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CARBON FOOTPRINTING FOR PORTS

GUIDANCE DOCUMENT

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Prepared by:
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World Ports Climate Initiative
Port of Los Angeles, Lead Port

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*

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Port of Antwerp
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Port of Rotterdam
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1.0 INTRODUCTION

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 gas (GHG) emissions 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.

Prior to starting the actual inventory process, there are several key questions that ports should address first. The answers to these questions will help frame the approach, determine what information is needed, define geographical boundaries, and establish the level of detail of the inventory. The key questions are:

- What are the drivers behind developing a GHG inventory?
- What uses will be made of the information?
- Will change over time be tracked and to what resolution?
- What source categories will be covered?
- What are the geographical boundaries of the inventory?
- What level of information detail will be needed?

There are several interrelated reasons for developing a carbon footprint inventory. One reason is simply to disclose the port operation's emissions of greenhouse gases, or the actual "footprint." If done in advance of regulatory requirements, it can present the port as a forward-looking organization and can serve as the basis of a record of subsequent emission reductions, especially if the disclosure is made through a formalized greenhouse gas registry. The development of a structured inventory of energy uses and other activities that produce greenhouse gas emissions can help identify areas in which improvements can be made, such as in energy efficiency or improved port operations. Understanding the sources of greenhouse gas emissions and identifying areas of improvement can greatly facilitate the development of emission reduction strategies that can provide a financial benefit as well as an environmental benefit. In addition to these beneficial uses of a carbon inventory, some ports may face a current or future requirement to document greenhouse gas emissions to a government-mandated registry.

Ports' carbon footprint inventories can be expanded beyond the immediate boundaries of the ports to include entire supply chains, from manufacturers or suppliers through intermodal shipment to distribution points or even to retail outlets. This type of expanded disclosure may be required by manufacturers, retailers, or other participants in the supply chain, and can lead to the identification of opportunities for efficiency improvements.

Carbon footprint inventories can be developed to different levels of detail, depending on the immediate purpose behind the inventory, the available resources to compile the inventory, and the time frame available to complete the inventory. Regardless of the starting point, a port's carbon footprint inventory can be expanded to include greater levels of detail or more scopes of operation over time, as needs and/or resources change. This document is intended to help ports in their footprinting process at whatever level of detail they deem appropriate.

There are several different approaches for developing carbon footprint inventories for port-related activities. Each approach is based on the needs of the inventory; the types and level of detail of data associated with the equipment/processes that are to be inventoried; and in some cases the time sensitivity of the results (i.e., how soon the information is needed). Regardless of the approach taken, it is important to identify and engage stakeholders up front, at the beginning of the process. Developing a collaborative approach, among tenants, customers, regulatory agencies, and the public, will enhance the quality of the data on which the inventory is based and will smooth the way for acceptance of the inventory. Having a working group of interested stakeholders in place will also be valuable in developing any emission reduction plans that may be the next step after preparing the inventory.

The following ports that have helped develop this document have experience in evaluating and conducting GHG inventories and can provide their perspectives on the approaches they have taken with their inventories.

Table 1.1 Supporting Ports

Port	Frequency of Update		Web Page
Port of Houston Authority	Every five years since - 2000		*http://www.portofhouston.com/*
Contact:	Dana Blume	dblume@pha.com	
Port of Long Beach	Annual - since 2002		*http://www.polb.com/environment/air/emissions.asp*
Contact:	Allyson Teramato	teramoto@polb.com	
Port of Los Angeles	Annual - since 2001		*http://www.portoflosangeles.org/environment/studies_reports.asp*
Contact:	Lisa Wunder	lwunder@portla.org	
Port Authority of New York & New Jersey	Annual - since 2006		*http://www.panynj.gov/DoingBusinessWith/seaport/html/index.html*
Contact:	Rubi Rajbanshi	rrajbanshi@panynj.gov	
Port of Oakland	Every three years - since 2005		*http://www.portofoakland.com/environm/airEmissions.asp*
Contact:	Anne Whittington	awhittington@portoakland.com	
Port of Oslo	Annual - since 2007		*http://www.oslohavn.no/english*
Contact:	Hilde Glåmseter	hilde.glaamseter@ohv.oslo.no	
Port of Rotterdam	Annual - since 2007		*http://www.portofrotterdam.com*
Contact:	Rob Houben	r.houben@portofrotterdam.com	
Port of Seattle/Puget Sound	Every five years - since 2005		*http://maritimeairforum.org/emissions.shtml*
Contact:	Sarah Flagg	Flagg.S@portseattle.org	
Port of Tacoma/Puget Sound	Every five years - since 2005		*http://maritimeairforum.org/emissions.shtml*
Contact:	Cindy Lin	clin@portoftacoma.com	

2.0 POLICY FRAMEWORK

This section provides a discussion of the types of activities at ports that typically result in GHG emissions, and provides a framework of policy considerations that are part of the GHG inventory planning and execution process. These policy issues include the physical and operational boundaries of the inventory, the period of time to be covered, and considerations regarding the potential for double counting and for making comparisons between two inventories or among several inventories.

2.1 Port-Related Emission Sources

Many emission-producing sources are directly and indirectly related to port operations. These emission sources include port administration vehicles, power plants providing power for administration offices, tenant buildings, electrified cargo handling equipment, fuel-powered cargo handling equipment, ships, harbor craft, trucks, rail locomotives, etc. These sources produce greenhouse gases, notably carbon dioxide (CO_2), methane (CH_4), and nitrous oxide (N_2O), and other pollutants of concern, such as oxides of nitrogen (NO_x), particulate matter (PM), and sulfur oxides (SO_x).

The relationships of these sources to the port administrative bodies vary by source type and between individual ports. In terms of ownership and responsibility, ports can be considered as one of two general types, with varying degrees of overlap between the two:

- **Landlord Ports** – These ports own the land or are given responsibility for managing the land on which the port is located, and in most cases develop the port facilities such as marine terminals, but lease the land and/or facilities to terminal operators who are responsible for the equipment used on the terminals.

- **Operating Ports** – These ports develop, own, and operate the marine terminal facilities and the equipment used on the terminals.

Some ports incorporate features of both types, such as a port that owns the land and the major terminal equipment, such as wharf cranes, but leases the terminal to an operator who operates the port-owned wharf cranes and the operator's own terminal equipment.

The relationship of the port's administrative authority to its operating terminals is important in determining the responsibility for categories into which various activities fall. In developing carbon footprint inventories, GHG quantification protocols delineate that the emission-producing activities for ports should be grouped into the following three scopes:

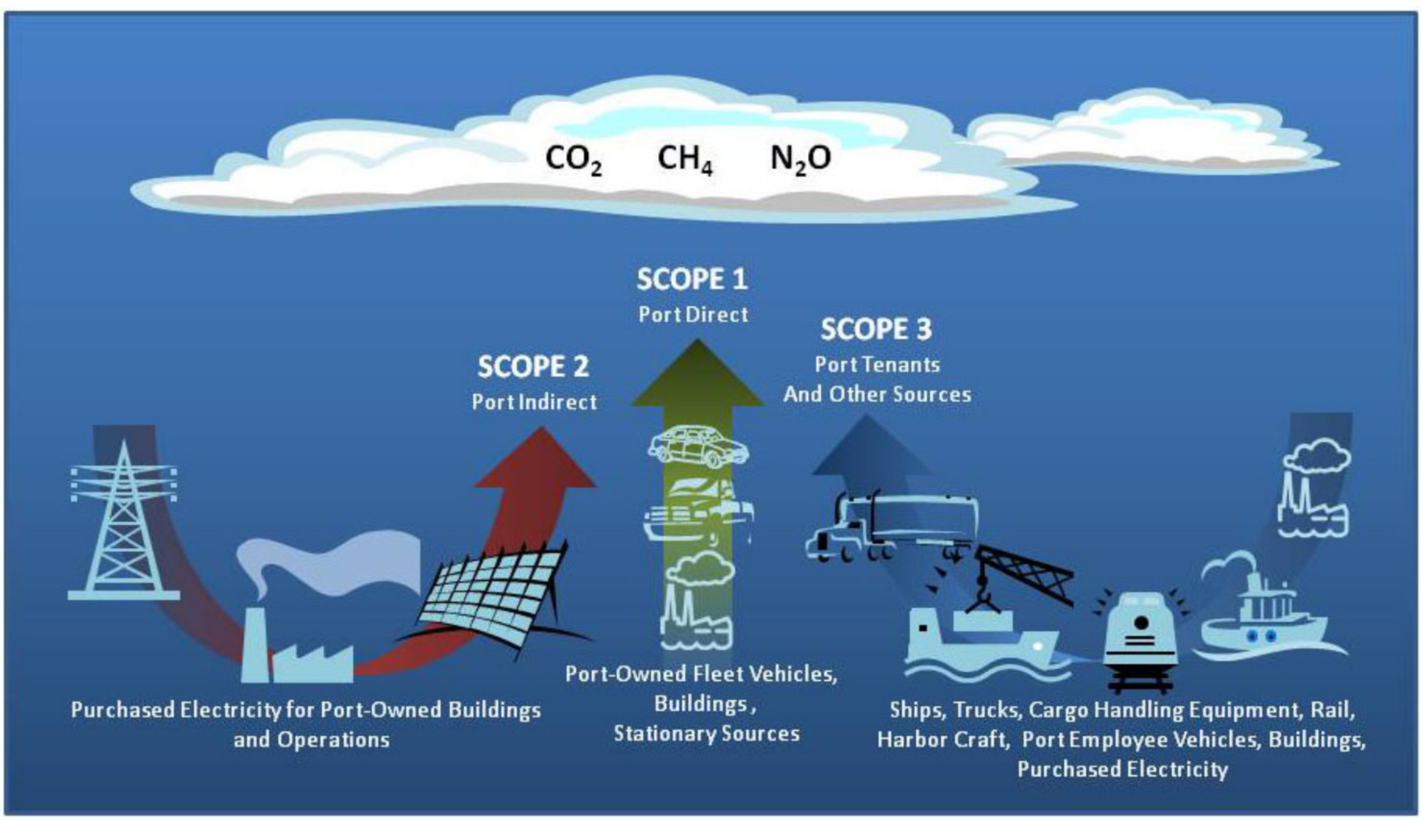
- **Scope 1 - Port Direct Sources**. These sources are directly under the control and operation of the port administration entity and include port-owned fleet vehicles, port administration owned or leased vehicles, buildings (e.g., boilers, furnaces, etc.), port-owned and operated cargo handling equipment (to the extent the port is an operating port as described above), and any other emissions sources that are owned and operated by the port administrative authority.

- **Scope 2 - Port Indirect Sources**. These sources include port purchased electricity for port administration owned buildings and operations. Tenant power and energy purchases are not included in this Scope.

- **Scope 3 - Other Indirect Sources**. These sources are typically associated with tenant operations and include ships, trucks, cargo handling equipment, rail locomotives, harbor craft, tenant buildings, tenant purchased electricity, and port and tenant employee commuting (train, personal car, public transportation, etc.).

The scopes are illustrated graphically in Figure 2.1. Scope 1 sources can include some of the sources shown under Scope 3 in the figure - operating ports, as noted above, may own some or all of these types of sources. Emissions from the generation of purchased electricity will be Scope 2 or Scope 3 emissions, depending on the ownership status of the electricity consuming operation; an operating port will have relatively more Scope 2 purchased electricity emissions than a landlord port.

Figure 2.1: Port-Related Emission Sources



2.2 Three Common Approaches to Developing an Emissions Inventory

One of the policy decisions to be made early in the process of planning a carbon footprint inventory is the approach to the level of detail that the inventory will be based. Three such approaches are commonly used in developing carbon footprint inventories:

- **Activity-Based** - Uses source specific data
- **Surrogate-Based** - Uses surrogates to estimate activity and/or emissions
- **Hybrid** - Uses varying combinations of activity and surrogate approaches

These three approaches are discussed in more detail below in Section 3 - Technical Framework. Activity-based inventories make use of the greatest levels of detail and provide the highest levels of accuracy. The surrogate approach has lower detail requirements and can be accomplished in less time and/or at lower cost, but is based on assumptions that can limit accuracy. The accuracy of hybrid approaches, which combine elements of the activity-based and surrogate approaches, is enhanced by higher levels of specific activity data versus the use of surrogate information.

The choice of an approach will determine a number of the steps that will need to be taken in developing the inventory. Figure 2.2 illustrates the pathways that can be taken in each of the three approaches. Once the decision is made to develop a carbon footprint inventory, the first step is to evaluate the drivers or reasons for developing the inventory and the resources available for the task. If the footprint is being developed for informational purposes and resources are extremely limited a surrogate approach may be chosen. If there is the desire or need to more finely determine the port's footprint knowing that further action will be needed and the resources are available, then a hybrid approach can be used to focus attention on the most significant source categories (typically ocean-going vessels, inland waterway vessels, and heavy-duty on-road transport but unique to each port). Finally, a detailed approach may be taken if it is known that emission reduction measures will be planned and implemented (either by regulation or voluntarily).

As illustrated in Figure 2.2, once the choice of an approach has been made, a series of steps are called for including identification of the emission source categories to be included, definition of geographical boundaries, review of estimating methodologies, data collection, and the calculation of emission estimates. In all approaches there may be a need to establish surrogates for some aspects of the inventory. More details are provided in the following sections on the technical implementation of a carbon footprint inventory.

Figure 2.2: Inventory Approach Process Flow Diagram

The choice of inventory method can cause significant differences between inventories, so this is an area that must be evaluated before comparing inventories. For example, comparing a detailed inventory to a surrogate inventory would not be an "apples-to-apples" comparison. The differences between methods and approaches should be noted prior to comparing footprints.

The choice of method influences the level of detail and data resolution that will underlie an inventory. This can also cause a significant difference between inventories due to the level of detailed data and assumptions made within each inventory. The more detailed the inventory, the narrower the assumptions used, while the lower the data resolution, the broader the assumptions. The data resolution differences should be noted prior to comparing footprints.

2.3 Inventory Boundaries

An important consideration in developing any emissions inventory is the physical and operational area or domain that encompasses the activities included in the inventory. The boundary definition helps answer the questions of "exactly which activities am I going to include in my inventory and where am I going to start counting?" For the pollutants that have localized effects, such as NO_x, SO_x, and PM, location and proximity to populated areas play a role in determining boundaries for emission inventories and subsequent control strategy development. However, the geographical area covered by an emissions inventory is not necessarily the exclusive domain of that inventory. There may be emission sources in the area that are not included in the inventory. For example, a port emissions inventory may include locomotive activity related to port operations over a wide area; the area may go beyond port boundaries and include other locomotive activity that is not related to port operations and, therefore not included in the port inventory. In this case, the inventory domain is operational as well as geographical, and the geographical extent of the port rail inventory would not include all rail activity within that area. This is also the case with road-going trucks (lorries) and, to a lesser extent, with marine vessels.

Greenhouse gas inventories include emissions from sources not typically included in traditional pollutant emissions inventories, such as upstream emissions from power plants due to purchased electricity. These are not included in traditional emissions inventories, because the emissions from power plants are separately inventoried and regulated by the existing stationary source regulatory structure. Because electricity can be generated at great distances from the point of use, the concept of a physical boundary to a carbon footprint inventory is less clear than for a more traditional emissions inventory, especially for Scope 2 and 3 emissions. Boundary considerations for the three scopes are discussed below.

- Scope 1 emission sources - The boundary typically encompasses a local or regional area where these sources are located and operate. As noted above, the inventory domain is not necessarily exclusive to the port, as in the case of port-owned motor vehicles that travel on public roads outside the port itself.

- Scope 2 emission sources - They may be local or relatively close by, but they can also be remote from the port since electrical power can be transmitted over great distances. A physical boundary is not appropriate for scope 2 emissions for this reason.

- Scope 3 emission sources - The domain may be global (for example, to include entire ocean voyages), national, regional, or more local, such as a political border or the port's own administrative boundary. Life cycle analysis (emissions associated with every aspect of sources [forging steel to build a ship, mining cooper, transporting to be made into wire, etc.]) is typically not included in Scope 3 source emissions analysis.

Boundaries are often based on the management or financial responsibility level of either the port or the tenants, shipping lines, etc. They may also be established by political entities (such as governing boards, city mayors, etc.) and/or regulatory agencies or by international agreements. If the port has leeway to establish its own boundaries or domain, the question of management responsibility is an important consideration because, once a port has "claimed" emissions as part of an inventory, the logical next expectation is that the port will work toward reducing those emissions. If the inventory is limited to activities or sources in locations the port has some measure of control over, then any emission reduction measures will affect all of the emissions in the inventory. If the inventory includes emissions from sources areas or from activities over which the port has no control (i.e., military activities, non-port related ship transits, etc.), then those emissions will not likely be affected by a port's emissions control measures and could dilute the perceived effectiveness of the measures.

2.3.1 Double Counting

Double counting is an important consideration in developing the boundaries of an emissions inventory, in comparing emissions inventories between ports or among different activities or economic sectors, and in compiling emissions information from diverse sources. Double counting occurs when greenhouse gas emitting activities are included in more than one emissions inventory. This can occur, for example, when a port includes the emissions from a tenant's activities in the port's inventory as Scope 3 emissions while the tenant includes the emissions in their inventory as Scope 1 emissions. Another example is the inclusion of emissions from the generation of electricity as Scope 2 emissions when the power plant's emissions are documented by the utility company as their Scope 1 emissions.

The concepts of Scope 1, 2, and 3 emissions guarantee the potential for double counting. One entity's Scope 3 emissions are necessarily the Scope 1 emissions of another entity. It is important, therefore, to clearly understand what is being included when emissions are being compiled and when comparisons are made across commercial or industrial boundaries. For example, if an international supply chain were being evaluated, the combined carbon footprints of a manufacturer, two inland transportation networks (one at each end of the chain), two seaports, two marine terminals, and a vessel operating company would make up the components of the chain. The carbon inventories of all of these components, if all are available, would need to be evaluated closely to remove common activities - for example, the seaports' inventories may include some, but not all, of the emissions from the respective marine terminals.

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:

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

Table 3.1: Global Warming Potentials

Gas	Global Warming Potential	Gas	Global Warming Potential
CO_2	1	HFC-227ea	2,900
CH_4	21	HFC-236fa	6,300
N_2O	310	HFC-4310mee	1,300
HFC-23	11,700	CF_4	6,500
HFC-32	650	C_2F_6	9,200
HFC-125	2,800	C_4F_{10}	7,000
HFC-134a	1,300	C_6F_{14}	7,400
HFC-143a	3,800	SF_6	23,900
HFC-152a	140		

3.4 Units

Greenhouse gas quantities are usually documented in units of tonnes, which are also known as metric tons and are equivalent to megagrams (Mg). There are 1,000 kilograms (kg) in one Mg.

Units used in the development of emission estimates can be metric or English, depending on the source of the reference. In some cases the units can be mixed metric/English, so care must be taken to understand the units and correctly make conversions. Tables 3.2 and 3.3 list the units most often used in developing emission estimates and present conversions between the two systems of units.

Table 3.2: Units, Metric to English Conversion

Parameter	Metric Units	English Units
Power	1 kilowatt (kW)	1.341 horsepower (hp)
Mass/weight	1 gram (g)	0.0022 pound (lb)
	1 kilogram (kg)	0.001 tonne
	1 megagram (Mg)	1.1023 ton
Volume	1 liter (l)	0.2642 U.S. gallon (gal)
Distance, lengt	1 meter (m)	3.2808 foot (ft)
	1 kilometer (km)	0.6214 mile (mi)
Emissions	1 gram per kilowatt hour (g/kW-hr)	0.7457 gram per horsepower-hour (g/hp-hr) (mixed)
	1 gram per kilometer (g/km)	1.6093 gram per mile (g/mi) (mixed)
	1 gram per liter (g/l)	3.7854 pound per gallon (lb/gal)

Table 3.3: Units, English to Metric Conversion

Parameter	English Units	Metric Units
Power	1 horsepower (hp)	0.7457 kilowatt (kW)
Mass/weight	1 pound (lb)	453.59 gram (g)
	1 tonne	1,000 kilogram (kg)
	1 ton	0.907 megagram (Mg)
Volume	1 U.S. gallon (gal)	3.7854 liter (l)
Distance, lengt	1 foot (ft)	0.3048 meter (m)
	1 mile (mi)	1.6093 kilometer (km)
Emissions	1 gram per horsepower-hour (g/hp-hr) (mixed)	1.341 gram per kilowatt hour (g/kW-hr)
	1 gram per mile (g/mi) (mixed)	0.6214 gram per kilometer (g/km)
	1 pound per gallon (lb/gal)	0.2642 gram per liter (g/l)

4.0 EXISTING REPORTING FRAMEWORKS

This section outlines and describes existing organizations and agencies that are involved with one or more aspects of the climate change arena. The first subsection lists and provides a brief overview of these groups, and more complete descriptions are provided in the following subsection.

4.1 Summary of Established Registries and Other Organizations & Information Sources

Table 4.1 summarizes the existing frameworks for documenting greenhouse gas emissions and emission reductions, both regulatory and voluntary, as well as sources of protocols, technical information, and policy aspects of greenhouse gases and climate change issues. The table is organized into categories that describe the primary focus of each organization. To avoid duplicate listings, each organization is listed only once, although some carry out functions of subsequent categories. For example, The Climate Registry has published documenting and verification protocols in addition to providing their registry service. The services and functions of each organization are more completely described in subsection 4.2.

Table 4.1: Existing Frameworks and Information Sources

Organization	Regional Focus	Function(s)
A - Greenhouse Gas Registries		
The Climate Registry	North America	Tracking and registration of GHG emissions and emission reductions. Participation is voluntary. Has issued reporting and verification protocols.
EU Emissions Trading Scheme (EU ETS)	European Union	Tracking and registration of GHG emissions and emission reductions as an aid to meeting Kyoto Protocol commitments.
Carbon Disclosure Project (CDP)	Worldwide	Collection and dissemination of GHG emissions information through voluntary annual surveys.
B - GHG Emission Estimating and/or Reporting Protocols		
Finnish Port Association (Portensys)	Finland	Web-based tool for estimating emissions (GHGs and other pollutants) from port activities. Designed for voluntary use by Finnish ports to meet reporting requirements.
Greenhouse Gas Protocol	Worldwide	Widely used protocol for estimating and reporting GHG emissions and emission reductions. Developed by WBCSD and WRI, adopted by ISO for ISO 14046.
ISO protocol 14046-1	Worldwide	Emission estimating and reporting protocol based on the Greenhouse Gas Protocol developed by WBCSD and WRI
C - Verification and/or Assistance in Developing GHG Estimates and Reports		
British Standards Institute (BSI)	Worldwide	Verifies and/or certifies organizations' compliance with ISO and other GHG estimating and reporting standards.
Global Reporting Initiative (GRI)	Worldwide	Reporting standards organization focused on consistency in organizational documents dealing with sustainability issues.
The Carbon Trust	Worldwide	Advocacy and support of GHG emission reductions – financial and technical support of low carbon practices and innovations. GHG emission calculation tools.

Table 4.1: Existing Frameworks and Information Sources (cont'd)

Organization	Regional Focus	Function(s)
D - Research, Development, Advocacy, and/or Funding Organizations		
Intergovernmental Panel on Climate Change (IPCC) – National GHG Inventories Programme	Worldwide	Development and dissemination of information related to climate change issues.
World Business Council for Sustainable Development (WBCSD)	Worldwide	Advocacy and support of GHG emission reductions from an energy and business perspective.
World Resources Institute (WRI)	Worldwide	"Think tank" focused on finding practical solutions to environmental issues, including climate change.
United Nations Framework Conventions on Climate Change (UNFCCC)	Worldwide	Intergovernmental coordination group focused on national strategic and policy issues related to GHG emissions and climate change.
International Carbon Action Partnership (ICAP)	Worldwide	Advocacy for development of effective global cap-and-trade system through information exchange among interested member parties (nations, state and local governments).
UK Department for Environment, Food and Rural Affairs (DEFRA)	Primarily United Kingdom (UK)	Sponsors research into climate change issues.
UK Department of Energy and Climate Change (DECC)	Primarily UK	Responsible for all aspects of UK energy policy, and for tackling global climate change on behalf of the UK.

4.2 Description of Established Registries and Other Organizations & Information Sources

4.2.1 - Greenhouse Gas Registries

The Climate Registry (North America)

- Website: *http://www.theclimateregistry.org/*
- The Climate Registry bills itself as "a nonprofit collaboration among North American states, provinces, territories and Native Sovereign Nations that sets consistent and transparent standards to calculate, verify and publicly document greenhouse gas emissions into a single registry." Founded in 2007.
- Currently there are over 330 members: corporations, universities, cities & counties, government agencies and environment organizations.

- They have issued general documentation and verification protocols, plus specific protocols for power/utility, local government, and oil & gas exploration & production.

- According to the Climate Registry's website, the organization is committed to the following actions:

  - Utilizing best practices in greenhouse gas emissions documentation.
  - Establishing a common data infrastructure for voluntary and mandatory reporting and emissions reduction programs.
  - Minimizing the burden on Members, Directors and Native Sovereign Nations.
  - Providing an opportunity for Members to establish an emissions baseline and document early action.
  - Developing a recognized platform for credible and consistent greenhouse gas emissions documentation.
  - Promoting full and public disclosure of greenhouse gas emissions while respecting business confidentiality.

European Union Emissions Trading Scheme (EU ETS)

- Website: *http://ec.europa.eu/environment/climat/emission/index_en.htm*

- First international trading scheme for CO_2 emissions, designed to aid in meeting the commitments of the Kyoto Protocol. Initiated in 2005.

- Covers "over 11,500 energy-intensive installations across the EU, which represent close to half of Europe's emissions of CO_2. These installations include combustion plants, oil refineries, coke ovens, iron and steel plants, and factories making cement, glass, lime, brick, ceramics, pulp and paper."

- Specific allocations designated by member states.

- The program has issued several publications related to its operations and to taking steps to address climate change issues.

Carbon Disclosure Project (CDP)

- Website: *http://www.cdproject.net/*

- The Carbon Disclosure Project (CDP) is an independent not-for-profit organization claiming to hold the largest database of corporate climate change information in the world. Founded in 2000.

- Requests information annually from more than 3,700 corporations worldwide – they received more than 1,550 responses in 2008.

- Mission statement: To collect and distribute high quality information that motivates investors, corporations and governments to take action to prevent dangerous climate change.
- They have issued numerous documents on the results of their surveys, covering regions, countries, industries, trends, etc.: *http://www.cdproject.net/reports.asp*

4.2.2 - GHG Emission Estimating and/or Reporting Protocols

Portensys: Finnish Port Association and Finnish Port Operators Association

- Website: *http://www.satamatieto.fi/portensys.html*

- Portensys is a Finnish Web-based inventory tool for Finnish ports to calculate their operational emissions.

- Contains two modules, one for marine vessels and one for landside sources such as cargo handling equipment, trucks, cars, and trains. Does not include electrically powered equipment.

- CO_2, N_2O, and CH_4 included among the pollutants that are estimated. Also includes fuel consumption estimates.

- Many Finnish port authorities are required by their environmental permit to document emissions on an annual basis. As of April 2009, 12 Finnish ports are using the system to develop their emission estimates. The GHG estimates will be a good start toward developing a carbon footprint baseline.

Greenhouse Gas Protocol

- Website: *http://www.ghgprotocol.org/*

- Partnership between the WBCSD and the WRI. Founded in 1997, first protocol published in 2001 (The Greenhouse Gas Protocol: A Corporate Accounting and Reporting Standard).

- The protocol is used by a large number of corporations worldwide as well as organizations such as the California Climate Action Registry, the Climate Registry (North America), and the EU Emissions Trading Scheme.

- The protocol has been adopted by the International Organization for Standardization (ISO) as the basis for their ISO 14064-1 standard.

International Organization for Standardization (ISO)

- Website: *http://www.iso.org/iso/home.htm*

- The International Organization for Standardization (ISO) is a major developer and publisher of standards for business, composed of a network of the national standards bodies of over 160 countries. Founded in 1946.

- Their relevant GHG standard is ISO 14046-1, covering the estimation and documenting of GHG emissions. It has been based on the Greenhouse Gas Protocol discussed above.

4.2.3 - Verification and/or Assistance in Developing GHG Estimates and Reports

British Standards Institute (BSI)

- Website: *http://www.bsi-global.com/*

- Standards and certification organization that issues ISO 14001 certifications, and the related ISO 14064-1 certifications for measuring, reporting, and verifying organizational and project level GHG emissions. Founded in 1901.

- Under "emission verification" they offer the following services:
  - Carbon footprint verification – review and verification of the methods used in establishing an organization's carbon footprint in accordance with ISO 14065, relative to the requirements of ISO 14064-1 and/or the requirements of the Greenhouse Gas Protocol (see below)
  - Greenhouse gas emission verification – review and verification of the methods used to estimate GHG emissions – baseline, annual, project-specific

- GHG management services details: http://www.bsi-global.com/en/Assessment-and-certification-services/management-systems/Business-areas/greenhouse-gas-management/

Global Reporting Initiative (GRI)

- Website: *http://www.globalreporting.org/Home*

- The Global Reporting Initiative (GRI) works to standardize reporting by organizations on their on economic, environmental, and social performance. Founded in 1997.

- As a general standardization organization, GRI is not related directly to GHG reporting but their reporting protocols could be used as a guide to developing a port GHG reporting framework.

The Carbon Trust

- Website: *http://www.carbontrust.co.uk*

- Private company formed by the UK government to "accelerate the move to a low carbon economy by working with organizations to reduce carbon emissions and develop commercial low carbon technologies." Founded in 2001.

- They have issued numerous documents related to carbon footprinting and low carbon technologies and business opportunities.

  See *http://www.carbontrust.co.uk/about/reports/*

- Their website includes carbon footprint calculator tools.

  See *http://www.carbontrust.co.uk/solutions/CarbonFootprinting/FootprintCalculators.htm*

- The Carbon Trust consists of five business areas:

  - Insights: Explanation of risks and opportunities
  - Solutions: Practical solutions for carbon emission reductions
  - Innovations: Low carbon technology development
  - Enterprises: Low carbon business creation
  - Investments: Financing of clean energy businesses

4.2.4 - Research, Development, Advocacy, and/or Funding Organizations

Intergovernmental Panel on Climate Change (IPCC) – National Greenhouse Gas Inventories Programme

- Website: *http://www.wri.org/*

- Main objective is to "assess scientific, technical and socio-economic information relevant to the understanding of human induced climate change, potential impacts of climate change and options for mitigation and adaptation." Founded in 1988.

- Offshoot of World Meteorological Organization and United Nations Environment Programme

- They have issued numerous publications primarily related to developing national GHG emissions inventories and have made available on the web a searchable emission factor database (*http://www.ipcc-nggip.iges.or.jp/EFDB/main.php*). They are also developing an emissions inventory software tool (*http://www.ipcc-nggip.iges.or.jp/support/support.html*) - a demonstration version for the energy sector is available for review.

World Business Council for Sustainable Development (WBCSD)

- Website: *http://www.wbcsd.org/*

- The World Business Council for Sustainable Development (WBCSD) is a CEO-led, global association of some 200 companies dealing exclusively with business and sustainable development. Founded in 1992.

- Provides a platform for companies to explore sustainable development, share knowledge, experiences and best practices, and to advocate business positions on these issues in a variety of forums, working with governments, non-governmental and intergovernmental organizations.

- Members from 20 major industrial sectors and 35 countries.

- Mission statement: To provide business leadership as a catalyst for change toward sustainable development, and to support the business license to operate, innovate and grow in a world increasingly shaped by sustainable development issues.

- Their relationship to GHGs is primarily from an energy perspective, "devising practical mechanisms, measurement tools and market-based solutions" to help companies reduce the impact of their current operations and prepare for future needs.

- They have issued numerous publications related to low-carbon business practices, carbon markets, and other topics related to GHGs and GHG reductions.

- The WBCSD's stated objectives are to:

    - Be a leading business advocate on sustainable development.
    - Participate in policy development to create the right framework conditions for business to make an effective contribution to sustainable human progress.
    - Develop and promote the business case for sustainable development.
    - Demonstrate the business contribution to sustainable development solutions and share leading edge practices among members.
    - Contribute to a sustainable future for developing nations and nations in transition.

World Resources Institute (WRI)

- Website: *http://www.wri.org/*

- The World Resources Institute (WRI) is an environmental "think tank" that goes beyond research to find practical ways to protect the earth and improve people's lives. Founded in 1982.

- Mission statement: To move human society to live in ways that protect Earth's environment and its capacity to provide for the needs and aspirations of current and future generations.

- Their relationship to GHGs is through "Climate, Energy, and Transport," an area where their stated goal is "to protect the global climate system from further harm due to emissions of greenhouse gases and help humanity and the natural world adapt to unavoidable climate change" with a focus on:

    - International Action
    - U.S. Action
    - Sustainable Business and Markets
    - Technology Options
    - Green Power / Renewable Energy Use
    - Information and Analysis Tools

- They have issued numerous publications related to economic, technological, and energy aspects of the climate change issue.

United Nations Framework Convention on Climate Change (UNFCCC)

- Website: *http://unfccc.int/2860.php*

- The United Nations Framework Convention on Climate Change (UNFCCC) "sets an overall framework for intergovernmental efforts to tackle the challenge posed by climate change. It recognizes that the climate system is a shared resource whose stability can be affected by industrial and other emissions of carbon dioxide and other greenhouse gases. The Convention enjoys near universal membership, with 192 countries having ratified." Entered into force in 1994.

- Under the Convention, signatory governments agree to:

    - Gather and share information on greenhouse gas emissions, national policies and best practices.
    - Launch national strategies for addressing greenhouse gas emissions and adapting to expected impacts, including the provision of financial and technological support to developing countries.
    - Cooperate in preparing for adaptation to the impacts of climate change.

International Carbon Action Partnership (ICAP)

- Website: *http://www.icapcarbonaction.com/*

- Made up of countries and regions that have implemented or are actively pursuing the implementation of carbon markets through mandatory cap and trade systems. Founded in 2007.

- Their stated goal is to "contribute to the establishment of a well-functioning global cap and trade carbon market. ICAP provides the opportunity for members to share best practice and learn from each others' experiences. State and regional programs must be in close contact with and have a clear line of sight to international programs as they design and implement their respective programs. Through this sharing, ICAP will enhance the design of other schemes by ensuring that design compatibility issues are recognized at an early stage. As a result, ICAP will make possible future linking of trading programs."

- Membership includes several EU countries, several member states of two U.S.-based GHG compacts, the Regional Greenhouse Gas Initiative and the Western Climate Initiative, five non-EU nations (Norway, New Zealand, Australia, Japan, Ukraine) and the Tokyo Municipal Government (*http://www.icapcarbonaction.com/members.htm*).

UK Department for Environment, Food and Rural Affairs (DEFRA)

- Website: *http://www.defra.gov.uk/*

- UK government department responsible for many issues related to climate change and its effects.

- Provides funding for research studies related to climate change.

UK Department of Energy & Climate Change (DECC)

- Website: *http://www.decc.gov.uk/*

- The Department of Energy and Climate Change is responsible for all aspects of UK energy policy, and for tackling global climate change on behalf of the UK.

- DECC's three overall objectives are to: ensure our energy is secure, affordable and efficient; bring about the transition to a low-carbon Britain; and achieve an international agreement on climate change at Copenhagen in December 2009.

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.

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

5.1 Mobile Sources

The mobile sources referred to above are discussed in the following subsections. Most of these sources are powered by fuel-burning engines, although some may be electrically powered. The most common type of fuel for these sources is diesel fuel, with biofuels, gasoline, propane, and natural gas (methane) also being used occasionally for some types of vehicles or equipment. Electric equipment is most commonly battery powered, since the use of power cables would be somewhat limiting to mobility. An exception is shore-side powering of vessels at berth, in which a vessel's electrical power needs are met by a connection to a shore-side power supply to allow the vessel's diesel engines to be turned off while the vessel is at berth. Also, modern wharf cranes, rail-mounted gantry cranes (RMG's) and rubber-tired gantry cranes (RTG's) are increasingly being installed with all-electric drives that use cable or bus-supplied electricity.

Fuel-burning mobile sources. The predominant greenhouse gas from fuel burning mobile sources, CO_2, is directly related to the amount of fuel burned, so fuel consumption is the key information needed to estimate emissions from these sources. As an alternative that may be more consistent with existing emissions inventories, energy output (in terms of kilowatt-hours, or kW-hrs) can also be used. Fuel consumption and energy output are linked by a value known as brake specific fuel consumption (BSFC), which is a measure of fuel consumption per unit of energy output, in units such as grams of fuel per kW-hr (g/kW-hr). The average value of BSFC varies for different types of engine, and even at different operating speeds for a given engine. In practice, an average value is assigned to different types of engine. Fuel consumption can be estimated from energy output by multiplying, taking care to use appropriate units, the energy output by the relevant value for BSFC. Conversely, the energy output can be estimated from fuel consumption by dividing the fuel consumption estimate by the BSFC value. The value of these conversions is that it allows the standardization of units in cases where data is collected in terms of energy and fuel consumption.

Electric mobile sources. Electric mobile sources produce secondary, or indirect, greenhouse gas emissions, when the source of electrical power generation is fossil fuel powered. Therefore, it must be remembered that electrification of equipment or activities is not necessarily a zero carbon solution. Estimates are made using the amount of electrical energy used by the equipment during its operation or input into the batteries during recharging. Because there is power lost in the charging process, estimates based on the energy used by the vehicle must be adjusted by the charging efficiency factor to calculate the amount of electricity used by the charger. Likewise, efficiency factors for transmission and conversion must be considered in comparing the amount of electricity consumed from the generation source with the amount of electricity used by the charger. While the electrical energy is measured as kW-hrs as for the fuel-burning sources, an important distinction is that the electrical energy is the energy **input to** the equipment, while the fuel-burning energy values relate to the energy **output from** the engine. These values are not the same because of the efficiency of mechanical systems - more energy is input into the system than is provided by the engine or motor, with the difference being lost through heat dissipation or other losses.

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

$$Total\ Emissions = Total\ Gallons\ \ x\ \ Grams\ per\ Gallon$$

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

$$Total\ Emissions\ =\ Pop\ \ x\ \ EF\ \ x\ \ ACT\ \ x\ \ FCF\ \ x\ \ CF$$

[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.axpx?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

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

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.

Figure 5.5: Electric Freight Train

The most simplistic form of assessment (Equation 5.10) requires the estimator only to have access to the amount of fuel consumed by locomotives within the region of interest over a given period of time. Greenhouse gas emission factors expressed in terms of grams of pollutant per kilogram of fuel consumed are readily available from both the CARB and the U.S. EPA, an example of which are listed in the table below.[12] However, this simplistic approach yields little detail regarding which particular modes of locomotive operation may contribute inordinately to overall emissions or where these emissions might occur. The acquisition of additional information regarding the specific operating characteristics of the locomotives in use tends to produce more accurate and informative estimates.

Table 5.5: Emission Factors for Diesel Locomotives, g/gal fuel

	CO_2	CH_4	N_2O	CO_2E
Locomotives	10,138	0.416	0.0832	10,172.5

12 *http://www.arb.ca.gov/cc/inventory/doc/doc_index.php*

In the table above, CO_2E is an expression of the carbon dioxide equivalent of the pollutants in terms of their combined global warming potential. Although total emissions are small in comparison to CO_2, each gram of CH_4 and N_2O has a relatively high global warming potential that is equivalent to 21 grams and 310 grams of CO_2, respectively.

Fuel consumption data can be obtained from fuel receipts or can be otherwise derived through the use of an estimate of BSFC. Commonly, BSFC is expressed in units of grams of fuel consumed per kilowatt-hour (g/kWh). This expression can also be converted to pounds of fuel consumed per horsepower-hour ([BSFC METRIC (g/kWh) x 0.001644= BSFC US(lbs/(hp-hr)]). That is, if the estimator knows the amount of work performed by the locomotives in terms of kilowatt-hours, the BSFC can be used to derive fuel consumption to estimate the total greenhouse gas emissions (Equation 5.11 below). BSFC estimates for line haul and switcher locomotives have been estimated at 0.355 lbs/hp-hr assuming a fuel density for distillate fuel oil (#1,2,4 Diesel) of 7.45 bbl/metric ton.[13]

Equation 5.11

Total Emissions = Pop x EF (g/kg fuel) x ACT (kW-hrs) x BSFC (g fuel/kW-hr)

Likewise, if the estimator is aware of the total ton miles of goods moved by rail, an estimate of total fuel consumption can be obtained by applying a locomotive fuel consumption factor expressed in terms of ton-miles per gallon. The American Railroad Association has estimated a U.S. average fuel consumption for locomotives of 392.4 ton-miles per gallon of fuel based on an industry average of 436 miles per gallon adjusted downward by 10 percent to account for geographic factors.[14] It is important to differentiate between the figures noted above, which apply to the weight of the cargo alone, and other fuel consumption figures that are expressed in terms of gross weight, which includes the weight of the locomotives and railcars as well as the cargo.

However, if the estimator has access to reliable information regarding the work performed by the locomotives being studied, emission factors expressed in terms of grams of pollutant per unit work can be used (Equation 5.12). The gram per horsepower-hour greenhouse gas emission rates for line haul and switcher locomotives are included in Table 5.6 below.

Equation 5.12

Total Emissions = Pop x EF (g/hp-hr) x ACT (hp-hrs)

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

[14] *http://www.aar.org/Environment/EconomicCalculator.aspx*

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

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

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_2 E/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

5.1.4 Harbor Craft and Inland Waterway Vessels

This section discusses methods that can be used to develop estimates of greenhouse gas emissions from harbor craft and vessels used in goods movement via inland waterways. Harbor craft are characterized by vessels that spend most of their time within or near a harbor and typically are in harbor transit, maneuvering, and idling modes. Vessels falling under the harbor craft source category include a wide variety of vessel types and applications that tend to operate in and around a harbor or port, relatively close to shore or that are used specifically for assisting with port operations or local public transportation. Harbor craft differ from ocean going vessels in that they do not traverse oceans or seas in typical operation. The harbor craft source category of vessels includes:

- Assist Tugboats – assist OVGs during maneuvering and docking
- Towboats and Push boats –move barges and other floating objects
- Local ferries –carry passengers to specified locations near ports, harbors, and cities
- Excursion vessels – used in commercial sightseeing
- Crew boats –ferry crew members between ships and shore
- Work boats –carry workers to offshore locations
- Government vessels – including police, fire, and coast guard vessels
- Commercial fishing vessels – used in the commercial fishing industry
- Pleasure craft – usually privately owned small boats and yachts

Harbor craft are routinely equipped with one or two propulsion engines and one or more auxiliary engines and typically utilize distillate fuels.

Figure 5.6: Harbor Craft

On several continents, including North and South America, China and Europe, a significant amount of the movement of tourists and commercial goods is through thousands of miles of inland waterways. Unlike harbor craft, these vessels spend most of their time transporting cargo or passengers from one destination to another (beyond the harbor area) using rivers, canals, tributaries, and inland seas. The vessels used in these trades tend to be smaller and narrower than either ocean going vessels or harbor craft in order to efficiently navigate the rivers and canals of the inland waterway networks. A variety of methods exist to classify vessels used in inland waterway navigation including the following:

- According to the area of navigation
    - River (canal) boats
    - River-sea vessels
    - Lakes
- According to dedicated purpose
    - Commercial vessels including
        - Cargo ships
        - Passenger ships
        - Tugboats and Push boats
        - Pleasure Craft
    - Government (police, customs, fire fighting, icebreakers, military, etc.)
- According to installed machinery
    - Self-propelled
    - Non-self propelled vessels
- According to type of propulsion
- According to floating regime when running, and
- According to hull configuration
    - Mono hull
    - Twin hulls
    - Trimarans

Like harbor craft, vessels used in the inland waterways tend to have one or two propulsion engines and one or more auxiliary engines to generate power for on-board instrumentation and amenities. Dependent upon location, the movement of goods via inland waterway is a preferred alternative to overland transport. In terms of environmental impact, the energy consumption per ton mile for goods moved via inland waterways can be up to 83% less compared to goods moved by truck and 50% less compared to rail transport.[16]

Figure 5.7 provides an illustration of an inland waterway network, that of the European continent. Typical inland waterway vessels are shown in Figure 5.8.

[16] European Commission "Inland waterway transport" *http://ec.europa.eu/transport/inland/*

Figure 5.7: European Inland Waterways

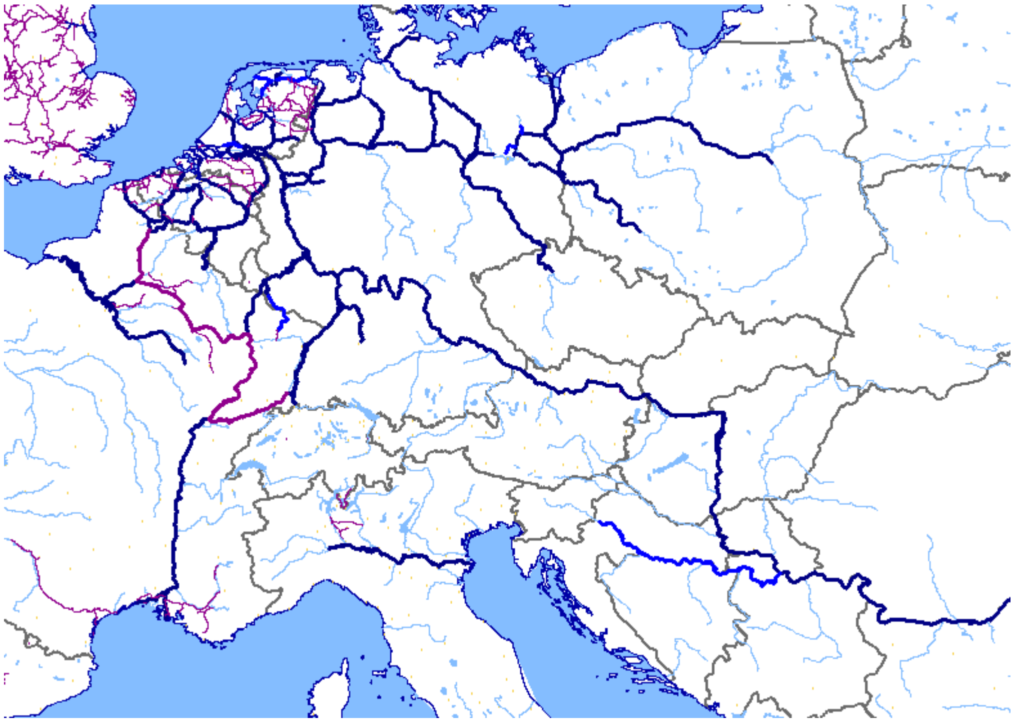


Figure 5.8: Typical Inland Waterway Vessels

Finally, there are cargo operations that are performed by larger ocean tugs that transit in coastal waters between ports. The routes can range from local to long distances. Ocean going tugs include large tug-tow barges, integrated tug-barges (ITB), and articulated tug-barges (ATB).

As with all mobile sources, estimating emissions from harbor craft and those vessels used on inland waterways requires gathering as much information as possible on the vessels and engines being modeled. Ideally, information would be collected on the population of the vessel fleet, the types and sizes of the vessels in use, the number and power rating of the engines in each vessel, the amount and types of fuel consumed, and the types of activities as in modes of operation that the vessels encounter in daily operation.

Once the characteristics of the fleet are known, greenhouse gas emissions from inland vessels can be estimated using the following general equation:

Equation 5.15

$$E = EF \times ACT$$

This is the simplest form of the estimation equation where ***E*** is the emissions of a particular greenhouse gas in grams, ***EF*** is the emission factor expressed as grams of pollutant per unit of work or time, and ***ACT*** is the measure of activity expressed in units that correspond to the emission factor. For example, the CARB provides greenhouse gas emission factors[17] on their website that are expressed as grams of pollutant per gallon of distillate fuel consumed by engines used in the transportation sector.

- 10,138 g (i.e. 10.14 kg) of CO_2 per gal of distillate consumed
- 0.0832 g of N_2O per gal of distillate consumed
- 0.416 g of CH_4 per gal of distillate consumed

In this case, the corresponding activity would be gallons of fuel consumed over a specified period. Although straightforward in its derivation, this simplified approach does not allow for the precise determination of what modes of operation may contribute disproportionately to the total greenhouse gas inventory.

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

The more precise the desired estimate, the more information that must be gathered with respect to the vessel fleet and its operation. This more precise method gives a better understanding and can provide more cost effective implementation of emissions control strategies. For example, if the emission factor is expressed in terms of grams of pollutant per kilowatt-hour rather than grams per gallon, the corresponding activity would be kilowatt-hours. In this example, additional information must be known about characteristics and operating parameters of each vessel engine. In the expanded equation below, these factors are taken into account.

Equation 5.16

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

In the equation above, two additional factors have been added to the basic equation. Where HP is the maximum rated horsepower (or kW) of the engine and LF is the Load Factor, a dimensionless multiplier that corrects for the fact that the engines are not constantly operated at their maximum power rating in use. That is, a LF of 0.5 for example, signifies that the engine experiences 50% of its maximum load typical operation. Stated another way, a LF of 0.5 suggests that the vessel typically utilizes half of its total installed power. Table 5.8 lists the default load factors by vessel type used by the state of California to estimate the emissions of various types of harbor craft.

Table 5.8: Vessel and Engine Specific Load Factors

	Engine Type	
Vessel Type	**Propulsion**	**Auxiliary**
Assist Tug	0.31	0.43
Commercial Fishing	0.27	0.43
Crew Boat	0.45	0.43
Excursion	0.42	0.43
Ferry	0.42	0.43
Government	0.51	0.43
Ocean Tug	0.68	0.43
Others	0.52	0.43
Tugboat	0.31	0.43
Workboat	0.45	0.43

Greenhouse gas emission factors for various sized engines expressed in terms of grams of pollutant per unit of work are typically available from state or national environmental protection or regulatory agencies. During the certification process, engines are tested under varying speed load combination to ensure that their emissions are below the allowable limits established through emission standards. Although CH_4 and CO_2 are routinely measured during certification, special testing is required to measure N_2O and this data may be harder to obtain.

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

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

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

5.1.5 Ocean-Going Vessels

This section discusses methods that can be used to develop estimates of greenhouse gas emissions from ocean-going vessels (OGVs or ships). OGVs represent the most efficient transportation mode compared with other mobile source categories. OGVs represent the most complex source category from an air quality modeling perspective as ships have several different sources, cargo types, power configurations, and operational modes. OGVs are typically one of the largest emissions source categories and therefore the quality of assumptions used in estimating their emissions are critical.

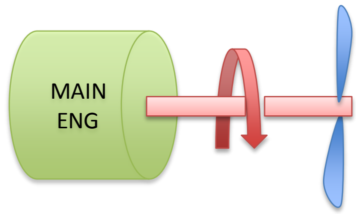
There is no universal rule for determining the geographical boundaries when planning an OGV inventory. Like all source categories, the geographical boundaries should be set at minimally to those areas in which the port is going to take responsibility for tracking and potentially reducing emissions. Ports in North America have taken several different approaches including: from the berth to the sea buoy(s) (designating open ocean), from berth to the edge of the regional/state over water boundaries, and from previous port to berth and from berth to the next port.

The emission sources for OGVs include propulsion systems that provide movement for the ship through water, auxiliary power systems that provide for the electrical demands during ship operations, and auxiliary boilers which produce hot water and steam for use in the engine room and for crew amenities. Within each of these activities there are various pieces of equipment that operate differently depending on the ship operating mode. It should be noted that incinerators are typically not included in the emissions estimates because incinerators are not used close to land and populated areas. Interviews with the vessel operators and marine industry personnel indicate that vessels do not use their incinerators while at berth or near coastal waters. However, if your boundaries are pan-oceanic then incinerators maybe included. They are typically run as batch processes and are not continuous. They are assumed to be significantly less than the three above mentioned emissions sources.

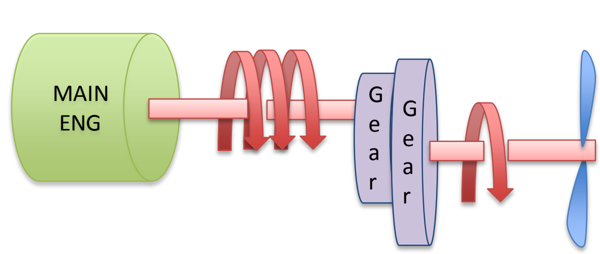
Propulsion systems produce power which is translated into OGV movement through the water. There are four typical propulsion system types found on OGVs: direct drive, geared drive, diesel/electric, and steam powered/gear-drive. There are various other types of propulsion systems such as gas turbine and steam/electric, however, these are relatively uncommon. The following figure illustrates the equipment associated with the four typical types of propulsion systems.

Figure 5.9: Propulsion Types

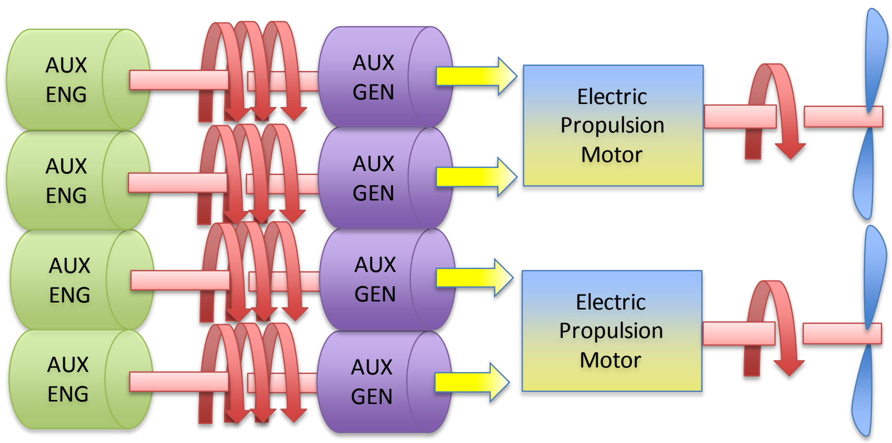
Direct-Drive



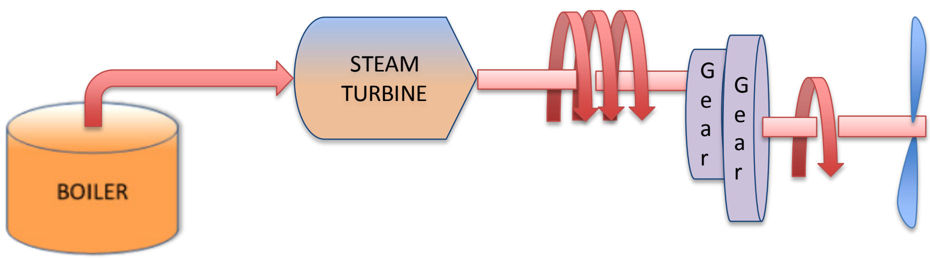
Gear-Drive



Diesel/Electric Drive



Steam Gear-Drive



Direct-Drive - Typically a large high-kW rated, slow speed engine that is directly connected to the propeller shaft (i.e., engine rpm = propeller rpm). This propulsion system is the most common propulsion type found in container ships, bulk carriers, reefers and RoRos.

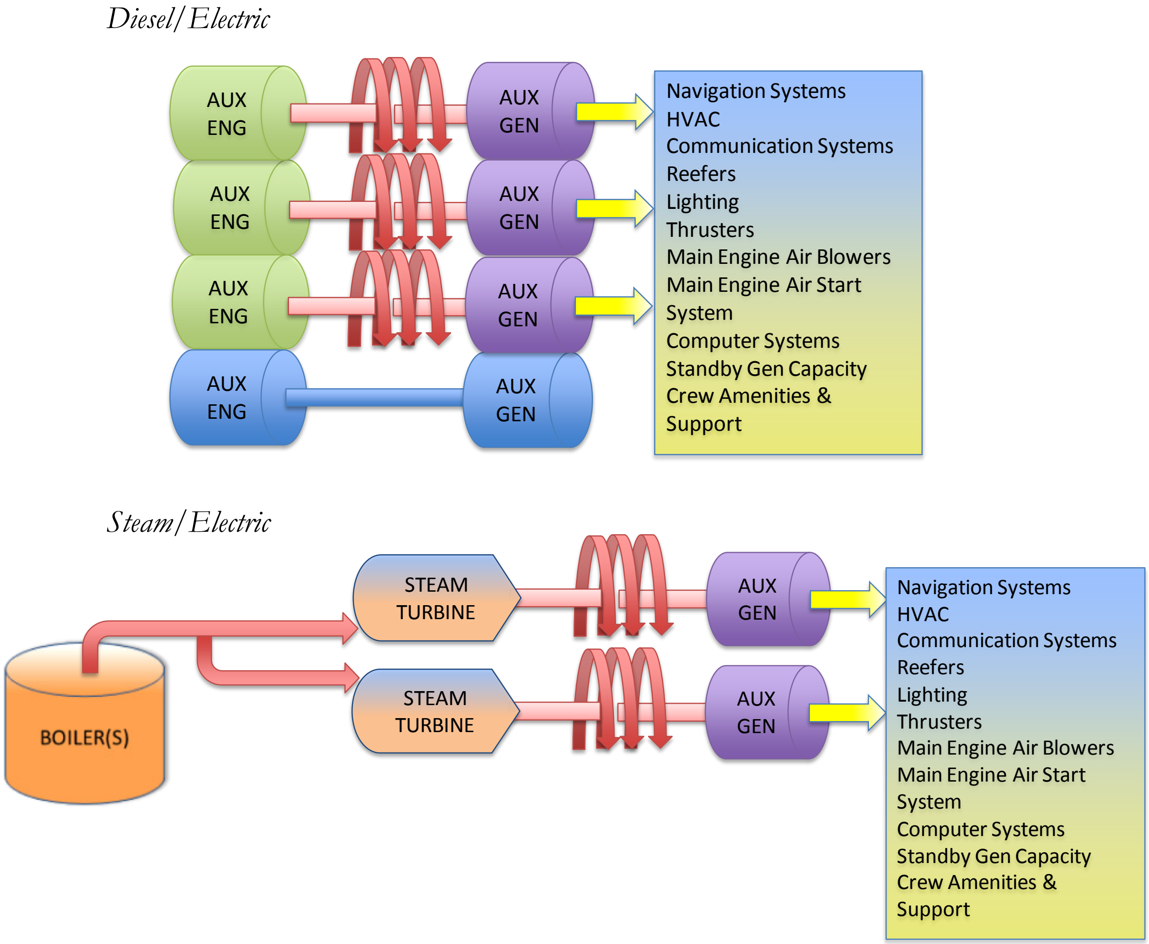
Gear-Drive - Typically a high- to medium-kW rated, medium speed engine that is connected to reduction gearing that reduces the engine rpm to an appropriate propeller rpm; i.e., the engine rpm is higher than the propeller rpm.

Diesel-Electric - Typically one or more high- to medium-kW rated, medium speed engines that are connected to an electrical generation system, which produces power for the electrical propulsion motor(s); i.e., the engine rpm is greater than the propeller rpm. This propulsion system is most commonly found in passenger cruise ships, passenger ferries, and some tankers, though its use is expanding into other vessel classes.

Steam Powered/Gear-Drive - Typically high- to medium-kW rated boilers that produce steam to turn a steam turbine, which is connected to reduction gearing that reduces the turbine rpm down to an appropriate propeller rpm, i.e., the turbine rpm is greater than the propeller rpm.

Auxiliary power systems supply the ship and crew with on-board generation capacity to meet the ship's power demand, (excluding propulsion) which varies depending on the ship's operational mode. In addition, auxiliary power systems are typically designed with additional capacity in the event that an engine shuts down due to a mechanical failure. Typically, direct-drive and gear-drive configured ships utilize auxiliary engines in a diesel/electric configuration to generate the various power demands of the ship, cargo, and crew during each of the operational modes. Some ships that have large steam plants may use a steam turbine to generate auxiliary power. Diesel/electric ships use the same system that produces the propulsion power.

Figure 5.10: Auxiliary Power Systems



Hot water and steam are generated on a vessel from either on-board boilers or heat exchangers, also known as economizers. Boilers use fuel oil for heating/boiling water, hot water and steam heating the fueling system, powering offloading pumps (tankers), engine heat jackets, and crew amenities. Economizers use waste heat from on-board engines (propulsion engines typically) for generating hot water and steam.

As mentioned previously, there are typically three modes of operations that are included in OGV GHG inventories: transit, maneuvering, and hotelling. Descriptions of these modes are provided below:

Transit - During this mode, a ship is sailing in the open ocean/unrestricted waters. Typically,

- ✓ Ship is traveling at its sea-speed or cruising speed;
- ✓ Propulsion engines are operating at their highest loads;
- ✓ Auxiliary engine loads required by the ship are at their lowest loads;
- ✓ Auxiliary boilers are off and economizers are on because of the high propulsion system loads;
- ✓ Fuel consumption is at its highest level due to the propulsion system's power requirements, and auxiliary fuel consumption is low.

Maneuvering - During this mode, a ship is typically operating within confined channels and within the harbor approaching or departing its assigned berth. The distance of this mode is unique for each port depending on geographical configuration of the port. Typically,

- ✓ Ship is transiting at its slowest speeds;
- ✓ Propulsion engines are operating at low loads;
- ✓ Auxiliary engine loads are at their highest load of any mode as additional on-board equipment such as thrusters, air scavengers/blowers, and additional generators are online in case an auxiliary engine/generator fails;
- ✓ Auxiliary boilers are on because the economizers are not functioning due to low propulsion engine loads; this generally does not apply to large diesel-electric vessels, which produce sufficient exhaust heat to power economizers at maneuvering speeds;
- ✓ Fuel consumption is very low for the propulsion system, is highest for the auxiliary engines, and low for the auxiliary boilers.

Hotelling - During this mode, a ship is either docked at a berth or anchored. Typically,

- ✓ Ship is not moving;
- ✓ Propulsion engines are off;
- ✓ Auxiliary engine loads can be high if the ship is self-discharging its cargo, as with general cargo vessels, auto carriers, and RoRos;
- ✓ Auxiliary boilers are operated typically to keep the propulsion engine and fuel systems warm in case the ship is ordered to leave port on short notice, for crew amenities, and, for certain types of tanker, for off-loading cargo through the use of steam-powered pumps;
- ✓ Fuel consumption can be medium to high for auxiliary engines and can be medium to very high for boilers.

Figures 5.11 through 5.13 provide a graphical representation of how the three power systems (propulsion system, auxiliary power system, and auxiliary boilers) change in activity by operating mode. Note that equipment in blue means that it is off.

Figure 5.11: Direct Drive/Gear Drive Operational Modes

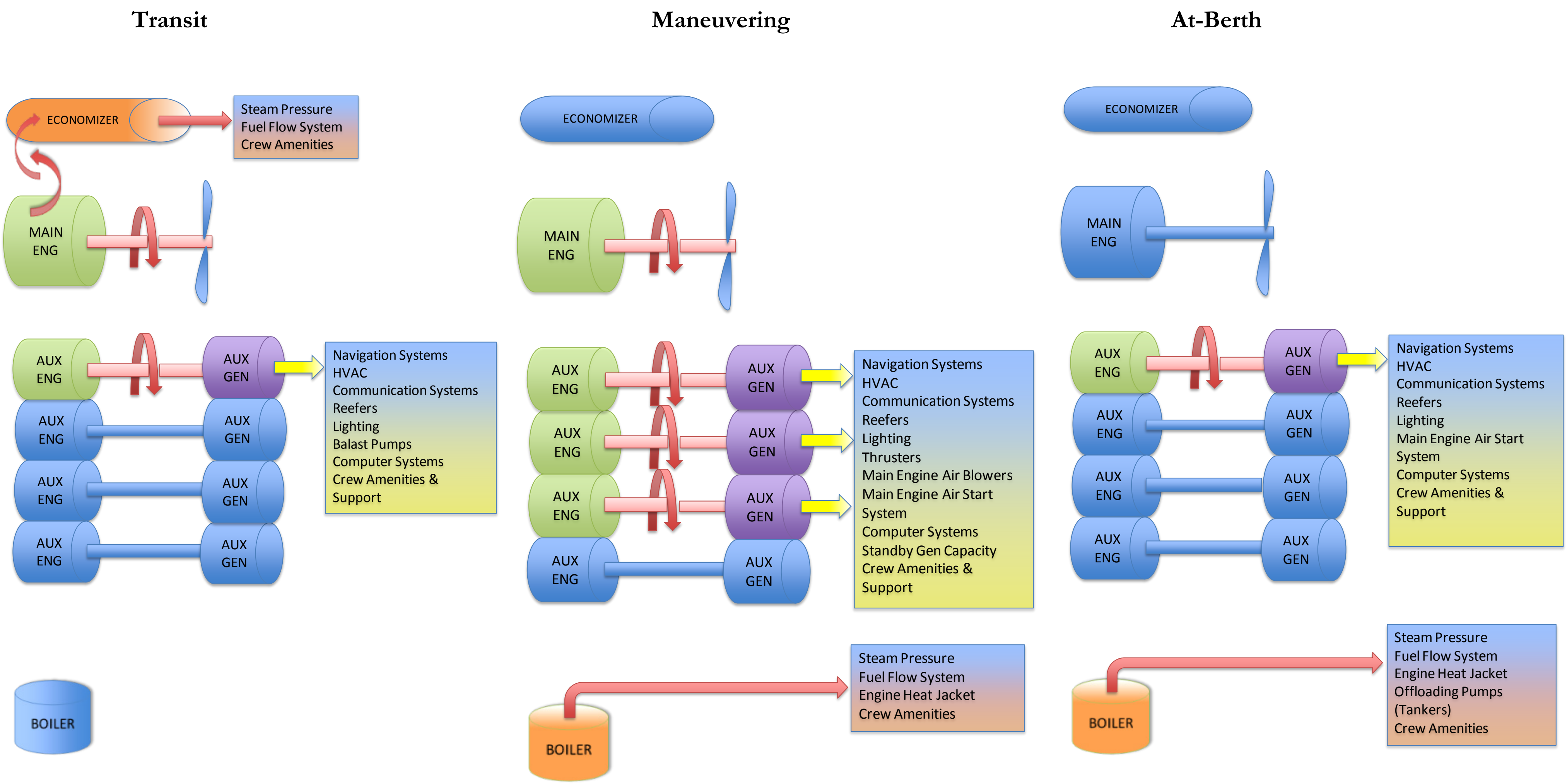


Figure 5.12: Diesel Electric- Operational Modes (Cruise/Ferry)

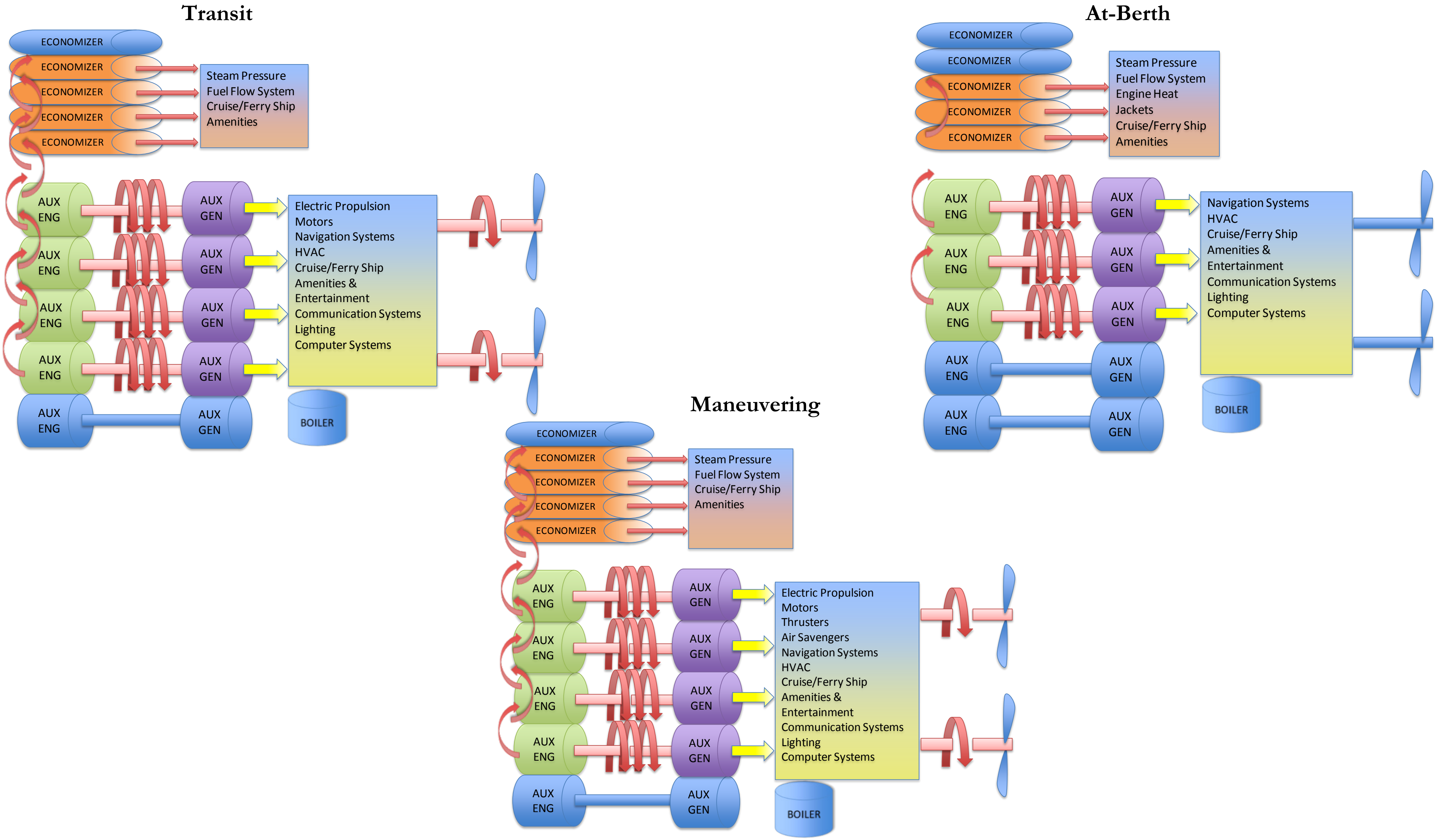
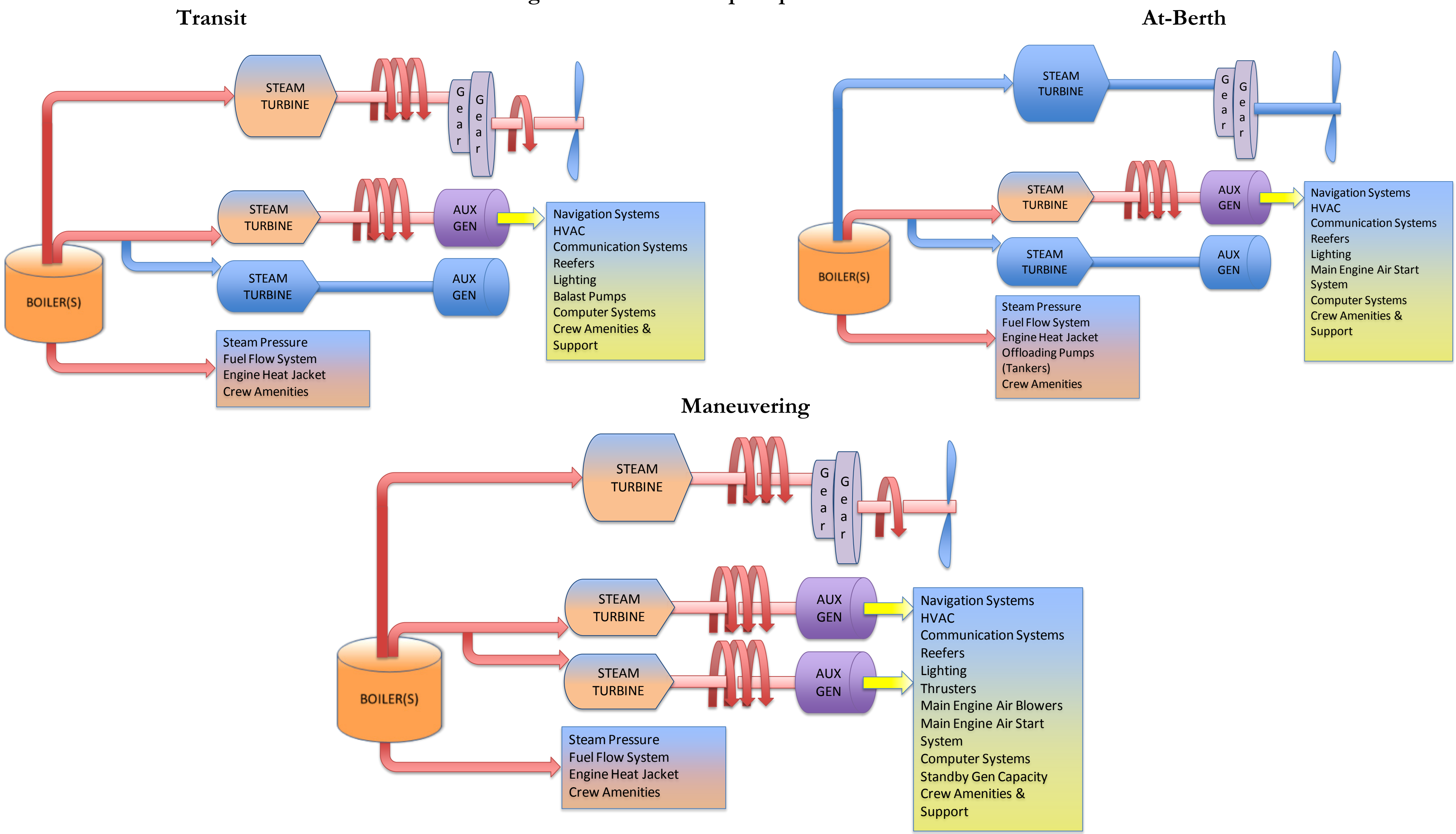


Figure 5.13: Steam Ship - Operational Modes



For emission estimation purposes, OGVs are typically categorized by the type of cargo they carry. Common categories include the following:

- Auto Carriers
- Dry Bulk Carriers
- Containerships
- Passenger Cruise Ships
- Passenger Vehicle Ferries
- General Cargo
- Integrated/Articulated Tug and Barge
- Refrigerated Vessels (Reefer)
- Roll-On Roll-Off Vessels(RoRos)
- Tankers
- Miscellaneous vessels

A brief description of each vessel class is provided below.

Auto Carriers - Auto carriers are specialized ships that are used to transport light and medium duty vehicles. Auto carriers are very similar in design to RoRos as discussed below because they have drivable ramps; however, auto carriers strictly carry light and medium duty vehicles. Both can have substantial ventilation systems to remove vehicle fuel vapors during voyages and engine exhaust during loading/unloading. Auto carriers are typically configured with direct-drive propulsion engines in combination with a diesel-electric auxiliary power system. Auto carriers' typical sea-speed ranges from 17 to 20 knots.

Dry Bulk Carriers - Bulk carriers have large open holds which are hatched closed during voyage. These ships carry dry goods that can be loaded from a conveyor belt and chute, such as coal, coke, salt, sugar, cement, gypsum, lime mix, agricultural products, alumina, and other similar fine-grained commodities that can be poured, scooped, or augured. Bulk carriers are typically configured with direct-drive propulsion engines in combination with a diesel-electric auxiliary power system. Dry bulk carriers' typical sea-speed ranges from 13 to 15 knots.

Containerships - Containerships are vessels that are specialized for only carrying 20- and 40-foot containers in their holds and on their decks. These ships are usually classified by the number of TEUs that they carry. TEU capacities for containerships range from 1,000 TEUs to 13,000 TEUs. Cargo types include almost everything that can be made to fit into the 20- or 40-foot containers. Because of the containership's high efficiency as a cargo conveyance system, containership activity is forecasted to continue to dominate the transport of goods for the foreseeable future. Containerships are typically configured with direct-drive propulsion engines in combination with a diesel-electric auxiliary power system. Containerships' typical sea-speed ranges from 18 to 26 knots.

Passenger Cruise Ships - Passenger cruise ships are known for their luxury accommodations, entertainment, speed, and their significant auxiliary power demands. Cruise vessels vary significantly in overall size, onboard auxiliary power, age, and engine configuration. Passenger cruise ships can carry over 3,500 passengers with over 1,300 crew members. Typically, the newer larger cruise ships are being built with diesel-electric configurations and some using turbines to generate electricity. Older cruise ships are typically configured with direct-drive, geared-drive, or even steam-powered propulsion systems in combination with a diesel-electric auxiliary power system. Passenger cruise ships' typical sea-speed ranges from 18 and 21 knots.

Passenger/Vehicle Ferries - Passenger/vehicle ferries are common in Europe, Asia, and the South Pacific. Newer passenger/vehicle ferries resemble cruise ships but typically have lower auxiliary power loads due to the shorter stay on-board by the passengers. They have the ability to carry light to heavy-duty vehicles and some can carry passenger trains. Their crew numbers are also typically smaller than cruise ships. Typically, the newer larger passenger/vehicle ferries are being configured in diesel-electric configurations, while older ships use direct-drive, geared-drive, or steam-powered in combination with a diesel-electric auxiliary power system. Passenger/vehicle ferries' typical sea-speed ranges from 17 and 20 knots.

General Cargo - General cargo ships are similar to dry bulk carriers in that they have large holds that hatched open for loading/unloading and hatched close for ocean transit. General cargo ships can carry diverse cargoes such as steel, palletized goods, turbines, containers (usually on the top deck), large excavating machinery, equipment, pipes, and other heavy loads. Most general cargo ships have electric boom cranes for self loading and unloading. General cargo ships are typically configured with direct-drive propulsion engines in combination with a diesel-electric auxiliary power system. General cargo carriers' typical sea-speed ranges from 13 to 16 knots.

Integrated/Articulated Tug and Barge - Integrated tug and barge (ITB) and articulated tug and barge (ATB) vessels are included in the ocean going vessel inventory since the ITB and ATBs are seen as a specialized single vessel. The barge stern is notched to accept a special tug which can be rigidly or articulately connected to the barge, forming a single vessel. The barge is built in the form of a normal ship-like hull. These vessels are configured with two propulsion engines in combination with a diesel-electric auxiliary power system. ITBs' and ATBs' typical sea-speed ranges from 13 to 15 knots.

Refrigerated Vessels - Refrigerated vessels, often called "reefers," are dominated by fruit and liquid carriers, which require cooling to prevent cargo spoilage. These are similar to bulk or general cargo carriers, but these ships typically carry fruits, vegetables, meats, juices, and other perishable cargos. Most of the cargo is stored below deck on pallets or transported inside refrigerated containers that are placed on top of the closed cargo hold. Reefers are typically configured with direct-drive propulsion engines in combination with a diesel-electric auxiliary power system. Oceanic reefer ships' typical sea-speed ranges from 16 to 21 knots.

Roll On – Roll Off Vessels (RoRos) - These OGVs are similar to the automobile carrier but can accommodate larger/heavier equipment like construction equipment, large heavy-duty trucks, farm equipment, and military equipment. RoRo ships are typically configured with direct-drive propulsion engines in combination with a diesel-electric auxiliary power system. RoRo ships' typical sea-speed ranges from 16 and 19 knots.

Tankers - Tankers range from approximately 10,000 deadweight tonnage (DWT) to over 300,000 DWTs. For estimating emissions, tankers have been divided into subcategories such as chemical, crude/oil products, and general. Tankers fall into several size categories depending on their dimensions and the categories change slightly depending on the cargo the tanker is carrying. The following are crude tankers categories and their typical DWT.

- Handyboat — 400 to 60,000 tons
- Panamax — 60,000 to 80,000 tons
- Aframax — 80,000 to 120,000 tons
- Suezmax — 120,000 to 200,000 tons
- Very Large Crude Carrier — 200,000 to 300,000
- Ultra Large Crude Carriers — 300,000+ tons

Tankers are typically configured with direct-drive propulsion engines in combination with a diesel-electric auxiliary power system. Tankers' typical sea-speed ranges from 12 to 15 knots.

As with all mobile sources, estimating emissions from OGVs requires gathering as much information as possible on the vessels, their activity level, and the operational modes within the geographical domain of the inventory. OGVs require the most data compared to the other mobile source categories. However, ports are in a unique position to best organize and gather the required data. The types of data required are described below:

Vessel Data - Commonly found using the Lloyd's Ship Registry (Lloyd's) which provides vessel characteristics such as propulsion type, main engine power, age of the vessel, speed, and sometimes information on installed auxiliary engines and boilers. Sea speed is estimated to be at 94% of the max rated speed. Several North American ports have supplemented the Lloyd's data with additional data collected through a Vessel Boarding Program (VBP) for their inventories because operational data such as auxiliary engine or boiler loads by mode are not available in Lloyd's. Surrogate operational data can also be sourced from published port inventories.

Activity Data - Can be provided through the port pilots, marine exchanges, or vessel traffic systems (VTS). Information obtained from these sources provides ship International Maritime Organization (IMO) number, date, time, location, berth/anchorage, and sometimes speed information. It should be noted that typically fuel consumption data is not available and, therefore, GHG emissions are estimated based on power. There are precautionary zones (PZ) located outside the entrance to most harbors. The PZ is an area controlled by the VTS where ships are required to slow down so the risk of collision is reduced. Ships transit through the PZ and usually begin to queue up to pick up port pilots who guide the ships to and from the berths. Speeds within this zone can be obtained from port pilots. Activity data is categorized as: arrival, departure, shift, at-berth, and at-anchorage.

Mode Data - Mode data is used to delineate the geographical domain of the inventory into the three operating modes discussed previously. This information can be gathered from port pilots, vessel traffic system operators, or ship captains.

Geographical Domain Data - Once the emission inventory's geographical domain is specified, information on location of ships traveling within that domain can be gathered from nautical charts and from discussions with port operations, port pilots, vessel traffic system operators, and ship captains.

OGV's greenhouse gas emissions can be estimated as a function of vessel power demand or energy expressed in kilowatt-hours (kW-hrs) multiplied by an emission factor (EF) expressed in terms of grams per kilowatt-hour (g/kW-hr). See Equation 5.18 below:

Equation 5.18

$$Emissions = Energy \ x \ EF$$

The 'Energy' term of the equation is where most of the location-specific information is used. Energy is a function of the engine's maximum continuous rated (MCR) power expressed in kW, multiplied by a load factor (LF) which represents the load on the engine during each operating mode and is unitless, multiplied by the operating time for each mode that emissions are being estimated for. See Equation 5.19 below:

Equation 5.19

$$Energy = MCR \ x \ LF \ x \ Act$$

MCR power is defined as the manufacturer's tested engine power; for this document, it is assumed that the Lloyd's 'Power' value is the best surrogate for MCR power. The international specification is to document MCR in kilowatts, and it is related to the highest power available from a ship engine during average cargo and sea conditions. However, operating a vessel at 100% of its MCR power is very costly from a fuel consumption and engine maintenance perspective, so most operators limit their maximum power to about 83% of MCR.

Load factor is the ratio of an engine's power output at a given speed to the engine's MCR power. Propulsion engine load factor is estimated using the Propeller Law, based on the theory that propulsion engine load varies by the cube of vessel speed. Therefore, propulsion engine load factor is estimated by dividing the actual speed (AS) in knots by the ship's maximum speed (MS) in knots, and taking the cube as illustrated by the Equation 5.20 below.

Equation 5.20

$$LF = (AS / MS)^3$$

For a few instances, the calculated load factor using the actual speed data recorded has exceeded the 83% MCR. This may be due to vessels traveling faster than the maximum rated speed because of wind conditions or currents. For the purpose of estimating emissions, it is recommended that the load factor be capped at 1.0 (100%) so that there are no calculated propulsion engine loads greater than 100%.

Activity is measured in hours of operation. The transit time in a zone is estimated by determining the time it takes to move through the zone. This is estimated by taking the distance (D) in nautical miles (nm) and dividing it by the ship's actual speed (AS) in knots. See Equation 5.21 below.

Equation 5.21

$$Act = D/AS$$

The main engine emission factors, worldwide, are based on limited data. The greenhouse gas emission factors for CO_2, CH_4 and N_2O were documented in an IVL 2004 study.[18] Vessels are assumed to operate their main engines on residual oil (RO) which is intermediate fuel oil (IFO 380) or one with similar specifications, with an average sulfur content of 2.7%. The average sulfur content of the fuel changes by year and location. The two predominant propulsion engine types are:

- Slow speed diesel engines, having maximum engine speeds less than 130 rpm
- Medium speed diesel engines, having maximum engine speeds over 130 rpm (and typically greater than 400 rpm).

[18] IVL, "*Methodology for Calculating Emissions from Ships: Update on Emission Factors*". Prepared by IVL Swedish Environmental Research Institute for the Swedish Environmental Protection Agency.

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.

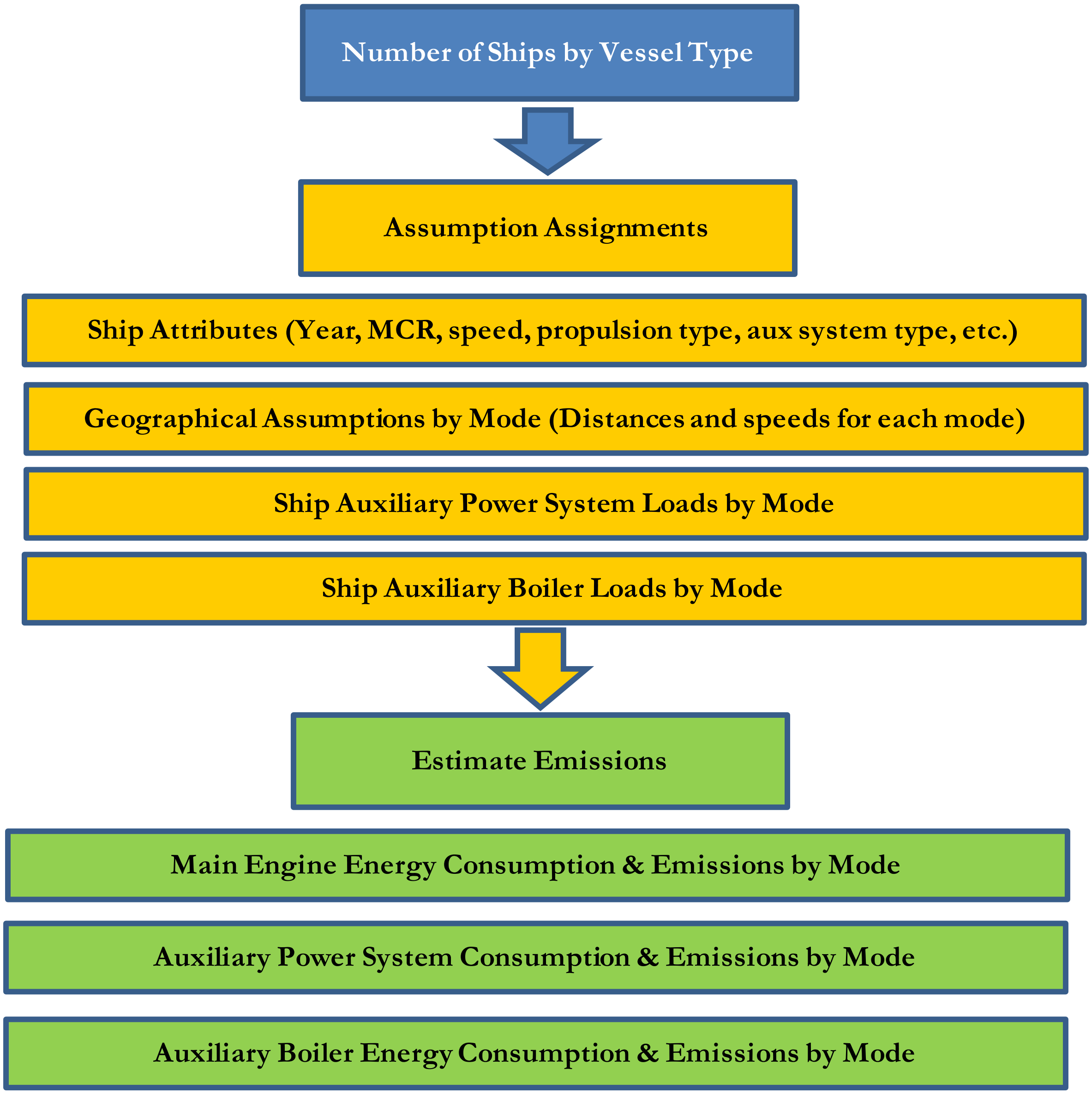
This surrogate approach is best for providing "order of magnitude" level estimates from port OGV activities.

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

Table 5.12: World Fleet Population, MCR, Max Rated Speed, and Sea-speed

Subtype	Population	Average Main MCR (kW)	Max Rated Speed (knots)	Sea-Speed (knots)
Auto Coastal	170	7,182	17.2	16.2
Auto Oceanic	612	12,705	19.2	18.0
Bulk Coastal	266	3,020	13.4	12.6
Bulk Over 10,000T	803	5,720	14.2	13.3
Bulk Over 25,000T	2,409	7,492	14.4	13.5
Bulk Over 50,000T	1,716	9,327	14.5	13.6
Bulk Over 75,000T	1,768	13,580	14.4	13.5
Bulk, Self Discharging	85	8,001	14.2	13.3
Container 1000	2,382	9,710	17.9	16.8
Container 2000	807	21,522	21.3	20.0
Container 3000	379	28,202	22.4	21.1
Container 4000	569	39,672	24.0	22.6
Container 5000	292	51,109	24.9	23.4
Container 6000	190	59,842	25.4	23.9
Container 7000	67	61,672	24.9	23.4
Container 8000	177	67,824	25.2	23.7
Container 9000	53	68,923	25.1	23.6
Container 10000	6	68,638	25.8	24.3
Container 11000	16	71,189	24.7	23.2
Container 12000	37	71,174	25.1	23.6
Container 13000	17	72,027	24.7	23.2
Cruise to 5,000T	74	16,613	19.5	18.3
Cruise over 5,000T to 9,999T	116	40,736	21.0	19.7
Cruise over 10,000T	43	68,890	22.3	21.0
General Cargo Coastal	3,422	2,917	13.7	12.9
General Cargo Oceanic	1,957	7,373	15.5	14.6
RORO Coastal	479	7,105	16.5	15.5
RORO Oceanic	238	14,624	18.5	17.4
Reefer Coastal	605	5,046	16.6	15.6
Reefer Oceanic	227	11,524	20.5	19.3
Tanker - Crude Handyboat	56	6,796	14.3	13.4
Tanker - Crude Panamax	77	10,167	14.7	13.8
Tanker - Crude Aframax	442	12,652	14.7	13.8
Tanker - Crude Suezmax	262	17,042	15.1	14.2
Tanker - Crude VLCC	269	22,828	15.2	14.3
Tanker - Crude ULCC	230	26,871	15.6	14.7
Tanker - General	286	4,159	13.5	12.7
Tanker - Oil Products	1,274	6,950	14.2	13.3

Figure 5.14: Recommended Approach for Surrogate Method of Estimating of GHG Emissions from OGVs



Example 1

The following is an example of a surrogate approach for estimating CO_2E emissions from a fleet of 8,000 TEU containerships:

- 30 Container 8,000 vessels visited in a year

Additional data would need to be assumed -

- Assume average vessel year built - 2000 or newer
- Assume propulsion system - slow speed, direct drive
- Assume auxiliary power system - medium speed diesel/electric
- Assume transit mode - 32 nm at sea-speed
- Assume maneuvering mode - 2 nm at 6 knots
- Assume average time at berth mode - 49 hours
- Assume IFO380 fuel @ 2.3% S
- Assume average MCR - 67,824 kW (Table 4.13)
- Assume average max rated speed - 25.2 knots (Table 4.13)
- Assume average sea-speed - 23.7 knots (Table 4.13)
- Assume average auxiliary loads - 1,557 kW transit/sea, 5,990 kW maneuvering, 2,156 kW at-berth (from Table 3.14, POLA Inventory of Air Emissions CY2007 Final Report)
- Assume average boiler loads - 0 kW transit/sea, 751 kW maneuvering, 751kW at-berth (from Table 3.17, POLA Inventory of Air Emissions CY2007 Final Report)

The estimates would be made in following steps:

Main Engines

Transit mode CO_2E emission calculation would be:

$E_{one\ way}$ = 67,824 kW x (23.7 knots/25.2 knots)^3 x 32 nm/23.7 knots x 629.9 g CO_2E/kW-hr
= 67,824 kW x 0.83 x 1.35 hours x 629.9 g CO_2E/kW-hr
= 47,870,379 g CO_2E or 47.9 tonnes CO_2E

$E_{transit}$ = 47.9 tonnes/leg x 2 legs/visit x 30 visits = 2,847 tonnes CO_2E

Maneuvering mode CO_2E emission calculation would be:

$E_{one\ way}$ = 67,824 kW x (6 knots/25.2 knots)^3 x 2 nm/6 knots x 629.9 g CO_2E/kW-hr
= 67,824 kW x 0.013 x 0.33 hours x 629.9 g CO_2E/kW-hr
= 183,279 g CO_2E or 0.18 tonnes CO_2E

E_{manu} = 0.18 tonnes/leg x 2 legs/visit x 30 visits = 10.8 tonnes CO_2E

Auxiliary Engines

Transit mode CO_2E emission calculation would be:

$E_{one\ way}$ = 1,557 kW/hr x 32 nm/23.7 knots x 692.8 g CO_2E/kW-hr
= 1,557 kW x 1.35 hours x 692.8 g CO_2E/kW-hr
= 1,456,230 g CO_2E or 1.46 tonnes CO_2E

$E_{transit}$ = 1.46 tonnes/leg x 2 legs/visit x 30 visits = 87.6 tonnes CO_2E

Maneuvering mode CO_2E emission calculation would be:

$E_{one\ way}$ = 5,990 kW/hr x 2 nm/6 knots x 692.8 g CO_2E/kW-hr
= 5,990 kW x 0.33 hours x 692.8 g CO_2E/kW-hr
= 1,369,458 g CO_2E or 1.37 tonnes CO_2E

E_{manu} = 1.37 tonnes/leg x 2 legs/visit x 30 visits = 82.2 tonnes CO_2E

Hotelling mode CO_2E emission calculation would be:

E_{berth} = 2,156 kW/hr x 49 hrs x 692.8 g CO_2E/kW-hr
E_{berth} = 73,190,163 g CO_2E or 73.2 tonnes CO_2E

Auxiliary Boilers

Maneuvering mode CO_2E emission calculation would be:

$E_{one\ way}$ = 751 kW/hr x 2 nm/6 knots x 994.8 g CO_2E/kW-hr
= 751 kW x 0.33 hours x 994.8 g CO_2E/kW-hr
= 246,541 g CO_2E or 0.25 tonnes CO_2E

E_{manu} = 0.25 tonnes/leg x 2 legs/visit x 30 visits = 15.0 tonnes CO_2E

Hotelling mode CO_2E emission calculation would be:

E_{berth} = 751 kW/hr x 49 hrs x 994.8 g CO_2E/kW-hr
E_{berth} = 36,607,645 g CO_2E or 36.6 tonnes CO_2E

Total CO_2E emissions -

Main Engines

$E_{transit}$ = 2,847 tonnes CO_2E
E_{manu} = 10.8 tonnes CO_2E

Auxiliary Engines

$E_{transit}$ = 87.6 tonnes CO_2E
E_{manu} = 82.2 tonnes CO_2E
E_{berth} = 73.2 tonnes CO_2E

Auxiliary Boilers

E_{manu} = 15.0 tonnes CO_2E
E_{berth} = 36.6 tonnes CO_2E

E_{Total} = 3,152.4 tonnes CO_2E

5.1.6 Construction Equipment

This section discusses the methods used to develop estimates of greenhouse gas emissions associated with the construction of new port facilities as well as periodic maintenance operations. Because these emissions tend to be short in terms of duration and sporadic in nature relative to normal port operations, they tend to be accounted for separately.

Construction activities include port funded wharf and breakwater construction, channel and berth deepening dredging and maintenance, terminal development and re-development, street improvements, etc. Construction activities can involve various types of mobile and portable equipment, some of which are specialized for construction such as:

- Portable concrete and asphalt batch plants;
- Dredges (clamshell, excavator, pan, cutter-suction head, etc.);
- Earth moving equipment (excavators, bull dozers, scrappers, trenchers, etc.);
- Paving equipment; and
- Portable worksite generators.

Some construction equipment are similar to the equipment found in the various port-related source categories described above, such as:

- Cranes (clamshell, mobile, etc.)
- Tugboats
- On-road trucks.

Construction activities are typically designed and executed according to detailed plans developed by the port engineers and/or their engineering design contractors. These plans provide the anticipated activity levels and equipment required to carry out the design plan. This information can be used to estimate activity and associated GHG emissions. It is important to note that construction equipment is not used for daily port operations; the equipment is typically owned and operated by a construction firm that has obtained a construction contract through the port.

One of the most common construction activities included in port related construction is dredging, excavation to remove sand, silt, rock or other underwater sea-bottom material (Figure 5.15). Channel maintenance dredging can be a routine/continuous operation that typically utilizes smaller dredges than those used for new channel construction. Maintenance and new construction dredging emissions are estimated using the same method; however activity data typically needs to be obtained from the dredger for maintenance dredging.

If construction activities are not calculated as a separate source category, the emissions of the dredge itself would fall into the harbor craft source category as well as the emissions of barges, tugs, work boats and crew boats used during construction. If the dredged material is ultimately transferred for over-the-road transport, the comprehensive estimate of related emissions may have a heavy-duty truck component, a rail component, or both.

Figure 5.15: Dredging Operations

Construction emissions are typically separated into two broad categories; landside operations and seaside operations. This distinction is made because different equipment and different modes of operation are exhibited according to these sub classifications. For example, landside operations (Figure 5.16) may include the emissions from passenger vehicles belonging to construction company employees, on-road heavy-duty trucks, off-road construction equipment (i.e. bulldozers, cranes and sweepers), and rail. As mentioned earlier, seaside operations tend to be limited to various types of harbor craft.

Figure 5.16: Landside Operations (Construction)

Whether on land or sea, construction activity tends to be performed by vehicles and vessels powered by diesel fuel (with the possible exception of employee vehicles) and their greenhouse gas emissions are estimated by pairing assumption of activity with emission rates expressed in terms of the amount of emissions per rate of activity (Equation 5.22).

Equation 5.22

Total Emissions = Pop x EF x ACT

Where Pop is the population, in this example the number of like pieces of equipment, EF is the emission factor expressed in grams of emissions per unit of activity (i.e., per gallon of fuel consumed, per ton of material displaced, per horsepower-hour or per kilowatt-hr) and ACT is the corresponding activity (i.e. gallons of fuel consumed per year, total tons of material, horsepower-hours per year or kilowatt-hours per year).

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

Total Running Emissions (HDVs) = # of Trucks x (Miles/Trip x # of trips) x EF g/mi

Total Idle Emissions (HDVs) = # of Trucks x idle hours/day x # of days x 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

Total Running Emissions (HDVs) = # of Trucks x gallons/trip x # of trips x EF g/gal

Total Idle Emissions (HDVs) = # of Trucks x idle hours/day x idle gallons/hour x # of days x 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

$$\text{Total Emissions} = \text{Pop} \times \text{EF (g/kW-hr)} \times \text{Total Rated Power (kW)} \times \text{LF} \times \text{Total Hours of Operation}$$

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

$$\text{Total Emissions} = \text{Pop} \times \text{EF (g/liter)} \times \text{Fuel Consumption (liters/hour)} \times \text{Total Hours of Operation}$$

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]

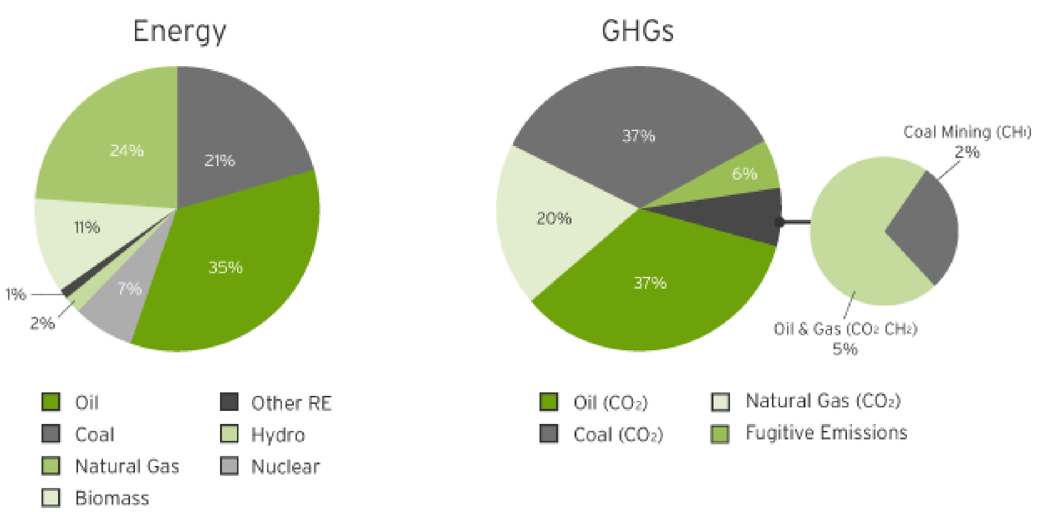


Figure 5.22: Refrigerated Container

[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).

$$\text{Total Emissions} = \text{MW-hrs} \times \text{kg } CO_2E/\text{MW-hr}$$

$$1 \text{ MW-hr} \times 400 \text{ kg } CO_2E/\text{MW-hr} = 400 \text{ kg } CO_2E/\text{day or } 0.4 \text{ tonnes } CO_2E/\text{day}$$

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:

$$\text{Total Emissions} = 1{,}000 \text{ containers/day} \times 1 \text{ lb. HFC-152a} \times 140 \text{ lb } CO_2E/\text{lb. HFC-152a} \times 1 \text{ tonne}/2{,}204.6 \text{ lb} = 63.5 \text{ tonnes of } CO_2E/\text{day}$$

6.0 Conclusions

This document has presented a detailed discussion of greenhouse gas emissions associated with port operations and has suggested methods to estimate the magnitude of these emissions. The information presented is intended to supplement rather than replace information and guidance issued by national or world bodies concerned with the reporting or control of greenhouse gas emissions. The user of this document is urged to consult the relevant protocols discussed in Section 4, especially if a carbon inventory is being prepared to comply with the requirements of one of these bodies.

This document is intended to be a living document, with updates being periodically prepared to expand the depth and breadth of the coverage based on user input. The following brief list includes some of the potential update topics.

- Port and tenant employee commuting
- Port-generated waste streams
- Computerized modeling of port emissions

While a large majority of port-related activities have been addressed in the previous sections, the interrelatedness of commercial enterprises and the ubiquitous nature of greenhouse gas producing activities mean that there are other aspects of port operations that have an impact on overall emissions of greenhouse gases. For example, port employees and port tenants' employees commute to and from port facilities, in most cases using transportation modes that directly or indirectly emit greenhouse gases. Delivery vehicles and repair service vehicles also make frequent visits to ports or their tenants. Waste streams generated by the port or port facilities must be treated on-site or transported off-site for treatment or disposal - once again, requiring the expenditure of energy and either directly or indirectly in the release of greenhouse gases to the atmosphere.

Initial efforts have been made to develop integrated computer models that can estimate a port's carbon emissions based on accepted factors and port-specific input. As one or more of these models are developed they may be referenced or integrated into the guidance on preparing port emissions footprint inventories.

Virtually all facets of port operations can be examined and seen to have an effect on a port's carbon footprint. This reflects the energy intensive nature of modern society as a whole and is not an indictment of port operations specifically. However, it does present multiple opportunities for a port to make changes that reduce the size of its footprint.