CARBON FOOTPRINTING FOR PORTS

GUIDANCE DOCUMENT

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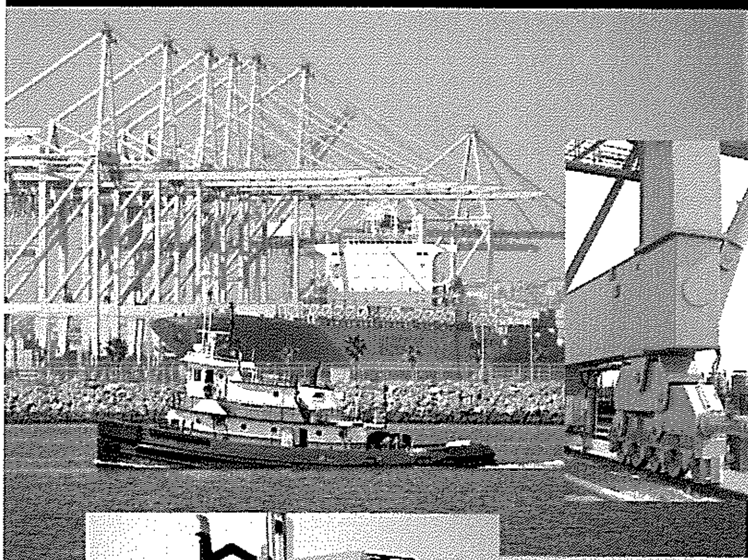

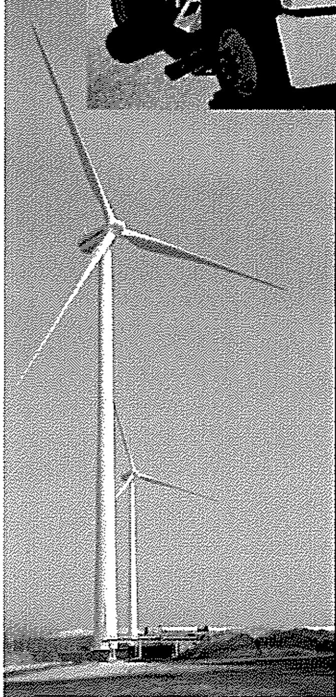

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PREFACE

The World Ports Climate Initiative (WPCI) was established to raise awareness in the port and maritime community of the need for action regarding greenhouse gas emissions, to initiate studies, strategies and actions to reduce greenhouse gas emissions, to provide a platform for the maritime port sector for the exchange of information, and to make available information on the effects of climate change on the maritime port environment and measures for its mitigation.[1]

As a part of the WPCI's mission to provide a platform for the exchange of information, this guidance document is intended to serve as an introduction to "carbon footprinting" and as a resource guide for ports wanting to develop or improve their greenhouse gases (GHG) emissions inventories. It has been developed in a collaborative process undertaken by several North American and European ports with a common interest in sharing knowledge and methods related to the planning and development of carbon footprint inventories.

The guidance document will be dynamic, in that user input will be sought to provide new information and improvements in content, to be incorporated into periodic updates. In this way, users can gain immediate benefit from the document's contents, and they can share their experience and expertise with other users through the updates. One aim for the document is for it to be relevant to all users, from those just beginning the carbon footprinting process to others having extensive experience at developing carbon inventories.

The WPCI hopes that all ports will consider developing a greenhouse gas emissions inventory, at least in regards to their own operations (known as Scopes 1 and 2, and defined in this document). As ports develop their inventories to encompass wider scopes and include, for example, customers and tenants, it will be important for them to build on relationships and develop a collaborative approach toward collecting information, estimating emissions, and developing plans to reduce the footprint of port operations.

[1] From WPCI Mission Statement, *http://wpci.nl/about_us/mission_statement.php*

TABLE OF CONTENTS

LIST OF FIGURES

LIST OF TABLES

2.3.2 Footprint Boundary Differences

Boundaries can be a source of significant differences between carbon footprints. The geographical boundaries for each port differ because of the port's geographical location, the drivers behind the carbon footprint, and the footprint domains for the source categories included in the inventory. The following examples show how various ports have determined their boundaries:

- The Port Authority of New York & New Jersey (PANYNJ) set their OGV geographical domain to include all vessels that call on Port Authority marine terminals within the three-mile demarcation line off the eastern coast of the United States.
- The Puget Sound Maritime Air Emissions Inventory included 12 counties, which make up the Puget Sound Air Basin, includes 6 major ports and numerous smaller ports and independent oil terminals. The inventory's domain ended at the Canadian border or the sea buoy at the entrance to the Straits of Juan De Fuca.
- The Ports of Los Angeles and Long Beach have included the South Coast Air Basin over-water boundaries which extend over 130 nautical miles (nm) out to sea and are bounded by the basin's borders to the north and south.
- The Port of Houston Authority's inventory includes over 45 nm of channels to the sea buoy.

Since there is a wide range of possible domains for the three emission source scopes, one needs to evaluate these domains prior to comparing inventories. The geographical boundary differences by source category should also be noted prior to comparing footprints. In addition, other air pollutants like oxides of nitrogen (NOx), sulfur oxides (SOx), and diesel particulate matter (DPM) may all have different geographical boundaries; again domain delineation depends on the intended use of the inventory.

Additionally, boundaries for reporting emissions for sources may vary based upon whether the sources are under the control of a landlord or operator port. For example, emissions from trucks under an operating port control would include their entire operations, whereas trucks under a landlord port's tenant's control might be only tracked to the port boundary or first point of drop-off/pick-up.

2.4 Inventory Period and Baseline Year

The logical "next step" after developing a carbon footprint emissions inventory is to take action to reduce the size of the footprint. Knowing this ahead of time can influence the choice of a "baseline year" against which to measure reductions. A baseline can be any time in the past, from the most recently completed calendar year to a time in the past. Some reporting protocols specify a baseline year as a target for future reductions (e.g., to reduce emissions to a level emitted during a specific year in the past, such as 1990). That year's emissions must be known in order to know the targeted level of emissions.

If past emission reductions can be documented, it may be helpful to choose a baseline year that is before those reductions took place, so the progress they represent can be credited. A more recent baseline year, however, is generally easier to document, because records are more readily available.

The time period (i.e., the year) an inventory covers can be a significant source of differences between inventories because annual changes in activities and emissions make a direct comparison difficult. Cargo volumes change, vessel and equipment fleets turn over, and control strategies may be implemented, all of which impact each inventory differently. For these reasons the year of each footprint should be noted prior to making comparisons.

2.5 Comparing Footprints

There are numerous decisions and assumptions that must be made when developing a carbon footprint inventory. One of the first reactions to a published inventory is to compare the newly published footprint to those of other ports in order to assess how one is operating in comparison to the others. However, due to the many variables involved, an apples-to-apples comparison typically cannot be made without modifying one or both to get them onto a common ground (i.e., the inventory data must be normalized to account for port size, throughput levels, etc.). As a simple example, to compare a port with a container throughput of 2.5 million twenty-foot equivalent units (TEUs) per year and annual GHG emissions of 80,000 tonnes with a larger port having a container throughput of 5 million TEUs per year and annual GHG emissions of 150,000 tonnes, one could normalize the emissions to tonnes per million TEUs.

The smaller port has an "emissions efficiency" of:

80,000 tonnes / 2.5 million TEUs = 32,000 tonnes/million TEU

The larger port's calculation would be:

150,000 tonnes / 5 million TEUs = 30,000 tonnes/million TEU

The larger port emits more greenhouse gases overall, but in normalized terms of emissions per unit of cargo volume its emissions are lower.

Several key elements need to be taken into account **prior** to comparing carbon footprints between two ports or among several ports in an appropriate manner. These elements include:

- Geographical Boundary
- Date (time period) of Inventory
- Method/Approach Taken
- Level of Data Resolution and Quality Utilized
- Type of Port (Landlord vs. Operating)
- Source Categories Included in Scopes 1, 2, and 3
- Units of Measure

3.0 TECHNICAL FRAMEWORK

This section provides technical background on emissions inventory development and a discussion of the major technical considerations associated with planning and developing a carbon footprint inventory.

3.1 Emissions Inventory Basics

Three data elements are critical to developing a carbon footprint inventory or an inventory of other pollutants (e.g., NO_x, SO_x, PM, etc.). These elements are:

- **Source Data** – This element details the emissions source characteristics which includes size or rating of the engine or power plant (typically expressed in kilowatts [kW] or megawatts [MW]), type of fuel consumed, engine technology information (2-stroke, 4-stroke, turbocharged, etc.), age of the engine, manufacturer, model, etc.

- **Activity Data** – This element details how the source operates over time and how engine loads and/or fuel consumption change by mode of operation, miles traveled by speed, power production rates, etc.

- **Emissions Test Data or Emission Factors** – This element provides the means to convert the estimates of energy output or fuel consumption into the pollutant emission rates that are to be modeled.

When considering a carbon footprint inventory, the availability of these three data elements affects the selection of the approach to be taken in conducting the inventory. Particular attention should be paid to the desired accuracy, the planned purpose of the inventory, and required time frame or constraints. All of these factors will inform the decision-making related to the inventory process.

3.2 Three Common Approaches

As noted in Section 2, three common inventory approaches are used in developing a carbon footprint inventory, as discussed below. Activity-based inventories provide the highest levels of accuracy, and the accuracy of hybrid approaches is enhanced by higher levels of specific activity data.

- **Activity-Based**

  - ✓ This approach most closely models actual port operations
  - ✓ Utilizes equipment specific source data such as actual engine ratings, actual power consumption, actual fuel consumption, etc.
  - ✓ Utilizes equipment specific activity data such as hours operated, load factor data, fuel consumption data, vessel call data, power/fuel consumption modal data, etc.
  - ✓ Utilizes either source specific emissions test data or emission factors for source categories/equipment types
  - ✓ Converts energy consumption figures, typically expressed as either power or fuel consumption, into emission estimates
  - ✓ Requires significant time to conduct first inventory, up to a year or longer
  - ✓ Can provide emission reduction strategy progress/tracking

Emissions are generally estimated using the following equation:

Equation 3.1

$$\textit{Emissions} = \textit{Energy or Fuel Consumption} \times \textit{Emission Factor}$$

Where,

Energy or Fuel Consumption – is the combination of source and activity data; typically expressed as hp-hrs, kW-hrs, or MW-hrs (energy) or gallons or kg (fuel consumption).

Emission Factor – represents the emission producing characteristics, varying by source types per unit of energy consumption; typically expressed in grams/hp-hr, grams/kW-hr, or grams/MW-hr; or, for fuel consumption, lb/gal or g/kg.

Emissions – expressed in either tons or metric tons (tonnes)

- **Surrogate-Based**

  - ✓ This approach utilizes "related" data or surrogates to substitute for source data, activity data, energy consumption, and/or emissions per activity
  - ✓ Is typically less accurate than the activity-based approach, which can be significant depending on the surrogate(s) used
  - ✓ Utilizes either a surrogate for source and/or activity data or a surrogate for emissions. These surrogates are usually developed from published studies, documents, or other port inventories
  - ✓ Accuracy depends on how close the surrogate matches actual operations
  - ✓ Takes relatively little time to conduct
  - ✓ Typically cannot provide emissions reduction strategy progress or tracking

Emissions are generally estimated by the following equations:

Equation 3.2

Emissions = Activity x Surrogate Emissions/Activity

or

Equation 3.3

Emissions = Surrogate Energy Consumption x Emissions Factor

Where,

Activity – port-related operations being modeled: ship calls, cargo handling equipment numbers, fuel purchased, employees, registered vessels, cargo throughput, etc.
Surrogate Emissions/Activity – emissions from a published study or inventory, etc. per activity: ship calls, cargo handling equipment numbers, fuel purchased, employees, registered vessels, cargo throughput, etc.

Emissions – expressed in either tons or metric tons (tonnes)

Surrogate Energy Consumption - energy consumption surrogates based on published studies, documents, inventories by equipment type, building square footage, vessel type, etc.

- **Hybrid**

  - ✓ This approach utilizes varying combinations of both activity-based and surrogate based inventories, depending on data availability, surrogates, time constraints, etc.
  - ✓ Accuracy depends on which sources are estimated using surrogates and how close those surrogates match actual operations
  - ✓ Can reduce the time needed to develop the inventory
  - ✓ Potentially could provide emissions reduction strategy progress/tracking, especially if the activity-based and surrogate-based components are differentiated, so the port can take advantage of the details available in the activity-based components
  - ✓ Components of the inventory that are developed using surrogates can potentially be "upgraded" to make use of specific activity information if that information becomes available

The inventory approach process flow diagram presented in Section 2.2 provides an overview diagram of some of the key elements in planning and developing a GHG inventory. This chart combines many of the topics introduced in the previous paragraphs, including the decisions that play into choice of methods and levels of detail.

3.3 Pollutants

Numerous gases have been identified as having the potential to contribute to global climate change. The most common greenhouse gases associated with port-related operations are the following combustion related pollutants:

- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxide (N_2O)

Guidelines from the Intergovernmental Panel on Climate Change (IPCC) also list the following compounds:

- Hydrofluorocarbons (HFCs)
- Perfluorocarbons (PFCs)
- Sulphur hexafluoride (SF_6)
- Nitrogen trifluoride (NF_3)
- Trifluoromethyl sulphur pentafluoride (SF_5CF_3)
- Halogenated ethers (e.g., $C_4F_9OC_2H_5$, $CHF_2OCF_2OC_2F_4OCHF_2$, $CHF_2OCF_2OCHF_2$)
- Other halocarbons not covered by the Montreal Protocol including CF_3I, CH_2Br_2, $CHCl_3$, CH_3Cl, CH_2Cl_2

CO_2, CH_4, and N_2O are by far the most significant for port emissions inventories. They are produced during the combustion of fossil fuel or biomass-derived fuel. It is important to note that emissions from biomass combustion must be accounted for separately from fossil fuel combustion emissions, because they have a different place in the global carbon cycle and are documented separately. Greenhouse gas emissions from fuel combustion are dominated by the CO_2 fraction because virtually all fuels are composed primarily of carbon while CH_4 and N_2O are formed as minor byproducts of combustion. CO_2 typically constitutes over 99% of combustion related greenhouse gas emissions.

Hydrofluorocarbons may be emitted in small amounts from leaks in refrigeration equipment such as air conditioning units used for comfort cooling in buildings or refrigerated containers (reefers). The remaining greenhouse gases are primarily released during specific industrial activities that are not normally a part of port operations.

Individual greenhouse gases vary in terms of their effectiveness in influencing climate change. As a convention, the gases are rated in comparison to the effectiveness of CO_2 so they can be compared. Each gas has been assigned a CO_2 equivalence (CO_2E) number known as its global warming potential (GWP), with CO_2 being equal to 1. The CO_2E /GWP values are presented in Table 3.1. In documenting GHG the individual compounds are listed separately along with a sum of the GWPs for all of the documented compounds. For example, the following emissions estimates need to be converted into CO_2E: CO_2 = 1,750 tonnes (GWP = 1), CH_4 = 0.15 tonnes (GWP = 21), and N_2O = 0.05 tonnes (GWP = 310). The CO_2 equivalents are calculated to be:

$$(1{,}750 \times 1) + (0.15 \times 21) + (0.05 \times 310) = 1{,}750 + 3.2 + 15.5 = 1{,}769 \text{ tonnes } CO_2 \text{ equivalents}$$

5.0 EMISSION ESTIMATION METHODS

This section discusses methods that can be used to develop estimates of greenhouse gas emissions from port-related sources. Many of the source types that may be included in a greenhouse gas inventory, whether as Scope 1, 2, or 3, may have already been included in an existing emissions inventory, such as for cargo handling equipment or marine vessels. For sources already included in an existing emissions inventory (developed for other pollutants), the greenhouse gas emission estimates can be developed as an extension of the existing inventory of pollutants. If there is no existing emissions inventory, there are a variety of methods that can be used to develop estimates. However, it is important first to develop a structure for the emission estimates that will organize emissions sources based on functional or operational characteristics. This structure will help to identify sources and reduce the chance of double-counting emissions.

The structure will be influenced by the planned approach, whether a detailed activity-based approach, a surrogate approach, or a hybrid of the two. Using a surrogate or hybrid approach will provide a less precise estimate of emissions than a more detailed approach.

The sources of greenhouse gas emissions at ports fall broadly into two categories, mobile sources and stationary sources. Mobile sources generally include cargo handling equipment that is not designed to operate on public roads, transport vehicles that move goods on public roads, smaller on-road vehicles that transport people, such as cars and vans, railroad locomotives, and vessels. Stationary sources include fuel-fired heating units, portable or emergency generators, electricity consuming equipment and buildings, and refrigeration/cooling equipment. There may be some overlap in categories that might be assumed to be exclusively mobile or stationary, as with fixed cranes (which are a category of cargo handling equipment), which may be powered by fuel-burning engines, or electrically powered mobile forklifts.

As noted in subsection 3.1, the key data elements in developing a detailed emissions inventory are source data, including the number, size, and age of sources; activity data, such as operating hours, miles driven, average load, and fuel consumption; and emission factors (i.e., the mass of pollutant per unit of fuel or energy). Source data must be obtained from the owner or operator of the emission source(s) because it is specific to the facility or the activities being performed. Some activity data, such as annual hours of operation, may be obtained from the owner or operator. Other types of activity information including, for example, average load factors for different types of equipment, may be obtained from published sources, such as documentation published by the U.S. Environmental Protection Agency (EPA) for their NONROAD emission estimating model[2].

Emission factors are also obtained from published sources, most suitably, for greenhouse gases, from the protocols listed in Section 4, Existing Reporting Frameworks, including the Greenhouse Gas Protocol and the protocol issued by The Climate Registry.

[2] See *http://www.epa.gov/oms/nonrdmdl.htm*

5.1.1 Cargo Handling Equipment

Cargo handling equipment includes cranes, container handlers, forklifts, and yard tractors. Other types of equipment commonly included with cargo handling equipment in emissions inventories, although not directly used to move cargo, include sweepers, backhoes, and other construction related equipment that may be used on the port's terminals. The following discussion refers to the three basic approaches to developing emissions inventories discussed in subsection 2.2: activity-based, surrogate-based, and hybrid.

For an annual activity-based inventory, the following list is an example of the data that can be collected for each piece of fuel-burning cargo handling equipment:

Source data:

- Internal equipment identification number/name
- Equipment type
- Model year
- Equipment and engine manufacturer(s)
- Model designation(s)
- Fuel type
- Rated power (e.g., kW or horsepower)
- Emission control devices or methods (other than standard for the model and year)

Activity data:

- Annual hours of operation
- Fuel consumption (per year or per hour)
- Average load factor while operating

Emissions data:

- Emission factors appropriate to the types of engines in the inventory, kg pollutant/kW-hr or kg pollutant/liter or kg fuel (or lbs pollutant/gallon fuel)
- Control factors (percent reduction offered by identified emission control devices or methods)

For electric-powered equipment, the source data will mostly include kW-hrs of recharging, if available. If recharging records are not available, the emissions from recharging may need to be included with overall building or facility electrical consumption. The emission factors should reflect power plant emissions, preferably specific to the mix of power generation technologies used to provide power to the region being inventoried. For other types of electric-powered cargo handling equipment such as electric wharf cranes, power consumption in MW-hrs may be estimated from utility bills or drop meters.

Not all of the source data listed above is directly needed for estimating emissions. Items such as the internal identification number, manufacturer, and model designations can be used in subsequent planning if equipment changes are considered as a means of reducing emissions.

Depending on the information collected, emissions can be estimated using fuel or energy figures. If fuel, the equation (using metric units) would be:

Equation 5.1

Emissions (kg pollutant/yr) = Fuel consumption (liters fuel/yr) x Emission Factor (kg pollutant/liter fuel)

This calculation could be made for each piece of equipment or for the fleet of equipment as a whole. Estimates for each piece of equipment are preferable because that method helps point out potential targets for emission reduction efforts.

Example 1

As an example based on the fuel-based equation shown above, assuming the following data:

- Fuel consumption: 10,000 liters/year (obtained from the equipment owner or operator, from fueling records or estimates)
- Emission factor: 2.75 kg CO_2/liter (from GHG Protocol value of 74.01 kg CO_2/gigajoule (GJ), with a lower heating value of 0.0371 GJ/liter: 74.01 kg/GJ x 0.0371 GJ/liter = 2.75 kg CO_2E/liter)

The calculation would be:

10,000 liters/year x 2.75 kg CO_2/liter = 27,500 kg CO_2/year or
27.5 tonnes CO_2E /year

The energy-based calculation would use the following equation:

Equation 5.2

Emissions (kg pollutant/yr) = Rated Power (kW) x Load Factor (unitless) x Operating Time (hours/yr) x Emission Factor (kg pollutant/kW-hr)

For both fuel-based and energy-based calculations, it is important to calculate the emissions from equipment using different fuels separately, because the emission factors are different for each fuel. In addition, fuels classified as biofuels (e.g., biodiesel and ethanol) should be calculated separately, even if the biofuel is a component of a fuel blend (such as a B20 blend of biodiesel and petroleum diesel).

Example 2

As an example based on the energy-based equation shown above, assuming the following data:

- Rated power: 450 kW (obtained from the equipment owner or operator; more specifically from documentation related to that specific piece of equipment or an identical piece of equipment)
- Load factor: 0.65 (e.g., obtained from U.S. EPA's NONROAD model documentation for the type of equipment, or a similar type of equipment)
- Operating time: 1,000 hours per year (obtained from the equipment owner or operator, either from hour meter or from an estimate based on operating schedule)
- CO_2 emission factor: 661 g CO_2/kW-hr (calculated from engine BSFC of 209 g/kW-hr[3], fuel C content of 86.3%[4]: 209 g/kW-hr x 0.863 x (44/12)[5] = 661 g/kW-hr or 0.661 kg/kW-hr)

The calculation would be:

$$450 \text{ kW} \times 0.65 \times 1{,}000 \text{ hrs/yr} \times 0.661 \text{ g } CO_2\text{/kW-hr}$$
$$= 193{,}343 \text{ kg } CO_2\text{/yr or } 193.3 \text{ tonnes } CO_2E\text{/yr}$$

An example of a surrogate approach would be the use of cargo handling equipment emissions from another port, preferably similar in cargo type and configuration. To use this information, it would be necessary to know the other port's throughput and/or the number of pieces of cargo handling equipment. In either case, the procedure would be to develop an "emission factor" in terms of mass of pollutant per unit of throughput or per piece of equipment:

Equation 5.3

Surrogate Port Emissions (tonnes/TEU) = Surrogate Port Emissions (tonnes/yr) / Surrogate Port Throughput (TEUs/yr)

or

Equation 5.4

Surrogate Port Emissions (tonnes/yr/unit) = Surrogate Port Emissions (tonnes/yr) / Surrogate Port CHE Fleet (number of units)

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[3] The BSFC is an example typical of large diesel engines

[4] The carbon content of diesel fuel is from "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2006 (15 April 2008) - Table A-37: Carbon Content Coefficients and Underlying Data for Petroleum Products"

[5] The factor of (44/12) is the ratio of the molecular weights of CO_2 (44) to carbon (12). This calculation assumes all of the carbon in the fuel is burned to CO_2, a close approximation.

Separating the emissions and number of units by type of equipment would enhance the value of using the number of units of equipment, if that level of detail was available.

Using Equations 5.3 or 5.4 the surrogate emission factor, based on throughput or number of units, would be multiplied by the subject port's throughput in TEUs or number of pieces of equipment, as appropriate, to estimate the annual emissions from the subject port:

Equation 5.5

Emissions (tonnes/yr) = Surrogate Port Emissions (tonnes/TEU) x Port Throughput (TEUs/yr)

or

Equation 5.6

Emissions (tonnes/yr) = Surrogate Port Emissions (tonnes/yr/unit) x number of units

The more similarities between the surrogate port and the subject port, the better the resulting emission estimates will be. Characteristics such as throughput, cargo types, land area, and operating practices have a significant effect on a port's emissions profile and will affect the validity of the comparison between ports.

A hybrid approach could be used if specific information were available for a certain type of equipment, such as yard tractors, but not for other types of equipment. In this case, equipment-specific emissions could be estimated for the yard tractors while surrogates would be developed for all remaining equipment. This would require, of course, that the surrogate port's emissions from equipment other than yard tractors be available.

5.1.2 Heavy-Duty On-Road Vehicles

This section discusses methods that can be used to develop estimates of emissions of greenhouse gases from heavy duty trucks. These vehicles, almost exclusively powered by diesel engines and classified as heavy-heavy duty (>33,000 lbs. Gross Vehicle Weight Rating [GVWR]), perform much of the movement of containerized cargo to the ports for overseas export and from the ports for local distribution. Heavy duty trucks are the preferred method for moving cargo within relatively short distances compared to rail. For longer distance transportation, these trucks are also used to move containers (drayage) to off-terminal facilities where they are transferred from truck chassis to railcars. Although the heavy duty truck fleet is predominately diesel powered, trucks powered by compressed natural gas (CNG), liquefied natural gas (LNG), propane and electricity are increasing in market share.

Figure 5.1: Heavy-Duty Diesel Truck

In estimating emissions from heavy-duty trucks (Figure 5.1), two modes of operation are considered; idle emissions occur when the engine is on yet the vehicle is not moving and running emissions occur when the engine is on and the vehicle is in motion. Greenhouse gas emissions from trucks can also be classified by area of truck operation; "on-terminal" as trucks idle waiting to pick up or drop off cargo, and traverse the terminals with their loads; "on-port," entering or exiting port property or traveling between terminals; and "regional," outside of port property as they are used to pick up or deliver goods. These geographic distinctions tend to be made because operational characteristics of the truck differ by zone as does the port's authority and ability to influence these operations.

Estimating the greenhouse gas emissions from heavy duty trucks requires knowledge of the fleet servicing the port and their operations. The basic estimation method is listed in Equation 1 below where "Pop" is the number of trucks, "EF" is the emission factor expressed as quantity of pollutant per some unit of activity, and ACT is the activity corresponding to the units of the emission factor.

The burning of fossil fuels such as diesel in trucks releases CO_2 and other greenhouse gases including CH_4 and N_2O. As new vehicles become more fuel efficient, the overall fleet tends to emit lower levels of greenhouse gases. The improvements gained in fuel economy within the heavy-duty diesel truck fleet over time, although modest, may suggest that the average age of the fleet should also be considered rather than just the population. Vehicles of varying model years may also be subject to different standards of allowable emissions; this also supports the argument to track the age distribution, or the number of trucks in each model year, of the port truck fleet.

Equation 5.7

$$Total Emissions = Pop \times EF \times ACT$$

On-road motor vehicle emission estimation models such as the U.S. EPA "MOBILE", the state of California's "EMFAC" and Europe's "COPERT" include a default assumption of the heavy duty truck age distribution that can be used for this purpose. Alternatively, the model year distribution of the port truck fleet can be determined by an examination of port tenants' records of vehicle arrival and departure if license plate information is collected at the gate(s). In many cases this information is gathered for accounting purposes either manually or electronically, however most modern terminals use optical character recognition systems (OCR) or radio frequency identification devices (RFID). Whether recorded manually or electronically, the gathered license plate information is ultimately forwarded to government motor vehicle departments, which maintain registration information of these vehicles, to determine trucks age distribution.

On-terminal activity includes idle or very low speed operation of trucks as they wait at gates or in queue, and running which occurs as goods are picked up or dropped off. Therefore, in estimating on-terminal greenhouse gas emissions, the activity component of Equation 5.7 above would include hours of idle operation as well as miles of travel. The corresponding emission factors would be expressed in terms of grams of pollutant per hour and grams of pollutant per mile or kilometer driven.

Estimates of the hours of idle operation can be obtained through survey of terminal operators or by actual measurement of queue times at gates. Emission rates of greenhouse gases expressed in terms of grams per hour are readily available from regulatory agencies such as the U.S. EPA and the California Air Resources Board (CARB), as presented in Table 5.1. Alternatively, fuel consumption rates and greenhouse gas emission factors per unit volume of fuel can be used to develop emission estimates.

Table 5.1: Example Greenhouse Gas Idle Emission Rates, g/hr[6]

	CO_2	CH_4	N_2O	CO_2E
Heavy-Duty Diesel	4,640	0.183	0.037	4,655

CO_2E is an expression of the carbon dioxide equivalent of the pollutants in terms of their combined global warming potential in which each gram of CH_4 is assumed to equal 21 grams of CO_2 and each gram of N_2O is assumed to equal 310 grams of CO_2 with respect to their relative global warming potential (Table 3.1).

[6] *http://www.arb.ca.gov/msei/msei.htm*

Distance of travel per vehicle trip while on terminal can be estimated by reviewing the physical layout of the terminal and estimating the average round trip distance between entry and exit gates. On public roads, short periods of idle, such as those experienced at traffic signals, are assumed to be integrated within the gram-per-mile emission rates obviating the need for separate assessment. Emission rates of greenhouse gases expressed in grams of pollutant per distance traveled by heavy duty diesel truck are also available from governmental agencies such as CARB, the U.S. EPA, United Kingdom's Department of Energy & Climate Change, and Environment Canada, as presented in Table 5.2.

Table 5.2: Greenhouse Gas Emission Factors for Highway Mobile Sources, g/km[7] [8] [9]

	CO_2	CH_4	N_2O	CO_2E
U.S. : Heavy Duty Diesel				
Advanaced Technology	987	0.04	0.03	997.1
Moderate Engine Controls	1,011	0.05	0.03	1,021.4
Uncontrolled	1,097	0.06	0.03	1,107.6
E.U.: Articulated Diesel Truck, >33t				
Average Load (60%)	943.7	1.53	1.02	1,293.0
Fully Loaded	1,123.5	1.53	1.02	1,472.7

On-port and regional activity are traditionally estimated on a gram-per-distance-traveled basis and take into consideration an overland boundary representing the extent to which the port has influence over, or is accountable for, the emissions associated with goods moved by truck. In some instances, it has been assumed that the port is responsible for and has influence over the emissions from trucks from the point of entry across the overland boundary on the way to the port, and to the first point of rest (initial destination) upon leaving the port. After the initial destination or the first point of rest, additional emissions associated with the movement of these goods is traditionally assumed to be under the influence of, and therefore, the responsibility of the importer or trans-loading agent.

The average distance driven per truck trip either on-port or regionally can vary widely. Average trip lengths can be determined through travel surveys where truck drivers or owners are questioned regarding their origin prior to visiting the port and their intended destination upon departure. Alternatively, devices such as global positioning systems (GPS) have been used to electronically track the activity of subsets of the heavy duty truck fleet. Once the average truck trip length has been established, emissions are estimated using a gram per distance traveled emission factor (Table 5.2 above) multiplied by the total miles driven.

[7] Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1996, Table C-10
[8] E.U. 60% Load - Transport Statistics Bulletin: Road Freight Statistics 2005, DfT SB (06), 27 June 2006
[9] E.U. Fuel Use - Digest of UK Energy Statistics, Department of Energy & Climate Change, 2008

It is important to note that the activity of heavy duty trucks involved in the movement of goods to and from the ports may be modeled by local, state or higher level governmental agencies as a part of their overall transportation plans. Agencies such as the Federal Highway Administration (FHWA) in the U.S. and local agencies such as the Southern California Association of Governments can be a valuable source of information as they periodically perform transportation analyses including origin and destination surveys that can be used to establish port-related activity levels. While ports tend to defer to these agencies' estimates for sake of consistency, it is not unusual for the ports to engage in a consultative capacity to ensure that the most accurate information is used in establishing these estimates.

An alternative approach to greenhouse gas inventory estimation requires the estimator to have knowledge of the amount of fuel consumed by the fleet of trucks in service to the port. These fuel consumption estimates, gathered through an analysis of fuel receipts or a survey of refueling habits, would ultimately be coupled with emission factors expressed in terms of grams of pollutant per gallon of fuel consumed (see Equation 5.2). Gram per gallon greenhouse gas emission factors are available from regulatory agencies or institutions involved in engine testing and certification, as presented in Table 5.3.

Equation 5.8

$$\textit{Total Emissions} = \textit{Total Gallons} \times \textit{Grams per Gallon}$$

Table 5.3: Greenhouse Gas Emission Factors, g/gal[10]

	CO_2	CH_4	N_2O	CO_2E
Heavy-Duty Diesel	10,138	0.342	0.332	10,248.1

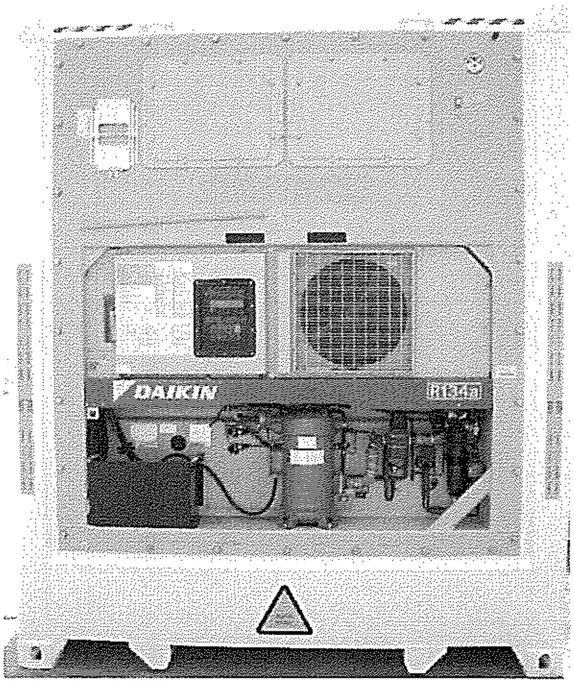
Finally, the properties of different fuels or engine technologies can have a dramatic impact on greenhouse gas emissions. During the certification process, engines are tested on standardized reference fuels that may differ from commercially available fuel. In the equation below, an additional fuel correction factor (FCF) which is dimensionless, is added to account for the differences between commercially dispensed and certification fuel. A control factor (CF) is also added which accounts for the change in emissions due to installation of an emissions control device or fuel efficiency measures such as modification to normal operating procedures. These FCFs and CFs can be obtained from either regulatory agencies or institutions involved in engine testing and emissions modeling.

Equation 5.9

$$\textit{Total Emissions} = Pop \times EF \times ACT \times FCF \times CF$$

[10] http://www.arb.ca.gov/cc/inventory/doc/doc_index.php

Figure 5.2: Refrigerated Container



In addition to emissions from heavy duty engines, the added emissions from refrigerated containers may be significant contributors to the port's greenhouse gas inventory. "Reefer" trucks have an integral, transportation refrigeration units (TRU) primarily powered by small diesel engines (Figure 5.2) that work to keep cargo at optimal temperatures when external electrical power is unavailable. TRUs are considered non road engines and the emission rates expressed in grams of greenhouse gas per unit of work performed (g/hp-hr or g/kW-hr) are obtainable from engine manufacturers or government agencies in the form of certification data and emissions models such as U.S. EPA's "NONROAD" and CARB's "OFFROAD".

In addition to the TRU emissions, refers utilize chemical refrigerants known to affect the atmosphere (depletion of the ozone layer) and contribute to global warming. Numerous gases are listed in the U.S. EPA regulations including N_2O, CH_4, CO_2, hydrofluorocarbons (HFCs), perfluorocarbons (PFCs), nitrogen trifluoride (NF_3), and ethers. Table 5.4 below displays the global warming potential of various refrigerants with respect to CO_2. The type of refrigerant being used is typically available on the units themselves (i.e., R134a in Figure 5.2 above).

Table 5.4: Global Warming Potential of Various Refrigerants

Compound	CO_2 Equivalents
Nitrous Oxide	310
Methane	21
Hydrofluorocarbons	140 (HFC-152a) to 11,700 (HFC-23)
Perfluorocarbons	6,500 (CF4) to 9,200 (C2F6)
Nitrogen Trifluoride	17,200
Dimethyl Ether	1

Instrumentation designed to detect and quantify the magnitude of refrigerant leaks is commercially available. As an alternative method of leak estimation, the recommended refrigerant charge frequency should be available from the container manufacturer. The annual charge amount can then be divided by the average time from pick up at the port to the container's first point of rest.

Example 1

As an example, greenhouse gas emissions are estimated using the following assumptions:

- 1,000 advanced technology heavy-duty trucks in the port truck fleet
- Average Idle Time: 30 minutes per truck trip
- Average Trip Distance On-Terminal: 1 kilometer per truck trip
- Average Regional Trip Distance: 60 kilometers per truck trip
- Truck Trips: 1,000 trips per year

The calculation for on-terminal idle CO_2E emissions would be:

1,000 trucks x 1,000 trips/year x 30 min/trip x 1 hr/60 min x 4,655.3 g CO_2E/hr = 2,327,650,000 g CO_2E /yr or 2,327.65 tonnes CO_2E /yr

The calculation for the on-terminal running activity would be:

1,000 trucks x 1,000 trips/year x 1 km/trip x 997.14 g CO_2E/km = 997,140,000 g CO_2E /yr or 997.14 tonnes CO_2E /yr

Total on-terminal emissions CO_2E = 2,327.65 +997.14 = 3,324.79 tonnes/year

The calculation for the on-port and regional running activity would be:

1,000 trucks x 1,000 trips/year x 60 km/trip x 997.14 g CO_2E/km = 59,828,400,000 g CO_2E /yr or 59,828.4 tonnes CO_2E /yr

Total heavy-duty diesel CO_2E = 3,325 + 59,828 = 63,153 tonnes/year

Example 2

As an example, based on the fuel consumption approach, greenhouse gas emissions are estimated using the following assumptions:

- 1,000 heavy-duty trucks in the port truck fleet
- Truck Trips: 1,000 trips per year
- Average Fuel Consumed per Trip: 5 gallons per truck trip

The calculation for port related heavy-duty diesel trucks would be:

$$1{,}000 \text{ trucks} \times 1{,}000 \text{ trips/year} \times 5 \text{ gallons/trip} \times 10{,}248.1 \text{ g } CO_2E/\text{gal} = 51{,}240{,}500{,}000 \text{ g } CO_2E \text{ /yr or } 51{,}241 \text{ tonnes } CO_2E \text{ /yr}$$

5.1.3 Railroad Locomotives

This section discusses methods that can be used to develop estimates of greenhouse gas emissions from locomotives used to move goods to and from ports via rail. Railroads are considered to be the "greenest," most fuel-efficient form of ground transportation, and are responsible for the movement of 43 percent of U.S. freight in recent years compared to 15 percent for China, and 10 percent for Europe. Freight trains are three or more times more fuel-efficient compared to heavy-duty diesel trucks with the capability to move a ton of freight an average of 436 miles per gallon of fuel consumed.[11]

Locomotives used in port operations are routinely classified by size and/or usage as either line haul or switchers. Line haul locomotives (Figure 5.3) tend to be large (3,000 to 4,000 hp) and are used to move cargo over relatively long distances as goods are either picked up for transport to destinations across the country or dropped off for shipment overseas. In contrast, switching locomotives (Figure 5.4) tend to be smaller (1,200 to 3,000 hp) and perform relatively short distance rail movements such as assembling and disassembling of trains at various locations in and around the Port, sorting of the cars of inbound cargo trains into contiguous "fragments" for subsequent delivery to terminals, and the hauling of rail cargo within the port.

[11] Association of American Railroads (AAR), *http://www.aar.org/Environment.aspx?p=1*

Figure 5.3: Line Haul Locomotive

Figure 5.4: Switching Locomotive

Diesel fuel is used almost exclusively by both line haul and switcher locomotives. However, most locomotives employ diesel electric systems, where diesel fuel is consumed to generate electricity which is used for locomotion. Therefore, unlike heavy-duty diesel trucks, engine load for locomotives is not a direct function of vehicle speed. The activity of locomotives tends to be expressed in terms of "time in notch" or throttle position which ranges from idle, to one of eight different operating modes each of which represents successively higher average engine load. Only the emissions associated with the combustion of diesel fuel would be considered in estimating greenhouse gases from these engines.

In many applications, external energy sources are used to propel locomotives rather than the internal combustion of diesel. These electric freight trains (Figure 5.5) receive electricity from overhead lines or by means of third rail. Among the advantages of electrification of rail is the complete absence of pollutants emitted from the locomotives themselves, higher performance, lower maintenance and lower energy costs. The emissions associated with power generation to move these trains would be considered as Scope 3 emissions. The emissions associated with port employees who commute to work by train are traditionally modeled separately from goods movement.

The basic equation for estimating greenhouse gas emissions from locomotives is similar to that of all other mobile source emissions where the population of vehicles or engines is multiplied by an emission factor expressed in terms of amount of pollutant per some unit of activity which in turn is multiplied by the corresponding activity per some unit of time (Equation 5.10).

Equation 5.10

$$Total\,Emissions = Pop \times EF \times ACT$$

Where Pop is the population, in this example the number of locomotives in operation, EF is the emission factor expressed in grams per gallon or kg of fuel, grams per ton-mile, or grams per horsepower-hour and ACT is the corresponding activity; i.e. gallons of fuel consumed per year, total ton-miles or horsepower-hours per year.

Table 5.6: GHG Emission Factors for Diesel Locomotives, g/hp-hr[15]

	CO_2	CH_4	N_2O	CO_2E
Line Haul	507.1	0.071	0.005	510.14
Switchers	502.5	0.071	0.005	505.54

Equation 5.12 (above) can also be used to estimate the greenhouse gas emissions of electric freight locomotives; however, the emission factors would vary depending upon the local feedstock (i.e., coal, natural gas, hydropower, etc.) used to generate electricity and to what extent these power plants are controlled for emissions. This information should be available from local utility companies.

Perhaps the most detailed information on locomotive operations is collected as they are actually being used. Time in notch data is recorded by the locomotive's engine management systems and may be obtained from rail operators. In addition to idle and the eight notch settings, many locomotives utilize dynamic braking, during which the electric drive engine operates as a generator to help slow the locomotive, with the resistance-generated power being dissipated as heat. While the engine is not generating motive power under dynamic braking, it is generating power to run cooling fans, so this operating condition is somewhat different from idling. Switch engines typically do not utilize dynamic braking.

As each notch is representative of a percent of the full power available from the locomotive's engine, emissions per notch could be estimated using Equation 5.13. In this instance, the emission factors in Table 5.6 can be coupled with activity estimates expressed in hp-hrs (time in notch multiplied by the percent of power in notch) to derive total emissions. This level of detail is needed to determine the localized impact of emission reduction strategies such as idle limiting. The estimated percent of full power experienced by notch is presented in Table 5.7.

Equation 5.13

Total Emissions = EF (g/hp-hr) x Total Rated Power (hp) x % Total Rated Power in Notch x Time in Notch (hours)

Table 5.7: Estimated Power Demand by Notch, Percent

Mode	% of Full Power	Mode	% of Full Power
Dynamic Braking	2.1	Notch 4	34.3
Idle	0.4	Notch 5	48.1
Notch 1	5.0	Notch 6	64.3
Notch 2	11.4	Notch 7	86.6
Notch 3	23.5	Notch 8	102.5

[15] Container Terminal Project, Appendix E 1.3, Los Angeles Harbor Department, April 2008

Finally, the properties of different fuels or engine technologies can have a dramatic impact on greenhouse gas emissions. During the certification process, engines are tested on standardized reference fuels that may differ from commercially available fuel. In the equation below, an additional FCF which is dimensionless, is added to account for the differences between commercially dispensed and certification fuel and a CF is also added which accounts for the change in emissions due to installation of an emissions control device such as exhaust gas recirculation or modification to normal operating procedures such as an idle abatement strategy. These FCFs and CFs can also be obtained from either regulatory agencies or institutions involved in engine testing and emissions modeling.

Equation 5.14

$$Total\ Emissions = Pop \times EF\ (g/kW\text{-}hr) \times ACT\ (kW\text{-}hrs) \times FCF \times CF$$

Example 1

As an example of a fuel-based estimate of emissions, assuming the following data:

- Fuel Consumption: 50,000 gallons/year (from fuel meter readings/fuel receipts)
- Emission factor: 10,172.5 kg CO_2E/gallon (Table 5.5)

The calculation would be:

50,000 gallons/year x 10,172.5 g CO_2E/gallon =
508,625,000 g CO_2E/year or 508.6 tonnes CO_2E/yr

Example 2

As an example of an energy-based estimate of emissions, assuming the following data:

- Rated power: 2,500 hp (obtained from the locomotive manufacturer, owner or operator)
- Load factor: 0.343 (Notch 4 from Table 5.7)
- Time in Notch: 1,000 hours per year (obtained from the equipment owner or operator)
- CO_2E emission factor: 510.14 g/hp-hr (Table 5.6)

Emissions (g pollutant/yr) = Rated Power (hp) x Load Factor (unitless) x Operating Time (hours/yr) x Emission Factor (g pollutant/hp-hr)

Total Emissions (Notch 4) =
2,500 hp x 0.343 x 1,000 hrs/yr x 510.14 g CO_2E/hp-hr =
437,325,000 g CO_2E/yr or 437.45 tonnes CO_2E/yr

Although mass emissions of CH_4 and N_2O tend to be small compared to CO_2, these emissions remain important because of their relatively high global warming potential. Each gram of N_2O has 310 times the global warming potential of CO_2 and each gram of CH_4 has 21 times the global warming potential of CO_2.

Finally, the properties of different fuels or engine technologies can have a dramatic impact on greenhouse gas emissions. During the certification process, engines are tested on standardized reference fuels that may differ substantially from commercially available fuel. In the equation below, an additional FCF, which like the load factor is dimensionless, is added to the equation to account for the differences between commercially dispensed and certification fuel and a CF which accounts for the change in emissions due to installation of an emissions control strategy or technology such as hybrid power systems. These FCFs and CFs can also be obtained from either regulatory agencies or institutions involved in engine testing and emissions modeling.

Equation 5.17

$$E = EF \times HP \times LF \times FCF \times ACT \times CF$$

Example 1
As an example of a fuel-based estimate of emissions, assuming the following data:

- Fuel consumption: 10,000 gallons/year (from fuel meter readings/fuel receipts)
- Emission factor: 10.14 kg CO_2/gallon (see above)

The calculation would be:

10,000 gallons/year x 10.14 kg CO_2/gallon = 101,400 kg CO_2/year or 101.4 tonnes CO_2/year

Example 2
As an example of an energy-based estimate of emissions, assuming the following data:

- Rated power: 1,000 kW for an excursion vessel (obtained from the engine manufacturer, owner or operator)
- Load factor: 0.42 (obtained from CARB's OFFROAD model documentation for propulsion engines of excursion vessels)
- Operating time: 1,000 hours per year (obtained from the equipment owner or operator, either from hour meter or from an estimate based on operating schedule)
- CO_2 emission factor: 652 g CO_2/kW-hr (obtained from CARB)

emissions (g pollutant/yr) =
rated power (kW) x load factor (unitless) x operating time (hours/yr)
x emission factor (g pollutant/kW-hr)

1,000 kW x 0.42 x 1,000 hrs/yr x 652 g CO_2/kW-hr =
273,840,000 g CO_2/yr or 273.84 tonnes CO_2/yr

Table 5.9 includes emission factors for the greenhouse gases namely carbon dioxide, methane, and nitrogen dioxide. Emission factors for CO_2E are based on the global warming potential of the three primary greenhouse gases (i.e., CO_2=1, CH_4=21, N_2O=310). It should be noted that fuel type changes do not typically affect GHG emission factors except for CH_4, which has a fuel correction factor of 0.94 for fuels lighter than residual.

Table 5.9: GHG Emission Factors for OGV Propulsion Power using Residual Oil, g/kW-hr

Engine	MY	CO_2	CH_4	N_2O	CO_2E
Slow speed diesel	≤1999	620	0.012	0.031	629.9
Medium speed diesel	≤1999	683	0.010	0.031	692.8
Slow speed diesel	2000+	620	0.012	0.031	629.9
Medium speed diesel	2000+	683	0.010	0.031	692.8
Gas Turbine	All	970	0.002	0.080	994.8
Steamship	All	970	0.002	0.080	994.8

Emission factors for auxiliary engines[19] are presented in Table 5.10 below.

Table 5.10: GHG Emission Factors for Auxiliary Engines using Residual Oil, g/kW-hr

Engine	MY	CO_2	CH_4	N_2O	CO_2E
Medium speed	all	683	0.008	0.031	692.8

In addition to the auxiliary engines that are used to generate electricity for on-board applications, most OGVs have one or more boilers used for fuel heating and for producing hot water or steam. Boilers are only assumed to be used at reduced speeds, such as during in-harbor maneuvering and when the vessel is at Port and the main engines are shut down. The emission factors used for the steam boilers based on ENTEC's emission factors for steam boilers (ENTEC 2002)[20] are presented below.

Table 5.11: GHG Emission Factors for OGV Auxiliary Boilers using Residual Oil, g/kW-hr

Engine	CO_2	CH_4	N_2O	CO_2E
Steam Boilers	970	0.002	0.08	994.8

[19] IVL 2004.

[20] ENTEC, Quantification of Emissions from Ships Associated with Ship Movements between Ports in the European Community, Final Report, July 2002. Prepared for the European Commission.

As with the other categories, one can model OGV GHG emissions from a detailed or surrogate approach. OGVs lend themselves to both approaches because there is good data available to ports on movement of ships within their domain. However, these efforts can be dauntingly complex and can take well over a year to complete an initial inventory. It is important to note that the methods, data quality, and approaches are constantly being improved as each inventory is completed. There are several ports that have completed detailed inventories and it is highly recommended that ports wishing to undertake such a detailed inventory to contact one of these ports to get the latest information. A list of these ports is included in Section 1, Introduction.

In looking to surrogate approaches, one can use a fuel-based approach; however, when estimating ship emissions by mode, the availability of ship's fuel consumption information for other modes other than at-sea is very limited. Therefore, the recommended surrogate approach is to utilize a combination of simplified assumptions, world fleet averages, and data published in the latest detailed port inventories. One would use simplified assumptions associated with speed, distances, time at berth, propulsion type, auxiliary power systems, boilers, modes, etc., and use world fleet averages for main engine and maximum rated ship speeds. Table 5.12 below provides the world population averages for MCR, max rated speed, and sea-speed by the most common type vessel classes.[21] The next step would be to obtain a count or estimate of the number and types of OGVs that called during the period of time associated with the inventory. As a subsequent step, utilize default averages for auxiliary engine and auxiliary boiler loads, by vessel class from the most recent published inventories. As the final step, estimate energy by vessel class, apply emission factors, and convert from grams to short or metric tons. A graphical representation of this approach is presented in Figure 5.14 after Table 5.12.

This surrogate approach is best for providing "order of magnitude" level estimates from port OGV activities.

[21] Selected vessel class averages from Lloyd's Ship Registry, 2008

Figure 5.17: On-Road Landside Emissions

On-road heavy-duty diesel trucks are routinely used in construction (Figure 5.17). The emissions of these vehicles tend to vary by age (model year) because of changes in applicable emission standards and fuel economy standards and of loss of combustion efficiency as vehicles age. It is therefore important to consider at least the average age of the on-road fleet used during construction however it is best to attempt to derive the actual model year distribution. Fleet average model year and age distribution and emission standard information can be obtained from the various on-road emissions estimation models such as MOBILE, EMFAC, and COPERT. Model year information is often available through the review of construction permits or obtainable directly from the construction company. An example of the greenhouse gas emission factors for on-road heavy-duty trucks included in Table 5.13 below.

Table 5.13: Greenhouse Gas Emission Factors for Highway Mobile Sources, g/km[22,23,24]

	CO_2	CH_4	N_2O	CO_2E
U.S. : Heavy Duty Diesel				
Advanaced Technology	987	0.04	0.03	997.1
Moderate Engine Controls	1,011	0.05	0.03	1,021.4
Uncontrolled	1,097	0.06	0.03	1,107.6
E.U.: Articulated Diesel Truck, >33t				
Average Load (60%)	943.7	1.53	1.02	1,293.0
Fully Loaded	1,123.5	1.53	1.02	1,472.7

[22] Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-1996, Table C-10
[23] E.U. 60% Load - Transport Statistics Bulletin: Road Freight Statistics 2005, DfT SB (06) 27, June 2006
[24] E.U. Fuel Use - Digest of UK Energy Statistics, Department of Energy & Climate Change, 2008

The activity associated with the on-road construction component would be the number of miles driven by trucks and the number of hours they spend at idle during the period of construction. For heavy duty trucks, it is important to group trucks by function (i.e., water trucks, cement trucks, fuel trucks, catering trucks, material haulers, etc.) and the vehicle miles of travel (VMT) would be estimated by the round trip distance from the fleet yard, truck terminal, operator's home, etc. to the job site and the distance from the job site to the most frequent destination whether that be, for example, a dumpsite for depositing material or a cement plant to pick up a load. This process of estimation is displayed for CO_2 emissions in Equation 5.23.

Equation 5.23

$$\textit{Total Running Emissions (HDVs)} = \#\,\textit{of Trucks} \times (\textit{Miles/Trip} \times \#\,\textit{of trips}) \times \textit{EF g/mi}$$

$$\textit{Total Idle Emissions (HDVs)} = \#\,\textit{of Trucks} \times \textit{idle hours/day} \times \#\,\textit{of days} \times \textit{EF g/hr}$$

In Equation 5.23 above, running emissions are defined as those that occur while the vehicle's engine is running and the vehicle is in motion. Idle emissions occur when the vehicle's engine is running but the vehicle is stationary as is the case when a truck is waiting to receive a load for transport.

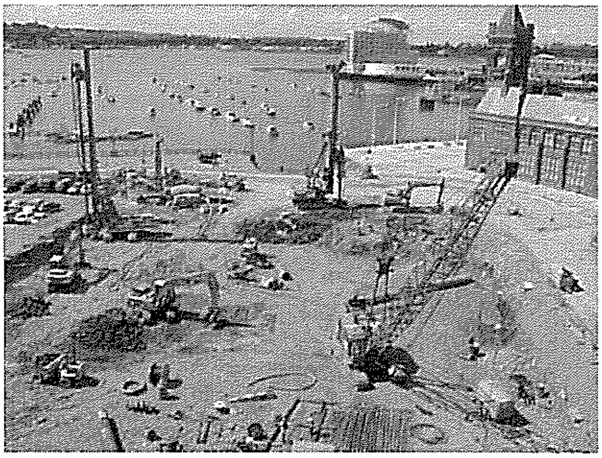
Alternatively, greenhouse gas emissions can be estimated as a function of the amount of fuel consumed during construction as illustrated in Equation 5.24. The total fuel consumed per period can be estimated using average fuel economy data or obtained from construction contractor's fueling records.

Equation 5.24

$$\textit{Total Running Emissions (HDVs)} = \#\,\textit{of Trucks} \times \textit{gallons/trip} \times \#\,\textit{of trips} \times \textit{EF g/gal}$$

$$\textit{Total Idle Emissions (HDVs)} = \#\,\textit{of Trucks} \times \textit{idle hours/day} \times \textit{idle gallons/hour} \times \#\,\textit{of days} \times \textit{EF g/gal}$$

Figure 5.18: Off-Road Landside Emissions



The greenhouse gas emissions of off-road construction equipment (Figure 5.18) can also be estimated using Equation 5.22 above. The major difference between the estimation of on- and off-road construction equipment emissions has to do with the availability of the activity information. While with on-road vehicles it is best to devise a strategy to obtain the number of miles driven during the project, hours of equipment operation during construction tends to be the best metric for off-road equipment. In this instance, Equation 5.25 tends to be used.

Equation 5.25

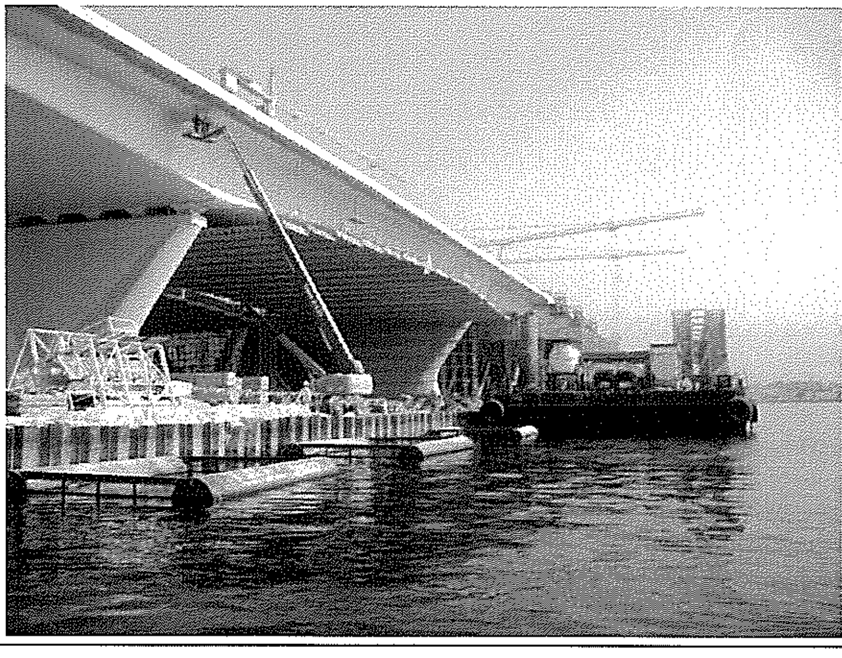
Total Emissions = Pop x EF (g/kW-hr) x Total Rated Power (kW) x LF x Total Hours of Operation

LF is the load factor which is a dimensionless multiplier expressing the percent of total rated engine power used in typical operation. For example, a load factor of 0.5 applied to a 450 kW engine suggests that this piece of equipment expends 225 kW over its normal duty cycle. Equipment specific emission and load factors are available from governmental agencies and engine manufacturers. Total hours of operation can be obtained through the recording of hour-meter readings if the vehicles are so equipped, through instrumentation, or by inquiry of the construction contractor. As with on-road commute and construction vehicles, per gallon greenhouse gas estimates can be made for off-road equipment if fuel consumption information is more easily obtainable. Finally, greenhouse gas emissions for material moved by train would be estimated on a ton-mile or fuel consumption basis, as shown in equation 5.26.

Equation 5.26

Total Emissions = Pop x EF (g/liter) x Fuel Consumption (liters/hour) x Total Hours of Operation

Figure 5.19: Overwater Construction Emissions



The greenhouse gas inventory of overwater construction equipment (Figure 5.19) includes emission from all vessels used during the project. Vessels are grouped by vessel type category or by similarity of purpose and the best determinant of activity is then assessed ranging from power expenditure (best) to fuel consumption (least desirable and least specific). Once this determination is made, either Equation 5.25 or 5.26 above can be utilized.

In the specific case of dredging operations, an additional alternative method of estimating emissions as a function of the weight of materials displaced is available. In this instance, an estimate of power or fuel required to move a specific amount of material is made prior to using the above equations. For example, if it is estimated that 250 kW-hrs are required to move a ton of dredged material, the estimator needs only to know the total tons of material to be moved during the construction project. The same would be true for estimates of fuel consumed per ton of material removed.

Equation 5.27

Total Emissions = Tons of Material x kW-hrs/ton x EF (g/kW-hr)

or

Total Emissions = Tons of Material x liters/ton x EF (g/liter)

Staying with our example of dredging, the emissions of barges and tugs must take into account the transiting distances from the dredge site to the dump site in much the same manner explored in the landside discussion for heavy-duty diesel trucks.

Example 1

As an example of an estimate of landside greenhouse gas emissions, assuming the following data:

- 10 heavy-duty diesel trucks traveling 20 miles per day (round trip) to the construction site and make 10 trips per day of 20 miles per trip (round trip) between the job site and dump site
- The heavy-duty diesels idle for 15 minutes per trip while being loaded
- One bulldozer 300 kW and one excavator 400 kW are used 6 hours per day at 40% engine load to load material into the heavy-duty trucks
- One catering truck visits the site per day at 5 miles/round trip and idles for 1 hour/day
- Total construction days = 60/year

The calculations for CO_2 emissions would be:

On-Road

Heavy-Duty Diesel Truck Running Emissions (tpy) = (10 trucks x 20 mi/day + 10 trucks x 10 trips/day x 20 mi/trip) x 60 days/yr x 1,891.6 g/mi CO_2 = 249,691,200 g CO_2/year or 249.69 tonnes CO_2/yr

Heavy-Duty Diesel Truck Idle Emissions (tons/year) = 10 trucks x 10 trips/day x 0.25 hrs idle/trip x 60 days/yr x 4,640 g CO_2/hr = 6,960,249 g CO_2/yr or 6.96 tonnes CO_2/yr

Catering Truck Running Emissions = 1 truck x 5 miles/day x 60 days/yr x 1,891.6 g CO_2/mi = 567,480 g CO_2/year or 0.57 tonnes CO_2/yr

Catering Truck Idle Emissions = 1 truck x 1 hour/day x 4,640 g CO_2/hr = 4,640 g CO_2/yr or 0.005 tonnes CO_2/yr

Total on-road CO_2 emissions = 249.69 + 6.96 +0.57 + 0.005 = 257.23 tonnes/yr

Off-Road

Bulldozer = 1 vehicle x 300 kW x 0.4(LF) x 6 hrs/day x 60 days/yr x 762 g CO_2 /kW-hr = 32,918,400 g CO_2/yr or 32.92 tonnes CO_2/yr

Excavator = 1 vehicle x 400 kW x 0.4 (LF) x 6 hrs/day x 60 days/yr x 762 g CO_2/kW-hr = 43,891,200 g/yr or 43.89 tonnes CO_2/yr

Total off-road CO_2 emissions = 32.92 + 43.89 = 76.18 tonnes/yr

Example 2

As an example of an estimate of seaside greenhouse gas emissions, assuming the following data:

- One dredge expends 1,000 kW–hr per ton of material removed
- The material is loaded on a barge and pushed by tug 5 nm round trip to dump the material
- The tug is equipped with a 1,450 kW main engine and operates at 25% load at a speed of 2.5 knots (trip time = 5 nm @ 2.5 knots = 2 hours/trip).
- The barge dumps 1,000 tons of material per day in five trips
- 100,000 tons of material will be moved during the project per year

The calculation would be:

Dredge Emissions = 1,000 kW-hrs/ton x 100,000 tons x 652 g CO_2/kW-hr x 1 tonne/1,000,000 g = 65,200 tonnes

Tug Emissions = 100,000 tons / 1,000 tons/day x 5 trips/day x 2 hrs/trip x 1,450 kW x 0.25(LF @ 2.5 knots) x 652 g CO_2/kW-hr x 1 tonne/1,000,000 g = 236.35 tonnes/yr

Total seaside CO_2 emissions = 65,200 + 236.35 = 65,436.35 tonnes/yr

5.2 Stationary Sources

Stationary sources such as electric wharf cranes, as presented in Figure 5.20, are the second group of sources found at ports. They typically account for significantly less greenhouse gas emissions than the mobile sources. This section discusses those methods used to develop estimates of greenhouse gas emissions associated with port facilities that fall under the stationary source category. Stationary source emissions come from fixed, particular, identifiable, localized sources, such as:

- Power plants;
- Boilers;
- Portable or emergency generators;
- Purchased electricity (buildings, lighting, reefer power demand, electrified cargo handling equipment, other terminal electrical demands, etc.); and
- Facilities that use combustion processes.

Electricity consumption at the ports includes the energy used in the routine operation of port and tenant facilities (i.e., lighting, instrumentation, comfort cooling, computers, ventilation, etc.), electrified cargo handling equipment (electric wharf cranes, electric rail-mounted gantries, electric rubber tired gantries, etc.), shore powering of vessels, tenant industrial facilities and reefer plugs. Even though electrified cargo handling equipment are typically thought of as mobile sources; from a greenhouse gas perspective, due to their electrification, the emissions from their operations are estimated based on purchased electricity.

Figure 5.20: Electric Wharf Cranes

Scope 1 greenhouse gas emissions include all direct emissions from a port's directly-controlled stationary sources including port-owned stationary generators and buildings. Scope 2 greenhouse gas emissions include those indirect emissions associated with the import and consumption of purchased electricity by a port for its directly-controlled sources.

Although significant, Scope 1 and 2 emissions represent a small fraction of the port's overall emissions, compared to Scope 3 emissions associated with port tenant operations. It should be noted that indirect emissions associated with purchased electricity by port tenants are also considered as Scope 3 emissions. The comprehensive estimates of port-related stationary source greenhouse gas emissions are accomplished though the use of Equation 5.28 below.

Equation 5.28

$$Total\ Emissions = EF \times ACT$$

Where EF is the emission factor expressed in terms of grams of greenhouse gas emissions per unit of activity and ACT is the corresponding activity. With respect to the consumption of electricity, the activity component of the equation is the estimated or measured kilowatts or megawatts of electricity consumed per unit of time (per day or per year) which can be determined through the audit of electricity bills. The greenhouse gas emission factor is dependent upon the means used to generate the electricity (i.e., burning of coal or natural gas, or use of renewable sources such as solar, wind, nuclear or hydropower).World energy consumption and GHG emissions distributions are presented in Figure 5.21. The composition of the electrical generation feedstock should be obtainable from the port's energy supplier. Table 5.14 below presents the CO_2 emission rates related to power generation from different feed stocks.

Table 5.14: CO_2 Emission Factors for Electricity Generation[25]

Fuel/Source	lbs CO_2/kw-hr	g CO_2/kw-hr
Coal	2.13	4.70
Natural Gas	1.03	2.27
Oil	1.56	3.44
Wind	0.00	0.00
Solar	0.00	0.00
Nuclear	0.00	0.00
Hydro	0.00	0.00
Tide	0.00	0.00
Country Averages	**lbs CO_2/kw-hr**	**g CO_2/kw-hr**
France	0.16	0.35
Germany	1.16	2.56
Italy	1.09	2.40
Japan	0.99	2.18
New Zealand	0.50	1.10
Nordic Countries	0.05	0.11
Switzerland	0.02	0.04
United Kingdom	1.20	2.65
United States	1.28	2.82

[25] International Energy Agency – *http://www.iea.org*

Figure 5.21 provides the relative composition of worldwide energy consumption and greenhouse gas emissions by fuel type.

Figure 5.21: World Primary Energy Consumption & Greenhouse Gas Emissions (by fuel)[26]

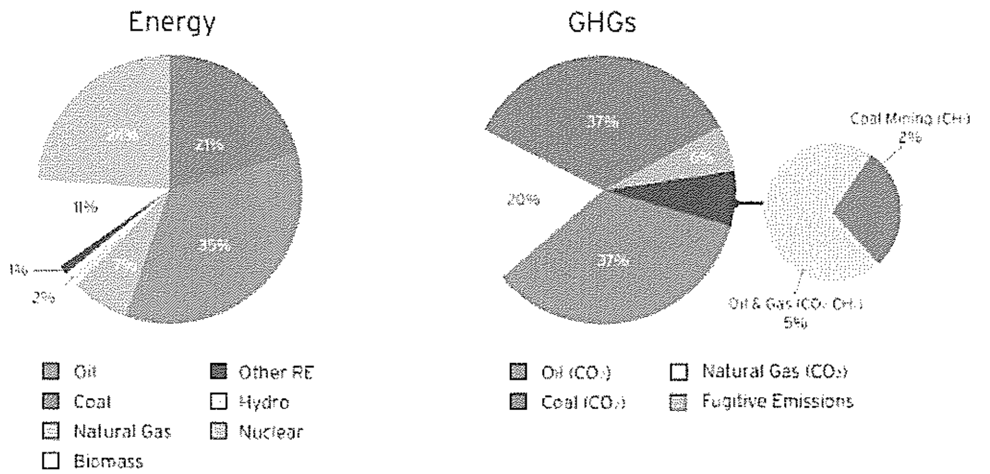
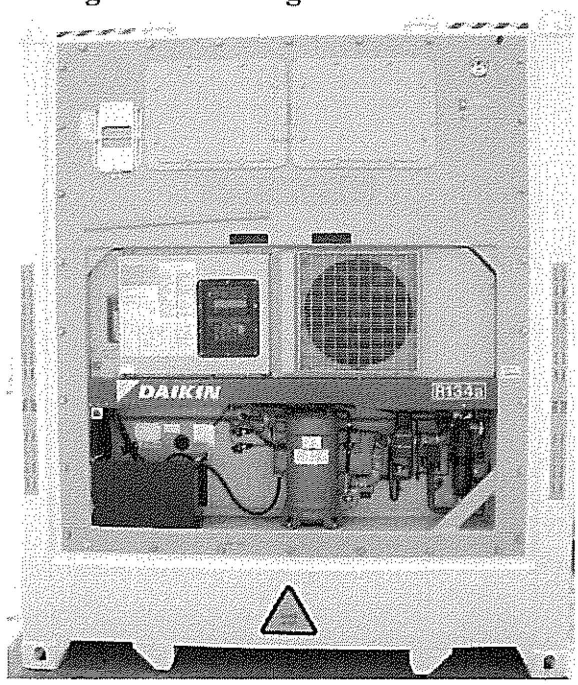


Figure 5.22: Refrigerated Container



[26] WRI, based on CAIT and IEA, 20104b. Data is for 2002; *http://www.willyoujoinus.com*

Although not a stationary source by the strictest definition, refrigerated containers may be significant contributors to the port's overall carbon footprint. While "reefers" have an integral refrigeration unit (Figure 5.22), they rely on external power from electrical power points at a land-based site while awaiting pick up and transport. In addition to this landside power consumption, reefers utilize chemical refrigerants known to affect the atmosphere (depletion of the ozone layer) and contribute to global warming. Numerous gases are listed in the U.S. EPA regulations including N_2O, CH_4, CO_2, HFCs, PFCs, NF_3, and ethers. Table 5.15 below displays the global warming potential of various refrigerants with respect to CO_2. The type of refrigerant being used is typically available on the units themselves (i.e., R134a in Figure 5.22).

Table 5.15: Global Warming potential of Various Refrigerants

Compound	CO2 Equivalents
Nitrous Oxide	310
Methane	21
Hydrofluorocarbons	140 (HFC-152a) to 11,700 (HFC-23)
Perfluorocarbons	6,500 (CF4) to 9,200 (C2F6)
Nitrogen Trifluoride	17,200
Dimethyl Ether	1

Instrumentation designed to detect and quantify the magnitude of refrigerant leaks is commercially available. As an alternative method of leak estimation, the recommended refrigerant charge frequency should be available from the container manufacturer. The annual charge amount can then be divided by the average residency time of the containers at the port.

Example 1

As an example of estimating port related stationary source emissions, assume that an audit of utility bills suggest a daily energy consumption of one megawatt-hour (MW-hr).

Total Emissions = MW-hrs x kg CO_2E/MW-hr

1 MW-hr x 400 kg CO_2E/MW-hr = 400 kg CO_2E/day or 0.4 tonnes CO_2E/day

Example 2

As an example of estimating greenhouse gas emissions from refrigerated containers, assuming the following data: 1,000 containers/day utilizing HFC-152a, each losing one pound of refrigerant per day.

The calculation would be:

Total Emissions = 1,000 containers/day x 1 lb. HFC-152a x 140 lb CO_2E/lb. HFC-152a x 1 tonne/2,204.6 lb = 63.5 tonnes of CO_2E/day