Memorandum

To: Adrienne Douglass-Scott, Port of Bellingham Date: December 11, 2024

From: Sarah Parker, Project Manager, Maul, Foster & Alongi Project No.: M0763.11.001

Re: Port of Bellingham 2023 Commercial Vessels Emissions Inventory

Introduction

Maul, Foster & Alongi, Inc. (MFA) partnered with the Port of Bellingham (Port) to prepare an emissions inventory (inventory) summarizing ocean-going vessel (OGV) and commercial harbor vessel emissions released during the 2023 calendar year. The purpose of the inventory is to estimate the nature, location, and magnitude of pollutant emissions associated with commercial vessel port calls during that historical time frame. The results of the inventory, and future inventories, may be used to inform the Port's climate and air quality investments as it plans for the expansion of its shipping activities.

Inventory Scope

The inventory includes emissions associated with marine vessels calling the following specific Port sites: Bellingham Shipping Terminal, C-Street Terminal, Bellingham Cold Storage, and Bellingham Cruise Terminal. It includes emissions associated with the following activities:

- Emissions from vessels traveling the last two miles inbound and the first two miles outbound from each port.
- Emissions from "hoteling" activities, where vessels are secured at berth while running auxiliary engines or generators.

Emissions from the generation of purchased electricity supplied to tugboats (shore power) at Bellingham Shipping Terminal have been accounted for in the Port's 2023 Greenhouse Gas Inventory and are included in this memo for reference only. These emissions are not included in any emissions totals discussed in the "Inventory Results" section.

The inventory focuses on the largest sources of emissions from marine vessels calling the sites noted above, including emissions from OGVs greater than 100 feet in length and commercial harbor vessels that assist these vessels during port calls. Vessels less than 100 feet in length are not included in the inventory because they typically have smaller engines and limited cargo capacities, resulting in lower fuel consumption and fewer emissions.

Emission estimates are limited to the following pollutants:

- Diesel particulate matter less than 10 micrometer in aerodynamic diameter (DPM_{10})
- Diesel particulate matter less than 2.5 micrometer in aerodynamic diameter ($DPM_{2.5}$)
- Total oxides of nitrogen (NO_x)
- Carbon monoxide (CO)

- Sulfur dioxide (SO_2)
- Volatile organic compounds (VOCs)
- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxide (N_2O)
- Black carbon (BC)

In this inventory, climate-related pollutants CO_2, CH_4, N_2O, and BC are reported individually and collectively as carbon dioxide equivalents (CO_2e). CO_2e is a measure that standardizes each climate-related pollutant according to its global warming potential (GWP). GWP values quantify the relative impact of different climate-related pollutants, expressed as the amount of potential climate warming a pollutant may cause over a 100-year period relative to CO_2.

The calculation of CO_2e emissions involves multiplying the total amount of each pollutant by its corresponding GWP. The 100-year GWP values for greenhouse gases (GHGs) CO_2, CH_4, and N_2O from the Intergovernmental Panel on Climate Change (IPCC) Sixth Assessment Report (AR6) are:

- CO_2: 1
- CH_4: 29.8
- N_2O: 273

The climate-related pollutant BC is a component of $PM_{2.5}$ emissions that is short-lived, remaining in the atmosphere only for a few days to weeks at a time. Conversely, CO_2 emissions have an atmospheric lifetime greater than 100 years. Although BC has a shorter atmospheric lifetime than CO_2, its relative short-term impact on climate change is far greater. MFA assumes a 100-year GWP of 900 for BC, consistent with the IPCC Fifth Assessment Report (AR5).

Methods

MFA developed the inventory consistent with the methods and assumptions presented in the Environmental Protection Agency (EPA) Ports Emissions Inventory Guidance ("Inventory Guidance") document dated April 2022. The following subsections present additional details on the inventory process, data sources, key assumptions, and limitations.

Process

To begin the inventory process, vessel calls were obtained and sorted by location (i.e., Bellingham Cold Storage, Bellingham Shipping Terminal, C-Street Terminal, Bellingham Cruise Terminal). These calls were then divided into smaller segments based on engine operating mode (i.e., transit, maneuvering, hoteling) and vessel type (i.e., refrigerated cargo ship, bulk carrier, barge, ferry, tugboat). Refrigerated cargo ships, bulk carriers, and ferries are categorized as OGVs in this inventory. Tugboats and barges are categorized as commercial harbor vessels.

For each operating mode and vessel type, emissions from both propulsion and auxiliary engines were calculated using estimated engine sizes, engine load factors, emission factors, the approximate time spent in each operating mode, and the number of trips per year. Low-load adjustment factors were applied to propulsion engine emission calculations as applicable based on assumed vessel speeds for each segment. Attachment A contains detailed documentation of emissions estimates and emission factors.

Data Sources

MFA requested vessel call records with vessel identifiers, dates of arrival and departure, and locations from the Marine Exchange of Puget Sound or the Port of Bellingham for Bellingham Cold Storage, Bellingham Shipping Terminal, and C-Street Terminal. Vessel calls for Bellingham Cruise Terminal were determined using publicly available information from Alaska Marine Highway System reports.

MFA conducted interviews with a Puget Sound pilot and a company providing harbor services to estimate trip segment durations, propulsion engine load factors, and propulsion engine sizes, where needed.

Select Automatic Identification System (AIS) records from Marine Cadastre, a collaboration between the Bureau of Ocean Energy Management, the National Oceanic and Atmospheric Administration, and the U.S. Coast Guard, were used to develop assumptions for engine operating times and propulsion engine load adjustment factors for vessel calls where specific data was not readily available.

For inputs not publicly or readily available, default or average values from the Inventory Guidance were used and documented in the "References" section of the inventory.

Key Assumptions and Limitations

Several assumptions were made where detailed data was unavailable or fell outside the scope of the inventory. These assumptions are outlined below:

- Simplifications were necessary to quantify commercial vessel emissions, as maritime operations are highly dynamic and engine load factors for specific segments of vessel calls (e.g., during ship assistance or docking) are difficult to determine precisely. MFA assumes that the input estimates provided by interviewed individuals (e.g., trip segment durations, engine load factors, engine sizes) are accurate for the purposes of quantifying emission estimates.
- Vessels in port are typically not using shore power and are instead running auxiliary engines during hoteling. At C-Street Terminal, vessels with hoteling times of one month or greater are not running any engines during hoteling.
- Engine loads for OGVs during maneuvering are assumed to be low, as vessels typically significantly reduce speed before arriving at the terminal and take time to return to service speed after departure.
- Vessel characteristics and engine load factors align with the data averages presented in the Inventory Guidance.

The inventory has several limitations due to data aggregation and the key assumptions made to simplify the emissions estimating process. These limitations include the following:

- Emissions were not calculated for each individual vessel call but were grouped by similar vessel types and call location (e.g., refrigerated cargo ships calling Bellingham Cold Storage). This approach involved averaging calculation inputs (e.g., propulsion engine power) using available vessel characteristics or selected Inventory Guidance averages. While this streamlines the calculations, it does not capture variability within vessel types or operating conditions.
- AIS records were not used as the primary vessel call data source in the inventory, as this was outside the inventory scope. AIS records were used selectively for more detailed information on vessel speed and engine operating times than vessel call records kept by the Port and its tenants, especially where this information was not readily available. Future inventories may

incorporate AIS data more extensively, depending on the availability of resources and project scope.

- The inventory is based on a select sample of operational estimates gathered from interviewed individuals. Increasing the diversity and size of this sample could enhance the accuracy of future emission estimates.

Inventory Results

Summary

Table 1 lists the total quantities of vessel emissions captured in the 2023 inventory, sorted by vessel type. The pollutants produced in the largest quantities were CO_2 (a component of CO_2e), NO_X, and CO. The total CO_2e emissions (CO_2, CH_4, N_2O, and BC) from commercial vessels recorded in this inventory amounted to 2,136 metric tons. Attachment A contains detailed inventory results tables as well.

According to the Port's 2023 Greenhouse Gas Inventory, which covers operational emissions under Port control (such as emissions from Port natural gas and mobile fuel combustion, electricity usage, refrigerants usage, and employee commutes), the Port's 2023 operational emissions totaled 910 metric tons CO_2e. This includes approximately 34.8 metric tons of CO_2e emitted from the generation of an estimated 82,160 kWh of shore power supplied to tugboats at Bellingham Shipping Terminal.

The quantity of CO_2e emissions estimated in this commercial vessels emissions inventory is 2.3 times greater than the Port's measured operational GHG emissions. This highlights the importance of the Port's ongoing efforts to reduce emissions from commercial vessel port calls, such as through the project to electrify and modernize Bellingham Shipping Terminal. These upgrades will allow vessels to connect to shore power, eliminating the need to run diesel engines while docked, and enhance the Port's capacity to accommodate next-generation electric and hybrid tugboats. As the modernization of Bellingham Shipping Terminal has the potential to increase the number of vessel calls to the Port, these investments can lead to even greater avoided emissions from vessels at berth and tugboat operations in the future.

Table 1: Total Vessel Emission Estimates by Vessel Type in 2023

Vessel type (# of calls)	Vessel Emission Estimates (metric tons)										
	DPM_{10}	$DPM_{2.5}$	NO_X	CO	SO_2	VOC	CO_2	CH_4	N_2O	BC	CO_2e
Refrigerated cargo (13)	0.24	0.22	17.7	1.42	0.54	0.55	889	0.010	0.037	6.7E-03	906
Bulk carrier (3)	0.035	0.032	2.56	0.21	0.079	0.082	128	1.5E-03	5.4E-03	9.07E-04	131
Tugboat (N/A)	0.045	0.043	2.71	0.59	3.8E-03	0.071	410	1.4E-03	0.020	0.033	446
Barge (40)	0.045	0.044	2.27	0.45	3.5E-03	0.077	383	1.5E-03	0.019	0.034	419
Ferry (41)	0.064	0.059	4.60	0.39	0.15	0.16	231	3.1E-03	9.7E-03	1.8E-03	235
Total	**0.43**	**0.40**	**29.8**	**3.05**	**0.78**	**0.94**	**2,042**	**0.018**	**0.091**	**0.076**	**2,136**

Note: Tugboats are used to operate barges, and all tugboat emissions from barge operations are attributed to tugboats.
Barges are assumed to have no propulsion engines. All emissions attributed to barges come from barge auxiliary engines or generators.

Figure 1 shows the relative amounts of each pollutant that can be attributed to specific vessel types. Refrigerated cargo ships accounted for the highest percentage (41-70%) of total emissions by

pollutant in 2023 for all pollutants except BC (9%). Refrigerated cargo ships either had a greater number of calls or longer hoteling times compared to other OGVs, resulting in higher emissions. In contrast, bulk carriers and ferries typically contributed a lower percentage of total emissions by pollutant, with bulk carriers accounting for only three vessel calls in 2023—the lowest number for any vessel type—and ferries having a higher number of vessel calls (41) but shorter hoteling times.

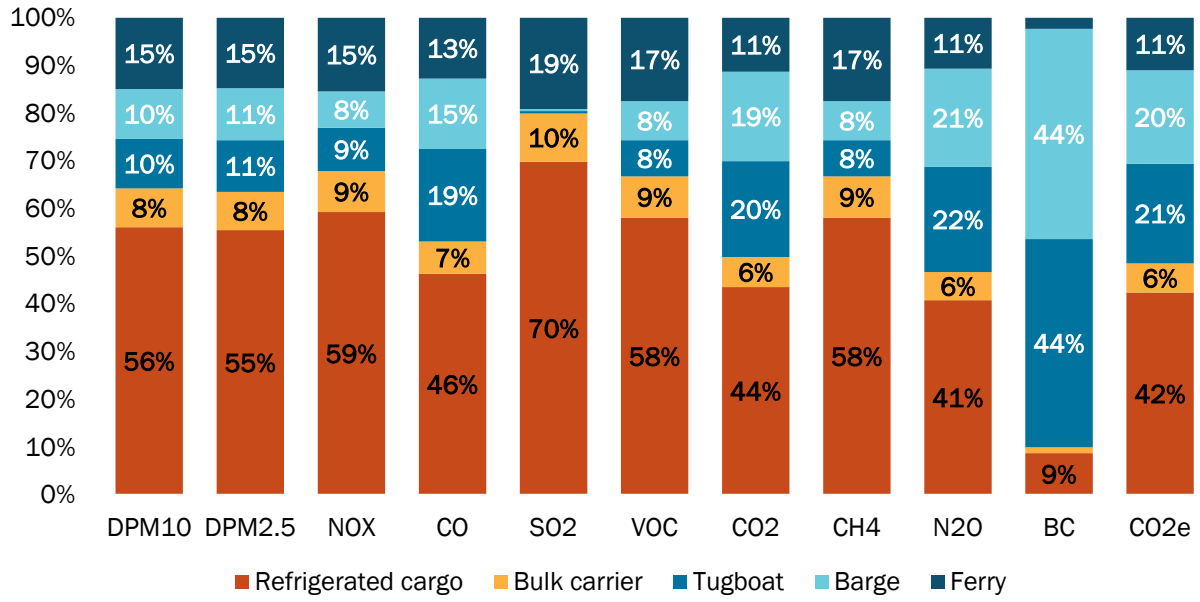

Figure 1: Percentage of 2023 Vessel Emissions by Vessel Type

Table 2 shows the total quantities of each pollutant included in the inventory, sorted by location. Vessel activity at Bellingham Cold Storage resulted in the highest emissions among all locations for every pollutant evaluated (except for BC), which is primarily due to the number of vessel calls and hoteling operating time for vessels at that location.

While mobile emissions sources (e.g., vessels) do not have air permitting requirements under Washington Administrative Code (WAC) 173-400-110(5), exemption levels can be used to provide context for the magnitude of emissions estimated in this inventory. Pollutant totals at each site included in the inventory are below the applicable exemption levels.

The International Maritime Organization (IMO) and EPA have adopted various regulations, standards, and policies to reduce mobile maritime emission sources, mainly from newly built vessels and vessels operating in areas where limitations have been placed on sulfur oxides (SO_x) and NO_x emissions (Emissions Control Areas). These regulations, standards, and policies were accounted for in inventory estimates where applicable, based on the Inventory Guidance.

Table 2: 2023 Total Vessel Emissions by Location

Location (# of vessel calls)	Vessel emissions (metric tons)										
	DPM_{10}	$DPM_{2.5}$	NO_X	CO	SO_2	VOC	CO_2	CH_4	N_2O	BC	CO_2e
Bellingham Cold Storage (13)	0.25	0.23	18.4	1.58	0.55	0.56	992	0.011	0.042	0.015	1,017

Location (# of vessel calls)	Vessel emissions (metric tons)										
	DPM_{10}	$DPM_{2.5}$	NO_X	CO	SO_2	VOC	CO_2	CH_4	N_2O	BC	CO_2e
Bellingham Shipping Terminal (31)	0.10	0.098	6.17	0.95	0.084	0.20	719	3.7E-03	0.034	0.052	776
C-Street Terminal (12)	0.011	0.011	0.65	0.14	9.2E-04	0.018	99.6	3.4E-04	4.9E-03	8.2E-03	108
Bellingham Cruise Terminal (41)	0.064	0.059	4.60	0.39	0.15	0.16	231	3.1E-03	9.7E-03	1.8E-03	235
Total	**0.43**	**0.40**	**29.8**	**3.05**	**0.78**	**0.94**	**2,042**	**0.018**	**0.091**	**0.076**	**2,136**

Figure 2 shows the percentage of each pollutant attributable to each Port location. Bellingham Cold Storage accounted for 46-70% of total emissions in 2023 depending on the pollutant, except for BC. This is mainly due to the number of vessel calls and length of barge hoteling times at Bellingham Cold Storage compared to activities at other locations captured in the inventory, as noted above.

C-Street Terminal and Bellingham Cruise Terminal accounted for a lower percentage of overall emissions, as hoteling times were lower at these locations.

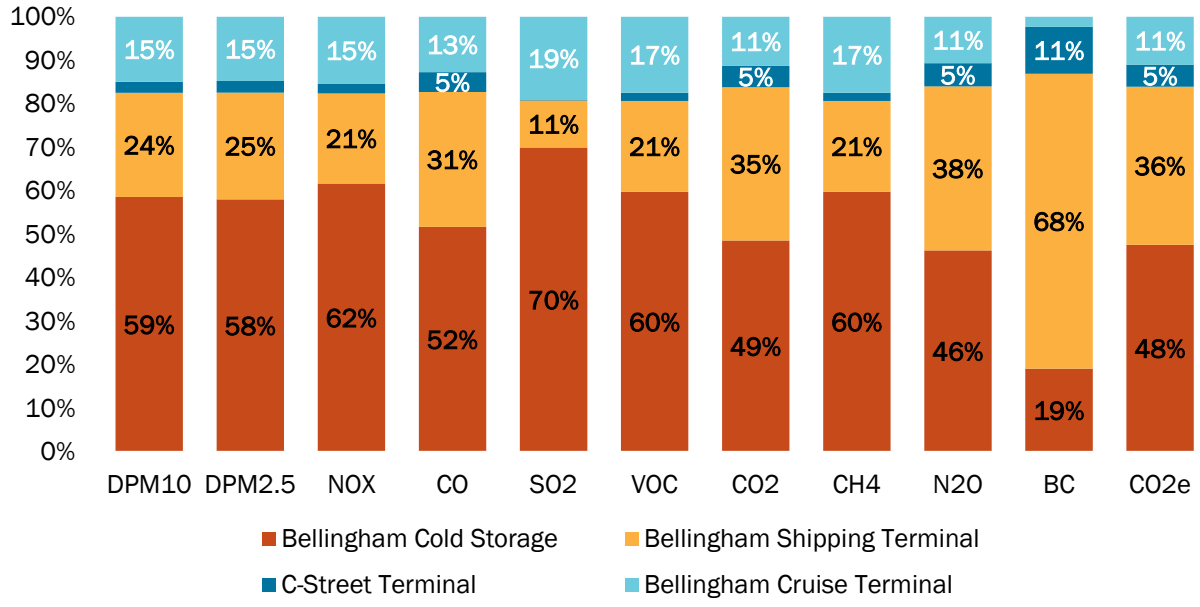

Figure 2: Percentage of 2023 Vessel Emissions by Location

Bellingham Cold Storage

This section of the inventory presents emission estimates from refrigerated cargo ships and tugboats involved in port calls at Bellingham Cold Storage. Vessel call records used to complete the calculations were obtained from the Marine Exchange of Puget Sound. Key assumptions for the calculations are listed in the Methods section of this memo and detailed in the inventory.

As shown in Table 3, most commercial vessel emissions at Bellingham Cold Storage accounted for 46-70% of inventory totals, depending on the pollutant, except for BC (19%).

Table 3: 2023 Bellingham Cold Storage Emissions

Parameter	DPM_{10}	$DPM_{2.5}$	NO_X	CO	SO_2	VOC	CO_2	CH_4	N_2O	BC	CO_2e
Total Emissions (metric tons)	0.25	0.23	18.4	1.58	0.55	0.56	992	0.011	0.042	0.015	1,017
Percentage of Total Port Emissions (%)	59%	58%	62%	52%	70%	60%	49%	60%	46%	19%	48%

As shown in Figure 3, refrigerated cargo ship hoteling accounted for most of the pollutant emissions at Bellingham Cold Storage in 2023, ranging from 44-97% of emissions at this location depending on the pollutant. Vessels calling Bellingham Cold Storage may only spend a few hours approaching and mooring at the terminal, but often remain at berth for several days before departing. Additionally, propulsion engine loads were estimated to be low for OGVs during maneuvering, as vessels must slow significantly before arriving at the terminal and take time to return to service speed after departure.

Tugboat activity contributed 54% of BC emissions from Bellingham Cold Storage commercial vessel activities. The BC emission factors for tugboats are higher than those used for refrigerated cargo ships, and it was assumed that each ship was accompanied by two tugboats during arrival and departure.

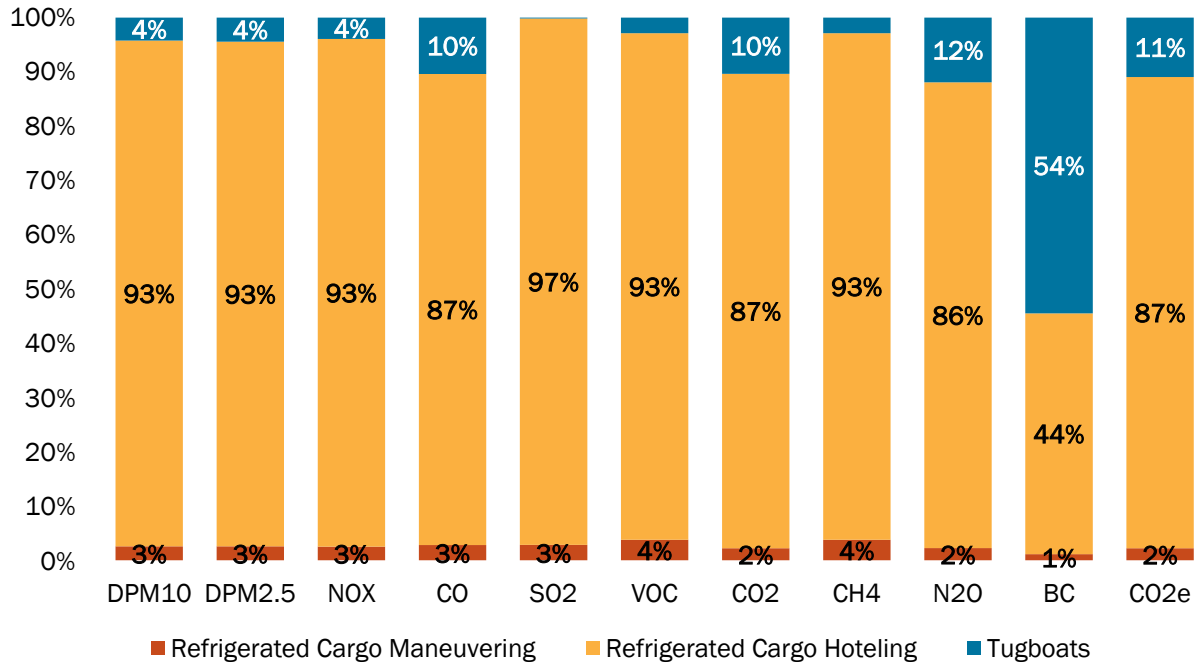

Figure 3: Bellingham Cold Storage Emissions by Ship Type and Activity

Bellingham Shipping Terminal

This section of the inventory includes emissions from bulk carriers, barges, and tugboats involved in port calls at Bellingham Shipping Terminal. Vessel call records used to complete the emission

estimates were obtained from the Port of Bellingham. Key assumptions for the emission estimate calculations are listed in the Methods section of this memo and detailed in the inventory.

Table 4 shows that vessel activity at Bellingham Shipping Terminal accounts for 11-38% of inventory totals by pollutant for all pollutants, except for BC, where it accounts for 68% of the inventory total. As noted in the previous section, BC emission factors for tugboats and barges are higher than those used for bulk carriers and other OGVs. Bellingham Shipping Terminal had the most tugboat and barge hoteling hours of the four Port locations included in this inventory, leading to the highest levels of BC emissions among those locations.

Table 4: 2023 Bellingham Shipping Terminal Emissions

Parameter	DPM_{10}	$DPM_{2.5}$	NO_X	CO	SO_2	VOC	CO_2	CH_4	N_2O	BC	CO_2e
Total Emissions (metric tons)	0.10	0.098	6.17	0.95	0.084	0.20	719	3.7E-03	0.034	0.052	776
Percentage of Total Port Emissions (%)	24%	25%	21%	31%	11%	21%	35%	21%	38%	68%	36%

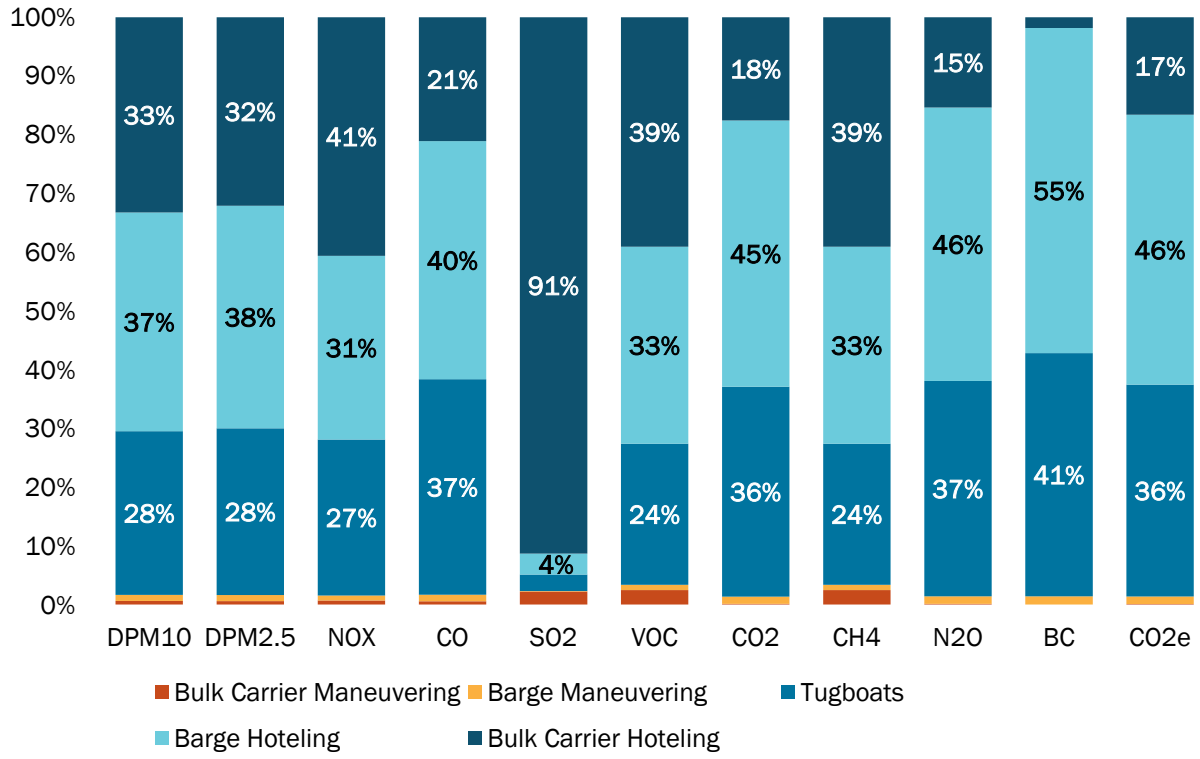

Figure 4: Bellingham Shipping Terminal Emissions by Ship Type and Activity

Figure 4 shows the relative amounts of each pollutant that can be attributed to the different vessel types and activities at Bellingham Shipping Terminal. Barge hoteling, bulk carrier hoteling, and tugboat activity represent the highest emitting activities for several reasons. MFA assumed that vessels hoteling at Bellingham Shipping Terminal were not connected to shore power (i.e., were running auxiliary engines), and many of the activity hours accounted for at Bellingham Shipping

Terminal were for barge and tugboat hoteling. Records indicated 28 calls that involved barge and tugboat hoteling with an assumed average of 64 hours of hoteling per call. Bulk carriers spent an average of 216 hours hoteling per call, although there were only three bulk carrier calls in the 2023 records. Bulk carriers were also assumed to have low propulsion engine load factors during maneuvering based on the necessity of slower vessel speeds approaching and departing the terminal.

C-Street Terminal

This section of the inventory includes emissions from barges and tugboats involved in port calls at C-Street Terminal. Vessel call records used to prepare the emission estimates were obtained from the Port. Key assumptions used for the emission estimate calculations are listed in the Methods section of this memo and detailed in the inventory.

As shown in Table 5, commercial vessel emissions at C-Street Terminal accounted for 3-11% of inventory totals by pollutant for all pollutants. C-Street accounted for the smallest share of each pollutant for all pollutants except BC.

Table 5: 2023 C-Street Terminal Emissions

Parameter	DPM_{10}	$DPM_{2.5}$	NO_X	CO	SO_2	VOC	CO_2	CH_4	N_2O	BC	CO_2e
Total Emissions (metric tons)	0.011	0.011	0.65	0.14	9.2E-04	0.018	99.6	3.4E-04	4.9E-03	8.2E-03	108
Percentage of Total Port Emissions (%)	3%	3%	2%	5%	0%	2%	5%	2%	5%	11%	5%

As shown in Figure 5, barge hoteling and tugboat operations represented the highest emitting operating scenarios at the C-Street Terminal. MFA assumed that vessels at C-Street Terminal for one month or longer were not running any engines during hoteling.

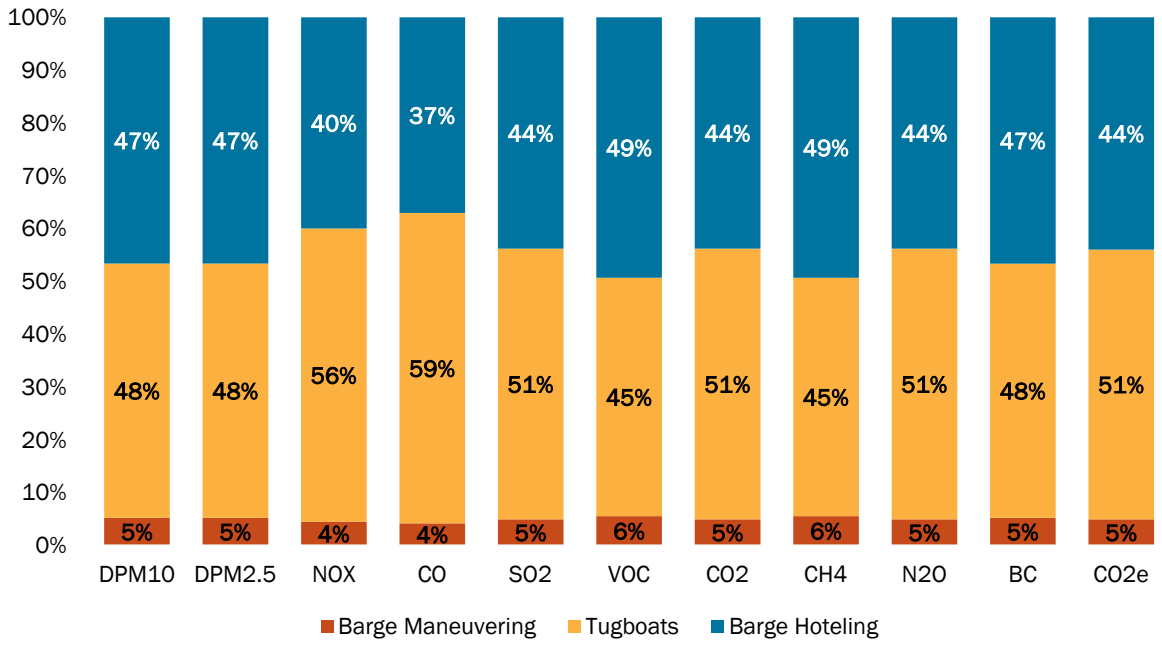

Figure 5: C-Street Terminal Emissions by Ship Type and Activity

Bellingham Cruise Terminal

This portion of the inventory includes emissions from Alaska Marine Highway System ferries calling Bellingham Cruise Terminal. Vessel call data used to prepare the emission estimates were collected from Alaska Marine Highway System annual traffic reports and the Marine Cadastre AIS database. Key assumptions used for the emission estimates calculations are listed in the Methods section of this memo and detailed in the inventory.

As depicted in Table 6, commercial vessel emissions at the Bellingham Cruise Terminal typically contributed between 11-19% of the total inventory emissions, except for BC (2%).

Table 6: 2023 Bellingham Cruise Terminal Emissions

Parameter	DPM_{10}	$DPM_{2.5}$	NO_X	CO	SO_2	VOC	CO_2	CH_4	N_2O	BC	CO_2e
Total Emissions (metric tons)	0.064	0.059	4.60	0.39	0.15	0.16	231	3.1E-03	9.7E-03	1.8E-03	235
Percentage of Total Port Emissions (%)	15%	15%	15%	13%	19%	17%	11%	17%	11%	2%	11%

Figure 6 shows that ferry maneuvering accounted for 12-25% of emissions by pollutant at Bellingham Cruise Terminal, and ferry hoteling accounted for 75-88% of emissions by pollutant. MFA assumed the average hoteling duration was 10 hours per call based on the Alaska Marine Highway System schedule, while approximately one hour of maneuvering and transit activity was included in the inventory scope for each vessel call. Propulsion engine load factors were assumed to be low during maneuvering and transit activity.

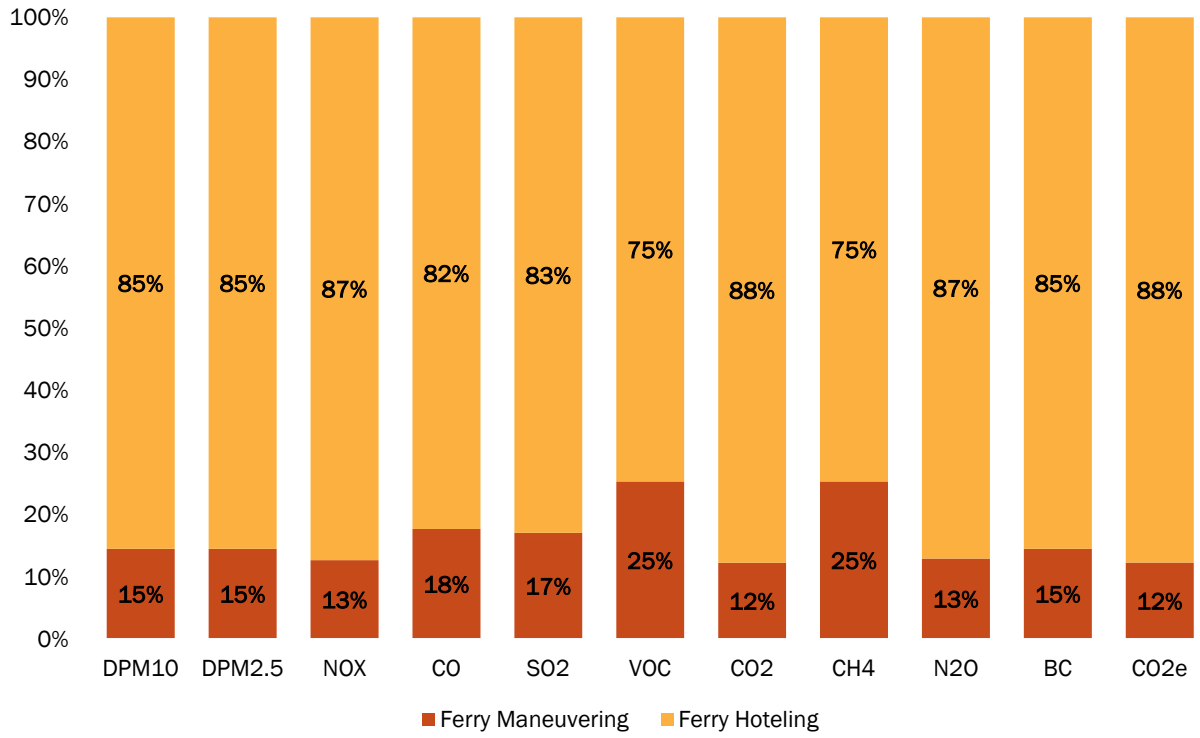

Figure 6: Bellingham Cruise Terminal Emissions by Ship Type and Activity

Conclusion

The inventory estimates various types of emissions generated by OGVs and commercial harbor vessels for the 2023 calendar year. As shown in the inventory, total GHG emissions from commercial vessels at the Port amounted to 2,136 metric tons of CO_2e for the 2023 calendar year. Emissions were primarily driven by vessel hoteling, with smaller emission contributions from vessel transit and maneuvering. Bellingham Cold Storage accounted for 46-70% of total emissions by pollutant in 2023, except for BC. This is mainly due to the number of vessel calls combined with the length of refrigerated cargo ship hoteling times at Bellingham Cold Storage.

This inventory serves as an initial estimate based on available data, standard emission calculation methods, and established emissions Inventory Guidance. Emissions estimates may be refined over time as more accurate data on vessel characteristics, fuel consumption, operational patterns, and emission factors become available. The emissions estimated documented in this memo represent a snapshot of 2023 activity, and future inventories are recommended to assess trends and identify opportunities for emissions reduction.

As part of the broader effort to reduce emissions from maritime operations, this inventory highlights the potential for emission reductions through the electrification or adoption of cleaner fuel-burning technologies, such as shore power and alternative fuels for vessels. Collaboration among port authorities, vessel operators, and other stakeholders will be key to achieving significant emissions reductions. Periodic updates to this inventory will help track progress and inform the development of targeted strategies to reduce commercial vessel emissions.

Attachment A

MAUL
FOSTER
ALONGI

Table 1
2023 Emissions Estimate Summary
Port of Bellingham
Bellingham, WA

Ship Type	Emission Estimates (metric tons/yr)										
	DPM_{10}	$DPM_{2.5}$	NO_X	CO	SO_2	VOC	CO_2	CH_4	N_2O	BC	CO_2e
Refrigerated cargo	0.24	0.22	17.7	1.42	0.54	0.55	889	0.010	0.037	6.7E-03	906
Bulk carrier	0.035	0.032	2.56	0.21	0.079	0.082	128	1.5E-03	5.4E-03	9.7E-04	131
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Ferry	0.064	0.059	4.60	0.39	0.15	0.16	231	3.1E-03	9.7E-03	1.8E-03	235
Total	0.43	0.40	29.8	3.05	0.78	0.94	2,042	0.018	0.091	0.076	2,136

Location	Emission Estimates (metric tons/yr)										
	DPM_{10}	$DPM_{2.5}$	NO_X	CO	SO_2	VOC	CO_2	CH_4	N_2O	BC	CO_2e
Bellingham Cold Storage	0.25	0.23	18.4	1.58	0.55	0.56	992	0.011	0.042	0.015	1,017
Bellingham Shipping Terminal	0.10	0.098	6.17	0.95	0.084	0.20	719	3.7E-03	0.034	0.052	776
C-Street Terminal	0.011	0.011	0.65	0.14	9.2E-04	0.018	99.6	3.4E-04	4.9E-03	8.2E-03	108
Bellingham Cruise Terminal	0.064	0.059	4.60	0.39	0.15	0.16	231	3.1E-03	9.7E-03	1.8E-03	235
Total	0.43	0.40	29.8	3.05	0.78	0.94	2,042	0.018	0.091	0.076	2,136

Bellingham Cold Storage	Emission Estimates (metric tons/yr)										
	DPM_{10}	$DPM_{2.5}$	NO_X	CO	SO_2	VOC	CO_2	CH_4	N_2O	BC	CO_2e
Refrigerated Cargo Maneuvering	6.9E-03	6.4E-03	0.50	0.047	0.016	0.022	23.8	4.2E-04	1.0E-03	1.9E-04	24.3
Refrigerated Cargo Hoteling	0.23	0.22	17.2	1.37	0.53	0.52	865	1.0E-02	0.036	6.5E-03	881
Tugboats	0.011	0.010	0.72	0.16	9.4E-04	0.016	103	3.1E-04	5.0E-03	8.0E-03	111
Total	0.25	0.23	18.4	1.58	0.55	0.56	992	0.011	0.042	0.015	1,017

Bellingham Shipping Terminal	Emission Estimates (metric tons/yr)										
	DPM_{10}	$DPM_{2.5}$	NO_X	CO	SO_2	VOC	CO_2	CH_4	N_2O	BC	CO_2e
Bulk Carrier Maneuvering	8.1E-04	7.5E-04	0.052	6.8E-03	2.0E-03	5.1E-03	2.06	9.7E-05	1.0E-04	2.2E-05	2.11
Barge Maneuvering	1.0E-03	1.0E-03	0.053	0.010	8.2E-05	1.8E-03	8.90	3.4E-05	4.4E-04	7.8E-04	9.73
Tugboats	0.029	0.028	1.64	0.35	2.4E-03	0.047	257	8.9E-04	0.013	0.021	279
Barge Hoteling	0.038	0.037	1.93	0.38	3.0E-03	0.066	326	1.2E-03	0.016	0.029	356
Bulk Carrier Hoteling	0.034	0.031	2.50	0.20	0.077	0.076	126	1.5E-03	5.3E-03	9.4E-04	129
Total	0.10	0.098	6.17	0.95	0.084	0.20	719	3.7E-03	0.034	0.052	776

C-Street Terminal	Emission Estimates (metric tons/yr)										
	DPM_{10}	$DPM_{2.5}$	NO_X	CO	SO_2	VOC	CO_2	CH_4	N_2O	BC	CO_2e
Barge Maneuvering	5.8E-04	5.6E-04	0.029	5.8E-03	4.5E-05	9.9E-04	4.91	1.9E-05	2.4E-04	4.3E-04	5.36
Tugboats	5.3E-03	5.1E-03	0.36	0.081	4.7E-04	8.0E-03	51.1	1.5E-04	2.5E-03	4.0E-03	55.3
Barge Hoteling	5.1E-03	5.0E-03	0.26	0.051	4.0E-04	8.8E-03	43.6	1.7E-04	2.1E-03	3.8E-03	47.7
Total	0.011	0.011	0.65	0.14	9.2E-04	0.018	99.6	3.4E-04	4.9E-03	8.2E-03	108

Bellingham Cruise Terminal	Emission Estimates (metric tons/yr)										
	DPM_{10}	$DPM_{2.5}$	NO_X	CO	SO_2	VOC	CO_2	CH_4	N_2O	BC	CO_2e
Ferry Maneuvering	9.3E-03	8.6E-03	0.58	0.069	0.025	0.042	28.3	7.9E-04	1.3E-03	2.6E-04	28.9
Ferry Hoteling	0.055	0.051	4.02	0.32	0.12	0.12	203	2.3E-03	8.4E-03	1.5E-03	206
Total	0.064	0.059	4.60	0.39	0.15	0.16	231	3.1E-03	9.7E-03	1.8E-03	235

Table 2
2023 Emissions Estimate Summary
Port of Bellingham
Bellingham, WA

Ship Type	Emissions Percentage by Ship Type (%)										
	DPM_{10}	$DPM_{2.5}$	NO_X	CO	SO_2	VOC	CO_2	CH_4	N_2O	BC	CO_2e
Refrigerated cargo	56%	55%	59%	46%	70%	58%	44%	58%	41%	9%	42%
Bulk carrier	8%	8%	9%	7%	10%	9%	6%	9%	6%	1%	6%
Tugboat	10%	11%	9%	19%	0%	8%	20%	8%	22%	44%	21%
Barge	10%	11%	8%	15%	0%	8%	19%	8%	21%	44%	20%
Ferry	15%	15%	15%	13%	19%	17%	11%	17%	11%	2%	11%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Location	Emissions Percentage by Location (metric tons/yr)										
	DPM_{10}	$DPM_{2.5}$	NO_X	CO	SO_2	VOC	CO_2	CH_4	N_2O	BC	CO_2e
Bellingham Cold Storage	59%	58%	62%	52%	70%	60%	49%	60%	46%	19%	48%
Bellingham Shipping Terminal	24%	25%	21%	31%	11%	21%	35%	21%	38%	68%	36%
C-Street Terminal	3%	3%	2%	5%	0%	2%	5%	2%	5%	11%	5%
Bellingham Cruise Terminal	15%	15%	15%	13%	19%	17%	11%	17%	11%	2%	11%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Bellingham Cold Storage	Emissions Percentage by Ship Type and Activity at Bellingham Cold Storage (%)										
	DPM_{10}	$DPM_{2.5}$	NO_X	CO	SO_2	VOC	CO_2	CH_4	N_2O	BC	CO_2e
Refrigerated Cargo Maneuvering	3%	3%	3%	3%	3%	4%	2%	4%	2%	1%	2%
Refrigerated Cargo Hoteling	93%	93%	93%	87%	97%	93%	87%	93%	86%	44%	87%
Tugboats	4%	4%	4%	10%	0%	3%	10%	3%	12%	54%	11%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Bellingham Shipping Terminal	Emissions Percentage by Ship Type and Activity at Bellingham Shipping Terminal (%)										
	DPM_{10}	$DPM_{2.5}$	NO_X	CO	SO_2	VOC	CO_2	CH_4	N_2O	BC	CO_2e
Bulk Carrier Maneuvering	1%	1%	1%	1%	2%	3%	0%	3%	0%	0%	0%
Barge Maneuvering	1%	1%	1%	1%	0%	1%	1%	1%	1%	2%	1%
Tugboats	28%	28%	27%	37%	3%	24%	36%	24%	37%	41%	36%
Barge Hoteling	37%	38%	31%	40%	4%	33%	45%	33%	46%	55%	46%
Bulk Carrier Hoteling	33%	32%	41%	21%	91%	39%	18%	39%	15%	2%	17%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

C-Street Terminal	Emissions Percentage by Ship Type and Activity at C-Street Terminal (%)										
	DPM_{10}	$DPM_{2.5}$	NO_X	CO	SO_2	VOC	CO_2	CH_4	N_2O	BC	CO_2e
Barge Maneuvering	5%	5%	4%	4%	5%	6%	5%	6%	5%	5%	5%
Tugboats	48%	48%	56%	59%	51%	45%	51%	45%	51%	48%	51%
Barge Hoteling	47%	47%	40%	37%	44%	49%	44%	49%	44%	47%	44%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Bellingham Cruise Terminal	Emissions Percentage by Ship Type and Activity at Bellingham Cruise Terminal (%)										
	DPM_{10}	$DPM_{2.5}$	NO_X	CO	SO_2	VOC	CO_2	CH_4	N_2O	BC	CO_2e
Ferry Maneuvering	15%	15%	13%	18%	17%	25%	12%	25%	13%	15%	12%
Ferry Hoteling	85%	85%	87%	82%	83%	75%	88%	75%	87%	85%	88%
Total	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%	100%

Table 3
Marine Vessel Input Assumption and Emission Estimates
Port of Bellingham
Bellingham, WA

Engine Type	Emission Factor [1] (g/kWh)										
	DPM_{10}	$DPM_{2.5}$	NO_X	CO	SO_2	VOC	CO_2	CH_4	N_2O	BC	CO_2e
Medium-Speed Diesel Propulsion Engine (C3)	0.19	0.17	13.2	1.10	0.40	0.53	657	0.010	0.029	5.2E-03	670
Slow-Speed Diesel Propulsion Engine (C3)	0.18	0.17	16.0	1.40	0.36	0.63	593	0.012	0.029	5.1E-03	606
Auxiliary Engine (C3)	0.19	0.17	13.8	1.10	0.42	0.42	696	8.0E-03	0.029	5.2E-03	709
Tugboat Propulsion Engine (C1)	0.070	0.068	4.81	1.10	6.2E-03	0.11	679	2.0E-03	0.033	0.052	736
Auxiliary Engine (C1)	0.080	0.078	4.02	0.80	6.2E-03	0.14	679	2.6E-03	0.033	0.060	742
C3 Propulsion Engine Low-Load Adjustment Factors 10% (unitless) [2]	1.38	1.38	1.22	1.96	1.95	2.20	1.25	2.20	1.22	1.38	--
C3 Propulsion Engine Low-Load Adjustment Factors 6% (unitless) [2]	2.04	2.04	1.60	3.25	3.21	4.35	1.59	4.35	1.60	2.04	--
C3 Propulsion Engine Low-Load Adjustment Factors 3% (unitless) [2]	4.33	4.33	2.92	6.46	6.38	11.7	2.44	11.7	2.92	4.33	--
C3 Propulsion Engine Low-Load Adjustment Factors =< 2% (unitless) [2]	7.29	7.29	4.63	9.68	9.54	21.2	3.28	21.2	4.63	7.29	--

Global Warming Potentials [1]		
CH_4 GWP	N_2O GWP	BC GWP
29.8	273	900

Marine Vessel Type	Engine Operating Mode	Operating Time (hrs/trip)	Number of Trips (trips/yr)	Propulsion Engine Size (kW)	Propulsion Engine Load Factor	Auxiliary Engine Size (kW)	Auxiliary Engine Load Factor	Auxiliary and Propulsion Engine Emissions [a] (metric tons/yr)										
								DPM_{10}	$DPM_{2.5}$	NO_X	CO	SO_2	VOC	CO_2	CH_4	N_2O	BC	CO_2e
BELLINGHAM COLD STORAGE - INBOUND MANEUVERING BEFORE TUGS (INCLUDES TUGS ARRIVING)																		
Refrigerated Cargo	Maneuvering	0.15 [3]	13 [6]	9,200 [7]	0.06 [8]	1,150 [11]	1.00 [11]	8.3E-04	7.6E-04	0.059	7.4E-03	2.2E-03	3.9E-03	2.58	7.4E-05	1.1E-04	2.3E-05	2.63
Tugboat	Transit	0.13 [4]	26 [5]	3,512 [17]	0.50 [4]	285 [17]	0.43 [12]	4.3E-04	4.2E-04	0.029	6.6E-03	3.8E-05	6.6E-04	4.15	1.2E-05	2.0E-04	3.2E-04	4.49
BELLINGHAM COLD STORAGE - INBOUND MANEUVERING																		
Refrigerated Cargo	Maneuvering	0.25 [3]	13 [6]	9,200 [7]	0.00 [8]	1,150 [11]	1.00 [11]	8.7E-04	8.0E-04	0.060	5.7E-03	2.0E-03	3.2E-03	2.83	6.0E-05	1.2E-04	2.4E-05	2.89
Tugboat	Maneuvering	0.25 [3]	26 [5]	3,512 [17]	0.50 [4]	285 [17]	0.43 [12]	8.6E-04	8.4E-04	0.058	0.013	7.6E-05	1.3E-03	8.30	2.5E-05	4.1E-04	6.4E-04	8.99
BELLINGHAM COLD STORAGE - DOCK ARRIVAL																		
Refrigerated Cargo	Maneuvering	0.75 [4]	13 [6]	9,200 [7]	0.00 [8]	1,150 [11]	1.00 [11]	2.1E-03	2.0E-03	0.16	0.012	4.8E-03	4.8E-03	7.82	9.2E-05	3.3E-04	5.9E-05	7.96
Tugboat	Maneuvering	0.75 [4]	26 [5]	3,512 [17]	0.75 [4]	285 [17]	0.43 [12]	3.8E-03	3.7E-03	0.26	0.058	3.4E-04	5.7E-03	36.5	1.1E-04	1.8E-03	2.8E-03	39.6
BELLINGHAM COLD STORAGE - TUGS LEAVING																		
Tugboat	Transit	0.25 [4]	26 [5]	3,512 [17]	0.50 [4]	285 [17]	0.43 [12]	8.6E-04	8.4E-04	0.058	0.013	7.6E-05	1.3E-03	8.30	2.5E-05	4.1E-04	6.4E-04	8.99
BELLINGHAM COLD STORAGE - HOTELING																		
Refrigerated Cargo	Hoteling	88.60 [6]	13 [4]	9,200 [7]	0.00 [10]	1,080 [11]	1.00 [11]	0.23	0.22	17.2	1.37	0.53	0.52	865	1.0E-02	0.036	6.5E-03	881
BELLINGHAM COLD STORAGE - TUGS ARRIVING																		
Tugboat	Transit	0.25 [4]	26 [5]	3,512 [17]	0.50 [4]	285 [17]	0.43 [12]	8.6E-04	8.4E-04	0.058	0.013	7.6E-05	1.3E-03	8.30	2.5E-05	4.1E-04	6.4E-04	8.99
BELLINGHAM COLD STORAGE - DOCK DEPARTURE																		
Refrigerated Cargo	Maneuvering	0.50 [3]	13 [6]	9,200 [7]	0.00 [8]	1,150 [11]	1.00 [11]	1.4E-03	1.3E-03	0.10	8.3E-03	3.2E-03	3.2E-03	5.21	6.1E-05	2.2E-04	3.9E-05	5.31
Tugboat	Maneuvering	0.50 [3]	26 [5]	3,512 [17]	0.75 [4]	285 [17]	0.43 [12]	2.5E-03	2.4E-03	0.17	0.039	2.2E-04	3.8E-03	24.3	7.3E-05	1.2E-03	1.9E-03	26.4
BELLINGHAM COLD STORAGE - OUTBOUND MANEUVERING																		
Refrigerated Cargo	Maneuvering	0.25 [3]	13 [6]	9,200 [7]	0.00 [8]	1,150 [11]	1.00 [11]	8.7E-04	8.0E-04	0.060	5.7E-03	2.0E-03	3.2E-03	2.83	6.0E-05	1.2E-04	2.4E-05	2.89
Tugboat	Maneuvering	0.25 [3]	26 [5]	3,512 [17]	0.50 [4]	285 [17]	0.43 [12]	8.6E-04	8.4E-04	0.058	0.013	7.6E-05	1.3E-03	8.30	2.5E-05	4.1E-04	6.4E-04	8.99
BELLINGHAM COLD STORAGE - OUTBOUND TRANSIT (INCLUDES TUGS LEAVING)																		
Refrigerated Cargo	Maneuvering	0.15 [3]	13 [6]	9,200 [7]	0.06 [8]	1,150 [11]	1.00 [11]	8.3E-04	7.6E-04	0.059	7.4E-03	2.2E-03	3.9E-03	2.58	7.4E-05	1.1E-04	2.3E-05	2.63
Tugboat	Transit	0.13 [4]	26 [5]	3,512 [17]	0.50 [4]	285 [17]	0.43 [12]	4.5E-04	4.4E-04	0.030	6.9E-03	4.0E-05	6.8E-04	4.31	1.3E-05	2.1E-04	3.4E-04	4.67

Table 3
Marine Vessel Input Assumption and Emission Estimates
Port of Bellingham
Bellingham, WA

BELLINGHAM SHIPPING TERMINAL - INBOUND MANEUVERING BEFORE TUGS (INCLUDES TUGS ARRIVING)																					
Bulk Carrier	Maneuvering	0.15 [3]	3 [6]	6,900 [13]	0.06 [9]	310 [14]	1.00 [14]	2.8E-04	2.5E-04	0.016	2.7E-03	7.0E-04	2.6E-03	0.46	4.8E-05	2.9E-05	7.6E-06	0.48
Tugboat	Transit	0.13 [4]	6 [5]	3,512 [17]	0.50 [4]	285 [17]	0.43 [12]	1.0E-04	9.7E-05	6.7E-03	1.5E-03	8.8E-06	1.5E-04	0.96	2.9E-06	4.7E-05	7.4E-05	1.04
BELLINGHAM SHIPPING TERMINAL - INBOUND MANEUVERING																					
Bulk Carrier	Maneuvering	0.25 [3]	3 [6]	6,900 [13]	0.01 [9]	310 [14]	1.00 [14]	1.0E-04	9.6E-05	6.6E-03	8.7E-04	2.6E-04	7.1E-04	0.25	1.3E-05	1.3E-05	2.9E-06	0.26
Tugboat	Maneuvering	0.25 [3]	34 [5]	3,512 [17]	0.50 [4]	285 [17]	0.43 [12]	1.1E-03	1.1E-03	0.076	0.017	1.0E-04	1.7E-03	10.8	3.3E-05	5.3E-04	8.4E-04	11.8
Barge	Maneuvering	0.25 [3]	28 [6]	0 [18]	0.00 [18]	622 [17]	0.43 [12]	1.5E-04	1.5E-04	7.5E-03	1.5E-03	1.2E-05	2.6E-04	1.27	4.9E-06	6.2E-05	1.1E-04	1.39
BELLINGHAM SHIPPING TERMINAL - DOCK ARRIVAL																					
Bulk Carrier	Maneuvering	0.75 [4]	3 [6]	6,900 [13]	0.00 [9]	310 [14]	1.00 [14]	1.4E-04	1.3E-04	1.0E-02	8.3E-04	3.1E-04	3.6E-04	0.49	6.8E-06	2.1E-05	3.8E-06	0.50
Tugboat	Maneuvering	0.75 [4]	34 [5]	3,512 [17]	0.75 [4]	285 [17]	0.43 [12]	5.0E-03	4.8E-03	0.34	0.076	4.4E-04	7.5E-03	47.8	1.4E-04	2.3E-03	3.7E-03	51.7
Barge	Maneuvering	0.75 [4]	28 [6]	0 [18]	0.00 [18]	622 [17]	0.43 [12]	4.5E-04	4.4E-04	0.023	4.5E-03	3.5E-05	7.7E-04	3.82	1.5E-05	1.9E-04	3.4E-04	4.17
BELLINGHAM SHIPPING TERMINAL - TUGS LEAVING																					
Tugboat	Transit	0.25 [4]	6 [5]	3,512 [17]	0.50 [4]	285 [17]	0.43 [12]	2.0E-04	2.1E-04	0.015	3.4E-03	1.9E-05	3.3E-04	2.11	6.3E-06	1.0E-04	1.6E-04	2.29
BELLINGHAM SHIPPING TERMINAL - HOTELING																					
Bulk Carrier	Hoteling	216 [6]	3 [6]	6,900 [13]	0 [10]	280 [14]	1.00 [14]	0.034	0.031	2.50	0.20	0.077	0.076	126	1.5E-03	5.3E-03	9.4E-04	129
Tugboat	Hoteling	64.0 [6]	28 [5]	3,512 [17]	0 [10]	285 [17]	0.43 [12]	0.018	0.017	0.88	0.18	1.4E-03	0.030	149	5.7E-04	7.3E-03	0.013	163
Barge	Hoteling	64.0 [6]	28 [6]	0 [18]	0 [18]	622 [17]	0.43 [12]	0.038	0.037	1.93	0.38	3.0E-03	0.066	326	1.2E-03	0.016	0.029	356
BELLINGHAM SHIPPING TERMINAL - TUGS ARRIVING																					
Tugboat	Transit	0.25 [4]	6 [5]	3,512 [17]	0.50 [4]	285 [17]	0.43 [12]	2.0E-04	1.9E-04	0.013	3.0E-03	1.8E-05	3.0E-04	1.91	5.7E-06	9.4E-05	1.5E-04	2.07
BELLINGHAM SHIPPING TERMINAL - DOCK DEPARTURE																					
Bulk Carrier	Maneuvering	0.50 [3]	3 [6]	6,900 [13]	0.00 [9]	310 [14]	1.00 [14]	9.2E-05	8.5E-05	6.6E-03	5.5E-04	2.1E-04	2.4E-04	0.33	4.5E-06	1.4E-05	2.5E-06	0.34
Tugboat	Maneuvering	0.50 [3]	34 [5]	3,512 [17]	0.75 [4]	285 [17]	0.43 [12]	3.3E-03	3.2E-03	0.22	0.051	2.9E-04	5.0E-03	31.8	9.5E-05	1.6E-03	2.5E-03	34.5
Barge	Maneuvering	0.50 [3]	28 [6]	0 [18]	0.00 [18]	622 [17]	0.43 [12]	3.0E-04	2.9E-04	0.015	3.0E-03	2.3E-05	5.1E-04	2.54	9.7E-06	1.2E-04	2.2E-04	2.78
BELLINGHAM SHIPPING TERMINAL - OUTBOUND MANEUVERING																					
Bulk Carrier	Maneuvering	0.25 [3]	3 [6]	6,900 [13]	0.01 [9]	310 [14]	1.00 [14]	1.0E-04	9.6E-05	6.6E-03	8.7E-04	2.6E-04	7.1E-04	0.25	1.3E-05	1.3E-05	2.9E-06	0.26
Tugboat	Maneuvering	0.25 [3]	34 [5]	3,512 [17]	0.50 [4]	285 [17]	0.43 [12]	1.1E-03	1.1E-03	0.076	0.017	1.0E-04	1.7E-03	10.8	3.3E-05	5.3E-04	8.4E-04	11.8
Barge	Maneuvering	0.25 [3]	28 [6]	0 [18]	0.00 [18]	622 [17]	0.43 [12]	1.5E-04	1.5E-04	7.5E-03	1.5E-03	1.2E-05	2.6E-04	1.27	4.9E-06	6.2E-05	1.1E-04	1.39
BELLINGHAM SHIPPING TERMINAL - OUTBOUND MANEUVERING																					
Bulk Carrier	Maneuvering	0.15 [3]	3 [6]	6,900 [13]	0.06 [9]	310 [14]	1.00 [14]	9.6E-05	8.8E-05	6.7E-03	1.0E-03	2.8E-04	5.7E-04	0.27	1.1E-05	1.3E-05	2.7E-06	0.28
Tugboat	Transit	0.13 [4]	6 [5]	3,512 [17]	0.50 [4]	622 [17]	0.43 [12]	1.1E-04	1.1E-04	7.4E-03	1.7E-03	9.9E-06	1.7E-04	1.07	3.3E-06	5.2E-05	8.4E-05	1.16
C-STREET TERMINAL - INBOUND MANEUVERING																					
Tugboat	Maneuvering	0.50 [24]	12 [5]	3,512 [17]	0.50 [4]	285 [17]	0.43 [12]	8.0E-04	7.7E-04	0.054	0.012	7.0E-05	1.2E-03	7.66	2.3E-05	3.7E-04	6.0E-04	8.30
Barge	Maneuvering	0.50 [24]	12 [6]	0 [18]	0.00 [18]	622 [17]	0.43 [12]	1.3E-04	1.2E-04	6.5E-03	1.3E-03	1.0E-05	2.2E-04	1.09	4.2E-06	5.3E-05	9.6E-05	1.19
C-STREET TERMINAL - DOCK ARRIVAL																					
Tugboat	Maneuvering	0.75 [4]	12 [5]	3,512 [17]	0.75 [4]	285 [17]	0.43 [12]	1.7E-03	1.7E-03	0.12	0.027	1.5E-04	2.6E-03	16.9	5.0E-05	8.2E-04	1.3E-03	18.3
Barge	Maneuvering	0.75 [4]	12 [6]	0 [18]	0.00 [18]	622 [17]	0.43 [12]	1.9E-04	1.9E-04	9.7E-03	1.9E-03	1.5E-05	3.3E-04	1.64	6.3E-06	8.0E-05	1.4E-04	1.79
C-STREET TERMINAL - TUGS LEAVING																					
Tugboat	Transit	0.25 [4]	12 [5]	3,512 [17]	0.50 [4]	285 [17]	0.43 [12]	4.0E-04	3.9E-04	0.027	6.1E-03	3.5E-05	6.1E-04	3.83	1.1E-05	1.9E-04	3.0E-04	4.15
C-STREET TERMINAL - HOTELING																					
Barge	Hoteling	120.00 [6]	2 [6]	0 [18]	0.00 [18]	622 [17]	0.43 [12]	5.1E-03	5.0E-03	0.26	0.051	4.0E-04	8.8E-03	43.6	1.7E-04	2.1E-03	3.8E-03	47.7
C-STREET TERMINAL - TUGS ARRIVING																					
Tugboat	Transit	0.25 [4]	12 [5]	3,512 [17]	0.50 [4]	285 [17]	0.43 [12]	4.0E-04	3.9E-04	0.027	6.1E-03	3.5E-05	6.1E-04	3.83	1.1E-05	1.9E-04	3.0E-04	4.15
C-STREET TERMINAL - DOCK DEPARTURE																					
Tugboat	Maneuvering	0.50 [4]	12 [5]	3,512 [17]	0.75 [4]	285 [17]	0.43 [12]	1.2E-03	1.1E-03	0.079	0.018	1.0E-04	1.8E-03	11.2	3.4E-05	5.5E-04	8.7E-04	12.2
Barge	Maneuvering	0.50 [4]	12 [6]	0 [18]	0.00 [18]	622 [17]	0.43 [12]	1.3E-04	1.2E-04	6.5E-03	1.3E-03	1.0E-05	2.2E-04	1.09	4.2E-06	5.3E-05	9.6E-05	1.19
C-STREET TERMINAL - OUTBOUND MANEUVERING																					
Tugboat	Maneuvering	0.50 [24]	12 [5]	3,512 [17]	0.50 [4]	285 [17]	0.43 [12]	8.0E-04	7.7E-04	0.054	0.012	7.0E-05	1.2E-03	7.66	2.3E-05	3.7E-04	6.0E-04	8.30
Barge	Maneuvering	0.50 [24]	12 [6]	0 [18]	0.00 [18]	622 [17]	0.43 [12]	1.3E-04	1.2E-04	6.5E-03	1.3E-03	1.0E-05	2.2E-04	1.09	4.2E-06	5.3E-05	9.6E-05	1.19
BELLINGHAM CRUISE TERMINAL - APPROACH																					
Ferry	Maneuvering	0.33 [22]	41 [20]	8,800 [6]	0.03 [23]	710 [21]	1.00 [21]	4.7E-03	4.3E-03	0.27	0.036	0.013	0.026	12.4	4.9E-04	5.8E-04	1.3E-04	12.7
BELLINGHAM CRUISE TERMINAL - INBOUND MANEUVERING																					
Ferry	Maneuvering	0.17 [22]	41 [20]	8,800 [6]	0.00 [23]	710 [21]	1.00 [21]	9.3E-04	8.6E-04	0.068	5.4E-03	2.1E-03	2.1E-03	3.44	4.0E-05	1.4E-04	2.6E-05	3.51
BELLINGHAM CRUISE TERMINAL - HOTELING																					
Ferry	Hoteling	10.00 [19]	41 [20]	8,800 [6]	0.00 [10]	710 [21]	1.00 [21]	0.055	0.051	4.02	0.32	0.12	0.12	203	2.3E-03	8.4E-03	1.5E-03	206
BELLINGHAM CRUISE TERMINAL - DEPARTURE																					
Ferry	Maneuvering	0.25 [22]	41 [20]	8,800 [6]	0.10 [23]	710 [21]	1.00 [21]	3.7E-03	3.4E-03	0.25	0.027	0.010	0.014	12.5	2.6E-04	5.3E-04	1.0E-04	12.7
Total Marine Vessel Emission Estimates								**0.43**	**0.40**	**29.8**	**3.05**	**0.78**	**0.94**	**2,042**	**0.018**	**0.091**	**0.076**	**2,136**

Table 3
Marine Vessel Input Assumption and Emission Estimates
Port of Bellingham
Bellingham, WA

Notes

g/kWh = grams per kilowatt-hour.

(a) Annual emissions estimate (tons/yr) = (([propulsion engine emission factor {g/kWh}] x [propulsion engine size {kW}] x [propulsion engine load factor] x [propulsion engine low load adjustment factor]) + [auxiliary engine emission factor {g/kWh}] x [auxiliary engine power {kW}] x [auxiliary engine load factor]) x [operating time {hrs/trip}] x [trips per year] x [auxiliary engine load adjustment factor]) x (operating time [hrs/trip]) x (number of trips [trips/yr]) x (lb/453.592 g) x (ton/2,000 lb)

References

(1) See Table 4, Marine Vessel Emmision actors.
(2) EPA Ports Emissions Inventory Guidance dated April 2022. See Section 3.7, Table 3.10.
(3) Information provided by Puget Sound pilot.
(4) Information provided by Foss Maritime.
(5) Assume two tugboats for each ship. Assume one tugboat for each barge.
(6) Number or average derived from vessel records.
(7) EPA Ports Emissions Inventory Guidance dated April 2022. See Appendix C, Table C.4. Assumes refrigerated cargo ship (reefer) equipped with a C3 slow-speed diesel engine is representative.
(8) EPA Ports Emissions Inventory Guidance dated April 2022. See Section 3.9.3.
Load factor can be calculated using Equations 3.13 and 3.14 and varies with the cube of vessel speed divided by maximum vessel speed.
Assume an average operating speed of 7.5 kn before tugs arrive, 3 kn for maneuvering with tugs, and 1 kn for dock arrival/departure. Assume maximum speed of 20 kn.
(9) EPA Ports Emissions Inventory Guidance dated April 2022. See Section 3.9.3.
Load factor can be calculated using Equations 3.13 and 3.14 and varies with the cube of vessel speed divided by maximum vessel speed.
Assume an average operating speed of 5.5 kn before tugs arrive, 3 kn for maneuvering with tugs, and 1 kn for dock arrival/departure. Assume maximum speed of 15 kn.
(10) EPA Ports Emissions Inventory Guidance dated April 2022. Per Section 3.8.6, propulsion engines can be assumed to be off while hoteling and at anchor.
(11) EPA Ports Emissions Inventory Guidance dated April 2022. See Appendix E, Table E.1. Assumes refrigerated cargo ship as representative.
(12) EPA Ports Emissions Inventory Guidance dated April 2022. Per Section 4.6., "an auxiliary engine load factor of 0.43 can be assumed for all ship types unless detailed local data indicate otherwise."
(13) EPA Ports Emissions Inventory Guidance dated April 2022. See Appendix C, Table C.1. Assumes handysize bulk carrier equipped with a C3 slow-speed diesel engine is representative.
(14) EPA Ports Emissions Inventory Guidance dated April 2022. See Appendix E, Table E.1. Assumes handysize bulk carrier is representative.
(15) EPA Ports Emissions Inventory Guidance dated April 2022. See Appendix G, Table G.1.
(16) EPA Ports Emissions Inventory Guidance dated April 2022. Per Table 4.4, "Default Harbor Craft Propulsion and Auxiliary Engine Load Factors."
(17) EPA Ports Emissions Inventory Guidance dated April 2022. See Appendix G, Table G.1, "Default Harbor Craft Engine Sizes and Annual Activity"
(18) EPA Ports Emissions Inventory Guidance dated April 2022. See Section 4.1. Assume barges do not have propulsion engines.
(19) Alaska Marine Highway System Sailing Calendar
(20) Alaska Marine Highway System Annual Traffic Volume Report, 2023
(21) EPA Ports Emissions Inventory Guidance dated April 2022. See Appendix E, Table E.1, "Default OGV Auxiliary Engine Operating Loads by Mode." Assumes largest ferry/roll-on/passenger is representative.
(22) Time approximations derived from plotting AIS records of AMHS vessels approaching and departing Cruise Terminal. AIS records assumed to be representative.
(23) EPA Ports Emissions Inventory Guidance dated April 2022. See Section 3.9.3.
Load factor can be calculated using Equations 3.13 and 3.14 and varies with the cube of vessel speed divided by maximum vessel speed.
Assume an average operating speed of 6 kn for Cruise Terminal approach, 0.5 kn for maneuvering, and 9 kn for departure. Assume maximum speed of 20 kn.
(24) Time approximations derived from plotting AIS records of vessels approaching and departing C-Street Terminal. AIS records assumed to be representative.

Table 4
Marine Vessel Emission Factors
Port of Bellingham
Bellingham, WA

Parameter	EPA Acronym	(Units)	Medium-Speed Diesel Propulsion Engine (C3)	Slow-Speed Diesel Propulsion Engine (C3)	Auxiliary Engine (C3)	Tugboat Propulsion Engine (C1)	Auxiliary Engine (C1)
Brake-Specific Fuel Consumption	BSFC	(g/kWh)	205 (1)	185 (1)	217 (1)	213 (2)	213 (2)
Base Emission Factor Assuming Zero Fuel Sulfur	PM_{base}	(g/kWh)	0.1545 (3)	0.1545 (3)	0.1545 (3)	--	--
Actual Fuel Sulfur Level	S_{act}	--	0.001 (3)	0.001 (3)	0.001 (3)	0.000015 (24)	0.000015 (24)
Fraction of Sulfur in Fuel that is Converted to Direct Sulfate PM	FSC	--	0.02247 (3)	0.02247 (3)	0.02247 (3)	--	--
Molecular Weight Ratio of Sulfate PM to Sulfur	MWR	--	7 (3)	7 (3)	7 (3)	--	--
Fraction of Sulfur in Fuel that is Converted to SO_2	FSC	--	0.97753 (4)	0.97753 (4)	0.97753 (4)	0.97753 (4)	0.97753 (4)
Molecular Weight Ratio of SO_2 to Sulfur	MWR	--	2 (4)	2 (4)	2 (4)	2 (4)	2 (4)
HC Emission Factor	--	(g/kWh)	0.5 (5)	0.6 (5)	0.4 (5)	0.1 (21)	0.13 (22)
Carbon Content Factor	CCF	(g-CO_2/g fuel)	3.206 (6)	3.206 (6)	3.206 (6)	3.19 (23)	3.19 (23)
CH_4 Percentage of HC Emission Factor	--	(%)	2 (7)	2 (7)	2 (7)	--	--
Black Carbon (BC) Percentage of $DPM_{2.5}$ Emission Factor	--	(%)	3 (10)	3 (10)	3 (10)	--	--
N_2O Conversion Factor	NCF	(g N_2O/g fuel)	--	--	--	0.000156 (24)	0.000156 (24)
CH_4 GWP	--	--	29.8 (13)	29.8 (13)	29.8 (13)	29.8 (13)	29.8 (13)
N_2O GWP	--	--	273 (13)	273 (13)	273 (13)	273 (13)	273 (13)
BC GWP	--	--	900 (14)	900 (14)	900 (14)	900 (14)	900 (14)
EMISSION FACTORS							
DPM_{10}	--	(g/kWh)	0.19 (a)	0.18 (a)	0.19 (a)	0.07 (15)	0.08 (16)
$DPM_{2.5}$	--	(g/kWh)	0.17 (9)	0.17 (9)	0.17 (9)	0.07 (15)	0.08 (16)
BC	--	(g/kWh)	0.01 (10)	0.01 (10)	0.01 (10)	0.05 (15)	0.06 (16)
NO_X	--	(g/kWh)	13.20 (11)	16.00 (12)	13.80 (11)	4.81 (17)	4.02 (18)
CO	--	(g/kWh)	1.10 (5)	1.40 (5)	1.10 (5)	1.10 (19)	0.80 (20)
SO_2	--	(g/kWh)	0.40 (b)	0.36 (b)	0.42 (b)	0.01 (b)	0.01 (b)
VOC	--	(g/kWh)	0.53 (c)	0.63 (c)	0.42 (c)	0.11 (21)	0.14 (22)
CO_2	--	(g/kWh)	657 (d)	593 (d)	696 (d)	679 (d)	679 (d)
CH_4	--	(g/kWh)	0.010 (e)	0.012 (e)	0.008 (e)	0.002 (21)	0.003 (22)
N_2O	--	(g/kWh)	0.029 (25)	0.029 (25)	0.029 (25)	0.03 (g)	0.03 (g)
CO_2e	--	(g/kWh)	670 (f)	606 (f)	709 (f)	736 (f)	742 (f)

See Notes and References on the following pages.

Table 4
Marine Vessel Emission Factors
Port of Bellingham
Bellingham, WA

Notes

g/kWh = grams per kilowatt-hour; GWP = global warming potential

(a) DPM_{10} emission factor (g/kWh) = (PM_{base} [g/kWh]) x ([S_{act}] x [BSFC {g/kWh}] x [FSC] x [MWR]) (3)

(b) SO_2 emission factor (g/kWh) = (BSFC [g/kWh]) x (S_{act}) x (FSC) x (MWR) (4)

(c) VOC emission factor (g/kWh) = (HC emission factor [g/kWh]) x (1.053) (7)

(d) CO_2 emission factor (g/kWh) = (BSFC [g/kWh]) x (CCF [g CO_2/g fuel]) (6)

(e) CH_4 emission factor (g/kWh) = (HC emission factor [g/kWh]) x (CH_4 percentage of HC emission factor [%] / 100 (7)

(f) CO_2e emission factor (g/kWh) = (CO_2 emission factor [g/kWh]) + (CH_4 emission factor [g/kWh]) x (CH_4 GWP) + (N_2O emission factor [g/kWh]) x (N_2O GWP) + (BC emission factor [g/kWh]) x (BC GWP)

(g) N_2O emission factor (g/kWh) = (BSFC [g/kWh]) x (NCF [g N_2O/g fuel]) (8)

References

(1) EPA Ports Emissions Inventory Guidance dated April 2022. See Table 3.6, "Category 3 Vessel BSFC Rates (g/kWh)."

(2) EPA Ports Emissions Inventory Guidance dated April 2022. See Table 4.3, "Category 1 and 2 BSFC Rates (g/kWh)."

(3) EPA Ports Emissions Inventory Guidance dated April 2022. See notes to Equation 3.3.

(4) EPA Ports Emissions Inventory Guidance dated April 2022. See notes to Equation 3.5.

(5) EPA Ports Emissions Inventory Guidance dated April 2022. See Table 3.8, "Category 3 Vessel HC and CO Emission Factors (g/kWh)."

(6) EPA Ports Emissions Inventory Guidance dated April 2022. See notes to Equation 3.4.

(7) EPA Ports Emissions Inventory Guidance dated April 2022. See Section 3.5.4.

(8) EPA Ports Emissions Inventory Guidance dated April 2022. See notes to Equation 4.3.

(9) EPA Ports Emissions Inventory Guidance dated April 2022. See notes to Section 3.5.3.

(10) EPA Ports Emissions Inventory Guidance dated April 2022. See Section 3.5.3.

(11) EPA Ports Emissions Inventory Guidance dated April 2022. See Table 3.5, "Category 3 Vessel NO_X Emission Factors (g/kWh)." Assumes medium-speed diesel engine and keel-laid year of 1999 and earlier as representative.

(12) EPA Ports Emissions Inventory Guidance dated April 2022. See Table 3.5, "Category 3 Vessel NO_X Emission Factors (g/kWh)." Assumes slow-speed diesel engine and keel-laid year of 2000-2010 and earlier as representative.

(13) IPCC Sixth Assessment Report. Climate Change 2021: The Physical Science Basis. Working Group I, Chapter 7, Table 7.15.

(14) IPCC Fifth Assessment Report, Climate Change 2013, Chapter 8, Table 8.A.6, "Global warming potential and global temperature potential from the literature for black carbon and organic carbon for time horizons of 20 and 100 years."

(15) EPA Ports Emissions Inventory Guidance dated April 2022. See Appendix H, Table H.2, "Category 1 and 2 PM ULSD Emission Factors (g/kWh)." Assume Tier 3 C1 propulsion engine with displacement of 3.5-7 liters per cylinder, power range > 1400 kW, and model year range 2012-2015 is representative.

(16) EPA Ports Emissions Inventory Guidance dated April 2022. See Appendix H, Table H.2, "Category 1 and 2 PM ULSD Emission Factors (g/kWh)." Assume Tier 3 C1 auxiliary engine with displacement of 0.9-1.2 liters per cylinder, power range < 600 kW, and model year range 2013+ is representative.

(17) EPA Ports Emissions Inventory Guidance dated April 2022. See Appendix H, Table H.1, "Category 1 and 2 NO_x Emission Factors (g/kWh)." Assume Tier 3 C1 propulsion engine with displacement of 3.5-7 liters per cylinder, power range > 1400 kW, and model year range 2012-2015 is representative.

(18) EPA Ports Emissions Inventory Guidance dated April 2022. See Appendix H, Table H.1, "Category 1 and 2 NOx Emission Factors (g/kWh)." Assume Tier 3 C1 auxiliary engine with displacement of 0.9-1.2 liters per cylinder, power range < 600 kW, and model year range 2013+ is representative.

(19) EPA Ports Emissions Inventory Guidance dated April 2022. See Appendix H, Table H.5, "Category 1 and 2 CO Emission Factors (g/kWh)." Assume Tier 3 C1 propulsion engine with displacement of 3.5-7 liters per cylinder, power range > 37 kW, and model year range 2007+ is representative.

(20) EPA Ports Emissions Inventory Guidance dated April 2022. See Appendix H, Table H.5, "Category 1 and 2 CO Emission Factors (g/kWh)." Assume Tier 3 C1 auxiliary engine with displacement of 0.9-1.2 liters per cylinder, power range > 37 kW, and model year range 2004+ is representative.

(21) EPA Ports Emissions Inventory Guidance dated April 2022. See Appendix H, Table H.4, "Category 1 and 2 HC, VOC, and CH_4 Emission Factors (g/kWh)." Assume Tier 3 C1 propulsion engine with displacement of 3.5-7 liters per cylinder, power range > 1400 kW, and model year range 2012-2015 is representative.

(22) EPA Ports Emissions Inventory Guidance dated April 2022. See Appendix H, Table H.4, "Category 1 and 2 HC, VOC, and CH_4 Emission Factors (g/kWh)." Assume Tier 3 C1 auxiliary engine with displacement of 0.9-1.2 liters per cylinder, power range < 600 kW, and model year range 2013+ is representative.

(23) EPA Ports Emissions Inventory Guidance dated April 2022. See notes to Equation 4.4.

(24) EPA Ports Emissions Inventory Guidance dated April 2022. See notes to Equation 4.5.

(25) EPA Ports Emissions Inventory Guidance dated April 2022. See Table 3.9, "Category 3 Vessel N_2O Emission Factors (g/kWh)."