Greenhouse Gas Route Comparison Tool

Overview and Description

Prepared for:

Pacific Merchant Shipping Association

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Summary

Greenhouse gas (GHG) emissions are on average 22% higher when cargo which orginiates in the Far East is diverted from the West Coast in favor of East Coast/Gulf Coast ports.

Regulations that are designed to reduce GHGs and other emissions from maritime and other logistics operations along the supply chain in California increase operational costs for cargo owners and may have the unintended consequence of shifting cargo flows to less expensive gateways with longer transit times - and therefore generate higher GHG emissions.

Overview

Shipping lines and cargo owners are influenced by three main factors when deciding on preferred cargo routes: speed to destination, reliability and cost. Those factors, particularly cost, are influenced by a number of variables that can be impacted by local policy. These variables include: port and inland infrastructure, availability of skilled labor, vessel and network capacity, government and regulatory issues, and environment and energy efficiency. In sum, cargo owners have many reasons for implementing route changes. One of the consequences when alternatives to West Coast ports are considered may be increased emissions of greenhouse gases (GHGs) due to the longer transit distances. Policy-makers need to keep these variables in mind when contemplating far-reaching decisions on regulations, infrastructure and green energy.

We developed a greenhouse gas comparison tool to assist policy-makers, cargo interests and others in evaluating the relative differences in GHG emissions between various cargo routes from originating ports in Asia to inland U.S. destinations. The results of this GHG route comparison tool demonstrate that West Coast ports generally have an advantage (i.e., fewer GHGs are emitted) over Gulf and East Coast ports in the total GHGs emitted per container (measured in twenty-foot equivalent units, or TEUs) shipped from the origin ports in Asia to inland destination cities in the U.S. The advantage varies considerably depending on many variables that include ocean route, vessel size, arrival port and ultimate inland destination. While in very few cases the advantage is insignificant or even slightly negative (i.e., slightly lower GHG emissions due to switching from West Coast to East Coast), emissions can be up to two times higher when cargo from Asia bypasses West Coast ports. GHG emissions are on average 22% higher when shipping lines use East Coast/Gulf Coast ports.

Cargo originating from Asia is often routed through the major gateways of the ports of Los Angeles and Long Beach because of their proximity to infrastructure and logistics networks across the United States, like truck and rail. In the past, shipping lines and cargo owners have paid increased operational costs related to environmental initiatives in order to access these gateways. However, due to the rapid investments in global transportation infrastructure, today cargo owners have more gateway choices than ever before. As a result, they are highly sensitive to changes in their three primary metrics to determine cargo routes and carriers: cost, time and reliability. In particular, cargo that is considered discretionary (i.e., cargo that can move through multiple gateways) is sensitive to changes in all three metrics and will seek the gateway that is most advantageous to the shipping line or cargo owner.

While it is true that many of these same cargo owners, particularly those in consumer-influenced retail sectors, have environmental goals to reduce GHGs from their transportation operations, it is also true that these same cargo owners have financial goals to reduce annual logistics expenditures. To date, most cargo owners have focused their efforts on logistics efficiency improvements such as increased container utilization, modal shifts, network optimization and supplier management. In many cases, improvements that lower costs also reduce environmental impact. In addition to the improvements noted above, the use of larger container vessels can lower costs for vessel operators and reduce overall emissions on a given route.

However, in today's hyper-competitive economic environment, cargo owners will almost always choose the gateway that gives them a market advantage. In such instances, efficiency and environmental goals may not be aligned. Therefore, as this analysis makes plain, selecting another gateway with lower costs will likely result in increased environmental impact (i.e., increased GHGs). Shipping lines will then be forced to alter their sailing schedules to meet market demand from cargo owners, resulting in a shift of cargo volumes to lower cost gateways.

Regulations that are designed to reduce GHGs and other emissions from maritime and other logistics operations in California may increase operational costs for cargo owners and may have the unintended consequence of shifting cargo flows to less expensive gateways with longer transit times - and therefore generate higher GHG emissions. This shift in cargo flows directly conflicts with the intent of the GHG-focused regulations. It would increase GHG emissions above what would have been emitted in the absence of such regulations, as cargo is naturally attracted to West Coast ports. These ports have the lowest carbon footprint per TEU for cargo originating from Asia.

Comparison Tool

The GHG Comparison Tool allows comparisons between emissions from shipments routed to inland locations through West Coast ports with emissions from shipments to the same inland locations routed through East Coast ports. The emissions include those from ocean-going vessels (OGVs) as they transit the open ocean and, depending on route, transit the Suez Canal or Panama Canal on their string from Asia to the U.S. and back to the originating port. The emissions also include cargo handling equipment at the receiving port and locomotive transportation by rail from the receiving port to the inland destination. The cargo movements that are included in this GHG comparison tool represent the direct movements associated with the specified ports. Once a unit of cargo has been removed from a ship, the remainder of the ship's voyage (i.e., the continuation of the string to the next port of call and beyond) is engaged in transporting other import cargo, export cargo, and empty containers, so no emissions beyond the destination port are included in this tool. Emissions from locomotives are included from the specified port to the destination but not the return trip because the railroad companies are able to make use of cargo logistics to move locomotives and railcars around their service areas without making specific trips back to a point of origin. Locomotives and railcars are used to move other cargo after they drop off the cargo evaluated in this emissions comparison tool so their emissions are not included in the comparison.

A detailed description of the comparison tool and of the methods used to evaluate the differences in emissions between routes is provided in Attachment A. In general, the comparison tool compares emissions associated with trips from South Korea, China and Singapore to U.S. West Coast, Gulf

Coast, and East Coast ports using typical routes across the Pacific Ocean for the West Coast ports and the Suez and Panama Canals for the East Coast ports. Ultimate inland cargo destinations of Chicago, St Louis and Memphis are available as choices in the tool.

The comparison tool was provided to the U.S. Environmental Protection Agency, California Air Rescources Board and South Coast Air Quality Management District for their review prior to publication.

Comparison Summary
As examples, the following tables summarize the relative changes in GHG emissions when comparing cargo arriving at West Coast ports with cargo arriving at East Coast and Gulf Coast ports. Each table includes the overall route between origin port and inland destination, the arrival port and the final destination. Other comparisons are possible when using the comparison tool.

Table 1: Overall GHG Emissions Comparison

	US West Coast Comparison Ports			
From Asia to:	**LA/LB**	**Oakland**	**Pacific Northwest**	**West Coast Combined**
		percentage change		
US Gulf Coast via Panama	31%	21%	36%	29%
US East Coast via Panama	22%	13%	27%	21%
US East Coast via Suez	25%	16%	30%	24%
US East Coast combined	23%	14%	28%	21%
US East and Gulf coasts	**24%**	**14%**	**29%**	**22%**

Table 1 provides an overview of the average percentage increase in emissions when comparing emissions for cargo bound for Chicago when the entry port is a West Coast port versus one of the Gulf Coast or East Coast ports included in the evaluation tool. The value in the lower right corner of Table 1 provides an overall estimate of the difference in emissions when comparing West Coast to Gulf and East Coast arrival ports. These are estimates, actual increases will depend on variables such as the specific routes that are taken, intermediate ports, transit speeds, etc. However, the trend of increasing emissions with diversion from the US West Coast is clear.

Table 2: GHG Emissions Comparison between California South Coast Ports and East Coast Ports

Ocean Route	Arrival port	Inland Destination	Vessel Size Class	GHG Emission Change
Overall route: Busan - Chicago				
Pacific Ocean	LA or Long Beach, CA	Chicago, IL	13,000 teu	---
			6,000 teu	---
Panama Canal	Houston, TX	Chicago, IL	13,000 teu	12%
			6,000 teu	62%
Panama Canal	Savannah, GA	Chicago, IL	13,000 teu	3%
			6,000 teu	52%
Suez Canal	Savannah, GA	Chicago, IL	13,000 teu	33%
			6,000 teu	104%
Overall route: Singapore - Chicago				
Pacific Ocean	LA or Long Beach, CA	Chicago, IL	13,000 teu	---
			6,000 teu	---
Panama Canal	Houston, TX	Chicago, IL	13,000 teu	11%
			6,000 teu	64%
Suez Canal	Savannah, GA	Chicago, IL	13,000 teu	-8%
			6,000 teu	38%
Overall route: Shanghai - Chicago				
Pacific Ocean	LA or Long Beach, CA	Chicago, IL	13,000 teu	---
			6,000 teu	---
Panama Canal	Savannah, GA	Chicago, IL	13,000 teu	0%
			6,000 teu	49%
Suez Canal	New York & New Jersey	Chicago, IL	13,000 teu	15%
			6,000 teu	75%

Table 2 illustrates relative differences for cargo arriving at the ports of Long Beach or Los Angeles on vessels in the 18,000-TEU size range with cargo arriving at Gulf and East Coast ports on vessels in the 13,000-TEU and 6,000-TEU size ranges, to provide a range of differences resulting from the different vessel sizes that may be used in trade. In almost all cases the change is emissions is an increase, represented by the positive percent changes.

Table 3: GHG Emissions Comparison between Port of Oakland and East Coast Ports

Ocean Route	Arrival port	Inland Destination	Vessel Size Class	GHG Emission Change
Overall route: Busan - Chicago				
Pacific Ocean	Oakland, CA	Chicago, IL	13,000 teu	---
			6,000 teu	---
Panama Canal	Houston, TX	Chicago, IL	13,000 teu	3%
			6,000 teu	48%
Panama Canal	Savannah, GA	Chicago, IL	13,000 teu	-6%
			6,000 teu	40%
Suez Canal	Savannah, GA	Chicago, IL	13,000 teu	22%
			6,000 teu	87%
Overall route: Singapore - Chicago				
Pacific Ocean	Oakland, CA	Chicago, IL	13,000 teu	---
			6,000 teu	---
Panama Canal	Houston, TX	Chicago, IL	13,000 teu	3%
			6,000 teu	52%
Suez Canal	Savannah, GA	Chicago, IL	13,000 teu	-15%
			6,000 teu	28%
Overall route: Shanghai - Chicago				
Pacific Ocean	Oakland, CA	Chicago, IL	13,000 teu	---
			6,000 teu	---
Panama Canal	Savannah, GA	Chicago, IL	13,000 teu	-8%
			6,000 teu	37%
Suez Canal	New York & New Jersey	Chicago, IL	13,000 teu	6%
			6,000 teu	61%

Table 3 illustrates relative differences for cargo arriving at the Port of Oakland on vessels in the 18,000-TEU size range with cargo arriving at Gulf or East Coast ports on vessels in the 13,000-TEU and 6,000-TEU size ranges. In almost all cases the change is emissions is an increase, represented by the positive percent changes.

Table 4: GHG Emissions Comparison between Pacific Northwest Ports and East Coast Ports

Ocean Route	Arrival port	Inland Destination	Vessel Size Class	GHG Emission Change
Overall route: Busan - Chicago				
Pacific Ocean	Pacific Northwest, WA	Chicago, IL	13,000 teu	---
			6,000 teu	---
Panama Canal	Houston, TX	Chicago, IL	13,000 teu	16%
			6,000 teu	68%
Panama Canal	Savannah, GA	Chicago, IL	13,000 teu	6%
			6,000 teu	58%
Suez Canal	Savannah, GA	Chicago, IL	13,000 teu	38%
			6,000 teu	111%
Overall route: Singapore - Chicago				
Pacific Ocean	Pacific Northwest, WA	Chicago, IL	13,000 teu	---
			6,000 teu	---
Panama Canal	Houston, TX	Chicago, IL	13,000 teu	13%
			6,000 teu	67%
Suez Canal	Savannah, GA	Chicago, IL	13,000 teu	-6%
			6,000 teu	41%
Overall route: Shanghai - Chicago				
Pacific Ocean	Pacific Northwest, WA	Chicago, IL	13,000 teu	---
			6,000 teu	---
Panama Canal	Savannah, GA	Chicago, IL	13,000 teu	6%
			6,000 teu	58%
Suez Canal	New York & New Jersey	Chicago, IL	13,000 teu	21%
			6,000 teu	85%

Table 4 illustrates relative differences for cargo arriving at the Pacific Northwest ports of Tacoma or Seattle on vessels in the 18,000-TEU size range with cargo arriving at Gulf or East Coast ports on vessels in the 13,000-TEU and 6,000-TEU size ranges. In almost all cases the change is emissions is an increase, represented by the positive percent changes.

Starcrest Consulting Group, LLC specializes in assisting ports and maritime clients address air quality, climate, business sustainability and data management needs.
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Attachment A - Methodology Description

Introduction

The greenhouse gas comparison tool has been developed to assist in evaluating the differences in greenhouse gas (GHG) emissions related to moving cargo through various routes from originating ports in Asia to inland U.S. destinations. The comparison tool is not intended to be used for conducting emissions inventories for the sources included. The tool allows comparisons between emissions from shipments routed to inland locations through West Coast ports with emissions from shipments of cargo to the same inland locations routed through East Coast ports. The emissions that are compared include those from ocean-going vessels (OGVs) as they transit the open ocean and, depending on route, transit the Suez Canal or Panama Canal on their string from Asia to the United States. The emissions also include cargo handling equipment at the receiving port and locomotive transportation by rail from the receiving port to the inland destination. This document describes the methods used by the comparison tool to estimate emissions from these sources.

Cargo Movements Included

The tool estimates emissions from cargo movements within the following geographical extents:

- Ocean-going vessels: Ships inbound to specified destination ports from a specified originating port.

- Cargo Handling Equipment (CHE): Equipment used to move containers within the terminal container yard at the receiving port.

- Rail locomotives: Class 1 rail movements from the specified port to major rail cargo destinations.

The cargo movements that are included in this GHG comparison tool represent the direct movements associated with the specified ports. Once a unit of cargo has been removed from a ship, the remainder of the ship's voyage (i.e., the remainder of the string back to the originating port) is engaged in transporting other cargo, including empty containers, so no emissions beyond the destination port are included in this tool. Emissions from locomotives are included from the specified port to the destination and not the return trip because the railroad companies are able to make use of cargo logistics to move locomotives and railcars around their service areas without making specific trips back to a point of origin. Locomotives and railcars are used to move other cargo after they drop off the cargo evaluated in this emissions comparison tool so their emissions are not included in the evaluation.

Greenhouse Gases Included

GHGs of concern in goods movement primarily include carbon dioxide (CO_2), methane (CH_4), and nitrous oxide, (N_2O). Certain fluorinated gases used in commercial and industrial applications are also GHGs but are not directly associated with goods movement. This tool estimates emissions of CO_2, CH_4, and N_2O because these are the GHGs emitted by the combustion emission sources that characterize the long-distance transport off goods in commerce. Because each greenhouse gas differs in its effect on the atmosphere, estimates of greenhouse gas emissions are presented in units of carbon dioxide equivalents (CO_2e), which weight each gas by its global warming potential (GWP) value. To normalize these values into a single greenhouse gas value, CO_2e, the GHG emission estimates are multiplied by the following GWP values[1] and summed. The resulting CO_2e emissions are presented in metric tons (tonnes).

Global warming equivalence factors:

- CO_2 – 1
- CH_4 – 25
- N_2O - 298

Methodology Overview

The methodology estimates GHG emissions associated with container movements by sea between Asia and various ports in the U.S., handling of the cargo at the receiving port, and rail transport from the arriving U.S. port to three inland destinations. From the originating port, ocean voyage emissions can be estimated via three routes: direct Pacific Ocean route, through the Panama Canal, and through the Suez Canal. The current version of the tool includes 13 strings making use of the three routes. While these strings represent actual routes taken by shipping lines, they are not the only possible routes that can be taken. The following list includes each string's originating port through the final U.S. port location in the string.

- Busan – Los Angeles – Oakland via the Pacific Ocean direct
- Busan – Vancouver – Pacific Northwest via the Pacific Ocean direct
- Busan – Cristobal – Houston – Mobile – Miami via the Panama Canal
- Busan – Savannah – Newark – Charleston – Jacksonville via the Panama Canal
- Busan – Shanghai – Ningbo – Chiwan – Singapore - New York – Norfolk – Savannah via the Suez Canal.
- Singapore – Nansha – Hong Kong – Yantian – Xiamen - Los Angeles – Oakland via the Pacific Ocean
- Singapore – Nansha, – Yantian – Shanghai – Busan – Vancouver – Pacific Northwest via the Pacific Ocean
- Singapore – Hong Kong – Chiwan – Shanghai – Ningbo – Busan – Manzanillo – Houston – Mobile – Miami – Jacksonville via the Panama Canal
- Singapore – New York – Norfolk – Savannah via the Suez Canal
- Shanghai – Yokohama – Long Beach – Oakland via the Pacific Ocean
- Shanghai – Busan – Vancouver – Pacific Northwest via the Pacific Ocean
- Shanghai – Busan – Savannah – Newark – Charleston via the Panama Canal
- Shanghai – Ningbo – Chiwan – Singapore – New York – Norfolk – Savannah via the Suez Canal

[1]U.S. EPA, *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014*, April 2016.

The U.S. port locations that are represented in the comparison tool are those in Houston, Jacksonville, Savannah, Charleston, Norfolk, New York/New Jersey, Los Angeles/Long Beach, Oakland, and the Pacific Northwest. The inland destinations are Chicago, Memphis, and St. Louis.

An activity-based methodology is used for the OGVs on the sea legs and for the locomotives on the land leg, while reported emissions from CHE at specific ports are used for the container handling component. For OGVs and locomotives, the activity is calculated and expressed as energy expended in kilowatt hours (kW-hrs) for OGVs and horsepower hours (hp-hrs) for locomotives, and emissions are calculated using emission factors expressed as grams per kW-hr or grams per hp-hr. Emissions from CHE are calculated on the basis of metric tons of GHG emissions per container measured as twenty-foot equivalent units (teu). The methods are described in detail below.

Ocean-going vessels

For OGVs, estimated energy consumption in kilowatt hours is calculated for the three primary emission sources installed on ships: propulsion or main engine(s), auxiliary generators, and auxiliary boilers. The operational profiles for these sources vary with the ship's mode of operation. Two operating modes are included, open sea transit (at sea) and canal transit. Other modes of operation, such as maneuvering and at-berth, are not included because they contribute low amounts of emissions (less than 1%) when compared to the modes that are included, and because they are roughly equivalent on all routes so would not contribute to a comparison of differences. Within the at-sea mode, transit within zones that are designated Emission Control Areas (ECAs) and within non-ECA zones are evaluated separately in order to include the effect on emissions of the different fuels that are used in these two zones.

The methods used to estimate energy and emissions are consistent with the International Maritime Organization's (IMO) *Third Greenhouse Gas Study*.[2] following equation is used to calculate the energy associated with the propulsion or main engine(s):

Equation 2

$$\textit{Energy (kW-hrs)} = \textit{MCR (kW)} \times \textit{LF (unitless)} \times \textit{Activity}$$

Where,

MCR = maximum continuous rated engine power, kW
LF = load factor (unitless)
Activity = activity of the engine at a given load, hours

[2] IMO, *http://www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Greenhouse-Gas-Studies-2014.aspx* [IMO 2014]

Load factor for a propulsion or main engine is expressed as the ratio of an engine's power output at a given speed to the engine's MCR rating. This calculation is based on the Propeller Law, which is the principle that a vessel's propulsion power requirement varies by the cube of its speed. The load factor is calculated using the following equation:

Equation 3

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

Where:

LF = load factor, percent
AS = actual speed, knots
MS = maximum speed or Lloyd's reported speed, knots

Information on the power levels of OGV main engines and on the vessels' maximum speed is obtained primarily from data commonly known as Lloyd's data, licensed from IHS Markit.[3] For each size class included in the comparison tool, Table 1 shows the averages of teu capacity, engine MCR power, maximum speed, observed actual open water transit speeds, and calculated load factor. The average capacity, average main engine, and average maximum speed were estimated using all container ships within the capacity category that were designated as "In-Service" in the IHS Markit database. Actual speeds are based on global satellite automated identification system (SAIS) data for 2012 and are published in Table 14 of IMO 2014. The actual speed was used for the entire port-to-port distance, which conservatively increases the estimated energy consumption compared to the various reduced speed zones ships pass through during arrival, departure, and maneuvering.

Table 1: Average Parameters for OGV Characteristics and Main Engines

Size Class teu	Average Capacity teu	Main Engine kW	Max Speed kts	Actual Speed kts	Load Factor
6,000	6,542	57,335	24.9	16.3	28.1%
8,000	8,480	61,007	24.5	16.8	32.3%
13,000	13,364	64,775	24.1	16.1	30.0%
15,000	15,259	67,044	21.3	14.8	33.6%
18,000	18,421	54,841	18.8	14.8	48.9%

[3] IHS Markit, *https://www.ihs.com/products/maritime-data-index.html*

Table 2 presents average vessel speeds while transiting the Panama and Suez Canals, and load factors for canal transits. Average speeds were developed by diving applicable canal transit times by the total distance of the canal. This approach should result in a slight over-estimate of propulsion emissions as the ships transiting the Panama Canal will not actually be using their propulsion engines during the time they are in the locks.

Table 2: Speeds and Main Engine Load Factors for Canal Transits

	Panama Canal		Suez Canal	
Size Class	**Speed**	**LF**	**Speed**	**LF**
teu	**kts**		**kts**	
6,000	5.0	0.8%	6.9	2.1%
8,000	5.0	0.9%	6.9	2.3%
13,000	5.0	0.9%	6.9	2.4%
15,000	5.0	1.3%	6.9	3.4%
18,000	5.0	1.9%	6.9	5.0%

Auxiliary engine and boiler information is usually not provided to IHS Markit by vessel owners since it is not required by IMO or the classification societies, so minimal auxiliary engine and boiler information is available from their data (i.e., Lloyd's data). Therefore, auxiliary engine and boiler data gathered from the VBP and Lloyd's data on ships making local calls to the San Pedro Bay Ports (Los Angeles and Long Beach) were used to estimate the actual loads for each vessel size class, including load factor. Table 3 summarizes the auxiliary engine and boiler loads used during transit for this comparison tool. Note that the emission calculations assume that boilers are not used during sea transit because most containerships use economizers when at speed, which recover main engine exhaust heat and allow the boilers to be turned off.

Table 3: Auxiliary Engine and Boiler Loads, kW

	Auxiliary Power		Boiler
Size Class	**Transit**	**Canal**	**Canal**
teu	**kW**	**kW**	**kW**
6,000	1,453	2,195	573
8,000	1,494	2,753	531
13,000	1,865	3,085	599
15,000	1,900	3,500	700
18,000	1,500	1,750	647

Activity for the OGV emission sources is estimated in hours by dividing the distance traveled by the vessel's average speed over that distance.

Equation 4

$$Activity = D/AS$$

Where:

Activity = activity, hours
D = distance, nautical miles
AS = actual ship speed, knots

For each component of a voyage (ECA and non-ECA open water, and canal transit), activity in hours is estimated assuming sea service speed for open water, and the reduced speeds shown in Table 2 for the canal transits. Energy associated with the propulsion engines, auxiliary engines, and boilers for each component is estimated for the route from the originating port to the destination port.

The power, load, and activity estimates are multiplied to calculate the energy demand in kW-hrs. Emission factors are used to estimate the quantity of emissions. The greenhouse gas emission factors for CO_2, CH_4 and N_2O were reported in an IVL 2004 study.[4] Vessels are assumed to operate in non-ECA areas on residual oil (RO), which is intermediate fuel oil (IFO 380) or one with similar specifications. This is supported by information collected during the VBP and 2005 CARB survey. For ECA areas, the emission factors are based on the use of marine diesel oil (MDO) in main and auxiliary engines, with boilers being turned off and not producing emissions. Table 4 presents the GHG emission factors for the three emission source types and two fuels in g/kW-hr.

[4] Methodology for Calculating Emissions from Ships: 1. Update of Emissions Factors,; Issued by David Cooper, IVL, 2004

Table 4: GHG Emission Factors for RO and MDO, g/kW-hr

Emission Source	Fuel	CO_2 g/kWh	N_2O g/kWh	CH_4 g/kWh
Main engine	MDO	589	0.029	0.012
Main engine	RO	620	0.031	0.012
Aux. engine	MDO	686	0.029	0.008
Aux. engine	RO	649	0.029	0.010
Boiler	MDO	992	0.075	0.002
Boiler	RO	970	0.080	0.002

Emissions in metric tons are calculated by multiplying energy demand in kW-hrs by the relevant emission factor in g/kW-hr and dividing by 1,000,000 grams per metric ton (tonne).

Equation 5

$$\text{Emissions (MT)} = \frac{\text{Energy (kW-hrs)} \times \text{EF (g/kW-hr)}}{1{,}000{,}000 \text{ g/tonne}}$$

Where,

Emissions = emissions in metric tons, MT, for the time period of activity
Energy = energy demand over the time period, kW-hr
EF = emission factor, g/kW-hr

For the canal transit portions, the emission factor for ship propulsion engines could be multiplied by a load adjustment factor of 1.11 to account for engine inefficiencies at low loads. However, the energy consumed in the canal portions compared to the total propulsion power never exceeds 0.2% and including the adjustment factor would have no impact on the results of the evaluations.[5]

The comparison tool calculates emissions of the three combustion-related GHGs, and CO_2 equivalents, from each of the three emission source types, for each component of the selected string(s) and for each of the four vessel size classes listed above, and presents a summary of OGV emissions for each string and vessel size class.

[5] San Pedro Bay Ports, *http://www.cleanairactionplan.org/documents/man-slide-valve-low-load-emissions-test.pdf*

Cargo Handling Equipment

Cargo handling equipment emissions represent a minor component of the overall GHG emissions, from approximately 2% to 7% of the total. The methodology for CHE is based on reported CHE emissions from each arrival port's container operations, if estimates are available, and on teu throughput for the same year as the CHE estimates. The annual emissions are divided by the port's annual container throughput for the reported year to derive an emissions efficiency value for each port of metric tons of CO_2 equivalents per teu (MT/teu). If an arrival port has not published an emissions inventory for CHE, the tool uses a weighted average MT/teu value calculated as the average of reported CHE emissions divided by the total of the corresponding ports' teu throughputs. The values for ports that have reported CHE emissions range from 0.015 to 0.065 MT/teu, with a weighted average of 0.023 MT/teu.

The emissions comparison tool calculates the CHE component of emissions by multiplying the emissions efficiency value by the number of teus input by the tool user.

Locomotives

The methodology for railroad locomotives moving containers from the selected arrival ports to selected inland destinations is based on energy demand over the distance travelled from port to destination (horsepower hours), and emission factors expressed in terms of grams of emissions per horsepower hour (g/hp-hr).

The energy demand calculation starts with multiplying the weight of an average train (tons) by the distance traveled between port and destination (miles), which calculates a gross ton-mile (GTM) value for each port-to-destination combination.

Fuel consumption, in gallons per GTM (gal/GTM), has been estimated from the annual R-1 reports filed by each Class 1 railroad with the Surface Transportation Board of the U.S. Department of Transportation.[6] Multiplying GTM by the gal/GTM fuel consumption average for the Class 1 railroads operating in either the eastern or western portions of the country, depending on the location of the arrival port, estimates the number of gallons of fuel consumed on each trip.

The energy demand in horsepower hours (hp-hrs) is estimated using a factor published by the U.S.EPA that correlates fuel consumption with power demand in horsepower hours per gallon of fuel (20.8 hp-hr/gal). Multiplying the estimated number of gallons by the hp-hr/gal factor estimates the total horsepower hours for each trip between arrival port and selected destination. Average values for horsepower hours per teu (hp-hr/teu) are calculated by dividing horsepower hours per train by the average number of teus on the average train for which weight has been estimated.

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[6] Surface Transportation Board, *https://www.stb.gov/stb/industry/econ_reports.html*

Emissions in metric tons are calculated by multiplying energy demand in hp-hrs by the relevant emission factor[7] in g/hp-hr and dividing by 1,000,000 grams per metric ton (tonne). Emissions of CO_2 equivalents per teu range from 0.14 to 0.65 MT/teu depending on the combination of arriving port and inland destination. The higher values occur when moving cargo from a west coast port to one of the inland destinations because the trip distances are further. This makes the rail component of a total trip a greater percentage of overall emissions when the arriving port is a west coast port than when arrival is to an east coast or Gulf coast port.

Table 5 lists the train parameters that have been used for estimating energy demand from locomotives. These are approximate values based on port-related emissions inventory work that do not reflect all of the variabilities in rail routes and train makeup but are believed to present a reasonable estimate of general train characteristics. Table 6 lists the emission factors that are used in the locomotive emission calculations.

Table 5: Parameters of Average Train used in Calculations

Parameter	Units	Rail Region	
		West	East
No. of cars per average train		26	20
Car capacity	teus/car	20	20
Total capacity	teus/train	520	400
teu weight	tons/teu	14	14
Cargo weight	tons	7,280	5,600
Car weight	tons/car	103	63
Car weight	tons	2,678	1,260
Locomotive weight	tons/loco	210	210
No. of locos	loco/train	3.1	2.4
Total loco weight	tons	840	630
Train weight	tons	10,609	7,364

Table 6: Emission Factors for Line Haul Locomotives

Emission Source	Fuel	CO_2 g/hp-hr	N_2O g/hp-hr	CH_4 g/hp-hr
Line Haul	ULSD	494	0.013	0.04

[7] EPA, Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014, April 2016