# Experiences conducting port emissions inventories in Canada

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## ABSTRACT

Transport Canada (TC) and SNC-Lavalin Environment (SLE) have developed a Ports Emissions Model for the preparation of port emission inventories (EIs) in Canada. This user-friendly MS Access-based tool allows terminals, port authorities and government agencies to reliably estimate the emissions associated with port activities from marine trade. The activities of 5 sources are captured: admin, cargo-handling equipment, on-road vehicles, marine and rail. Emission factors are sourced from EPA models such as MOBILE and NONROAD as well as emissions test data for rail (and non-conventional or hybridized equipment). The TC Ports Model is the actualization of the TC Ports Protocol, which details how to conduct inventories consistently across different regions and geographical boundaries.

The first comprehensive activity-based port EI in Canada was completed for Port Metro Vancouver (PMV) for the 2005 inventory year. Similar inventories have since been completed for the Ports of Montreal, Hamilton, Sept-Îles and Halifax. SLE recently completed the updated 2010 inventory for PMV which now includes the activity of over 115 terminals spread across the Lower Fraser Valley. TC and SLE are using this tool to complete a 2010 baseline inventory for all 18 Canadian Port Authorities. The 2010 baseline will benefit from a 2010 national marine inventory currently being finalized by SLE and Environment Canada.

This paper shares the experiences gained conducting port inventories in Canada, the evolution of methodologies and how these lessons can be applied to other port jurisdictions to improve our understanding of port activities, marine trade and the associated emissions.

## INTRODUCTION

There are 18 federally regulated Canada Port Authorities (CPAs). They range in size from 1 terminal (Oshawa Port Authority [(1)]) to over 100 terminals (Port Metro Vancouver[(2)]). The locations of the CPAs are shown in Figure 1.

**Figure 1. Location of Canadian Port Authorities.**

CPAs handled 268.6 million tonnes of cargo in 2010, more than half of all marine cargo handled in Canada that year[3]. Like many major ports worldwide (e.g., Port of Rotterdam[4], Port of Los Angeles[5]), Canadian ports are experiencing substantial growth. Table 1 lists the 2010 tonnages handled at each CPA, as well as the growth relative to 2009. Port Metro Vancouver (PMV), Port Saint John and Port of Montreal handled the most cargo, while the ports of Nanaimo and Hamilton experienced the most growth.

**Table 1: Canadian Port Authorities 2010 tonnages and growth rates***

| Port Authority | 2010 throughput (millions of tonnes) | 2010 growth rate relative to 2009 |
|---|---|---|
| Port Metro Vancouver | 104.7 | 15.9% |
| Saint John Port Authority | 30.6 | 16.0% |
| Montreal Port Authority (including Contrecoeur) | 24.8 | 4.2% |
| Sept-Iles Port Authority (including Pointe-Noire) | 24.6 | 22.6% |
| Quebec Port Authority | 24.6 | 10.4% |
| Prince Rupert Port Authority | 15.0 | 33.2% |
| Hamilton Port Authority | 11.4 | 38.8% |
| Halifax Port Authority | 10.2 | -0.2% |
| Thunder Bay Port Authority | 6.8 | -6.4% |
| Windsor Port Authority | 5.3 | 12.5% |
| Trois-Rivieres | 2.9 | 18.2% |

| | | |
|---|---|---|
| Belledune Port Authority | 2.1 | -19.2% |
| Toronto Port Authority | 1.5 | -8.3% |
| St. John's Port Authority | 1.5 | 3.5% |
| Nanaimo Port Authority | 1.3 | 71.9% |
| Port Alberni Port Authority | 1.0 | -1.3% |
| Saguenay Port Authority | 0.4 | 27.0% |

* Oshawa became a port authority in 2011 so 2010 tonnage data is not available.

Canada Port Authorities were created by the 1998 Canada Marine Act, replacing the Harbour Commissions Act. They are empowered by Transport Canada (TC) as independent and self-sufficient bodies to manage public port lands and seaways under their control[(6)]. The mandate of TC includes the importance of developing environmentally responsible transportation(7). Furthermore, CPAs are subject to the Canadian Environmental Protection Act and other federal regulations covering environmental assessments of its project.

Environmental stewardship has developed substantially at Canadian ports over the past decade. Port of Montreal adopted an environmental policy in 2001 which included environmental compliance of its operations, protection of the environment, environmental management and awareness of environmental commitment[(8)]. Most CPAs now have some form of environmental policy governing protection of land, water and air. Air quality in particular has been a growing concern recently; a 2008 study indicated that 2,700 Canadians die prematurely from air pollution each year[(9).]

An important step in managing air pollution at ports has been the development of port emissions inventories (EIs). An inventory calculates the emissions of all the activities associated with port operations, generally over a single calendar year. Port EIs have historically included four different source groups:

- Cargo-handling equipment;
- Marine;
- Onroad vehicles; and
- Rail.

A fifth source group, Admin, is now optionally included. This paper will describe the history of port emissions inventories, the framework currently used in Canada, recent experiences conducting port EIs as well as future applications and directions.

## BODY

### Port emissions inventory history

The effects of industrial and consumer activity on air quality remain a concern to regulators and health authorities. In the United States, regions where air pollution levels persistently exceed National Ambient Air Quality Standards (NAAQSs) are classified as "non-attainment" areas by the US Environmental Protection Agency (EPA). Jurisdictions with non-attainment areas must develop State Implementation Plans (SIPs) to address how emissions will be reduced to attain and maintain NAAQSs[(10)]. Many non-attainment areas occur in large urban counties with major ports, such as Los Angeles, Houston and New York[(11)]. It was natural, therefore, for port authorities to become involved in the development of SIPs in the 1990s.

It is difficult to assess opportunities for emission reductions and to quantify reductions over time without an inventory of port emissions as a whole. The first port emission inventory was carried out by the Port of Houston/Galveston in 2000 (for the 1997 inventory year), for marine vessels only. The ports of San Pedro Bay (Los Angeles and Long Beach) followed in 2007 and the New York Port Authority completed their first port EI in 2009[(12)]. At least 14 US port authorities have now completed some form of port emissions inventory[(13)]. With the data available from port EIs, port authorities are setting goals and developing strategies to reduce emissions. For example, the San Pedro Bay ports committed in 2006 to reducing port-related emissions by 45% within five years[(14)], a goal they have largely met.

It quickly became clear that the early inventories suffered from several deficiencies, including significant variability in emission factors, incomplete operational data and relatively little guidance from regulatory agencies. The EPA commissioned the first "Best Practices" document on port emission inventories in 2006 [12]. This document was updated in 2009 based on the rapid advances in methodology[13].

North of the border, Canada lacks the same air quality pressures as the USA. In general, air quality in Canada has been improving since the 1970s; however, the concentrations of some pollutants, such as ground level ozone, continue to increase [15][16]. It is estimated that poor air quality leads to the premature death of 2,700 Canadians each year[9]. For Canadian ports, public perception about air quality and environmental management is also a key issue. Recent news reports note increasing ship emissions from dirty fuels at the largest Canadian ports, Vancouver and Montreal in particular. Furthermore, there is growing competition between major Canadian ports (Halifax, Montreal, Prince Rupert, Saint John and Vancouver) and their US counterparts. Container terminals in particular are experiencing pressure to assess and mitigate their air emissions because of the relatively high degree of cargo handling and transportation activity associated with container movement[17].

These concerns lead Port Metro Vancouver to conduct the first Canadian port EI in 2008, for the 2005 inventory year[18]; this inventory focused only on land side activities. A complementary study by the BC Chamber of Shipping investigated emissions from marine sources for the 2005/2006 inventory years[19]. A complete inventory of both land side and marine emissions was completed for the Port of Montreal in 2009, with funding from Transport Canada[20].

During this period, TC was also providing funding to industry partners through several initiatives. The largest program was ecoFREIGHT, which supported the transportation industry to reduce fuel consumption and air pollution. Port terminals in Vancouver and Montreal received funding to upgrade gantry cranes and facility locomotives, respectively, from this program. These and other ecoFREIGHT projects demonstrated the emission reduction potential of technology improvements. In January 2012 Transport Canada announced a new $CDN 27 million funding program for installing marine shore power (i.e., cold ironing)[21]. However, one of the complaints from operators about these funding programs was the difficulty in meeting program requirements and consistency in the evaluation metrics.

To address this issue, TC contracted SENES Consultants to develop a national Ports Emissions Inventory Protocol (Ports Protocol), to apply uniformly for all ports in Canada[22]. This protocol extended the EPA "Best Practices" document into a formal guidance document outlining scope, pollutants, boundaries, source groups, etc. (The Ports Protocol is described in more detail in the following section.)

Complementing the Ports Protocol, Transport Canada funded the development of a national Ports Emissions Inventory Database Model (Ports Model). The Ports Model was an implementation of the Ports Protocol and was based on the port EI database models developed for Port Metro Vancouver and Port of Montreal. (More details are also provided on the Ports Model in the next section.)

In 2010/2011, the Ports Model was used to calculate the 2009 emissions for three other Canadian ports: Hamilton, Ontario; Sept-Iles, Quebec; and Halifax, Nova Scotia. The Ports Model was the template for the recent update of the PMV landside emissions inventory, for the 2010 calendar year. This inventory was the most detailed completed to date in Canada and included all port-related activity in the Lower Fraser Valley[23]. In 2011, Transport Canada contracted SNC-Lavalin Environment (SLE) to conduct port EIs for all 18 Canadian Port Authorities for the 2010 inventory year. These inventory projects are ongoing and will be completed for the west coast ports in 2012 and the east in 2013.

Several other areas of national port environmental management complement the Ports Model and should be noted. First, Green Marine (GM) is a joint US-Canada initiative to implement a marine industry environmental program throughout North America. Founded in 2007 in the Great Lakes, GM's environmental program includes certification for managing air quality by conducting an emissions inventory[24]. GM is a stakeholder on the TC 2010 national ports EI project.

The second initiative is the Environment Canada (EC) National Marine Inventory, completed in 2012 for the 2010 calendar year[25]. The inventory includes all commercial marine vessels tracked by the

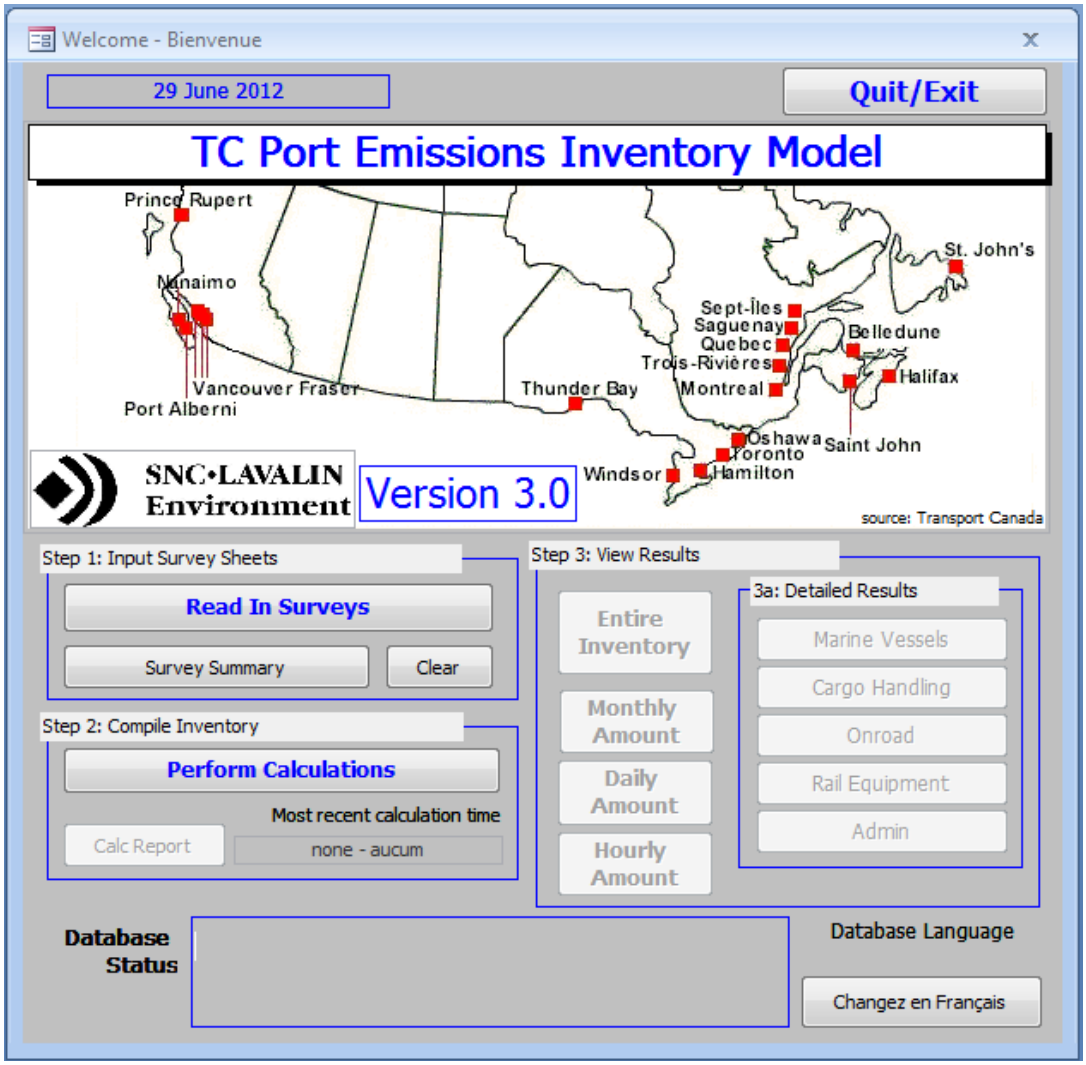
Canadian Coast Guard within Canada's territorial waters as well as smaller commercial crafts such as tugs and ferries. A large project advisory committee of 30 representatives from shipping associations, port authorities, provincial governments and regulatory agencies provided direction and supporting data to better characterize the marine vessel movements and emissions. EC is also a stakeholder on the TC 2010 national ports EI project.

The efforts of Green Marine and Environment Canada, combined with recent port EI experiences, showed that the Ports Protocol and the Ports Model both required updating. As part of the 2010 national ports EI project, TC hired SLE to clarify and add new elements to the Ports Protocol[17]. SLE also upgraded the Ports Model to improve the calculation methodology and simplify the data collection burden for terminals. The updated version of the Ports Model can also be used to generate EI reports suitable for submission to GM. Transport Canada will release the Ports Model to the public in 2012 so other port authorities and operators can benefit from the experience.

**Port emission inventory framework**

This section describes the Transport Canada Ports Emission Inventory Protocol and the Ports Emissions Inventory Model. The Ports Model is an implementation of the Ports Protocol. An image of the welcome screen to the Transport Canada Ports Model is shown in Figure 2. From this screen, users can load data, run calculations and view emissions results. Subsections below describe the EI methodology, air contaminants, boundaries, activity measures, emission factors, forecasts and emission reduction initiatives as they relate to the Ports Protocol and Model.

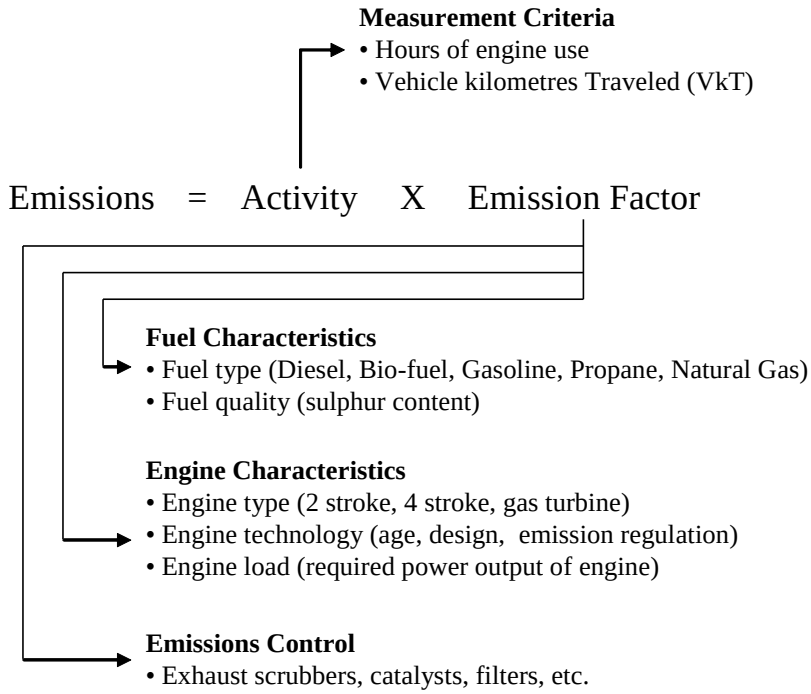
**Figure 2. Welcome screen of version 3.0 of Transport Canada Ports Model.**



Emission inventory methodology

A port emissions inventory is an accounting of emissions from significant sources under the influence of a port or its terminals. All emissions in the Ports Model are calculated using the base equation shown in Figure 3. This equation follows a bottom-up approach referred to as an activity-based inventory, which accounts for different modes of activity. Each activity measure (e.g., 20 hours of driving) is multiplied by an appropriate emission factor (e.g., 10 grams of $NO_x$ emitted per hour of driving) to generate an emission value (e.g. 200 grams of $NO_x$). More details about emission factors and activity measures are provided later in this section.

**Figure 3. Base emission calculation equation used in an activity-based emission inventories.**




It should be noted that the EPA "Best Practices" document includes a streamlined approach to generate a port EI without the additional time and effort of collecting detailed port activity data[13]. A streamlined EI assumes relationships between activity intensities and cargo tonnage handled at a representative terminal for each commodity type. However, since the activity intensities are estimated from aggregated values, a streamlined EI provides limited insight on emission reduction opportunities so they have not been widely used in Canada.

Air contaminants

The following air contaminants are included in a port EI:

1. Common Air Contaminants (CACs, known as Criteria Air Contaminants in the USA):
    a. Nitrogen oxides ($NO_x$);
    b. Sulphur oxides ($SO_x$);
    c. Carbon monoxide (CO);
    d. Total hydrocarbons (THC);
    e. Suspended particulate matter of diameter 10 microns or less ($PM_{10}$);
    f. Suspended particulate matter of diameter 2.5 microns or less ($PM_{2.5}$);
2. Greenhouse Gases (GHGs):
    a. Carbon dioxide ($CO_2$);
    b. Methane ($CH_4$);
    c. Nitrous oxide ($N_2O$);
    d. Carbon dioxide equivalent units ($CO_2e$).

Carbon dioxide equivalent units are calculated using the global warming potential (GWP) factors published in the 2th Assessment Report of the Intergovernmental on Panel Climate Change (IPCC)[26], consistent with the Environment Canada (EC) National Inventory Report.

Boundaries

The boundaries of an emission inventory determine which sources and modes of activity are included in reporting. The two primary boundaries of interest are organizational (extent of an organization's activities) and operational (emission sources to include). A third boundary relates to processing activities.

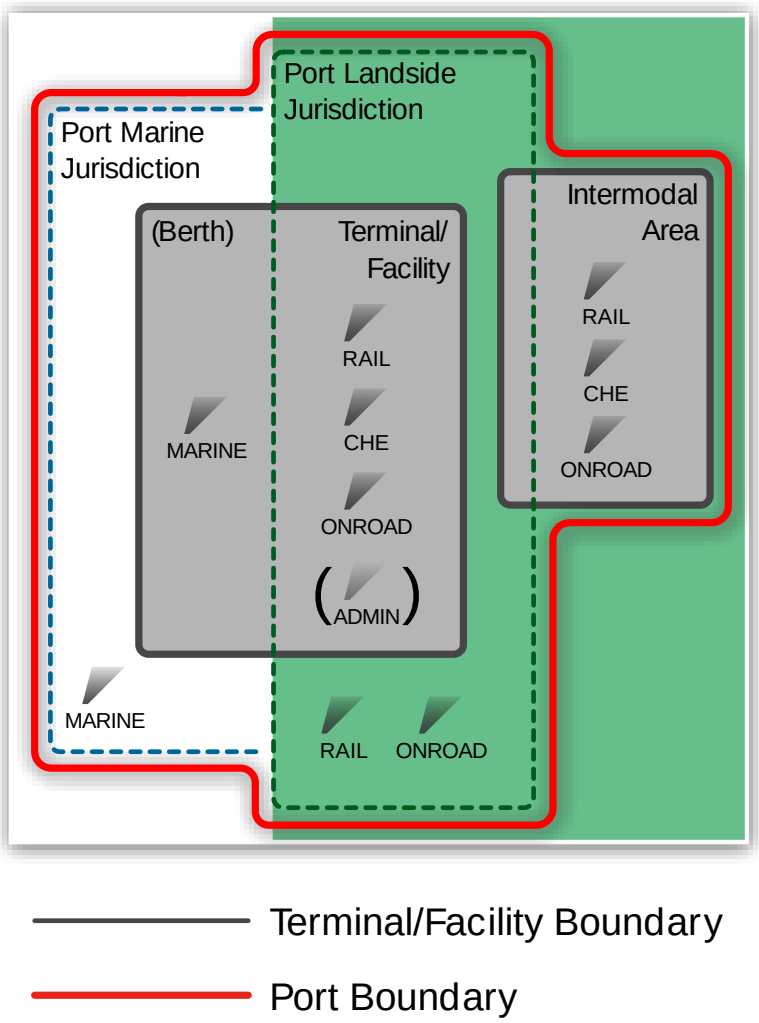
Similar to GHG inventories, the organizational boundary is defined with no dependence on land ownership or corporate relationships[27]. A port EI includes all port terminals involved in the marine movement of goods. If a port terminal engaged in marine trade leases a water lot from the port authority but no land (or only a small area of land near the dock), its land side operations are still included because they support the marine activities. Furthermore, the organizational boundary includes facilities not directly involved in marine movements but whose operations support port-related activities (e.g., a container re-packing facility or an intermodal facility inland from the waterways). This also includes the port authority's operations even if they do not operate a terminal.

Two specific organizational boundaries are defined in the Ports Protocol:

1. Terminal/facility boundary: A port terminal or facility property that is directly managed by a port of port terminal. Its extent is distinguished by clear features such as the facility legal boundary or its fence line. Any marine berths that are part of the terminal/facility are included as well.
2. Port boundary: All land side and water side areas managed by the port where port-related activity occurs. On the water side, this includes at least the port marine jurisdiction but may extend to the location(s) where marine pilots board the commercial marine vessel. On the land side, this includes at least all port landside property but may extend to areas outside port property where substantial port-related activities occur.

Figure 4 is a schematic of the organizational and operational boundaries. The terminal/facility boundary is similar for every port and should be used when comparing the emissions of one port authority against another. However, the port boundary will likely differ depending on how far port-related activities extend beyond the terminal/facility boundary. For smaller ports, the port boundary will probably correspond to the terminal/facility boundary. At larger ports, intermodal and/or marshaling areas should be included depending on the environmental goals of the port authority or terminals, such as a reduction in regional emissions. The land side intermodal area shown in Figure 4 extends to an intermodal point where port-related rail and/or onroad vehicle traffic converge at a modal shift (e.g., transfer of goods from truck to rail, or from one truck to another). In some cases the intermodal point may not correspond to a modal shift; instead the point may represent the location where a traffic corridor used exclusively by port traffic merges with transportation networks used by the general public.

**Figure 4. Organizational and operational boundaries for a port emission inventory*.**



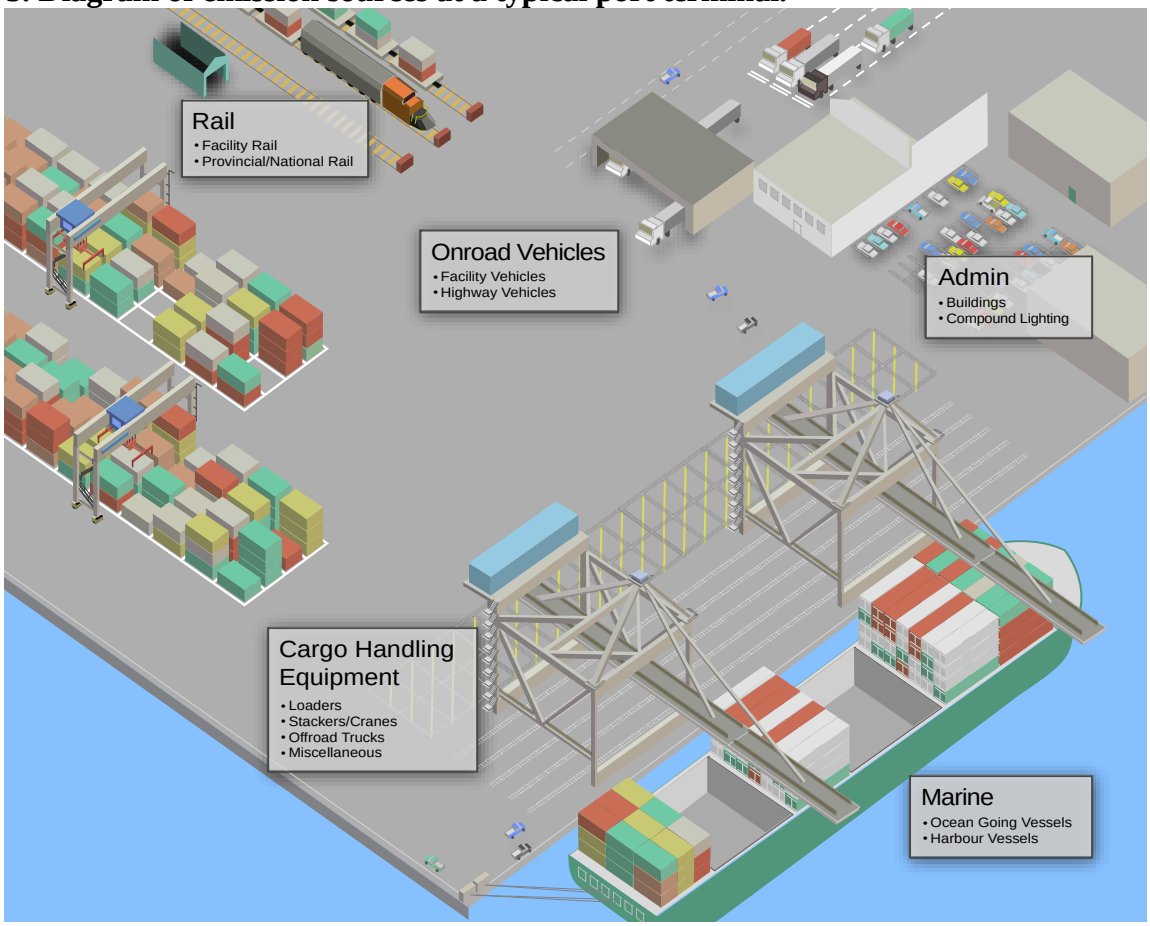

* Figure courtesy of Ports Protocol[17].

Operational boundaries are defined to identify the sources to be included in the inventory. The included emission sources are:

1. Marine vessels:
    a. Commercial ocean-going vessels (OGVs)
    b. Harbour craft (e.g., tugs, ferries, boom boats, etc.)
2. Cargo-handling equipment (CHE)
    a. Cranes and stackers
    b. Loaders
    c. Off-road trucks
    d. Miscellaneous (e.g., refrigerated containers, generators, aerial lifts, etc.)
3. Rail
    a. Switch and line haul locomotives (operated by external rail providers)
    b. Facility locomotives (operated by the terminal)
4. Onroad vehicles
    a. Highway vehicles (drive on site to drop off and/or pick up products)
    b. Facility vehicles (used only on terminal/facility grounds)
5. Admin/Stationary (optional)
    a. Facility lighting
    b. Building energy consumption

Administrative or stationary emission sources are optional because they generally produce the smallest emissions relative to the other source groups. However, there is often opportunity for reducing Admin energy consumption so the Ports Protocol recommends including this source. Figure 5 shows the different emission sources at a typical port terminal. All fuel types are included in the port EI, such as diesel, propane, biofuels, marine distillate oil (MDO) and electricity.

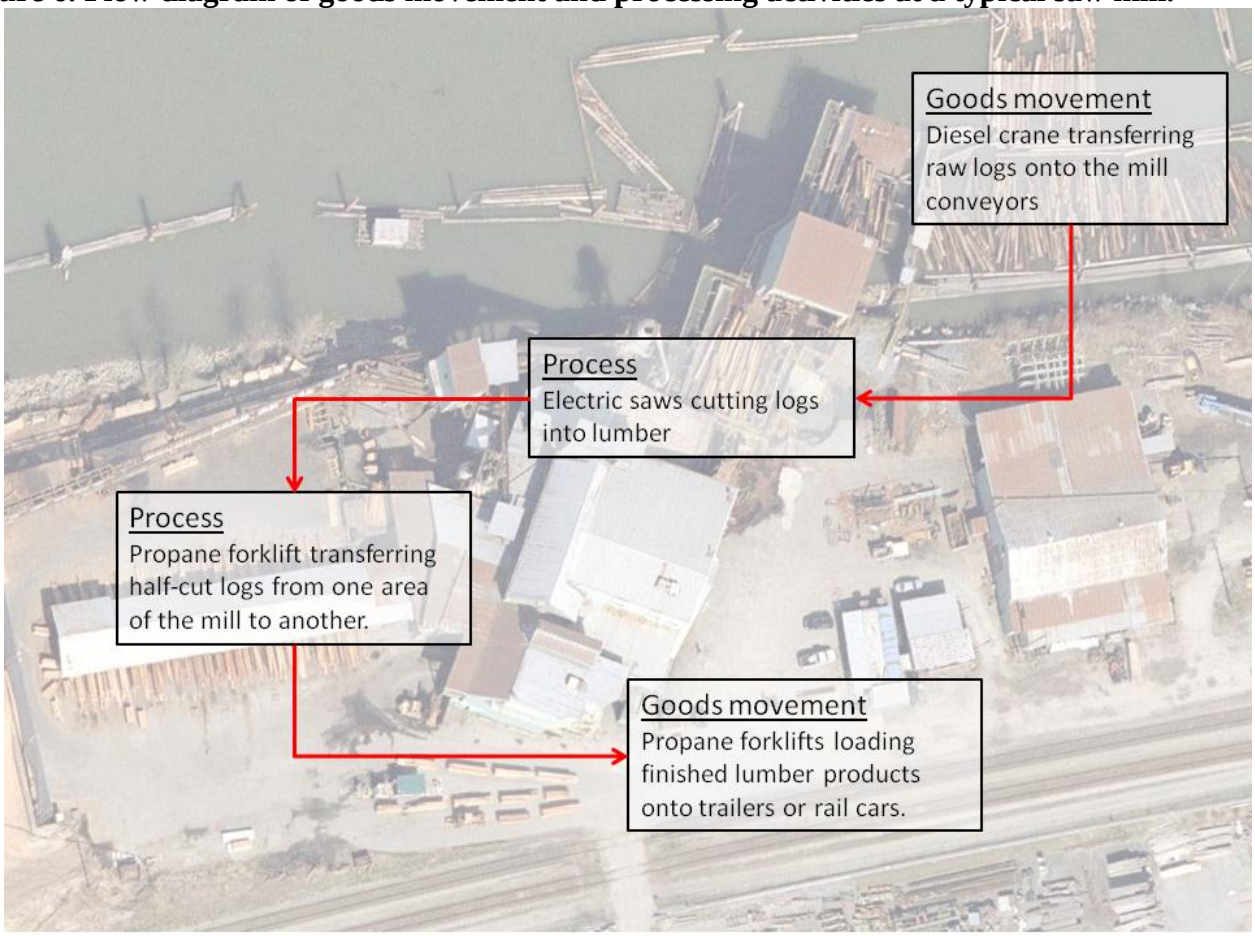
**Figure 5. Diagram of emission sources at a typical port terminal.**




A third boundary relates to processing activities. Recent Canadian port EI projects have highlighted this problem where terminals within the port jurisdiction conduct manufacturing or processing activities in addition to the movement of goods. According to the Ports Protocol, a processing facility is defined as an operation where the form of the inbound and outbound commodity changes. An example of a processing facility is a saw mill where raw logs arrive by water but lumber and byproducts (e.g., chips, sawdust, etc.) are shipped out by truck or rail. Although processing activities may be integral to the operation of a terminal/facility, they are not specifically related to the marine movement of goods. Therefore, the Ports Protocol states that processing activities are not included in a port EI. Furthermore, these activities and emissions are often captured under other reporting initiatives such as Environment Canada's National Pollutant Release Inventory[28].

Terminal representatives often have difficulty differentiating goods movement activity from processing. As such, the Ports Protocol indicates that at processing facilities, good movement is only the unloading of inbound products and the loading of outbound products. All other activities are defined as processing. As an example, Figure 6 shows a flow diagram of goods movement and processing activities at a typical saw mill. The crane pulling logs out of the water corresponds to unloading the inbound products, and the forklift placing finished lumber onto trucks corresponds to loading the outbound product. The electric saw and other forklifts are processing activities and are not included in a port EI.

**Figure 6. Flow diagram of goods movement and processing activities at a typical saw mill.**




Activity measures

As shown in Figure 3 one of the two components of calculating emissions is measuring activity. According to the Ports Protocol, activities are required for the 5 emission sources at the 2 geographical boundaries. The activity measures captured by a port EI dictate the emission factors needed in the Ports Model.

Activity data are easily understood by all stakeholders in a port EI process. However, not all activity data can be easily obtained. Acquiring accurate activity data requires cooperation between EI practitioners, port authority staff and terminal representatives.

Table 2 provides a general overview of the activity information captured in port EIs, organized by source group. The basic activity metrics are hours of operation, distance driven and fuel consumed. The resulting air emissions vary depending on the following elements:

- Mode (the actions being assessed);
- Fuel; and
- Engine type.

The activity metrics listed in Table 2 reflect the potential significance of the activity in terms of emissions as well as the types of records that terminals keep. For example, facility vehicle emissions are assessed in a simpler way than highway vehicles (fuel instead of hours of operation) due to the lack of usage records and the relatively low emissions of facility vehicles. In contrast, highway vehicle emissions are generally more significant and terminals usually keep better records of gate counts.

**Table 2. Activity criteria in port emission inventories.**

| Source Group | Equipment | Metric | Modes | Fuel | Engine Type |
|---|---|---|---|---|---|
| Marine | Ocean-going vessels | Hours of engine use, boiler fuel consumption | Berthing, anchoring, maneuvering and transit | Heavy fuel oil, marine distillate oil | 2-stroke, 4-stroke, boilers and turbines |
| | Harbour vessels | | | | |
| Cargo-handling equipment | Stacker/crane | Hours of engine use, fuel consumption | All modes for equipment-specific duty cycles | Diesel, electricity, gasoline, propane, natural gas, biofuels | Electric, 2-stroke, 4-stroke spark ignition and 4-stroke compression-ignition |
| | Loader | | | | |
| | Off-road truck | | | | |
| | Miscellaneous | | | | |
| Rail | Line haul locomotives | Hours of engine use, fuel consumption | All modes represented in duty cycles established for each type of locomotive | Diesel | 2- and 4-stroke compression ignition |
| | Switch locomotives | | | | |
| | Facility locomotives | | | | |
| Onroad Vehicles | Highway vehicles | VKT* or hours of engine use | Driving cycle and idling | Diesel and gasoline | 4-stroke spark and compression ignition |
| | Facility vehicles | Fuel consumption | All modes represented in driving cycle | Diesel, electricity, gasoline, propane and natural gas | |
| Admin | Facility lighting | Fuel consumption | All modes for equipment-specific duty cycles | Electricity, heating oil, propane and natural gas | Boilers and electricity |
| | Building energy consumption | | | | |

* VKT = vehicle kilometers travelled

In the Ports Model, activity data is collected from terminal representatives using a Microsoft Excel "questionnaire" with multiple sheets, where each sheet represents a particular source group. The latest version of the questionnaire has been simplified and re-organized to ensure only the activity data required is requested from the terminal representatives. Figure 7 shows an example of a sheet from the questionnaire, specifically for the terminal/facility vehicles. In this table a user enters the vehicle type, age, number, fuel type as well as the relative intensity of use. Drop-down boxes and hints assist the user in filling out the questionnaire.

**Figure 7. Example table from Ports Model activity questionnaire for terminal/facility vehicles.**

| Item | Vehicle type | Fleet age | Number of similar vehicles | Relative intensity of use | Fuel type (refer to Table 10) |
|---|---|---|---|---|---|
| Example | Van / Pickup - small utility | 2005 - 2009 | 5 | 3 - Medium (average) | 1 - Gasoline |
| 1 | | | | | |
| 2 | | | | | |
| 3 | | | | | |
| 4 | | | | | |
| 5 | | | | | |
| 6 | | | | | |

Heavy commercial truck
Medium commercial truck
Light commercial truck
Bus (transit or passenger)
Van / pickup - small utility
Taxi
Car
Hybrid

Hint
Select a vehicle type from the drop-down menu.

Emission factors

The second component to calculating emissions is sourcing appropriate emission factors for the activities measured, as shown in Figure 3. Emission factors are used from the following sources:

- Admin: Boiler emission rates from the EPA AP-42 dataset[29];
- Cargo-handling equipment: EPA NONROAD model, version 2008[30];
- Marine: Canadian Marine Emissions Inventory Tool (MEIT)[25];
- Onroad: EPA MOBILE model, version 6.2.3C[31]; and
- Rail: Locomotive emissions test data and EPA tier emissions standards.

In general, the emission factors are based on models of engine emissions tests for engines currently in-use over factors based on emission limits. Emissions limits are values not to be exceeded and therefore may be higher than the actual rates for a particular engine model. In some cases there was no alternative and emission limits were employed. All the models employed have been widely used in Canada or the USA and are supported by the regulatory authorities.

The implementation of some of the models is worth describing in more detail, starting with NONROAD. This model assumes a single national load factor (LF) for each equipment type. These LFs may not adequately represent the duty cycles of units in use at port terminals. Therefore, the Ports Model adjusts the reported CHE activity by the ratio of the reported fuel use and the fuel use estimated by NONROAD (itself based on the national LF and the initial reported age, engine size, equipment type and hours of use).

MEIT was developed by Environment Canada to support calculation of marine vessel emissions throughout Canadian waters. MEIT was updated to version 4.0 as part of the Environment Canada 2010 National Marine Emissions Inventory study[25]. Emission factors are generated based on vessel characteristics mostly sourced from the IHS Fairplay (formerly Lloyd's) Sea-web dataset. The current version of MEIT includes vessel profiles specific to Canadian waters, accounting for variability in sulphur content from domestic or international fuels.

The last implementation of note is MOBILE 6.2C, a Canadianized version of the EPA MOBILE model. The EPA MOVES model has replaced MOBILE but MOVES has not yet been approved for use by Canadian regulators. One known shortcoming of MOBILE is that it does not adequately represent idle and creep activities. Factors from a 2003 study on heavy truck emissions are used in conjunction with MOBILE to represent accurate emissions for idle and slow-speed activities[32].

Forecasts

The first port emissions inventories only included the base inventory year. However, estimates of future emissions are important to predict changes in pollution over time. The first port EI to include

forecasts was the 2005 inventory conducted for Port Metro Vancouver[18]. Most inventories now include some form of forecast in their results.

Generating meaningful forecasts requires detailed baseline activity measures and appropriate future emission factors. In the Ports Model, future activity levels are calculated by linearly scaling the baseline activity level with an expected growth rate. The growth rates are generally commodity-specific and sourced from port authorities or terminals (national growth rates can be used when port-level values are not available).

Future emission factors depend on fuel and emission standards as well as expected equipment populations. Future federal and provincial regulations will reduce the sulphur content of fuel in rail locomotives and marine vessels while increasing the biofuel content of diesel and gasoline[33][34]. Equipment populations will change in the future as older more polluting engines are retired from port fleets. The expected service life of equipment used at port terminals depends on the source group. Large marine vessels have an expected life expectancy of 25 – 35 years while cargo-handling equipment is generally replaced after 10 years of active service. The Ports Model accounts for these changing emission factor these effects when calculating forecasts emissions.

Evaluation of emission reduction initiatives

The final important component of the Canadian port EI framework is emission reduction initiatives (ERIs). ERIs are actions implemented by ports or their terminals to reduce air pollution. Initiatives include the following:

- Equipment replacement (dockside cranes, genset locomotives);
- Equipment retrofits (oxidation catalysts, particulate filters);
- Alternative fuels (low sulphur diesel, biodiesel blends);
- Port infrastructure (shore power); and
- Logistical programs (truck reservation system, transport corridors, short sea shipping, intermodal centres).

These initiatives are the next logical step for a port authority once it has completed an inventory of its emissions. Development of ERIs supports port-wide goals of reducing emissions. It should also be noted that development of reduction strategies satisfies Level 4 of the Green Marine certification for Air Emissions. By loading different activity questionnaires, the Ports Model can be used to characterize the effect of emission reduction initiatives.

## Canadian experiences conducting port emissions inventories

This section describes recent Canadian experiences conducting port emissions inventories. It focuses on the 2010 landside emissions inventory conducted for Port Metro Vancouver, as well as strategies for conducting a successful inventory.

Port Metro Vancouver 2010 Landside Emissions Inventory

Port Metro Vancouver is the largest port in Canada and handles over $75 billion worth of imports and exports each year[2]. Most PMV terminals have a water lease with the port authority but operate on a mixture of private and public land. PMV was the first port in Canada to conduct a port emissions inventory, for the 2005 inventory year[18], which focused on the landside activities of terminals in the Burrard Inlet and Roberts Bank in Delta. A second inventory was recently completed by SLE for the 2010 calendar year[23]. The 2010 inventory expanded the project scope to include over 115 terminals from the Burrard Inlet, Fraser River and Roberts Bank.

The 2010 inventory used a customized version of the Transport Canada Ports Model. Four source groups were included in the inventory: Admin, CHE, Onroad and Rail (marine was included in the EC 2010 National Marine Inventory[25]). Five zones in the Lower Fraser Valley where port-related activity dominated were chosen to represent the port boundary. Figure 8 shows the results of the PMV 2010 inventory to the port boundary. Cargo-handling emissions dominated, followed by Onroad.

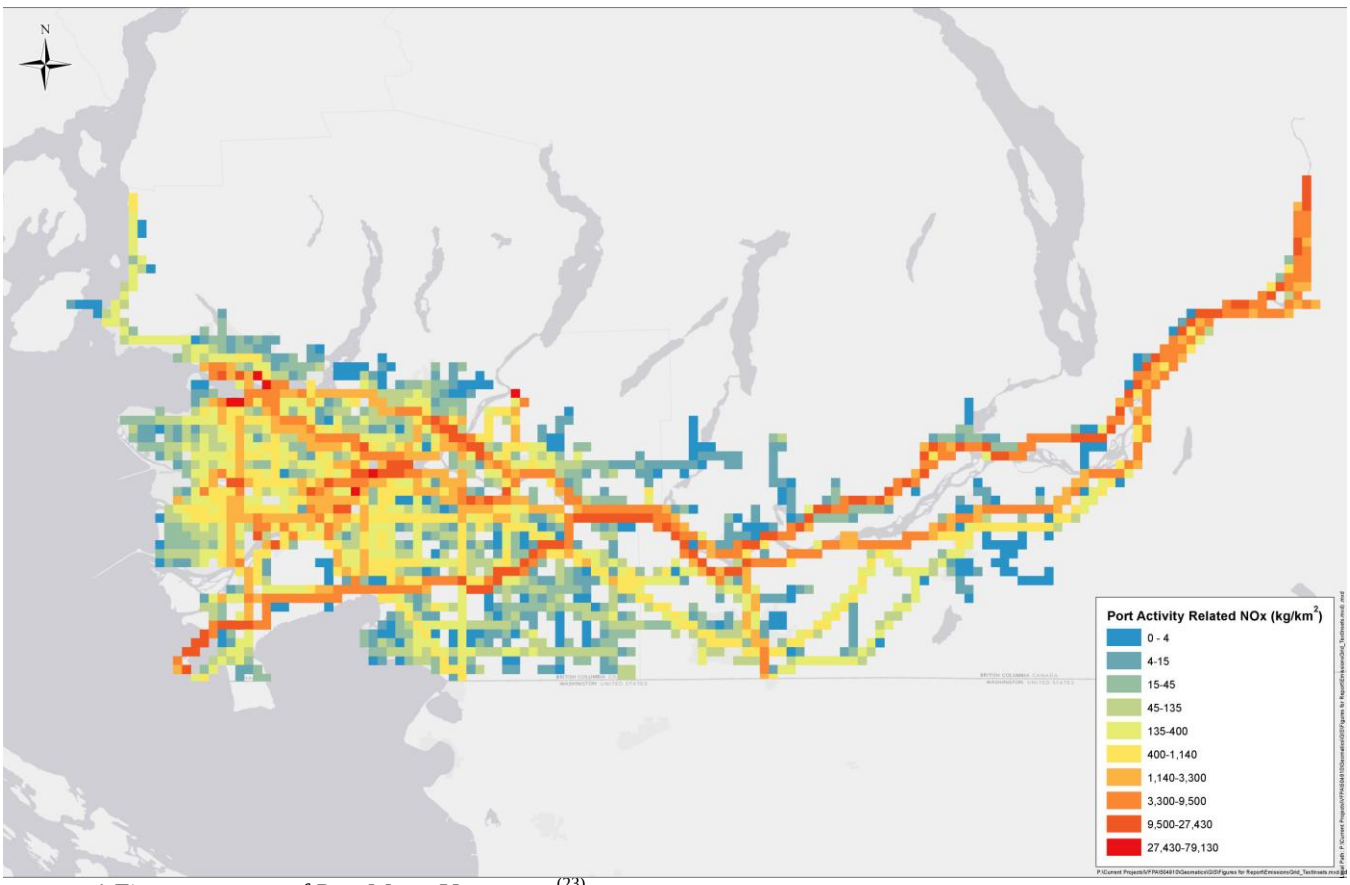
**Figure 8. Port Metro Vancouver 2010 landside emissions, to the port boundary (tonnes)*.**

| Source Group | Common Air Contaminants (CACs) | | | | | | | Greenhouse Gases (GHGs) | | |
|---|---|---|---|---|---|---|---|---|---|---|
| | $NO_x$ | $SO_x$ | CO | VOCs | $PM_{10}$ | $PM_{2.5}$ | $NH_3$ | $CO_2$ | $CH_4$ | $N_2O$ |
| Admin | 9.0 | 0.1 | 4.9 | 0.5 | 0.5 | 0.5 | 0.3 | 6,587 | 0.1 | 0.2 |
| CHE | 643.4 | 0.8 | 773.8 | 83.4 | 40.9 | 39.7 | 1.1 | 65,624 | 8.0 | 22.9 |
| Onroad | 89.9 | 0.3 | 112.1 | 15.7 | 1.7 | 1.2 | 2.0 | 18,711 | 0.8 | 0.4 |
| Rail | 202.7 | 0.8 | 22.8 | 8.3 | 6.4 | 5.9 | 1.2 | 10,944 | 0.6 | 4.3 |
| **TOTAL** | **945.0** | **2.0** | **913.5** | **107.9** | **49.5** | **47.3** | **4.5** | **101,865** | **9.5** | **27.9** |

* Figure courtesy of Port Metro Vancouver [23].

A third organizational boundary was also added to the PMV inventory, to represent the entire air shed of the Lower Fraser Valley. Rail and trucking activities were estimated in the valley using traffic activity models scaled by annual commodity throughput. Figure 9 shows a map of the 2010 nitrogen oxides emissions in the Lower Fraser Valley. As can be seen a substantial amount of the total emissions are released along major rail lines and highways.

**Figure 9. Map of 2010 port-related nitrogen oxides emissions in the Lower Fraser Valley*.**




* Figure courtesy of Port Metro Vancouver[23].

The 2010 LEI also included forecasts out to 2025 in 5-year increments. Even though PMV throughput is expected to increase by approximately 63% by 2025, emissions of most criteria air contaminants will decrease over that period as older equipment is replaced by units with higher emission

standards. In contrast, newer engines are not much more fuel efficient so emissions of greenhouse gases are expected to increase during that period ($CO_2$ emissions scale roughly linearly with fuel use).

Along with the forecasts, recent and future emission reduction initiatives were evaluated for their effect on port emissions. Some initiatives implemented by individual terminals were new genset locomotives as well as variable-speed and hybrid cranes. At a port level, PMV introduced a truck licensing system in 2008 which prohibited older heavy duty diesel trucks from operating at PMV terminals. Taken together, these ERIs reduced emissions of all major pollutants by between 1 and 7% versus a business-as-usual case.

Strategies for conducting a successful port emissions inventory

Port emission inventory projects are challenging to conduct, in large part because they remain foreign to most terminals and port authorities. Assuming a database similar to the TC Ports Model is available, data collection is the most time-consuming component of a port EI. The data provided by port authorities and terminals for port EIs is not data they generally tabulate for other regulatory requirements so errors and misunderstandings are common.

Terminal representatives were skeptical when port EIs were first conducted in Canada; they did not understand the need and assumed the data collection was in advance of new regulations. However, greater attention towards environmental stewardship at port authorities and terminals has developed in the past 10 years so recent terminal response has been more positive. Proper terminal engagement ensures participation is high and data collection progresses smoothly. An initial engagement session is recommended where all terminals are invited to attend. In addition to describing the data collection process, the engagement session should describe the benefits of conducting a port EI such as Green Marine certification or potential fuel cost savings through ERIs.

Once data collection has begun, proper data management is critical since data will be collected from a variety of sources, including terminals, port authorities, regulators and equipment manufacturers. Medium-size and large terminals all have logs of equipment activity and some have even conducted their own emissions inventories. Most of these inventories were for greenhouse gases where simpler fuel-based emission factors can be used. To calculate CAC emissions, more details are generally required, which is often not clear to terminal representatives.

## Future Work

Emissions inventories were initially developed in Canada to catalogue emissions from port-related activities. However, they are now be used in other areas of air quality and port environmental management. This section briefly outlines some recent work where results port EIs can be applied.

In 2010, SLE conducted a port carbon assessment for the Prince Rupert Port Authority (PRPA). Following the TC Ports Model methodology, the study assessed the energy consumption and GHG emissions of the entire transportation chain of containerized goods from Asia through five North American port gateways. The study indicated that Prince Rupert had the lowest carbon footprint for goods destined for Chicago, Memphis or Toronto[35]. This study followed from similar work conducted for the Port of Seattle[36]. Such investigations are becoming increasingly important as major retailers such as Walmart are developing requirements for their supply chains to provide carbon intensity metrics[37].

As indicated at the beginning of the report, the Ports Protocol and Model have developed at the same time as the Green Marine program, a voluntary environmental program for the Canadian and American marine industry[24]. Green Marine is becoming the industry standard for ports and terminals to demonstrate their environmental performance. Both ship owners and port/terminals can satisfy the Level 3 Air Emissions criteria with Green Marine by completing a port emissions inventory. Furthermore, operators that implement emission reduction strategies will satisfy Level 4. Again, this supports generation of carbon intensity metrics for ports and terminals as part of supply chain requirements from major retailers.

Another known area where port EIs are proving useful is during applications for government equipment funding programs. As indicated in the introduction, Transport Canada has recently allocated

$27 million for shore power development. With a completed port emissions inventory, terminals can accurately demonstrate the emission reductions possible by implementing shore power. Furthermore, results from the Transport Canada 2010 national ports inventory may well indicate other technological solutions that are more cost effective funding program than shore power.

Finally, emissions results from port EIs can also be used as input data to dispersion modelling simulations. SLE is currently modelling the airshed of Prince Rupert with the California Puff (CALPUFF) Model [38] and using emission products from the 2010 port EI completed for PRPA as part of the national ports emissions inventory project. The dispersion model will be compared to applicable Canadian Air Quality Objectives and Standards. It will also establish a baseline against which for the port authority can judge future development.

## CONCLUSION

The Ports Model includes a harmonized set of emission factors for all five source groups: admin, cargo-handling equipment, marine, onroad vehicles and rail. Harmonization is important for comparative analyses or larger scale air quality assessments that may cross jurisdictions or borders. In addition, harmonization of estimation methods in general reduces the burden on an individual port to assess its emissions.

In addition, the Ports Model serves complementary goals such as port environmental reporting as well as broader programs such as Green Marine. It allows port authorities to assist their tenants with emission reduction projects, including applying for financial support. The harmonized nature of the Ports Model allows consistent emission tracking over time and an efficient means of supporting terminal development over time. This is turns facilitates new operation energy planning decisions.

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**KEYWORDS**

Emissions inventories
Particulate matter
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