combustion and therefore the ratios noted above may not be consistent with the current understanding.

Air Toxic Emissions

Air toxic emission estimates are presented in Table C-5. These estimates are due to all marine engines but not boilers (since representative speciation profiles for boilers could not be identified).

Table C-1: Innocent Passage Activity and Emission Estimates by Vessel Class, Eastern Canada and Arctic (tonnes)

Vessel Class	Activity (hours)	Total Trips	Criteria Air Contaminants (CACs)								Greenhouse Gases (GHGs)		
			NOx	SO_x	CO	HC	PM	PM10	PM25	NH3	CO2	CH4	N2O
Coast Guard	18,142.3	1,144	66.8	0.9	4.5	2.3	1.1	1.1	1.0	0.1	2,465.1	0.0	0.1
Fishing	62,804.1	148	50.8	0.8	4.2	1.9	1.0	1.0	0.9	0.1	2,563.3	0.0	0.1
Merchant Bulk	1,953,563.5	50,557	2,539.4	1,673.2	231.7	98.6	224.3	215.3	198.1	3.0	113,129.8	2.0	3.0
Merchant Container	62,220.4	530	84.3	70.1	9.1	4.0	9.4	9.0	8.3	0.1	4,829.9	0.1	0.1
Merchant Cruise	344.6	20	7.7	3.9	0.6	0.3	0.5	0.5	0.5	0.0	395.2	0.0	0.0
Merchant Other	1,243,249.3	10,446	668.7	510.1	59.4	25.0	67.4	64.7	59.5	0.9	33,857.0	0.5	0.9
Merchant Passenger	2,273.1	474	15.3	7.3	1.6	0.6	1.0	0.9	0.9	0.0	787.9	0.0	0.0
Special Purpose	17,320.7	1,372	27.9	0.4	2.3	1.0	0.6	0.6	0.5	0.0	1,409.2	0.0	0.0
Tanker	23,948.3	199	10.3	9.5	1.0	0.4	1.2	1.2	1.1	0.0	637.3	0.0	0.0
Tug Boat	541,447.1	12,582	631.4	9.2	45.3	22.9	11.3	10.9	10.0	0.9	25,704.0	0.2	0.7
Other	270.2	12	1.9	0.0	0.2	0.1	0.0	0.0	0.0	0.0	103.9	0.0	0.0
Total	**3,925,583.8**	**77,484**	**4,104.4**	**2,285.5**	**359.9**	**157.0**	**317.9**	**305.1**	**280.7**	**5.1**	**185,882.6**	**2.9**	**4.9**

Table C-2: 2010 Activity Hours by Voyage Type (Domestic and International), Eastern Canada and Arctic

Vessel Class	Annual Hours of Activity			
	Domestic	International – US	International – Other	Total
Barge	11,106	1,727		12,833
Coast Guard	37,715	48,323	5,666	91,704
DFO	5,865	20,468		26,333
Fishing	30,610,707	65,252	9,787	30,685,746
INNAV Test	808	1,592	64	2,464
Merchant Bulk	2,093	147,707	195,360	345,160
Merchant Container		15,162	92,664	107,826
Merchant Cruise		5,666	5,781	11,447
Merchant Other	9,099	24,665	120,945	154,709
Merchant Passenger	1,947,496	72,193	4,934	2,024,623
Other	2,131	1,116		3,247
Pleasure Craft	11,467	9,643	976	22,085
Special Purpose	44,079	19,773	6,274	70,125
Tanker	9,554	84,427	154,452	248,434
Tug Boat	91,960	66,463	11,656	170,079
U.S. Coast Guard	9	458	65	533
Unknown		1,910		1,910
War	1,843	1,859	135	3,837
Total	**32,785,934**	**588,402**	**608,757**	**33,983,093**

Table C-3: 2010 Emissions by Voyage Type (Domestic and International), Eastern Canada and Arctic

Voyage Type and Vessel Class	CACs (tonnes)							GHGs (tonnes)		
	NOx	SO_x	CO	HC	PM10	PM25	NH3	CO2	CH4	N2O
Domestic										
Coast Guard	432	7	35	15	8	8	0	21,438	0	1
Fishing	11,980	163	1,458	870	258	238	12	519,062	3	13
Merchant Bulk	483	299	42	17	38	35	1	19,847	0	1
Merchant Other	352	298	36	13	35	32	0	20,851	1	1
Merchant Pass	5,146	516	549	191	140	128	6	340,166	11	9
Special Purpose	419	7	34	15	8	8	1	20,938	0	1
Tanker	650	612	71	74	69	63	1	44,047	2	1
Tug Boat	2,527	66	207	95	52	48	4	123,742	1	3
War	95	1	9	5	2	2	0	4,233	0	0
Total - Domestic	**22,085**	**1,969**	**2,442**	**1,293**	**610**	**561**	**26**	**1,114,325**	**18**	**28**
Int - US										
Coast Guard	1,566	24	128	56	31	28	2	77,809	0	2
Fishing	1,161	18	98	47	23	21	2	56,049	0	1
Merchant Bulk	8,706	6,147	813	326	771	710	10	431,540	9	11
Merchant Container	1,604	1,333	148	60	165	152	2	88,636	2	2
Merchant Cruise	1,717	964	156	67	128	118	3	96,315	1	2
Merchant Other	1,291	1,060	120	47	129	119	2	71,993	1	2
Merchant Pass	1,876	179	184	72	52	47	3	110,280	3	3
Special Purpose	108	2	9	4	2	2	0	5,436	0	0
Tanker	7,935	5,426	734	1,722	674	620	8	369,062	8	10
Tug Boat	1,792	43	131	65	33	30	2	74,935	1	2
War	59	1	5	2	1	1	0	2,656	0	0
Total – INT - US	**27,815**	**15,196**	**2,527**	**2,468**	**2,010**	**1,849**	**34**	**1,384,712**	**25**	**36**
INT-Other										
Coast Guard	338	5	28	12	7	6	0	17,001	0	0
Fishing	222	3	17	9	4	4	0	9,211	0	0
Merchant Bulk	18,898	11,626	1,648	667	1,473	1,355	20	775,919	14	21
Merchant Container	20,978	13,245	1,764	733	1,687	1,552	22	818,425	12	22
Merchant Cruise	1,507	869	139	58	113	104	3	85,634	1	2
Merchant Other	8,543	6,165	759	306	772	710	10	413,525	7	11
Merchant Passenger	469	182	40	16	25	23	1	19,718	0	1
Special Purpose	333	5	27	11	6	6	0	15,979	0	0

Table C-3 (Cont'd): 2010 Emissions by Voyage Type (Domestic and International), Eastern Canada and Arctic

Voyage Type and Vessel Class	CACs (tonnes)							GHGs (tonnes)		
	NOx	SO_x	CO	HC	PM10	PM25	NH3	CO2	CH4	N2O
Tanker	17,884	11,407	1,600	7,078	1,442	1,327	19	763,210	14	20
Tug Boat	504	14	41	19	10	10	1	24,516	0	1
War	2	0	0	0	0	0	0	126	0	0
Total – INT - Other	**69,678**	**43,521**	**6,064**	**8,909**	**5,539**	**5,096**	**75**	**2,943,266**	**50**	**78**
GRAND TOTAL	**119,578**	**60,687**	**11,032**	**12,670**	**8,159**	**7,506**	**135**	**5,442,302**	**93**	**143**

Table C-4: Estimates of Elemental Carbon, Organic Carbon and Sulphates from all Marine Sources (kilograms)

Mode of Activity	Elemental Carbon	Organic Carbon	Sulphates
Anchoring	37,423	52,346	190,324
Berthing	104,304	147,890	557,125
Underway	950,617	2,033,482	8,465,475
Total	**1,092,345**	**2,233,718**	**9,212,924**

Table C-4: Estimates of Air Toxics from all Marine Engines (kilograms)

Pollutant	Dioxins/Furans	HAP	Metals	PAH	PCB's
2,2,4-Trimethylpentane		1,837.7			
Acenaphthene				34.1	
Acenaphthylene				52.5	
Acetaldehyde		101,539.3			
Acrolein		16,098.5			
Anthracene				52.5	
Arsenic			1,005.7		
Benz(a)anthracene				56.8	
Benzene		27,517.7			
Benzo(a)pyrene				15.8	
Benzo(b)fluoranthene				31.7	
Benzo(g,h,i)perylene				12.8	
Benzo(k)fluoranthene				15.8	
Beryllium			7.1		
Cadmium			254.2		
Chromium (Cr3+)			1,437.8		
Chromium (Cr6+)			739.3		
Chrysene				10.0	
Cobalt			770.4		
Dibenzo(a,h)anthracene				-	
Dioxin	0.016				
Ethyl Benzene		9,188.6			
Fluoranthene				31.4	
Fluorene				69.6	
Formaldehyde		210,361.8			
Hexachlorobenzene		0.1			
Indeno(1,2,3,c,d)pyrene				31.7	
Lead			484.5		
Manganese			618.4		
Mercury			3.0		
Naphthalene				1,991.6	
n-Hexane		23,215.7			
Nickel					1.6
Phenanthrene		28,006.9			

Phosphorous				55.5	
Polychlorinated Biphenyls			20.6		
Propionaldehyde		9,629.7			
Pyrene		14,701.8			
Selenium		22,052.7			
Styrene		23,215.7			
Toluene					1.6
Xylene		28,006.9			
Grand Total	**0.016**	**489,437.6**	**42,481.3**	**2,541.3**	**1.6**