Puget Sound Maritime Air Emissions Inventory

February 2018

PUGET SOUND MARITIME AIR FORUM

United States Environmental Protection Agency
pscleanair.org Puget Sound Clean Air Agency
Port of Anacortes Est. 1926
WSPA Western States Petroleum Association
Port of Seattle
Port of Port Angeles
CLIA Cruise Lines International Association North West & Canada
Port of Everett
Port of Olympia
Washington State Department of Transportation
Puget Sound Regional Council
The Northwest Seaport Alliance Gateway to Solutions
PMSA Pacific Merchant Shipping Association
Washington State Department of Ecology
Port of Tacoma
northwest Clean Air agency

Prepared by:

Starcrest Consulting Group, LLC
Environmental Management • Air Quality • Climate • Sustainability

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Prepared by:

Starcrest Consulting Group, LLC

Poulsbo, Washington 98370

STARCREST CONSULTING GROUP, LLC
ENVIRONMENTAL MANAGEMENT · AIR QUALITY · CLIMATE · SUSTAINABILITY

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ACKNOWLEDGEMENTS

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ACRONYMS AND ABBREVIATIONS

ATB	articulated tug-barge
BNSF	BNSF Railway Company
bhp	brake horsepower
BSFC	brake-specific fuel consumption
CARB	California Air Resource Board
CAS	Northwest Ports Clean Air Strategy
CFR	Code Federal Regulations
CH_4	methane
CHE	cargo-handling equipment
CO	carbon monoxide
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalents
DOC	diesel oxidation catalyst
DPF	diesel particulate filter
DPM	diesel particulate matter
DWT	deadweight in metric tons
ECA	emission control area
EF	emission factor
EMD	Electro-Motive Diesel, Inc.
EPA	U.S. Environmental Protection Agency
FCF	fuel correction factor
Forum	Puget Sound Maritime Air Forum
g	gram
gensets	electrical generator sets
GVWR	gross vehicle weight rating
HAL	Holland America Line
HC	hydrocarbon
HDDV	heavy-duty diesel fueled vehicle
HDGV	heavy-duty gasoline vehicle
HDV	heavy-duty vehicles
hp	horsepower
hr	hour
IFO	intermediate fuel oil
IMO	International Maritime Organization
kg	kilogram
K-Line	Kawasaki Kisen Kaisha
kW	kilowatts
kW-hr	kilowatt-hour
lbs	pounds
LDGT	light-duty gasoline truck
LDGV	light-duty gasoline vehicle
LDV	light-duty vehicles
LF	load factor
LLA	low load adjustment
LPG	liquefied petroleum gas
MarEx	Marine Exchange of Puget Sound
MARPOL	International Convention for the Prevention of Pollution from Ships
MCR	maximum continuous rated (power)
MOBILE	EPA on-road vehicle emission modeling software (superseded by MOVES)
mph	miles per hour
MOVES	Latest EPA emission modeling software for onroad and certain nonroad sources
N_2O	nitrous oxide
NAAQS	National Ambient Air Quality Standards
NO_x	oxides of nitrogen
NONROAD	EPA non-road equipment emission modeling software (superseded by MOVES)
NWCAA	Northwest Clean Air Agency
NWSA	Northwest Seaport Alliance
OGVs	ocean-going vessels
ORCAA	Olympic Region Clean Air Agency
PM	particulate matter
PM_{10}	particulate matter, diameter of ten microns or less
$PM_{2.5}$	particulate matter, diameter of 2.5 microns or less; fine particulate
POLA	Port of Los Angeles
POLB	Port of Long Beach
ppb	parts per billion
ppm	parts per million
PSCAA	Puget Sound Clean Air Agency
PSEI	Puget Sound Emissions Inventory
PSRC	Puget Sound Regional Council
RFID	radio-frequency identification
RIA	regulatory impact analysis
RO	residual oil
RoRo	roll-on/roll-off
rpm	revolutions per minute
RSD	Regulatory Support Document
RTG	rubber tired gantry (crane)
SIG	Seattle International Gateway
SO_2	sulfur dioxide
SO_x	sulfur oxides
TEU	twenty-foot equivalent units
tonnes	1,000 kg also known as a metric ton
TOTE	Totem Ocean Trailer Express
tpy	tons per year
U.S.	United States
USCG	United States Coast Guard
ULSD	ultra-low sulfur diesel (fuel)
UP	Union Pacific (Railroad)
VBP	Vessel Boarding Program
VLCC	very large crude carriers
VMT	vehicle miles traveled
VOCs	volatile organic compounds
VTS	Vessel Traffic Service
WDOE	Washington State Department of Ecology
WSF	Washington State Ferries
WSPA	Western States Petroleum Association

EXECUTIVE SUMMARY

The 2016 Puget Sound Maritime Emissions Inventory quantifies maritime-related emissions for calendar year 2016 and compares emissions and activity levels against previous inventories conducted in 2005 and 2011. These emission inventories allow ports, their partners and the public to track progress made in reducing emissions as a result of individual or collaborative emission reduction efforts.

The Puget Sound Maritime Emissions Inventory is the result of a unique partnership between ports around the Puget Sound, government agencies, and private business partners. The inventory includes data from major Puget Sound ports, the Washington State ferry system, regional rail operators, port related petroleum facilities and other non-military vessel operators.

Why were the inventories developed?
The purpose of the inventories is to provide a quantitative evaluation of emissions from maritime-related activities in the greater Puget Sound airshed. These studies improve the understanding of the nature, location, and magnitude of emissions from maritime-related operations, aid in the planning and prioritization of pollution prevention investments in the region, and evaluate the success of existing emission reduction programs.

Who developed the emissions inventory?
The inventory was funded by the Puget Sound Maritime Air Forum, a voluntary group of private and public maritime organizations, ports, air agencies, environmental, and other parties with operational or regulatory responsibilities related to the maritime industry. The Puget Sound Maritime Air Forum selected Starcrest Consulting Group, LLC (Starcrest) to be the technical lead for the inventory in collaboration with the Air Forum members. Some of the Puget Sound Maritime Air Forum members collected and provided data for the inventory update and/or provided estimates of regional on-road vehicle emissions.

What does the inventory measure?
This emissions inventory quantifies annual emissions from maritime-related activities associated with U.S. operations in a defined portion of the greater Georgia Basin/Puget Sound International Airshed (see Figure 1.1). The geographical domain used in the 2016 inventory is the same as the domain used in the 2005 and 2011 inventories and is referred to as the greater Puget Sound airshed in this report.

The 2016 inventory update is an activity-based inventory following a similar methodology as the 2005 and 2011 inventories. Data was gathered for the following source categories: ocean-going vessels (OGV), harbor vessels, recreational vessels, cargo-handling equipment (CHE), heavy-duty diesel trucks (HDV), fleet vehicles and locomotive operations.

Pollutants inventoried include relevant U.S. Environmental Protection Agency (EPA) criteria pollutants and precursors, including carbon monoxide, nitrogen oxides, sulfur dioxides, volatile organic compounds and fine particulate matter, as well as greenhouse gases (GHG), diesel particulate matter (DPM), and black carbon (BC). The 2016 PSEI marks the first time that black carbon emissions are included.

What are the findings?

Emissions were lower for all pollutants in 2016 as compared to 2005. Much of the emission reductions were due to significant voluntary investments by ports, the maritime industry and government agencies in cleaner equipment, vessels, trucks, and fuels, along with efforts to improve operational efficiency. The federal emission standards that are applicable to new vehicles and equipment since the baseline 2005 calendar year also lowered the emissions of several pollutants across many sectors.

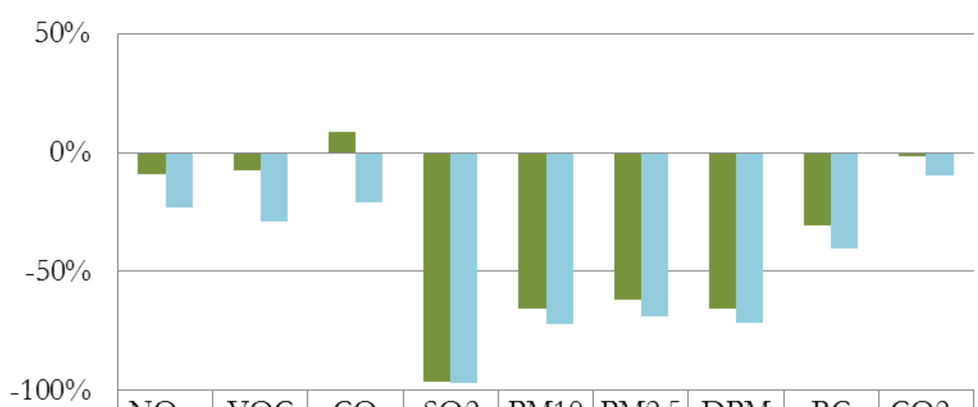
The NO_x and VOC emission reductions are mainly due to the lower emission standards for new equipment, trucks, and vessels along with fleet turnover. The SO_2 and PM_{10}/$PM_{2.5}$/DPM emissions were significantly reduced in 2016 due to the North American Emissions Control Area (ECA) established by the International Maritime Organization (IMO) since 2015, requiring that OGV use fuels with 0.1% sulfur within 200 miles from the U.S. coast.

The 2016 emissions compared to 2011 were lower for all pollutants, except for CO emissions. The 2016 vs 2011 CO emissions are higher mainly due to the harbor vessels increase in CO emissions resulting from newer engines with higher CO emission standards.

Table ES.1: Total Study Area Maritime-related Emissions Change, tpy and %

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	21,824	2,760	16,432	384	575	535	524	238	1,538,368
2011	24,040	2,988	15,086	10,899	1,679	1,403	1,515	342	1,560,273
2005	28,445	3,877	20,786	13,473	2,073	1,730	1,843	401	1,702,475
2016 vs 2011 Change	**-9%**	**-8%**	**9%**	**-96%**	**-66%**	**-62%**	**-65%**	**-30%**	**-1%**
2016 vs 2005 Change	**-23%**	**-29%**	**-21%**	**-97%**	**-72%**	**-69%**	**-72%**	**-41%**	**-10%**

Figure ES.1: Total Study Area Maritime-related Emissions Change, %



	NOx	VOC	CO	SO2	PM10	PM2.5	DPM	BC	CO2e
2016-2011	-9%	-8%	9%	-96%	-66%	-62%	-65%	-30%	-1%
2016-2005	-23%	-29%	-21%	-97%	-72%	-69%	-72%	-41%	-10%

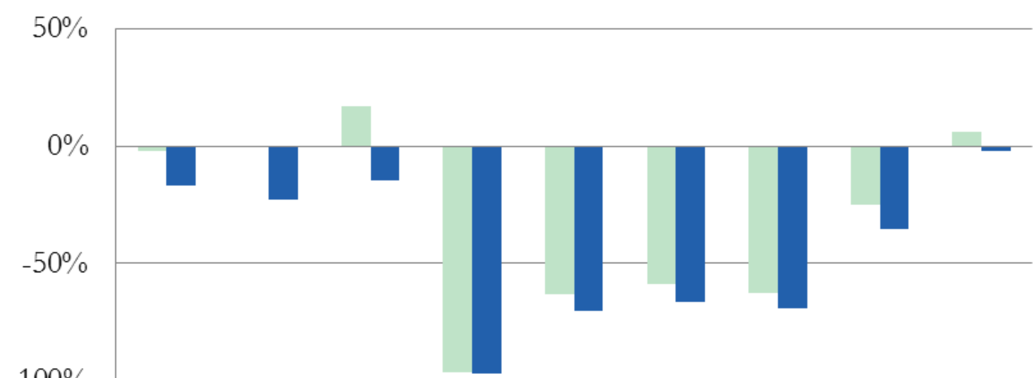
Table ES.2 and Figure ES.2 compare the emissions per 10,000 tons of cargo for the entire study area for 2016, 2011, and 2005. Emissions were normalized to cargo throughput to remove the effect of increasing or decreasing port business on emission trends and instead focus on impact of emission reduction measures. Results demonstrate that emissions of all pollutants were reduced relative to cargo throughput between 2005 and 2016.

Similarly, emissions for all pollutants per 10,000 tons of cargo, except for CO and CO_2e, decreased between 2011 and 2016. The CO and CO_2e (i.e., greenhouse gas) emissions per 10,000 tons of cargo increased primarily due to the harbor vessel and recreational vessel increases in activity not tied to the movement of cargo. Detailed comparisons of cargo normalized emissions for each port are presented in Sections 2 and 9, providing a more direct comparison of emissions related to the movement of cargo.

Table ES.2: Total Study Area Maritime-related Tons of Emissions per 10,000 Tons of Cargo Comparison

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	5.70	0.72	4.29	0.10	0.15	0.14	0.14	0.06	402
2011	5.84	0.73	3.67	2.65	0.41	0.34	0.37	0.08	379
2005	6.86	0.94	5.01	3.25	0.50	0.42	0.44	0.10	411
2016 vs 2011 Change	**-2%**	**-1%**	**17%**	**-96%**	**-63%**	**-59%**	**-63%**	**-25%**	**6%**
2016 vs 2005 Change	**-17%**	**-23%**	**-14%**	**-97%**	**-70%**	**-67%**	**-69%**	**-36%**	**-2%**

Figure ES.2: Total Study Area Maritime-related Tons of Emissions per 10,000 Tons of Cargo Change, %



	NOx	VOC	CO	SO2	PM10	PM2.5	DPM	BC	CO2e
2016-2011	-2%	-1%	17%	-96%	-63%	-59%	-63%	-25%	6%
2016-2005	-17%	-23%	-14%	-97%	-70%	-67%	-69%	-36%	-2%

Table ES.3 compares the total study area maritime-related 2016 emissions to 2005 by source category. Ocean-going vessel emissions decreased due lower sulfur fuel requirements of the North American ECA and due to an 8% reduction in vessel movements in 2016. More comprehensive marina data was available for year 2016, causing inventoried recreational vessel counts to increase. This increase does not likely reflect a real increase in regional emissions from recreational vessels when compared with 2011 and 2005, but rather more complete reporting. The commercial harbor vessel emissions increased for NO_x, VOC, CO, and CO_2e mainly due to increased activity. Locomotive emissions decreased due to cleaner locomotive engine standards and use of ultra-low sulfur diesel. Cargo handling equipment emissions decreased due to lowered emission standards and fleet turnover to newer, cleaner equipment. Heavy-duty vehicles emissions decreased due to significantly lower emissions standards for 2007 and newer trucks along with fleet turnover. The fleet vehicle emissions decreased due to lower activity and fleet turnover.

Table ES.3: 2016 vs 2005 Total Study Area Maritime-related Emissions by Source Category, tpy and %

	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016									
Ocean-going vessels	11,516	346	964	374	192	181	178	11	587,994
Harbor vessels	6,590	478	2,332	4	235	216	230	163	443,948
Recreational vessels	989	1,774	12,416	2	38	35	5	10	139,381
Locomotives	1,099	63	206	1	32	29	32	23	77,366
Cargo-handling equipment	332	32	182	0	17	17	17	12	49,838
Heavy-duty vehicles	1,297	66	320	2	61	57	61	19	238,805
Fleet vehicles	3	1	12	0.02	0.07	0.06	0.04	0.03	1,037
Total	**21,824**	**2,760**	**16,432**	**384**	**575**	**535**	**524**	**238**	**1,538,368**
2005									
Ocean-going vessels	15,836	542	1,202	12,789	1,514	1,212	1,336	36	827,705
Harbor vessels	6,122	380	1,144	405	277	255	274	194	368,087
Recreational vessels	734	2,590	15,966	23	55	51	6	11	113,354
Locomotives	2,460	123	308	193	67	61	67	47	106,058
Cargo-handling equipment	763	96	1,477	47	49	48	49	36	77,769
Heavy-duty vehicles	2,516	143	646	16	112	103	112	76	206,028
Fleet vehicles	13	3	42	0.23	0.44	0.40	0.36	0.26	3,474
Total	**28,445**	**3,877**	**20,786**	**13,473**	**2,073**	**1,730**	**1,843**	**401**	**1,702,475**
2016 vs 2005 Change									
Ocean-going vessels	-27%	-36%	-20%	-97%	-87%	-85%	-87%	-70%	-29%
Harbor vessels	8%	26%	104%	-99%	-15%	-15%	-16%	-16%	21%
Recreational vessels	35%	-32%	-22%	-89%	-31%	-31%	-16%	-11%	23%
Locomotives	-55%	-48%	-33%	-100%	-52%	-52%	-52%	-51%	-27%
Cargo-handling equipment	-57%	-67%	-88%	-99%	-65%	-65%	-65%	-66%	-36%
Heavy-duty vehicles	-48%	-54%	-50%	-87%	-45%	-45%	-45%	-75%	16%
Fleet vehicles	-80%	-79%	-72%	-92%	-85%	-85%	-89%	-88%	-70%
Total	**-23%**	**-29%**	**-21%**	**-97%**	**-72%**	**-69%**	**-72%**	**-41%**	**-10%**

Table ES.4 compares the total maritime-related 2016 emissions to 2011 by source category. Ocean-going vessel emissions decreased due to the lower fuel sulfur requirements of the North American ECA and due a 4% reduction in vessel movements in 2016. The commercial harbor vessel emissions increased for NO_x, VOC, CO, and CO_2e mainly due to increased activity. More comprehensive marina data was available for year 2016, causing inventoried recreational vessel count to increase. This increase does not likely reflect a real increase in regional emissions when compared with 2011 and 2005 from recreational vessels, but rather more complete reporting. Locomotive emissions decreased due to cleaner locomotive engine standards and use of ultra-low sulfur diesel fuel. Cargo handling equipment emissions decreased due to newer and cleaner equipment. Heavy-duty vehicles emissions decreased due to vehicle turnover to newer, cleaner vehicles. The fleet vehicle emissions decreased due to lower activity and fleet turnover.

Table ES.4: 2016 vs 2011 Total Study Area Maritime-related Emissions by Source Category, tpy and %

	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016									
Ocean-going vessels	11,516	346	964	374	192	181	178	11	587,994
Harbor vessels	6,590	478	2,332	4	235	216	230	163	443,948
Recreational vessels	989	1,774	12,416	2	38	35	5	10	139,381
Locomotives	1,099	63	206	1	32	29	32	23	77,366
Cargo-handling equipment	332	32	182	0	17	17	17	12	49,838
Heavy-duty vehicles	1,297	66	320	2	61	57	61	19	238,805
Fleet vehicles	3	1	12	0.02	0.07	0.06	0.04	0.03	1,037
Total	**21,824**	**2,760**	**16,432**	**384**	**575**	**535**	**524**	**238**	**1,538,368**
2011									
Ocean-going vessels	13,284	400	999	10,880	1,202	962	1,076	29	699,104
Harbor vessels	6,270	438	1,417	4	278	255	274	194	392,613
Recreational vessels	810	1,909	11,654	2	39	37	5	9	106,523
Locomotives	1,293	82	205	11	46	42	46	33	77,187
Cargo-handling equipment	456	32	251	1	29	28	29	21	57,961
Heavy-duty vehicles	1,919	125	523	2	85	78	85	56	223,681
Fleet vehicles	8	2	38	0.06	0.21	0.19	0.13	0.10	3,204
Total	**24,040**	**2,988**	**15,086**	**10,899**	**1,679**	**1,403**	**1,515**	**342**	**1,560,273**
2016 vs 2011 Change									
Ocean-going vessels	-13%	-14%	-3%	-97%	-84%	-81%	-83%	-63%	-16%
Harbor vessels	5%	9%	64%	15%	-15%	-15%	-16%	-16%	13%
Recreational vessels	22%	-7%	7%	34%	-5%	-5%	11%	10%	31%
Locomotives	-15%	-22%	0%	-93%	-31%	-30%	-31%	-30%	0%
Cargo-handling equipment	-27%	-2%	-27%	-40%	-40%	-40%	-40%	-41%	-14%
Heavy-duty vehicles	-32%	-47%	-39%	6%	-28%	-27%	-28%	-67%	7%
Fleet vehicles	-66%	-71%	-68%	-68%	-69%	-69%	-71%	-70%	-68%
Total	**-9%**	**-8%**	**9%**	**-96%**	**-66%**	**-62%**	**-65%**	**-30%**	**-1%**

Table ES.5 presents the 2016 contribution of the source categories to the maritime-related emissions of pollutants.

Table ES.5: 2016 Total Study Area Maritime-related Emissions Contribution by Source Category, %

Source Category	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
Ocean-going vessels, transit	42%	9%	5%	65%	24%	24%	26%	3%	26%
Ocean-going vessels, hotelling & maneuvering	11%	3%	1%	32%	10%	10%	8%	1%	13%
Harbor vessels	30%	17%	14%	1%	41%	40%	44%	69%	29%
Recreational vessels	5%	64%	76%	1%	7%	7%	1%	4%	9%
Locomotives	5%	2%	1%	0%	6%	6%	6%	10%	5%
Cargo-handling equipment	2%	1%	1%	0%	3%	3%	3%	5%	3%
Heavy-duty vehicles	6%	2%	2%	1%	11%	11%	12%	8%	16%
Fleet vehicles	<1%	<1%	<1%	<1%	<1%	<1%	<1%	<1%	<1%

What's being done now to reduce maritime air pollution?

The Puget Sound Maritime Air Forum partners are working within their own organizations on local, national, and international initiatives to reduce maritime-related emissions. The Forum partners and their customers are switching to cleaner fuels, replacing older engines with newer, cleaner engines, retrofitting older engines with advanced pollution control devices, rebuilding engines to lower emissions, and implementing strategies to use equipment more efficiently. In 2016, the ocean-going vessels calling the Puget Sound ports complied with the International Maritime Association (IMO) North American Emission Control Area (ECA) which considerably reduced SO_x and PM emissions by burning lower sulfur fuel (0.1% S) in their engines. In addition, some vessels are using shore power instead of ship auxiliary engines when they are in port.

The Northwest Ports Clean Air Strategy (NWPCAS) was developed collaboratively by the Port of Tacoma, the Port of Seattle and Port Metro Vancouver, British Columbia, along with the Puget Sound Clean Air Agency (PSCAA), EPA, the Washington State Department of Ecology (WDOE) and Environment Canada in 2007. The NWPCAS updated its goals in 2013. Since its formation in 2015, the NWSA is now also a full port partner to the NWPCAS. The NWPCAS defines voluntary air emission reduction goals, sector specific benchmarks, and implementation strategies. The NWPCAS's overarching goals were for an 80% reduction in DPM and a 15% reduction in CO_2e per ton of cargo by 2020 relative to the 2005 baseline year.

Implementation of the NWPCAS over the last ten years has achieved significant emission reductions in several areas: at-berth emissions for ocean going vessels using low-sulfur fuels and shore power; on-terminal emissions for cargo-handling equipment through exhaust retrofits and cleaner engines, on-terminal emissions for drayage trucks through engine retrofits and scrap-and-replace incentive programs, and regional emissions for locomotives through engine replacement and application of idle-reduction technologies. Based on results of the 2016 PSEI, the NWPCAS partners are on target to meet these emission reduction goals.

What's next?

This inventory provides the most complete and up to date summary of the maritime-related emissions in the greater Puget Sound region. The 2016 inventory results will help the maritime community continue to track progress on pollution reduction efforts and focus future investments to reduce air pollution and greenhouse gas emissions.

SECTION 1 INTRODUCTION

This section provides an overview of the inventory scope, a background of current regulations that impact maritime emissions, and emission reduction efforts by Ports and other goods movement and maritime-related entities in the region.

1.1 Scope of Study

The scope of the inventory is defined by the year of activity being reviewed, the source categories included, the pollutants evaluated, and the geographical extent.

Year of Activity (2016)
To the extent practicable, the emission estimates are based on activities that occurred during the calendar year 2016. If information specific to 2016 was not available, reasonable estimates of operational characteristics were developed and identified in the report sections.

Emission Source Categories
The following emission source categories are included in the report:

- Ocean-going vessels
- Commercial harbor vessels
- Recreational vessels
- Cargo-handling equipment
- Locomotives
- Heavy-duty vehicles
- Fleet vehicles

Pollutants
Exhaust emissions of the following pollutants are estimated:

- Criteria pollutants, surrogates, and precursors
    - Oxides of nitrogen (NO_x)
    - Sulfur dioxide (SO_2)
    - Coarse Particulate matter (PM_{10}), 10 micrometer aerodynamic diameter and smaller
    - Fine Particulate matter ($PM_{2.5}$), 2.5 micrometer aerodynamic diameter and smaller
    - Volatile organic compounds (VOCs)
    - Carbon monoxide (CO)
- Diesel particulate matter[1] (DPM), a toxic[2] air pollutant, 10 micrometer aerodynamic diameter and smaller
- Black carbon (BC), new addition for 2016 PSEI, and a component of $PM_{2.5}$
- Greenhouse gases presented as carbon dioxide equivalent (CO_2e)

[1] DPM is particulate matter emitted from diesel-fueled internal combustion engines.
[2] In 1998, the California Air Resources Board(CARB) identified diesel particulate matter as a toxic air contaminant. CARB, Resolution 98-35, 27 August 1998. See: *http://www.arb.ca.gov/regact/diesltac/res98-35.pdf.*

GHG emissions are presented in terms of carbon dioxide (CO_2) equivalents (CO_2e), a measure that weights each gas by its global warming potential (GWP) value. The CO_2e emissions include CO_2, methane (CH_4) and nitrous oxide (N_2O); the CO_2e value is calculated by multiplying each GHG's total emissions by its corresponding GWP value from EPA's latest report "Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2014"[3]. The sum of the three GHGs is reported as one CO_2e value.

This inventory includes black carbon (BC) emissions for the first time and BC is listed separately from CO_2e, even though it is a climate influencer. Black carbon is a component of particulate matter ($PM_{2.5}$). Black carbon is a 'short term climate pollutant', meaning it only stays in the atmosphere for days to weeks as opposed to CO_2 that has an atmospheric lifetime of more than 100 years. Although it does not remain in the atmosphere long, its short-term climate potency is far greater than CO_2. Recent studies have highlighted black carbon's impact on climate change: for example, black carbon that settles on snow packs absorbs heat from the sun, increasing the rate of melting. More research is needed on estimating BC because there are few widely agreed upon emission factors for mobile sources. The BC/$PM_{2.5}$ factors[4] used in the 2016 PSEI are as follows:

- BC/$PM_{2.5}$ =0.77 for non DPF equipped equipment and harbor vessel engines
- BC/$PM_{2.5}$ =0.10 for DPF equipped equipment
- BC/$PM_{2.5}$ factor of 0.03 for ocean-going vessels using residual fuel
- BC/$PM_{2.5}$ factor of 0.06 for ocean-going vessels using low sulfur fuel

[3] See: *www.epa.gov/ghgemissions/us-greenhouse-gas-inventory-report-1990-2014*

[4] EPA, "Black Carbon Emissions Inventory Methods and Comparisons", Appendix 2, pages 276 to 278, EPA's report to Congress

Geographical Boundary

The Puget Sound Maritime Air Emissions Inventory covers activities within defined geographical areas depending on emission source type. The boundary of this inventory includes the U.S. portions of the Georgia Basin/Puget Sound International Airshed including the entire Straits of Juan de Fuca and the waters east of Vancouver Island (stopping at the U.S./Canada border to the north). The 2016 emissions inventory domain is the area bounded by the black dotted line to the north and the red line to the south, as illustrated in Figure 1.1.

Figure 1.1: Georgia Basin/Puget Sound International Airshed

The following twelve counties are located within the emissions inventory domain or airshed:

- Clallam County
- Island County
- Jefferson County
- King County
- Kitsap County
- Mason County
- Pierce County
- San Juan County
- Skagit County
- Snohomish County
- Thurston County
- Whatcom County

Figure 1.2: Puget Sound Counties and Major Ports

The major ports in the inventory domain include:

- Port of Anacortes in Skagit County
- Port of Everett in Snohomish County
- Port of Port Angeles in Clallam County
- Port of Olympia in Thurston County
- Port of Seattle in King County
- Port of Tacoma in Pierce County
- The Northwest Seaport Alliance (NWSA), including NWSA North Harbor in King County and NWSA South Harbor in Pierce County

In 2015, the Port of Seattle and the Port of Tacoma entered into a partnership for their marine cargo operations to manage the container, breakbulk, auto and some bulk terminals. This partnership is called the Northwest Seaport Alliance (NWSA). The NWSA utilizes licensed properties from the homeports of the Port of Seattle and the Port of Tacoma, who still have their own operations outside of the NWSA.

The NWSA Terminals are allocated accordingly for 2016 and previous inventory years (2005 and 2011). Please note that some of the terminal names for NWSA South Harbor changed during 2017, but the former terminal names as they were in 2016 are used in this study.

NWSA North Harbor
Terminal 5
Terminal 18
Terminal 30
Terminal 46
Terminal 115

NWSA South Harbor
APM Terminals (APMT)
Husky
Olympic Container Terminal (OCT)
Pierce County Terminal (PCT)
Washington United Terminal (WUT)
TOTE Maritime Tacoma Terminal
Terminal 7
East Blair 1
Blair
West Hylebos Facility
Marshal Ave Auto Facility

1.2 Background Air Quality Conditions and Regulations

State and federal regulations impact the emissions from ports as well as the region as a whole. Understanding what is going on in the regulatory world put the findings from the emission inventory into perspective.

1.2.1 EPA National Ambient Air Quality Standards
The National Ambient Air Quality Standards (NAAQS) are the maximum allowable levels of 6 criteria air pollutants (CO, NO_2, O_3, Pb, SO_2, and PM) set by the EPA to protect public health. Regions that have measured concentrations below the NAAQS are deemed to be in attainment with the standards, while areas that have concentrations of criteria pollutants that exceed any of the standards are deemed to be in nonattainment for the pollutant that is in violation. For the year 2016, all areas of the Puget Sound Region met the requirements of the EPA National Ambient Air Quality Standards and were not found to be in non-attainment.

1.2.2 Tacoma-Pierce County Attainment Designations
In December 2009 the EPA designated the Tacoma-Pierce County area a "non-attainment area", because it was in violation of the EPA's National Ambient Air Quality 24-hour standard for $PM_{2.5}$. Although wood smoke from residential homes was the main contributor to the non-attainment status, the designation status impacted rules and policies for the entire area.

After significant efforts from the county, cities, and local agencies, the air quality of this area has improved. EPA re-designated the area as "maintenance/attainment" in March 2015, as the area meets the $PM_{2.5}$ 24-hour standard and has an approved maintenance plan. This maintenance plan covers the first 10 years of a 20-year planning cycle designed to ensure that the area remains below the federal standard[5].

1.2.3 State Regulated Actions
On May 31, 2016, Ecology[6] adopted amendments to three state rules:

- General Regulations for Air Pollution Sources – Chapter 173-400 WAC
- Ambient Air Quality Standards – Chapter 173-476 WAC
- Low Emission Vehicles – Chapter 173-423 WAC

The first amendments brought the state rules into compliance with the EPA regulations standards for excess emissions and major stationary sources located in nonattainment areas. The second amendment adopted the new lower EPA ozone standard and associated monitoring requirements. The third amendment adopted the updates to the California motor vehicle emission standards.

Another state regulation that may impact port-owned fleet vehicles and cargo-handling equipment in the future is the Washington State Department of Commerce's Electricity and Biofuel rule, WAC194-29[7]. The regulation's goal is to require all local governments, to the extent practicable, to transition the publicly owned vehicles, vessels, and construction equipment to electricity or biofuel, effective June 1, 2018. For purposes of assessing

[5] Department of Ecology, State of Washington, *www.ecology.wa.gov/Regulations-Permits/Plans-policies/State-implementation-plans/Maintenance-SIPs*
[6] Department of Ecology, State of Washington, *www.ecology.wa.gov/Regulations-Permits?topics=27,32*
[7] Department of Commerce, *www.commerce.wa.gov/wp-content/uploads/2016/11/Energy-LG-Alt-Fuel-Vehicle-Final-Rules.pdf*

compliance with this rule, each local government is required to submit an annual report by July 1 of each year.

1.2.4 Federal Regulations Impacting Maritime Operations

The following tables present a list of current regulatory programs that influenced the 2016 emissions from the maritime-related emission sources included in this inventory. Table 1.1 specifically outlines regulations governing OGVs while Table 1.2 covers the remaining emission source categories.

Table 1.1: OGV Regulations, Standards and Policies

Agency	Regulation/Standard/Policy	Targeted Pollutants	Years Effective	Impact
International Maritime Organization (IMO)	NO_x Emission Standard for Marine Engines[8]	NO_x	2011 – Tier 2 2016 – Tier 3 for ECA only	Auxiliary and propulsion engines over 130 kW output power on newly built vessels
IMO	Emissions Control Area, Low Sulfur Fuel Requirements for Marine Engines[9]	DPM, PM, and SO_x	2012 ECA – 1% Sulfur 2015 ECA – 0.1% Sulfur	Significantly reduce emissions due to low sulfur content in fuel by creating Emissions Control Area (ECA)
IMO	Energy Efficiency Design Index (EEDI) for International Shipping[10]	CO_2 and other pollutants	2013	Increases the design efficiencies of ships relating to energy and emissions
EPA	Emission Standards for Marine Diesel Engines above 30 Liters per Cylinder (Category 3 Engines); Aligns with IMO Annex VI marine engine NO_x standards and low sulfur requirement[11]	DPM, PM, NO_x, and SO_x	2011 – Tier 2 2016 – Tier 3	Auxiliary and propulsion category 3 engines on US flagged new built vessels and requires use of low sulfur fuel

[8] IMO*, www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Nitrogen-oxides-%28NOx%29-%E2%80%93-Regulation-13.aspx*

[9] IMO, *www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Sulphur-oxides-%28SOx%29-%E2%80%93-Regulation-14.aspx*

[10] IMO, *www.imo.org/en/OurWork/Environment/PollutionPrevention/AirPollution/Pages/Technical-and-Operational-Measures.aspx*

[11] EPA, *www.epa.gov/otaq/oceanvessels.htm#engine-fuel*

Table 1.2: Other (non-ocean-going vessel) Regulations

Agency	Regulation	Targeted Pollutants	Years Effective	Impact
EPA	Emission Standards for Harbor Craft Engines[12]	All	2009 – Tier 3 2014 – Tier 4 for 800 hp or greater	Commercial marine diesel engines with displacement less than 30 liters per cylinder
EPA	Emission Standards for Non-Road Diesel Powered Equipment[13]	All	2008 through 2015	All non-road equipment
EPA	Emission Standards for New and Remanufactured Locomotives and Locomotive Engines- Latest Regulation[14]	DPM and NO_x	2011 through 2013 – Tier 3 2015 – Tier 4	All new and remanufactured locomotive engines
EPA	Control of Emissions of Air Pollution from Nonroad Diesel Engines and Fuel[15]	SO_x and PM	2010	All locomotive engines
EPA	Emission Standards for New 2007+ On-Road Heavy-Duty Vehicles	NO_x and PM	2007 2010	All new on-road diesel heavy-duty vehicles

[12] EPA, *www3.epa.gov/otaq/marine.htm*
[13] EPA, *www.epa.gov/otaq/standards/nonroad/nonroadci.htm*
[14] EPA, *www.epa.gov/otaq/standards/nonroad/locomotives.htm*
[15] EPA, *www.epa.gov/otaq/fuels/dieselfuels/regulations.htm*

1.3 Emission Reduction Strategies

Emission reduction strategies undertaken since the 2005 baseline inventory are listed below for participating ports and maritime partners. Many of these strategies were implemented with grant funding and technical assistance of EPA, Ecology, PSRC, local air pollution control agencies and other federal agencies.

Table 1.3: Emission Reduction Strategies

Entity	Emission Reduction Strategy
BNSF	Replaced older locomotives with new fuel-efficient locomotives Installed idle control mechanisms on switch engines Reduced train resistance through low torque bearings Implemented rail lubrication to increase fuel efficiency Perform opacity tests on locomotives Optimize train operations and fuel savings Installed electrically-powered wide-span cranes Installed semi-automated gate system for trucks
Tacoma Rail	Repowered older locomotives with cleaner fuel efficient engines Acquired fuel efficient low emission genset locomotive Installed fuel efficient fuel injectors on existing locomotives Installed idle reduction equipment on existing locomotives
Union Pacific	Limit train speeds and shut down idle locomotives to save fuel New locomotives have idle reduction devices Pioneered genset locomotive technology that reduces emissions
Washington State Ferries	Replaced older ferries with new ones Repowered existing ferries with newer engines Connect to shore power during tie-up at night
Port of Everett	Purchased new Gottwald mobile harbor crane with Tier 4 engine Purchased new reach stackers with Tier 4 engines Obtained state grant to retrofit marina boom truck Obtained CMAQ grant to provide electrical shore power infrastructure for vessels and cranes Use electric mounted gantry cranes

Table 1.3: Emission Reduction Strategies, cont.

Entity	Emission Reduction Strategy
Port of Seattle and NWSA North Harbor	Provided shore power at Terminal 91 cruise terminal for cruise and commercial fishing fleet
	Retrofitted some cargo-handling equipment with diesel oxidation catalysts
	Encouraged cleaner vehicle purchases
	Adopted Clean Truck Program and Drayage Truck Registry
	Implemented truck scrappage and replacement program
	Installed drayage truck traffic monitoring systems to reduce idling
	Encouraged equipment modernization program
	Participated in regional idle reduction effort
	Installed idle reduction equipment on cargo-handling equipment
	Equipped switching locomotives with idle reduction equipment
	Provided electric ship to shore cranes for cargo terminals
	Repowered harbor vessel engines with new cleaner engines
	Provided emission control system maintenance training and assistance
	Offered financial incentives for ships to burn cleaner fuel at berth
Port of Tacoma and NWSA South Harbor	Installed diesel particulate filters on port and terminal equipment
	Repowered existing diesel forklifts with cleaner engines
	Installed diesel oxidation catalysts on terminal equipment
	Adopted Clean Truck Program and Drayage Truck Registry
	Installed drayage truck traffic monitoring systems to reduce idling
	Truck scrappage and replacement program
	Participated in regional idle reduction effort
	Installed idle reduction equipment on cargo-handling equipment
	Encouraged equipment modernization program
	Provided shore power at the TOTE Terminal
	Provided shore power for tugboats
	Equipped switching locomotives with idle reduction equipment
	Electric ship to shore cranes for cargo terminals
	Provided electric plug-ins for refrigerated containers at a terminal
	Repowered harbor vessel engines with new cleaner engines
	Provided emission control system maintenance training and assistance
	Replaced yard truck with new yard truck with Tier 4 engine
Port of Olympia	Retrofitted equipment with grant
	Installed electric vehicle charging station

SECTION 2 SUMMARY RESULTS

The summary results for the 2016 Puget Sound Maritime Air Emissions Inventory are provided both for the total maritime-related emissions and for the ports associated with this study. Detailed information for each source category is provided in subsequent sections. The maritime-related emission source categories for this inventory consist of the activities associated with U.S. related maritime operations and include the following:

- Ocean-going vessels (including hoteling, maneuvering, and transiting modes)
- Harbor vessels (including commercial and government non-military vessels only)
- Recreational vessels
- Cargo-handling equipment
- Locomotives (including switch and line-haul operations)
- Heavy-duty vehicles (including on-terminal and first drop activities within the inventory domain)
- Fleet vehicles (including terminal fleet vehicles, cruise terminal passenger shuttles/vans, and import/export vehicles)

2.1 Maritime Emissions for the Total Inventory Airshed

Table 2.1 presents the overall 2016 U.S. maritime-related emissions within the airshed listed by emission source category. Greenhouse gases are presented in CO_2e for carbon dioxide, nitrous oxide, and methane, combined.

Table 2.1: 2016 Total Study Area Maritime-related Emissions, tpy

Source Category	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
Ocean-going vessels	11,516	346	964	374	192	181	178	11	587,994
Harbor vessels	6,590	478	2,332	4	235	216	230	163	443,948
Recreational vessels	989	1,774	12,416	2	38	35	5	10	139,381
Locomotives	1,099	63	206	1	32	29	32	23	77,366
Cargo-handling equipment	332	32	182	0	17	17	17	12	49,838
Heavy-duty vehicles	1,297	66	320	2	61	57	61	19	238,805
Fleet vehicles	3	1	12	0	0	0	0	0	1,037
Total	**21,824**	**2,760**	**16,432**	**384**	**575**	**535**	**524**	**238**	**1,538,368**

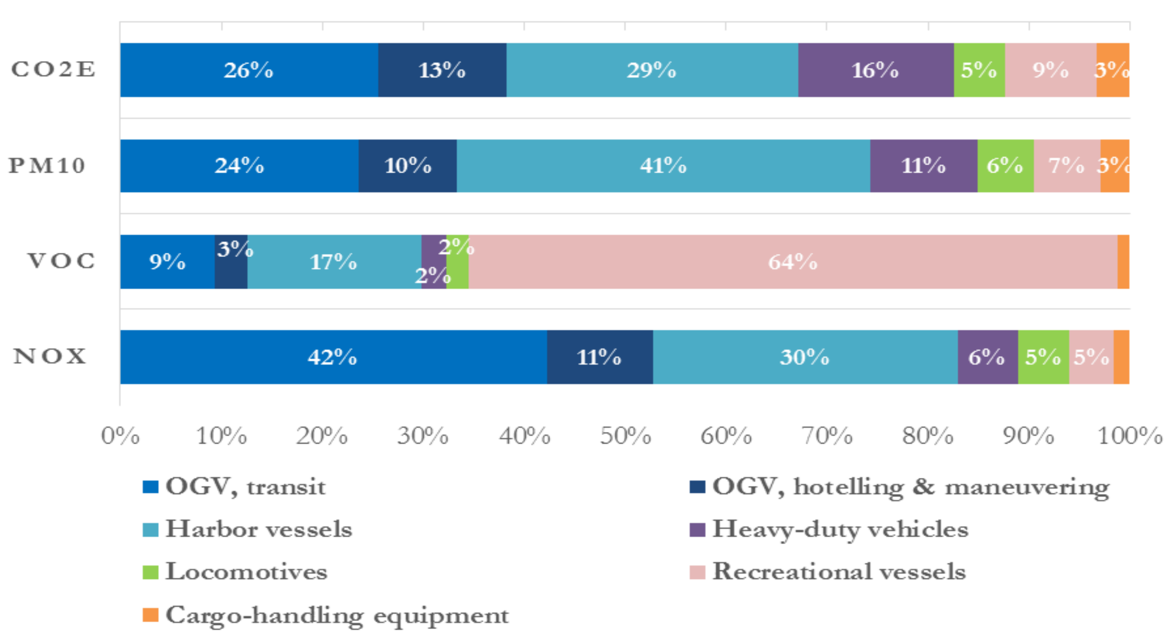
Table 2.2 and Figure 2.1 present the contribution of the source categories to the maritime-related emissions of pollutants. Table 2.2 shows that OGV and harbor vessels made up the majority of the NO_x, PM_{10}, $PM_{2.5}$, DPM, BC, and CO_2e emissions in 2016. Recreational vessels produce the majority of the VOC and CO emissions due the number of gasoline engines in this source category. The contribution of black carbon (BC) from harbor vessels is significantly higher than any other source category due to the $BC/PM_{2.5}$ ratio assigned to it per current guidance.

Table 2.2: 2016 Total Study Area Maritime-related Emissions Contribution by Source Category, %

Source Category	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
Ocean-going vessels, transit	42%	9%	5%	65%	24%	24%	26%	3%	26%
Ocean-going vessels, hotelling & maneuvering	11%	3%	1%	32%	10%	10%	8%	1%	13%
Harbor vessels	30%	17%	14%	1%	41%	40%	44%	69%	29%
Recreational vessels	5%	64%	76%	1%	7%	7%	1%	4%	9%
Locomotives	5%	2%	1%	0%	6%	6%	6%	10%	5%
Cargo-handling equipment	2%	1%	1%	0%	3%	3%	3%	5%	3%
Heavy-duty vehicles	6%	2%	2%	1%	11%	11%	12%	8%	16%
Fleet vehicles	<1%	<1%	<1%	<1%	<1%	<1%	<1%	<1%	<1%

Figure 2.1 depicts graphically the percent contribution by source category for four pollutants (NO_x, VOC, PM_{10} and CO_2e).

Figure 2.1: 2016 Total Study Area Maritime-related Emissions Contribution by Source Category and Selected Pollutants, %



2.2 Maritime Emissions by Regional Clean Air Agency

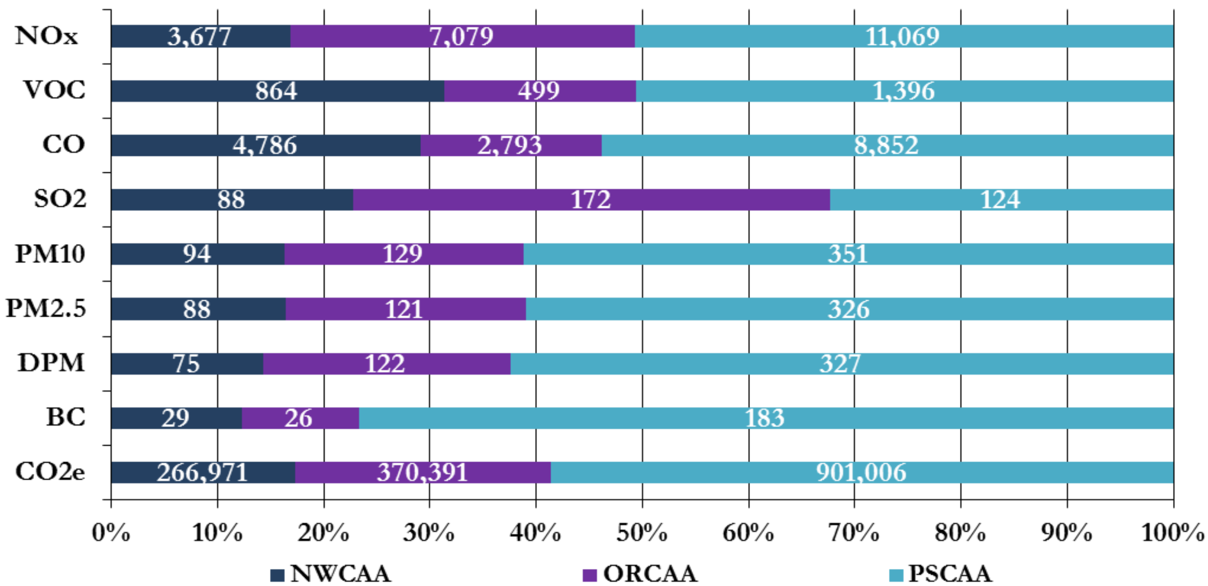
Table 2.3 and Figure 2.2 present total maritime-related emissions within the airshed by regional clean air agency jurisdiction. The regional clean air agencies and the counties within their jurisdictions are as follows:

- Northwest Clean Air Agency (NWCAA) – Island, Skagit, Whatcom, San Juan counties[16]
- Olympic Region Clean Air Agency (ORCAA) – Clallam, Jefferson, Mason, Thurston counties
- Puget Sound Clean Air Agency (PSCAA) – Pierce, King, Kitsap, and Snohomish counties

Table 2.3: 2016 Total Study Area Maritime-related Emissions by Regional Clean Air Agency, tpy

Clean Air Agency	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
NWCAA	3,677	864	4,786	88	94	88	75	29	266,971
ORCAA	7,079	499	2,793	172	129	121	122	26	370,391
PSCAA	11,069	1,396	8,852	124	351	326	327	183	901,006
Total	**21,824**	**2,760**	**16,432**	**384**	**575**	**535**	**524**	**238**	**1,538,368**

Figure 2.2: Distribution of Total Study Area Maritime-related Emissions by Regional Clean Air Agency, tpy and %



[16] Maritime-related emissions for San Juan County are included in the totals for the Northwest Clean Air Agency (NWCAA) even though the air program in San Juan County is administered by the WDOE.

2.3 Maritime Activity Levels and Emission Comparison to Previous Inventories

The 2016 emission inventory was developed using the latest and best available emissions estimation models and methodologies. In order to conduct equivalent comparisons of 2016 emissions to 2005 and 2011 emissions, the 2005 and 2011 emissions were re-estimated with the updated 2016 emissions methodology and modeling parameter changes based on the activity levels used in the previous inventories. The scope of the inventory was the same across all years for all source types except recreational vessels, for which additional private marinas were identified in 2016 that were not included in the previous inventories. This means that an equivalent comparison of recreational vessels is not provided across all model years due to an increase in scope.

Table 2.4: Methodology Changes

Source Category	Methodology Change
OGV	Updated load adjustment factors for propulsion engines with slide valves and conventional valves Updated auxliary engine loads for all vessel types Updated boiler load defaults
Harbor vessels	Updated emission factors
Recreational vessels	Used MOVES2014/NONROAD; 2016 private marina counts higher than previous years due to inclusion of more marinas
Heavy-duty trucks	Used MOVES2014a
Fleet vehicles	Used MOVES2014a
Locomotives	Used latest EPA emission factors for 2016 only; updated switcher activity at grain terminals

Table 2.5 compares the 2016, 2011 and 2005 cargo throughput in twenty-foot-equivalent units (TEU) and total cargo tonnage in metric tons (MT) for the ports of Everett, Olympia, Seattle, NWSA North Harbor, NWSA South Harbor and Tacoma. Compared to 2005, the TEU throughput and tons of cargo decreased overall in 2016. Compared to 2011, the TEU throughput increased and tons of cargo decreased in 2016.

Table 2.5: Port Throughput Comparison

Year	TEU	Cargo (MT)
2016	3,643,133	38,263,683
2011	3,543,248	41,145,315
2005	4,168,393	41,454,241
2016 vs 2011 Change	**3%**	**-7%**
2016 vs 2005 Change	**-13%**	**-8%**

Table 2.6 compares the 2016, 2011 and 2005 total vessel movements for Puget Sound geographical domain. Compared to 2005 and 2011, the total vessel movements including arrivals, departures, and shifts decreased overall in 2016. The total vessel movement decrease may be attributed to less throughput in 2016 and larger containerships calling the ports in 2016.

Table 2.6: Total Study Area Vessel Movement Comparison

Year	Total Vessel Movements
2016	6,578
2011	6,824
2005	7,161
2016 vs 2011 Change	**-4%**
2016 vs 2005 Change	**-8%**

Table 2.7 compares the total 2016 maritime-related airshed emissions to 2005 and 2011 emissions. Emissions decreased for most pollutants in 2016 as compared to 2005 and 2011. For the 2016 vs 2011 emissions comparison, CO emissions increased due to recreational vessels and commercial harbor vessels. The CO emission factor for diesel marine engines used by recreational vessels and commercial harbor vessels is higher for newer engines than unregulated engines.

Table 2.7: Total Study Area Maritime-related Emissions Comparison, tpy and %

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	21,824	2,760	16,432	384	575	535	524	238	1,538,368
2011	24,040	2,988	15,086	10,899	1,679	1,403	1,515	342	1,560,273
2005	28,445	3,877	20,786	13,473	2,073	1,730	1,843	401	1,702,475
2016 vs 2011 Change	**-9%**	**-8%**	**9%**	**-96%**	**-66%**	**-62%**	**-65%**	**-30%**	**-1%**
2016 vs 2005 Change	**-23%**	**-29%**	**-21%**	**-97%**	**-72%**	**-69%**	**-72%**	**-41%**	**-10%**

Figure 2.3 depicts the maritime-related emissions percentage change for 2005 and 2011.

Figure 2.3: Total Study Area Maritime-related Emissions Change, %

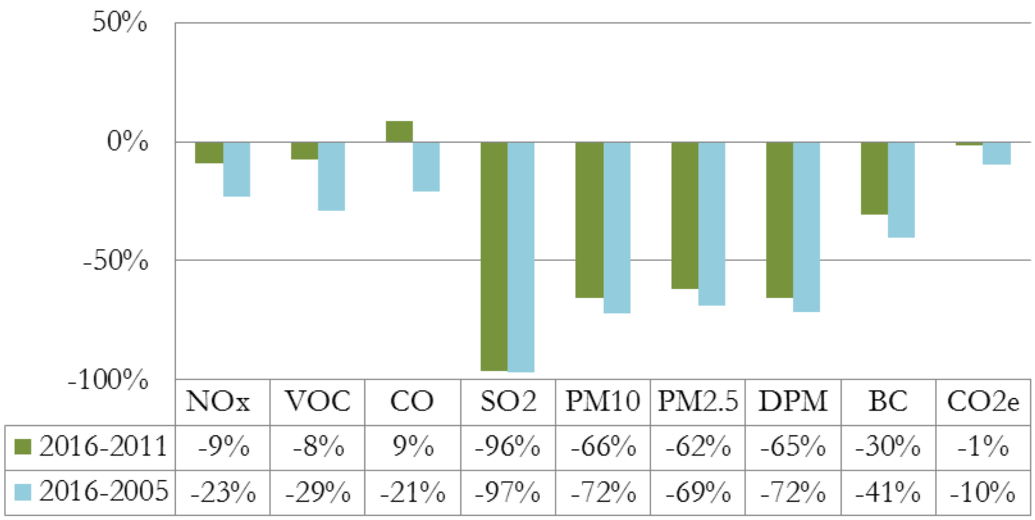


Figure 2.4 demonstrates NO_x, VOC, PM, SO_2 and CO_2e emissions changes (lines in graph) relative to metric tons of cargo (vertical green bars in graph) for the total study area. Metric tons of cargo overall were higher in 2005 than in 2011 and 2016. PM_{10} and SO_2 emissions decreased significantly in 2016 due to the ocean-going vessels burning fuel with lower sulfur content as a result of the North American ECA. The CO_2e emissions are dependent on the activity and therefore the CO_2e emissions changed similarly to the tons of cargo changes. NO_x and VOC emissions decreased proportionally more than throughput decrease due to cleaner trucks, vessels, and equipment used in 2016 at the Puget Sound ports which have cleaner engines with lower NO_x engine standards.

Figure 2.4: Total Study Area Maritime-related Emissions Change Relative to Metric Tons of Cargo

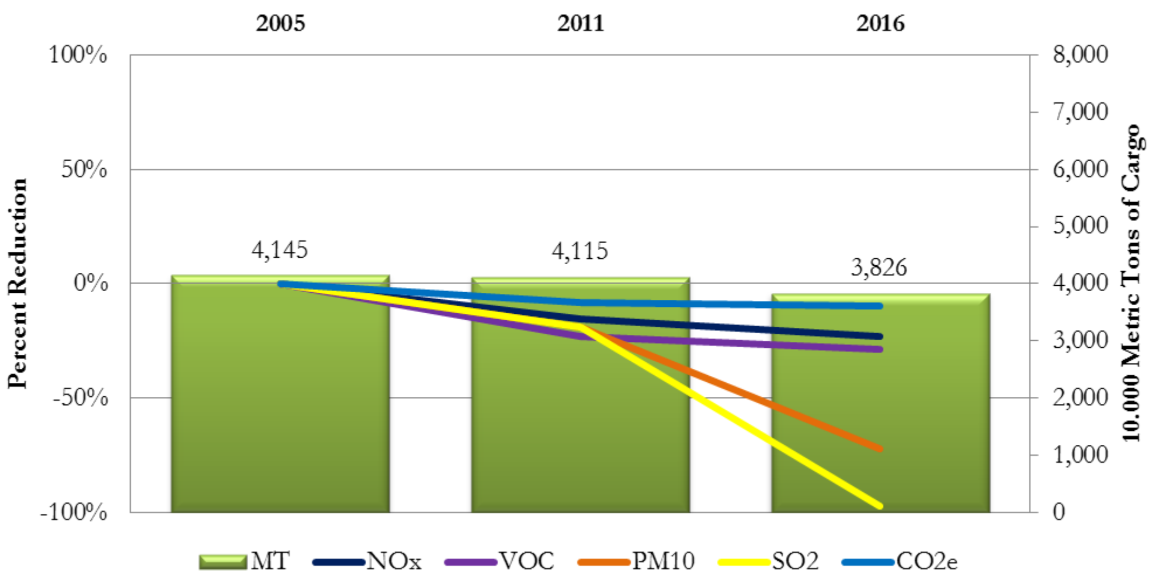
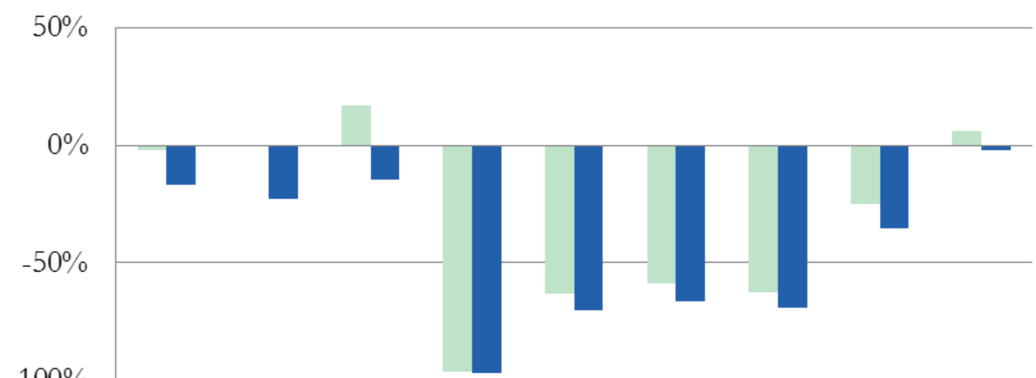


Table 2.8 and Figure 2.5 compare the tons of emissions per 10,000 tons of cargo for the total study area. It shows that between 2016 and 2005, there were reductions for all the pollutants. Comparing 2016 and 2011, CO and CO_2e emissions increased, while all other emissions decreased. The CO emissions per 10,000 tons of cargo are higher due to the harbor vessels increase in CO emissions for the newer engines and the recreational vessel emissions increase due to more marinas included in 2016. The CO_2e emissions per 10,000 tons of cargo are higher due to the increase in recreational vessel emissions in 2016 when additional marinas were added to 2016, but not to the previous years.

Table 2.8: Total Study Area Maritime-related Tons of Emissions per 10,000 Tons of Cargo Comparison

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	5.70	0.72	4.29	0.10	0.15	0.14	0.14	0.06	402
2011	5.84	0.73	3.67	2.65	0.41	0.34	0.37	0.08	379
2005	6.86	0.94	5.01	3.25	0.50	0.42	0.44	0.10	411
2016 vs 2011 Change	**-2%**	**-1%**	**17%**	**-96%**	**-63%**	**-59%**	**-63%**	**-25%**	**6%**
2016 vs 2005 Change	**-17%**	**-23%**	**-14%**	**-97%**	**-70%**	**-67%**	**-69%**	**-36%**	**-2%**

Figure 2.5: Total Study Area Maritime-related Tons of Emissions per 10,000 Tons of Cargo Change, %



	NOx	VOC	CO	SO2	PM10	PM2.5	DPM	BC	CO2e
2016-2011	-2%	-1%	17%	-96%	-63%	-59%	-63%	-25%	6%
2016-2005	-17%	-23%	-14%	-97%	-70%	-67%	-69%	-36%	-2%

2.4 Maritime-related Emissions Comparison by Source Category

Table 2.9 compares the total maritime-related 2016 emissions to 2005 by source category.

Table 2.9: 2016 vs 2005 Total Study Area Maritime-related Emissions by Source Category, tpy and %

	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016									
Ocean-going vessels	11,516	346	964	374	192	181	178	11	587,994
Harbor vessels	6,590	478	2,332	4	235	216	230	163	443,948
Recreational vessels	989	1,774	12,416	2	38	35	5	10	139,381
Locomotives	1,099	63	206	1	32	29	32	23	77,366
Cargo-handling equipment	332	32	182	0	17	17	17	12	49,838
Heavy-duty vehicles	1,297	66	320	2	61	57	61	19	238,805
Fleet vehicles	3	1	12	0.02	0.07	0.06	0.04	0.03	1,037
Total	**21,824**	**2,760**	**16,432**	**384**	**575**	**535**	**524**	**238**	**1,538,368**
2005									
Ocean-going vessels	15,836	542	1,202	12,789	1,514	1,212	1,336	36	827,705
Harbor vessels	6,122	380	1,144	405	277	255	274	194	368,087
Recreational vessels	734	2,590	15,966	23	55	51	6	11	113,354
Locomotives	2,460	123	308	193	67	61	67	47	106,058
Cargo-handling equipment	763	96	1,477	47	49	48	49	36	77,769
Heavy-duty vehicles	2,516	143	646	16	112	103	112	76	206,028
Fleet vehicles	13	3	42	0.23	0.44	0.40	0.36	0.26	3,474
Total	**28,445**	**3,877**	**20,786**	**13,473**	**2,073**	**1,730**	**1,843**	**401**	**1,702,475**
2016 vs 2005 Change									
Ocean-going vessels	-27%	-36%	-20%	-97%	-87%	-85%	-87%	-70%	-29%
Harbor vessels	8%	26%	104%	-99%	-15%	-15%	-16%	-16%	21%
Recreational vessels	35%	-32%	-22%	-89%	-31%	-31%	-16%	-11%	23%
Locomotives	-55%	-48%	-33%	-100%	-52%	-52%	-52%	-51%	-27%
Cargo-handling equipment	-57%	-67%	-88%	-99%	-65%	-65%	-65%	-66%	-36%
Heavy-duty vehicles	-48%	-54%	-50%	-87%	-45%	-45%	-45%	-75%	16%
Fleet vehicles	-80%	-79%	-72%	-92%	-85%	-85%	-89%	-88%	-70%
Total	**-23%**	**-29%**	**-21%**	**-97%**	**-72%**	**-69%**	**-72%**	**-41%**	**-10%**

A description of the factors that contributed to the 2016 vs 2005 emission changes is listed below for each source category.

Ocean-going vessels
Contributing factors to the decrease in emissions for OGV include:

- The North American ECA introduced in 2015, requiring 0.1% sulfur content in diesel fuel compared to heavy fuel oil with high sulfur content (2.7%) used by the majority of vessels in 2005
- Increase in shore power calls from 42 calls in 2005 to 169 calls in 2016 which helped lower the at-berth emissions
- Fewer vessel movements in 2016 (8%) and activity in kW-hr (23%)

Commercial harbor vessels
Contributing factors to the decrease in SO_2, PM and black carbon emissions for commercial harbor vessels include:

- Emissions decreased due to newer vessels accounting for the 7% of engines that have Tier 3 and 4 engines in 2016 compared to 0% in 2005
- Emissions decreased due to newer vessels mean lower emissions for most pollutants, except for CO
- The use of ULSD in 2016 versus use of off-road fuel in 2005 by diesel engines, reducing SO_2 emissions significantly
- The use of EPA certified kits lowered the PM emissions by 25% for the propulsion engines that used them

Contributing factors to the increase in NO_x, VOC, CO, and CO_2e emissions for commercial harbor vessels include:

- Emissions increased due to increased engine activity (20% more) and more engines (7% more)
- Emissions increased due to increase in activity was more significant than emission reduction from newer vessels with cleaner engines
- CO emissions increased for newer vessels due to engine standards

Recreational vessels
Contributing factors to the decrease in emissions for recreational vessels include:

- All other emissions decreased due to fleet turnover to cleaner vessels assumption in MOVES2014a model

Contributing factors to the increase of NO_x and CO_2e emissions for recreational vessels include:

- Increased activity as more private marinas were included in 2016 than in 2005

Locomotives

Contributing factors to the decrease in emissions from locomotives include:

- Lower fuel usage (27% lower)
- Lower activity measured in hp-hr (29% lower)
- Lower throughput measured as intermodal[17] lifts (33%)
- All locomotive engines used ULSD in 2016, reducing SO_2 emissions significantly

Cargo-handling equipment

Contributing factors to the decrease in emissions for CHE include:

- Less equipment (5% less) and lower activity (35% less)
- Cleaner equipment - 32% of engines are Tier 3 and 4 engines in 2016 compared to 0% in 2005
- All equipment used ULSD in 2016 compared to a few pieces of equipment in 2005, reducing SO_2 emissions significantly

Heavy-duty vehicles

Contributing factors to the decrease in emissions for HDV include:

- Fleet turnover (newer and cleaner trucks) resulted in the reductions of most pollutants
- All heavy-duty vehicles used ULSD in 2016, reducing SO_2 emissions significantly

Contributing factors to the increase in CO_2e emissions for HDV include:

- CO_2e emissions increased because there has not been a significant decrease in truck fuel consumption with newer trucks

[17] In the context of port operations, intermodal refers to ship-to-rail or truck-to-rail movement of cargo.

Table 2.10 compares the total maritime-related 2016 emissions to 2011 by source category.

Table 2.10: 2016 vs 2011 Total Study Area Maritime-related Emissions by Source Category, tpy and %

	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016									
Ocean-going vessels	11,516	346	964	374	192	181	178	11	587,994
Harbor vessels	6,590	478	2,332	4	235	216	230	163	443,948
Recreational vessels	989	1,774	12,416	2	38	35	5	10	139,381
Locomotives	1,099	63	206	1	32	29	32	23	77,366
Cargo-handling equipment	332	32	182	0	17	17	17	12	49,838
Heavy-duty vehicles	1,297	66	320	2	61	57	61	19	238,805
Fleet vehicles	3	1	12	0.02	0.07	0.06	0.04	0.03	1,037
Total	**21,824**	**2,760**	**16,432**	**384**	**575**	**535**	**524**	**238**	**1,538,368**
2011									
Ocean-going vessels	13,284	400	999	10,880	1,202	962	1,076	29	699,104
Harbor vessels	6,270	438	1,417	4	278	255	274	194	392,613
Recreational vessels	810	1,909	11,654	2	39	37	5	9	106,523
Locomotives	1,293	82	205	11	46	42	46	33	77,187
Cargo-handling equipment	456	32	251	1	29	28	29	21	57,961
Heavy-duty vehicles	1,919	125	523	2	85	78	85	56	223,681
Fleet vehicles	8	2	38	0.06	0.21	0.19	0.13	0.10	3,204
Total	**24,040**	**2,988**	**15,086**	**10,899**	**1,679**	**1,403**	**1,515**	**342**	**1,560,273**
2016 vs 2011 Change									
Ocean-going vessels	-13%	-14%	-3%	-97%	-84%	-81%	-83%	-63%	-16%
Harbor vessels	5%	9%	64%	15%	-15%	-15%	-16%	-16%	13%
Recreational vessels	22%	-7%	7%	34%	-5%	-5%	11%	10%	31%
Locomotives	-15%	-22%	0%	-93%	-31%	-30%	-31%	-30%	0%
Cargo-handling equipment	-27%	-2%	-27%	-40%	-40%	-40%	-40%	-41%	-14%
Heavy-duty vehicles	-32%	-47%	-39%	6%	-28%	-27%	-28%	-67%	7%
Fleet vehicles	-66%	-71%	-68%	-68%	-69%	-69%	-71%	-70%	-68%
Total	**-9%**	**-8%**	**9%**	**-96%**	**-66%**	**-62%**	**-65%**	**-30%**	**-1%**

A description of the factors that contributed to the 2016 as compared 2011 emission changes is listed below for each source category.

Ocean-going vessels

Contributing factors to the decrease in emissions for OGV include:

- The North American ECA introduced in 2015, requiring 0.1% sulfur content in diesel fuel compared to heavy fuel oil with high sulfur content (2.7%) used by those vessels in 2011 that were not voluntarily switching to a low sulfur diesel fuel
- Increase in shore power calls from 141 calls in 2011 to 169 calls in 2016
- Lower vessel movements in 2016 (4%) resulting in lower activity in kW-hr (10%)

Commercial harbor vessels
Contributing factors to the decrease in SO_2, PM and black carbon emissions for commercial harbor vessels include:

- Emissions decreased due to newer vessels accounting for the 7% of engines that have Tier 3 and 4 engines in 2016 compared to 1% in 2011
- Emissions decreased due to newer vessels lower emission factors for most pollutants, except for CO. However, for some pollutants, the increased activity negated the benefit of the lower emissions from Tier 3 and 4 engines.

Contributing factors to the increase in NO_x, VOC, CO, and CO_2e emissions for commercial harbor vessels include:

- Emissions increased due to increased engine activity (13% more) and more engines (5% more)
- CO emissions increased for newer vessels due to engine standards

Recreational vessels
Contributing factors to the decrease in VOC and PM emissions, while most other emissions increased for recreational vessel include:

- Increased number of vessels (34% more) resulting in increased engine activity (34% more) and increased emissions
- Majority of emissions are attributed to the activity of vessels with 2-stroke gasoline engines which traditionally have high VOC, CO and NOx emissions compared to diesel or 4-stroke gasoline engines. The emissions standards regulations for 2-stroke gasoline vessels result in more VOC and CO emissions reductions than NO_x due to trade-off between VOC/CO controls versus NO_x controls. Therefore VOC, CO and PM emissions decreased due to model fleet turnover to cleaner vessels assumption for recreational vessel in USEPA's MOVES2014a model, but the fleet turnover was not enough to significantly lower NO_x emissions

Locomotives
Contributing factors to the decrease in emissions from locomotives include:

- All locomotive engines used ULSD in 2016, reducing SO_2 emissions significantly

Contributing factors to the increase in CO and CO_2e emissions from locomotives include:

- Increased throughput measured as intermodal lifts (11%)

Cargo-handling equipment
Contributing factors to the decrease in emissions from CHE include:

- Less equipment (8% less) resulting in lower activity (14% less)
- Cleaner equipment - 32% of engines are Tier 3 and 4 engines in 2016 compared to 12% in 2011

Heavy-duty vehicles
Contributing factors to the decrease in emissions from HDV include:

- Fleet turnover (newer and cleaner trucks) resulted in the reductions of most pollutants

Contributing factors to the increase in SO_2 and CO_2e emissions from HDV include:

- Higher TEU throughput (3%) caused the SO_2 and CO_2e emissions to increase since there has not been a significant decrease in truck fuel consumption with newer trucks and SO_2 and CO_2e emissions are directly related to fuel consumption

2.5 Maritime-related Activity Level Comparison by Source Category

Ocean-going Vessels
Table 2.11 compares the ocean-going vessel activity or energy consumption (measured in kW-hr), vessel calls and movements, and count of shore power calls. This table shows overall decreases in kW-hr, inbound calls from the sea, and vessel movements. It also shows an increase in shore power calls which contributed to the emission decreases.

Table 2.11: Ocean-going Vessel Activity and Shore Power Calls Comparison

Year	Energy Consumption kW-hr	Inbound Calls	Total Vessel Movements	Shore Power Calls
2016	791,183,583	2,520	6,578	169
2011	880,097,783	2,700	6,824	141
2005	1,034,139,096	2,912	7,161	42
2016 vs 2011 Change	**-10%**	**-7%**	**-4%**	**20%**
2016 vs 2005 Change	**-23%**	**-13%**	**-8%**	**302%**

Harbor Vessels
Table 2.12 compares the harbor vessel energy consumption in kW-hr, and counts of vessels and engines.

Table 2.12: Commercial and Government Harbor Vessel Activity Comparison

Year	Energy Consumption kW-hr	Vessel Count	Engine Count
2016	573,526,886	741	2,274
2011	507,836,145	727	2,170
2005	477,193,901	722	2,131
2016 vs 2011 Change	**13%**	**2%**	**5%**
2016 vs 2005 Change	**20%**	**3%**	**7%**

Table 2.13 compares the harbor vessel diesel engine tier count. It shows that in 2016, even though the majority of diesel engines are Tier 0 and 1, there is a slight increase in newer engines due to vessel repowers. The unknown column is for diesel engines that had unknown model year or horsepower.

Table 2.13: Commercial and Government Harbor Vessel Diesel Engine Tier Count

Year	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Unknown	Total Engine Count
2016	985	189	208	124	24	700	2,230
2011	1,369	201	123	11	0	446	2,150
2005	1,911	156	33	0	0	4	2,104
2016 Percent of total	**44%**	**8%**	**9%**	**6%**	**1%**	**31%**	
2011 Percent of total	**64%**	**9%**	**6%**	**1%**	**0%**	**21%**	
2005 Percent of total	**91%**	**7%**	**2%**	**0%**	**0%**	**0%**	

The recreational vessel count reflects a significant increase in 2016 because additional private marinas were included for the first time. Table 2.14 summarizes the recreational vessel counts for both private and port marinas in the three inventory years. This comparison for recreational vessels cannot be a direct comparison due to the inclusion of the additional marinas in 2016, but it is provided for sake of completeness.

Table 2.14: Recreational Vessel Count Comparison

Year	Total Vessel Count	Private Marina Vessel Count	Port-owned Marina Vessel Count
2016	31,818	19,843	11,975
2011	23,771	11,501	12,270
2005	24,390	11,795	12,595
2016 vs 2011 Change	**34%**	**73%**	**-2%**
2016 vs 2005 Change	**30%**	**68%**	**-5%**

Locomotives

Table 2.15 provides the locomotive activity comparison, consisting of the number of intermodal lifts, the overall horsepower-hour energy demand, and estimated fuel consumption. The locomotive intermodal lifts were higher in 2016 as compared to 2011 and lower as compared to 2005.

Table 2.15: Locomotive Activity Comparison

Year	Throughput thousand IM lifts	Activity million hp-hr	Fuel Usage million gallons
2016	801	131	6.91
2011	723	132	6.89
2005	1,198	186	9.42
2016 vs 2011 Change	**10.8%**	**-0.5%**	**0.3%**
2016 vs 2005 Change	**-33.1%**	**-29.4%**	**-26.6%**

Cargo-handling Equipment

Table 2.16 compares the CHE activity in terms of energy consumption and number of engines (roughly equivalent to equipment population) and Table 2.17 shows the fleet turnover to cleaner Tier 3 and Tier 4 diesel engines.

Table 2.16: CHE Activity Comparison

Year	Energy Consumption kW-hr	Engine Count
2016	60,364,027	1,102
2011	70,346,044	1,199
2005	93,090,639	1,154
2016 vs 2011 Change	**-14%**	**-8%**
2016 vs 2005 Change	**-35%**	**-5%**

Table 2.17: CHE Diesel Engine Tier Count

Year	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4i	Tier 4f	Onroad	Unknown	Total
2016	119	128	274	110	113	60	46	33	883
2011	219	239	280	103	7	0	113	0	961
2005	366	249	225	0	0	0	50	0	890
2016 Percent of total	**13%**	**14%**	**31%**	**12%**	**13%**	**7%**	**5%**	**4%**	
2011 Percent of total	**23%**	**25%**	**29%**	**11%**	**1%**	**0%**	**12%**	**0%**	
2005 Percent of total	**41%**	**28%**	**25%**	**0%**	**0%**	**0%**	**6%**	**0%**	

Heavy-Duty Vehicles

Emissions from heavy-duty vehicles have decreased due to fleet turnover to newer, cleaner vehicles, the implementation of Clean Truck Programs by the Ports of Tacoma, Port of Seattle, and now the NWSA, and increased the use of ULSD. For fleet vehicles, the varying emission changes are due to the different fleet mix, reported activity levels, and vehicle fuel types included in the two inventories. Table 2.18 lists the on-terminal vehicle miles traveled (VMT) and idling hours for heavy-duty vehicles.

Table 2.18: Heavy-duty Vehicles On-Terminal VMT and Idling Hours Comparison

Year	VMT	Idling Hours
2016	2,989,786	1,298,867
2011	3,075,692	1,316,984
2005	2,815,667	1,334,889
2016 vs 2011 Change	**-3%**	**-1%**
2016 vs 2005 Change	**6%**	**-3%**

2.6 Port Emissions and Activity Summaries

This section includes summaries of U.S. maritime-related emissions associated with the Ports of Anacortes, Everett, Olympia, Port Angeles, Seattle, Tacoma and the Northwest Seaport Alliance. For the participating ports' comparisons, the port emissions within port terminals, adjacent rail yards and adjacent waterways, are tabulated as follows:

- Ocean-going vessel emissions (hoteling and maneuvering activities)
- Recreational vessel emissions (includes only 10% of total recreational vessel emissions related to port-owned marinas)
- Cargo-handling equipment emissions
- Locomotive emissions (switching activities on-terminal and adjacent rail yards)
- Heavy-duty vehicle emissions (queuing and on-terminal activities)
- Fleet vehicle emissions (on-terminal activities)

The following were not included in the Port summaries in this section:

- Ocean-going vessels transiting mode emissions and emissions from activities that are not directly associated with the operations at port terminals or petroleum facilities.
- Commercial harbor vessel emissions.
- Line-haul locomotive emissions (line-haul activities were not identified at these ports).
- Heavy-duty vehicles on-road emissions outside the ports' terminals.

2.6.1 Port of Anacortes

Table 2.19 presents 2016 emissions associated with the Port of Anacortes.

Table 2.19: Port of Anacortes 2016 Port Emissions, tpy

Source Category	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
OGV, hotelling	14.3	0.5	1.4	0.73	0.34	0.32	0.29	0.02	1,152
OGV, maneuvering	0.1	0.0	0.0	0.00	0.00	0.00	0.00	0.00	7
Recreational vessels	3.1	5.6	39.0	0.01	0.12	0.11	0.02	0.03	438
Locomotives	na	na	na	na	na	na	na	na	na
Cargo-handling equipment	0.2	0.0	0.2	0.00	0.01	0.01	0.01	0.01	11
Heavy-duty vehicles	0.2	0.0	0.0	0.00	0.01	0.01	0.01	0.00	15
Fleet vehicles	0.0	0.0	0.2	0.00	0.00	0.00	0.00	0.00	12
Total	**17.9**	**6.1**	**40.8**	**0.75**	**0.49**	**0.46**	**0.33**	**0.07**	**1,636**

Table 2.20 presents the tons of cargo and total vessel movements associated with the Port of Anacortes. The vessel movements include arrival, departure, and shift calls. There was no change in movements comparing 2011 and 2016. In 2016, there was an 18% increase in vessel movement as compared to 2005. There is no TEU throughput associated with the Port of Anacortes because the Port does not handle containerized cargo. The tons of cargo increased significantly in 2016.

Table 2.20: Port of Anacortes Throughput and Vessel Movements Comparison

Year	Cargo (MT)	Total Vessel Movements
2016	440,510	46
2011	247,854	46
2005	256,112	39
2016 vs 2011 Change	**78%**	**0%**
2016 vs 2005 Change	**72%**	**18%**

Table 2.21 and Figure 2.6 present the emissions comparison for Port of Anacortes.

Table 2.21: Port of Anacortes Port Emissions Comparison, tpy and %

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	17.9	6.1	40.8	0.7	0.5	0.5	0.3	0.1	1,636
2011	16.8	8.5	50.9	13.8	1.7	1.3	1.3	0.1	1,339
2005	14.1	11.2	68.5	11.2	1.4	1.2	1.1	0.1	1,206
2016 vs 2011 Change	**7%**	**-28%**	**-20%**	**-95%**	**-71%**	**-66%**	**-75%**	**-18%**	**22%**
2016 vs 2005 Change	**27%**	**-45%**	**-40%**	**-93%**	**-66%**	**-61%**	**-70%**	**-30%**	**36%**

Figure 2.6: Port of Anacortes Emissions Change, %

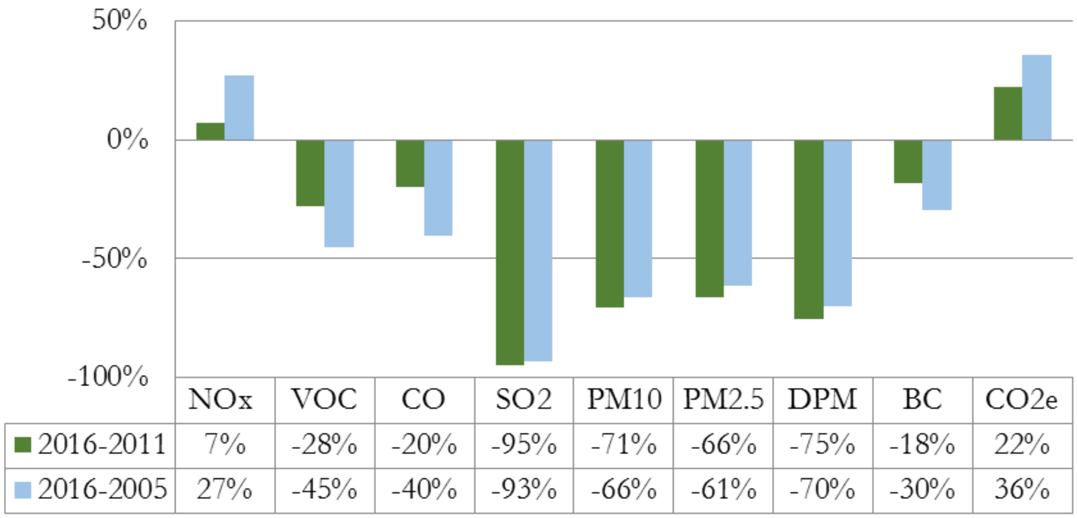
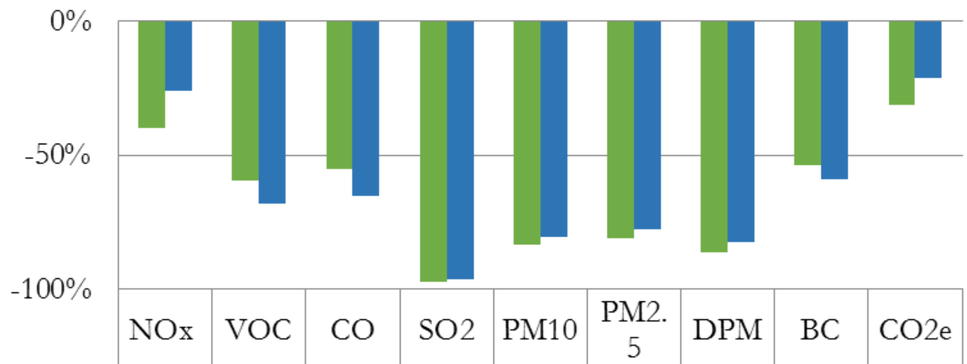


Table 2.22 and Figure 2.7 present the tons emissions per 10,000 metric tons of cargo comparison for Port of Anacortes.

Table 2.22: Port of Anacortes Port Emissions per 10,000 Metric Tons of Cargo Comparison, tpy and %

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	0.41	0.14	0.93	0.02	0.01	0.01	0.01	0.001	37.1
2011	0.68	0.34	2.06	0.56	0.07	0.05	0.05	0.003	54.0
2005	0.55	0.44	2.67	0.44	0.06	0.05	0.04	0.004	47.1
2016 vs 2011 Change	**-40%**	**-59%**	**-55%**	**-97%**	**-83%**	**-81%**	**-86%**	**-54%**	**-31%**
2016 vs 2005 Change	**-26%**	**-68%**	**-65%**	**-96%**	**-80%**	**-78%**	**-83%**	**-59%**	**-21%**

Figure 2.7: Port of Anacortes Emissions per 10,000 Metric Tons of Cargo Change, %



	NOx	VOC	CO	SO2	PM10	PM2.5	DPM	BC	CO2e
2016-2011	-40%	-59%	-55%	-97%	-83%	-81%	-86%	-54%	-31%
2016-2005	-26%	-68%	-65%	-96%	-80%	-78%	-83%	-59%	-21%

2.6.2 Port of Everett

Table 2.23 presents the 2016 emissions associated with the Port of Everett.

Table 2.23: Port of Everett 2016 Port Emissions, tpy

Source Category	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
OGV, hotelling	24.5	0.8	2.3	1.3	0.6	0.5	0.5	0.0	1,997
OGV, maneuvering	1.0	0.1	0.1	0.0	0.0	0.0	0.0	0.0	54
Recreational vessels	6.1	11.0	76.8	0.0	0.2	0.2	0.0	0.1	862
Locomotives	56.5	4.5	8.2	0.0	2.0	1.8	2.0	1.4	2,997
Cargo-handling equipm	9.5	2.1	10.2	0.0	0.7	0.7	0.7	0.5	856
Heavy-duty vehicles	0.2	0.0	0.1	0.0	0.0	0.0	0.0	0.0	20
Fleet vehicles	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	9.5
Total	**97.9**	**18.6**	**97.8**	**1.4**	**3.5**	**3.3**	**3.2**	**2.0**	**6,795**

Table 2.24 presents the throughput and total vessel movements associated with the Port of Everett. The vessel movements include arrival, departure, and shift calls. TEU increased at Port of Everett in 2016 as compared to 2005. From 2011 to 2016, the tons of cargo and vessel movements decreased, but there was a 31% increase in TEU throughput.

Table 2.24: Port of Everett Throughput and Vessel Movements Comparison

Year	TEU	Cargo (MT)	Total Vessel Movements
2016	27,380	139,252	124
2011	20,918	152,995	145
2005	9,561	103,757	82
2016 vs 2011 Change	**31%**	**-9%**	**-14%**
2016 vs 2005 Change	**186%**	**34%**	**51%**

Table 2.25 and Figure 2.8 present the emissions comparison for Port of Everett. Despite an increase in throughput, emissions decreased in 2016 as compared to 2011 and 2005.

Table 2.25: Port of Everett Port Emissions Comparison, tpy and %

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	97.9	18.6	97.8	1.4	3.5	3.3	3.2	2.0	6,795
2011	132.8	27.0	149.0	48.7	9.4	8.1	8.4	3.1	8,834
2005	144.1	30.0	166.1	43.5	8.6	7.6	7.8	3.2	6,946
2016 vs 2011 Change	**-26%**	**-31%**	**-34%**	**-97%**	**-62%**	**-60%**	**-62%**	**-35%**	**-23%**
2016 vs 2005 Change	**-32%**	**-38%**	**-41%**	**-97%**	**-59%**	**-57%**	**-58%**	**-37%**	**-2%**

Figure 2.8: Port of Everett Emissions Change, %

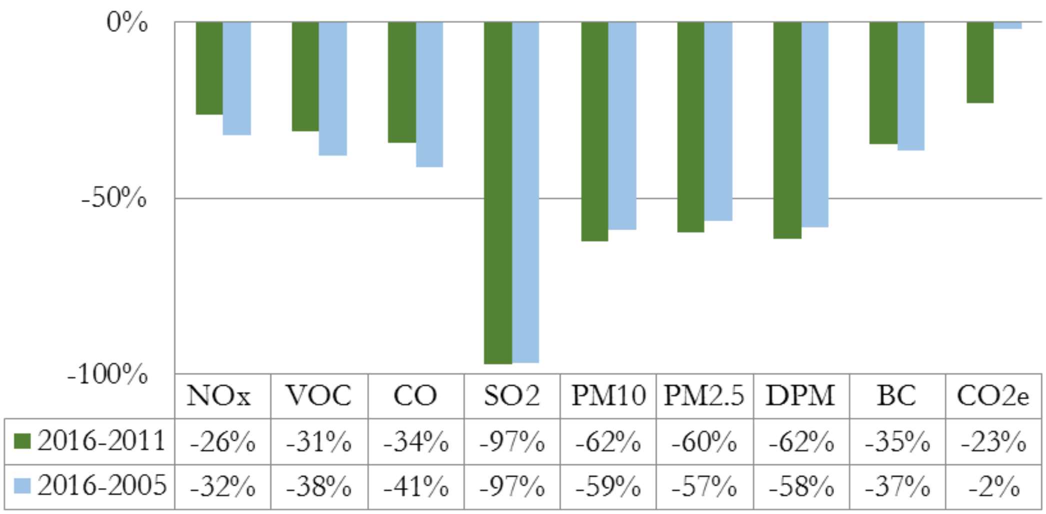
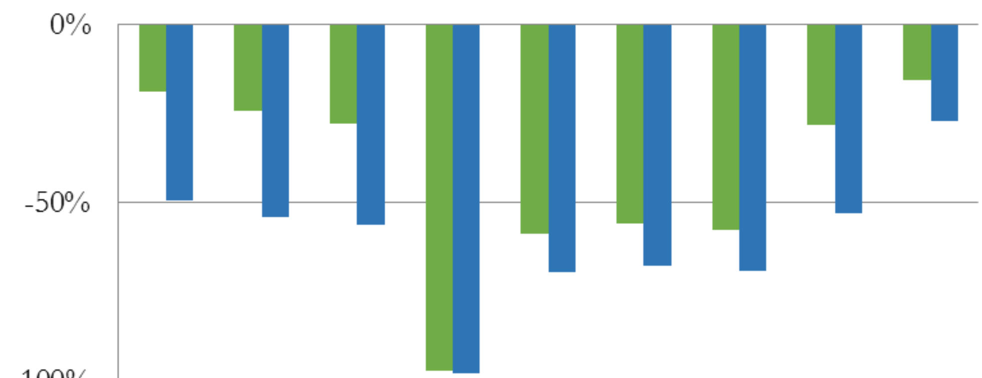


Table 2.26 and Figure 2.9 present the emissions per 10,000 metric tons of cargo comparison for Port of Everett.

Table 2.26: Port of Everett Port Emissions per 10,000 Metric Tons of Cargo Comparison, tpy and %

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	7.0	1.3	7.0	0.1	0.3	0.2	0.2	0.1	488
2011	8.7	1.8	9.7	3.2	0.6	0.5	0.5	0.2	577
2005	13.9	2.9	16.0	4.2	0.8	0.7	0.7	0.3	669
2016 vs 2011 Change	**-19%**	**-24%**	**-28%**	**-97%**	**-59%**	**-56%**	**-58%**	**-28%**	**-15%**
2016 vs 2005 Change	**-49%**	**-54%**	**-56%**	**-98%**	**-69%**	**-68%**	**-69%**	**-53%**	**-27%**

Figure 2.9: Port of Everett Emissions per 10,000 Metric Tons of Cargo Change, %



	NOx	VOC	CO	SO2	PM10	PM2.5	DPM	BC	CO2e
2016-2011	-19%	-24%	-28%	-97%	-59%	-56%	-58%	-28%	-15%
2016-2005	-49%	-54%	-56%	-98%	-69%	-68%	-69%	-53%	-27%

2.6.3 Port of Olympia

Table 2.27 presents emissions associated with the Port of Olympia.

Table 2.27: Port of Olympia 2016 Port Emissions, tpy

Source Category	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
OGV, hotelling	25.5	0.9	2.3	1.3	0.6	0.6	0.5	0.0	1,983
OGV, maneuvering	0.3	0.0	0.0	0.0	0.0	0.0	0.0	0.0	12
Recreational vessels	2.2	3.9	27.3	0.0	0.1	0.1	0.0	0.0	307
Locomotives	24.5	1.4	2.6	0.0	0.6	0.6	0.6	0.4	940.7
Cargo-handling equipment	22.6	2.1	11.3	0.0	1.4	1.3	1.4	1.0	2,442
Heavy-duty vehicles	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14
Fleet vehicles	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	7
Total	**75.1**	**8.3**	**43.7**	**1.3**	**2.7**	**2.5**	**2.5**	**1.5**	**5,706**

Table 2.28 presents the throughput and total vessel movements associated with the Port of Olympia. The vessel movements include arrival, departure, and shift calls. The tons of cargo throughput have increased significantly at Port of Olympia in 2016 as compared to 2005. The vessel movement also increased in 2016 as compared to 2011 and 2005.

Table 2.28: Port of Olympia Throughput and Vessel Movements Comparison

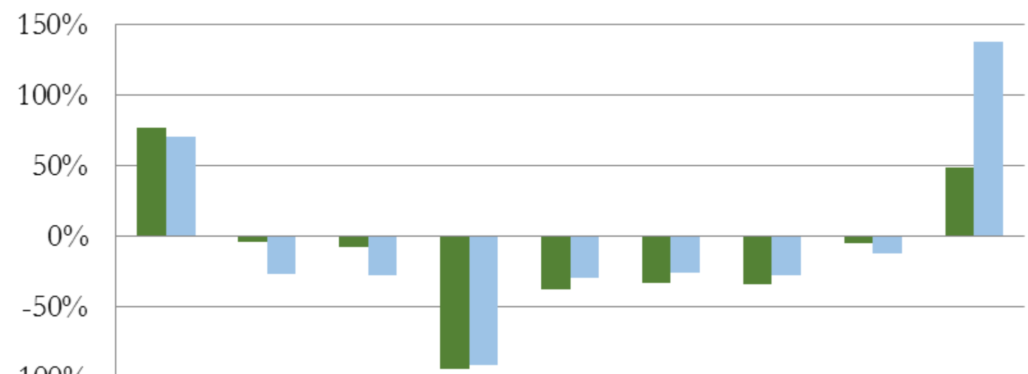
Year	TEU	Cargo (MT)	Total Vessel Movements
2016	0	854,735	60
2011	0	711,536	49
2005	903	129,512	36
2016 vs 2011 Change	**0%**	**20%**	**22%**
2016 vs 2005 Change	**-100%**	**560%**	**67%**

Table 2.29 and Figure 2.10 present the emissions comparison for Port of Olympia. Due to the increase in throughput, some emissions increased in 2016 as compared to 2011 and 2005. The SO_2 and PM emissions decreased in 2016 as compared to 2011 and 2005 due to the North American ECA which had an effect on the fuel used by vessels.

Table 2.29: Port of Olympia Port Emissions Comparison, tpy and %

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	75.1	8.3	43.7	1.3	2.7	2.5	2.5	1.5	5,706
2011	42.6	8.7	47.3	21.0	4.3	3.8	3.8	1.6	3,846
2005	44.1	11.3	60.7	15.4	3.8	3.4	3.5	1.7	2,399
2016 vs 2011 Change	**76%**	**-4%**	**-8%**	**-94%**	**-38%**	**-33%**	**-34%**	**-5%**	**48%**
2016 vs 2005 Change	**70%**	**-26%**	**-28%**	**-92%**	**-30%**	**-26%**	**-27%**	**-13%**	**138%**

Figure 2.10: Port of Olympia Emissions Change, %



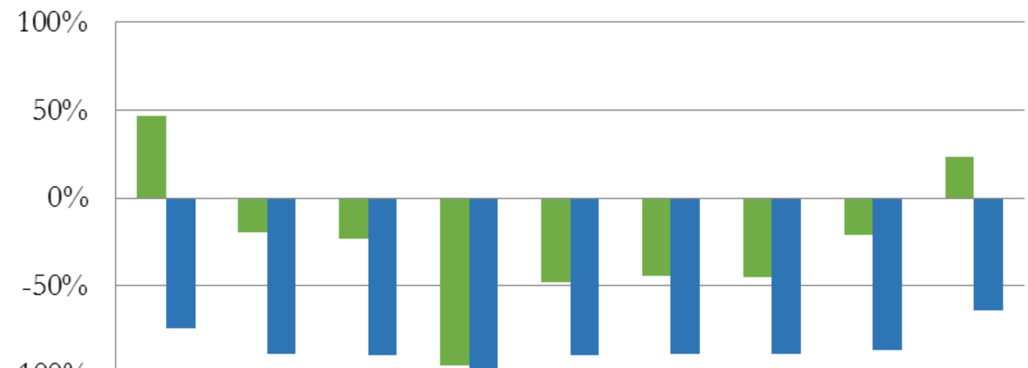
	NOx	VOC	CO	SO2	PM10	PM2.5	DPM	BC	CO2e
2016-2011	76%	-4%	-8%	-94%	-38%	-33%	-34%	-5%	48%
2016-2005	70%	-26%	-28%	-92%	-30%	-26%	-27%	-13%	138%

Table 2.30 and Figure 2.11 present the emissions per 10,000 metric tons of cargo comparison for Port of Olympia.

Table 2.30: Port of Olympia Port Emissions per 10,000 Metric Tons of Cargo Comparison, tpy and %

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	0.879	0.098	0.511	0.015	0.031	0.030	0.029	0.018	67
2011	0.598	0.122	0.665	0.295	0.060	0.053	0.054	0.023	54
2005	3.404	0.869	4.691	1.191	0.295	0.266	0.268	0.135	185
2016 vs 2011 Change	**47%**	**-20%**	**-23%**	**-95%**	**-48%**	**-44%**	**-45%**	**-21%**	**24%**
2016 vs 2005 Change	**-74%**	**-89%**	**-89%**	**-99%**	**-89%**	**-89%**	**-89%**	**-87%**	**-64%**

Figure 2.11: Port of Olympia Emissions per 10,000 Metric Tons of Cargo Change, %



	NOx	VOC	CO	SO2	PM10	PM2.5	DPM	BC	CO2e
2016-2011	47%	-20%	-23%	-95%	-48%	-44%	-45%	-21%	24%
2016-2005	-74%	-89%	-89%	-99%	-89%	-89%	-89%	-87%	-64%

2.6.4 Port of Port Angeles

Table 2.31 presents emissions associated with the Port of Port Angeles.

Table 2.31: Port of Port Angeles 2016 Port Emissions, tpy

Source Category	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
OGV, hotelling	125.1	4.3	11.8	5.40	2.77	2.61	2.58	0.16	8,482
OGV, maneuvering	0.7	0.0	0.1	0.03	0.01	0.01	0.01	0.00	41
Recreational vessels	na	na	na	na	na	na	na	na	na
Locomotives	na	na	na	na	na	na	na	na	na
Cargo-handling equipment	1.8	0.3	0.9	0.00	0.21	0.20	0.21	0.15	111
Heavy-duty vehicles	na	na	na	na	na	na	na	na	na
Fleet vehicles	na	na	na	na	na	na	na	na	na
Total	**127.6**	**4.6**	**12.8**	**5.43**	**2.99**	**2.82**	**2.80**	**0.31**	**8,635**

Table 2.32 presents the total vessel movements associated with the Port of Port Angeles. The vessel movements include arrival, departure, and shift calls. The total vessel movements decreased in 2016 as compared to 2005 and 2011.

Table 2.32: Port of Port Angeles Vessel Movements Comparison

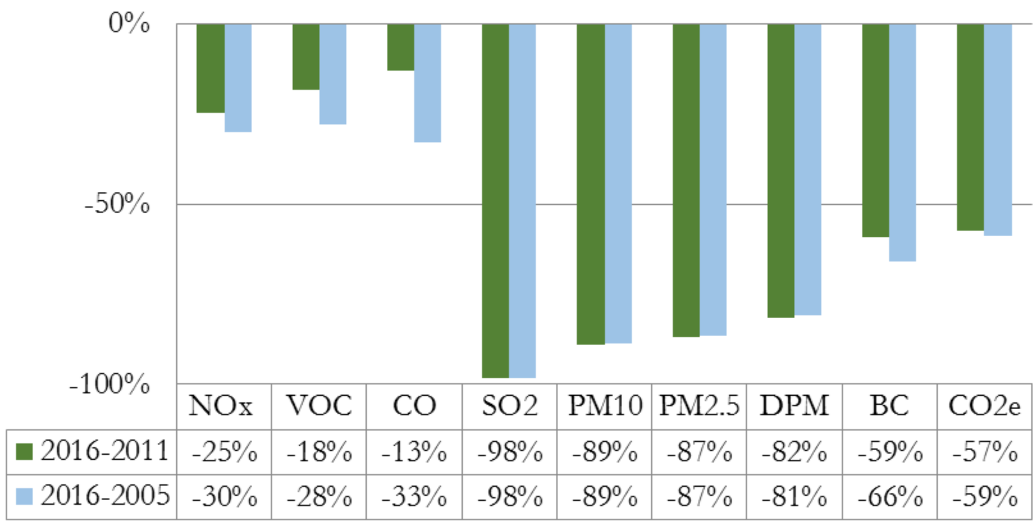
Year	Total Vessel Movements
2016	29
2011	36
2005	51
2016 vs 2011 Change	**-19%**
2016 vs 2005 Change	**-43%**

Table 2.33 and Figure 2.12 present the emissions comparison for Port of Port Angeles. The SO_2 and PM emissions decreased in 2016 as compared to 2011 and 2005 due to the North American ECA which had an effect on the fuel used by vessels.

Table 2.33: Port of Port Angeles Port Emissions Comparison, tpy and %

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	127.6	4.6	12.8	5.4	3.0	2.8	2.8	0.3	8,635
2011	169.4	5.7	14.8	327.6	26.9	21.5	15.2	0.8	20,218
2005	182.2	6.4	19.1	309.3	26.5	21.2	14.7	0.9	21,018
2016 vs 2011 Change	**-25%**	**-18%**	**-13%**	**-98%**	**-89%**	**-87%**	**-82%**	**-59%**	**-57%**
2016 vs 2005 Change	**-30%**	**-28%**	**-33%**	**-98%**	**-89%**	**-87%**	**-81%**	**-66%**	**-59%**

Figure 2.12: Port of Port Angeles Emissions Change, %



2.6.5 Port of Seattle

Table 2.34 presents the 2016 port emissions associated with the Port of Seattle operations, excluding NWSA operations. Therefore, the Port of Seattle emissions included here are only for non-NWSA activities which include the cruise terminal operations, grain terminal, fishing fleet a, marinas, and port-owned equipment. Port of Seattle emissions within the airshed are discussed in Section 9.8.1.

Table 2.34: Port of Seattle 2016 Port Emissions, tpy

Source Category	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
OGV, hotelling	211.2	6.8	18.6	8.62	4.39	4.12	4.05	0.25	13,540
OGV, maneuvering	17.0	0.6	1.5	0.61	0.33	0.31	0.32	0.02	962
Recreational vessels	5.2	9.4	65.8	0.01	0.20	0.18	0.03	0.05	739
Locomotives	13.0	0.6	2.4	0.01	0.33	0.31	0.33	0.24	923
Cargo-handling equipm	6.0	1.1	18.0	0.00	0.29	0.28	0.26	0.20	623
Heavy-duty vehicles	0.3	0.0	0.1	0.00	0.00	0.00	0.00	0.01	16
Fleet vehicles	0.9	0.2	3.6	0.01	0.01	0.01	0.01	0.01	287
Total	**253.5**	**18.7**	**109.9**	**9.27**	**5.56**	**5.22**	**5.00**	**0.78**	**17,090**

Table 2.35 presents the cargo throughput in metric tons, total vessel movements, and cruise passenger counts associated with the Port of Seattle. Please note that the 2005 and 2011 cargo and vessel movements were recalculated to exclude NWSA operations. The vessel movements include arrival, departure, and shift calls. The tonnes of cargo throughput have decreased by 13% at Port of Seattle in 2016 as compared to 2005 and 2011. The number of cruise passengers increased in 2016 as compared to 2011 and 2005.

Table 2.35: Port of Seattle Throughput and Vessel Movements Comparison

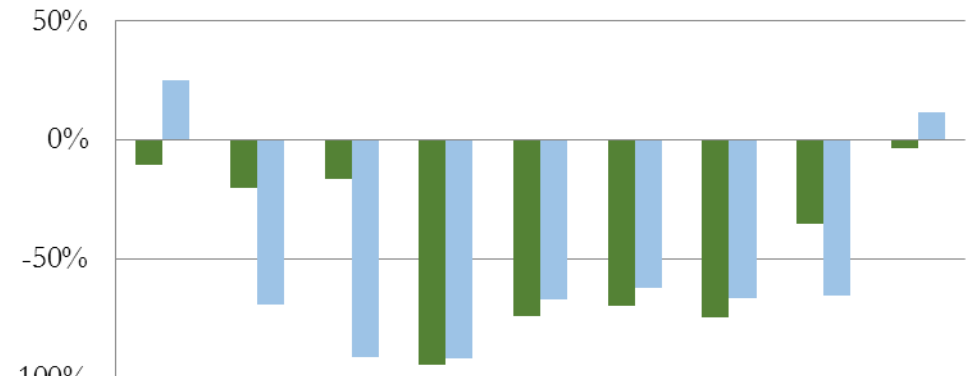
Year	Cargo (MT)	Total Vessel Movements	Cruise Passengers
2016	4,389,089	535	983,539
2011	5,026,868	554	885,949
2005	5,049,107	339	686,978
2016 vs 2011 Change	**-13%**	**-3%**	**11%**
2016 vs 2005 Change	**-13%**	**58%**	**43%**

Table 2.36 and Figure 2.13 present the emissions comparison for Port of Seattle. The SO_2 and PM emissions decreased in 2016 as compared to 2011 and 2005 due to the use of cleaner fuel within the North American ECA as required by law.

Table 2.36: Port of Seattle Port Emissions Comparison, tpy and %

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	254	19	110	9	6	5	5	0.8	17,090
2011	283	24	132	169	21	17	20	1.2	17,687
2005	203	61	1,282	114	17	14	15	2.2	15,348
2016 vs 2011 Change	**-10%**	**-20%**	**-17%**	**-95%**	**-74%**	**-70%**	**-74%**	**-36%**	**-3%**
2016 vs 2005 Change	**25%**	**-69%**	**-91%**	**-92%**	**-67%**	**-62%**	**-67%**	**-65%**	**11%**

Figure 2.13: Port of Seattle Emissions Change, %



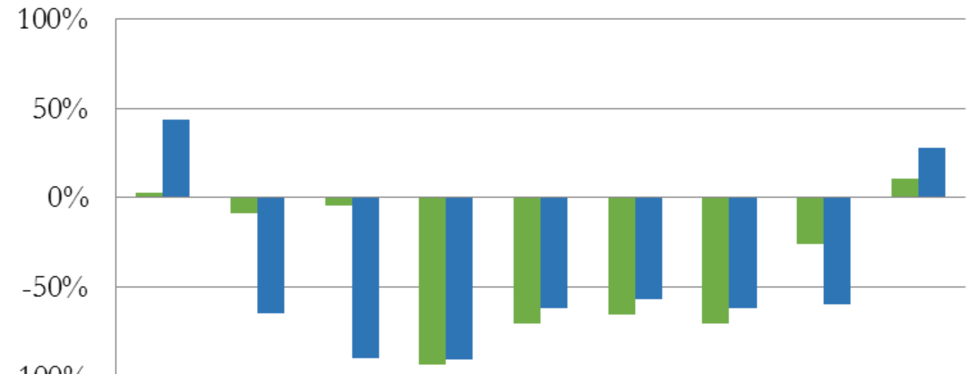
	NOx	VOC	CO	SO2	PM10	PM2.5	DPM	BC	CO2e
2016-2011	-10%	-20%	-17%	-95%	-74%	-70%	-74%	-36%	-3%
2016-2005	25%	-69%	-91%	-92%	-67%	-62%	-67%	-65%	11%

Table 2.37 and Figure 2.14 present the emissions per 10,000 metric tons of cargo comparison for Port of Seattle. Port of Seattle's lines of business include cruise, commercial harbor vessel, and recreational vessel activities which are not associated with cargo; however, the tons of emissions per ton of cargo metric is a common metric applied to gauge emission efficiency.

Table 2.37: Port of Seattle Port Emissions per 10,000 Metric Tons of Cargo Comparison, tpy and %

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	0.578	0.043	0.250	0.021	0.013	0.012	0.011	0.002	39
2011	0.563	0.047	0.263	0.337	0.043	0.035	0.039	0.002	35
2005	0.402	0.120	2.538	0.225	0.033	0.028	0.030	0.004	30
2016 vs 2011 Change	**3%**	**-9%**	**-5%**	**-94%**	**-70%**	**-66%**	**-71%**	**-26%**	**11%**
2016 vs 2005 Change	**44%**	**-65%**	**-90%**	**-91%**	**-62%**	**-57%**	**-62%**	**-60%**	**28%**

Figure 2.14: Port of Seattle Emissions per 10,000 Metric Tons of Cargo Change, %



	NOx	VOC	CO	SO2	PM10	PM2.5	DPM	BC	CO2e
2016-2011	3%	-9%	-5%	-94%	-70%	-66%	-71%	-26%	11%
2016-2005	44%	-65%	-90%	-91%	-62%	-57%	-62%	-60%	28%

2.6.6 Port of Tacoma

Table 2.38 present port emissions associated with the Port of Tacoma. In 2015, the Port of Tacoma and Port of Seattle formed an alliance to manage their marine cargo, the Northwest Seaport Alliance (NWSA). Therefore, the Port of Tacoma emissions included here are only for the non-NWSA activities which only include the grain terminal. Port of Tacoma emissions within the airshed are discussed in Section 9.8.2.

Table 2.38: Port of Tacoma 2016 Port Emissions, tpy

Source Category	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
OGV, hotelling	33.6	1.2	3.2	1.78	0.82	0.77	0.68	0.05	2,796
OGV, maneuvering	1.6	0.1	0.1	0.04	0.02	0.02	0.02	0.00	65
Recreational vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Locomotives	18.3	1.0	3.1	0.01	0.49	0.45	0.49	0.35	1,166
Cargo-handling equipme	0.2	0.0	0.9	0.00	0.00	0.00	0.00	0.00	12
Heavy-duty vehicles	0.3	0.0	0.1	0.00	0.01	0.01	0.01	0.01	28
Fleet vehicles	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	116
Total	**54.0**	**2.3**	**7.7**	**1.83**	**1.35**	**1.26**	**1.20**	**0.41**	**4,183**

Table 2.39 presents the cargo throughput and total vessel movements associated with the Port of Tacoma. Please note that the 2005 and 2011 cargo and vessel movements were recalculated to exclude NWSA operations. The vessel movements include arrival, departure, and shift calls. The total vessel movements decreased in 2016 as compared to 2011 and 2005.

Table 2.39: Port of Tacoma Throughput and Vessel Movements Comparison

Year	Cargo (MT)	Total Vessel Movements
2016	4,413,228	132
2011	5,390,022	183
2005	6,968,667	223
2016 vs 2011 Change	**-18%**	**-28%**
2016 vs 2005 Change	**-37%**	**-41%**

Table 2.40 and Figure 2.15 present the emissions comparison for Port of Tacoma. The emissions are lower in 2016 as compared to 2011 and 2005.

Table 2.40: Port of Tacoma Port Emissions Comparison, tpy and %

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	54.0	2.3	7.7	1.8	1.3	1.3	1.2	0.4	4,183
2011	63.1	3.1	11.3	53.8	6.1	4.9	5.1	0.6	4,548
2005	79.2	3.9	13.7	64.3	7.2	5.9	6.1	0.8	5,139
2016 vs 2011 Change	**-14%**	**-24%**	**-32%**	**-97%**	**-78%**	**-75%**	**-77%**	**-29%**	**-8%**
2016 vs 2005 Change	**-32%**	**-41%**	**-44%**	**-97%**	**-81%**	**-79%**	**-80%**	**-47%**	**-19%**

Figure 2.15: Port of Tacoma Emissions Change, %

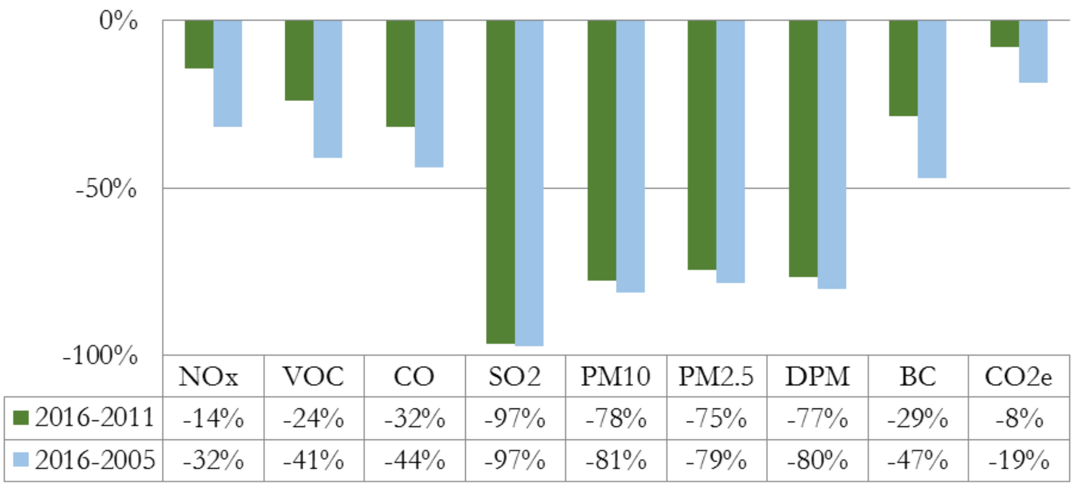
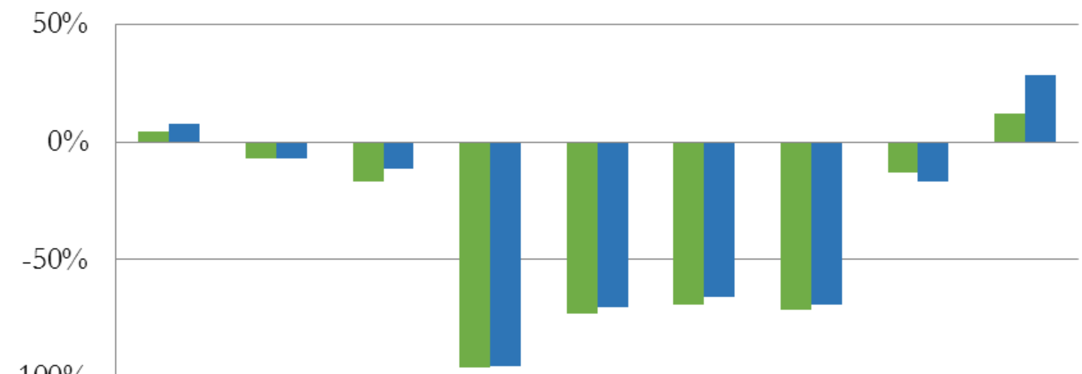


Table 2.41 and Figure 2.16 present the emissions per 10,000 metric tons of cargo comparison for Port of Tacoma.

Table 2.41: Port of Tacoma Port Emissions per 10,000 Metric Tons of Cargo Comparison, tpy and %

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	0.122	0.005	0.017	0.004	0.003	0.003	0.003	0.001	9
2011	0.117	0.006	0.021	0.100	0.011	0.009	0.010	0.001	8
2005	0.114	0.006	0.020	0.092	0.010	0.008	0.009	0.001	7
2016 vs 2011 Change	**4%**	**-7%**	**-17%**	**-96%**	**-73%**	**-69%**	**-71%**	**-13%**	**12%**
2016 vs 2005 Change	**8%**	**-7%**	**-11%**	**-95%**	**-70%**	**-66%**	**-69%**	**-17%**	**29%**

Figure 2.16: Port of Tacoma Emissions per 10,000 Metric Tons of Cargo Change, %



	NOx	VOC	CO	SO2	PM10	PM2.5	DPM	BC	CO2e
2016-2011	4%	-7%	-17%	-96%	-73%	-69%	-71%	-13%	12%
2016-2005	8%	-7%	-11%	-95%	-70%	-66%	-69%	-17%	29%

2.6.7 Northwest Seaport Alliance

For the Northwest Seaport Alliance (NWSA) port comparisons, the port emissions within port terminals, adjacent rail yards and waterways are tabulated as follows:

- Ocean-going vessel emissions (hoteling and maneuvering activities)
- Commercial harbor vessel emissions (includes assist tug emissions based on percentage of total vessel movements for NWSA North Harbor and NWSA South Harbor)
- Cargo-handling equipment emissions
- Locomotive emissions (switching activities on-terminal and adjacent rail yards)
- Heavy-duty vehicle emissions (queuing and on-terminal activities)
- Fleet vehicle emissions (on-terminal activities)

The following were not included in the Port summaries for the Northwest Seaport Alliance:

- Ocean-going vessels transiting mode emissions and emissions from activities that are not directly associated with the operations at port terminals or petroleum facilities.
- Recreational vessels (marinas are not part of NWSA).
- Commercial harbor vessel emissions (except for assist tug emissions associated with the total vessel movements for NWSA).
- Line-haul locomotive emissions (line-haul activities were not identified at these ports).
- Heavy-duty vehicles on-road emissions outside the ports' terminals.

2.6.8 Northwest Seaport Alliance Port Emissions

Table 2.42 presents the 2016 port emissions associated with the NWSA North Harbor and South Harbor combined operations. NWSA emissions within the airshed are discussed in Section 9.7.

Table 2.42: NWSA Combined 2016 Port Emissions, tpy

Source Category	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
OGV, hotelling	728	24.9	66.3	42.2	18.2	17.0	13.4	1.0	66,385
OGV, maneuvering	163	12.4	16.9	4.4	2.9	2.8	2.8	0.1	6,931
Harbor vessels	407	12.9	67.2	0.2	13.4	12.3	13.4	9.5	24,195
Locomotives	611	39.8	106.9	0.4	18.9	17.4	18.9	13.5	39,869
Cargo-handling equipment	274	24.7	135.2	0.3	13.5	13.1	13.5	9.7	43,581
Heavy-duty vehicles	149	16.7	45.8	0.1	7.3	6.7	7.3	3.5	16,780
Fleet vehicles	2	0.4	7.5	0.0	0.0	0.0	0.0	0.0	592
Total	**2,334**	**131.9**	**445.8**	**47.6**	**74.2**	**69.3**	**69.3**	**37.4**	**198,332**

Table 2.43 presents the throughput and total vessel movements associated with the NWSA. The vessel movements include arrival, departure, and shift calls. The throughput and total vessel movements decreased in 2016 as compared to 2005 and 2011.

Table 2.43: NWSA Combined Throughput and Vessel Movements Comparison

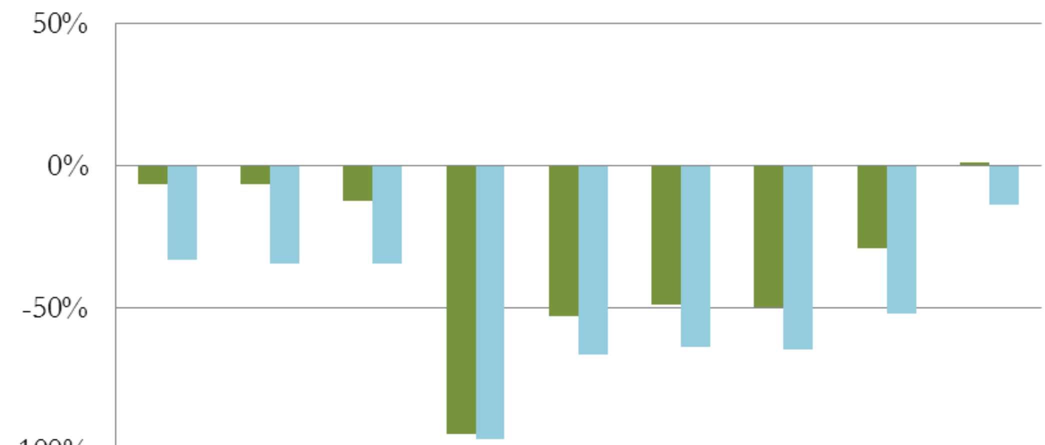
Year	TEU	Cargo (MT)	Total Vessel Movements
2016	3,615,753	28,026,869	2,810
2011	3,522,330	29,616,040	3,087
2005	4,157,929	28,947,086	3,538
2016 vs 2011 Change	**3%**	**-5%**	**-9%**
2016 vs 2005 Change	**-13%**	**-3%**	**-21%**

Table 2.44 and Figure 2.17 present the emissions comparison for NWSA. The emissions decreased in 2016 as compared to 2011 and 2005 due decreased throughput and the North American ECA which affected the fuel used by vessels. The CO_2e emissions increased slightly in 2016 as compared to 2011.

Table 2.44: NWSA Combined Port Emissions Comparison, tpy and %

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	2,334	132	446	48	74	69	69	37.4	198,332
2011	2,501	141	509	821	157	136	138	52.8	195,946
2005	3,483	201	682	1,259	220	191	196	78.2	229,679
2016 vs 2011 Change	**-7%**	**-7%**	**-12%**	**-94%**	**-53%**	**-49%**	**-50%**	**-29%**	**1%**
2016 vs 2005 Change	**-33%**	**-35%**	**-35%**	**-96%**	**-66%**	**-64%**	**-65%**	**-52%**	**-14%**

Figure 2.17: NWSA Combined Emissions Change, %



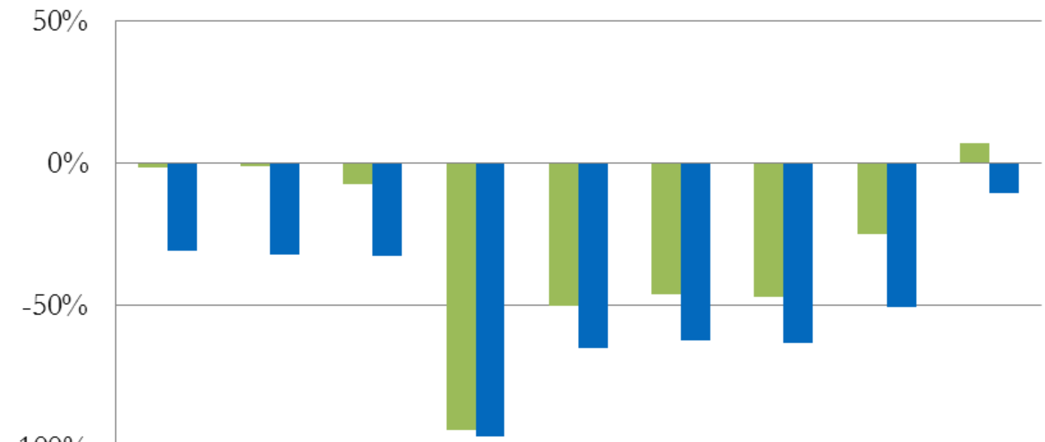
	NOx	VOC	CO	SO2	PM10	PM2.5	DPM	BC	CO2e
2016-2011	-7%	-7%	-12%	-94%	-53%	-49%	-50%	-29%	1%
2016-2005	-33%	-35%	-35%	-96%	-66%	-64%	-65%	-52%	-14%

Table 2.45 and Figure 2.18 present the emissions per 10,000 metric tons comparison for NWSA.

Table 2.45: NWSA Combined Port Emissions per 10,000 Metric Tons of Cargo Comparison, tpy and %

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	0.83	0.05	0.16	0.02	0.03	0.02	0.02	0.01	71
2011	0.84	0.05	0.17	0.28	0.05	0.05	0.05	0.02	66
2005	1.20	0.07	0.24	0.43	0.08	0.07	0.07	0.03	79
2016 vs 2011 Change	**-1%**	**-1%**	**-8%**	**-94%**	**-50%**	**-46%**	**-47%**	**-25%**	**7%**
2016 vs 2005 Change	**-31%**	**-32%**	**-32%**	**-96%**	**-65%**	**-62%**	**-63%**	**-51%**	**-11%**

Figure 2.18: NWSA Combined Emissions per 10,000 Metric Tons of Cargo Change, %



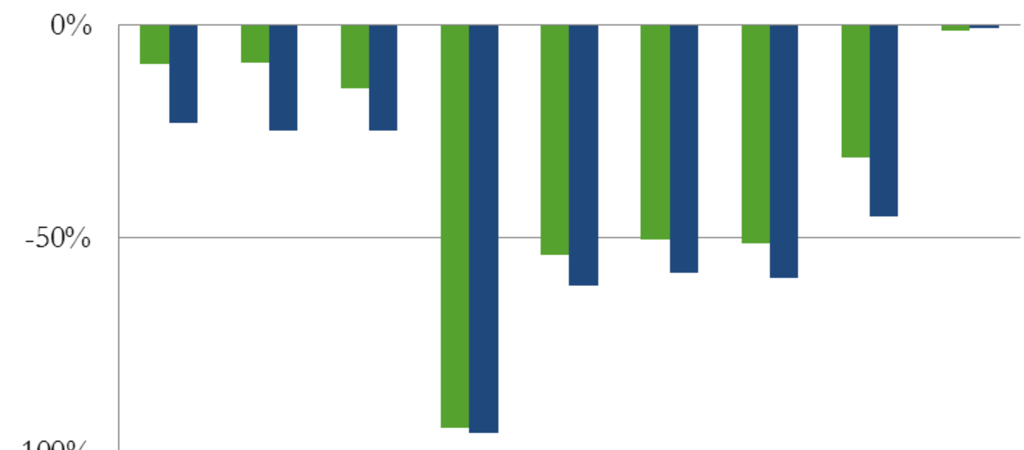
	NOx	VOC	CO	SO2	PM10	PM2.5	DPM	BC	CO2e
2016-2011	-1%	-1%	-8%	-94%	-50%	-46%	-47%	-25%	7%
2016-2005	-31%	-32%	-32%	-96%	-65%	-62%	-63%	-51%	-11%

Table 2.46 and Figure 2.19 present the emissions per 10,000 metric tons comparison for NWSA.

Table 2.46: NWSA Combined Port Emissions per 10,000 TEU Comparison, tpy and %

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	6.45	0.36	1.23	0.13	0.21	0.19	0.19	0.10	549
2011	7.10	0.40	1.45	2.33	0.45	0.39	0.39	0.15	556
2005	8.38	0.48	1.64	3.03	0.53	0.46	0.47	0.19	552
2016 vs 2011 Change	**-9%**	**-9%**	**-15%**	**-94%**	**-54%**	**-50%**	**-51%**	**-31%**	**-1%**
2016 vs 2005 Change	**-23%**	**-25%**	**-25%**	**-96%**	**-61%**	**-58%**	**-59%**	**-45%**	**-1%**

Figure 2.19: NWSA Combined Emissions per 10,000 TEU Change, %



	NOx	VOC	CO	SO2	PM10	PM2.5	DPM	BC	CO2e
2016-2011	-9%	-9%	-15%	-94%	-54%	-50%	-51%	-31%	-1%
2016-2005	-23%	-25%	-25%	-96%	-61%	-58%	-59%	-45%	-1%

2.6.9 NWSA North Harbor

Table 2.47 present the 2016 port emissions associated with the NWSA North Harbor operations in Seattle.

Table 2.47: NWSA North Harbor 2016 Port Emissions, tpy

Source Category	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
OGV, hotelling	239	8.4	22.2	14.3	6.1	5.8	4.5	0.3	22,589
OGV, maneuvering	53	4.2	5.5	1.4	0.9	0.9	0.9	0.0	2,185
Harbor vessels	133	4.2	21.9	0.1	4.4	4.0	4.4	3.1	7,877
Locomotives	154	10.1	26.7	0.1	4.8	4.4	4.8	3.4	9,971
Cargo-handling equipment	109	7.4	27.0	0.1	5.7	5.5	5.7	4.2	15,301
Heavy-duty vehicles	73	8.2	22.3	0.1	3.5	3.3	3.5	1.7	8,112
Fleet vehicles	1	0.2	3.0	0.0	0.0	0.0	0.0	0.0	176
Total	**760**	**42.6**	**128.6**	**16.1**	**25.5**	**23.9**	**23.8**	**12.8**	**66,213**

Table 2.48 presents the throughput and total vessel movements associated with the NWSA North Harbor in Seattle. The vessel movements include arrival, departure, and shift calls. The throughput and total vessel movements decreased in 2016 as compared to 2005 and 2011.

Table 2.48: NWSA North Harbor Throughput and Vessel Movements Comparison

Year	TEU	Cargo (MT)	Total Vessel Movements
2016	1,394,343	11,276,112	928
2011	2,033,535	17,735,810	1,622
2005	2,087,929	15,515,753	1,703
2016 vs 2011 Change	**-31%**	**-36%**	**-43%**
2016 vs 2005 Change	**-33%**	**-27%**	**-46%**

Table 2.49 and Figure 2.20 present the emissions comparison for NWSA North Harbor in Seattle. The emissions decreased in 2016 as compared to 2011 and 2005 due to decreased throughput and due to the North American ECA which had an effect on the fuel used by vessels.

Table 2.49: NWSA North Harbor Port Emissions Comparison, tpy and %

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	760	43	129	16	25	24	24	12.8	66,213
2011	1,352	75	264	381	81	71	72	29.1	108,625
2005	1,763	105	319	667	116	100	104	40.1	112,731
2016 vs 2011 Change	**-44%**	**-43%**	**-51%**	**-96%**	**-69%**	**-66%**	**-67%**	**-56%**	**-39%**
2016 vs 2005 Change	**-57%**	**-59%**	**-60%**	**-98%**	**-78%**	**-76%**	**-77%**	**-68%**	**-41%**

Figure 2.20: NWSA North Harbor Emissions Change, %

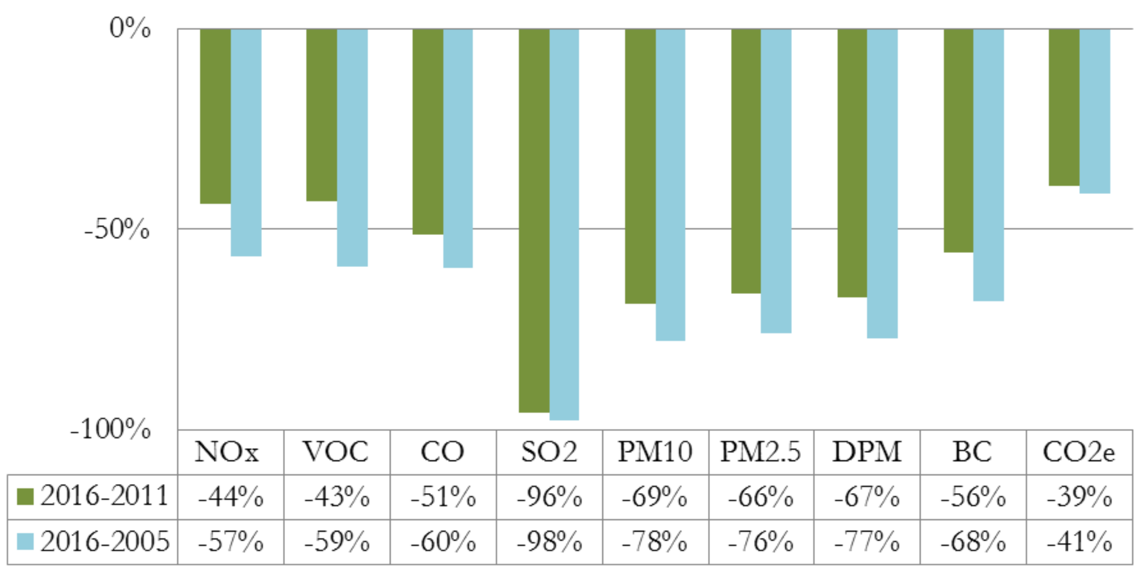
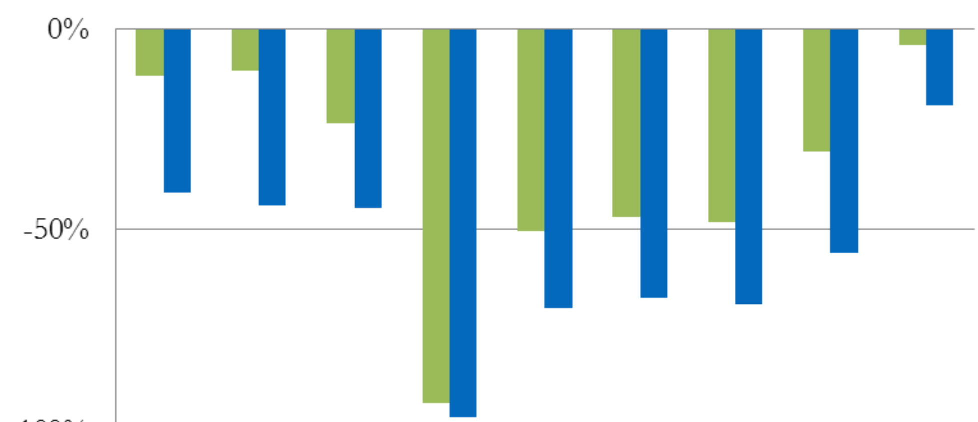


Table 2.50 and Figure 2.21 present the emissions per 10,000 metric tons comparison for NWSA North Harbor in Seattle.

Table 2.50: NWSA North Harbor Port Emissions per 10,000 Metric Tons of Cargo Comparison, tpy and %

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	0.67	0.04	0.11	0.01	0.02	0.02	0.02	0.01	59
2011	0.76	0.04	0.15	0.21	0.05	0.04	0.04	0.02	61
2005	1.14	0.07	0.21	0.43	0.07	0.06	0.07	0.03	73
2016 vs 2011 Change	**-12%**	**-10%**	**-24%**	**-93%**	**-50%**	**-47%**	**-48%**	**-31%**	**-4%**
2016 vs 2005 Change	**-41%**	**-44%**	**-45%**	**-97%**	**-70%**	**-67%**	**-69%**	**-56%**	**-19%**

Figure 2.21: NWSA North Harbor Emissions per 10,000 Metric Tons of Cargo Change, %



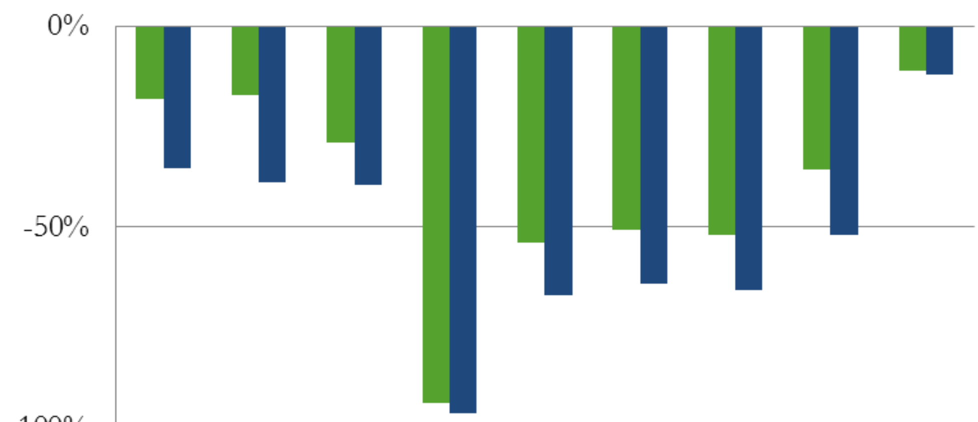
	NOx	VOC	CO	SO2	PM10	PM2.5	DPM	BC	CO2e
2016-2011	-12%	-10%	-24%	-93%	-50%	-47%	-48%	-31%	-4%
2016-2005	-41%	-44%	-45%	-97%	-70%	-67%	-69%	-56%	-19%

Table 2.51 and Figure 2.22 present the emissions per 10,000 TEU for NWSA North Harbor in Seattle.

Table 2.51: NWSA North Harbor Port Emissions per 10,000 TEU Comparison, tpy and %

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	5.45	0.31	0.92	0.12	0.18	0.17	0.17	0.09	475
2011	6.65	0.37	1.30	1.87	0.40	0.35	0.35	0.14	534
2005	8.45	0.50	1.53	3.19	0.55	0.48	0.50	0.19	540
2016 vs 2011 Change	**-18%**	**-17%**	**-29%**	**-94%**	**-54%**	**-51%**	**-52%**	**-36%**	**-11%**
2016 vs 2005 Change	**-35%**	**-39%**	**-40%**	**-96%**	**-67%**	**-64%**	**-66%**	**-52%**	**-12%**

Figure 2.22: NWSA North Harbor Emissions per 10,000 TEU Change, %



	NOx	VOC	CO	SO2	PM10	PM2.5	DPM	BC	CO2e
2016-2011	-18%	-17%	-29%	-94%	-54%	-51%	-52%	-36%	-11%
2016-2005	-35%	-39%	-40%	-96%	-67%	-64%	-66%	-52%	-12%

2.6.10 NWSA South Harbor

Table 2.52 presents the port emissions associated with the NWSA South Harbor in Tacoma.

Table 2.52: NWSA South Harbor 2016 Port Emissions, tpy

Source Category	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
OGV, hotelling	489	16.6	44.1	27.8	12.0	11.3	8.9	0.7	43,796
OGV, maneuvering	110	8.2	11.4	3.0	2.0	1.9	1.9	0.1	4,745
Harbor craft	275	8.7	45.3	0.2	9.0	8.3	9.0	6.4	16,317
Locomotives	458	29.7	80.1	0.3	14.1	12.9	14.1	10.1	29,897
Cargo-handling equipment	165	17.4	108.1	0.2	7.8	7.6	7.8	5.5	28,279
Heavy-duty vehicles	77	8.5	23.6	0.1	3.7	3.4	3.7	1.8	8,668
Fleet vehicles	1	0.2	4.5	0.0	0.0	0.0	0.0	0.0	416
Total	**1,573**	**89.2**	**317.2**	**31.5**	**48.7**	**45.5**	**45.5**	**24.5**	**132,119**

Table 2.53 presents the throughput and total vessel movements associated with the NWSA South Harbor in Tacoma. The vessel movements include arrival, departure, and shift calls. The throughput and total vessel movements decreased in 2016 as compared to 2005 and 2011.

Table 2.53: NWSA South Harbor Throughput and Vessel Movements Comparison

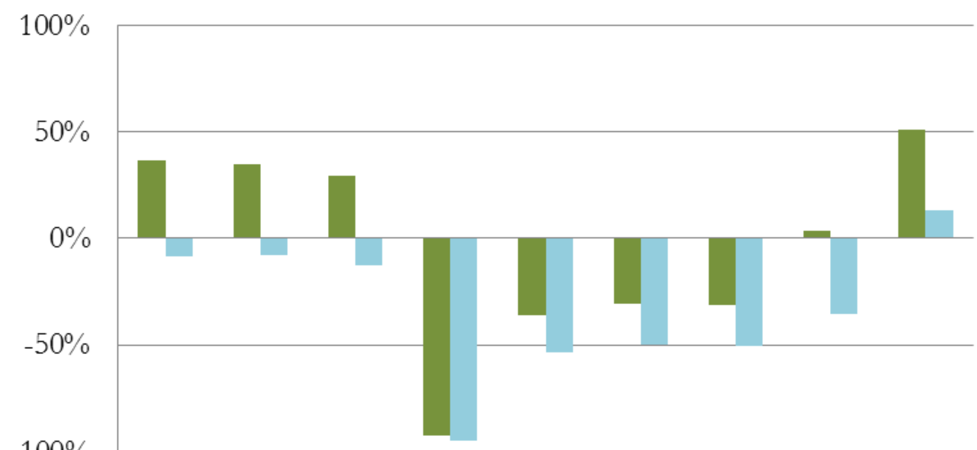
Year	TEU	Cargo (MT)	Total Vessel Movements
2016	2,221,410	16,750,757	1,882
2011	1,488,795	11,880,230	1,465
2005	2,070,000	13,431,333	1,835
2016 vs 2011 Change	**49%**	**41%**	**28%**
2016 vs 2005 Change	**7%**	**25%**	**3%**

Table 2.54 and Figure 2.23 present the emissions comparison for NWSA South Harbor in Tacoma. The SO_2 and PM emissions decreased in 2016 as compared to 2011 and 2005 due to the North American ECA which had an effect on the fuel used by vessels. The emissions increases are due to increased activity and throughput in 2016.

Table 2.54: NWSA South Harbor Port Emissions Comparison, tpy and %

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	1,573	89	317	32	49	45	46	24.5	132,119
2011	1,149	66	245	440	76	65	66	23.6	87,321
2005	1,720	97	363	592	104	91	92	38.1	116,948
2016 vs 2011 Change	**37%**	**35%**	**29%**	**-93%**	**-36%**	**-30%**	**-31%**	**4%**	**51%**
2016 vs 2005 Change	**-9%**	**-8%**	**-13%**	**-95%**	**-53%**	**-50%**	**-50%**	**-36%**	**13%**

Figure 2.23: NWSA South Harbor Emissions Change, %



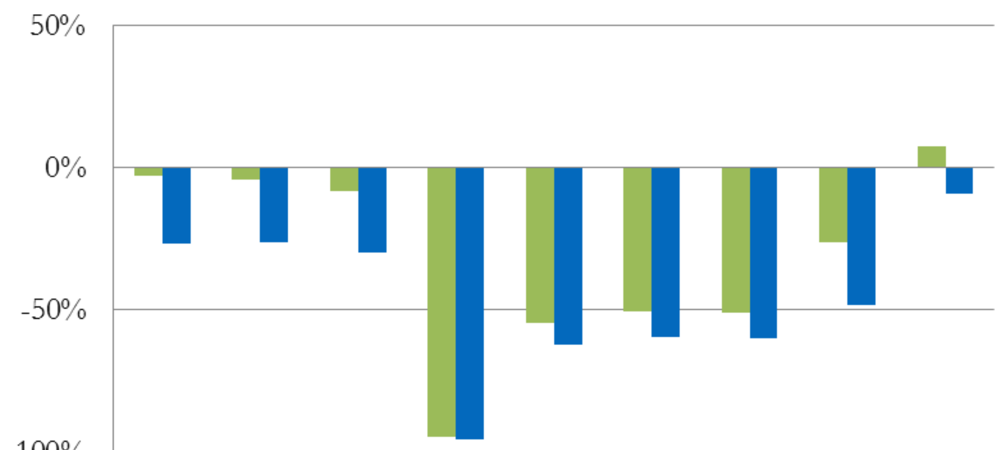
	NOx	VOC	CO	SO2	PM10	PM2.5	DPM	BC	CO2e
2016-2011	37%	35%	29%	-93%	-36%	-30%	-31%	4%	51%
2016-2005	-9%	-8%	-13%	-95%	-53%	-50%	-50%	-36%	13%

Table 2.55 and Figure 2.24 present the emissions per 10,000 metric tons of cargo comparison for NWSA South Harbor in Tacoma.

Table 2.55: NWSA South Harbor Port Emissions per 10,000 Metric Tons of Cargo Comparison, tpy and %

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	0.94	0.05	0.19	0.02	0.03	0.03	0.03	0.01	79
2011	0.97	0.06	0.21	0.37	0.06	0.06	0.06	0.02	74
2005	1.28	0.07	0.27	0.44	0.08	0.07	0.07	0.03	87
2016 vs 2011 Change	**-3%**	**-4%**	**-8%**	**-95%**	**-55%**	**-51%**	**-51%**	**-26%**	**7%**
2016 vs 2005 Change	**-27%**	**-26%**	**-30%**	**-96%**	**-63%**	**-60%**	**-60%**	**-48%**	**-9%**

Figure 2.24: NWSA South Harbor Emissions per 10,000 Metric Tons of Cargo Change, %



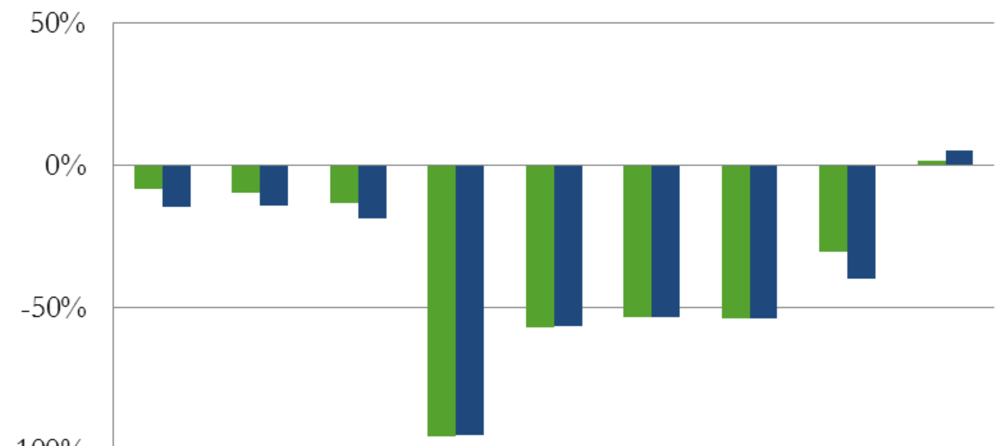
	NOx	VOC	CO	SO2	PM10	PM2.5	DPM	BC	CO2e
2016-2011	-3%	-4%	-8%	-95%	-55%	-51%	-51%	-26%	7%
2016-2005	-27%	-26%	-30%	-96%	-63%	-60%	-60%	-48%	-9%

Table 2.56 and Figure 2.25 present the emissions per 10,000 TEU comparison for NWSA South Harbor in Tacoma.

Table 2.56: NWSA South Harbor Port Emissions per 10,000 TEU Comparison, tpy and %

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	7.08	0.40	1.43	0.14	0.22	0.20	0.20	0.11	595
2011	7.72	0.44	1.65	2.95	0.51	0.44	0.44	0.16	587
2005	8.31	0.47	1.75	2.86	0.50	0.44	0.44	0.18	565
2016 vs 2011 Change	**-8%**	**-10%**	**-13%**	**-95%**	**-57%**	**-53%**	**-54%**	**-30%**	**1%**
2016 vs 2005 Change	**-15%**	**-14%**	**-19%**	**-95%**	**-56%**	**-53%**	**-54%**	**-40%**	**5%**

Figure 2.25: NWSA South Harbor Emissions per 10,000 TEU Change, %



	NOx	VOC	CO	SO2	PM10	PM2.5	DPM	BC	CO2e
2016-2011	-8%	-10%	-13%	-95%	-57%	-53%	-54%	-30%	1%
2016-2005	-15%	-14%	-19%	-95%	-56%	-53%	-54%	-40%	5%

SECTION 3 OCEAN-GOING VESSELS

Section 3 provides an overview of the emissions from ocean-going vessels calling at U.S. maritime facilities located within the Georgia Basin/Puget Sound International Airshed in 2016. Details of the methodology used to estimate emissions are available in Appendix B. The 2011 and 2005 emissions presented in this report are not exactly the same as the emissions originally reported in the 2011 and 2005 PSEI reports, but represent the latest science with respect to OGV emission calculations. For comparisons of 2016 to 2005 and 2011, please use the comparison sections in this 2016 PSEI report since 2005 and 2011 emissions have been recalculated to be directly comparable to 2016 emissions.

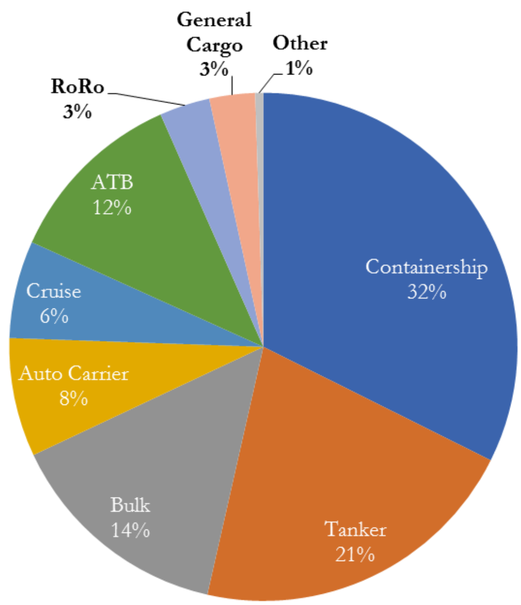
3.1 Source Category Description and Operational Characteristics

The ocean-going vessel source category typically consists of cargo carrying vessels equipped with large marine propulsion engines known as slow speed engines. These are in contrast to harbor vessels, which are typically equipped with medium speed and high speed propulsion engines, which are discussed in Section 4. Ocean-going vessels are categorized by the following main vessel types for purposes of this emissions inventory:

- Articulated tug-barge (ATB)
- Auto carriers
- Bulk carriers
- Containerships
- General cargo vessels
- Miscellaneous vessels
- Passenger cruise vessels
- Refrigerated vessels (Reefers)
- Roll-on/roll-off vessels (RoRo)
- Tankers

Figure 3.1 presents the percentage of ocean-going vessels for the total vessel movements in 2016 in Puget Sound. Vessel movements include arrivals, departures and shifts. The other category includes miscellaneous vessels and reefers.

Figure 3.1: 2016 OGV Total Vessel Movements Distribution by Vessel Type, %



The main vessel types are further subdivided for more accurate emissions estimates, as needed. Military vessels, such as aircraft carriers and submarines, are not included in the inventory due to security considerations.

Articulated Tug Barges (ATB)

Commonly known as articulated tug barges (ATB), the barge stern is notched to accept a special tug which can be rigidly connected to the barge forming a single vessel.

Auto Carriers

Auto carriers transport vehicles. They have drivable ramps and can have substantial ventilation systems to prevent vehicle fuel vapors from pooling in the lower decks.

Bulk Carriers

Bulk carriers have open holds with giant hatches to carry dry goods in bulk such as agricultural products, coal, petroleum coke, salt, sugar, cement, gypsum, and other similar fine-grained commodities.

Containerships

Containerships carry predominantly 20- and 40-foot containers on their decks and in their holds, and are primarily used by shipping lines to transport retail goods. Containerships are divided into subtypes based on their TEU capacity.

General Cargo Vessels

General cargo vessels carry diverse cargos such as steel, palletized goods, large heavy-duty machinery, and other heavy loads. Containers can also be carried on the vessel's top deck.

Passenger Cruise Vessels

Cruise vessels carry passengers for pleasure voyages. These vessels have significant auxiliary engine demands to provide hotel amenities such as heating, air conditioning and electricity for thousands of passengers.

Refrigerated Vessels (Reefer)

Often called reefers, these vessels are able to keep perishable cargo such as fruits, vegetables, and meats cool for the durations of the vessel's journey. 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.

Roll-on roll-off Vessels (RoRos)

RoRos, as they are typically known, are similar to automobile carriers, but can accommodate larger wheeled equipment, such as construction equipment.

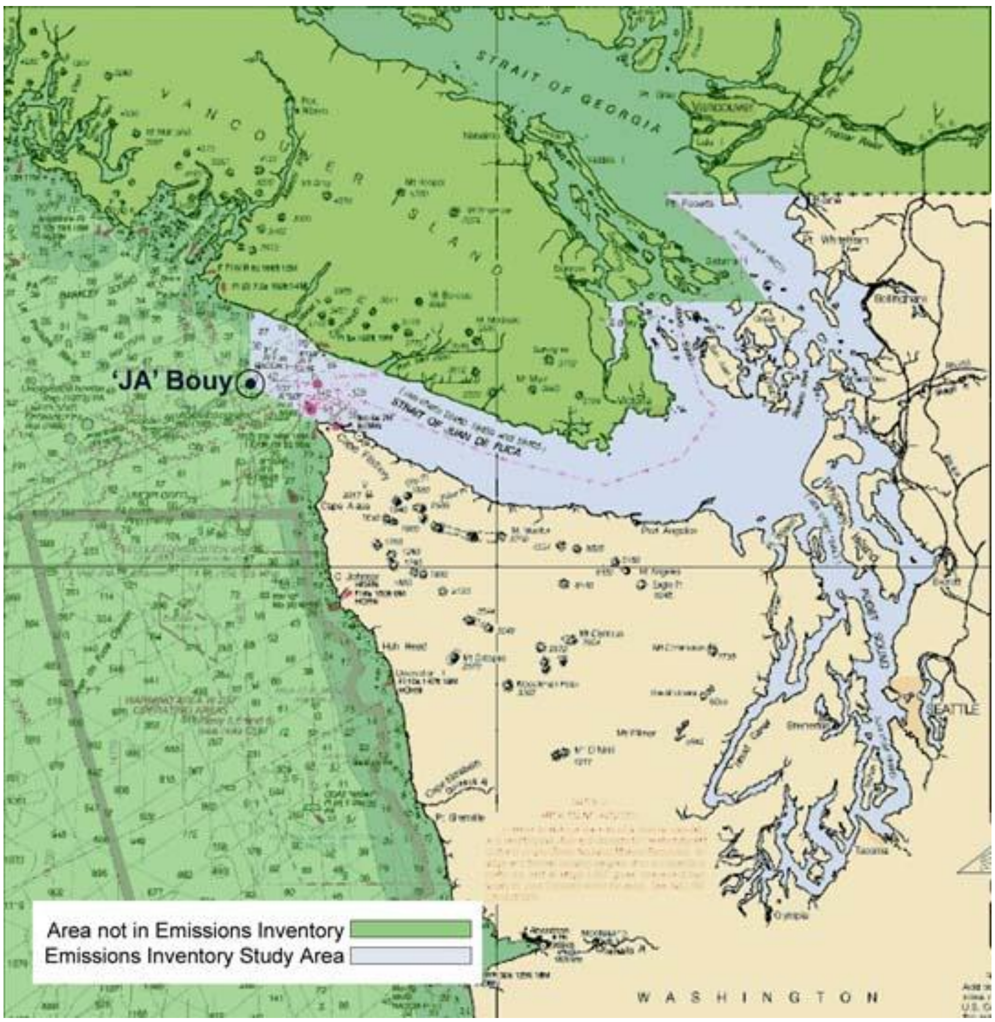
Tanker Vessels

Tanker vessels transport liquids in bulk such as oil, chemicals, and specialty products such as tallow and molasses. Crude oil tankers are categorized into different categories depending on their dimensions.

3.2 Geographical Description

The geographical area for ocean-going vessels for the 2016 emissions inventory includes the greater Puget Sound area and associated waterways, and the Strait of Juan de Fuca out to the JA buoy (located at the entrance to the Strait of Juan de Fuca) as presented in Figure 3.2. Emissions are estimated from OGVs that arrived at a U.S. berth from sea or departed to sea from a U.S. berth, regardless of whether the vessels traveled on the U.S. side or the Canadian side of the international border. For OGVs that shifted to Canadian berths, or shifted from Canadian berths to U.S. berths, this inventory includes emissions only in U.S. waters. The geographical area and guidelines were used for both 2005 and 2011 emissions inventories.

Figure 3.2: 2016 OGV Inventory Boundary



This area includes the twelve counties and seven ports described in Section 1.2.4. Other maritime facilities not associated with the seven ports, and within the geographical boundary are also included in this inventory. These facilities include privately-owned facilities, anchorages, ferry terminals and smaller ports. There are also oil and chemical facilities in the study area which are included in the inventory for the vessels that call at these petroleum facilities. In addition, Vendovi Island is also included since there is an area where vessel bunkering and de-bunkering occurs.

3.3 Data Collection

There were several information sources used to compile the data necessary to define activities and operational profiles which are then used to estimate emissions. These sources included:

- 2016 Marine Exchange of Puget Sound (MarEx) activity data which included vessel IMO numbers, arrival, shift, and departure dates and times, route information, and berth information.
- IHS Markit, Lloyd's Register of Ships – was used for obtaining vessel information such as main engine power and vessel speed rating.
- Puget Sound Pilots – confirmed average vessel speeds within Puget Sound.
- Vessel operational data – auxiliary engine load and boiler load data obtained from Starcrest's averages of Vessel Boarding Program (VBP) data.

3.4 Operational Profiles

The operational profiles for OGVs are based on vessel activity and routing, as discussed below.

For the purpose of this report, the definition of a vessel call is an arrival from the sea (JA Buoy), Canada or another port within the airshed to a berth or anchorage. Calls to anchorages associated with maritime facilities are also included, and thus the number of calls described in this report may not completely match the port statistics on vessel calls for 2016. The arrivals, as determined by this study, approximate the true number of vessel calls, which may not match the number of terminal calls typically reported for port statistics, which include shifts or movements within a port facility. Shifts within Port facilities are simply accounted for separately in the PSEI to increase the accuracy of emission calculations because shifts do not have a "transit" component associated with them as arrivals and departures do. Ship movements are tracked as to:

- Arrivals (vessels arriving from the sea or from another port to a terminal).
- Departures (vessels leaving a terminal to go out to sea or to another port).
- Shift (vessels that move within the Puget Sound to another terminal, berth, anchorage, or from one port to another port within the airshed domain).
- Total movements (sum of all the above).

Vessel activity is defined as the number of vessel trips by trip type and segment. Trip types include arrivals, departures, and shifts. Shifts are vessel movements from one berth within the Puget Sound area to another. The MarEx activity data was used to identify arrivals, departures and shifts in a logical sequence. Arrivals were assumed to come from the "last port of call" or from the sea. For departures, vessels were assumed to depart from the designated port and travel to the "next port of call" or travel out to sea. Shifts which involved trips internal to the area of study were processed as being from the last arrival to the next departure. One result of the data processing was the creation of three variables: trip origin, trip destination, and elapsed time (for hoteling estimates).

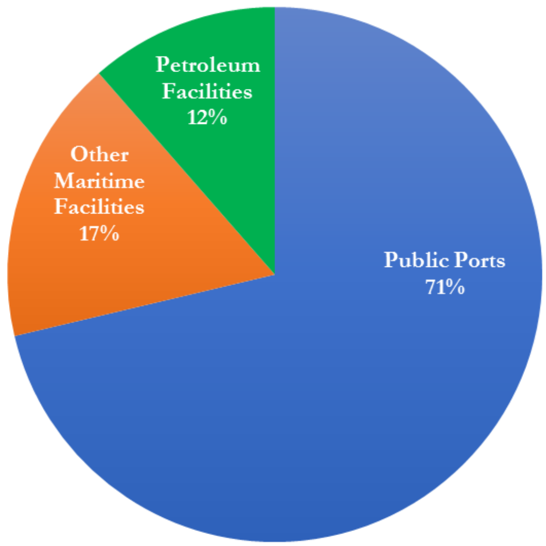
Table 3.1 presents the arrivals, departures, shifts and total movements for the Puget Sound study area in 2016 by vessel type. Containerships are classified into subtypes using a standardized unit to describe their carrying capacity, which is called a twenty-foot equivalent unit (TEU) and is based on the size of a 20-foot shipping container. In this inventory, a containership classified as Container-1000 vessel can accommodate up to 1,999 TEUs.

Table 3.1: 2016 OGV Movements by Vessel Type

Vessel Type	Inbound	Outbound	Shift	Movements
Auto Carrier	227	228	42	497
Bulk	315	317	248	880
Bulk - Heavy Load	4	6	8	18
Bulk - Self Discharging	21	21	11	53
Container - 1000	115	116	3	234
Container - 2000	90	90	33	213
Container - 3000	44	44	0	88
Container - 4000	137	137	16	290
Container - 5000	152	151	3	306
Container - 6000	106	107	6	219
Container - 7000	52	52	1	105
Container - 8000	165	165	77	407
Container - 9000	28	28	0	56
Container - 10000	81	80	44	205
Container - 11000	2	2	0	4
Container - 17000	1	1	0	2
Cruise	203	204	1	408
General Cargo	76	76	39	191
ATB	189	190	385	764
Miscellaneous	5	5	2	12
Reefer	8	8	6	22
RoRo	100	100	11	211
Tanker - Chemical	199	197	210	606
Tanker - Handysize	10	11	15	36
Tanker - Panamax	30	30	50	110
Tanker - Aframax	37	37	69	143
Tanker - Suezmax	123	123	252	498
Total	**2,520**	**2,526**	**1,532**	**6,578**

Figure 3.3 presents the distribution of 2016 inbound calls by facility type showing that 71% of the inbound calls were to the main public ports in the area. Other maritime facilities, such as privately-owned terminals and anchorages throughout the study area accounted for 17% of the inbound calls in 2016. Petroleum terminals and their associated anchorages accounted for 12% of inbound calls in 2016.

Figure 3.3: 2016 OGV Inbound Calls by Facility Type, %



Vessel routing is the underlying geographic element on which the emissions estimates are based. Using the 2016 MarEx data, distinct trip routes were derived. The route methodology was consistent with 2011 and 2005 PSEI, but updated for new trip routes found in 2016 to ensure all activity was included.

3.5 Emission Reduction Initiatives Identified

In 2016, the North American Emission Control Area (ECA) was in effect for the entire year, as it was introduced in 2015. The entire inventory domain is within the ECA since the boundary is within 200 nm from the U.S. coastline. All vessels were assumed to comply with the ECA 0.1% sulfur content in the fuel used within the study area.

At the Port of Seattle, some cruise vessels used shore power in 2016. At a NWSA South Harbor terminal, vessels operated by one vessel operator also used shore power in 2016. Except for when preparing to hook up to shore power, vessels using shore power at berth had zero emissions. For all vessels that used shore power, a minimum of 1.5 hours on auxiliary engine power hours was used for hoteling time to allow time for vessels to plug in. In 2016, there were a total of 169 shore power calls which included both the overall shore power calls at both the Port of Seattle and NWSA South Harbor.

3.6 Emission Estimates

Please refer to Appendix B for OGV emissions estimating methodology. The 2016 ocean-going vessel emissions for Puget Sound are summarized in this section. Table 3.2 presents the 2016 ocean-going vessel's emissions by county and regional air agency in tons per year. The links in the routing were cut at the county lines so that all links within a county could be easily divided up and their respective emissions summarized.

Table 3.2: 2016 Total Study Area OGV Emissions by County and Regional Clean Air Agency, tpy

County	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
Island	882	24	72	24	13.3	12.5	13.2	0.8	37,582
San Juan	670	17	52	17	9.0	8.5	9.0	0.5	27,120
Skagit	448	16	42	23	10.7	10.0	8.7	0.6	36,585
Whatcom	335	12	31	22	8.8	8.3	6.0	0.5	33,949
NWCAA Total	**2,335**	**70**	**197**	**86**	**41.8**	**39.3**	**36.8**	**2.4**	**135,236**
Clallam	5,291	151	436	151	81.4	76.7	79.7	4.6	236,635
Jefferson	705	19	58	19	10.5	9.9	10.5	0.6	29,846
Mason	0	0	0	0	0.0	0.0	0.0	0.0	16
Thurston	29	1	3	1	0.6	0.6	0.5	0.0	2,117
ORCAA Total	**6,025**	**172**	**497**	**171**	**92.6**	**87.3**	**90.7**	**5.2**	**268,615**
King	1,309	43	111	48	23.4	22.0	20.7	1.3	75,826
Kitsap	1,001	28	82	28	14.9	14.1	14.6	0.8	43,432
Pierce	761	31	70	38	17.5	16.4	13.7	0.9	60,267
Snohomish	85	3	7	3	1.5	1.4	1.4	0.1	4,619
PSCAA Total	**3,156**	**104**	**270**	**117**	**57.4**	**54.0**	**50.4**	**3.2**	**184,143**
Total	**11,516**	**346**	**964**	**374**	**191.8**	**180.5**	**178.0**	**10.7**	**587,994**

Table 3.3 presents the 2016 ocean-going vessel criteria pollutant emissions by vessel type.

Table 3.3: 2016 Total Study Area OGV Emissions by Vessel Type, tpy

Vessel Type	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
Auto Carrier	659	19	56	18	9.9	9.3	9.6	0.6	28,093
Bulk	770	20	67	27	13.4	12.6	12.2	0.8	42,215
Bulk - Heavy Load	21	1	2	1	0.5	0.4	0.4	0.0	1,499
Bulk - Self Discharging	56	1	4	2	0.9	0.8	0.8	0.1	2,853
Container - 1000	328	12	28	13	6.1	5.8	4.7	0.3	20,742
Container - 2000	314	9	27	9	4.8	4.6	4.6	0.3	14,023
Container - 3000	208	8	17	5	3.1	2.9	3.0	0.2	8,082
Container - 4000	799	23	61	22	11.3	10.7	10.9	0.6	33,854
Container - 5000	1,073	34	84	30	16.0	15.1	15.1	0.9	47,739
Container - 6000	777	21	65	22	11.4	10.7	10.7	0.6	34,261
Container - 7000	436	17	40	12	7.2	6.8	7.0	0.4	18,579
Container - 8000	1,483	35	120	41	20.6	19.4	19.4	1.1	64,790
Container - 9000	202	4	17	6	2.9	2.7	2.8	0.2	8,898
Container - 10000	705	11	57	20	9.4	8.9	9.0	0.5	31,455
Container - 11000	18	0	1	0	0.2	0.2	0.2	0.0	760
Container - 17000	9	0	1	0	0.1	0.1	0.1	0.0	458
Cruise	1,080	39	94	38	21.1	19.8	20.8	1.2	59,417
General Cargo	199	7	13	6	3.2	3.0	3.0	0.2	9,806
ATB	295	12	27	10	6.0	5.6	6.0	0.3	16,182
Miscellaneous	5	0	0	0	0.1	0.1	0.1	0.0	471
Reefer	24	1	2	1	0.5	0.4	0.4	0.0	1,509
RoRo	428	17	38	16	8.8	8.2	8.4	0.5	25,180
Tanker - Chemical	423	12	40	18	8.5	8.0	7.4	0.5	28,426
Tanker - Handysize	34	1	3	2	0.8	0.7	0.5	0.0	3,177
Tanker - Panamax	115	4	10	9	3.1	2.9	1.5	0.2	13,677
Tanker - Aframax	153	4	13	11	3.8	3.6	2.0	0.2	16,944
Tanker - Suezmax	902	34	75	35	18.1	17.0	17.2	1.0	54,903
Total	**11,516**	**346**	**964**	**374**	**191.8**	**180.5**	**178.0**	**10.7**	**587,994**

Table 3.4 presents the total 2016 OGV emissions by engine type. The engines include main (i.e., propulsion) engines, auxiliary engines and auxiliary boilers. The main engines are used during transit and maneuvering. Auxiliary engines are used during transit, maneuvering and hoteling. Hoteling can be at a berth or at an anchorage. All vessels, except the ocean tugboats, have auxiliary boilers.

Table 3.4: 2016 Total Study Area OGV Emissions by Engine Type, tpy

Engine Type	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
Main Engine	8,605	246	696	226	123.3	116.2	121.9	6.9	354,723
Auxiliary Engine	2,755	92	252	102	56.1	52.7	56.1	3.2	159,137
Auxiliary Boiler	155	8	16	47	12.4	11.6	0.0	0.7	74,134
Total	**11,516**	**346**	**964**	**374**	**191.8**	**180.5**	**178.0**	**10.7**	**587,994**

Table 3.5 presents the total 2016 OGV emissions by mode in Puget Sound in tons per year. The transit emissions include all transits within the study area. Hoteling and maneuvering is for all movements within the study area, including public and private facilities and anchorages.

Table 3.5: 2016 Total Study Area OGV Emissions by Mode, tpy

Mode	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
Transit	9,213	258	749	250	135.9	128.1	134.5	7.7	392,791
Hotelling	2,080	72	194	118	51.8	48.6	39.7	2.9	185,079
Maneuvering	223	15	22	6	4.0	3.8	3.8	0.2	10,124
Total	**11,516**	**346**	**964**	**374**	**191.8**	**180.5**	**178.0**	**10.7**	**587,994**

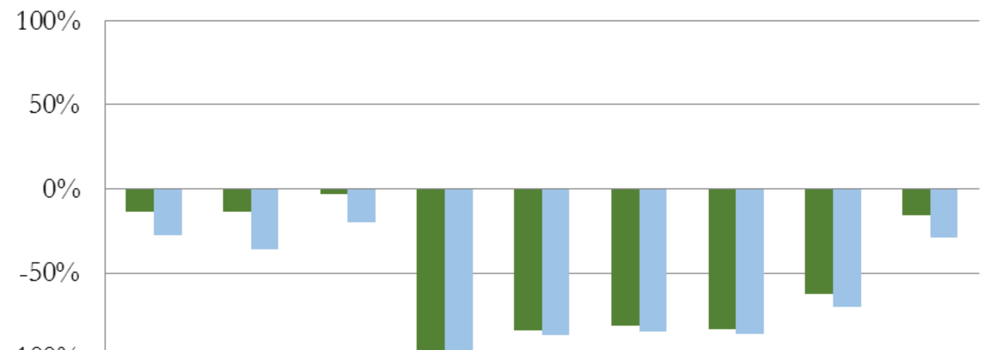
3.7 Emission Comparison

The 2005 and 2011 emissions were re-estimated using the updated 2016 OGV emission calculation methodology. Therefore, emissions values included in this section will not match those provided in the previous 2005 and 2011 PSEI published reports. Table 3.6 and Figure 3.4 compare the total 2016 OGV emissions with 2005 and 2011.

Table 3.6: Total Study Area OGV Emissions Comparison, tpy

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	11,516	346	964	374.3	192	181	178	11	587,994
2011	13,284	400	999	10,879.9	1,202	962	1,076	29	699,104
2005	15,836	542	1,202	12,788.8	1,514	1,212	1,336	36	827,705
2016 vs 2011 Change	**-13%**	**-14%**	**-3%**	**-97%**	**-84%**	**-81%**	**-83%**	**-63%**	**-16%**
2016 vs 2005 Change	**-27%**	**-36%**	**-20%**	**-97%**	**-87%**	**-85%**	**-87%**	**-70%**	**-29%**

Figure 3.4: Total Study Area OGV Emissions Change, %



	NOx	VOC	CO	SO2	PM10	PM2.5	DPM	BC	CO2e
2016-2011	-13%	-14%	-3%	-97%	-84%	-81%	-83%	-63%	-16%
2016-2005	-27%	-36%	-20%	-97%	-87%	-85%	-87%	-70%	-29%

Comparing 2016 to 2005, the emissions for all pollutants have decreased. The SO_2 and PM emissions have decreased significantly due to the lower sulfur fuel used by vessels to comply with the North American ECA. The decrease in NO_x and CO_2e emissions is mainly due to lower activity level in 2016 and an increase in shore power calls as summarized in Table 3.7. The energy consumption in kW-hr does not include the electricity usage kW-hrs from the shore power calls, as grid based electricity was used to power the ships during shore power.

Table 3.7: Total OGV Inbound Movements Comparison

Year	Energy Consumption kW-hr	Inbound Calls	Total Vessel Movements	Shore Power Calls
2016	791,183,583	2,520	6,578	169
2011	880,097,783	2,700	6,824	141
2005	1,034,139,096	2,912	7,161	42
2016 vs 2011 Change	**-10%**	**-7%**	**-4%**	**20%**
2016 vs 2005 Change	**-23%**	**-13%**	**-8%**	**302%**

The 2016 vs 2011 OGV emission decreases are mainly due to:

- The North American ECA may reduce emissions up to: 6% for NO_x; 96% for SO_2; 83% for PM_{10} and DPM; 80% for $PM_{2.5}$ and BC; and 5% for CO_2e
- Increase in shore power calls from 141 calls in 2011 to 169 calls in 2016
- Fewer vessel movements in 2016 (4%) and activity measured in kW-hr (10%)

The 2016 vs 2005 OGV emission decreases are mainly due to:

- The North American ECA may reduce emissions up to: 6% for NO_x; 96% for SO_2; 83% for PM_{10} and DPM; 80% for $PM_{2.5}$ and BC; and 5% for CO_2e
- Increase in shore power calls from 42 calls in 2005 to 169 calls in 2016
- Fewer vessel movements in 2016 (8%) and activity measured in kW-hr (23%)

SECTION 4 HARBOR VESSELS

Section 4 provides an overview of the harbor vessels operating in Puget Sound and their estimated emissions for 2016. Details of the methodology used to estimate emissions are available in Appendix C. The 2011 and 2005 emission totals presented in this report are not the same as the numbers originally reported in the 2011 and 2005 PSEI reports, but represent the latest science with respect to harbor vessel emission calculations. For comparisons of 2016 to 2005 and 2011, please use the comparison sections in this 2016 PSEI report since 2005 and 2011 emissions have been recalculated to be directly comparable to 2016 emissions.

4.1 Source Description

Harbor vessels operations vary based on the type of service they provide. The following designations are used to estimate engine efficiency and other characteristics impacting emission calculations. This inventory only considers emissions that are produced in the Puget Sound boundary. This report groups harbor vessels into two categories:

1) Commercial and Government (non-military) harbor vessels
2) Recreational vessels

Assist tugboats

Assist tugboats help ocean going vessels maneuver in the harbor during arrival, departure, and shifts.

Harbor and ocean tugboats

Tugboats, towboats and push-boats transport barges and other vessels. Harbor tugs work locally near the harbor and ocean tugs provide linehaul and ocean-going services.

Ferry vessels

Ferry vessels transport passengers and vehicles throughout Puget Sound. They range from larger Washington State Ferries (WSF) to smaller local county and city ferries.

Excursion vessels

Excursion and charter vessels are smaller than ferry vessels and are used for harbor cruises, dining cruises, whale watching, and other specialty cruises.

Government vessels

Coast Guard vessels, research vessels, police patrol boats and fireboats, are included in this vessel type. Pilot boats also included in this category because they all have similar operations. Military vessels are excluded.

Work boats

Work boats perform duties such as utility inspection, surveying, spill response, training and construction.

Commercial Fishing

Commercial fishing vessels are vessels dedicated to procuring fish. They range from the small fishing vessels to the larger commercial fishing vessels that go to Alaska.

Barges

Tank barges and derrick barges are included in the PSEI. The barges are not self-propelled, but they do have generators and/or auxiliary engines that are included in the inventory. The picture shows a typical derrick barge used by a construction company.

Recreational Vessels

Recreational vessels are privately owned watercraft used for pleasure boating and are not associated with commercial or cargo related activities.

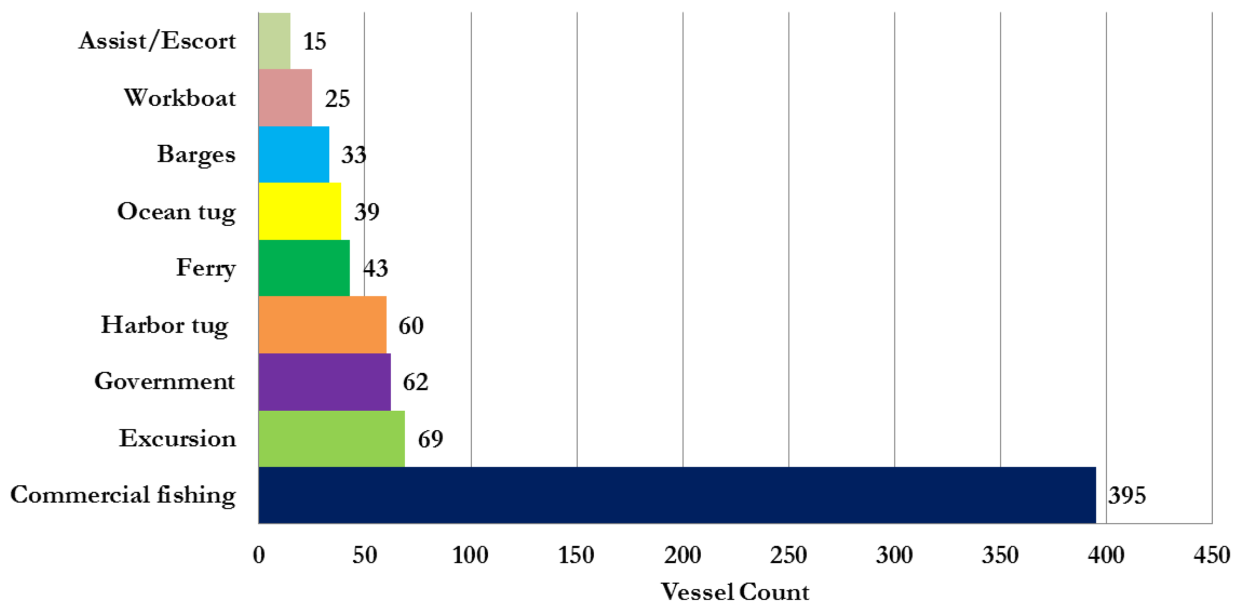
Table 4.1 presents the number of commercial harbor and government vessels inventoried for the Puget Sound in 2016 for each vessel type. The vessel count in Table 4.1 does not include recreational vessels, which are discussed in Section 4.8.

Table 4.1: 2016 Commercial Harbor and Government Vessel Counts by Vessel Type

Type	Vessel Count
Commercial fishing	395
Excursion	69
Government	62
Harbor tug	60
Ferry	43
Ocean tug	39
Barges	33
Workboat	25
Assist/Escort	15
Total	**741**

Figure 4.1 presents the distribution of commercial harbor and government vessels inventoried for Puget Sound in 2016.

Figure 4.1: 2016 Commercial Harbor and Government Vessels Count by Vessel Type



4.2 Geographical Description

The geographical area for harbor vessels in this inventory includes the U.S. portions of the Puget Sound area and associated waterways, and the Strait of Juan de Fuca out to the JA buoy located at the entrance to the Strait of Juan de Fuca. For U.S. based harbor vessels that cross the international border, only emissions from the U.S. side of the border are included in this inventory with the exception of harbor vessels that traverse the Strait of Juan de Fuca, in which case emissions from both sides of the international border are included.

4.3 Data Collection

Data for the commercial harbor and government vessels inventory was collected directly from vessel owners and operators identified has owning or operating harbor vessel. The data collected includes the following:

- Vessel type
- Number, type and horsepower (or kilowatts) of main engine(s)
- Number, type and horsepower (or kilowatts) of auxiliary engines
- Hours of operation in Puget Sound for 2016
- Information on percentage of time operating within Puget Sound regions
- Engine model year, and if engines on vessel had been replaced
- Emission reduction strategies

For the 395 commercial fishing vessels that transited Puget Sound in 2016, a slightly different data collection approach was used as compared to the other commercial harbor vessels. The Puget Sound Vessel Traffic Services (VTS) data for commercial fishing vessels was used to update the commercial fishing vessels that transited Puget Sound in 2016. Similar to the way Marine Exchange data that is used for the ocean-going vessels, the VTS data captures all of the commercial fishing activity in Puget Sound, but does not include specific engine data such as horsepower, model year or activity hours. The model year of the vessel was researched using the United States Coast Guard (USCG) Maritime information exchange[18]. It was assumed that the engine model year is the same as the vessel year.

4.4 Commercial Harbor and Government Vessel Operational Profiles

While in transit, most harbor vessels only use one auxiliary engine along with the main engine(s). The activity hours for all engines are reflected in this inventory. Tank barges and derrick barges are not self-propelled; therefore they do not have propulsion engines, but do have auxiliary engines. The commercial fishing vessels only include hours for transit within Puget Sound as they do not spend too much time in the study area and when they are at dock, they use either shore power or turn off their engines. Tables 4.2 and 4.3 summarize the propulsion and auxiliary engine data respectively for the vessels.

Table 4.2: 2016 Commercial Harbor and Government Vessel Propulsion Engines Inventory

Type	Vessel	Engine	Model year			Horsepower			Annual Hours		
	Count	Count	Min	Max	Avg	Min	Max	Avg	Min	Max	Avg
Assist/Escort	15	32	1967	2010	1993	1,500	4,100	2,682	248	5,391	3,249
Commercial fishing	395	771	1913	2012	1974	110	6,200	776	48	96	48
Derrick barge	16	0	na	na	na	na	na	na	na	na	na
Excursion	69	122	1970	2016	1996	85	2,200	385	0	3,000	858
Ferry	43	106	1959	2015	1999	300	4,400	2,028	0	6,836	4,373
Government	60	111	1966	2016	2000	10	3,500	1,010	0	6,549	390
Harbor tug	60	107	1944	2014	1993	135	2,200	961	0	4,368	1,411
Ocean tug	39	78	1968	2016	1992	850	5,100	2,394	0	5,000	1,470
Pilot boat	2	4	1999	2001	2000	1,100	1,100	1,100	763	834	799
Tank barge	17	0	na	na	na	na	na	na	na	na	na
Workboat	25	37	1989	2016	2009	15	600	298	282	1,151	723
Total	**741**	**1,368**									

[18] See: *www.sgmix.uscg.mil/psix/psixsearch.aspx*

Table 4.3: 2016 Commercial Harbor and Government Vessel Auxiliary Engines Inventory

Type	Vessel Count	Engine Count	Model year Min	Model year Max	Model year Avg	Horsepower Min	Horsepower Max	Horsepower Avg	Annual Hours Min	Annual Hours Max	Annual Hours Avg
Assist/Escort	15	37	1977	2016	2003	56	550	214	2	5,811	3,081
Commercial fishing	395	390	1913	2016	1975	100	1,609	326	48	96	48
Derrick barge	16	58	1963	2015	1995	20	2,800	309	0	2,200	472
Excursion	69	44	1974	2016	1997	7	67	37	0	2,837	707
Ferry	43	97	1959	2015	2002	13	1,210	341	23	7,015	2,207
Ferry boilers		42	1959	2015	2002	60	60	60	0	3000	1275
Government	60	32	1966	2014	1987	19	1,555	653	0	1,040	186
Harbor tug	60	81	1944	2016	1998	10	180	99	0	5,682	1,842
Ocean tug	39	94	1968	2016	1995	70	311	157	0	4,636	900
Pilot boat	2	4	1999	2001	2000	43	50	47	327	357	342
Tank barge	17	62	1980	2015	2008	25	441	249	14	3,577	990
Workboat	25	7	1990	2016	2001	30	85	58	120	375	224
Total	**741**	**948**									

4.5 Emission Reduction Initiatives Identified

In 2016, all of the diesel-powered commercial harbor vessels used ULSD. Various companies repowered their vessels at their own expense and/or with assistance from federal and state grants. The reductions due to these repowers are also included in the 2016 inventory. As of 2016, 140 engines have been repowered on 67 vessels since the baseline year 2005.

In 2008, the federal Inland Marine and Locomotive Rule came into effect. It requires that when commercial harbor vessels marine engines meeting certain criteria are overhauled, an EPA certified kit that reduces PM emissions by at least 25% must be installed. For 2016 inventory, 20 engines on 10 vessels were included for this emission reduction per the information provided by vessel owners.

4.6 Commercial Harbor and Government Vessel Emissions

Table 4.4 and Figure 4.2 present the 2016 harbor vessel emissions by vessel type and pollutant in tons per year. Almost half of the commercial harbor and government vessel emissions are attributable to ferries. Assist tugs, ocean tugs and government vessels are the next largest contributors of emissions. Please refer to Appendix C for harbor vessel emissions estimating methodology and Appendix D for recreational vessels emissions estimation methodology.

Table 4.4: 2016 Total Study Area Commercial Harbor and Government Vessel Emissions, tpy

Type	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
Assist/Escort	947	30.0	156	0.5	31.1	28.6	31.1	22.1	56,267
Commercial fishing	92	2.5	14	0.1	2.5	2.3	2.5	1.8	6,122
Derrick barge	21	0.6	8	0.0	0.6	0.5	0.6	0.4	1,769
Excursion	122	222.6	556	0.2	8.0	7.4	3.5	2.9	11,031
Ferry	3,423	120.3	726	2.0	131.0	120.7	131.3	92.9	220,019
Government	222	27.9	193	0.2	6.5	6.1	6.2	4.4	16,621
Harbor tug	409	12.9	182	0.3	11.9	10.9	12.0	8.4	34,051
Ocean tug	1,302	42.8	392	0.9	41.7	38.2	41.7	29.4	92,478
Tank barge	36	1.1	23	0.0	1.0	0.9	1.0	0.7	3,555
Workboat	16	17.6	81	0.0	0.7	0.6	0.3	0.3	2,034
Total	**6,590**	**478.3**	**2,332**	**4.3**	**234.9**	**216.3**	**230.2**	**163.3**	**443,948**

Figure 4.2: 2016 Commercial Harbor and Government Vessel Emissions

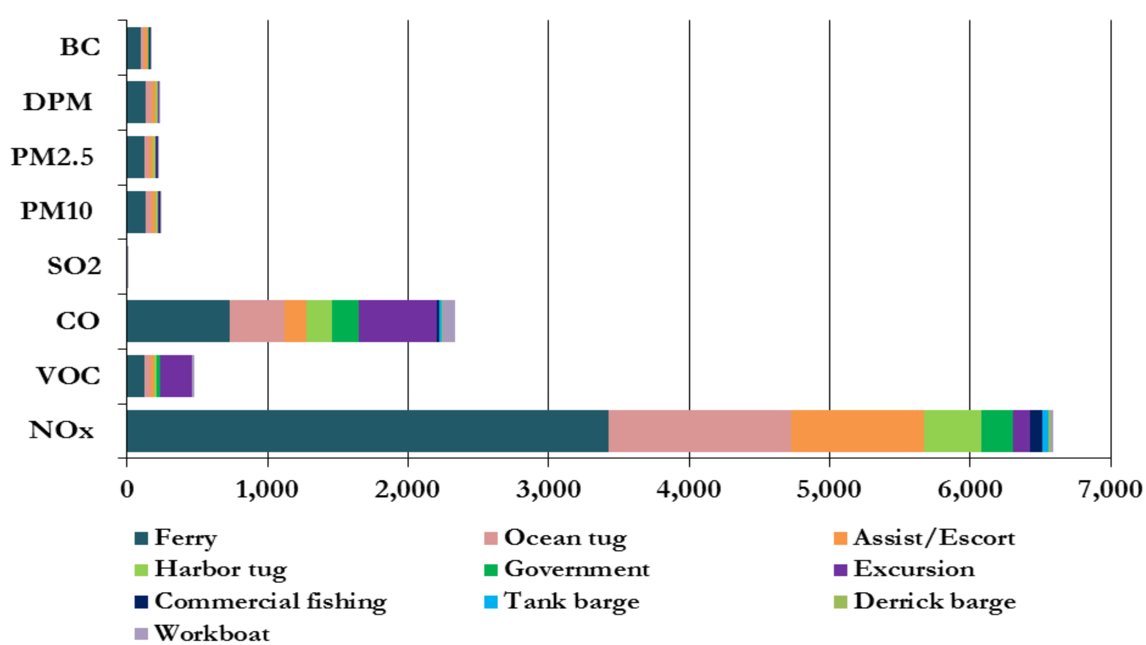


Table 4.5 summarizes the emissions estimated within the jurisdiction of the three regional clean air agencies covered by this inventory. Approximately 80% of the commercial harbor and government vessel emissions are in PSCAA region. The emissions are distributed to the jurisdiction based on discussions with vessel owners regarding typical route operations. Vessel owners provided estimates on how often their vessels were in each of the following five zones (ORCAA, PSCAA1, PSCAA2, PSCAA3, and NWCAA). Each county was assigned a specific percentage of emissions from each zone. These percentages are shown below:

- NWCAA: Island 25%, San Juan 25%, Skagit 25%, and Whatcom 25%
- ORCAA: Clallam 80%, Jefferson 0%, Mason 10%, and Thurston 10%
- PSCAA1: Pierce County 100%
- PSCAA2: King County 75% and Kitsap County25%
- PSCAA3: Snohomish 100%

Table 4.5: 2016 Total Study Area Commercial Harbor and Government Vessel Emissions by County and Regional Clean Air Agency, tpy

County	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
Island	229	62	196	0	9	8	8	6	16,347
San Juan	229	62	196	0	9	8	8	6	16,347
Skagit	229	62	196	0	9	8	8	6	16,347
Whatcom	229	62	196	0	9	8	8	6	16,347
NWCAA Total	**916**	**249**	**782**	**1**	**35**	**33**	**31**	**22**	**65,387**
Clallam	522	17	143	0	17	16	17	12	36,708
Jefferson	0	0	0	0	0	0	0	0	0
Mason	65	2	18	0	2	2	2	1	4,588
Thurston	65	2	18	0	2	2	2	1	4,588
ORCAA Total	**653**	**22**	**179**	**0**	**21**	**19**	**21**	**15**	**45,885**
King	2,105	92	599	1	77	71	77	54	138,019
Kitsap	702	31	200	0	26	24	26	18	46,006
Pierce	777	36	211	0	26	24	25	18	51,092
Snohomish	1,438	48	360	1	50	46	50	36	97,558
PSCAA Total	**5,022**	**207**	**1,370**	**3**	**178**	**164**	**178**	**126**	**332,675**
Total	**6,590**	**478**	**2,332**	**4**	**235**	**216**	**230**	**163**	**443,948**

4.7 Emission Comparison for Commercial Harbor and Government Vessel

The 2016 emissions calculation methodology was updated to use more recent diesel and gasoline emission factors based on MOVES2014a. The 2016 data collection also had more complete activity level data than the previous inventories. Both the 2005 and 2011 emissions were re-estimated using the new emission factors in order to make the comparison more relevant. The estimated emissions for 2005 and 2011 will not match with the tables included in the previous 2005 and 2011 PSEI published reports. For comparisons of 2016 to 2005 and 2011, please use this 2016 PSEI report.

Table 4.6 shows that 2016 had a 13% increase in activity (energy consumption) compared to 2011 and a 20% increase compared to 2005. The 2016 vessel count increased by 2% since 2011 and 3% since 2005. The engine count increased by 5% since 2011 and 7% since 2005. The count does not include 42 boilers included for ferries.

Table 4.6: Harbor Vessel Activty and Count Comparison

Year	Energy Consumption kW-hr	Vessel Count	Engine Count
2016	573,526,886	741	2,274
2011	507,836,145	727	2,170
2005	477,193,901	722	2,131
2016 vs 2011 Change	**13%**	**2%**	**5%**
2016 vs 2005 Change	**20%**	**3%**	**7%**

Table 4.7 compares the harbor vessel diesel engine tier count. It shows that in 2016, even though the majority of diesel engines are Tier 0 and 1, there is a slight increase in newer engines due to vessel repowers. The unknown column is for diesel engines that had unknown model year or horsepower. For emissions estimation, default model year and engine power were used. For 2005 data, the defaults were included and thus the low number of unknowns. For this study, if the commercial and government harbor vessel engine year is unknown, it is more than likely a Tier 0 engine.

Table 4.7: Commercial and Government Harbor Vessel Diesel Engine Tier Count

Year	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4	Unknown	Total Engine Count
2016	985	189	208	124	24	700	2,230
2011	1,369	201	123	11	0	446	2,150
2005	1,911	156	33	0	0	4	2,104
2016, %	**44%**	**8%**	**9%**	**6%**	**1%**	**31%**	
2011, %	**64%**	**9%**	**6%**	**1%**	**0%**	**21%**	
2005, %	**91%**	**7%**	**2%**	**0%**	**0%**	**0%**	

Table 4.8 and Figure 4.3 present the percent change in emissions for commercial and government vessels in 2016 as compared to 2011 and 2005.

Table 4.8: Total Study Area Commercial Harbor and Government Vessel Emissions Comparison, tpy

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	6,590	478	2,332	4.3	235	216	230	163	443,948
2011	6,270	438	1,417	3.8	278	255	274	194	392,613
2005	6,122	380	1,144	404.7	277	255	274	194	368,087
2016 vs 2011 Change	**5%**	**9%**	**64%**	**15%**	**-15%**	**-15%**	**-16%**	**-16%**	**13%**
2016 vs 2005 Change	**8%**	**26%**	**104%**	**-99%**	**-15%**	**-15%**	**-16%**	**-16%**	**21%**

Comparing 2016 to 2011, the harbor vessels emissions increased for all pollutants, except for PM and black carbon. The PM emissions were reduced due to newer engines in the 2016 fleet as compared to the 2011 fleet and the PM reduction for engines that use EPA certified kits to lower emissions. The increase in other emissions is mainly due to the increased activity in 2016. The 5% increase in NO_X emissions was lower than the 13% increase in activity due to the cleaner engines, but it was not enough to counteract the increased activity. The CO increase is greater than the activity increase in 2016 because newer diesel engines have higher CO emission factor, in addition to an increase in activity for gasoline engines with higher CO emission rates than the diesel engines. The SO_x emissions went up in 2016 due to increase in activity and the fact that some vessels were burning ULSD in 2011, before the compliance date, as an early implementation strategy for emission reductions. The CO_2e emissions increase also reflects the 13% increase in activity.

As a recap, the 2016 vs 2011 harbor vessel emission changes are mainly due to:

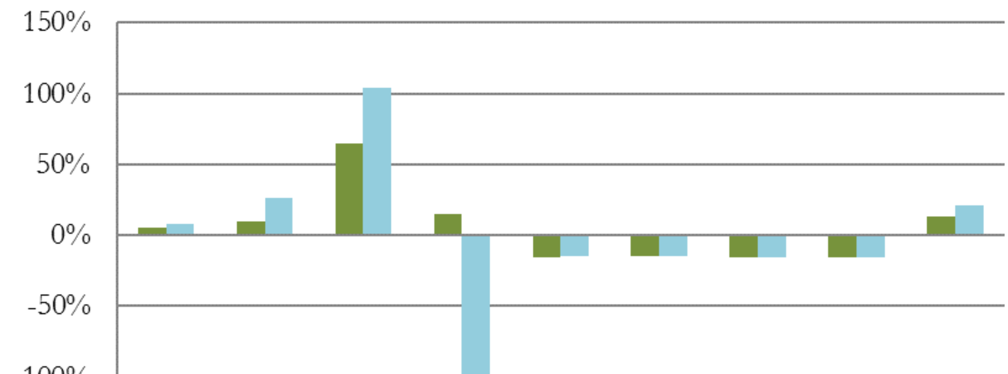
- Increased engine activity (13% more) and more engines (5% more)
- Newer vessels - 7% of engines have Tier 3 and 4 engines in 2016 compared to 1% in 2011
- Newer vessels mean lower emission factors, except for CO which increased

Comparing 2016 to 2005, the emissions increased for NO_x, VOC, CO and CO_2e. The emissions decreased for SO_2 and PM in 2016. The VOC and CO increase is greater than the activity increase due to an increase in gasoline engines in the 2016 inventory and the fact that CO emission factors are higher for newer diesel engines. Gasoline engines emit more CO and VOCs on an activity level basis than diesel engines. The SO_2 emissions decreased significantly in 2016 due to the use of ULSD in 2016 by all diesel-powered vessels. The CO_2e emissions increased 21% in 2016, scaling directly with the 20% activity increase.

The 2016 vs 2005 harbor vessel emission changes are mainly due to:

- Increased engine activity (20% more) and more engines (7% more)
- Newer vessels - 7% of engines have Tier 3 and 4 engines in 2016 compared to 0% in 2005
- Newer vessels mean lower emission factors, except for CO which increased since newer vessels have higher CO emission standards

Figure 4.3: Total Study Area Commercial Harbor and Government Vessel Emissions Change, %



	NOx	VOC	CO	SO2	PM10	PM2.5	DPM	BC	CO2e
2016-2011	5%	9%	64%	15%	-15%	-15%	-16%	-16%	13%
2016-2005	8%	26%	104%	-99%	-15%	-15%	-16%	-16%	21%

Table 4.9 presents the changes in activity in kW-hr by vessel type. In 2016, the activity increased for various vessel types which in turn increased the emissions for some of the pollutants. Assist tugs, commercial fishing, ferry, harbor tug, ocean tug, and tank barge all saw an increase in activity in 2016.

Table 4.9: Harbor Vessel Activity Comparison

Type	2005 kW-hr	2011 kW-hr	2016 kW-hr	2016 vs 2005 % Change	2016 vs 2011 % Change
Assist/Escort	60,581,846	66,582,086	72,973,752	20%	10%
Commercial fishing	6,786,158	7,109,280	7,940,299	17%	12%
Derrick barge	0	4,385,294	2,294,017	na	na
Excursion	13,484,054	14,721,500	12,958,619	-4%	-12%
Ferry	250,182,528	264,183,478	285,348,604	14%	8%
Government	37,861,906	42,390,105	19,570,692	-48%	-54%
Harbor tug	33,943,752	43,225,182	44,161,365	30%	2%
Ocean tug	64,406,498	59,742,923	119,937,078	86%	101%
Pilot boat	4,535,656	1,356,090	1,356,090	-70%	0%
Tank barge	2,241,644	3,118,303	4,611,223	106%	48%
Workboat	3,169,859	1,021,904	2,329,886	-26%	128%
Total	**477,193,901**	**507,836,145**	**573,481,623**	**20%**	**13%**

4.8 Recreational Vessels

Recreational vessels were included in the inventory for the sake of completeness and because several of the participating ports owned public marinas. Port authorities have little or no control over recreational vessels, as the recreational vessels are privately owned vessels and not under port jurisdiction.

Due to better online data, the 2016 PSEI data collection included approximately 40% more private marinas than the 2005 and 2011 inventories and may not be comparable to 2005 or 2011 for that reason. The 2016 number of recreational vessels was determined using two online marina directories to establish an up to date listing of marinas in Puget Sound[19]. When additional verification was needed, the marina website was consulted. When necessary Google maps satellite imagery were used to verify the existence of a marina or slip counts. Slip counts included open slips, side slips, covered slips and boathouses. Buoy moorage and dry storage was not included. A list of marinas included in the 2016 emission inventory is included in Appendix D.

[19] See: *www.boatmanager.com/marina-listing.html* and *ww.pugetsoundmagazine.com/dir/boaters/marina/php*

Table 4.10 presents the 2016 total recreational vessel emissions in tons per year.

Table 4.10: 2016 Total Study Area Recreational Vessel Emissions by Marina Type, tpy

Category	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
Port-owned marina	372	668	4,673	0.9	14.1	13.1	2.1	3.8	52,457
Private marina	617	1,106	7,743	1.5	23.4	21.7	3.4	6.3	86,924
Total	**989**	**1,774**	**12,416**	**2.5**	**37.6**	**34.8**	**5.5**	**10.0**	**139,381**

Table 4.11 presents the 2016 total recreational vessel emissions by county in tons per year. These emissions include vessels in port-owned marinas, private marinas, and marinas of other non-port, public entities.

Table 4.11: 2016 Total Study Area Recreational Vessel Emissions by County Regional Clean Air Agency, tpy

County	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
Island	28	49	346	0.1	1.0	1.0	0.2	0.3	3,881
San Juan	87	155	1,088	0.2	3.3	3.1	0.5	0.9	12,208
Skagit	79	143	998	0.2	3.0	2.8	0.4	0.8	11,204
Whatcom	107	192	1,346	0.3	4.1	3.8	0.6	1.1	15,113
NWCAA Total	**301**	**540**	**3,778**	**0.8**	**11.4**	**10.6**	**1.7**	**3.1**	**42,406**
Clallam	45	80	559	0.1	1.7	1.6	0.2	0.5	6,273
Jefferson	56	100	703	0.1	2.1	2.0	0.3	0.6	7,891
Mason	7	13	93	0.0	0.3	0.3	0.0	0.1	1,047
Thurston	56	101	705	0.1	2.1	2.0	0.3	0.6	7,916
ORCAA Total	**164**	**294**	**2,060**	**0.4**	**6.2**	**5.8**	**0.9**	**1.7**	**23,126**
King	255	458	3,207	0.6	9.7	9.0	1.4	2.6	36,003
Kitsap	77	138	963	0.2	2.9	2.7	0.4	0.8	10,808
Pierce	113	203	1,420	0.3	4.3	4.0	0.6	1.1	15,941
Snohomish	79	141	988	0.2	3.0	2.8	0.4	0.8	11,096
PSCAA Total	**524**	**940**	**6,578**	**1.3**	**19.9**	**18.5**	**2.9**	**5.3**	**73,849**
Total	**989**	**1,774**	**12,416**	**2.5**	**37.6**	**34.8**	**5.5**	**10.0**	**139,381**

4.9 Emission Comparison for Recreational Vessels

The 2016 emission inventory uses the most recent EPA model MOVES2014a. Calendar year 2005 and 2011 data were remodeled with the MOVES2014a so the emissions comparisons between 2005 and 2011 were all calculated using the same methodology. As a result, the emissions will not match the data in the 2005 and 2011 reports. For emission comparisons to prior years, use the results in this report.

The differences in emissions between 2016 and 2011 and 2005 in Table 4.12 are due to the following contributing factors: 1) increase in the number of recreational vessels at private marinas included in the inventory for 2016 including the fact that more marinas were counted; 2) the use of ULSD in 2016 by diesel powered recreational vessels and the use of lower sulfur gasoline in 2016 by gasoline powered recreational vessels compared to 2005; and 3) fleet turnover assumed by the MOVES model for each calendar year. Due to the increase in private marina count in 2016, the comparison is not a direct comparison to either 2011 or 2005. The increased 2016 private marina count was included for sake of completeness and the 2005 and 2011 private marina counts were not increased since it was difficult to determine vessel counts for these marinas for previous years and also to verify the existence of some marinas in 2011 and 2005.

Table 4.12: Total Study Area Recreational Vessels Emissions Comparison

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	989	1,774	12,416	2	38	35	5	10	139,381
2011	810	1,909	11,654	2	39	37	5	9	106,523
2005	734	2,590	15,966	23	55	51	6	11	113,354
2016 vs 2011 Change	**22%**	**-7%**	**7%**	**34%**	**-5%**	**-5%**	**11%**	**10%**	**31%**
2016 vs 2005 Change	**35%**	**-32%**	**-22%**	**-89%**	**-31%**	**-31%**	**-16%**	**-11%**	**23%**

Table 4.13 presents the recreational vessel count in 2016 as compared to 2011 and 2005. The significant increase in private marina vessel count is due to better data collection in 2016 with the use of online databases and google maps. The public port-owned marina vessel count decreased slightly in 2016.

Table 4.13: Recreational Vessels Count Comparison

Year	Total Vessel Count	Private Marina Vessel Count	Port-owned Marina Vessel Count
2016	31,818	19,843	11,975
2011	23,771	11,501	12,270
2005	24,390	11,795	12,595
2016 vs 2011 Change	**34%**	**73%**	**-2%**
2016 vs 2005 Change	**30%**	**68%**	**-5%**

SECTION 5 CARGO-HANDLING EQUIPMENT

Section 5 provides an overview of the cargo-handling and related equipment found at Puget Sound ports and their estimated emissions for 2016. Details of the methodology used to estimate emissions are available in Appendix E.

5.1 Source Description

Cargo-handling equipment includes equipment used to move cargo (containers, general cargo, and bulk cargo) to and from marine vessels, railcars, and on-road trucks. The equipment, typically owned by terminal operators, is used at marine terminals or at rail yards and is assumed not to operate on public roadways or land. This inventory includes cargo-handling equipment using diesel, gasoline, propane or electricity. Below are pictures of typical equipment:

Forklifts

Top Handler

Straddle Carriers

Yard Tractors

Side Handlers

Table 5.1 presents the 1,102 pieces of equipment inventoried in 2016, including diesel, gasoline, propane and electric equipment. Each port's equipment is summarized in detail in Section 5.4. Other diesel equipment includes: backhoe, compressor, crane, generator, light tower, loader, log stacker, manlift, rail pusher, reach stacker, roller, rubber tired gantry (RTG) crane, side handler, sweeper, tractor, and truck.

Table 5.1: 2016 CHE Distribution by Type

Equipment	Count
Yard Tractor, diesel	366
Other Diesel	181
Forklift, diesel	149
Top Handler, diesel	105
Propane Equipment	98
Electric Equipment	96
Straddle Carrier, diesel	82
Gasoline Equipment	25
Total	**1,102**

Table 5.2 presents the equipment by port and engine type (diesel, gasoline, propane, and electric).

Table 5.2: 2016 CHE Distribution by Port

Port	Diesel Fueled	Gasoline Fueled	Propane Fueled	Electric	Total Count
Anacortes	3	0	4	0	7
Everett	50	6	8	0	64
NWSA North Harbor	267	0	6	33	306
NWSA South Harbor	443	12	38	26	519
Olympia	48	0	3	0	51
Port Angeles	4	0	0	0	4
Rail yards	34	1	1	4	40
Seattle	34	6	37	33	110
Tacoma	0	0	1	0	1
Total	**883**	**25**	**98**	**96**	**1,102**

5.2 Geographical Description

The geographical extent for the cargo-handling equipment is the marine terminals and facilities associated with the following Puget Sound ports:

- Port of Anacortes
- Port of Everett
- Port of Olympia
- Port of Port Angeles
- NWSA North Harbor
- Port of Seattle
- NWSA South Harbor
- Port of Tacoma
- Rail Yards

5.3 Data Collection

Data was collected from terminal owners, equipment operators, and others having firsthand knowledge of equipment details and/or operational parameters. The data collection approach focused on equipment details and operational profiles (activity data). The data is summarized by port and discussed in the following subsections. Some examples of equipment details that were collected include such parameters as:

- Equipment type (e.g., yard tractor)
- Rated power (primarily horsepower)
- Equipment manufacturer and model year
- Engine make, model, model year, and technology
- Type of fuel used (e.g., ULSD, gasoline, liquefied petroleum gas or LPG)
- Emission reduction technology (e.g., DOC, DPF)

Where data was unavailable, reasonable assumptions based on similar equipment in the inventory were used. Default values by port, engine type and equipment type were assigned when the activity hour, horsepower, or model year was unavailable.

5.4 Operational Profiles

Table 5-3 summarizes the engine characteristics for all equipment included in the inventory including: the average, minimum and maximum engine power, the model year and the estimated annual operating hours. Port-specific CHE characteristics are included in Appendix K.

Table 5.3: Puget Sound 2016 CHE Characteristics

Equipment	Engine Type	Count	Power (hp)			Model Year			Annual Hours		
			Min	Max	Average	Min	Max	Average	Min	Max	Average
Backhoe	Diesel	6	63	350	207	1985	2016	1998	65	2,080	693
Compressor	Diesel	6	10	10	10	1977	2004	1989	4	61	27
Crane	Diesel	11	100	1,135	230	1992	2000	1997	10	720	409
Forklift	Diesel	149	50	375	151	1961	2017	1998	0	2,586	369
Generator	Diesel	8	36	602	273	2000	2013	2006	10	102	44
Light tower	Diesel	1	25	25	25	1991	1991	1991	300	300	300
Loader	Diesel	27	51	440	296	1970	2011	1997	131	2,080	1,432
Log stacker	Diesel	23	197	500	345	1986	2015	2004	500	2,000	1,311
Manlift	Diesel	7	185	185	185	2005	2015	2009	54	215	133
Rail pusher	Diesel	1	215	215	215	2013	2013	2013	200	200	200
Reach stacker	Diesel	16	200	375	325	2000	2014	2009	128	1,292	552
Roller	Diesel	2	84	84	84	2013	2015	2014	25	50	38
RTG crane	Diesel	17	300	972	727	1995	2012	2007	0	1,577	937
Side handler	Diesel	28	152	250	207	1991	2013	2004	350	1,690	840
Skid steer loader	Diesel	4	100	200	150	1991	2012	1999	20	250	102
Straddle carrier	Diesel	82	185	455	317	1991	2014	2003	147	2,330	1,338
Sweeper	Diesel	8	36	250	168	1987	2016	2003	82	2,500	589
Top handler	Diesel	105	200	365	306	1970	2015	2004	0	4,285	1,459
Tractor	Diesel	3	33	50	42	2006	2012	2009	85	500	262
Truck	Diesel	13	180	460	249	1972	2016	1993	4	350	146
Yard tractor	Diesel	366	110	275	190	1984	2016	2006	0	2,639	1,005
Crane	Electric	47	0	0	0	na	na	na	na	na	na
Forklift	Electric	16	0	0	0	na	na	na	na	na	na
Golf cart	Electric	4	0	0	0	na	na	na	na	na	na
Manlift	Electric	1	0	0	0	na	na	na	na	na	na
Pallet Jacks	Electric	24	0	0	0	na	na	na	na	na	na
RMG cranes	Electric	4	0	0	0	na	na	na	na	na	na
Compressor	Gasoline	5	10	50	18	1978	2001	1994	250	253	252
Forklift	Gasoline	7	35	175	102	1968	1993	1982	20	250	146
Generator	Gasoline	4	5	100	46	1999	2007	2004	5	1,264	419
Manlift	Gasoline	5	30	82	56	1984	2004	1993	25	300	131
Truck	Gasoline	2	130	130	130	1999	2003	2001	47	1,665	856
Welder	Gasoline	1	76	76	76	1968	1968	1968	250	250	250
Yard tractor	Gasoline	1	110	110	110	2003	2003	2003	65	65	65
Forklift	Propane	93	45	200	87	1970	2016	1997	3	1,500	343
Manlift	Propane	3	50	87	66	1997	2008	2002	8	218	146
Sweeper	Propane	2	50	130	90	1989	2002	1996	8	23	16
Total count		**1,102**									

5.5 Emission Reduction Initiatives Identified

Table 5.4 summarizes the count of cargo-handling equipment equipped with emission reduction technologies. For cargo-handling equipment operated at the Puget Sound ports in 2016, emission control measures include the use of electric equipment, diesel oxidation catalyst retrofits, diesel particulate filter retrofits, and on-road engines in place of non-road engines. On-road engines have more stringent emission standards compared to non-road engines of same model year.

Table 5.4: 2016 CHE Count of Emission Reduction Technologies

Port	Electric	Diesel Oxydation Catalyst	Diesel Particulate Filter	On-road Engine
Anacortes	0	0	0	0
Everett	0	0	0	0
NWSA North Harbor	33	126	5	2
NWSA South Harbor	26	73	50	40
Olympia	0	0	0	4
Port Angeles	0	0	0	0
Rail Yards	4	11	0	0
Seattle	33	0	0	0
Tacoma	0	0	0	0
Total	**96**	**210**	**55**	**46**

Please note that in 2016, the number of retrofits and on-road engines went down from 2011 due to the new equipment having engines that comply with the latest engine standards and are also equipped with original equipment manufacturer (OEM) technologies to reduce emissions. In other words, the terminals elected to replace older equipment with newer equipment instead of retrofitting an existing piece of equipment.

5.6 Emission Estimates

Please refer to Appendix E for CHE emissions estimating methodology. The cargo-handling emissions are summarized by port in Table 5.5.

Table 5.5: 2016 CHE Total Emissions, tpy

Port	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
Anacortes	0.2	0.0	0.2	0.0	0.0	0.0	0.0	0.0	11
Everett	9.5	2.1	10.2	0.0	0.7	0.7	0.7	0.5	856
NWSA North Harbor	108.8	7.4	27.0	0.1	5.7	5.5	5.7	4.2	15,301
NWSA South Harbor	164.7	17.4	108.1	0.2	7.8	7.6	7.8	5.5	28,279
Olympia	22.6	2.1	11.3	0.0	1.4	1.3	1.4	1.0	2,442
Port Angeles	1.8	0.3	0.9	0.0	0.2	0.2	0.2	0.2	111
Rail Yards	17.7	1.2	5.5	0.0	1.0	1.0	1.0	0.7	2,204
Seattle	6.0	1.1	18.0	0.0	0.3	0.3	0.3	0.2	623
Tacoma	0.2	0.0	0.9	0.0	0.0	0.0	0.0	0.0	12
Total	**331.6**	**31.7**	**182.3**	**0.3**	**17.2**	**16.6**	**17.1**	**12.4**	**49,838**

Table 5.6 summarizes the cargo-handling emissions by county and regional clean air agency.

Table 5.6: 2016 CHE Emissions by County and Regional Clean Air Agency, tpy

County	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
Island	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
San Juan	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
Skagit	0.2	0.0	0.2	0.0	0.0	0.0	0.0	0.0	11
Whatcom	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
NWCAA Total	**0.2**	**0.0**	**0.2**	**0.0**	**0.0**	**0.0**	**0.0**	**0.0**	**11**
Clallam	1.8	0.3	0.9	0.0	0.2	0.2	0.2	0.2	111
Jefferson	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
Mason	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
Thurston	22.6	2.1	11.3	0.0	1.4	1.3	1.4	1.0	2,442
ORCAA Total	**24.4**	**2.4**	**12.3**	**0.0**	**1.6**	**1.5**	**1.6**	**1.2**	**2,553**
King	127.5	9.6	49.9	0.1	6.7	6.5	6.7	5.0	17,583
Kitsap	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0
Pierce	170.0	17.5	109.8	0.2	8.1	7.9	8.1	5.7	28,836
Snohomish	9.5	2.1	10.2	0.0	0.7	0.7	0.7	0.5	856
PSCAA Total	**307.0**	**29.3**	**169.9**	**0.3**	**15.5**	**15.1**	**15.5**	**11.2**	**47,275**
Total	**331.6**	**31.7**	**182.3**	**0.3**	**17.2**	**16.6**	**17.1**	**12.4**	**49,838**

5.7 Emission Comparison

The emission calculation methodology was updated in 2016 to use the latest EPA model, MOVES2014a. To ensure consistent comparison, the 2005 and 2011 emissions presented in this report have been re-calculated using MOVES2014a. Therefore, the estimated emissions for 2005 and 2011 will not match the results presented in the 2005 and 2011 PSEI published reports. For comparisons of 2016 to 2005 and 2011, please use this 2016 PSEI report.

Table 5.7 presents a 14% decrease in activity, presented as energy consumption in kW-hr, in 2016 as compared to 2011 and a 35% decrease in 2016 activity as compared to 2005. The engine count is included instead of equipment count because some equipment may have more than one engine. The lower activity is due to lower engine/equipment count and lower hours of use.

Table 5.7: CHE Activity and Engine Count Comparison

Year	Energy Consumption kW-hr	Engine Count
2016	60,364,027	1,129
2011	70,346,044	1,227
2005	93,090,639	1,184
2016 vs 2011 Change	**-14%**	**-8%**
2016 vs 2005 Change	**-35%**	**-5%**

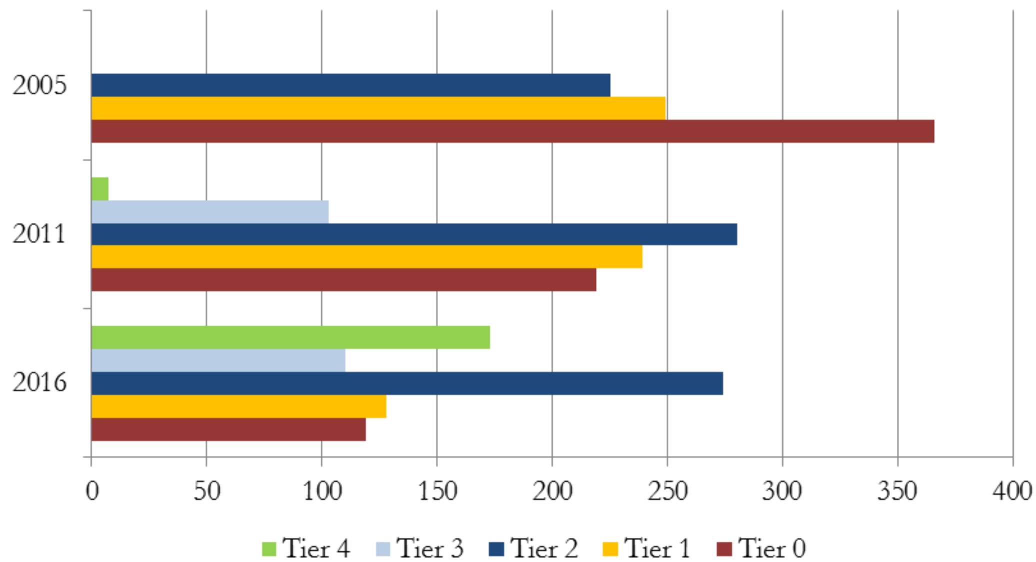
Table 5.8 presents the distribution of diesel equipment by off-road engine standards (by tier) for each emission inventory year. The table also includes diesel onroad engine counts since they are diesel engines, but do not have an off-road Tier assigned to them. The values show the fleet turnover progression since 2005 when the equipment was mainly Tier 0, 1 and 2. In 2016, the equipment with Tier 0 and Tier 1 engines make up a smaller percentage as they were replaced with cleaner Tier 3 and Tier 4 engines. The Tier 4 engines are shown separately as Tier 4 interim (Tier 4i) and Tier 4 final (Tier 4f).

Table 5.8: CHE Engine Standards Comparison for Diesel Equipment

Year	Tier 0	Tier 1	Tier 2	Tier 3	Tier 4i	Tier 4f	Onroad	Unknown	Total
2016	119	128	274	110	113	60	46	33	883
2011	219	239	280	103	7	0	113	0	961
2005	366	249	225	0	0	0	50	0	890
2016 Percent of total	13%	14%	31%	12%	13%	7%	5%	4%	
2011 Percent of total	23%	25%	29%	11%	1%	0%	12%	0%	
2005 Percent of total	41%	28%	25%	0%	0%	0%	6%	0%	

Figure 5.1 compares the Tier or engine standard count for all three years. Tier 4 interim and Tier 4 final are included as Tier 4 in the figure. Tier 3 and 4 engines were 32% of the total diesel equipment count in 2016.

Figure 5.1: CHE Tier Count Comparison



As an example, for the newer equipment emission reductions, the following is a summary of the emission standards for an average piece of equipment with a 200 hp engine:

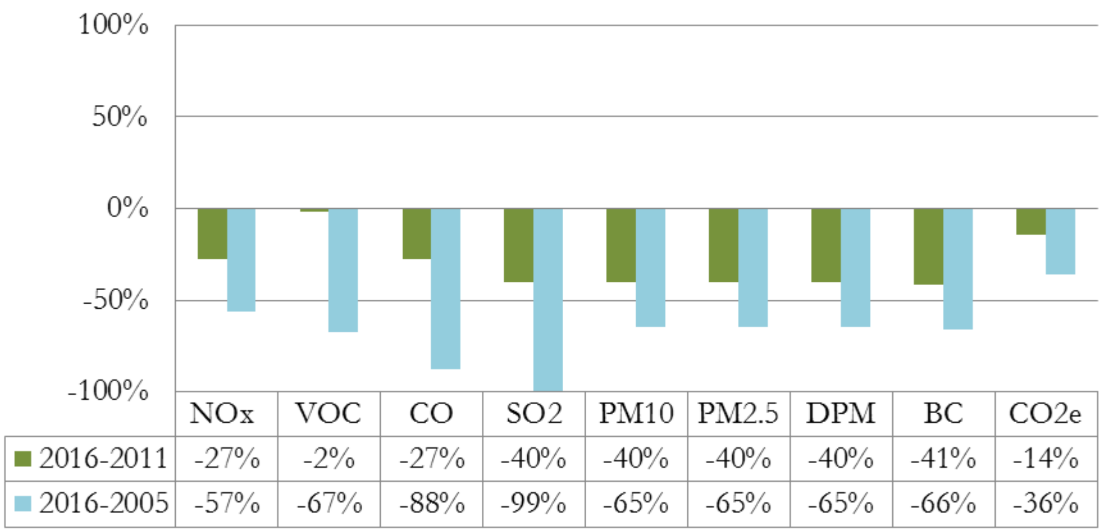
- 40% (Tier 1) to 97% (Tier 4) decrease in NO_x emission standards as compared to Tier 0 (uncontrolled level)
- 31% (Tier 1) to 97% (Tier 4) decrease in PM emission standards as compared to Tier 0 (uncontrolled level)
- 36% (Tier 1) to 46% (Tier 4) decrease in PM emission standards as compared to Tier 0 (uncontrolled level)
- For VOC and CO, Tier 0 and Tier 1 levels are the same
- 86% decrease in CO emission standards for Tier 2 to Tier 4 engines as compared to Tier 0 (uncontrolled level) and Tier 1.
- 36% (Tier 1) to 46% (Tier 4) decrease in VOC emission standards as compared to Tier 0 (uncontrolled level) and Tier 1.

Table 5.9 and Figure 5.2 present the change in emissions for cargo-handling equipment in 2016 as compared to 2011 and 2005. As shown in previous tables and figures, activity decreased and there is a cleaner fleet in 2016 due to fleet turnover since 2011 and 2005. Port-related emissions decreased for all pollutants in 2016 when compared to 2011 and 2005. The 2016 emissions decrease is due to fleet turnover, reduced equipment activity, and implementation of emission reduction strategies (retrofits). The 99% percent reduction in SO_2 emissions in 2016 as compared to 2005 is due to the use of ULSD in 2016.

Table 5.9: CHE Emissions Comparison, tpy and %

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	332	32	182	0.3	17	17	17	12	49,838
2011	456	32	251	0.5	29	28	29	21	57,961
2005	763	96	1,477	47.4	49	48	49	36	77,769
2016 vs 2011 Change	**-27%**	**-2%**	**-27%**	**-40%**	**-40%**	**-40%**	**-40%**	**-41%**	**-14%**
2016 vs 2005 Change	**-57%**	**-67%**	**-88%**	**-99%**	**-65%**	**-65%**	**-65%**	**-66%**	**-36%**

Figure 5.2: CHE Emissions Change, %



Comparing 2016 vs 2011, the CHE emissions decreased and this is mainly due to:

- Smaller number of equipment (8% less) and lower activity in kW-hr (14% less)
- Cleaner equipment - 32% of engines have Tier 3 and 4 engines in 2016 compared to 12% in 2011

Comparing 2016 vs 2005, the CHE emissions decreased and this is mainly due to:

- Smaller number of equipment (5% less) and lower activity in kW-hr (35% less)
- Cleaner equipment - 32% of engines have Tier 3 and 4 engines in 2016 compared to 0% in 2005
- All equipment used ULSD in 2016 compared to a few pieces of equipment in 2005

SECTION 6 LOCOMOTIVES

Section 6 provides an overview of the maritime-related railroad locomotives operating in and around the Puget Sound study area and their estimated emissions for 2016. Details of the methodology used to estimate emissions are available in Appendix F. The 2011 and 2005 emissions presented in this report are not the same as the emissions originally reported in the 2011 and 2005 PSEI reports, but represent the latest science with respect to locomotive emission calculations. For comparisons of 2016 to 2005 and 2011, please use the comparison sections in this 2016 PSEI report.

6.1 Source Description

The railroad system is a nationwide enterprise consisting of national and local railroad companies that together serve to move a diverse variety of cargo over long distances. The activity and emission estimates presented in this section represent emissions from locomotive activities that take place within and between ports and the near-dock rail yards that handle port-related cargos, and between these places and the airshed boundary. This does not include all trains that transit through the Puget Sound region.

Port terminals that offer on-dock rail service can load or receive cargo directly to or from railcars. These terminals include the NWSA North Harbor's Terminal 18, most of NWSA South Harbor's container terminals, and the grain terminals at the Port of Seattle and the Port of Tacoma. Imported containers are either taken from the terminal to destinations across the country or are moved to a rail yard for consolidation into a cross-country train.

Rail is also used in a "near-dock" capacity, where cargo is moved a short distance by truck before being loaded onto railcars. An example of near-dock services in the region is intermodal operations at NWSA's South Harbor West Sitcum Terminal (formerly APM). In addition to these on-port rail-related activities, cargo can be moved between the ports and nearby rail yards, which may also handle cargo that is not related to port activity. The cargo movements are bi-directional, with cargo being brought into the ports by rail for export on ships as well as being transported from the ports to points around the country.

Locomotive operations are typically described in terms of line-haul and switching operations. Line-haul refers to the movement of cargo over long distances (e.g., cross-country) and occurs within a port, marine terminal, or rail yard as the initiation or termination of a line-haul trip, as cargo is either picked up for transport to destinations across the country or is dropped off for shipment overseas. Switching refers to the assembling and disassembling of trains, sorting of the railcars of inbound cargo trains into contiguous "fragments" for subsequent delivery to terminals, and the short distance hauling of rail cargo within a port or rail yard.

Locomotives used for line-haul operations are typically large, powerful diesel engines of 4,000 hp or more, while switch engines are smaller, typically having 1,200 to 3,000 hp. Older line-haul locomotives have often been converted to switch duty as newer line-haul locomotives with more horsepower have become available. Rather than having finely adjustable throttle controls such as those used in automobiles and most powered equipment, locomotive throttles are operated in a series of discrete power steps called notches, which range from positions one through eight (with one being the lowest power setting and eight providing full power), plus an idle setting. Many locomotives also have a setting called dynamic braking, which is a means of slowing the locomotive using the drive system.

6.2 Geographical Description

The geographical parameters of the emissions inventory for railroad-related sources include the rail yards at Northwest Seaport Alliance and the Ports of Seattle, Tacoma, Everett, and Olympia, several near-port rail yards, and rail lines used for moving cargo between these rail yards and the boundary of the Puget Sound airshed.

The near-port rail yards include the Fife Yard in Tacoma (storage and switching yard), the Seattle International Gateway (SIG) Yard operated by Burlington Northern Santa Fe (BNSF) and the Argo Yard operated by Union Pacific (UP) in Seattle, and rail operations associated with the Port of Everett. The SIG and Argo yards are intermodal yards where cargo is transferred to or from railcars prior to or following international shipment.

In addition to operating the intermodal yards noted above, UP and BNSF provide line-haul rail services to the Puget Sound area ports.[20] These railroads are designated as Class 1 railroads based on annual revenues.[21] The Class 1 railroads, of which there are currently seven in the U.S., are the largest of the railroads in terms of revenue.

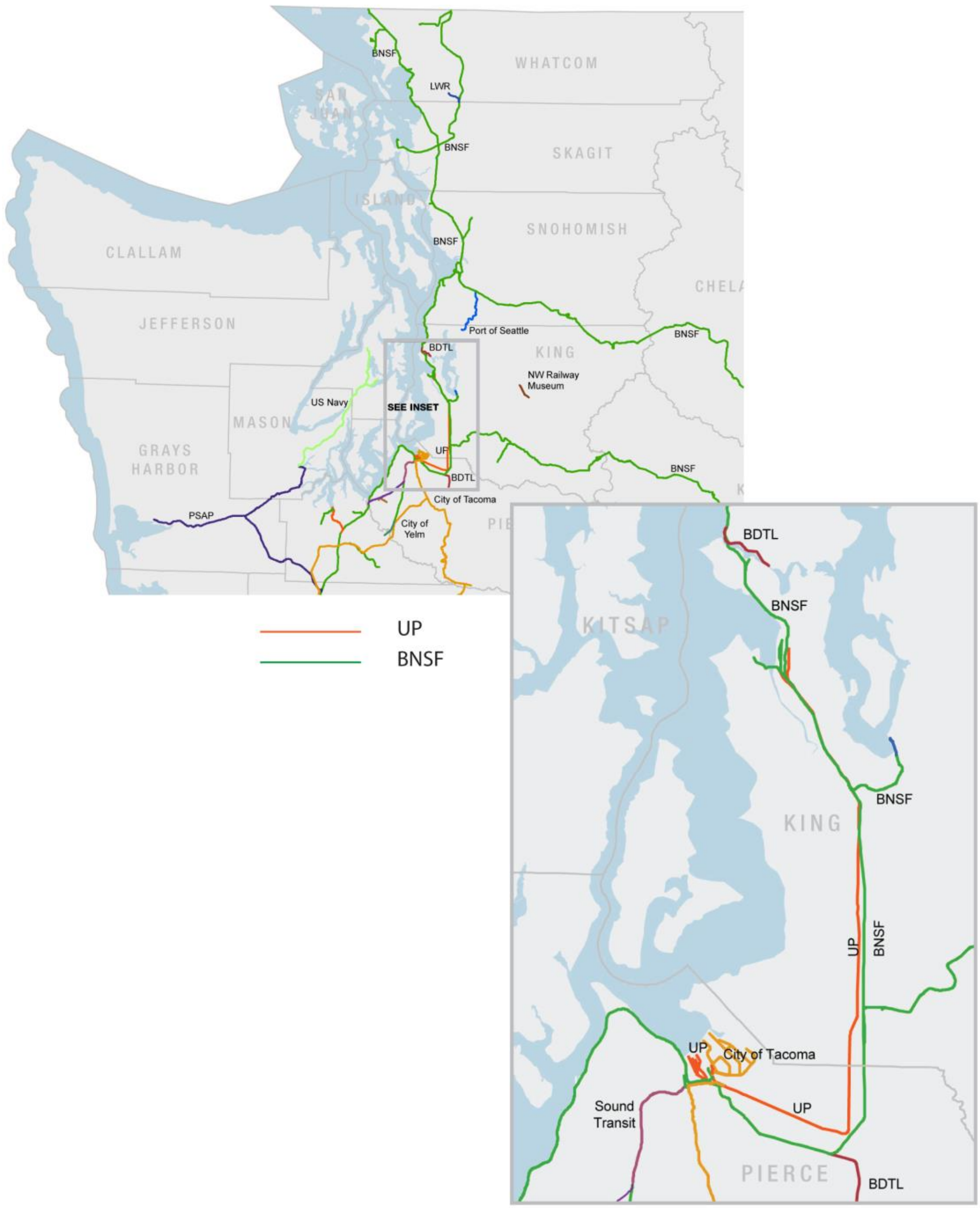
On-terminal switching and terminal rail services are provided at the NWSA South Harbor by Tacoma Rail, a division of Tacoma Public Utilities, and PacRail, and to the Port of Olympia by the Olympia & Belmore Railroad and at Terminal 18 at the NWSA North Harbor.

[20] American Association of Railroads, *http://www.aar.org*.

[21] Railroad classes are based on annual revenues. See: *https://www.fra.dot.gov/Page/P0362*

Figure 6.1 illustrates an overall view of the rail system within the State of Washington, and more specifically within the study area.[22] This map presents UP's tracks (orange line) running north and south from Seattle through Tacoma and south toward Portland, Oregon, whereas BNSF's tracks (green line) run north to Canada and east from Seattle and Tacoma to points in eastern Washington and further east.

Figure 6.1: Puget Sound Area Rail System Map



[22] WA State Department of Transportation, *www.wsdot.wa.gov/NR/rdonlyres/1FA0FD58-C5AD-46A8-BE95-1D2FC904D66F/0/2015WashingtonRailSystem.pdf.*

6.3 Data Collection

The rail locomotive source category is comprised of on-terminal and near-port activity, and port-related off-port activity within the airshed.

On-Terminal and near-port activity includes:

- Switching
- On-terminal and near port line-haul

Airshed port-related activity includes:

- Off-port line-haul activity within the airshed

The data collection processes for these are summarized below.

On-Terminal and Near-Port Switching
The data provided by the local operators and grain terminal operators included detailed information on their switching locomotives (e.g., make, model, year, and emissions tier level), fuel consumption information, and operational information such as the number of hours of operation during 2016. The smaller switching operations provided updated operating hour or fuel consumption information. The Class 1 railroads (BNSF and UP) and PSCAA provided data on switching and line-haul operations for prior years that was updated to 2016 by scaling using throughput changes between the inventory years. PSCAA provided more recent information on the Class 1 switchers that supplemented the Class 1 submittals.

On-Terminal and Near-Port Line-Haul
The NWSA provided information on the amount of cargo entering and leaving their terminals in 2016, overall and by rail, and 2016 cargo throughput data related to the Port of Everett was obtained from that port.

Airshed Port-Related
The estimates of port-related locomotive emissions within the airshed are based primarily on information previously provided by the Class 1 railroads and the NWSA, including fuel consumption (by county), cargo movements, and train arrivals/departures. In addition, the improvement in overall fuel efficiency of the Class 1 railroads was estimated from information provided by the Class 1 railroads to the Surface Transportation Board of the U.S. Department of Transportation that reflects each railroad's system-wide activity and fuel consumption.[23] Emission factors were obtained from the most recent EPA publication on projected locomotive emission factors by calendar year.[24]

[23] *www.stb.gov/stb/industry/econ_reports.html*
[24] Office of Transportation and Air Quality, EPA-420-F-09-025. *Emission Factors for Locomotives*, April 2009

6.4 Operational Profiles

Locomotive operations are described below in terms of the two major activity delineations; switching and line haul (on-terminal/near-port and airshed).

Switching Locomotives

Switching consists of short distance moves of railcars and the assembly of trains in a pre-ordered sequence. A train is organized according to where the cargo in each railcar is destined and the nature of the cargo. Safety requirements determine whether certain materials can be loaded in adjacent cars and by how many cars they must be separated, so railcars and groups of railcars are moved around a switching yard to appropriately organize the train as a whole.

In addition to moving line-haul trains into and out of the port areas, BNSF and Union Pacific operate switching locomotives in their near-port rail yards. Tacoma Rail operates switching locomotives within and near the South Harbor and the Olympia & Belmore Railroad operates switching locomotives at the Port of Olympia. At the terminal level, the grain terminals at the Port of Seattle and the Port of Tacoma operate two and three switching locomotives, respectively.

Tacoma Rail and Olympia & Belmore Railroad provided switching fleet information and the annual amount of fuel used in their locomotives in 2016. The grain terminals provided information on their switchers, including overall annual fuel consumption. Union Pacific cited a generalized EPA estimate of switching locomotive annual fuel consumption for the 2005, 2011, and 2016 emissions inventories,[25] basing their overall fuel consumption estimate on the number of locomotives and their normal operating schedule. BNSF, for the 2005 emissions inventory, used a general estimate of annual fuel consumption per yard locomotive, citing an internal yard equipment fuel study. The fuel usage was factored for 2011 and 2016 based on the changes in throughput at the ports during the periods between 2005, 2011, and 2016 using the assumption that switching activity correlates with changes in cargo throughput.

Line-Haul Locomotives

The NWSA offers on-dock or near-dock rail service at four locations in the South Harbor area: the North Intermodal Rail Yard, the South Intermodal Rail Yard, the Hyundai Intermodal Rail Yard, and the Pierce County Intermodal Rail Yard. In each of these yards, containers are loaded onto railcars for rail shipment across the country or are unloaded from railcars for placement onto ships for export. As mentioned, the NWSA North Harbor's Terminal 18 offers on-dock rail service; the other NWSA North Harbor terminals move rail-bound cargo to one of the near-port rail yards operated by the Class 1 railroads. The Port of Everett and the Port of Olympia are also served by the Class 1 railroads.

When a westbound train enters a port terminal or a near-port rail yard, the locomotives can be detached from the railcars and can depart in a fairly short period of time, leaving the railcars to be emptied of their cargo and to wait for reloading. Eastbound trains can be loaded and made ready before the arrival of the locomotives that will pull them. An

[25] EPA, *Procedures for Emission Inventory Preparation – Vol. IV: Mobile Source*, December 1992.

eastbound train must go through lengthy safety checks attached to the locomotives before it can depart. Average times of one hour per train for westbound trains and two hours per train for eastbound trains have been assumed for the emissions inventory calculations.

The locomotives in line-haul service vary in their horsepower ratings. Data previously provided by BNSF on the horsepower and engine tier level of locomotives calling in 2011 indicated that the BNSF locomotives averaged approximately 4,300 hp. This is similar to 2005, when an average of 4,000 horsepower was used in developing emission estimates and remains the line haul locomotive average power assumption. The average of 4,300 hp locomotives underlies the 2016 emission estimates.

6.5 Emission Reduction Initiatives Identified

Tacoma Rail has implemented several emission reduction techniques over the past few years.[26] Fifteen of their sixteen switching locomotives are equipped with an idle reduction technology that reduces idling while keeping the locomotive's battery charged and its engine ready to run when needed. One of their switchers is a genset locomotive, powered by three small, Tier 3 diesel engine/electrical generator sets (gensets) that provide only the level of power needed for a particular job, saving fuel and lowering emissions. Two of Tacoma Rail's switchers have been repowered to meet Tier 2 emission levels, and two locomotives meet Tier 3 standards. All of their locomotives have been equipped with improved fuel injectors that lower smoke and particulate emissions. The three switching locomotives at the Port of Tacoma and the two locomotives at the Port of Seattle have been equipped with automatic engine startup-shutdown (AESS) devices to reduce idling. BNSF has also reported installing AESS devices.

6.6 Emission Estimates

The 2016 maritime-related locomotive emissions within the port areas and for the Puget Sound area as a whole are summarized in this section. Please refer to Appendix F for locomotive emissions estimating methodology. Table 6.1 presents the total locomotive emissions estimated for 2016. Near-port line haul refers to emissions near and within the ports from locomotives as they move into and out of the port areas and as they idle during preparation for departure, while off-port line haul refers to emissions within the airshed from locomotives as they transport trains to and from the ports included in the inventory. The locomotives spend almost as much time on terminal/near-port as off-port due to lower speeds and longer periods of idling.

Table 6.1: 2016 Locomotive Emissions within the Airshed, tpy

Activity	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
Switching	472	37	68	0.22	15.9	14.4	15.9	11.2	24,799
Line-haul near-port	251	11	55	0.22	6.5	6.0	6.5	4.8	21,096
Line-haul off-port	375	16	82	0.32	9.7	9.0	9.7	7.1	31,471
Total	**1,099**	**63.4**	**205.6**	**0.8**	**32.0**	**29.5**	**32.0**	**23.0**	**77,366**

On-Terminal and Near-Port Emissions

Table 6.2 presents the 2016 emissions by county from switching activities on and near the NWSA North and South Harbors, the Ports of Seattle, Tacoma, and Olympia, and switching activity in Snohomish County associated with the Port of Everett.

Table 6.2: 2016 Switching Locomotive On-Terminal/Near-Port Emissions by County, tpy

County	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
King	98	8	14	0.05	3.4	3.1	3.4	2.4	5,153
Pierce	293	23	43	0.14	9.9	9.0	9.9	7.0	15,709
Snohomish	56	5	8	0.03	2.0	1.8	2.0	1.4	2,997
Thurston	24	1	3	0.01	0.6	0.6	0.6	0.4	941
Total	**472**	**37**	**68**	**0.22**	**15.9**	**14.4**	**15.9**	**11.2**	**24,799**

Table 6.3 presents the 2016 emissions from line-haul locomotives as they move maritime-related cargo within the NWSA North and South Harbors, the associated near-port/adjacent rail yards that handle port cargo, and as they service the Port of Seattle and Port of Tacoma grain terminals. Emissions from line-haul locomotive operations associated with the Ports of Olympia and Everett have not been included in these tables because sufficient information was not available to differentiate maritime-related from other locomotive activities in the region (i.e., rail movements not associated with international goods movement).

Table 6.3: 2016 Line-Haul Locomotive On-Terminal/Near-Port Emissions, tpy

Port	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
NWSA North Harbor	59	3	13	0.05	1.5	1.4	1.5	1.1	4,957
NWSA South Harbor	174	7	38	0.15	4.5	4.2	4.5	3.3	14,567
Seattle	9	0.4	2.1	0.01	0.2	0.2	0.2	0.2	784
Tacoma	9	0.4	2.1	0.01	0.2	0.2	0.2	0.2	788
Total	**251**	**10.8**	**55.3**	**0.22**	**6.5**	**6.0**	**6.5**	**4.8**	**21,096**

Line-Haul Emissions within the Airshed

Table 6.4 presents estimated 2016 line-haul locomotive off-port emissions associated with the NWSA North and South Harbors and the Ports of Seattle and Tacoma. Table 6.5 presents these emissions on a county-specific basis, based on the routes taken by the trains into and out of the inventory domain.

Table 6.4: 2016 Line-Haul Locomotive Off-Port Airshed Emissions, tpy

Port	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
NWSA North Harbor	125	5	27	0.11	3.2	3.0	3.2	2.4	10,485
NWSA South Harbor	157	7	34	0.13	4.0	3.8	4.0	3.0	13,157
Seattle	49	2	11	0.04	1.3	1.2	1.3	0.9	4,081
Tacoma	45	2	10	0.04	1.2	1.1	1.2	0.8	3,748
Total	**375**	**16**	**82**	**0.32**	**9.7**	**9.0**	**9.7**	**7.1**	**31,471**

Table 6.5: 2016 Line-Haul Locomotive Off-Port Airshed Emissions by County, tpy

County	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
King	130	6	29	0.11	3.3	3.1	3.3	2.5	10,893
Pierce	44	2	10	0.04	1.1	1.1	1.1	0.8	3,691
Snohomish	134	6	30	0.12	3.5	3.2	3.5	2.5	11,261
Thurston	67	3	15	0.06	1.7	1.6	1.7	1.3	5,626
Total	**375**	**16**	**82**	**0.32**	**9.7**	**9.0**	**9.7**	**7.1**	**31,471**

6.7 Emission Comparison

Activity and emissions comparisons between and among 2016, 2011, and 2005 for locomotives are presented in this section. Table 6.6 presents a comparison of 2016, 2011, and 2005 annual activity levels for locomotives in terms of intermodal (IM) lifts (containers moved by rail), horsepower-hours, and fuel consumption in gallons.

Table 6.6: Locomotive Activity and Fuel Consumption Comparison

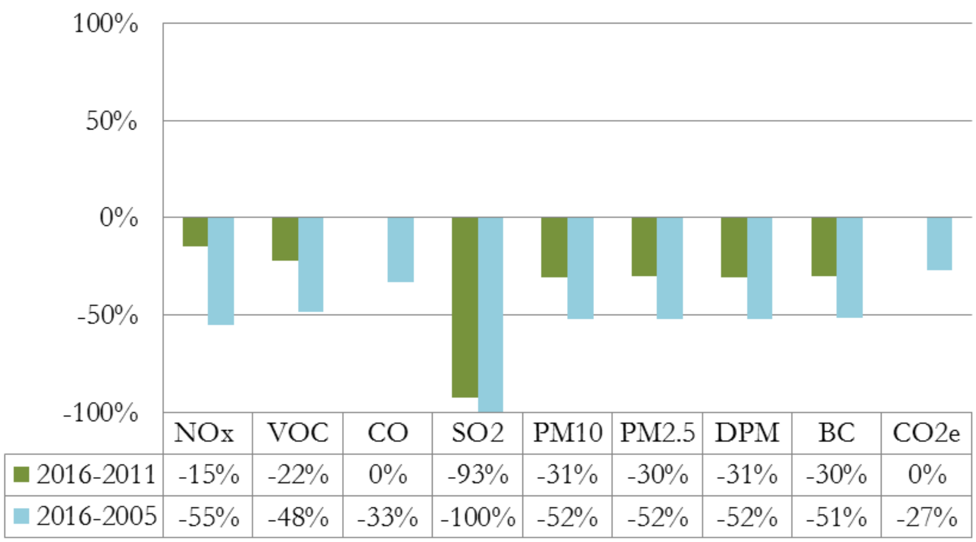
Year	Throughput thousand IM lifts	Activity million hp-hr	Fuel Usage million gallons
2016	801	131	6.91
2011	723	132	6.89
2005	1,198	186	9.42
2016 vs 2011 Change	**10.8%**	**-0.5%**	**0.3%**
2016 vs 2005 Change	**-33.1%**	**-29.4%**	**-26.6%**

The 2016, 2011, and 2005 comparisons for locomotive emissions within the airshed are summarized in Table 6.7. Locomotive emissions within the airshed in 2016 were generally lower than 2011 and 2005, except for CO and CO_2e emissions which were essentially unchanged from 2011 to 2016. The reductions were primarily due to changes in port throughput which affected the amount of line haul and switching locomotive activity. Newer, lower emitting line haul locomotives and improved fuel efficiency of locomotive operations likely also played a role, although specific data on the line haul locomotives was not collected. The large decrease in SO_2 emissions was a result of the continued lowering of the sulfur content of diesel fuels, with the line haul locomotives using fuel with approximately 3,500 parts per million (ppm) in 2005, 234 ppm in 2011, and ultra-low sulfur diesel (ULSD) at 15 ppm during the 2016 EI period. Some of the switching locomotives, such as those operated by Tacoma Rail, used ULSD starting in 2005.

Table 6.7: Total Locomotive Emissions Comparison, tpy

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	1,099	63	206	1	32	29	32	23	77,366
2011	1,293	82	205	11	46	42	46	33	77,187
2005	2,460	123	308	193	67	61	67	47	106,058
2016 vs 2011 Change	**-15%**	**-22%**	**0%**	**-93%**	**-31%**	**-30%**	**-31%**	**-30%**	**0%**
2016 vs 2005 Change	**-55%**	**-48%**	**-33%**	**-100%**	**-52%**	**-52%**	**-52%**	**-51%**	**-27%**

Figure 6.2: Total Locomotive Emissions Change, %



Comparing 2016 vs 2011, the locomotive emissions decreased for all pollutants except CO and CO_2e for the following reasons:

- Newer, lower emitting line haul locomotives
- Improved fuel efficiency of locomotive operations
- Use of ULSD in all locomotives in 2016, reducing SO_2 emissions significantly

Emissions of CO and CO_2e were essentially the same in 2011 and 2016 despite an 11% increase in throughput measured as intermodal lifts.[27] Activity measured as hp-hr increased only 1%, contributing to the minimal change in CO and CO_2.

Comparing 2016 vs 2005, the locomotive emissions of all pollutants decreased primarily due to:

- Newer, lower emitting line haul locomotives
- Lower overall fuel consumption (27% lower)
- Lower activity measured in hp-hr (29% lower)
- Lower throughput measured as intermodal lifts (33%)
- Use of ULSD in all locomotives in 2016, reducing SO_2 emissions significantly

[27] See: *www.freightquote.com/define/what-is-intermodal-transportation "Intermodal is the use of two modes of freight, such as truck and rail, to transport goods from shipper to consignee."*
In the context of port operations, intermodal refers to ship-to-rail or truck-to-rail movement of cargo.

SECTION 7 HEAVY-DUTY VEHICLES

Section 7 provides an overview of the emissions from on-road heavy-duty vehicles (trucks) that transport port-related cargo, and from buses that shuttle cruise passengers at the cruise terminals to and from the airport and area hotels. Virtually all of these heavy-duty vehicles are diesel-fueled. While some are fueled with liquefied or compressed natural gas (LNG/CNG) there is insufficient detail on the number of such vehicles and how they are used in goods movement in the area to separately estimate their emissions. Given their small numbers, considering these alternately fueled trucks is not likely to appreciably change the emissions estimates. Details of the methodology used to estimate emissions are available in Appendix G. The 2011 and 2005 emissions presented in this report are not the same as the emissions originally reported in the 2011 and 2005 PSEI reports, but represent the latest science with respect to vehicle emission calculations. For comparisons of 2016 to 2005 and 2011, please use the comparison sections in this 2016 PSEI report.

7.1 Source Description

This inventory includes maritime-related heavy-duty trucks and cruise-related passenger buses, not all heavy-duty trucks or vehicles in the region. Heavy-duty trucks are used extensively to deliver cargo to and from port terminals, local distribution centers, and national destinations and to transfer cargo between port terminals and off-port railcar loading facilities. They are also driven on the public roads near ports and throughout the region. Trucks that move cargo short distances to and from the ports are called drayage trucks.

Generally, the trucks and associated equipment, such as chassis and refrigeration gensets, and buses are not under the direct control of the ports, their terminals, or most of the shippers who use the terminals. The trucks are largely a combination of vehicles owned by transportation companies and independently owned and operated trucks while the buses are operated by transportation companies.

This section details the estimated emissions from truck activities within the ports' terminals as they drop off or pick up cargo, and the idling emissions of the heavy-duty commercial buses that transport cruise line passengers to and from the airport and hotels in the area for the time that they idle during unloading and loading of cruise passengers. The on-terminal cargo truck activities covered include idling at pre-gate queue lines prior to entering terminal gates, idling within the terminals, and travel within the terminals. Emissions from trucks transporting cargo on the public roadways to or from the ports have been estimated by the Puget Sound Regional Council (PSRC), and are presented in this section as representing regional port-related emissions. These estimates do not include the on-road travel of the cruise terminal buses.

The following figures illustrate a truck transporting a container and truck without a trailer attached, referred to as a bobtail.

Container truck

Bobtail

7.2 Geographical Description

The geographical extent of the heavy-duty vehicle inventory consists of the marine terminals (cargo and cruise) and, for trucks, the public roadways within the greater Puget Sound airshed as described in the Introduction. Figure 7.1 shows Washington State's major interstate highways.[28]

Figure 7.1: Washington State Major Interstate Map

[28] Washington State Department of Transportation, *www.wsdot.wa.gov/Traffic/InterstateGuide/#i90*

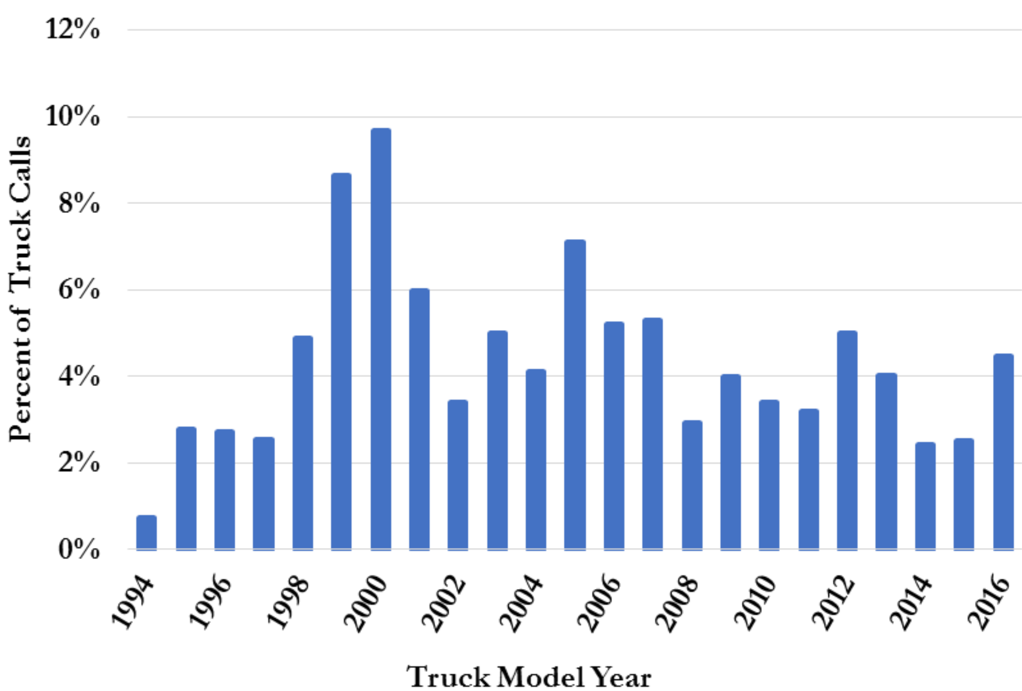
7.3 Data Collection

The heavy-duty vehicle emission source category is comprised of two activity components: on-terminal activity and regional port-related on-road activity. The data collection methods for each are summarized below.

Truck Model Year Distribution

The NWSA provided model year information for 2016 consisting of the number of truck calls made by each model year of truck to their international container terminals. The model year distribution is important because vehicle emissions vary by model year, and newer model vehicles generally emit less than older vehicles. It has been assumed for this inventory that the NWSA truck model year distribution is representative of the trucks that visit the other ports and NWSA domestic terminals included in the 2016 PSEI. The 2016 port-related model year distribution reflecting the calls to the NWSA ports is illustrated in Figure 7.2, which presents the percentage of truck trips by model year. A call-based distribution represents vehicle activity better than a population-based distribution because vehicles are typically driven less, or on shorter trips, as they age. A call-based distribution reflects this while looking only at the number of vehicles of each model year does not.

Figure 7.2: 2016 Heavy-Duty Vehicle Model Year Distribution



On-Terminal
Terminal operators provided information on truck throughput for calendar year 2016, the average speed and distance driven on-terminal, and the average amount of time trucks wait at the entrance gate, the exit gate, and while loading/unloading. The Port of Seattle provided information on cruise terminal passenger counts and the typical bus idling times on arrival to and departure from the cruise terminals.

On-Road Port-Related
The PSRC developed estimates of on-road truck emissions within the Puget Sound area from trucks engaging in port-related freight movements. They based these estimates on their regional travel demand model and emission factors obtained from the MOVES2014a model, using the port-specific model year distribution discussed above. Their methodology in developing estimates of vehicle miles of travel (VMT) was consistent with their methods used for the 2005 and 2011 PSEI, although the emission factor model used for the earlier inventories was a different, older, EPA model as discussed in this report.

7.4 Operational Profiles

Port-related, on-road trucking is a unique subset of the overall truck activity that occurs in the Puget Sound region. Long-haul trucks transport goods out of the region to far away destinations, and drayage trucks drive relatively short distances to deliver containers to and from terminals, intermodal yards, and local distribution centers. In Seattle, the intermodal yards are approximately one to two miles from the terminals and many port-related truck trips stay within the Duwamish Industrial area. The local distribution centers, concentrated in the Green River Valley area, are approximately 10 to 35 miles from the terminals. In Tacoma, the containers bound to and from intermodal yards are transported via truck or on-dock rail, while containers bound for the local distribution centers are trucked approximately 15 to 25 miles to the Green River Valley.

The total number of trips associated with the terminals is a function of cargo throughput or number of cruise passengers and frequency of cruises. The vehicles have periods of idling during each trip, for example while waiting to enter the terminal or while waiting to drop off and/or pick up cargo or passengers. The vehicles also travel a certain distance within the terminal from entry gate to drop-off/pick-up locations, and to the exit gate. The amount of on-terminal idling depends in part on the mode of operation – idling is reduced if cargo is ready to be loaded upon the vehicle's arrival compared to operations in which a vehicle must wait for a loader to bring the cargo.

Bus idling occurs while queuing to park in designated areas and while loading or discharging passengers. It should be noted that both trucks and buses do not necessarily idle all the time that they are at rest – drivers may turn off the vehicles' engines if stationary for an extended period. As there is no reliable data about the actual percentage of time the vehicles' engines run at idle, the conservatively high assumption has been made that the vehicles are idling whenever they are not in motion (i.e., the assumption is the total time on terminal from entry gate wait to exit is spent either driving or idling). It should be noted that many ports, including the Port of Seattle, the Port of Tacoma, and the NWSA have anti-idling policies and signage that limit the amount of idling during periods of vehicle inactivity. On-terminal travel distance depends on the size of the terminal and on the route taken by the vehicles within the terminal.

The vehicle miles of travel (VMT) of port-related on-road trucks as estimated by the PSRC depends on the destination of the cargo being transported. Idling of vehicles while in transit, such as at traffic signals, is included in the gram-per-mile emission factors produced by the MOVES2014a model.

7.5 Emission Reduction Initiatives Identified

In 2016, the diesel trucks and buses addressed in this section used ultra-low sulfur diesel (ULSD) with a sulfur content of 15 ppm or less, because this is the fuel commercially available nation-wide for on-road vehicle use. This ULSD fuel significantly reduces emissions of sulfur oxides and particulate emissions. Fleet turnover to newer vehicles has also had an effect on reducing overall heavy-duty vehicles emissions. In 2011, the NWSA banned trucks with engines older than 1994 from calling at their international container terminals, and fleet turnover continues to make the fleet lower in emissions overall.

7.6 Emission Estimates

The EPA on-road vehicle emission modeling software, designated MOVES2014a, has been used to estimate emissions from these on-road mobile sources. Details of the methodology used to estimate emissions are available in Appendix G. The heavy-duty vehicle emission estimates are presented in this section in tow components:

- On-terminal – includes heavy-duty truck emissions while on-terminal and in queues both on-terminal and adjacent to the terminal, and commercial bus emissions from idling while at the terminal, dropping off or picking up cruise passengers.
- On-road – includes heavy-duty truck emissions beyond the port domain to the airshed boundary (i.e., within the Puget Sound airshed).

Table 7.1 summarizes the total heavy-duty vehicle emissions in 2016.

Table 7.1: 2016 Total Study Area On-Terminal and On-Road Heavy-Duty Vehicle Emissions, tpy

Activity	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
On-terminal	173	19	53	0.17	8.4	7.7	8.4	4.0	19,443
On-road	1,124	46	267	1.88	52.9	48.9	52.9	14.7	219,362
Total	**1,297**	**66**	**320**	**2.05**	**61.3**	**56.7**	**61.3**	**18.8**	**238,805**

Table 7.2 summarizes the port heavy-duty vehicle emission estimates which include both driving and idling emissions while on-terminal and in queues both on-terminal and adjacent to the terminal.

Table 7.2: 2016 On-Terminal Heavy-Duty Vehicle Emissions by Terminal, tpy

Terminal	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
PSA010	0.1	0.0	0.0	0.00	0.0	0.0	0.0	0.0	15
PSE010	0.2	0.0	0.1	0.00	0.0	0.0	0.0	0.0	20
PSO010	0.1	0.0	0.0	0.00	0.0	0.0	0.0	0.0	14
PSS020	0.3	0.0	0.1	0.00	0.0	0.0	0.0	0.0	16
PSS030	0.9	0.1	0.3	0.00	0.0	0.0	0.0	0.0	106
PSS050	36.8	4.1	11.3	0.04	1.8	1.6	1.8	0.9	4,125
PSS060	10.4	1.1	3.2	0.01	0.5	0.5	0.5	0.2	1,190
PSS070	24.6	2.8	7.5	0.02	1.2	1.1	1.2	0.6	2,691
PSS080	0.0	0.0	0.0	0.00	0.0	0.0	0.0	0.0	0
PST010	0.1	0.0	0.0	0.00	0.0	0.0	0.0	0.0	11
PST020	13.5	1.6	4.1	0.01	0.7	0.6	0.7	0.3	1,446
PST030	6.3	0.7	1.9	0.01	0.3	0.3	0.3	0.1	686
PST040	2.9	0.3	0.9	0.00	0.1	0.1	0.1	0.1	342
PST050	7.8	0.9	2.4	0.01	0.4	0.3	0.4	0.2	883
PST060	42.1	4.6	13.1	0.04	2.0	1.9	2.0	1.0	4,893
PST070	3.3	0.4	1.0	0.00	0.2	0.1	0.2	0.1	351
PST090	0.2	0.0	0.0	0.00	0.0	0.0	0.0	0.0	17
PST100	2.1	0.2	0.7	0.00	0.1	0.1	0.1	0.0	274
PST110	0.4	0.0	0.1	0.00	0.0	0.0	0.0	0.0	39
PST120	0.2	0.0	0.1	0.00	0.0	0.0	0.0	0.0	27
PST130	0.9	0.1	0.3	0.00	0.0	0.0	0.0	0.0	102
SIG Yard	7.3	0.8	2.2	0.01	0.4	0.3	0.4	0.2	817
UP Seattle	12.6	1.5	3.8	0.01	0.6	0.6	0.6	0.3	1,378
Total	**173.2**	**19.4**	**53.1**	**0.17**	**8.4**	**7.7**	**8.4**	**4.0**	**19,443**

Table 7.3 provides the estimated annual emissions from the port-related on-road truck activity by county. These estimates do not include the on-terminal emissions.

Table 7.3: 2016 Port-Related On-Road Heavy-Duty Vehicle Emissions by County, tpy

County	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
Clallam	16	0.6	4	0.03	0.9	0.8	0.9	0.2	3,461
Island	13	0.4	3	0.02	0.7	0.6	0.7	0.2	2,818
Jefferson	11	0.4	3	0.02	0.5	0.5	0.5	0.2	2,349
King	516	21.5	123	0.85	23.9	22.0	23.9	6.6	100,394
Kitsap	7	0.3	2	0.01	0.3	0.3	0.3	0.1	1,312
Mason	15	0.5	3	0.03	0.7	0.7	0.7	0.2	3,040
Pierce	258	11.0	63	0.44	13.2	12.1	13.2	3.7	51,133
San Juan	2	0.1	0	0.00	0.1	0.1	0.1	0.0	323
Skagit	56	2.3	12	0.09	2.2	2.1	2.2	0.6	10,147
Snohomish	97	4.0	23	0.17	4.6	4.3	4.6	1.3	18,997
Thurston	79	3.3	18	0.13	3.3	3.2	3.3	1.0	14,774
Whatcom	55	2.2	13	0.09	2.5	2.3	2.5	0.7	10,616
Total	**1,124**	**46.5**	**267**	**1.88**	**52.9**	**48.9**	**52.9**	**14.7**	**219,362**

Table 7.4 provides the total estimated annual emissions for the sum of on-terminal and the port-related on-road heavy-duty vehicle activity by county and clean air agency region.

Table 7.4: 2016 Total Study Area On-Terminal and On-Road Heavy-Duty Vehicle Emissions by County and Clean Air Agency, tpy

County	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
Island	13	0	3	0.0	0.7	0.6	0.7	0.2	2,818
San Juan	2	0	0	0.0	0.1	0.1	0.1	0.0	323
Skagit	56	2	12	0.1	2.2	2.1	2.2	0.6	10,147
Whatcom	55	2	13	0.1	2.5	2.3	2.5	0.7	10,616
NWCAA Total	**126**	**5**	**29**	**0.2**	**5.4**	**5.1**	**5.4**	**1.5**	**23,903**
Clallam	16	1	4	0.0	0.9	0.8	0.9	0.2	3,476
Jefferson	11	0	3	0.0	0.5	0.5	0.5	0.2	2,349
Mason	15	1	3	0.0	0.7	0.7	0.7	0.2	3,040
Thurston	79	3	18	0.1	3.3	3.2	3.3	1.0	14,788
ORCAA Total	**121**	**5**	**28**	**0.2**	**5.4**	**5.1**	**5.4**	**1.5**	**23,653**
King	609	32	151	0.9	28.4	26.2	28.4	8.8	110,716
Kitsap	7	0	2	0.0	0.3	0.3	0.3	0.1	1,312
Pierce	338	20	88	0.5	17.1	15.7	17.1	5.5	60,204
Snohomish	97	4	23	0.2	4.6	4.3	4.6	1.3	19,016
PSCAA Total	**1,050**	**56**	**264**	**1.6**	**50.5**	**46.4**	**50.5**	**15.7**	**191,248**
Total	**1,297**	**66**	**320**	**2.0**	**61.3**	**56.7**	**61.3**	**18.8**	**238,805**

7.7 Emission Comparison

Heavy-duty vehicle emissions have been estimated for this inventory using EPA's most recent MOVES2014a model. The previous PSEIs (2011 and 2005) were prepared using versions of the previous EPA model for on-road mobile sources known as the MOBILE series of models (MOBILE2010 was the last version released). As a result, 2011 and 2005 emissions have been re-estimated using MOVES2014a to allow comparison of the three inventories using the most recent data and latest available science. The 2011 and 2005 emissions presented in this report are not the same as the emissions originally reported in the 2011 and 2005 PSEI reports, which were estimated using the older EPA model. A discussion and resource list providing information on the major differences between the models are included in Appendix G. The 2011 emissions in this report also reflect revisions the PSRC made to the 2011 VMT estimates to make the estimates more consistent with their 2005 and 2016 VMT estimates.

Table 7.5 and Figure 7.3 summarize the total heavy-duty vehicle emissions comparison, including both on-terminal and on-road emissions.

Table 7.5: Total Study Area On-Terminal and On-Road Heavy-Duty Vehicle Emissions Comparison, tpy and %

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	1,297	66	320	2	61	57	61	19	238,805
2011	1,919	125	523	2	85	78	85	56	223,681
2005	2,516	143	646	16	112	103	112	76	206,028
2016 vs 2011 Change	**-32%**	**-47%**	**-39%**	**6%**	**-28%**	**-27%**	**-28%**	**-67%**	**7%**
2016 vs 2005 Change	**-48%**	**-54%**	**-50%**	**-87%**	**-45%**	**-45%**	**-45%**	**-75%**	**16%**

With the exception of CO_2e and SO_2 emissions, emissions in 2016 were lower than in both 2011 and 2005. The emissions are lower primarily due to changes in the truck fleet model year distribution caused by natural truck fleet turnover and the enhanced fleet turnover from the "Clean Truck Program" implemented by the NWSA. The changes include both fewer older trucks and the presence of newer trucks that were not on the market previously. CO_2 and SO_2 increased slightly between 2011 and 2016 primarily because of higher VMT resulting from increased container throughput. There has not been a substantial improvement in fuel economy among heavy-duty vehicles that would have moderated the effect of higher VMT on CO_2 emissions (CO_2 emissions from vehicles are a direct result of fuel combustion), and with the sulfur content of fuel remaining essentially static during the period the SO_2 emissions have scaled the same as the CO_2.

Figure 7.3: Total Study Area Heavy-Duty Vehicle Emissions Change, %

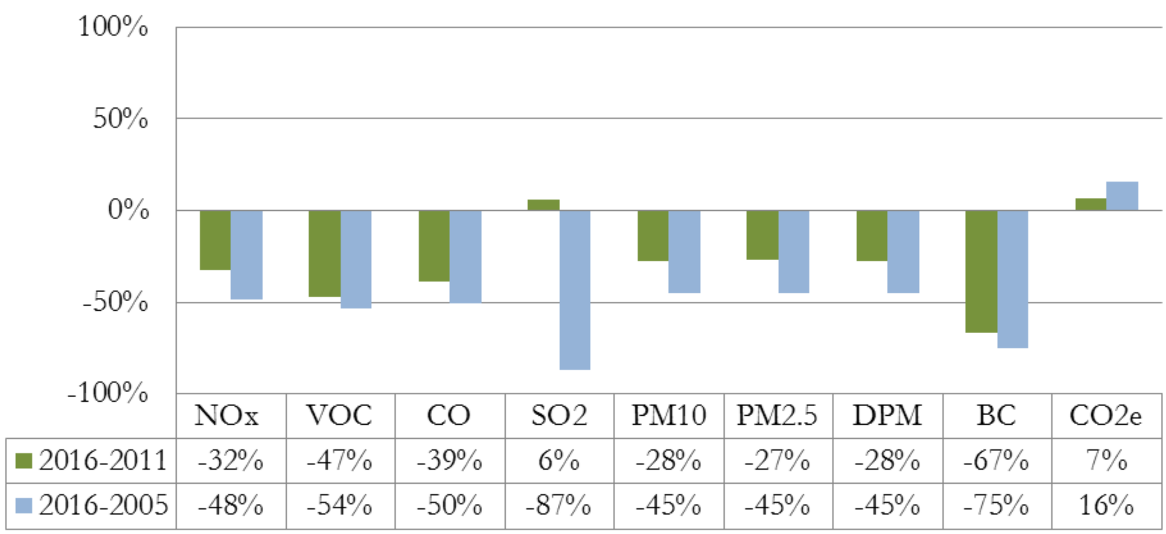


Table 7.6 presents the total on-terminal truck emissions comparison and Table 7.7 provides the VMT and idling hours comparison.

Table 7.6: Total On-Terminal Heavy-Duty Vehicle Emissions Comparison, tpy

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	173	19	53	0	8	8	8	4	19,443
2011	288	28	74	0	12	11	12	8	19,896
2005	327	30	77	1	13	12	13	9	19,321
2016 vs 2011 Change	**-40%**	**-31%**	**-28%**	**-2%**	**-31%**	**-31%**	**-31%**	**-47%**	**-2%**
2016 vs 2005 Change	**-47%**	**-36%**	**-31%**	**-89%**	**-37%**	**-37%**	**-37%**	**-57%**	**1%**

Table 7.7: Total On-Terminal Heavy-Duty Vehicle VMT and Idling Hours Comparison

Year	VMT	Idling Hours
2016	2,989,786	1,298,867
2011	3,075,692	1,316,984
2005	2,815,667	1,334,889
2016 vs 2011 Change	**-3%**	**-1%**
2016 vs 2005 Change	**6%**	**-3%**

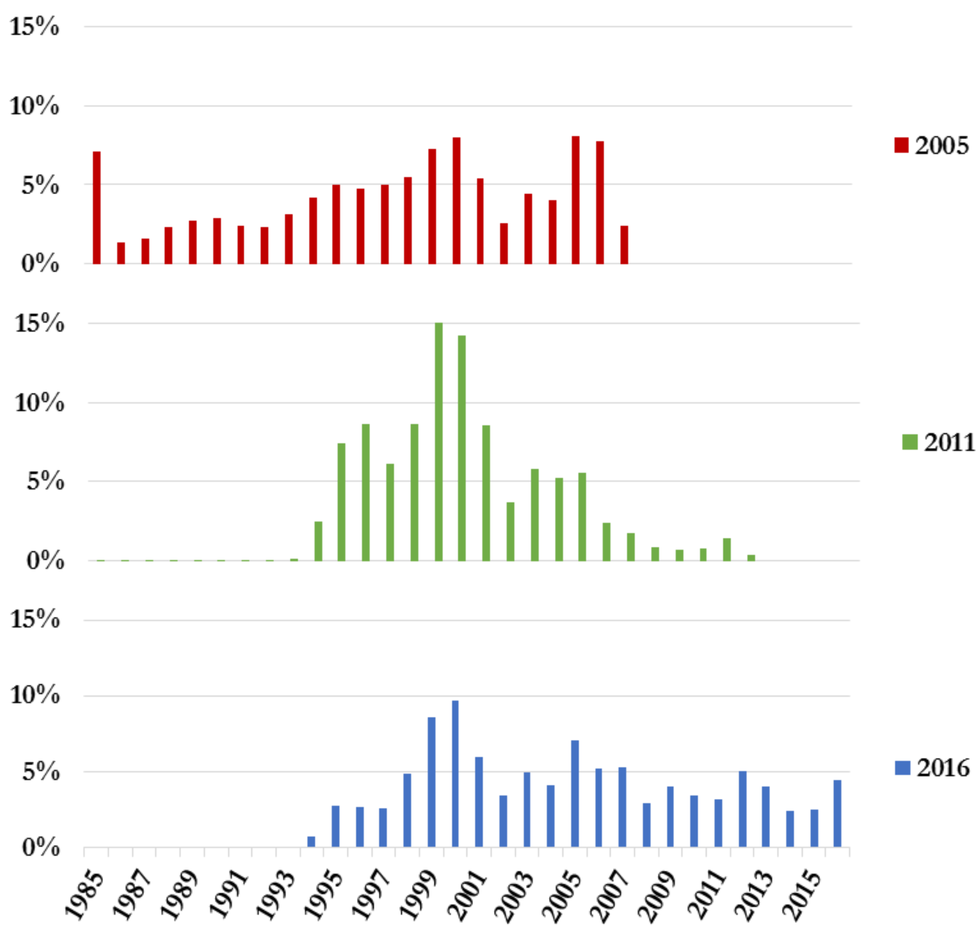
Table 7.8 summarizes the on-road port-related heavy-duty vehicle emissions, which do not include the on-terminal emissions presented above. The increases and decreases are similar to those seen for the on-road emissions as a whole presented in Table 7.5, with CO_2 and SO_2 increasing slightly because of higher on-road VMT.

Table 7.8: On-Road Heavy-Duty Vehicle Emissions Comparison, tpy

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	1,124	46	267	2	53	49	53	15	219,362
2011	1,631	97	449	2	72	67	72	49	203,786
2005	2,189	112	569	14	98	90	98	66	186,708
2016 vs 2011 Change	**-31%**	**-52%**	**-40%**	**7%**	**-27%**	**-27%**	**-27%**	**-70%**	**8%**
2016 vs 2005 Change	**-49%**	**-59%**	**-53%**	**-87%**	**-46%**	**-46%**	**-46%**	**-78%**	**17%**

Figure 7.4 illustrates the differences in the heavy-duty vehicle model year distributions used for the 2016, 2011, and 2005 emissions inventories. Because the port truck-specific information was not available in 2005, the distribution for 2005 was a general distribution of heavy-duty trucks operating in the Puget Sound area, not specific to port trucks. In 2016 and 2011, the ports provided model year distribution information specific to trucks that called at the marine terminal truck gates at ports. Figure 7.4 shows that the 2005 distribution included more gate calls by the older, high-emitting, pre-1994 trucks that have since been prohibited from working at the NWSA terminals. Fleet turnover accounts for most of the emission reductions observed when comparing the 2016 inventory with 2011 and 2005.

Figure 7.4: Heavy-Duty Vehicle Model Year Distribution Comparison



SECTION 8 FLEET VEHICLES

Section 8 provides an overview of the fleet vehicle source category and their estimated emissions in 2016. Fleet vehicles consist primarily of light-duty vehicles and some heavy-duty vehicles used primarily on marine terminals. Details of the methodology used to estimate emissions are available in Appendix H. The 2011 and 2005 emissions presented in this report are not the same as the emissions originally reported in the 2011 and 2005 PSEI reports, but represent the latest science with respect to vehicle emission calculations. For comparisons of 2016 to 2005 and 2011, please use the comparison sections in this 2016 PSEI report.

8.1 Source Description

This section includes terminal fleet vehicles from all ports along with cruise terminal vehicles in the Port of Seattle and import/export vehicles at Port of Tacoma.

Three categories of fleet vehicles are included in the inventory:

- Terminal fleet vehicles - vehicles owned and/or operated by the terminal operators or a Port that spend most of their time on the terminals. These vehicles include light-duty and heavy-duty vehicles, such as fueling trucks, shuttle/passenger vehicles, terminal cars/trucks, maintenance trucks, etc. Cargo related heavy-duty vehicles are reported in Section 7.
- Cruise terminal vehicles – vehicles that operate on cruise terminals including privately owned vehicles owned by cruise passengers and commercial minivans picking up and dropping off passengers. These are typically light-duty vehicles. Only vehicles associated with the Port of Seattle cruise terminals have been included, vehicles associated with ferry and other commercial harbor vessel services have not been included.
- Import/export vehicles - New import or export vehicles driven on or off ocean-going vessels at the NWSA Auto Terminal. These are typically passenger vehicles and light-duty trucks.

This section does not include emissions from:

- Commercial buses and taxis that drop off or pick up passengers at the cruise terminals. Commercial buses idling on or near cruise terminals associated with the drop-off or pick-up of cruise passengers (reported in Section 7).
- Heavy-duty trucks that transport the new import or export vehicles to/from the Marshall Auto Terminal (reported in Section 7).
- Cargo related heavy-duty vehicles (reported in Section 7).
- Employee personal vehicles.

8.2 Geographical Description

The geographical extent for fleet vehicles is described below:

- Terminal fleet vehicles – on-terminal
- Cruise terminal vehicles – on-terminal and cruise terminal related areas
- Import/export vehicles – on-terminal

8.3 Data Collection

The data collection approach focused on collecting relevant information for the three categories of vehicles listed above. Data for the terminal fleet data included vehicle type, model year, and annual miles of use within the terminal boundary. Cruise terminal vehicle activity data consisted of total passenger counts and cruise ship call data by terminal. Import/export vehicle data consisted of the annual vehicle throughput and the average miles traveled on-terminal. Summarized information on these three categories is presented below.

8.4 Operational Profiles

Terminal Fleet Vehicles

Terminal fleet vehicles consist of 853 passenger cars, trucks, and non-commercial (terminal shuttle) buses with a model year range of 1978 to 2016 (average model year, 2003). The 2016 mileage per vehicle (excluding vehicles that traveled zero miles) ranged from 27 to 9,724 with an average of 1,875. Table 8.1 shows the breakdown of the terminal fleet vehicles by terminal, number of vehicles, model year range and average, and fuel type.

Table 8.1: 2016 Terminal Fleet Vehicle Characteristics

		Fuel/Engine Type					
Terminal ID	Count	Gasoline	Diesel	Biodiesel	Hybrid (gasoline)	CNG	Propane
PSA010	15	15	0	0	0	0	0
PSE010	19	5	14	0	0	0	0
PSE040	3	3	0	0	0	0	0
PSO010	14	11	3	0	0	0	0
PSS010	217	156	5	27	27	2	0
PSS050	105	99	6	0	0	0	0
PSS060	9	9	0	0	0	0	0
PSS070	66	60	6	0	0	0	0
PST010	110	109	0	0	0	0	1
PST020	32	30	2	0	0	0	0
PST030	44	42	2	0	0	0	0
PST040	40	25	15	0	0	0	0
PST055	32	32	0	0	0	0	0
PST060	95	86	9	0	0	0	0
PST070	40	32	8	0	0	0	0
PST080	2	2	0	0	0	0	0
PST100	5	5	0	0	0	0	0
PST130	5	4	1	0	0	0	0
Totals	**853**	**725**	**71**	**27**	**27**	**2**	**1**

Cruise Terminal Vehicles

The Port of Seattle reported a total of 983,539 passengers passed through their cruise terminals in 2016 for 203 vessel cruises. It was assumed that 40%[29] of the passengers used personal vehicles (rather than commercial transportation) to get to the cruise terminals, and that each personal vehicle carried an average of three persons, for a total of 131,139 vehicles. Of the 203 cruises, 54 trips (27%) were from Pier 66 and 149 trips (73%) were from Terminal 91. Therefore, 34,884 vehicles were assigned to Pier 66 and 96,254 vehicles were assigned to Terminal 91.

In addition to the passenger-owned vehicles, commercial minivans used to transport passengers were included in the inventory. Consistent with 2011, 240 commercial minivan trips were assumed in 2016 and the distance traveled on-terminal or adjacent to the terminal was estimated to be 0.25 miles, with a speed of 15 mph. All commercial minivans were assumed to be gasoline-fueled.

It should be noted that all off-terminal vehicle miles traveled and associated emissions are accounted for by the PSRC and regional clean air agencies in their area emissions inventories. Annual trips related to cruise operations are a very small fraction of total regional vehicle miles traveled and thus are not calculated separately in this inventory.

Import/Export Vehicles

The Port of Tacoma Marshall Avenue Auto Terminal throughput was 160,836 vehicles in 2016. The vehicles were assumed to have a model year of 2016 because they are new vehicles. Each vehicle was assumed to be driven two miles because of the size of the terminal and the fact they are driven off the ship and to a parking area on the terminal (or driven from the terminal parking area onto a ship). Ninety-nine percent of the vehicles were assumed to be cars and one percent of the vehicles were assumed to be light trucks, as reported by the Port. All vehicles were assumed to be gasoline fueled.

8.5 Emission Reduction Initiatives Identified

Approximately seven percent of the terminal fleet vehicles (57) were alternatively fueled (including gasoline/electric hybrids) in 2016. The alternatively fueled terminal fleet vehicles included 27 vehicles using biodiesel (B20), 27 hybrid vehicles, 2 vehicles using natural gas and 1 using propane. No electric vehicles were identified in the inventory.

[29] Consistent with data reported by Heffron Transportation, Inc., *Transportation Technical Report for Draft EIS Cruise Terminal at Terminal 91*, 14 September 2006.

8.6 Emission Estimates

Please refer to Appendix H for fleet vehicles emissions estimating methodology. This section summarizes fleet vehicle related emissions as described above. The 2016 emissions from terminal fleet, cruise terminal vehicles, and import/export vehicles are presented in Table 8.2.

Table 8.2: 2016 Total Terminal Fleet Vehicle Emissions by Clean Air Agency, tpy

Clean Air A	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
NWCAA	0.03	0.01	0.17	0.00	0.00	0.00	0.00	0.00	12
ORCAA	0.01	0.00	0.06	0.00	0.00	0.00	0.00	0.00	7
PSCAA	2.58	0.63	11.65	0.02	0.06	0.06	0.04	0.03	1,017
Total	**2.63**	**0.65**	**11.88**	**0.02**	**0.06**	**0.06**	**0.04**	**0.03**	**1,037**

8.7 Emission Comparison

The comparison among 2016, 2011, and 2005 emissions from terminal fleet vehicles, cruise terminal vehicles, and import/export vehicles is summarized in Table 8.3. It should be noted that the previous PSEIs (2011 and 2005) were prepared using versions of the previous EPA model for on-road mobile sources known as the MOBILE series of models (MOBILE2010 being the last version released). The MOVES model was developed using the latest information available to EPA and produces estimates that can differ considerably from estimates produced using the MOBILE model versions. As a result, 2011 and 2005 emissions have been re-estimated using MOVES2014a to allow comparison of the three inventories. The 2011 and 2005 emissions presented in this report are not the same as the emissions originally reported in the 2011 and 2005 PSEI reports, but represent the latest science with respect to vehicle emissions. A discussion and resource list providing information on the major differences between the models are included in Appendix G.

In 2016, despite an increase in terminal fleet vehicle counts compared with 2011 and 2005, there was an overall reduction of reported vehicle mileage and, therefore, a reduction of emissions of all pollutants. When evaluated for average grams of emissions per mile of travel of each pollutant, emissions also decreased between 2011 and 2016. These reductions were due to a newer and cleaner fleet and use of hybrid vehicles and alternative fuel, such as biodiesel.

Table 8.3: Terminal Fleet Vehicle Emissions Comparison, tpy

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	2.6	0.6	11.9	0.019	0.065	0.059	0.038	0.030	1,037
2011	7.8	2.2	37.6	0.059	0.208	0.189	0.129	0.100	3,204
2005	13.1	3.1	42.3	0.233	0.441	0.402	0.355	0.259	3,474
2016 vs 2011 Change	**-66%**	**-71%**	**-68%**	**-68%**	**-69%**	**-69%**	**-71%**	**-70%**	**-68%**
2016 vs 2005 Change	**-80%**	**-79%**	**-72%**	**-92%**	**-85%**	**-85%**	**-89%**	**-88%**	**-70%**

Table 8.4 summarizes the terminal fleet vehicle counts and overall miles traveled, illustrating the increases in vehicle counts and the decreases in reported miles traveled.

Table 8.4: Terminal Fleet Vehicle Count Comparison

Year	Fleet Count	Total Miles Traveled
2016	853	1,944,169
2011	805	4,174,224
2005	614	4,340,473
2016 vs 2011 Change	**6%**	**-53%**
2016 vs 2005 Change	**39%**	**-55%**

The number of vehicles increased slightly between 2011 and 2016 while the total VMT decreased substantially because the average reported miles per vehicle decreased substantially. A similar decrease in average reported VMT per vehicle also occurred between the 2005 and 2011 inventory years although total VMT between the two earlier inventories are similar because the fleet size increased between 2005 and 2011. The decreases in average reported annual mileage per vehicle can probably be attributed to improved terminal operations and better recordkeeping practices.

SECTION 9 EMISSIONS COMPARISON BY PORT

This section summarizes maritime-related emissions associated with the ports included in this study. Emission comparisons are provided between the 2016 vs 2011 and 2016 vs 2005. For the Port of Anacortes, Port of Everett, Port of Olympia, Port of Port Angeles, Port of Seattle, and Port of Tacoma comparisons, the source category emissions are tabulated for near the port emissions, which mean that the emissions within port terminals, adjacent rail yards and adjacent waterways were included. These port emissions are included in Sections 9.1 through 9.6.

Port Emissions Defined
The emission categories included in near port emissions are as follows:

- Ocean-going vessel emissions (hoteling and maneuvering activities)
- Recreational vessel emissions (10% of total recreational vessel emissions related to port-owned marinas)
- Cargo-handling equipment emissions
- Locomotive emissions (on-terminal and adjacent rail yards switching activities)
- Heavy-duty vehicle emissions (queuing and on-terminal activities)
- Fleet vehicle emissions (on-terminal activities)

The following are not included in near port emissions:

- Ocean-going vessels transiting mode and activities that are not directly associated with the operations at port terminals
- Commercial harbor vessels
- Line-haul locomotives
- Heavy-duty vehicles outside the ports' terminals

The 2016, 2011 and 2005 emissions are all estimated using the latest methodology to allow the comparisons to be made on an equivalent basis. In addition, Sections 9.7.4 through 9.7.6 for NWSA and Section 9.8 for Port of Seattle and Port of Tacoma include emissions within the entire airshed, respectively.

9.1 Port of Anacortes

Table 9.1 summarizes the tons of cargo and total vessel movements. Table 9.2 compares tons of emissions per 10,000 metric tons of cargo. The cargo in metric tons (MT) increased significantly in 2016 as compared to 2005 and 2011. Despite the throughput increase, Table 9.2 shows that fewer emissions were emitted in 2016 on a ton of emissions per 10,000 metric tons of cargo basis.

Table 9.1: Port of Anacortes Tons of Cargo and Vessel Movements Comparison

Year	Cargo (MT)	Total Vessel Movements
2016	440,510	46
2011	247,854	46
2005	256,112	39
2016 vs 2011 Change	**78%**	**0%**
2016 vs 2005 Change	**72%**	**18%**

Table 9.2: Port of Anacortes Port Tons of Emissions per 10,000 Tons of Cargo Comparison

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	0.41	0.14	0.93	0.02	0.01	0.01	0.01	0.001	37
2011	0.68	0.34	2.06	0.56	0.07	0.05	0.05	0.003	54
2005	0.55	0.44	2.67	0.44	0.06	0.05	0.04	0.004	47
2016 vs 2011 Change	**-40%**	**-59%**	**-55%**	**-97%**	**-83%**	**-81%**	**-86%**	**-54%**	**-31%**
2016 vs 2005 Change	**-26%**	**-68%**	**-65%**	**-96%**	**-80%**	**-78%**	**-83%**	**-59%**	**-21%**

Table 9.3 provides the 2016 and 2005 port emissions comparison for Port of Anacortes. The overall emissions are lower in 2016 as compared to 2005, with the exception of NO_x and CO_2e which increased as a result of increased activity.

Table 9.3: Port of Anacortes 2016 vs 2005 Port Emissions Comparison, tpy and %

	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016									
Ocean-going vessels	14.5	0.5	1.4	0.7	0.3	0.3	0.3	0.0	1,159
Recreational vessels	3.1	5.6	39.0	0.0	0.1	0.1	0.0	0.0	438
Locomotives	na	na	na	na	na	na	na	na	na
Cargo-handling equipment	0.2	0.0	0.2	0.0	0.0	0.0	0.0	0.0	11
Heavy-duty vehicles	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15
Fleet vehicles	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	12
Total	**17.9**	**6.1**	**40.8**	**0.7**	**0.5**	**0.5**	**0.3**	**0.1**	**1,636**
2005									
Ocean-going vessels	10.4	0.3	0.8	11.0	1.2	0.9	1.0	0.0	676
Recreational vessels	3.1	10.8	66.5	0.1	0.2	0.2	0.0	0.0	472
Locomotives	na	na	na	na	na	na	na	na	na
Cargo-handling equipment	0.2	0.0	0.6	0.0	0.0	0.0	0.0	0.0	15
Heavy-duty vehicles	0.4	0.0	0.1	0.0	0.0	0.0	0.0	0.0	23
Fleet vehicles	0.1	0.0	0.5	0.0	0.0	0.0	0.0	0.0	21
Total	**14.1**	**11.2**	**68.5**	**11.2**	**1.4**	**1.2**	**1.1**	**0.1**	**1,206**
2016 vs 2005 Change									
Ocean-going vessels	40%	67%	66%	-93%	-71%	-65%	-72%	-31%	71%
Recreational vessels	2%	-48%	-41%	-92%	-48%	-48%	-36%	-33%	-7%
Locomotives	na	na	na	na	na	na	na	na	na
Cargo-handling equipment	-22%	-19%	-74%	-99%	40%	41%	47%	46%	-29%
Heavy-duty vehicles	-55%	-51%	-50%	-100%	-56%	-52%	-56%	-64%	-33%
Fleet vehicles	-64%	-75%	-65%	-100%	-100%	-100%	-100%	-100%	-39%
Total	**27%**	**-45%**	**-40%**	**-93%**	**-66%**	**-61%**	**-70%**	**-30%**	**36%**

A description of the factors that contributed to the 2016 vs 2005 emission changes is listed below for each source category.

Ocean-going vessels

Contributing factors to the decrease in PM and SO_2 emissions for OGV include:

- The North American ECA introduced in 2015, requiring 0.1% sulfur content in diesel fuel compared to heavy fuel oil with high sulfur content (2.7%) used by the majority of vessels in 2005

Contributing factors to the increase in NO_x, VOC, and CO_2e emissions for OGV include:

- Increase in total vessel movement

Recreational vessels
Contributing factors to the decrease in emissions for recreational vessels include:

- Fleet turnover to cleaner vessels assumption in MOVES2014a model

Cargo-handling equipment
Contributing factors to the decrease in emissions for CHE include:

- All equipment used ULSD in 2016 compared to a few pieces of equipment in 2005, reducing SO_2 emissions significantly

Heavy-duty vehicles
Contributing factors to the decrease in emissions for HDV include:

- Fleet turnover (newer and cleaner trucks) resulted in the reductions of most pollutants
- All heavy-duty vehicles used ULSD in 2016, reducing SO_2 emissions significantly

Table 9.4 provides the 2016 and 2011 port emissions comparison for the Port of Anacortes. The overall emissions are lower in 2016 as compared to 2011, with the exception of NO_x and CO_2e which increased as a result of increased activity.

Table 9.4: Port of Anacortes 2016 vs 2011 Port Emissions Comparison, tpy and %

	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016									
Ocean-going vessels	14.5	0.5	1.4	0.7	0.3	0.3	0.3	0.0	1,159
Recreational vessels	3.1	5.6	39.0	0.0	0.1	0.1	0.0	0.0	438
Locomotives	na	na	na	na	na	na	na	na	na
Cargo-handling equipment	0.2	0.0	0.2	0.0	0.0	0.0	0.0	0.0	11
Heavy-duty vehicles	0.2	0.0	0.0	0.0	0.0	0.0	0.0	0.0	15
Fleet vehicles	0.0	0.0	0.2	0.0	0.0	0.0	0.0	0.0	12
Total	**17.9**	**6.1**	**40.8**	**0.7**	**0.5**	**0.5**	**0.3**	**0.1**	**1,636**
2011									
Ocean-going vessels	13.0	0.4	1.0	13.8	1.5	1.2	1.3	0.0	847
Recreational vessels	3.4	8.0	49.0	0.0	0.2	0.2	0.0	0.0	448
Locomotives	na	na	na	na	na	na	na	na	na
Cargo-handling equipment	0.1	0.0	0.4	0.0	0.0	0.0	0.0	0.0	6
Heavy-duty vehicles	0.2	0.0	0.1	0.0	0.0	0.0	0.0	0.0	15
Fleet vehicles	0.1	0.0	0.4	0.0	0.0	0.0	0.0	0.0	23
Total	**16.8**	**8.5**	**50.9**	**13.8**	**1.7**	**1.3**	**1.3**	**0.1**	**1,339**
2016 vs 2011 Change									
Ocean-going vessels	12%	33%	33%	-95%	-77%	-72%	-78%	-45%	37%
Recreational vessels	-9%	-31%	-20%	0%	-29%	-29%	-17%	-18%	-2%
Locomotives	na	na	na	na	na	na	na	na	na
Cargo-handling equipment	77%	40%	-62%	na	873%	847%	1209%	1100%	81%
Heavy-duty vehicles	-24%	-25%	-21%	na	-26%	-19%	-26%	-31%	0%
Fleet vehicles	-63%	-74%	-62%	na	-100%	-100%	-100%	-100%	-45%
Total	**7%**	**-28%**	**-20%**	**-95%**	**-71%**	**-66%**	**-75%**	**-18%**	**22%**

9.2 Port of Everett

Table 9.5 summarizes the throughput and total vessel movements. Table 9.6 compares the tons of emissions per 10,000 TEU and Table 9.7 compares tons of emissions per 10,000 metric tons of cargo. Despite the throughput increase, fewer emissions were emitted in 2016 on a ton of emissions per 10,000 TEU and per 10,000 metric tons of cargo basis.

Table 9.5: Port of Everett Throughput and Vessel Movements Comparison

Year	TEU	Cargo (Tonnes)	Total Vessel Movements
2016	27,380	139,252	124
2011	20,918	152,995	145
2005	9,561	103,757	82
2016 vs 2011 Change	**31%**	**-9%**	**-14%**
2016 vs 2005 Change	**186%**	**34%**	**51%**

Table 9.6: Port of Everett Port Tons of Emissions per 10,000 TEU Comparisons

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	35.8	6.8	35.7	0.5	1.3	1.2	1.2	0.7	2,482
2011	63.5	12.9	71.2	23.3	4.5	3.9	4.0	1.5	4,223
2005	150.8	31.4	173.7	45.5	9.0	7.9	8.1	3.3	7,265
2016 vs 2011 Change	**-44%**	**-47%**	**-50%**	**-98%**	**-71%**	**-69%**	**-71%**	**-50%**	**-41%**
2016 vs 2005 Change	**-76%**	**-78%**	**-79%**	**-99%**	**-86%**	**-85%**	**-85%**	**-78%**	**-66%**

Table 9.7: Port of Everett Port Tons of Emissions per 10,000 Tons of Cargo Comparison

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	7.0	1.3	7.0	0.1	0.3	0.2	0.2	0.1	488
2011	8.7	1.8	9.7	3.2	0.6	0.5	0.5	0.2	577
2005	13.9	2.9	16.0	4.2	0.8	0.7	0.7	0.3	669
2016 vs 2011 Change	**-19%**	**-24%**	**-28%**	**-97%**	**-59%**	**-56%**	**-58%**	**-28%**	**-15%**
2016 vs 2005 Change	**-49%**	**-54%**	**-56%**	**-98%**	**-69%**	**-68%**	**-69%**	**-53%**	**-27%**

Table 9.8 provides the 2016 and 2005 port emissions comparison for the Port of Everett. Overall, the emissions decreased for all pollutants in 2016 as compared to 2005.

Table 9.8: Port of Everett 2016 vs 2005 Port Emissions Comparison, tpy and %

	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016									
Ocean-going vessels	25.6	0.9	2.4	1.3	0.6	0.6	0.5	0.0	2,051
Recreational vessels	6.1	11.0	76.8	0.0	0.2	0.2	0.0	0.1	862
Locomotives	56.5	4.5	8.2	0.0	2.0	1.8	2.0	1.4	2,997
Cargo-handling equipment	9.5	2.1	10.2	0.0	0.7	0.7	0.7	0.5	856
Heavy-duty vehicles	0.2	0.0	0.1	0.0	0.0	0.0	0.0	0.0	20
Fleet vehicles	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	10
Total	**97.9**	**18.6**	**97.8**	**1.4**	**3.5**	**3.3**	**3.2**	**2.0**	**6,795**
2005									
Ocean-going vessels	36.2	1.0	2.8	37.3	4.0	3.2	3.6	0.1	2,298
Recreational vessels	6.3	22.1	136.4	0.2	0.5	0.4	0.1	0.1	968
Locomotives	79.7	4.6	8.4	4.4	2.0	1.9	2.0	1.4	2,241
Cargo-handling equipment	19.3	1.9	17.8	1.7	2.0	2.0	2.0	1.5	1,281
Heavy-duty vehicles	2.7	0.3	0.6	0.0	0.1	0.1	0.1	0.1	158
Fleet vehicles	na	na	na	na	na	na	na	na	na
Total	**144.1**	**30.0**	**166.1**	**43.5**	**8.6**	**7.6**	**7.8**	**3.2**	**6,946**
2016 vs 2005 Change									
Ocean-going vessels	-29%	-13%	-16%	-97%	-85%	-82%	-86%	-65%	-11%
Recreational vessels	-2%	-50%	-44%	-92%	-50%	-50%	-39%	-35%	-11%
Locomotives	-29%	-2%	-2%	-99%	-3%	-4%	-3%	-2%	34%
Cargo-handling equipment	-51%	11%	-43%	-100%	-64%	-64%	-64%	-64%	-33%
Heavy-duty vehicles	-94%	-93%	-92%	-99%	-93%	-93%	-93%	-95%	-87%
Fleet vehicles	na	na	na	na	na	na	na	na	na
Total	**-32%**	**-38%**	**-41%**	**-97%**	**-59%**	**-57%**	**-58%**	**-37%**	**-2%**

A description of the factors that contributed to the 2016 vs 2005 emission changes is listed below for each source category.

Ocean-going vessels
Contributing factors to the decrease in emissions for OGV include:

- The North American ECA introduced in 2015, requiring 0.1% sulfur content in diesel fuel compared to heavy fuel oil with high sulfur content (2.7%) used by the majority of vessels in 2005

Recreational vessels
Contributing factors to the decrease in emissions for recreational vessels include:

- Fleet turnover to cleaner vessels assumption in MOVES2014a model

Locomotives
Contributing factors to the decrease in emissions from locomotives include:

- All locomotive engines used ULSD in 2016, reducing SO_2 emissions significantly

Cargo-handling equipment
Contributing factors to the decrease in emissions for CHE include:

- All equipment used ULSD in 2016 compared to a few pieces of equipment in 2005, reducing SO_2 emissions significantly

Heavy-duty vehicles
Contributing factors to the decrease in emissions for HDV include:

- Fleet turnover (newer and cleaner trucks) resulted in the reductions of most pollutants
- All heavy-duty vehicles used ULSD in 2016, reducing SO_2 emissions significantly

Table 9.9 provides the 2016 and 2011 port emissions comparison for the Port of Everett. Overall, the emissions decreased for all pollutants in 2016 as compared to 2011.

Table 9.9: Port of Everett 2016 vs 2011 Port Emissions Comparison, tpy and %

	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016									
Ocean-going vessels	25.6	0.9	2.4	1.3	0.6	0.6	0.5	0.0	2,051
Recreational vessels	6.1	11.0	76.8	0.0	0.2	0.2	0.0	0.1	862
Locomotives	56.5	4.5	8.2	0.0	2.0	1.8	2.0	1.4	2,997
Cargo-handling equipment	9.5	2.1	10.2	0.0	0.7	0.7	0.7	0.5	856
Heavy-duty vehicles	0.2	0.0	0.1	0.0	0.0	0.0	0.0	0.0	20
Fleet vehicles	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	10
Total	**97.9**	**18.6**	**97.8**	**1.4**	**3.5**	**3.3**	**3.2**	**2.0**	**6,795**
2011									
Ocean-going vessels	43.4	1.3	3.5	48.1	5.0	4.0	4.3	0.1	2,947
Recreational vessels	7.8	18.3	111.5	0.0	0.4	0.3	0.0	0.1	1,019
Locomotives	62.1	5.0	9.0	0.5	2.2	2.0	2.2	1.5	3,292
Cargo-handling equipment	18.3	1.9	17.6	0.0	1.8	1.8	1.8	1.4	1,261
Heavy-duty vehicles	0.3	0.0	0.1	0.0	0.0	0.0	0.0	0.0	20
Fleet vehicles	1.1	0.5	7.3	0.0	0.0	0.0	0.0	0.0	294
Total	**132.8**	**27.0**	**149.0**	**48.7**	**9.4**	**8.1**	**8.4**	**3.1**	**8,834**
2016 vs 2011 Change									
Ocean-going vessels	-41%	-30%	-32%	-97%	-88%	-86%	-89%	-72%	-30%
Recreational vessels	-21%	-40%	-31%	-13%	-38%	-38%	-28%	-29%	-15%
Locomotives	-9%	-9%	-9%	-95%	-9%	-9%	-9%	-9%	-9%
Cargo-handling equipment	-48%	12%	-42%	na	-60%	-60%	-60%	-61%	-32%
Heavy-duty vehicles	-40%	-30%	-28%	na	-33%	-32%	-33%	-52%	0%
Fleet vehicles	-96%	-98%	-98%	na	-98%	-98%	-95%	-97%	-97%
Total	**-26%**	**-31%**	**-34%**	**-97%**	**-62%**	**-60%**	**-62%**	**-35%**	**-23%**

9.3 Port of Olympia

Table 9.10 summarizes the throughput and total vessel movements for the Port of Olympia. Table 9.11 compares tons of emissions per 10,000 tons of cargo. Since the Port of Olympia had 0 TEU throughput in 2011 and 2016, there is no table comparing emission per TEU for the Port of Olympia.

Table 9.10: Port of Olympia 2016 vs 2005 TEU and Tonnage Comparison

Year	TEU	Cargo (Tonnes)	Total Vessel Movements
2016	0	854,735	60
2011	0	711,536	49
2005	903	129,512	36
2016 vs 2011 Change	**0%**	**20%**	**22%**
2016 vs 2005 Change	**-100%**	**560%**	**67%**

Despite the metric tons of cargo increase, Table 9.11 shows that there were fewer emissions emitted in 2016 on a ton of emissions per 10,000 metric tons of cargo basis. The exception is NO_x and CO_2e emissions.

Table 9.11: Port of Olympia Port Tons of Emissions per 10,000 Tons of Cargo Comparison

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	0.879	0.098	0.511	0.015	0.031	0.030	0.029	0.018	67
2011	0.598	0.122	0.665	0.295	0.060	0.053	0.054	0.023	54
2005	3.404	0.869	4.691	1.191	0.295	0.266	0.268	0.135	185
2016 vs 2011 Change	**47%**	**-20%**	**-23%**	**-95%**	**-48%**	**-44%**	**-45%**	**-21%**	**24%**
2016 vs 2005 Change	**-74%**	**-89%**	**-89%**	**-99%**	**-89%**	**-89%**	**-89%**	**-87%**	**-64%**

Table 9.12 provides the 2016 and 2005 port emissions comparison for the Port of Olympia. NO_x and CO_2e emissions increased due to increased activity. All of the other pollutants decreased in 2016 as compared to 2005.

Table 9.12: Port of Olympia 2016 vs 2005 Port Emissions Comparison, tpy and %

	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016									
Ocean-going vessels	25.7	0.9	2.4	1.3	0.6	0.6	0.5	0.0	1,996
Recreational vessels	2.2	3.9	27.3	0.0	0.1	0.1	0.0	0.0	307
Locomotives	24.5	1.4	2.6	0.0	0.6	0.6	0.6	0.4	941
Cargo-handling equipment	22.6	2.1	11.3	0.0	1.4	1.3	1.4	1.0	2,442
Heavy-duty vehicles	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14
Fleet vehicles	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	7
Total	**75.1**	**8.3**	**43.7**	**1.3**	**2.7**	**2.5**	**2.5**	**1.5**	**5,706**
2005									
Ocean-going vessels	12.3	0.4	1.0	13.5	1.4	1.1	1.2	0.0	824
Recreational vessels	2.1	7.6	46.6	0.1	0.2	0.1	0.0	0.0	331
Locomotives	14.9	0.9	1.6	0.8	0.4	0.3	0.4	0.3	420
Cargo-handling equipment	14.7	2.5	11.7	1.1	1.9	1.8	1.9	1.4	825
Heavy-duty vehicles	na	na	na	na	na	na	na	na	na
Fleet vehicles	na	na	na	na	na	na	na	na	na
Total	**44.1**	**11.3**	**60.7**	**15.4**	**3.8**	**3.4**	**3.5**	**1.7**	**2,399**
2016 vs 2005 Change									
Ocean-going vessels	108%	148%	149%	-91%	-57%	-50%	-58%	1%	142%
Recreational vessels	2%	-48%	-41%	-92%	-48%	-48%	-36%	-33%	-7%
Locomotives	64%	64%	64%	-99%	63%	61%	63%	64%	124%
Cargo-handling equipment	54%	-15%	-3%	-99%	-27%	-27%	-27%	-27%	196%
Heavy-duty vehicles	na	na	na	na	na	na	na	na	na
Fleet vehicles	na	na	na	na	na	na	na	na	na
Total	**70%**	**-26%**	**-28%**	**-92%**	**-30%**	**-26%**	**-27%**	**-13%**	**138%**

A description of the factors that contributed to the 2016 vs 2005 emission changes is listed below for each source category.

Ocean-going vessels

Contributing factors to the decrease in emissions for OGV include:

- The North American ECA introduced in 2015, requiring 0.1% sulfur content in diesel fuel compared to heavy fuel oil with high sulfur content (2.7%) used by the majority of vessels in 2005

Contributing factors to the increase in emissions for OGV include:

- Increased vessel movements (67%)

Recreational vessels
Contributing factors to the decrease in emissions for recreational vessels include:

- Fleet turnover to cleaner vessels assumption in MOVES2014a model

Locomotives
Contributing factors to the decrease in SO_2 emissions from locomotives include:

- All locomotive engines used ULSD in 2016, reducing SO_2 emissions significantly

Contributing factors to the increase in NO_x and CO_2e emissions from locomotives include:

- Increased cargo throughput

Cargo-handling equipment
Contributing factors to the decrease in emissions for CHE include:

- All equipment used ULSD in 2016 compared to a few pieces of equipment in 2005, reducing SO_2 emissions significantly
- Cleaner equipment

Contributing factors to the increase in NO_x and CO_2e emissions for CHE include:

- Increased cargo throughput
- Increased equipment activity

Heavy-duty vehicles
Contributing factors to the decrease in emissions for HDV include:

- Fleet turnover (newer and cleaner trucks) resulted in the reductions of most pollutants
- All heavy-duty vehicles used ULSD in 2016, reducing SO_2 emissions significantly

Table 9.13 provides the 2016 and 2011 port emissions comparison for the Port of Olympia. NO_x and CO_2e emissions increased due to increased activity. All of the other pollutants decreased in 2016 as compared to 2011.

Table 9.13: Port of Olympia 2016 vs 2011 Port Emissions Comparison, tpy and %

	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016									
Ocean-going vessels	25.7	0.9	2.4	1.3	0.6	0.6	0.5	0.0	1,996
Recreational vessels	2.2	3.9	27.3	0.0	0.1	0.1	0.0	0.0	307
Locomotives	24.5	1.4	2.6	0.0	0.6	0.6	0.6	0.4	941
Cargo-handling equipment	22.6	2.1	11.3	0.0	1.4	1.3	1.4	1.0	2,442
Heavy-duty vehicles	0.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	14
Fleet vehicles	0.0	0.0	0.1	0.0	0.0	0.0	0.0	0.0	7
Total	**75.1**	**8.3**	**43.7**	**1.3**	**2.7**	**2.5**	**2.5**	**1.5**	**5,706**
2011									
Ocean-going vessels	16.8	0.5	1.4	20.9	2.1	1.7	1.8	0.1	1,283
Recreational vessels	2.4	5.6	34.3	0.0	0.1	0.1	0.0	0.0	314
Locomotives	3.5	0.2	0.4	0.0	0.1	0.1	0.1	0.1	157
Cargo-handling equipment	19.6	2.3	11.0	0.0	2.0	1.9	2.0	1.5	2,076
Heavy-duty vehicles	0.2	0.0	0.1	0.0	0.0	0.0	0.0	0.0	14
Fleet vehicles	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	1
Total	**42.6**	**8.7**	**47.3**	**21.0**	**4.3**	**3.8**	**3.8**	**1.6**	**3,846**
2016 vs 2011 Change									
Ocean-going vessels	53%	64%	66%	-94%	-72%	-67%	-72%	-34%	55%
Recreational vessels	-9%	-31%	-20%	0%	-29%	-29%	-17%	-18%	-2%
Locomotives	596%	515%	498%	299%	517%	517%	517%	517%	498%
Cargo-handling equipment	15%	-7%	3%	na	-29%	-29%	-29%	-29%	18%
Heavy-duty vehicles	-38%	-30%	-26%	na	-28%	-28%	-28%	-44%	0%
Fleet vehicles	125%	48%	69%	na	300%	300%	na	na	399%
Total	**76%**	**-4%**	**-8%**	**-94%**	**-38%**	**-33%**	**-34%**	**-5%**	**48%**

9.4 Port of Port Angeles

Table 9.14 provides the 2016 and 2005 port emissions comparison for the Port of Port Angeles. Since throughput data was not provided, only the emissions comparisons will be summarized for the Port of Port Angeles. There are only 29 vessel movements associated with Port of Port Angeles in 2016; 36 vessel movements in 2011 and 51 vessel movements in 2005. The overall emissions decreased in 2016 as compared to 2005.

Table 9.14: Port of Port Angeles 2016 vs 2005 Port Emissions Comparison, tpy and %

	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016									
Ocean-going vessels	125.8	4.4	11.9	5.4	2.8	2.6	2.6	0.2	8,524
Recreational vessels	na	na	na	na	na	na	na	na	na
Locomotives	na	na	na	na	na	na	na	na	na
Cargo-handling equipment	1.8	0.3	0.9	0.0	0.2	0.2	0.2	0.2	111
Heavy-duty vehicles	na	na	na	na	na	na	na	na	na
Fleet vehicles	na	na	na	na	na	na	na	na	na
Total	**127.6**	**4.6**	**12.8**	**5.4**	**3.0**	**2.8**	**2.8**	**0.3**	**8,635**
2005									
Ocean-going vessels	177.1	5.6	14.5	308.9	26.1	20.9	14.3	0.6	20,683
Recreational vessels	na	na	na	na	na	na	na	na	na
Locomotives	na	na	na	na	na	na	na	na	na
Cargo-handling equipment	4.4	0.7	4.5	0.4	0.4	0.3	0.4	0.3	294
Heavy-duty vehicles	0.7	0.1	0.2	0.0	0.0	0.0	0.0	0.0	41.0
Fleet vehicles	na	na	na	na	na	na	na	na	na
Total	**182.2**	**6.4**	**19.1**	**309.3**	**26.5**	**21.2**	**14.7**	**0.9**	**21,018**
2016 vs 2005 Change									
Ocean-going vessels	-29%	-22%	-18%	-98%	-89%	-87%	-82%	-75%	-59%
Recreational vessels	na	na	na	na	na	na	na	na	na
Locomotives	na	na	na	na	na	na	na	na	na
Cargo-handling equipment	-60%	-62%	-79%	-100%	-43%	-43%	-42%	-42%	-62%
Heavy-duty vehicles	na	na	na	na	na	na	na	na	na
Fleet vehicles	na	na	na	na	na	na	na	na	na
Total	**-30%**	**-28%**	**-33%**	**-98%**	**-89%**	**-87%**	**-81%**	**-66%**	**-59%**

A description of the factors that contributed to the 2016 vs 2005 emission changes is listed below for each source category.

Ocean-going vessels
Contributing factors to the decrease in emissions for OGV include:

- The North American ECA introduced in 2015, requiring 0.1% sulfur content in diesel fuel compared to heavy fuel oil with high sulfur content (2.7%) used by the majority of vessels in 2005
- Decreased total vessel movements

Cargo-handling equipment
Contributing factors to the decrease in emissions for CHE include:

- All equipment used ULSD in 2016 compared to a few pieces of equipment in 2005, reducing SO_2 emissions significantly
- Cleaner equipment

9.5 Port of Seattle

Table 9.15 summarizes the cargo throughput, cruise passenger count and total vessel movements for the Port of Seattle. Table 9.16 compares tons of emissions per 10,000 metric tons of cargo. Port of Seattle's lines of business include cruise, commercial harbor vessel and recreational vessel activities which are not associated with cargo; however, emissions per ton of cargo is a common metric applied to normalize emissions.

Table 9.15: Port of Seattle Throughput and Vessel Movements Comparison

Year	Cargo (Tonnes)	Total Vessel Movements	Cruise Passengers
2016	4,389,089	535	983,539
2011	5,026,868	554	885,949
2005	5,049,107	339	686,978
2016 vs 2011 Change	**-13%**	**-3%**	**11%**
2016 vs 2005 Change	**-13%**	**58%**	**43%**

Table 9.16 shows that fewer emissions were emitted in 2016 on a ton of emissions per 10,000 metric tons of cargo basis. The exception is NO_x and CO_2e emissions which were impacted by more vessel calls in 2016 as compared to 2005.

Table 9.16: Port of Seattle Port Tons of Emissions per 10,000 Tons of Cargo Comparison

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	0.578	0.043	0.250	0.021	0.013	0.012	0.011	0.002	39
2011	0.563	0.047	0.263	0.337	0.043	0.035	0.039	0.002	35
2005	0.402	0.120	2.538	0.225	0.033	0.028	0.030	0.004	30
2016 vs 2011 Change	**3%**	**-9%**	**-5%**	**-94%**	**-70%**	**-66%**	**-71%**	**-26%**	**11%**
2016 vs 2005 Change	**44%**	**-65%**	**-90%**	**-91%**	**-62%**	**-57%**	**-62%**	**-60%**	**28%**

Table 9.17 presents a summary comparison of the 2016 vs 2005 Port of Seattle emissions by source category. The overall emissions are lower in 2016 as compared to 2005, with the exception of NO_x and CO_2e which increased as a result of increased OGV emissions due to more vessel calls.

Table 9.17: Port of Seattle 2016 vs 2005 Port Emissions Comparison, tpy and %

	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016									
Ocean-going vessels	228.1	7.4	20.1	9.2	4.7	4.4	4.4	0.3	14,502
Recreational vessels	5.2	9.4	65.8	0.0	0.2	0.2	0.0	0.1	739
Locomotives	13.0	0.6	2.4	0.0	0.3	0.3	0.3	0.2	923
Cargo-handling equipment	6.0	1.1	18.0	0.0	0.3	0.3	0.3	0.2	623
Heavy-duty vehicles	0.3	0.0	0.1	0.0	0.0	0.0	0.0	0.0	16
Fleet vehicles	0.9	0.2	3.6	0.0	0.0	0.0	0.0	0.0	287
Total	**253.5**	**18.7**	**109.9**	**9.3**	**5.6**	**5.2**	**5.0**	**0.8**	**17,090**
2005									
Ocean-going vessels	138.1	4.1	11	110.1	13.7	11.0	12.5	0.3	8,267
Recreational vessels	5.6	19.8	122	0.2	0.4	0.4	0.0	0.1	867
Locomotives	22.6	1.4	3	2.5	0.8	0.7	0.8	0.6	1,145
Cargo-handling equipment	33.3	34.8	1,134	0.8	1.9	1.8	1.6	1.2	4,328
Heavy-duty vehicles	0.5	0.0	0	0.0	0.0	0.0	0.0	0.0	14
Fleet vehicles	2.6	0.7	11	0.0	0.0	0.0	0.0	0.0	727
Total	**202.8**	**60.8**	**1,282**	**113.6**	**16.8**	**13.9**	**15.0**	**2.2**	**15,348**
2016 vs 2005 Change									
Ocean-going vessels	65%	81%	84%	-92%	-66%	-60%	-65%	-19%	75%
Recreational vessels	-7%	-53%	-46%	-93%	-52%	-52%	-42%	-38%	-15%
Locomotives	-43%	-55%	-26%	-100%	-58%	-57%	-58%	-57%	-19%
Cargo-handling equipment	-82%	-97%	-98%	-100%	-84%	-84%	-84%	-84%	-86%
Heavy-duty vehicles	-42%	-20%	-14%	-91%	-28%	-27%	-28%	261%	13%
Fleet vehicles	-68%	-74%	-69%	-89%	-60%	-59%	-56%	-50%	-60%
Total	**25%**	**-69%**	**-91%**	**-92%**	**-67%**	**-62%**	**-67%**	**-65%**	**11%**

A description of the factors that contributed to the 2016 vs 2005 emission changes is listed below for each source category.

Ocean-going vessels
Contributing factors to the decrease in PM and SO_2 emissions for OGV include:

- The North American ECA introduced in 2015, requiring 0.1% sulfur content in diesel fuel compared to heavy fuel oil with high sulfur content (2.7%) used by the majority of vessels in 2005

Contributing factors to the increase in NO_x, VOC, and CO_2e emissions for OGV include:

- Increase in total vessel movement
- Increase in cruise passengers and cruise ship size

Recreational vessels
Contributing factors to the decrease in emissions for recreational vessels include:

- All other emissions decreased due to fleet turnover to cleaner vessels assumption in MOVES2014a model

Locomotives
Contributing factors to the decrease in emissions from locomotives include:

- All locomotive engines used ULSD in 2016, reducing SO_2 emissions significantly
- Cleaner locomotives

Cargo-handling equipment
Contributing factors to the decrease in emissions for CHE include:

- All equipment used ULSD in 2016 compared to a few pieces of equipment in 2005, reducing SO_2 emissions significantly
- Cleaner equipment

Heavy-duty vehicles
Contributing factors to the decrease in emissions for HDV include:

- Fleet turnover (newer and cleaner trucks) resulted in the reductions of most pollutants
- All heavy-duty vehicles used ULSD in 2016, reducing SO_2 emissions significantly

Table 9.18 presents a summary comparison of the 2016 vs 2011 Port of Seattle emissions by source category. Overall, all emissions are lower in 2016 as compared to 2011.

Table 9.18: Port of Seattle 2016 vs 2011 Port Emissions Comparison, tpy and %

	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016									
Ocean-going vessels	228.1	7.4	20.1	9.2	4.7	4.4	4.4	0.3	14,502
Recreational vessels	5.2	9.4	65.8	0.0	0.2	0.2	0.0	0.1	739
Locomotives	13.0	0.6	2.4	0.0	0.3	0.3	0.3	0.2	923
Cargo-handling equipment	6.0	1.1	18.0	0.0	0.3	0.3	0.3	0.2	623
Heavy-duty vehicles	0.3	0.0	0.1	0.0	0.0	0.0	0.0	0.0	16
Fleet vehicles	0.9	0.2	3.6	0.0	0.0	0.0	0.0	0.0	287
Total	**253.5**	**18.7**	**109.9**	**9.3**	**5.6**	**5.2**	**5.0**	**0.8**	**17,090**
2011									
Ocean-going vessels	251.4	7.6	20.6	169.2	20.2	16.3	18.6	0.5	14,900
Recreational vessels	5.7	13.5	82.7	0.0	0.3	0.3	0.0	0.1	756
Locomotives	18.6	1.1	3.0	0.2	0.7	0.6	0.7	0.5	1,142
Cargo-handling equipment	5.3	0.9	20.7	0.0	0.2	0.2	0.2	0.1	449
Heavy-duty vehicles	0.4	0.0	0.1	0.0	0.0	0.0	0.0	0.0	14
Fleet vehicles	1.3	0.3	5.0	0.0	0.0	0.0	0.0	0.0	426
Total	**282.8**	**23.6**	**132.0**	**169.4**	**21.4**	**17.4**	**19.5**	**1.2**	**17,687**
2016 vs 2011 Change									
Ocean-going vessels	-9%	-3%	-3%	-95%	-77%	-73%	-77%	-49%	-3%
Recreational vessels	-9%	-31%	-20%	0%	-29%	-29%	-17%	-18%	-2%
Locomotives	-30%	-46%	-19%	-94%	-51%	-50%	-51%	-50%	-19%
Cargo-handling equipment	13%	19%	-13%	-3%	59%	59%	65%	63%	39%
Heavy-duty vehicles	-21%	-15%	-11%	0%	-15%	-14%	-15%	427%	10%
Fleet vehicles	-35%	-32%	-28%	-33%	-34%	-34%	-44%	-45%	-33%
Total	**-10%**	**-20%**	**-17%**	**-95%**	**-74%**	**-70%**	**-74%**	**-36%**	**-3%**

9.6 Port of Tacoma

The Port of Tacoma emissions included here are only for the non-NWSA activities which only include the grain terminal. Table 9.19 summarizes the throughput and total vessel movements for the Port of Tacoma. Table 9.20 compares the tons of emissions per 10,000 metric tons of cargo.

Table 9.19: Port of Tacoma Throughput and Vessel Movements Comparison

Year	Cargo (Tonnes)	Total Vessel Movements
2016	4,413,228	132
2011	5,390,022	183
2005	6,968,667	223
2016 vs 2011 Change	**-18%**	**-28%**
2016 vs 2005 Change	**-37%**	**-41%**

Table 9.20: Port of Tacoma Port Tons of Emissions per 10,000 Tons of Cargo Comparison

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	0.122	0.005	0.017	0.004	0.003	0.003	0.003	0.001	9
2011	0.117	0.006	0.021	0.100	0.011	0.009	0.010	0.001	8
2005	0.114	0.006	0.020	0.092	0.010	0.008	0.009	0.001	7
2016 vs 2011 Change	**4%**	**-7%**	**-17%**	**-96%**	**-73%**	**-69%**	**-71%**	**-13%**	**12%**
2016 vs 2005 Change	**8%**	**-7%**	**-11%**	**-95%**	**-70%**	**-66%**	**-69%**	**-17%**	**29%**

Table 9.21 presents a summary comparison of the 2016 vs 2005 Port of Tacoma emissions by source category. Overall, the emissions are lower in 2016 compared to 2005 across all pollutants.

Table 9.21: Port of Tacoma 2016 vs 2005 Port Emissions Comparison, tpy and %

	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016									
Ocean-going vessels	35.1	1.27	3.34	1.82	0.84	0.79	0.70	0.05	2,861
Recreational vessels	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Locomotives	18.3	0.98	3.10	0.01	0.49	0.45	0.49	0.35	1,166
Cargo-handling equipment	0.2	0.05	0.93	0.00	0.00	0.00	0.00	0.00	12
Heavy-duty vehicles	0.3	0.03	0.08	0.00	0.01	0.01	0.01	0.01	28
Fleet vehicles	0.0	0.00	0.27	0.00	0.00	0.00	0.00	0.00	116
Total	**54.0**	**2.32**	**7.71**	**1.83**	**1.35**	**1.26**	**1.20**	**0.41**	**4,183**
2005									
Ocean-going vessels	53.3	1.76	4.41	61.28	6.31	5.04	5.25	0.15	3,754
Recreational vessels	0.2	0.76	4.66	0.01	0.02	0.01	0.00	0.00	33
Locomotives	25.4	1.37	3.61	2.99	0.87	0.80	0.87	0.62	1,336
Cargo-handling equipment	0.3	0.06	1.04	0.00	0.00	0.00	0.00	0.00	15
Heavy-duty vehicles	na	na	na	na	na	na	na	na	na
Fleet vehicles	na	na	na	na	na	na	na	na	na
Total	**79.2**	**3.94**	**13.73**	**64.27**	**7.20**	**5.85**	**6.11**	**0.77**	**5,139**
2016 vs 2005 Change									
Ocean-going vessels	-34%	-28%	-24%	-97%	-87%	-84%	-87%	-68%	-24%
Recreational vessels	-100%	-100%	-100%	-100%	-100%	-100%	-100%	-100%	-100%
Locomotives	-28%	-29%	-14%	-100%	-43%	-43%	-43%	-43%	-13%
Cargo-handling equipment	-22%	-14%	-11%	0%	-8%	-8%	0%	0%	-23%
Heavy-duty vehicles	na	na	na	na	na	na	na	na	na
Fleet vehicles	na	na	na	na	na	na	na	na	na
Total	**-32%**	**-41%**	**-44%**	**-97%**	**-81%**	**-79%**	**-80%**	**-47%**	**-19%**

A description of the factors that contributed to the 2016 vs 2005 emission changes is listed below for each source category.

Ocean-going vessels

Contributing factors to the decrease in emissions for OGV include:

- The North American ECA introduced in 2015, requiring 0.1% sulfur content in diesel fuel compared to heavy fuel oil with high sulfur content (2.7%) used by the majority of vessels in 2005
- Fewer total vessel movements

Recreational vessels

Contributing factors to the decrease in emissions for recreational vessels include:

- In 2016, there are no port-owned marina while in 2005, there was one port-owned marina

Locomotives

Contributing factors to the decrease in emissions from locomotives include:

- All locomotive engines used ULSD in 2016, reducing SO_2 emissions significantly
- Cleaner locomotives
- Less throughput

Cargo-handling equipment

Contributing factors to the decrease in emissions for CHE include:

- All equipment used ULSD in 2016 compared to a few pieces of equipment in 2005, reducing SO_2 emissions significantly
- Cleaner equipment

Heavy-duty vehicles

Contributing factors to the change in emissions for HDV include:

- All heavy-duty vehicles used ULSD in 2016
- No trucks included in 2005

Table 9.22 presents a summary comparison of the 2016 vs 2011 Port of Tacoma emissions by source category. Overall, the total emissions are lower in 2016 compared to 2011 across all pollutants.

Table 9.22: Port of Tacoma 2016 vs 2011 Port Emissions Comparison, tpy and %

	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016									
Ocean-going vessels	35.1	1.27	3.34	1.82	0.84	0.79	0.70	0.05	2,861
Recreational vessels	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Locomotives	18.3	0.98	3.10	0.01	0.49	0.45	0.49	0.35	1,166
Cargo-handling equipment	0.2	0.05	0.93	0.00	0.00	0.00	0.00	0.00	12
Heavy-duty vehicles	0.3	0.03	0.08	0.00	0.01	0.01	0.01	0.01	28
Fleet vehicles	0.0	0.00	0.27	0.00	0.00	0.00	0.00	0.00	116
Total	**54.0**	**2.32**	**7.71**	**1.83**	**1.35**	**1.26**	**1.20**	**0.41**	**4,183**
2011									
Ocean-going vessels	45.6	1.46	3.74	53.60	5.46	4.36	4.53	0.13	3,284
Recreational vessels	0.2	0.56	3.43	0.00	0.01	0.01	0.00	0.00	31
Locomotives	16.7	0.94	2.72	0.15	0.60	0.55	0.60	0.43	1,036
Cargo-handling equipment	0.2	0.05	0.93	0.00	0.00	0.00	0.00	0.00	12
Heavy-duty vehicles	0.4	0.04	0.10	0.00	0.02	0.02	0.02	0.01	28.0
Fleet vehicles	0.0	0.01	0.38	0.00	0.00	0.00	0.00	0.00	157.0
Total	**63.1**	**3.05**	**11.31**	**53.76**	**6.09**	**4.94**	**5.14**	**0.57**	**4,548**
2016 vs 2011 Change									
Ocean-going vessels	-23%	-13%	-11%	-97%	-85%	-82%	-85%	-63%	-13%
Recreational vessels	-100%	-100%	-100%	-100%	-100%	-100%	-100%	-100%	-100%
Locomotives	10%	4%	14%	-92%	-18%	-18%	-18%	-18%	13%
Cargo-handling equipment	0%	0%	0%	0%	0%	0%	0%	0%	0%
Heavy-duty vehicles	-38%	-29%	-26%	na	-28%	-28%	-28%	-45%	0%
Fleet vehicles	-48%	-76%	-30%	na	11%	11%	-100%	-100%	-26%
Total	**-14%**	**-24%**	**-32%**	**-97%**	**-78%**	**-75%**	**-77%**	**-29%**	**-8%**

9.7 The Northwest Seaport Alliance

This section summarizes maritime-related emissions associated with the Northwest Seaport Alliance (NWSA) which was formed in 2015. The NWSA is a marine cargo operating partnership of the Port of Seattle and Port of Tacoma which manages the container, breakbulk, auto and some bulk terminals in Seattle and Tacoma. Facilities and activities in Seattle are referred to as the 'North Harbor', and facilities and activities based in Tacoma are referred to as the 'South Harbor'.

Emission comparisons are provided between the 2016 vs 2011 and 2016 vs 2005 for total NWSA combined, NWSA North Harbor and NWSA South Harbor. The 2011 and 2005 terminal emissions were re-allocated to the new partnership terminal allocation in order for equivalent comparison for this 2016 inventory. The NWSA Terminals are allocated accordingly:

NWSA North Harbor
Terminal 5
Terminal 18
Terminal 30
Terminal 46
Terminal 115

NWSA South Harbor
APM Terminals (APMT)
Husky
Olympic Container Terminal (OCT)
Pierce County Terminal (PCT)
Washington United Terminal (WUT)
TOTE Maritime Tacoma Terminal
Terminal 7
East Blair 1
Blair
West Hylebos Facility
Marshal Ave Auto Facility

For the NWSA, the source category emissions are tabulated for port emissions and for total maritime-related emissions within the airshed.

NWSA Port Emissions Defined
For the Northwest Seaport Alliance port comparisons, the port emissions within port terminals, adjacent rail yards and waterways are tabulated as follows:

- Ocean-going vessel emissions (hoteling and maneuvering activities)
- Commercial harbor vessel emissions (includes assist tug emissions based on percentage of total vessel movements for North Harbor and South Harbor)
- Cargo-handling equipment emissions
- Locomotive emissions (switching activities on-terminal and adjacent rail yards)
- Heavy-duty vehicle emissions (queuing and on-terminal activities)
- Fleet vehicle emissions (on-terminal activities)

The following were not included in the Port summaries for the Northwest Seaport Alliance:

- Ocean-going vessels transiting mode emissions and emissions from activities that are not directly associated with the operations at port terminals or petroleum facilities.
- Recreational vessels (marinas are not part of NWSA).
- Commercial harbor vessel emissions that are not associated with assist tugs for the total vessel movements for NWSA.
- Line-haul locomotive emissions (line-haul activities were not identified at these ports).
- Heavy-duty vehicles on-road emissions outside the ports' terminals.

NWSA Emissions within the Airshed Defined
For the Northwest Seaport Alliance emission within the airshed comparisons, the sum of maritime-related emissions within the entire emission inventory domain are included and tabulated as follows:

- Ocean-going vessel emissions (hoteling, maneuvering, and transit emissions)
- Commercial harbor vessel emissions (includes assist tug emissions based on percentage of total vessel movements for North Harbor and South Harbor)
- Cargo-handling equipment emissions
- Locomotive emissions (on-port, off-port, switching and line-haul emissions)
- Heavy-duty vehicle emissions (on-port and off-port emissions)
- Fleet vehicle emissions (on-terminal activities)

The following were not included in the maritime-related emissions within the airshed summaries for the Northwest Seaport Alliance:

- Ocean-going vessels emissions from activities that is not directly associated with North Harbor or South Harbor.
- Recreational vessels (marinas are not part of NWSA).
- Commercial harbor vessel emissions that is not associated with the assist tugs used for total vessel movements for NWSA.

9.7.1 Northwest Seaport Alliance Port Emissions
Table 9.23 summarizes the TEU and tons of cargo throughput for the NWSA, in addition to the total vessel movements including arrivals, departures and shifts.

Table 9.23: NWSA Activity Comparison

Year	TEU	Cargo (Tonnes)	Total Vessel Movements
2016	3,615,753	28,026,869	2,810
2011	3,522,330	29,616,040	3,087
2005	4,157,929	28,947,086	3,538
2016 vs 2011 Change	**3%**	**-5%**	**-9%**
2016 vs 2005 Change	**-13%**	**-3%**	**-21%**

Table 9.24 summarizes the port emissions total and comparison for 2016, 2011 and 2005 for the NWSA. The NWSA emissions are lower in 2016 as compared to 2011 and 2005 due to lower activity and the various initiatives discussed in section 2.

Table 9.24: NWSA Port Emissions Comparison

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	2,334	132	446	48	74	69	69	37.4	198,332
2011	2,501	141	509	821	157	136	138	52.8	195,946
2005	3,483	201	682	1,259	220	191	196	78.2	229,679
2016 vs 2011 Change	**-7%**	**-7%**	**-12%**	**-94%**	**-53%**	**-49%**	**-50%**	**-29%**	**1%**
2016 vs 2005 Change	**-33%**	**-35%**	**-35%**	**-96%**	**-66%**	**-64%**	**-65%**	**-52%**	**-14%**

Table 9.25 compares the tons of emissions per 10,000 TEU and Table 9.26 compares tons of emissions per 10,000 metric tons of cargo.

Table 9.25: NWSA Port Tons of Emissions per 10,000 TEU Comparison

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	6.45	0.36	1.23	0.13	0.21	0.19	0.19	0.10	549
2011	7.10	0.40	1.45	2.33	0.45	0.39	0.39	0.15	556
2005	8.38	0.48	1.64	3.03	0.53	0.46	0.47	0.19	552
2016 vs 2011 Change	**-9%**	**-9%**	**-15%**	**-94%**	**-54%**	**-50%**	**-51%**	**-31%**	**-1%**
2016 vs 2005 Change	**-23%**	**-25%**	**-25%**	**-96%**	**-61%**	**-58%**	**-59%**	**-45%**	**-1%**

Table 9.26: NWSA Port Tons of Emissions per 10,000 Tons of Cargo Comparison

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	0.83	0.05	0.16	0.02	0.03	0.02	0.02	0.01	71
2011	0.84	0.05	0.17	0.28	0.05	0.05	0.05	0.02	66
2005	1.20	0.07	0.24	0.43	0.08	0.07	0.07	0.03	79
2016 vs 2011 Change	**-1%**	**-1%**	**-8%**	**-94%**	**-50%**	**-46%**	**-47%**	**-25%**	**7%**
2016 vs 2005 Change	**-31%**	**-32%**	**-32%**	**-96%**	**-65%**	**-62%**	**-63%**	**-51%**	**-11%**

Table 9.27 presents a summary comparison of the NWSA 2016 vs 2005 port emissions by source category. The overall emissions are lower in 2016 as compared to 2005. SO_2 and PM_{10}, $PM_{2.5}$, DPM and black carbon emissions are significantly lower in 2016 due to the North American ECA which required the use of lower sulfur fuel. NO_x, VOC and CO emissions are lower in 2016 due to the emission reduction initiatives such as fleet turnover.

Table 9.27: NWSA Combined 2016 vs 2005 Port Emissions Comparison, tpy and %

	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016									
Ocean-going vessels	891	37.3	83.2	46.6	21.1	19.8	16.2	1.1	73,316
Harbor vessels	407	12.9	67.2	0.2	13.4	12.3	13.4	9.5	24,195
Locomotives	611	39.8	106.9	0.4	18.9	17.4	18.9	13.5	39,869
Cargo-handling equipment	274	24.7	135.2	0.3	13.5	13.1	13.5	9.7	43,581
Heavy-duty vehicles	149	16.7	45.8	0.1	7.3	6.7	7.3	3.5	16,780
Fleet vehicles	2	0.4	7.5	0.0	0.0	0.0	0.0	0.0	592
Total	**2,334**	**131.9**	**445.8**	**47.6**	**74.2**	**69.3**	**69.3**	**37.4**	**198,332**
2005									
Ocean-going vessels	1,017	42.8	89.7	1,084.2	115.6	92.6	91.4	2.6	73,237
Harbor vessels	413	13.1	54.1	43.4	18.0	16.6	18.0	12.8	23,356
Locomotives	1,035	57.6	126.0	86.4	30.3	27.9	30.3	21.5	40,661
Cargo-handling equipment	685	55.8	305.6	42.9	42.5	41.2	42.5	31.7	70,617
Heavy-duty vehicles	323	29.8	76.2	1.5	13.2	12.2	13.2	9.4	19,085
Fleet vehicles	10	2.3	30.3	0.2	0.4	0.4	0.3	0.2	2,723
Total	**3,483**	**201.5**	**681.9**	**1,258.5**	**220.0**	**190.8**	**195.8**	**78.2**	**229,679**
2016 vs 2005 Change									
Ocean-going vessels	-12%	-13%	-7%	-96%	-82%	-79%	-82%	-57%	0%
Harbor vessels	-1%	-1%	24%	-99%	-26%	-26%	-26%	-26%	4%
Locomotives	-41%	-31%	-15%	-100%	-38%	-38%	-38%	-37%	-2%
Cargo-handling equipment	-60%	-56%	-56%	-99%	-68%	-68%	-68%	-69%	-38%
Heavy-duty vehicles	-54%	-44%	-40%	-90%	-45%	-45%	-45%	-63%	-12%
Fleet vehicles	-84%	-82%	-75%	-94%	-88%	-88%	-91%	-90%	-78%
Total	**-33%**	**-35%**	**-35%**	**-96%**	**-66%**	**-64%**	**-65%**	**-52%**	**-14%**

Table 9.28 presents a summary comparison of the NWSA 2016 vs 2011 port emissions by source category. The overall emissions are lower in 2016 as compared to 2011. SO_2 and PM_{10}, $PM_{2.5}$, DPM and black carbon emissions are significantly lower in 2016 due to the North American ECA which required the use of lower sulfur fuel. NO_x, VOC, CO and CO_2e emissions are lower in 2016 due to lower throughput and activity.

Table 9.28: NWSA 2016 vs 2011 Port Emissions Comparison, tpy and %

	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016									
Ocean-going vessels	891	37.3	83.2	46.6	21.1	19.8	16.2	1.1	73,316
Harbor vessels	407	12.9	67.2	0.2	13.4	12.3	13.4	9.5	24,195
Locomotives	611	39.8	106.9	0.4	18.9	17.4	18.9	13.5	39,869
Cargo-handling equipment	274	24.7	135.2	0.3	13.5	13.1	13.5	9.7	43,581
Heavy-duty vehicles	149	16.7	45.8	0.1	7.3	6.7	7.3	3.5	16,780
Fleet vehicles	2	0.4	7.5	0.0	0.0	0.0	0.0	0.0	592
Total	**2,334**	**131.9**	**445.8**	**47.6**	**74.2**	**69.3**	**69.3**	**37.4**	**198,332**
2011									
Ocean-going vessels	825	33.3	72.2	814.9	85.3	68.7	66.3	2.1	64,691
Harbor vessels	385	13.2	58.9	0.2	15.3	14.1	15.4	10.8	23,102
Locomotives	648	44.2	98.2	4.8	22.6	20.6	22.6	16.0	36,579
Cargo-handling equipment	401	26.2	196.1	0.5	23.9	23.1	23.8	17.5	52,989
Heavy-duty vehicles	237	23.0	60.8	0.1	10.1	9.3	10.1	6.3	16,406
Fleet vehicles	5	1.3	23.3	0.0	0.2	0.1	0.1	0.1	2,178
Total	**2,501**	**141.1**	**509.5**	**820.7**	**157.2**	**136.0**	**138.2**	**52.8**	**195,946**
2016 vs 2011 Change									
Ocean-going vessels	8%	12%	15%	-94%	-75%	-71%	-76%	-45%	13%
Harbor vessels	6%	-2%	14%	5%	-13%	-13%	-13%	-13%	5%
Locomotives	-6%	-10%	9%	-92%	-16%	-16%	-16%	-16%	9%
Cargo-handling equipment	-32%	-6%	-31%	-43%	-43%	-43%	-43%	-44%	-18%
Heavy-duty vehicles	-37%	-27%	-25%	3%	-28%	-28%	-28%	-44%	2%
Fleet vehicles	-67%	-69%	-68%	-73%	-69%	-69%	-71%	-70%	-73%
Total	**-7%**	**-7%**	**-12%**	**-94%**	**-53%**	**-49%**	**-50%**	**-29%**	**1%**

9.7.2 NWSA North Harbor Port Emissions

Table 9.29 summarizes the TEU and tons of cargo throughput for the NWSA North Harbor, in addition to the total vessel movements included arrivals, departures and shifts.

Table 9.29: NWSA North Harbor Activity Comparison

Year	TEU	Cargo (Tonnes)	Total Vessel Movements
2016	1,394,343	11,276,112	928
2011	2,033,535	17,735,810	1,622
2005	2,087,929	15,515,753	1,703
2016 vs 2011 Change	**-31%**	**-36%**	**-43%**
2016 vs 2005 Change	**-33%**	**-27%**	**-46%**

Table 9.30 summarizes the port emissions total and comparison for 2016, 2011 and 2005 for NWSA North Harbor. The NWSA North Harbor emissions are lower in 2016 as compared to 2011 and 2005 due to lower activity and the various initiatives discussed in section 2

Table 9.30: NWSA North Harbor Port Emissions Comparison, tpy and %

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	760	43	129	16	25	24	24	12.8	66,213
2011	1,352	75	264	381	81	71	72	29.1	108,625
2005	1,763	105	319	667	116	100	104	40.1	112,731
2016 vs 2011 Change	**-44%**	**-43%**	**-51%**	**-96%**	**-69%**	**-66%**	**-67%**	**-56%**	**-39%**
2016 vs 2005 Change	**-57%**	**-59%**	**-60%**	**-98%**	**-78%**	**-76%**	**-77%**	**-68%**	**-41%**

Table 9.31 compares the tons of emissions per 10,000 TEU and Table 9.32 compares tons of emissions per 10,000 metric tons of cargo.

Table 9.31: NWSA North Harbor Port Tons of Emissions per 10,000 TEU Comparison

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	5.45	0.31	0.92	0.12	0.18	0.17	0.17	0.09	475
2011	6.65	0.37	1.30	1.87	0.40	0.35	0.35	0.14	534
2005	8.45	0.50	1.53	3.19	0.55	0.48	0.50	0.19	540
2016 vs 2011 Change	**-18%**	**-17%**	**-29%**	**-94%**	**-54%**	**-51%**	**-52%**	**-36%**	**-11%**
2016 vs 2005 Change	**-35%**	**-39%**	**-40%**	**-96%**	**-67%**	**-64%**	**-66%**	**-52%**	**-12%**

Table 9.32: NWSA North Harbor Port Tons of Emissions per 10,000 Tons of Cargo Comparison

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	0.67	0.04	0.11	0.01	0.02	0.02	0.02	0.01	59
2011	0.76	0.04	0.15	0.21	0.05	0.04	0.04	0.02	61
2005	1.14	0.07	0.21	0.43	0.07	0.06	0.07	0.03	73
2016 vs 2011 Change	**-12%**	**-10%**	**-24%**	**-93%**	**-50%**	**-47%**	**-48%**	**-31%**	**-4%**
2016 vs 2005 Change	**-41%**	**-44%**	**-45%**	**-97%**	**-70%**	**-67%**	**-69%**	**-56%**	**-19%**

Table 9.33 presents a summary comparison of the North Harbor 2016 vs 2005 port emissions by source category. The overall emissions are lower in 2016 as compared to 2005. SO_2 and PM_{10}, $PM_{2.5}$, DPM and black carbon emissions are significantly lower in 2016 due to the North American ECA which required the use of lower sulfur fuel. NO_x, VOC, CO and CO_2e emissions are lower in 2016 due to lower activity and the emission reduction initiatives such as fleet turnover.

Table 9.33: NWSA North Harbor 2016 vs 2005 Port Emissions Comparison, tpy and %

	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016									
Ocean-going vessels	292	12.6	27.7	15.7	7.1	6.6	5.4	0.4	24,775
Harbor vessels	133	4.2	21.9	0.1	4.4	4.0	4.4	3.1	7,877
Locomotives	154	10.1	26.7	0.1	4.8	4.4	4.8	3.4	9,971
Cargo-handling equipment	109	7.4	27.0	0.1	5.7	5.5	5.7	4.2	15,301
Heavy-duty vehicles	73	8.2	22.3	0.1	3.5	3.3	3.5	1.7	8,112
Fleet vehicles	1	0.2	3.0	0.0	0.0	0.0	0.0	0.0	176
Total	**760**	**42.6**	**128.6**	**16.1**	**25.5**	**23.9**	**23.8**	**12.8**	**66,213**
2005									
Ocean-going vessels	524	22.3	46.3	568.8	62.2	49.7	50.5	1.4	37,220
Harbor vessels	198	6.3	26.0	20.8	8.6	7.9	8.6	6.1	11,211
Locomotives	447	24.8	55.1	38.4	13.3	12.2	13.3	9.4	18,004
Cargo-handling equipment	325	25.3	118.0	37.6	20.8	20.2	20.8	15.5	30,142
Heavy-duty vehicles	267	25.1	62.7	1.2	10.8	10.0	10.8	7.7	15,640
Fleet vehicles	2	0.8	11.2	0.0	0.0	0.0	0.0	0.0	514
Total	**1,763**	**104.6**	**319.2**	**666.9**	**115.8**	**100.0**	**103.9**	**40.1**	**112,731**
2016 vs 2005 Change									
Ocean-going vessels	-44%	-44%	-40%	-97%	-89%	-87%	-89%	-72%	-33%
Harbor vessels	-33%	-33%	-16%	-100%	-50%	-50%	-50%	-50%	-30%
Locomotives	-66%	-59%	-51%	-100%	-64%	-64%	-64%	-63%	-45%
Cargo-handling equipment	-67%	-71%	-77%	-100%	-73%	-73%	-73%	-73%	-49%
Heavy-duty vehicles	-73%	-67%	-64%	-94%	-67%	-67%	-67%	-78%	-48%
Fleet vehicles	-69%	-77%	-73%	-90%	-63%	-63%	-50%	-54%	-66%
Total	**-57%**	**-59%**	**-60%**	**-98%**	**-78%**	**-76%**	**-77%**	**-68%**	**-41%**

Table 9.34 presents a summary comparison of the NWSA North Harbor 2016 vs 2011 port emissions by source category. The overall emissions are lower in 2016 as compared to 2011. SO_2 and PM_{10}, $PM_{2.5}$, DPM and black carbon emissions are significantly lower in 2016 due to the North American ECA which required the use of lower sulfur fuel. NO_x, VOC, CO and CO_2e emissions are lower in 2016 due to lower activity and the emission reduction initiatives such as fleet turnover.

Table 9.34: NWSA North Harbor 2016 vs 2011 Port Emissions Comparison, tpy and %

	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016									
Ocean-going vessels	292	12.6	27.7	15.7	7.1	6.6	5.4	0.4	24,775
Harbor vessels	133	4.2	21.9	0.1	4.4	4.0	4.4	3.1	7,877
Locomotives	154	10.1	26.7	0.1	4.8	4.4	4.8	3.4	9,971
Cargo-handling equipment	109	7.4	27.0	0.1	5.7	5.5	5.7	4.2	15,301
Heavy-duty vehicles	73	8.2	22.3	0.1	3.5	3.3	3.5	1.7	8,112
Fleet vehicles	1	0.2	3.0	0.0	0.0	0.0	0.0	0.0	176
Total	**760**	**42.6**	**128.6**	**16.1**	**25.5**	**23.9**	**23.8**	**12.8**	**66,213**
2011									
Ocean-going vessels	448	18.0	39.2	378.1	41.0	33.2	32.1	1.0	35,392
Harbor vessels	205	7.0	31.4	0.1	8.2	7.5	8.2	5.8	12,321
Locomotives	285	19.7	44.4	2.4	10.2	9.3	10.2	7.2	16,578
Cargo-handling equipment	232	12.2	92.7	0.3	13.9	13.5	13.8	10.3	31,186
Heavy-duty vehicles	179	17.4	46.0	0.1	7.6	7.0	7.6	4.7	12,409
Fleet vehicles	2	0.6	10.8	0.0	0.1	0.1	0.0	0.0	739
Total	**1,352**	**74.9**	**264.5**	**381.1**	**80.9**	**70.6**	**72.0**	**29.1**	**108,625**
2016 vs 2011 Change									
Ocean-going vessels	-35%	-30%	-29%	-96%	-83%	-80%	-83%	-64%	-30%
Harbor vessels	-35%	-40%	-30%	-36%	-47%	-47%	-47%	-47%	-36%
Locomotives	-46%	-49%	-40%	-96%	-53%	-53%	-53%	-52%	-40%
Cargo-handling equipment	-53%	-40%	-71%	-65%	-59%	-59%	-59%	-59%	-51%
Heavy-duty vehicles	-59%	-53%	-52%	-34%	-54%	-54%	-54%	-64%	-35%
Fleet vehicles	-68%	-70%	-72%	-76%	-76%	-76%	-82%	-81%	-76%
Total	**-44%**	**-43%**	**-51%**	**-96%**	**-69%**	**-66%**	**-67%**	**-56%**	**-39%**

9.7.3 NWSA South Harbor Port Emissions

Table 9.35 summarizes the TEU and tons of cargo throughput for the NWSA South Harbor, in addition to the total vessel movements included arrivals, departures and shifts.

Table 9.35: NWSA South Harbor Activity Comparison

Year	TEU	Cargo (Tonnes)	Total Vessel Movements
2016	2,221,410	16,750,757	1,882
2011	1,488,795	11,880,230	1,465
2005	2,070,000	13,431,333	1,835
2016 vs 2011 Change	**49%**	**41%**	**28%**
2016 vs 2005 Change	**7%**	**25%**	**3%**

Table 9.36 summarizes the port emissions total and comparison for 2016, 2011 and 2005 for NWSA South Harbor. Emissions decreased for SO_2, PM_{10}, $PM_{2.5}$ and DPM in 2016 as compared to 2011 due to the North American ECA. NO_x, VOC, black carbon and CO_2e increased in 2016 as compared to 2011 due to increased throughput and activity.

Table 9.36: NWSA South Harbor Port Direct Emissions Comparison, tpy and %

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	1,573	89	317	32	49	45	46	24.5	132,119
2011	1,149	66	245	440	76	65	66	23.6	87,321
2005	1,720	97	363	592	104	91	92	38.1	116,948
2016 vs 2011 Change	**37%**	**35%**	**29%**	**-93%**	**-36%**	**-30%**	**-31%**	**4%**	**51%**
2016 vs 2005 Change	**-9%**	**-8%**	**-13%**	**-95%**	**-53%**	**-50%**	**-50%**	**-36%**	**13%**

Table 9.37 compares the tons of emissions per 10,000 TEU and Table 9.38 compares tons of emissions per 10,000 metric tons of cargo.

Table 9.37: NWSA South Harbor Port Tons of Emissions per 10,000 TEU Comparison

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	7.08	0.40	1.43	0.14	0.22	0.20	0.20	0.11	595
2011	7.72	0.44	1.65	2.95	0.51	0.44	0.44	0.16	587
2005	8.31	0.47	1.75	2.86	0.50	0.44	0.44	0.18	565
2016 vs 2011 Change	**-8%**	**-10%**	**-13%**	**-95%**	**-57%**	**-53%**	**-54%**	**-30%**	**1%**
2016 vs 2005 Change	**-15%**	**-14%**	**-19%**	**-95%**	**-56%**	**-53%**	**-54%**	**-40%**	**5%**

Table 9.38: NWSA South Harbor Port Tons of Emissions per 10,000 Tons of Cargo Comparison

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	0.94	0.05	0.19	0.02	0.03	0.03	0.03	0.01	79
2011	0.97	0.06	0.21	0.37	0.06	0.06	0.06	0.02	74
2005	1.28	0.07	0.27	0.44	0.08	0.07	0.07	0.03	87
2016 vs 2011 Change	**-3%**	**-4%**	**-8%**	**-95%**	**-55%**	**-51%**	**-51%**	**-26%**	**7%**
2016 vs 2005 Change	**-27%**	**-26%**	**-30%**	**-96%**	**-63%**	**-60%**	**-60%**	**-48%**	**-9%**

Table 9.39 presents a summary comparison of the NWSA South Harbor 2016 vs 2005 port emissions by source category. The overall emissions are lower in 2016 as compared to 2005. SO_2 and PM_{10}, $PM_{2.5}$, DPM and black carbon emissions are significantly lower in 2016 due to the North American ECA which required the use of lower sulfur fuel. NO_x, VOC and CO emissions are lower in 2016 due to the emission reduction initiatives such as fleet turnover. CO_2e emissions increased in 2016 due to increased throughput and activity.

Table 9.39: NWSA South Harbor 2016 vs 2005 Port Emissions Comparison, tpy and %

	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016									
Ocean-going vessels	598	24.7	55.5	30.8	14.0	13.2	10.8	0.7	48,542
Harbor vessels	275	8.7	45.3	0.2	9.0	8.3	9.0	6.4	16,317
Locomotives	458	29.7	80.1	0.3	14.1	12.9	14.1	10.1	29,897
Cargo-handling equipment	165	17.4	108.1	0.2	7.8	7.6	7.8	5.5	28,279
Heavy-duty vehicles	77	8.5	23.6	0.1	3.7	3.4	3.7	1.8	8,668
Fleet vehicles	1	0.2	4.5	0.0	0.0	0.0	0.0	0.0	416
Total	**1,573**	**89.2**	**317.2**	**31.5**	**48.7**	**45.5**	**45.5**	**24.5**	**132,119**
2005									
Ocean-going vessels	493	20.5	43.4	515.4	53.3	42.9	41.0	1.2	36,017
Harbor vessels	215	6.8	28.1	22.6	9.4	8.6	9.4	6.6	12,145
Locomotives	588	32.8	70.9	47.9	17.1	15.7	17.1	12.1	22,657
Cargo-handling equipment	360	30.5	187.7	5.3	21.7	21.1	21.7	16.2	40,475
Heavy-duty vehicles	56	4.7	13.5	0.3	2.4	2.2	2.4	1.7	3,445
Fleet vehicles	8	1.5	19.1	0.1	0.4	0.3	0.3	0.2	2,209
Total	**1,720**	**96.9**	**362.8**	**591.6**	**104.2**	**90.8**	**91.8**	**38.1**	**116,948**
2016 vs 2005 Change									
Ocean-going vessels	21%	21%	28%	-94%	-74%	-69%	-74%	-39%	35%
Harbor vessels	28%	28%	61%	-99%	-4%	-4%	-4%	-4%	34%
Locomotives	-22%	-10%	13%	-99%	-17%	-18%	-17%	-17%	32%
Cargo-handling equipment	-54%	-43%	-42%	-97%	-64%	-64%	-64%	-66%	-30%
Heavy-duty vehicles	37%	81%	74%	-71%	55%	55%	55%	5%	152%
Fleet vehicles	-88%	-85%	-77%	-95%	-91%	-91%	-92%	-92%	-81%
Total	**-9%**	**-8%**	**-13%**	**-95%**	**-53%**	**-50%**	**-50%**	**-36%**	**13%**

Table 9.40 presents a summary comparison of the NWSA South Harbor 2016 vs 2011 port emissions by source category. Emissions decreased for SO_2, PM_{10}, $PM_{2.5}$ and DPM in 2016 as compared to 2011 due to the North American ECA. NO_x, VOC, black carbon and CO_2e increased in 2016 as compared to 2011 due to increased throughput and activity.

Table 9.40: NWSA South Harbor 2016 vs 2011 Port Emissions Comparison, tpy and %

	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016									
Ocean-going vessels	598	24.7	55.5	30.8	14.0	13.2	10.8	0.7	48,542
Harbor vessels	275	8.7	45.3	0.2	9.0	8.3	9.0	6.4	16,317
Locomotives	458	29.7	80.1	0.3	14.1	12.9	14.1	10.1	29,897
Cargo-handling equipment	165	17.4	108.1	0.2	7.8	7.6	7.8	5.5	28,279
Heavy-duty vehicles	77	8.5	23.6	0.1	3.7	3.4	3.7	1.8	8,668
Fleet vehicles	1	0.2	4.5	0.0	0.0	0.0	0.0	0.0	416
Total	**1,573**	**89.2**	**317.2**	**31.5**	**48.7**	**45.5**	**45.5**	**24.5**	**132,119**
2011									
Ocean-going vessels	378	15.3	33.0	436.8	44.3	35.5	34.2	1.0	29,298
Harbor vessels	180	6.1	27.5	0.1	7.1	6.6	7.2	5.1	10,781
Locomotives	363	24.5	53.8	2.4	12.4	11.3	12.4	8.8	20,002
Cargo-handling equipment	168	13.9	103.4	0.2	10.0	9.7	10.0	7.2	21,803
Heavy-duty vehicles	58	5.6	14.8	0.0	2.5	2.3	2.5	1.5	3,997
Fleet vehicles	3	0.7	12.5	0.0	0.1	0.1	0.1	0.1	1,439
Total	**1,149**	**66.2**	**245.0**	**439.6**	**76.3**	**65.4**	**66.2**	**23.6**	**87,321**
2016 vs 2011 Change									
Ocean-going vessels	58%	61%	68%	-93%	-68%	-63%	-68%	-27%	66%
Harbor vessels	53%	42%	65%	51%	26%	26%	26%	26%	51%
Locomotives	26%	21%	49%	-88%	14%	15%	14%	15%	49%
Cargo-handling equipment	-2%	24%	5%	-13%	-22%	-22%	-22%	-24%	30%
Heavy-duty vehicles	33%	52%	59%	118%	52%	52%	52%	17%	117%
Fleet vehicles	-66%	-68%	-64%	-71%	-64%	-64%	-66%	-66%	-71%
Total	**37%**	**35%**	**29%**	**-93%**	**-36%**	**-30%**	**-31%**	**4%**	**51%**

9.7.4 Northwest Seaport Alliance Maritime-related Emissions within the Airshed

Table 9.41 summarizes the 2016 NWSA emissions within the airshed, including transit emissions for OGV and the regional emissions for locomotive and heavy-duty vehicle emissions.

Table 9.41: 2016 NWSA Combined Maritime-related Emissions within the Airshed, tpy and %

Source Category	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
OGVs, hotelling + maneuvering	891	37	83	47	21	20	16	1	73,316
Ocean-going vessels, transit	6,464	172	520	166	90	85	88	5	260,573
Harbor vessels	407	13	67	0	13	12	13	9	24,195
Locomotives	893	52	169	1	26	24	26	19	63,510
Cargo-handling equipment	274	25	135	0	14	13	13	10	43,581
Heavy-duty vehicles	972	51	244	2	47	43	47	14	177,909
Fleet vehicles	2	0	8	0	0	0	0	0	592
Total	**9,901**	**350**	**1,226**	**215**	**211**	**197**	**204**	**59**	**643,676**

Table 9.42 summarizes the total emissions within the airshed and comparison for 2016, 2011 and 2005 for NWSA.

Table 9.42: NWSA Combined Maritime-related Emissions within the Airshed Comparison, tpy and %

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	9,901	350	1,226	215	211	197	204	58.7	643,676
2011	11,434	442	1,455	5,640	801	661	764	114	675,984
2005	15,281	638	1,928	7,440	1,121	924	1,070	164	800,140
2016 vs 2011 Change	**-13%**	**-21%**	**-16%**	**-96%**	**-74%**	**-70%**	**-73%**	**-49%**	**-5%**
2016 vs 2005 Change	**-35%**	**-45%**	**-36%**	**-97%**	**-81%**	**-79%**	**-81%**	**-64%**	**-20%**

Table 9.43 and Figure 9.1 compare tons of emissions per 10,000 metric tons of cargo.

Table 9.43: NWSA Combined Tons of Emissions within the Airshed per 10,000 Tons of Cargo Comparison

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	3.53	0.12	0.44	0.08	0.08	0.07	0.07	0.02	230
2011	3.86	0.15	0.49	1.90	0.27	0.22	0.26	0.04	228
2005	5.28	0.22	0.67	2.57	0.39	0.32	0.37	0.06	276
2016 vs 2011 Change	**-8%**	**-16%**	**-11%**	**-96%**	**-72%**	**-68%**	**-72%**	**-46%**	**1%**
2016 vs 2005 Change	**-33%**	**-43%**	**-34%**	**-97%**	**-81%**	**-78%**	**-80%**	**-63%**	**-17%**

Figure 9.1: NWSA Combined Emissions within the Airshed per 10,000 Metric Tons of Cargo Change, %

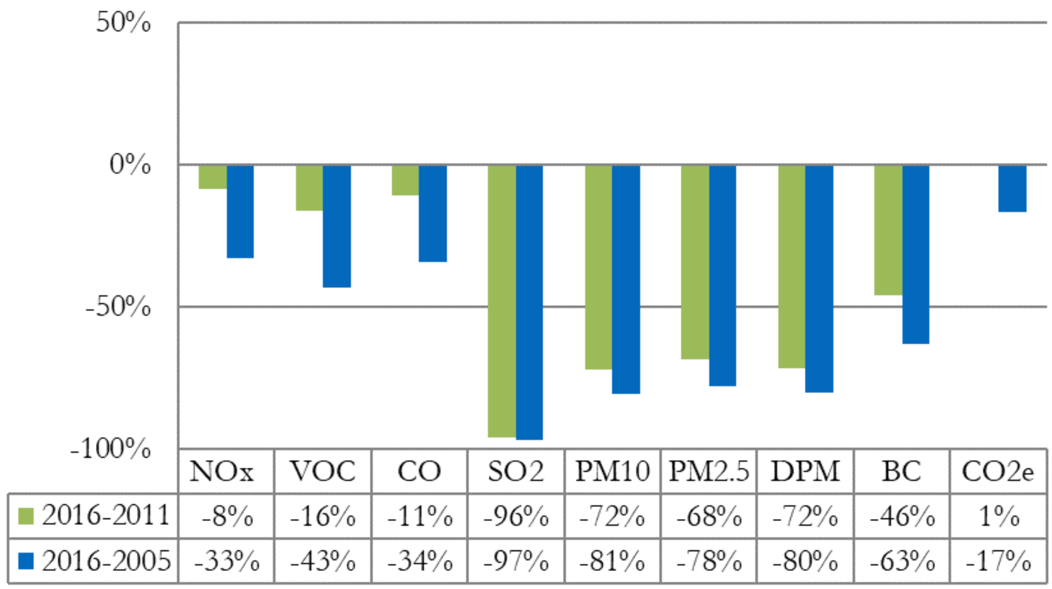


Table 9.44 presents a summary comparison of the NWSA 2016 vs 2005 emissions within the airshed by source category. The overall emissions are lower in 2016 as compared to 2005. SO_2 and PM_{10}, $PM_{2.5}$, DPM and black carbon emissions are significantly lower in 2016 due to the North American ECA which required the use of lower sulfur fuel. NO_x, VOC and CO emissions are lower in 2016 due to the emission reduction initiatives such as fleet turnover.

Table 9.44: NWSA Combined 2016 vs 2005 Maritime-related Emissions within the Airshed Comparison, tpy and %

	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016									
Ocean-going vessels	7,354	209	603	212	111	104	105	6	333,889
Harbor vessels	407	13	67	0	13	12	13	9	24,195
Locomotives	893	52	169	1	26	24	26	19	63,510
Cargo-handling equipment	274	25	135	0	14	13	13	10	43,581
Heavy-duty vehicles	972	51	244	2	47	43	47	14	177,909
Fleet vehicles	2	0	8	0	0	0	0	0	592
Total	**9,901**	**350**	**1,226**	**215**	**211**	**197**	**204**	**59**	**643,676**
2005									
Ocean-going vessels	10,237	353	783	7,188	918	736	868	22	458,066
Harbor vessels	413	13	54	43	18	17	18	13	23,356
Locomotives	1,928	97	241	153	53	49	53	38	82,659
Cargo-handling equipment	685	56	306	43	43	41	42	32	70,617
Heavy-duty vehicles	2,007	116	514	12	89	82	89	60	162,720
Fleet vehicles	10	2	30	0	0	0	0	0	2,723
Total	**15,281**	**638**	**1,928**	**7,440**	**1,121**	**924**	**1,070**	**164**	**800,140**
2016 vs 2005 Change									
Ocean-going vessels	-28%	-41%	-23%	-97%	-88%	-86%	-88%	-72%	-27%
Harbor vessels	-1%	-1%	24%	-99%	-26%	-26%	-26%	-26%	4%
Locomotives	-54%	-47%	-30%	-100%	-51%	-50%	-51%	-50%	-23%
Cargo-handling equipment	-60%	-56%	-56%	-99%	-68%	-68%	-68%	-69%	-38%
Heavy-duty vehicles	-52%	-56%	-53%	-88%	-47%	-47%	-47%	-76%	9%
Fleet vehicles	-84%	-82%	-75%	-94%	-88%	-88%	-91%	-90%	-78%
Total	**-35%**	**-45%**	**-36%**	**-97%**	**-81%**	**-79%**	**-81%**	**-64%**	**-20%**

A description of the factors that contributed to the 2016 vs 2005 emission changes is listed below for each source category.

Ocean-going vessels
Contributing factors to the decrease in emissions for OGV include:

- The North American ECA introduced in 2015, requiring 0.1% sulfur content in diesel fuel compared to heavy fuel oil with high sulfur content (2.7%) used by the majority of vessels in 2005
- Fewer total vessel movements

Harbor vessels
Contributing factors to the decrease in emissions for harbor vessels include:

- Fewer total vessel movements, thus fewer assist tugs required

Locomotives
Contributing factors to the decrease in emissions from locomotives include:

- All locomotive engines used ULSD in 2016, reducing SO_2 emissions significantly
- Lower fuel usage
- Lower activity measured in hp-hr
- Lower throughput measured as intermodal lifts

Cargo-handling equipment
Contributing factors to the decrease in emissions for CHE include:

- All equipment used ULSD in 2016 compared to a few pieces of equipment in 2005, reducing SO_2 emissions significantly
- Cleaner equipment
- Lower activity

Heavy-duty vehicles
Contributing factors to the change in emissions for HDV include:

- All heavy-duty vehicles used ULSD in 2016
- Fleet turnover

Contributing factors to the increase in CO_2e emissions for HDV include:

- CO_2e emissions increased because there has not been a significant decrease in truck fuel consumption with newer trucks

Table 9.45 presents a summary comparison of the NWSA 2016 vs 2011 emissions within the airshed by source category. The overall emissions are lower in 2016 as compared to 2011. SO_2 and PM_{10}, $PM_{2.5}$, DPM and black carbon emissions are significantly lower in 2016 due to the North American ECA which required the use of lower sulfur fuel. NO_x, VOC and CO emissions are lower in 2016 due to the emission reduction initiatives such as fleet turnover.

Table 9.45: NWSA Combined 2016 vs 2011 Maritime-related Emissions within the Airshed Comparison, tpy and %

	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016									
Ocean-going vessels	7,354	209	603	212	111	104	105	6	333,889
Harbor vessels	407	13	67	0	13	12	13	9	24,195
Locomotives	893	52	169	1	26	24	26	19	63,510
Cargo-handling equipment	274	25	135	0	14	13	13	10	43,581
Heavy-duty vehicles	972	51	244	2	47	43	47	14	177,909
Fleet vehicles	2	0	8	0	0	0	0	0	592
Total	**9,901**	**350**	**1,226**	**215**	**211**	**197**	**204**	**59**	**643,676**
2011									
Ocean-going vessels	8,107	238	605	5,630	659	529	622	16	362,594
Harbor vessels	385	13	59	0	15	14	15	11	23,102
Locomotives	1,046	66	165	8	37	34	37	26	62,139
Cargo-handling equipment	401	26	196	0	24	23	24	18	52,989
Heavy-duty vehicles	1,490	98	406	1	66	60	66	44	172,982
Fleet vehicles	5	1	23	0	0	0	0	0	2,178
Total	**11,434**	**442**	**1,455**	**5,640**	**801**	**661**	**764**	**114**	**675,984**
2016 vs 2011 Change									
Ocean-going vessels	-9%	-12%	0%	-96%	-83%	-80%	-83%	-61%	-8%
Harbor vessels	6%	-2%	14%	5%	-13%	-13%	-13%	-13%	5%
Locomotives	-15%	-22%	2%	-93%	-30%	-29%	-30%	-29%	2%
Cargo-handling equipment	-32%	-6%	-31%	-43%	-43%	-43%	-43%	-44%	-18%
Heavy-duty vehicles	-35%	-48%	-40%	2%	-29%	-29%	-29%	-67%	3%
Fleet vehicles	-67%	-69%	-68%	-72%	-69%	-69%	-71%	-70%	-73%
Total	**-13%**	**-21%**	**-16%**	**-96%**	**-74%**	**-70%**	**-73%**	**-49%**	**-5%**

9.7.5 NWSA North Harbor Airshed Emissions

Table 9.46 summarizes the 2016 NWSA North Harbor in Seattle emissions within the airshed, including transit emissions for OGV.

Table 9.46: 2016 NWSA North Harbor Maritime-related Emissions within the Airshed, tpy and %

Source Category	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
OGVs, hotelling + maneuvering	292	12.6	27.7	15.7	7.1	6.6	5.4	0.38	24,775
Ocean-going vessels, transit	2,340	56.0	190.2	58.6	31.3	29.5	30.9	1.8	92,116.2
Harbor vessels	133	4.2	21.9	0.1	4.4	4.0	4.4	3.09	7,877.3
Locomotives	278	15.5	54.2	0.2	8.0	7.4	8.0	5.80	20,455.8
Cargo-handling equipment	109	7.4	27.0	0.1	5.7	5.5	5.7	4.23	15,301
Heavy-duty vehicles	478	24.8	118.5	0.8	23.1	21.2	23.1	7.09	87,774
Fleet vehicles	1	0.2	3.0	0.0	0.0	0.0	0.0	0.00	176
Total	**3,630**	**120.6**	**442.6**	**75.5**	**79.5**	**74.3**	**77.4**	**22.35**	**248,475**

Table 9.47 summarizes the total emissions within the airshed and comparison for 2016, 2011 and 2005 for NWSA North Harbor in Seattle.

Table 9.47: NWSA North Harbor Maritime-related Emissions within the Airshed Comparison, tpy and %

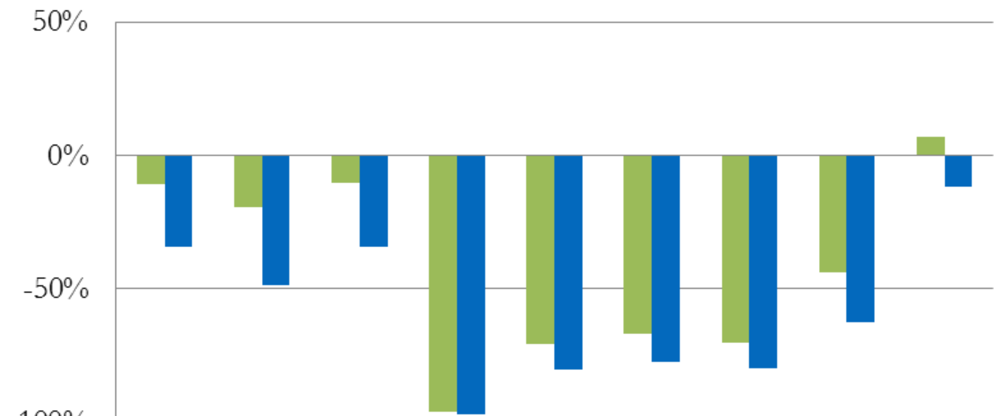
Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	3,630	121	443	76	80	74	77	22.4	248,475
2011	6,398	235	775	2,973	425	351	411	63	364,496
2005	7,573	323	925	3,555	552	456	532	82	387,625
2016 vs 2011 Change	**-43%**	**-49%**	**-43%**	**-97%**	**-81%**	**-79%**	**-81%**	**-64%**	**-32%**
2016 vs 2005 Change	**-52%**	**-63%**	**-52%**	**-98%**	**-86%**	**-84%**	**-85%**	**-73%**	**-36%**

Table 9.48 and Figure 9.2 compare tons of emissions per 10,000 metric tons of cargo.

Table 9.48: NWSA North Harbor Tons of Emissions within the Airshed per 10,000 Tons of Cargo Comparison

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	3.22	0.11	0.39	0.07	0.07	0.07	0.07	0.02	220
2011	3.61	0.13	0.44	1.68	0.24	0.20	0.23	0.04	206
2005	4.88	0.21	0.60	2.29	0.36	0.29	0.34	0.05	250
2016 vs 2011 Change	**-11%**	**-19%**	**-10%**	**-96%**	**-71%**	**-67%**	**-70%**	**-44%**	**7%**
2016 vs 2005 Change	**-34%**	**-49%**	**-34%**	**-97%**	**-80%**	**-78%**	**-80%**	**-63%**	**-12%**

Figure 9.2: NWSA North Harbor Emissions within the Airshed per 10,000 Metric Tons of Cargo Change, %



	NOx	VOC	CO	SO2	PM10	PM2.5	DPM	BC	CO2e
2016-2011	-11%	-19%	-10%	-96%	-71%	-67%	-70%	-44%	7%
2016-2005	-34%	-49%	-34%	-97%	-80%	-78%	-80%	-63%	-12%

Table 9.49 presents a summary comparison of the NWSA North Harbor 2016 vs 2005 emissions within the airshed by source category. The overall emissions are lower in 2016 as compared to 2005. SO_2 and PM_{10}, $PM_{2.5}$, DPM and black carbon emissions are significantly lower in 2016 due to the North American ECA which required the use of lower sulfur fuel. NO_x, VOC and CO emissions are lower in 2016 due to the emission reduction initiatives such as fleet turnover.

Table 9.49: NWSA North Harbor 2016 vs 2005 Maritime-related Emissions within the Airshed Comparison, tpy and %

	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016									
Ocean-going vessels	2,632	68.6	217.9	74.4	38.3	36.1	36.2	2.1	116,891
Harbor vessels	133	4.2	21.9	0.1	4.4	4.0	4.4	3.1	7,877
Locomotives	278	15.5	54.2	0.2	8.0	7.4	8.0	5.8	20,456
Cargo-handling equipment	109	7.4	27.0	0.1	5.7	5.5	5.7	4.2	15,301
Heavy-duty vehicles	478	24.8	118.5	0.8	23.1	21.2	23.1	7.1	87,774
Fleet vehicles	1	0.2	3.0	0.0	0.0	0.0	0.0	0.0	176
Total	**3,630**	**120.6**	**442.6**	**75.5**	**79.5**	**74.3**	**77.4**	**22.4**	**248,475**
2005									
Ocean-going vessels	5,088	179.3	383.9	3,418.8	450.4	360.9	429.9	10.6	221,815
Harbor vessels	198	6.3	26.0	20.8	8.6	7.9	8.6	6.1	11,211
Locomotives	875	44.6	111.0	71.1	24.8	22.8	24.8	17.6	38,543
Cargo-handling equipment	325	25.3	118.0	37.6	20.8	20.2	20.8	15.5	30,142
Heavy-duty vehicles	1,085	67.1	275.3	6.5	47.5	43.7	47.5	32.3	85,399
Fleet vehicles	2	0.8	11.2	0.0	0.0	0.0	0.0	0.0	514
Total	**7,573**	**323.3**	**925.3**	**3,554.8**	**552.2**	**455.6**	**531.7**	**82.2**	**387,625**
2016 vs 2005 Change									
Ocean-going vessels	-48%	-62%	-43%	-98%	-91%	-90%	-92%	-80%	-47%
Harbor vessels	-33%	-33%	-16%	-100%	-50%	-50%	-50%	-50%	-30%
Locomotives	-68%	-65%	-51%	-100%	-68%	-67%	-68%	-67%	-47%
Cargo-handling equipment	-67%	-71%	-77%	-100%	-73%	-73%	-73%	-73%	-49%
Heavy-duty vehicles	-56%	-63%	-57%	-88%	-51%	-51%	-51%	-78%	3%
Fleet vehicles	-69%	-77%	-73%	-91%	-63%	-63%	-49%	-54%	-66%
Total	**-52%**	**-63%**	**-52%**	**-98%**	**-86%**	**-84%**	**-85%**	**-73%**	**-36%**

A description of the factors that contributed to the 2016 vs 2005 emission changes is listed below for each source category.

Ocean-going vessels
Contributing factors to the decrease in emissions for OGV include:

- The North American ECA introduced in 2015, requiring 0.1% sulfur content in diesel fuel compared to heavy fuel oil with high sulfur content (2.7%) used by the majority of vessels in 2005
- Fewer total vessel movements

Harbor vessels
Contributing factors to the decrease in emissions for harbor vessels include:

- Fewer total vessel movements, thus fewer assist tugs required

Locomotives
Contributing factors to the decrease in emissions from locomotives include:

- All locomotive engines used ULSD in 2016, reducing SO_2 emissions significantly
- Lower fuel usage
- Lower activity measured in hp-hr
- Lower throughput measured as intermodal lifts

Cargo-handling equipment
Contributing factors to the decrease in emissions for CHE include:

- All equipment used ULSD in 2016 compared to a few pieces of equipment in 2005, reducing SO_2 emissions significantly
- Cleaner equipment
- Lower activity

Heavy-duty vehicles
Contributing factors to the change in emissions for HDV include:

- All heavy-duty vehicles used ULSD in 2016
- Fleet turnover

Contributing factors to the increase in CO_2e emissions for HDV include:

- CO_2e emissions increased because there has not been a significant decrease in truck fuel consumption with newer trucks

Table 9.50 presents a summary comparison of the NWSA North Harbor 2016 vs 2011 emissions within the airshed by source category. The overall emissions are lower in 2016 as compared to 2011. SO_2 and PM_{10}, $PM_{2.5}$, DPM and black carbon emissions are significantly lower in 2016 due to the North American ECA which required the use of lower sulfur fuel. NO_x, VOC and CO emissions are lower in 2016 due to the emission reduction initiatives such as fleet turnover.

Table 9.50: NWSA North Harbor 2016 vs 2011 Maritime-related Emissions within the Airshed Comparison, tpy and %

	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016									
Ocean-going vessels	2,632	68.6	217.9	74.4	38.3	36.1	36.2	2.1	116,891
Harbor vessels	133	4.2	21.9	0.1	4.4	4.0	4.4	3.1	7,877
Locomotives	278	15.5	54.2	0.2	8.0	7.4	8.0	5.8	20,456
Cargo-handling equipment	109	7.4	27.0	0.1	5.7	5.5	5.7	4.2	15,301
Heavy-duty vehicles	478	24.8	118.5	0.8	23.1	21.2	23.1	7.1	87,774
Fleet vehicles	1	0.2	3.0	0.0	0.0	0.0	0.0	0.0	176
Total	**3,630**	**120.6**	**442.6**	**75.5**	**79.5**	**74.3**	**77.4**	**22.4**	**248,475**
2011									
Ocean-going vessels	4,585	125.3	331.3	2,966.7	347.3	279.0	332.6	8.4	195,809
Harbor vessels	205	7.0	31.4	0.1	8.2	7.5	8.2	5.8	12,321
Locomotives	585	36.2	94.8	5.2	21.2	19.5	21.2	15.1	35,807
Cargo-handling equipment	232	12.2	92.7	0.3	13.9	13.5	13.8	10.3	31,186
Heavy-duty vehicles	789	53.8	214.0	0.8	34.7	31.9	34.7	22.9	88,634
Fleet vehicles	2	0.6	10.8	0.0	0.1	0.1	0.0	0.0	739
Total	**6,398**	**235.1**	**775.0**	**2,973.1**	**425.3**	**351.4**	**410.6**	**62.5**	**364,496**
2016 vs 2011 Change									
Ocean-going vessels	-43%	-45%	-34%	-97%	-89%	-87%	-89%	-75%	-40%
Harbor vessels	-35%	-40%	-30%	-36%	-47%	-47%	-47%	-47%	-36%
Locomotives	-52%	-57%	-43%	-96%	-62%	-62%	-62%	-62%	-43%
Cargo-handling equipment	-53%	-40%	-71%	na	-59%	-59%	-59%	-59%	-51%
Heavy-duty vehicles	-39%	-54%	-45%	na	-34%	-34%	-34%	-69%	-1%
Fleet vehicles	-68%	-70%	-72%	na	-76%	-76%	-82%	-81%	-76%
Total	**-43%**	**-49%**	**-43%**	**-97%**	**-81%**	**-79%**	**-81%**	**-64%**	**-32%**

9.7.6 NWSA South Harbor Airshed Emissions

Table 9.51 summarizes the 2016 South Harbor emissions within the airshed, including transit emissions for OGV.

Table 9.51: 2016 NWSA South Harbor Maritime-related Emissions within the Airshed, tpy

Source Category	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
OGVs, hotelling + maneuvering	598	24.7	55.5	30.8	14.0	13.2	10.8	0.75	48,542
Ocean-going vessels, transit	4,124	115.5	329.8	107.3	58.4	55.1	57.5	3.3	168,457
Harbor vessels	275	8.7	45.3	0.2	9.0	8.3	9.0	6	16,317
Locomotives	615	36	115	0	18	17	18	13	43,054
Cargo-handling equipment	165	17.4	108.1	0.2	7.8	7.6	7.8	5.52	28,279
Heavy-duty vehicles	494	26.4	125.0	0.8	23.7	21.8	23.7	7.30	90,135
Fleet vehicles	1	0.2	4.5	0.0	0.0	0.0	0.0	0.02	416
Total	**6,271**	**229.3**	**782.9**	**139.6**	**131.2**	**122.7**	**127.0**	**36.31**	**395,201**

Table 9.52 summarizes the total emissions within the airshed and comparison for 2016, 2011 and 2005 for NWSA South Harbor.

Table 9.52: NWSA South Harbor Maritime-related Emissions within the Airshed Comparison, tpy and %

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	6,271	229	783	140	131	123	127	36.3	395,201
2011	5,035	207	680	2,667	376	309	353	52	311,489
2005	7,707	315	1,003	3,885	569	469	539	82	412,516
2016 vs 2011 Change	**25%**	**11%**	**15%**	**-95%**	**-65%**	**-60%**	**-64%**	**-30%**	**27%**
2016 vs 2005 Change	**-19%**	**-27%**	**-22%**	**-96%**	**-77%**	**-74%**	**-76%**	**-56%**	**-4%**

Table 9.53 and Figure 9.3 compare tons of emissions per 10,000 metric tons of cargo.

Table 9.53: NWSA South Harbor Tons of Emissions within the Airshed per 10,000 Tons of Cargo Comparison

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	3.74	0.14	0.47	0.08	0.08	0.07	0.08	0.02	236
2011	4.24	0.17	0.57	2.25	0.32	0.26	0.30	0.04	262
2005	5.74	0.23	0.75	2.89	0.42	0.35	0.40	0.06	307
2016 vs 2011 Change	**-12%**	**-21%**	**-18%**	**-96%**	**-75%**	**-72%**	**-74%**	**-50%**	**-10%**
2016 vs 2005 Change	**-35%**	**-42%**	**-37%**	**-97%**	**-82%**	**-79%**	**-81%**	**-65%**	**-23%**

Figure 9.3: NWSA South Harbor Emissions within the Airshed per 10,000 Metric Tons of Cargo Change, %

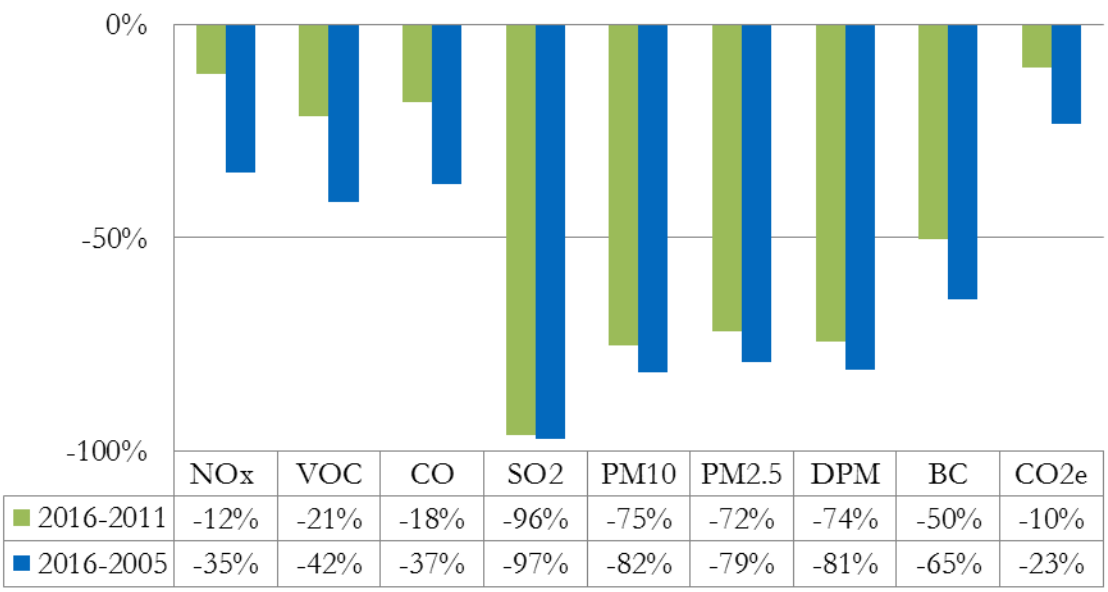


Table 9.54 presents a summary comparison of the South Harbor 2016 vs 2005 emissions within the airshed by source category. The overall emissions are lower in 2016 as compared to 2005. SO_2 and PM_{10}, $PM_{2.5}$, DPM and black carbon emissions are significantly lower in 2016 due to the North American ECA which required the use of lower sulfur fuel. NO_x, VOC and CO emissions are lower in 2016 due to the emission reduction initiatives such as fleet turnover.

Table 9.54: NWSA South Harbor 2016 vs 2005 Maritime-related Emissions within the Airshed Comparison, tpy and %

	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016									
Ocean-going vessels	4,722	140.3	385.4	138.1	72.5	68.3	68.4	4.0	216,999
Harbor vessels	275	9	45	0	9	8	9	6	16,317
Locomotives	615	36.4	114.6	0.4	18.1	16.7	18.1	13.0	43,054
Cargo-handling equipment	165	17.4	108.1	0.2	7.8	7.6	7.8	5.5	28,279
Heavy-duty vehicles	494	26.4	125.0	0.8	23.7	21.8	23.7	7.3	90,135
Fleet vehicles	1	0.2	4.5	0.0	0.0	0.0	0.0	0.0	416
Total	**6,271**	**229.3**	**782.9**	**139.6**	**131.2**	**122.7**	**127.0**	**36.3**	**395,201**
2005									
Ocean-going vessels	5,150	173.6	399.1	3,768.9	467.9	375.0	437.9	11.2	236,250
Harbor vessels	215	6.8	28.1	22.6	9.4	8.6	9.4	6.6	12,145
Locomotives	1,053	52.8	130.1	82.0	28.2	25.9	28.2	20.0	44,116
Cargo-handling equipment	360	30.5	187.7	5.3	21.7	21.1	21.7	16.2	40,475
Heavy-duty vehicles	922	49.2	238.7	5.9	41.3	38.0	41.3	27.8	77,321
Fleet vehicles	8	1.5	19.1	0.1	0.4	0.3	0.3	0.2	2,209
Total	**7,707**	**314.5**	**1,002.9**	**3,884.8**	**568.8**	**468.9**	**538.8**	**82.1**	**412,516**
2016 vs 2005 Change									
Ocean-going vessels	-8%	-19%	-3%	-96%	-85%	-82%	-84%	-64%	-8%
Harbor vessels	28%	28%	61%	-99%	-4%	-4%	-4%	-4%	34%
Locomotives	-42%	-31%	-12%	-99%	-36%	-35%	-36%	-35%	-2%
Cargo-handling equipment	-54%	-43%	-42%	-97%	-64%	-64%	-64%	-66%	-30%
Heavy-duty vehicles	-46%	-46%	-48%	-87%	-43%	-43%	-43%	-74%	17%
Fleet vehicles	-88%	-85%	-77%	-95%	-91%	-91%	-92%	-92%	-81%
Total	**-19%**	**-27%**	**-22%**	**-96%**	**-77%**	**-74%**	**-76%**	**-56%**	**-4%**

A description of the factors that contributed to the 2016 vs 2005 emission changes is listed below for each source category.

Ocean-going vessels
Contributing factors to the decrease in emissions for OGV include:

- The North American ECA introduced in 2015, requiring 0.1% sulfur content in diesel fuel compared to heavy fuel oil with high sulfur content (2.7%) used by the majority of vessels in 2005
- Shore power

Harbor vessels
Contributing factors to the decrease in emissions for harbor vessels include:

- All harbor vessels used ULSD in 2016

Contributing factors to the increase in emissions for harbor vessels include:

- Increased total vessel movement which increased activity for assist tugs

Locomotives
Contributing factors to the decrease in emissions from locomotives include:

- All locomotive engines used ULSD in 2016, reducing SO_2 emissions significantly

Cargo-handling equipment
Contributing factors to the decrease in emissions for CHE include:

- All equipment used ULSD in 2016 compared to a few pieces of equipment in 2005, reducing SO_2 emissions significantly
- Cleaner equipment

Heavy-duty vehicles
Contributing factors to the change in emissions for HDV include:

- All heavy-duty vehicles used ULSD in 2016
- Fleet turnover

Contributing factors to the increase in emissions for HDV include:

- CO_2e emissions increased because there has not been a significant decrease in truck fuel consumption with newer trucks
- Increased throughput

Table 9.55 presents a summary comparison of the NWSA South Harbor 2016 vs 2011 emissions within the airshed by source category. SO_2 and PM_{10}, $PM_{2.5}$, DPM and black carbon emissions are significantly lower in 2016 due to the North American ECA which required the use of lower sulfur fuel. NO_x, VOC, black carbon and CO_2e increased in 2016 as compared to 2011 due to increased throughput and activity.

Table 9.55: NWSA South Harbor 2016 vs 2011 Maritime-related Emissions within the Airshed Comparison, tpy and %

	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016									
Ocean-going vessels	4,722	140.3	385.4	138.1	72.5	68.3	68.4	4.0	216,999
Harbor vessels	275	8.7	45.3	0.2	9.0	8.3	9.0	6.4	16,317
Locomotives	615	36.4	114.6	0.4	18.1	16.7	18.1	13.0	43,054
Cargo-handling equipment	165	17.4	108.1	0.2	7.8	7.6	7.8	5.5	28,279
Heavy-duty vehicles	494	26.4	125.0	0.8	23.7	21.8	23.7	7.3	90,135
Fleet vehicles	1	0.2	4.5	0.0	0.0	0.0	0.0	0.0	416
Total	**6,271**	**229.3**	**782.9**	**139.6**	**131.2**	**122.7**	**127.0**	**36.3**	**395,201**
2011									
Ocean-going vessels	3,522	112.4	274.0	2,662.9	311.4	249.6	289.1	7.4	166,784
Harbor vessels	180	6.1	27.5	0.1	7.1	6.6	7.2	5.1	10,781
Locomotives	461	29.9	70.3	3.3	16.0	14.6	16.0	11.3	26,333
Cargo-handling equipment	168	13.9	103.4	0.2	10.0	9.7	10.0	7.2	21,803
Heavy-duty vehicles	701	44.0	191.9	0.7	31.0	28.5	31.0	20.7	84,348
Fleet vehicles	3	0.7	12.5	0.0	0.1	0.1	0.1	0.1	1,439
Total	**5,035**	**207.2**	**679.6**	**2,667.3**	**375.6**	**309.1**	**353.2**	**51.8**	**311,489**
2016 vs 2011 Change									
Ocean-going vessels	34%	25%	41%	-95%	-77%	-73%	-76%	-46%	30%
Harbor vessels	53%	42%	65%	51%	26%	26%	26%	26%	51%
Locomotives	33%	22%	63%	-87%	14%	14%	14%	15%	64%
Cargo-handling equipment	-2%	24%	5%	-13%	-22%	-22%	-22%	-24%	30%
Heavy-duty vehicles	-30%	-40%	-35%	6%	-24%	-24%	-24%	-65%	7%
Fleet vehicles	-66%	-68%	-64%	-70%	-64%	-64%	-66%	-66%	-71%
Total	**25%**	**11%**	**15%**	**-95%**	**-65%**	**-60%**	**-64%**	**-30%**	**27%**

9.8 Port of Seattle and Port of Tacoma Emissions within the Airshed

For the Port of Seattle and Port of Tacoma, the sum of maritime-related emissions within the entire emission inventory domain is included to support the NWPCAS effort. The emissions within the airshed include the following for Port of Seattle and Port of Tacoma:

- Ocean-going vessel emissions (hoteling, maneuvering, and transit emissions)
- Commercial harbor vessel emissions (includes assist tug emissions based on percentage of total vessel movements for North Harbor and South Harbor)
- Recreational vessels (marinas are not part of NWSA)
- Locomotive emissions (on-port, off-port, switching and line-haul emissions)
- Cargo-handling equipment emissions
- Heavy-duty vehicle emissions (on-port and off-port emissions)
- Fleet vehicle emissions (on-terminal activities)

9.8.1 Port of Seattle Emissions within the Airshed

Table 9.56 summarizes the 2016 Port of Seattle emissions within the airshed and Table 9.57 summarizes the comparison for 2016, 2011 and 2005 for Port of Seattle.

Table 9.56: 2016 Port of Seattle Maritime-related Emissions within the Airshed, tpy

Source Category	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
OGVs, hotelling + maneuvering	228.1	7.4	20.1	9.24	4.72	4.43	4.37	0.27	14,502
Ocean-going vessels, transit	945.5	33.8	82.4	31.92	17.93	16.83	17.92	1.01	50,024
Harbor vessels	75.7	2.4	12.5	0.04	2.49	2.29	2.49	1.76	4,501
Recreational vessels	52.4	94.0	657.9	0.13	1.99	1.85	0.29	0.53	7,386
Locomotives	61.6	2.7	13.1	0.05	1.59	1.48	1.59	1.16	5,004
Cargo-handling equipment	6.0	1.1	18.0	0.00	0.29	0.28	0.26	0.20	623
Heavy-duty vehicles	0.3	0.0	0.1	0.00	0.00	0.00	0.00	0.01	16
Fleet vehicles	0.9	0.2	3.6	0.01	0.01	0.01	0.01	0.01	287
Total	**1,370.6**	**141.6**	**807.6**	**41.39**	**29.02**	**27.18**	**26.92**	**4.95**	**82,343**

Table 9.57: Port of Seattle Maritime-related Emissions within the Airshed Comparison, % and tpy

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	1,371	142	808	41	29	27	27	4.9	82,343
2011	1,970	203	1,018	1,336	176	142	171	9.6	115,427
2005	1,128	270	2,459	529	87	71	82	8.6	65,865
2016 vs 2011 Change	**-30%**	**-30%**	**-21%**	**-97%**	**-83%**	**-81%**	**-84%**	**-48%**	**-29%**
2016 vs 2005 Change	**22%**	**-48%**	**-67%**	**-92%**	**-67%**	**-62%**	**-67%**	**-42%**	**25%**

Table 9.58 and Figure 9.4 compare tons of emissions per 10,000 metric tons of cargo.

Table 9.58: Port of Seattle Tons of Emissions within the Airshed per 10,000 Tons of Cargo Comparison

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	3.1	0.32	1.84	0.09	0.07	0.06	0.06	0.011	188
2011	3.9	0.40	2.03	2.66	0.35	0.28	0.34	0.019	230
2005	2.2	0.54	4.87	1.05	0.17	0.14	0.16	0.017	130
2016 vs 2011 Change	**-20%**	**-20%**	**-9%**	**-96%**	**-81%**	**-78%**	**-82%**	**-41%**	**-18%**
2016 vs 2005 Change	**40%**	**-40%**	**-62%**	**-91%**	**-61%**	**-56%**	**-62%**	**-34%**	**44%**

Figure 9.4: Port of Seattle Emissions within the Airshed per 10,000 Metric Tons of Cargo Change, %

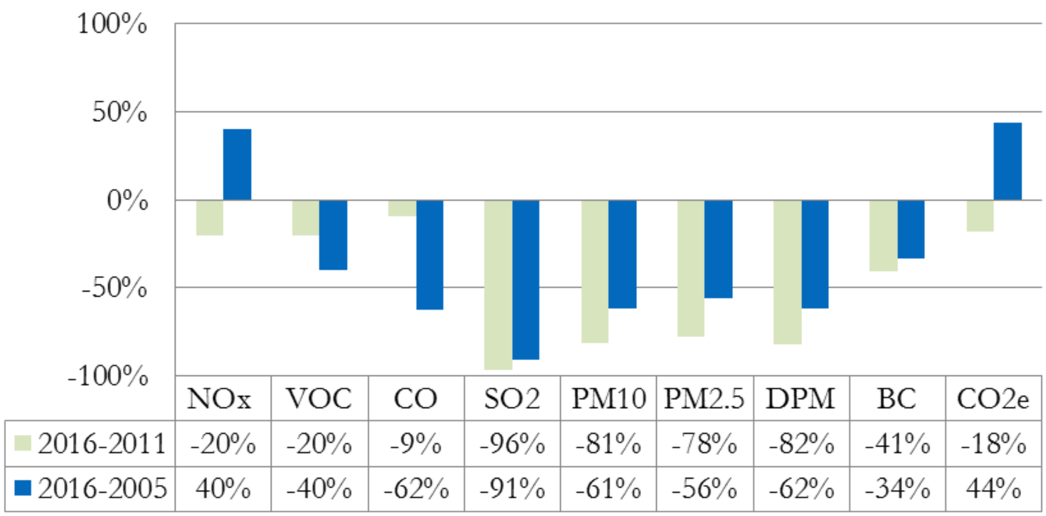


Table 9.59 presents a summary comparison of the Port of Seattle 2016 vs 2005 emissions within the airshed by source category. The overall emissions are lower in 2016 as compared to 2005, with the exception of NO_x and CO_2e which increased as a result of increased OGV emissions due more vessel calls.

Table 9.59: Port of Seattle 2016 vs 2005 Maritime-related Emissions within the Airshed Comparison, tpy and %

	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016									
Ocean-going vessels	1,174	41	102	41	23	21	22	1	64,527
Harbor vessels	75.7	2.40	12.51	0.04	2.49	2.29	2.49	1.76	4,501
Recreational vessels	52.4	94.0	657.9	0.1	2.0	1.8	0.3	0.5	7,386
Locomotives	61.6	2.7	13.1	0.1	1.6	1.5	1.6	1.2	5,004
Cargo-handling equipment	6.0	1.1	18.0	0.0	0.3	0.3	0.3	0.2	623
Heavy-duty vehicles	0.3	0.0	0.1	0.0	0.0	0.0	0.0	0.0	16
Fleet vehicles	0.9	0.2	3.6	0.0	0.0	0.0	0.0	0.0	287
Total	**1,370.6**	**141.6**	**807.6**	**41.4**	**29.0**	**27.2**	**26.9**	**4.9**	**82,343**
2005									
Ocean-going vessels	821.9	27.2	64.4	508.1	73.9	59.1	72.7	1.8	41,472
Harbor vessels	41.3	1.31	5.41	4.34	1.80	1.66	1.80	1.28	2,336
Recreational vessels	56.1	198.2	1,221.4	1.8	4.2	3.9	0.5	0.9	8,672
Locomotives	172.0	8.3	22.8	13.9	4.8	4.4	4.8	3.4	8,317
Cargo-handling equipment	33.3	34.8	1,133.9	0.8	1.9	1.8	1.6	1.2	4,328
Heavy-duty vehicles	0.5	0.0	0.1	0.0	0.0	0.0	0.0	0.0	14
Fleet vehicles	2.6	0.7	11.3	0.0	0.0	0.0	0.0	0.0	727
Total	**1,127.8**	**270.5**	**2,459.4**	**529.0**	**86.7**	**70.9**	**81.5**	**8.6**	**65,865**
2016 vs 2005 Change									
Ocean-going vessels	43%	52%	59%	-92%	-69%	-64%	-69%	-28%	56%
Harbor vessels	83%	84%	131%	-99%	38%	38%	38%	38%	93%
Recreational vessels	-7%	-53%	-46%	-93%	-52%	-52%	-42%	-38%	-15%
Locomotives	-64%	-67%	-42%	-100%	-67%	-67%	-67%	-66%	-40%
Cargo-handling equipment	-82%	-97%	-98%	-100%	-84%	-84%	-84%	-84%	-86%
Heavy-duty vehicles	-42%	-20%	-14%	-91%	-28%	-27%	-28%	261%	13%
Fleet vehicles	-68%	-74%	-69%	-89%	-60%	-59%	-56%	-50%	-60%
Total	**22%**	**-48%**	**-67%**	**-92%**	**-67%**	**-62%**	**-67%**	**-42%**	**25%**

Table 9.60 presents a summary comparison of the Port of Seattle 2016 vs 2011 emissions within the airshed by source category.

Table 9.60: Port of Seattle 2016 vs 2011 Maritime-related Emissions within the Airshed Comparison, tpy and %

	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016									
Ocean-going vessels	1,173.7	41.2	102.5	41.2	22.7	21.3	22.3	1.3	64,527
Harbor vessels	75.7	2.40	12.51	0.04	2.49	2.29	2.49	1.76	4,501
Recreational vessels	52.4	94.0	657.9	0.1	2.0	1.8	0.3	0.5	7,386
Locomotives	61.6	2.7	13.1	0.1	1.6	1.5	1.6	1.2	5,004
Cargo-handling equipment	6.0	1.1	18.0	0.0	0.3	0.3	0.3	0.2	623
Heavy-duty vehicles	0.3	0.0	0.1	0.0	0.0	0.0	0.0	0.0	16
Fleet vehicles	0.9	0.2	3.6	0.0	0.0	0.0	0.0	0.0	287
Total	**1,370.6**	**141.6**	**807.6**	**41.4**	**29.0**	**27.2**	**26.9**	**4.9**	**82,343**
2011									
Ocean-going vessels	1,729.2	57.8	137.4	1,335.2	166.2	132.8	164.1	4.0	95,999
Harbor vessels	68.4	2.34	10.47	0.04	2.72	2.50	2.73	1.93	4,107
Recreational vessels	57.5	135.4	826.6	0.1	2.8	2.6	0.4	0.6	7,555
Locomotives	107.8	6.1	18.0	1.0	4.0	3.6	4.0	2.8	6,877
Cargo-handling equipment	5.3	0.9	20.7	0.0	0.2	0.2	0.2	0.1	449
Heavy-duty vehicles	0.4	0.0	0.1	0.0	0.0	0.0	0.0	0.0	14
Fleet vehicles	1.3	0.3	5.0	0.0	0.0	0.0	0.0	0.0	426
Total	**1,970.0**	**202.8**	**1,018.2**	**1,336.3**	**175.9**	**141.7**	**171.4**	**9.6**	**115,427**
2016 vs 2011 Change									
Ocean-going vessels	-32%	-29%	-25%	-97%	-86%	-84%	-86%	-68%	-33%
Harbor vessels	11%	3%	19%	10%	-9%	-8%	-9%	-8%	10%
Recreational vessels	-9%	-31%	-20%	0%	-29%	-29%	-17%	-18%	-2%
Locomotives	-43%	-56%	-27%	-95%	-60%	-59%	-60%	-59%	-27%
Cargo-handling equipment	13%	19%	-13%	-3%	59%	59%	65%	63%	39%
Heavy-duty vehicles	-21%	-15%	-11%	0%	-15%	-14%	-15%	427%	10%
Fleet vehicles	-35%	-32%	-28%	-33%	-34%	-34%	-44%	-45%	-33%
Total	**-30%**	**-30%**	**-21%**	**-97%**	**-83%**	**-81%**	**-84%**	**-48%**	**-29%**

9.8.2 Port of Tacoma Emissions within the Airshed

Table 9.61 summarizes the 2016 Port of Tacoma emissions within the airshed and Table 9.62 summarizes the comparison for 2016, 2011 and 2005.

Table 9.61: 2016 Port of Tacoma Maritime-related Emissions within the Airshed, tpy

Source Category	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
OGVs, hotelling + maneuvering	35.1	1.27	3.34	1.82	0.84	0.79	0.70	0.05	2,861
Ocean-going vessels, transit	71.9	1.5	6.0	1.87	0.99	0.93	0.99	0.06	2,932
Harbor vessels	18.9	0.6	3.1	0.0	0.6	0.6	0.6	0.4	1,125.3
Recreational vessels	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Locomotives	63.0	2.9	12.9	0.05	1.64	1.53	1.64	1.20	4,915
Cargo-handling equipment	0.2	0.0	0.9	0.00	0.00	0.00	0.00	0.00	12
Heavy-duty vehicles	0.3	0.0	0.1	0.00	0.01	0.01	0.01	0.01	28
Fleet vehicles	0.0	0.0	0.3	0.0	0.0	0.0	0.0	0.0	116
Total	**189.5**	**6.3**	**26.6**	**3.75**	**4.11**	**3.84**	**3.96**	**1.75**	**11,988**

Table 9.62: Port of Tacoma Maritime-related Emissions within the Airshed Comparison, tpy and %

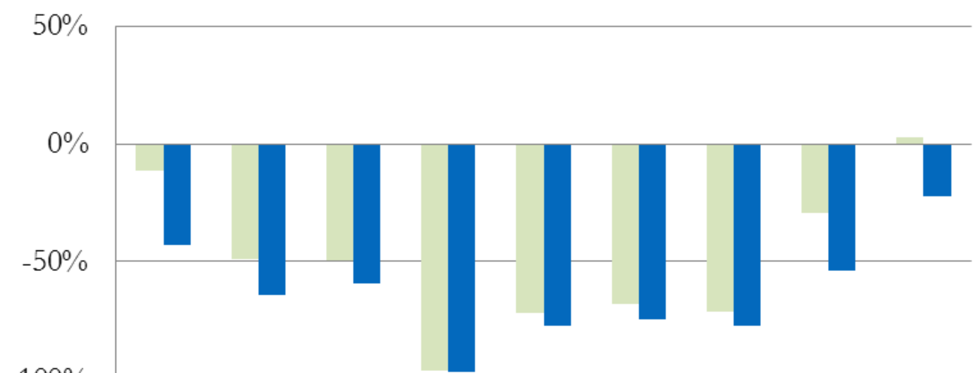
Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	189.5	6.3	26.6	3.7	4.1	3.8	4.0	1.7	11,988
2011	260.4	15.0	64.1	122.6	17.8	14.7	16.8	3.0	14,233
2005	524.6	27.7	102.7	190.7	28.8	24.0	27.6	6.0	24,416
2016 vs 2011 Change	**-27%**	**-58%**	**-59%**	**-97%**	**-77%**	**-74%**	**-76%**	**-42%**	**-16%**
2016 vs 2005 Change	**-64%**	**-77%**	**-74%**	**-98%**	**-86%**	**-84%**	**-86%**	**-71%**	**-51%**

Table 9.63 and Figure 9.5 compare tons of emissions per 10,000 metric tons of cargo.

Table 9.63: Port of Tacoma Tons of Emissions within the Airshed per 10,000 Tons of Cargo Comparison

Year	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016	0.429	0.014	0.060	0.008	0.009	0.009	0.009	0.004	27
2011	0.483	0.028	0.119	0.227	0.033	0.027	0.031	0.006	26
2005	0.753	0.040	0.147	0.274	0.041	0.034	0.040	0.009	35
2016 vs 2011 Change	**-11%**	**-49%**	**-49%**	**-96%**	**-72%**	**-68%**	**-71%**	**-30%**	**3%**
2016 vs 2005 Change	**-43%**	**-64%**	**-59%**	**-97%**	**-77%**	**-75%**	**-77%**	**-54%**	**-22%**

Figure 9.5: Port of Tacoma Emissions within the Airshed per 10,000 Metric Tons of Cargo Change, %



	NOx	VOC	CO	SO2	PM10	PM2.5	DPM	BC	CO2e
2016-2011	-11%	-49%	-49%	-96%	-72%	-68%	-71%	-30%	3%
2016-2005	-43%	-64%	-59%	-97%	-77%	-75%	-77%	-54%	-22%

Table 9.64 presents a summary comparison of the Port of Tacoma 2016 vs 2005 emissions within the airshed by source category. Overall, the emissions are lower in 2016 compared to 2005.

Table 9.64: Port of Tacoma 2016 vs 2005 Maritime-related Emissions within the Airshed Comparison, tpy and %

	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016									
Ocean-going vessels	107.0	2.72	9.29	3.69	1.83	1.73	1.69	0.10	5,793
Harbor vessels	18.9	0.60	3.13	0.01	0.62	0.57	0.62	0.44	1,125
Recreational vessels	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Locomotives	63.0	2.89	12.92	0.05	1.64	1.53	1.64	1.20	4,915
Cargo-handling equipment	0.2	0.05	0.93	0.00	0.00	0.00	0.00	0.00	12
Heavy-duty vehicles	0.3	0.03	0.08	0.00	0.01	0.01	0.01	0.01	28
Fleet vehicles	0.0	0.00	0.27	0.00	0.00	0.00	0.00	0.00	116
Total	**189.5**	**6.29**	**26.61**	**3.75**	**4.11**	**3.84**	**3.96**	**1.75**	**11,988**
2005									
Ocean-going vessels	231.8	7.57	17.66	167.44	21.01	16.83	19.94	0.50	10,248
Harbor vessels	24.8	0.78	3.25	2.60	1.08	0.99	1.08	0.77	1,401
Recreational vessels	2.1	7.56	46.57	0.07	0.16	0.15	0.02	0.03	331
Locomotives	265.7	11.71	34.19	20.59	6.60	6.05	6.60	4.69	12,421
Cargo-handling equipment	0.3	0.06	1.04	0.00	0.00	0.00	0.00	0.00	15
Heavy-duty vehicles	na	na	na	na	na	na	na	na	na
Fleet vehicles	na	na	na	na	na	na	na	na	na
Total	**524.6**	**27.68**	**102.70**	**190.71**	**28.84**	**24.03**	**27.64**	**5.99**	**24,416**
2016 vs 2005 Change									
Ocean-going vessels	-54%	-64%	-47%	-98%	-91%	-90%	-92%	-79%	-43%
Harbor vessels	-24%	-23%	-4%	-100%	-42%	-42%	-42%	-42%	-20%
Recreational vessels	-100%	-100%	-100%	-100%	-100%	-100%	-100%	-100%	-100%
Locomotives	-76%	-75%	-62%	-100%	-75%	-75%	-75%	-75%	-60%
Cargo-handling equipment	-22%	-14%	-11%	0%	-8%	-8%	0%	0%	-23%
Heavy-duty vehicles	na	na	na	na	na	na	na	na	na
Fleet vehicles	na	na	na	na	na	na	na	na	na
Total	**-64%**	**-77%**	**-74%**	**-98%**	**-86%**	**-84%**	**-86%**	**-71%**	**-51%**

Table 9.65 presents a summary comparison of the Port of Tacoma 2016 vs 2011 emissions within the airshed by source category. Overall, the emissions are lower in 2016 compared to 2011.

Table 9.65: Port of Tacoma 2016 vs 2011 Maritime-related Emissions within the Airshed Comparison, tpy

	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
2016									
Ocean-going vessels	107.0	2.72	9.29	3.69	1.83	1.73	1.69	0.10	5,793
Harbor vessels	18.9	0.60	3.13	0.01	0.62	0.57	0.62	0.44	1,125
Recreational vessels	0.0	0.00	0.00	0.00	0.00	0.00	0.00	0.00	0
Locomotives	63.0	2.89	12.92	0.05	1.64	1.53	1.64	1.20	4,915
Cargo-handling equipment	0.2	0.05	0.93	0.00	0.00	0.00	0.00	0.00	12
Heavy-duty vehicles	0.3	0.03	0.08	0.00	0.01	0.01	0.01	0.01	28
Fleet vehicles	0.0	0.00	0.27	0.00	0.00	0.00	0.00	0.00	116
Total	**189.5**	**6.29**	**26.61**	**3.75**	**4.11**	**3.84**	**3.96**	**1.75**	**11,988**
2011									
Ocean-going vessels	157.8	4.31	12.11	121.92	13.97	11.19	13.03	0.33	7,462
Harbor vessels	25.7	0.88	3.93	0.01	1.02	0.94	1.02	0.72	1,540
Recreational vessels	2.4	5.62	34.32	0.01	0.12	0.11	0.01	0.03	314
Locomotives	74.0	4.11	12.38	0.68	2.71	2.49	2.71	1.94	4,721
Cargo-handling equipment	0.2	0.05	0.93	0.00	0.00	0.00	0.00	0.00	12
Heavy-duty vehicles	0.4	0.04	0.10	0.00	0.02	0.02	0.02	0.01	28.0
Fleet vehicles	0.0	0.01	0.38	0.00	0.00	0.00	0.00	0.00	157.0
Total	**260.4**	**15.01**	**64.14**	**122.62**	**17.84**	**14.75**	**16.80**	**3.03**	**14,233**
2016 vs 2011 Change									
Ocean-going vessels	-32%	-37%	-23%	-97%	-87%	-85%	-87%	-69%	-22%
Harbor vessels	-26%	-32%	-20%	-27%	-39%	-39%	-39%	-39%	-27%
Recreational vessels	-100%	-100%	-100%	-100%	-100%	-100%	-100%	-100%	-100%
Locomotives	-15%	-30%	4%	-93%	-39%	-39%	-39%	-38%	4%
Cargo-handling equipment	0%	0%	0%	0	0%	0%	0%	0%	0%
Heavy-duty vehicles	-38%	-29%	-26%	na	-28%	-28%	-28%	-45%	0%
Fleet vehicles	-48%	-76%	-30%	na	11%	11%	-100%	-100%	-26%
Total	**-27%**	**-58%**	**-59%**	**-97%**	**-77%**	**-74%**	**-76%**	**-42%**	**-16%**

APPENDIX A: GLOSSARY

Air toxics – Toxic air pollutants, also known as hazardous air pollutants, are those pollutants that are known or suspected to cause cancer or other serious, chronic health effects, such as reproductive effects or birth defects, or adverse environmental effects.

Alternative fuel – All fuels used in mobile sources, except for gasoline and diesel; and for ocean-going vessels, except for heavy fuel oil (HFO) and marine distillate fuel (MDO). The term "alternative fuel" can refer to a source of which energy is renewable (See "renewable fuel").

Area source – A general term for a source that is an aggregate of all emission sources within a defined spatial boundary. Though emissions from individual sources in an area are relatively small, collectively their emissions can be of concern - particularly where large numbers of sources are located in heavily populated areas.

Auxiliary engine – A secondary engine often used when a ship is in-transit, maneuvering, or hoteling.

Baseline Air Emissions Inventory – For a given air emission source category, a baseline inventory establishes a reference point with more detailed emission data than previously existed. An established baseline allows comparison with future inventories of similar precision to describe changes to the characteristics of the source category and intensity of the emissions.

Black carbon – A component of fine particulate matter ($PM_{2.5}$), black carbon is formed through the incomplete combustion of fossil fuels, biofuel and biomass. It is emitted in both anthropogenic and non-anthropogenic soot (for example, a forest fire caused by lightning).

Brake-Specific Fuel Consumption – A way to measure the efficiency of an engine by dividing rate of fuel consumption by the rate of power production.

Cargo-handling equipment (CHE) – Equipment used to move cargo to and from marine vessels, railcars and trucks. This includes equipment such as cranes, rubber tired gantry cranes, terminal trucks, container handlers, bulk loaders, and forklifts.

Cold Ironing – Also called "Alternative Maritime Power" in application at the Port of Los Angeles and more generally referred to as "Shore Power." This specifically refers to an electrical connection made between the vessel and the terminal to provide full or partial operational power during hoteling periods. The primary motivation for cold ironing has been as a method to reduce emissions from the exhausts of auxiliary engines that would normally operate during hoteling. "Cold iron" is a reference to when ships mainly used boilers to produce steam for propulsion, heat, and power. When the steam production was shut down, the iron in the boiler housing would go cold.

Commercial vessel – Any vessel involved in commercial trade or business.

Criteria pollutants – A regulatory term that refers specifically to six outdoor air pollutants for which EPA is required to develop National Ambient Air Quality Standards (NAAQS), as codified in the federal Clean Air Act. These six are carbon monoxide (CO), lead, nitrogen dioxide (NO_2), particulate matter (PM), ozone, and sulfur oxides.

Deadweight tonnage – Refers to the total amount of weight that a vessel is carrying, minus the actual weight of the vessel.

Deterioration factor – For use in emission or performance calculation, this number accounts for the effect of gradual wear in the internal engine components in the course of normal operation.

Diesel – In standard use, this refers to a specific fractional distillate of fuel oil that is used as fuel in a compression-ignition (CI) engine. Practically, diesel can refer generally to any hydrocarbon-dense oil with relatively low volatility that can be used as a combustion fuel. In common maritime use, diesel can refer to several varieties of distillate fuels including "Marine Diesel Oil" (MDO, aka DMB or DMC) and "Marine Gas Oil" (MGO, aka DMA or DMX) as specified by ISO 8217. Diesel can also be referred to by its sulfur content, such as the case of LSD (low sulfur diesel with less than 500ppm sulfur) or ULSD.

Diesel-electric – Refers to equipment that uses electric motive systems that rely on electricity from diesel generators.

Diesel Oxidation Catalyst (DOC) – A flow-through canister, fit to an engine exhaust pipe, containing a honeycomb-like structure or substrate. The substrate has a large surface area that is coated with an active catalyst layer. This layer contains a small, well dispersed amount of precious metals such as platinum or palladium. As exhaust gases pass over the catalyst, carbon monoxide, gaseous hydrocarbons and liquid hydrocarbon particles (unburned fuel and oil) are oxidized, thereby reducing harmful emissions.

Diesel Particulate Matter (DPM) – Refers to particulate components of combustion products that are directly emitted from diesel engines. The DPM presented in the tables has a cutoff of 10 um. The particulate components include soot (elemental or black carbon) and other aerosols that are complex aggregates of hydrocarbons, metals, silicates, and other chemicals. In recent years, DPM has been singled out as posing a carcinogenic risk to people who are regularly exposed to it over the course of many years.

Diesel Particulate Filter (DPF) – A filter installed on the exhaust pipe of diesel engine to physically separate particulate matter from the exhaust stream. Some filters are single use (disposable), while others are designed to burn off the accumulated particulate, either through the use of a catalyst (passive), or through an active technology, such as a fuel burner which heats the filter to soot combustion temperatures

Economizer – A heat exchanger that transfers heat from the exhaust stream to a water circulation system to produce steam. Often used when a vessel is in transit, an economizer can allow the regular diesel-powered boiler to be shut off.

Emission factor – A number specific to an engine or system that describes the amount of a pollutant that is generated per unit of activity, e.g. mg/mile or g/hr.

Emulsified fuel – A homogenized blend of water into diesel fuel that changes the fuel combustion characteristics and resulting emissions. This strategy is mainly employed to reduce NO_x emissions but may also reduce PM and improve fuel economy.

Energy consumption – emissions source activity, expressed as kW-hrs.

EPA NONROAD model – NONROAD is a computer modeling program created and regularly updated by EPA that calculates past, present, and future emission inventories (i.e., tons of pollutant) for all non-road equipment categories except commercial marine, locomotives, and aircraft. For a specified geographic area, time period, and fuel type, the model estimates exhaust and evaporative hydrocarbons (HC), carbon monoxide (CO), oxides of nitrogen (NO_x), particulate matter (PM), sulfur dioxide (SO_2), and carbon dioxide (CO_2). The NONROAD model was incorporated into MOVES, EPA's emission modeling system that estimates emissions from mobile sources at the national, county, and project level for criteria air pollutants, greenhouse gases, and air toxics.

Exhaust gas recirculation (EGR) – A technique used in most gasoline and diesel-powered engines to control emissions. Engine exhaust is mixed with engine intake air and recirculated through the combustion process. The result is a reduction in NO_x emissions due to lower combustion temperatures and reduction of excess oxygen.

Fine particulate matter – See *Particulate Matter*

Four-stroke engines – The most common type of engine for cars and trucks. This engine uses the 'Otto cycle' and consists of four strokes. 1. intake stroke, 2. compression stroke, 3. power (ignition) stroke, and 4. exhaust stroke.

Fuel correction factor (FCF) – A number used in emission inventory models to reflect the impact on emissions of commercially dispensed fuel compared to fuel used during the certification process. These factors are derived as the ratio of the impact of the dispensed fuel to the impact of the certification fuel.

Fuel Oil – A general term for viscous liquid fuels used for powering engines. In the maritime industry the following classifications are used.

- ***Marine gas oil (MGO) –*** A purely distillate fuel (see "diesel")
- ***Marine diesel oil (MDO) –*** A blend of gas oil and heavy fuel oil
- ***Intermediate fuel oil (IFO) –*** A blend of gas oil and heavy fuel oil, with less gas oil than marine diesel oil
- ***Medium fuel oil (MDO) –*** A blend of gas oil and heavy fuel oil, with less gas oil than intermediate fuel oil
- ***Heavy fuel oil (HFO)*** – Pure or nearly pure residual oil (bunker fuel)

Fugitive emissions – Emissions not created through a defined process or controlled by a dedicated system. These can be due to equipment leaks, evaporative processes, materials processing, and windblown disturbances

GHG equivalent – Similar to "carbon equivalent" this refers to a method by which air emissions are standardized for comparison based on their "global warming potential" (GWP) as greenhouse gases. Each greenhouse gas differs in its ability to absorb heat in the atmosphere so will be presented in units of carbon equivalents, which weighs each gas by its GWP relative to carbon dioxide. The time period usually used for GWPs is 100 years.

Greenhouse Gas – Substances in the atmosphere that absorb radiated heat form the earth's surface and also radiate heat back to the surface, causing a net retention of heat energy. Carbon dioxide, methane, and nitrous oxide are common examples.

Gross vehicle weight rating – The estimated total weight of a road vehicle that is loaded to capacity, including the weight of the vehicle, the passengers, fuel, cargo, and miscellaneous items. The rating allows the vehicle driver to know what routes are acceptable, depending on whether the roadways can accommodate a vehicle of the estimated weight.

Harbor vessel– A term that generally refers to vessels that do not make regular ocean passage. These include commercial fishing boats, tug boats, ferries, workboats, etc.; governmental (non-military) vessels such as ferries and other vessels; tank barges; and recreational vessels. For the purpose of this report, any vessel that is not an ocean-going vessel, recreational vessel, or tank barge, has been categorized as a commercial harbor vessel, government (non-military) vessels, tank barges, or recreational vessels.

Heavy-duty vehicle – A class 8 truck fueled by diesel and has a gross vehicle weight of 33,001 lbs or higher.

Hoteling – The period during which a vessel is secured at berth

Hydrocarbon – A chemical term referring to compounds that consists of carbon and hydrogen in various structures. Most common liquid fuels are primarily comprised of some form of hydrocarbon.

Intermodal Container Transfer Facility – A rail yard that is located close to a port facility and is where a cargo transition between two different transportation modes (e.g. trucks, trains, or ships) occurs.

Light-duty vehicle (LDV) – Class 1 and 2 vehicles that can use gas or diesel fuel and have a gross vehicle weight of 6,000 lbs or less (class 1) or between 6,001 and 10,000 lbs (class 2).

Liquefied Natural Gas (LNG) – Natural gas that has been processed to remove impurities and heavy hydrocarbons and is then condensed into a liquid using extremely low temperature or high pressure.

Liquefied Petroleum Gas (LPG) – A mixture of hydrocarbon gases that are commonly used to fuel heating appliances and vehicles. The two most common forms of liquefied petroleum gas are propane and butane.

Load Factor (LF) – A ratio of an engine's average actual power used to its maximum power rating.

Low Sulfur Diesel (LSD) – See "Diesel"

Main line locomotives – Also called "line-haul," these are the largest class of locomotives and are designed for the heaviest loads, longest distances, and steepest grades.

Main propulsion engine – The engines on a vessel that are dedicated to movement of a ship over long distances.

Marine Diesel Oil (MDO) – See "Fuel Oil"

Maximum continuous rating – A value assigned to a piece of equipment by its manufacturer that sets a guideline for which the equipment can be operated for an unlimited period of time without damage.

National Ambient Air Quality Standards (NAAQS) – A term referring to a specific legal instrument under the federal Clean Air Act that creates enforceable limits to airborne concentrations of "criteria pollutants." NAAQS are currently required for six substances (See "criteria pollutants"). NAAQS can be of two types: "Primary NAAQS" are designed to protect human health, including sensitive populations such as children, the elderly, and individuals suffering from respiratory disease. "Secondary" NAAQS are designed to protect public welfare (e.g., building facades, visibility, crops, and domestic animals).

Non-Methane Organic Gas (NMOG) – Organic gases that exclude methane but account for all other organic pollutants that form a foundation for the formation of ozone.

Ocean-going vessel (OGV) – Vessels that operate in open oceanic waters.

Particulate Matter (PM) – A general term for any substance, except pure water, that exists as a liquid or solid in the atmosphere under normal conditions and is of microscopic or sub-microscopic size but larger than molecular dimensions. Airborne PM can result from direct emissions of particles (primary PM) or from condensation of certain gases that have themselves been directly emitted or chemically transformed in the atmosphere (secondary PM). PM is often classified by size:

- ***$PM_{2.5}$***– Also known as "fine" particulate matter, $PM_{2.5}$ refers to the fraction of PM in a sample that is 2.5 microns in diameter or less. This size of PM is commonly associated with combustion and secondary PM.
- ***PM_{10}***– Also known as "coarse" particulate matter, PM_{10} refers to the fraction of PM in a sample that is 10 microns in diameter or less.

Renewable Fuels – Fuels derived from sources that are regenerative or for all practical purposes cannot be depleted.

Residual oil – "Residual Fuel Oil" or "Bunker Fuel" – See "Fuel Oil"

Roll-on/Roll-off (RoRo) – A vessel featuring a built-in ramp for wheeled cargo to be 'rolled-on' and 'rolled-off' of the vessel.

Rubber Tired Gantry (RTG) Crane – A common piece of cargo-handling equipment at marine terminals used to transfer containers from stacked storage to a vehicle.

Selective Catalytic Reduction (SCR) – A process where a gaseous or liquid reductant (most commonly ammonia or urea) is added to the flue or exhaust gas stream and absorbed onto a catalyst. The reductant reacts with NO_x in the exhaust gas to form H_2O (water vapor) and N_2 (nitrogen gas).

Sea water scrubbing – An exhaust treatment technique used on ships to reduce emissions by through physical and chemical interaction with sea water. When the exhaust comes in contact with the seawater, the SO_2 reacts with calcium carbonate to form a solid calcium sulfate and CO_2. Scrubbers also function by physically scavenging particles and gases from the air.

Shaft generators – Provides electric power to a moving vessel by generating current from the rotation of the vessel's drive shaft.

Shore power – See "Cold Ironing"

Point source – A single, stationary point source of emissions that is immoveable for all practical purposes.

Switching locomotive – A locomotive that is used exclusively in a facility where rail cars are organized and assembled into trains.

Total organic gases – The sum of reactive and non-reactive organic gases in the air.

Twenty-foot Equivalent Unit (TEU) – A measure used for containerized cargo. One TEU is equivalent to one standard cargo container measured 20' x 8' x 8'6".

Two-stroke engines – A type of internal combustion engine that completes the same four processes as a four-stroke engine (intake, compression, power, and exhaust) in only two strokes of the piston rather than four. This is accomplished by using the space below the piston for air intake and compression, thus allowing the chamber above the piston to be used for just the power and exhaust strokes. This results in a power stroke with every revolution of the crank, instead of every second revolution as in a four-stroke engine. For this reason, two-stroke engines provide high specific power, so they are valued for use in portable, lightweight applications. Two stoke diesel engines are common in large marine vessels.

Ultra-Low Sulfur Diesel (ULSD) – See "diesel"

Volatile Organic Compound (VOC) – A very broad term used to describe the entire set of vapor-phase atmospheric organic chemicals except CO and CO_2.

APPENDIX B: OGV EMISSIONS ESTIMATING METHODOLOGY

OGV Emissions Estimating Methodology

In developing an activity-based emissions inventory for marine vessels, emissions are estimated as a function of vessel power demand (expressed in kW-hrs) multiplied by an emission factor, where the emission factor is expressed in terms of grams per kilowatt-hour (g/kW-hr). Since the basic emission factors are based on E3 cycle and HFO fuel, these factors are further adjusted to the fuel currently used due to ECA (see Section 3.5), and for propulsion engines. The emission factors are further adjusted to reflect the change in emissions at loads different than E3 marine cycle for propulsion engine. The load adjustment factors are further explained later in this section.

Equation 1

$$E_i = Energy_i \times EF \times FCF$$

Where:
E_i = Emissions by mode
$Energy_i$ = Energy demand by mode, calculated using Equation 2 below as the energy output of the engine(s) or boiler(s) over the period of time, kW-hr
EF = emission factor, expressed in terms of g/kW-hr
FCF = fuel correction factor, dimensionless

The 'Energy' term of the equation is where most of the location-specific information is used. Energy is calculated using Equation 2:

Equation 2

$$Energy_i = Load \times Activity$$

Where:
$Energy_i$ = Energy demand by mode, kW-hr
Load = maximum continuous rated (MCR) times load factor (LF) for propulsion engine power (kW); reported operational load of the auxiliary engine(s), by mode (kW); or reported operational load of the auxiliary boiler, by mode (kW)
Activity = activity, hours

Propulsion Engine Maximum Continuous Rated Power

MCR power is defined as the manufacturer's tested engine power; for this study, it is assumed that the Lloyd's 'Power' value included in IHS Markit vessel data, commonly known as Lloyd's data (IHS) is the MCR power. The international specification is to report 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 80% of MCR. For diesel-electric configured ships, MCR is the combined rated electric propulsion motor(s) rating, in kW.

Propulsion Engine Load Factor

Propulsion engine load factor is estimated using the Propeller Law, which is expressed with the cube of ratio of actual vessel speed to vessel's maximum rated speed.

Equation 3

$$LF = (Speed_{Actual} / Speed_{Maximum})^3$$

Where:
LF = load factor, percent
$Speed_{Actual}$ = actual speed, knots
$Speed_{Maximum}$ = maximum speed, knots

Propulsion Engine Time in Mode

Activity is measured in hours of operation within the geographical boundary. Vessel transit and maneuvering times were estimated by dividing the distance traveled by ship speed. The distance and ship speed are defined in the routing data.

Equation 4

$$Activity = D/Speed_{Actual}$$

Where:
Activity = activity, hours
D = distance, nautical miles
$Speed_{Actual}$ = actual ship speed, knots

Hoteling time is calculated by subtracting the vessel departure time from the arrival time to estimate hours of hoteling for both at berth and anchorage. Vessel speeds and route distances previously established[1] based on data collected during vessel boardings and discussion with Pilots were maintained in this study. A sample set of Automatic Identification System data (AIS), which contains information on vessel position and speed, was analyzed using Geographic Information System (GIS) software and used to verify vessel speed assumptions. The AIS data sample contained data from vessel activities transiting the Puget Sound during the typically high traffic months of June and July, for the year 2016. The sample set included the northern area of Puget Sound from Point No Point and extended south to Elliot Bay, since vessels calling the larger Puget Sound Ports must transit through some or all of this area. If specific vessel speeds were not assigned for a particular route segment, the vessel was assumed to be traveling at its "service speed". In this study, the service speed was assumed to be 80% of the vessel's max rated speed.

Propulsion Engine Emission Factors

The main engine emission factors used in this study were reported in the ENTEC 2002 study,[2] except for PM, CO and greenhouse gas emission factors. An IVL Swedish Environmental Research Institute 2004 study[3] was the source for the PM emission factors for gas turbine and steamship vessels, as well as CO, CO_2, and N_2O. Per IVL 2004 study data, CH_4 were assumed to be 0.2% of HC emission factors.

[1] 2011 Puget Sound Maritime Air Emissions Inventory, May 2013 Update.

[2] ENTEC, *Quantification of Emissions from Ships Associated with Ship Movements between Ports in the European Community, Final Report*, July 2002

[3] IVL, *Methodology for Calculating Emissions from Ships: Update on Emission Factors,* 2004. (IVL 2004)

The main and auxiliary engine particulate matter (PM_{10}) and SO_x emission factors are based on the following equations[4] for HFO fuel with 2.7% sulfur content:

Equation 5

$$PM_{10}\ EF\ (g/kW-hr)\ for\ HFO = 1.35 + BSFC\ x\ 7\ x\ 0.02247\ x\ (Fuel\ Sulfur\ Fraction - 0.0246)$$

Where:
BSFC = brake specific fuel consumption in g/kW-hr

Equation 6

$$SO_2\ EF\ (g/kW-hr) = BSFC\ x\ 2\ x\ 0.97753\ x\ (Fuel\ Sulfur\ Fraction)$$

Where:
0.97753 is the fraction of fuel sulfur converted to SO_2 and 2 is the ratio of molecular weights of SO_2 and S.

The base emission factors are based on residual fuel oil/ heavy fuel oil (HFO) with average sulfur content of 2.7%. Starting in 2015, the North American Emission Control Area (ECA) requires all ships operating within ECA boundary of 200 nautical miles from U.S. coastline to utilize fuels with 0.1% S or lower. The emission factors were corrected using fuel correction factors (FCFs) from the baseline HFO 2.7% S to marine diesel oil (MDO) 0.1% S. The fuel correction factors reflect the change in emissions due to different S content and formulation of HFO versus MDO fuels and are based on fuel correction factors included in the California Air Resources Board's (CARB) regulatory report entitled "Emissions Estimation Methodology for Ocean-Going Vessels"[5]. The fuel correction factors developed in this report are based on information that CARB and EPA have collected. Table B.1 lists the FCFs used[6].

Table B.1: OGV Fuel Correction Factors for MDO 0.1% S

Actual Fuel	Sulfur Content	NO_x	HC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2
MDO	0.10%	0.94	1.00	1.00	0.037	0.17	0.20	0.17	0.40	0.95

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 (typically greater than 400 rpm) and less than 2,000 rpm.

[4] Current Methodologies in Preparing Mobile Source Port-Related Emission Inventories, Final Report, April 2009
[5] ARB, *www.arb.ca.gov/regact/2011/ogv11/ogv11appd.pdf*
[6] ARB, *www.arb.ca.gov/regact/2011/ogv11/ogv11appd.pdf*

Vessel specific NO_x emission factors from Engine International Air Pollution Prevention certificates (EIAPP) collected as part of the Vessel Boarding Program (VBP) program were used for propulsion and auxiliary engines. In this inventory, there were 34 vessels with EIAPP NO_x factors. The default emission factors were used for vessels that did not have EIAPP certificates available. NO_x emission factors are based on the IMO Tier of the vessel engines, which is based on the keel laid date provided in the IHS data. Table B.2 list the adjusted emission factors for propulsion engines using 0.1% sulfur MDO. The 0.1% sulfur MDO emission factors were calculated by multiplying the 2.7% sulfur HFO base emission factors by the appropriate pollutant FCF shown in Table B.1.

Table B.2: Emission Factors for Propulsion Engines using 0.1 %S MDO, g/kW-hr

Engine Category	Model Year Range	NO_x	HC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon
Slow speed main (Tier 0)	1999 and older	17.0	0.60	1.40	0.38	0.24	0.23	0.24	0.0137
Slow speed main (Tier 1)	2000 to 2011	16.0	0.60	1.40	0.38	0.24	0.23	0.24	0.0137
Slow speed main (Tier 2)	2011 to 2016	14.4	0.60	1.40	0.38	0.24	0.23	0.24	0.0137
Slow speed main (Tier 3)	2016 +	3.4	0.60	1.40	0.38	0.24	0.23	0.24	0.0137
Medium speed main (Tier 0)	1999 and older	13.2	0.50	1.10	0.42	0.24	0.23	0.24	0.0137
Medium speed main (Tier 1)	2000 to 2011	12.2	0.50	1.10	0.42	0.24	0.23	0.24	0.0137
Medium speed main (Tier 2)	2011 to 2016	10.5	0.50	1.10	0.42	0.24	0.23	0.24	0.0137
Medium speed main (Tier 3)	2016 +	2.6	0.50	1.10	0.42	0.24	0.23	0.24	0.0137
Gas turbine	All	5.7	0.10	0.20	0.60	0.01	0.01	0.00	0.0006
Steam main engine and boiler	All	2.0	0.10	0.20	0.60	0.16	0.15	0.00	0.0089

Engine Category	Model Year Range	CO_2	N_2O	CH_4
Slow speed main (Tier 0)	1999 and older	589	0.029	0.012
Slow speed main (Tier 1)	2000 to 2011	589	0.029	0.012
Slow speed main (Tier 2)	2011 to 2016	589	0.029	0.012
Slow speed main (Tier 3)	2016 +	589	0.029	0.012
Medium speed main (Tier 0)	1999 and older	649	0.029	0.010
Medium speed main (Tier 1)	2000 to 2011	649	0.029	0.010
Medium speed main (Tier 2)	2011 to 2016	649	0.029	0.010
Medium speed main (Tier 3)	2016 +	649	0.029	0.010
Gas turbine	All	922	0.075	0.002
Steam main engine and boiler	All	922	0.075	0.002

Propulsion Engines Load Adjustment Factors

In general terms, diesel-cycle engines are not as efficient when operating at low loads. An EPA study[7] prepared by Energy and Environmental Analysis, Inc. (EEAI) established a formula for calculating emission factors for low engine load conditions such as those encountered during harbor maneuvering and when traveling slowly at sea. While mass emissions, pounds per hour, tend to go down as vessel speeds and engine loads decrease, the emission factors, g/kW-hr increase. This is based on observations that compression-cycle combustion engines are less efficient at low loads.

The following equations describe the low-load effect where emission rates can increase, based on a limited set of data from Lloyd's Maritime Program and the USCG. The low load effect was also described in a study conducted for the EPA by ENVIRON.[8] Equation 7 is the equation developed by EEAI to generate emission factors for the range of load factors from 2% to <20% for each pollutant:

Equation 7

$$y = a\,(fractional\ load)^{-x} + b$$

Where:
y = emission factor, g/kW-hr
a = coefficient
b = intercept
x = exponent (negative)
fractional load = propulsion engine load factor (2% - <20%), derived by the Propeller Law, percent

Table B.3 lists the load adjustment factors (LAF), multipliers used for non-MAN diesel propulsion engines. Adjustments to N_2O and CH_4 emission factors are made based on the NO_x and HC low load adjustments, respectively. The LAF adjustment is not applied at engine loads greater than 20%. For main engine loads below 20%, the LAF increases to reflect increased emissions on a g/kW-hr basis due to engine inefficiency. Low load emission factors do not apply to steamships or ships having gas turbines because the EPA study only observed an increase in emissions from diesel engines.

[7] EPA, *Analysis of Commercial Marine Vessels Emissions and Fuel Consumption Data,* February 2000
[8] EPA, *Commercial Marine Inventory Development,* July 2002

Table B.3: 2-Stroke non-MAN Propulsion Engines Load Adjustment Factors

Load	NO_x	HC	CO	SO_2	PM	$PM_{2.5}$	DPM	CO_2	N_2O	CH_4
2%	4.63	21.18	9.68	3.30	7.29	7.29	7.29	3.28	4.63	21.18
3%	2.92	11.68	6.46	2.45	4.33	4.33	4.33	2.44	2.92	11.68
4%	2.21	7.71	4.86	2.02	3.09	3.09	3.09	2.01	2.21	7.71
5%	1.83	5.61	3.89	1.77	2.44	2.44	2.44	1.76	1.83	5.61
6%	1.60	4.35	3.25	1.60	2.04	2.04	2.04	1.59	1.60	4.35
7%	1.45	3.52	2.79	1.47	1.79	1.79	1.79	1.47	1.45	3.52
8%	1.35	2.95	2.45	1.38	1.61	1.61	1.61	1.38	1.35	2.95
9%	1.27	2.52	2.18	1.31	1.48	1.48	1.48	1.31	1.27	2.52
10%	1.22	2.20	1.96	1.26	1.38	1.38	1.38	1.25	1.22	2.20
11%	1.17	1.96	1.79	1.21	1.30	1.30	1.30	1.21	1.17	1.96
12%	1.14	1.76	1.64	1.17	1.24	1.24	1.24	1.17	1.14	1.76
13%	1.11	1.60	1.52	1.14	1.19	1.19	1.19	1.14	1.11	1.60
14%	1.08	1.47	1.41	1.11	1.15	1.15	1.15	1.11	1.08	1.47
15%	1.06	1.36	1.32	1.09	1.11	1.11	1.11	1.08	1.06	1.36
16%	1.05	1.26	1.24	1.06	1.08	1.08	1.08	1.06	1.05	1.26
17%	1.03	1.18	1.17	1.05	1.06	1.06	1.06	1.04	1.03	1.18
18%	1.02	1.11	1.11	1.03	1.04	1.04	1.04	1.03	1.02	1.11
19%	1.01	1.05	1.05	1.01	1.02	1.02	1.02	1.01	1.01	1.05
20%	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00	1.00

A recent emissions test study[9] sponsored by the Ports of Los Angeles and Long Beach on two MAN B&W engines provided additional test data indicating emissions vary across all loads and the HC and CO emission factors for MAN B&W engines are significantly lower than the emission factors obtained from literature and used for all engines. Based on the test results, improvements were made to the emission factors. The following emission factor adjustments (EFA) were applied to CO and HC for which test results were significantly different in magnitude than the default emission factors used in previous inventories. Consequently, the 2005 and 2011 PSEI OGV emissions have changed as a result of this emission factor adjustment.

- HC/VOC EFA for MAN B&W engines with slide valves = 0.43;
- HC/VOC EFA for MAN B&W engines with conventional valves = 1.0;
- CO EFA for MAN B&W engines with slide valves = 0.59;
- CO EFA for MAN B&W engines with conventional valves = 0.44.
- EFA for all the other pollutants is 1.0.

[9] MAN Slide Valve Low-Load Emissions Test, Final Report; June 2013; Prepared by Starcrest Consulting Group, LLC, Mitsui Engineering & Shipbuilders LTD & MAN DieselTurboA/S

Tables B.4 and B.5 present the load adjustment factors (LAF) used across the entire engine load range for MAN 2-stroke propulsion engines with slide valves (Table B.4) and with conventional valves (Table B.5).

Table B.4: Load Adjustment Factors for MAN 2-Stroke Propulsion Engines with Slide Valves

Load	NO_x	HC	CO	SO_2	PM	$PM_{2.5}$	DPM	Black Carbon	CO_2	N_2O	CH_4
1%	1.90	1.36	0.12	1.10	0.36	0.36	0.36	0.36	1.10	1.90	1.36
2%	1.86	1.32	0.12	1.10	0.37	0.37	0.37	0.37	1.10	1.86	1.32
3%	1.82	1.28	0.12	1.09	0.38	0.38	0.38	0.38	1.09	1.82	1.28
4%	1.78	1.24	0.12	1.09	0.38	0.38	0.38	0.38	1.09	1.78	1.24
5%	1.74	1.20	0.12	1.09	0.39	0.39	0.39	0.39	1.09	1.74	1.20
6%	1.70	1.17	0.12	1.08	0.40	0.40	0.40	0.40	1.08	1.70	1.17
7%	1.67	1.14	0.12	1.08	0.41	0.41	0.41	0.41	1.08	1.67	1.14
8%	1.63	1.11	0.12	1.08	0.41	0.41	0.41	0.41	1.08	1.63	1.11
9%	1.60	1.08	0.12	1.07	0.42	0.42	0.42	0.42	1.07	1.60	1.08
10%	1.57	1.05	0.12	1.07	0.43	0.43	0.43	0.43	1.07	1.57	1.05
11%	1.53	1.02	0.26	1.07	0.44	0.44	0.44	0.44	1.07	1.53	1.02
12%	1.50	0.99	0.39	1.07	0.45	0.45	0.45	0.45	1.07	1.50	0.99
13%	1.47	0.97	0.52	1.06	0.45	0.45	0.45	0.45	1.06	1.47	0.97
14%	1.45	0.94	0.64	1.06	0.46	0.46	0.46	0.46	1.06	1.45	0.94
15%	1.42	0.92	0.75	1.06	0.47	0.47	0.47	0.47	1.06	1.42	0.92
16%	1.39	0.90	0.85	1.06	0.48	0.48	0.48	0.48	1.06	1.39	0.90
17%	1.37	0.88	0.95	1.05	0.49	0.49	0.49	0.49	1.05	1.37	0.88
18%	1.34	0.86	1.04	1.05	0.49	0.49	0.49	0.49	1.05	1.34	0.86
19%	1.32	0.84	1.12	1.05	0.50	0.50	0.50	0.50	1.05	1.32	0.84
20%	1.30	0.82	1.20	1.05	0.51	0.51	0.51	0.51	1.05	1.30	0.82
21%	1.28	0.81	1.27	1.04	0.52	0.52	0.52	0.52	1.04	1.28	0.81
22%	1.26	0.79	1.34	1.04	0.53	0.53	0.53	0.53	1.04	1.26	0.79
23%	1.24	0.78	1.40	1.04	0.54	0.54	0.54	0.54	1.04	1.24	0.78
24%	1.22	0.76	1.46	1.04	0.54	0.54	0.54	0.54	1.04	1.22	0.76
25%	1.20	0.75	1.51	1.03	0.55	0.55	0.55	0.55	1.03	1.20	0.75

Table B.4 (continued): Load Adjustment Factors for MAN 2-Stroke Propulsion Engines with Slide Valves

Load	NO_x	HC	CO	SO_2	PM	$PM_{2.5}$	DPM	Black Carbon	CO_2	N_2O	CH_4
26%	1.19	0.74	1.55	1.03	0.56	0.56	0.56	0.56	1.03	1.19	0.74
27%	1.17	0.73	1.59	1.03	0.57	0.57	0.57	0.57	1.03	1.17	0.73
28%	1.16	0.72	1.63	1.03	0.58	0.58	0.58	0.58	1.03	1.16	0.72
29%	1.14	0.71	1.66	1.03	0.59	0.59	0.59	0.59	1.03	1.14	0.71
30%	1.13	0.70	1.68	1.02	0.60	0.60	0.60	0.60	1.02	1.13	0.70
31%	1.12	0.70	1.70	1.02	0.60	0.60	0.60	0.60	1.02	1.12	0.70
32%	1.10	0.69	1.72	1.02	0.61	0.61	0.61	0.61	1.02	1.10	0.69
33%	1.09	0.69	1.74	1.02	0.62	0.62	0.62	0.62	1.02	1.09	0.69
34%	1.08	0.68	1.75	1.02	0.63	0.63	0.63	0.63	1.02	1.08	0.68
35%	1.07	0.68	1.75	1.02	0.64	0.64	0.64	0.64	1.02	1.07	0.68
36%	1.06	0.68	1.75	1.01	0.65	0.65	0.65	0.65	1.01	1.06	0.68
37%	1.05	0.67	1.75	1.01	0.66	0.66	0.66	0.66	1.01	1.05	0.67
38%	1.05	0.67	1.75	1.01	0.67	0.67	0.67	0.67	1.01	1.05	0.67
39%	1.04	0.67	1.74	1.01	0.68	0.68	0.68	0.68	1.01	1.04	0.67
40%	1.03	0.67	1.73	1.01	0.69	0.69	0.69	0.69	1.01	1.03	0.67
41%	1.03	0.67	1.72	1.01	0.70	0.70	0.70	0.70	1.01	1.03	0.67
42%	1.02	0.68	1.71	1.01	0.70	0.70	0.70	0.70	1.01	1.02	0.68
43%	1.02	0.68	1.69	1.01	0.71	0.71	0.71	0.71	1.01	1.02	0.68
44%	1.01	0.68	1.67	1.00	0.72	0.72	0.72	0.72	1.00	1.01	0.68
45%	1.01	0.69	1.65	1.00	0.73	0.73	0.73	0.73	1.00	1.01	0.69
46%	1.00	0.69	1.62	1.00	0.74	0.74	0.74	0.74	1.00	1.00	0.69
47%	1.00	0.70	1.60	1.00	0.75	0.75	0.75	0.75	1.00	1.00	0.70
48%	1.00	0.70	1.57	1.00	0.76	0.76	0.76	0.76	1.00	1.00	0.70
49%	0.99	0.71	1.54	1.00	0.77	0.77	0.77	0.77	1.00	0.99	0.71
50%	0.99	0.71	1.51	1.00	0.78	0.78	0.78	0.78	1.00	0.99	0.71

Table B.4 (continued): Load Adjustment Factors for MAN 2-Stroke Propulsion Engines with Slide Valves

Load	NO_x	HC	CO	SO_2	PM	$PM_{2.5}$	DPM	Black Carbon	CO_2	N_2O	CH_4
51%	0.99	0.72	1.48	1.00	0.79	0.79	0.79	0.79	1.00	0.99	0.72
52%	0.99	0.73	1.45	1.00	0.80	0.80	0.80	0.80	1.00	0.99	0.73
53%	0.99	0.74	1.41	1.00	0.81	0.81	0.81	0.81	1.00	0.99	0.74
54%	0.99	0.75	1.38	1.00	0.82	0.82	0.82	0.82	1.00	0.99	0.75
55%	0.98	0.75	1.35	0.99	0.83	0.83	0.83	0.83	0.99	0.98	0.75
56%	0.98	0.76	1.31	0.99	0.84	0.84	0.84	0.84	0.99	0.98	0.76
57%	0.98	0.77	1.27	0.99	0.85	0.85	0.85	0.85	0.99	0.98	0.77
58%	0.98	0.78	1.24	0.99	0.86	0.86	0.86	0.86	0.99	0.98	0.78
59%	0.98	0.80	1.20	0.99	0.87	0.87	0.87	0.87	0.99	0.98	0.80
60%	0.98	0.81	1.16	0.99	0.88	0.88	0.88	0.88	0.99	0.98	0.81
61%	0.98	0.82	1.13	0.99	0.89	0.89	0.89	0.89	0.99	0.98	0.82
62%	0.98	0.83	1.09	0.99	0.90	0.90	0.90	0.90	0.99	0.98	0.83
63%	0.99	0.84	1.06	0.99	0.91	0.91	0.91	0.91	0.99	0.99	0.84
64%	0.99	0.85	1.02	0.99	0.92	0.92	0.92	0.92	0.99	0.99	0.85
65%	0.99	0.87	0.98	0.99	0.93	0.93	0.93	0.93	0.99	0.99	0.87
66%	0.99	0.88	0.95	0.99	0.94	0.94	0.94	0.94	0.99	0.99	0.88
67%	0.99	0.89	0.92	0.99	0.95	0.95	0.95	0.95	0.99	0.99	0.89
68%	0.99	0.91	0.88	0.99	0.97	0.97	0.97	0.97	0.99	0.99	0.91
69%	0.99	0.92	0.85	0.99	0.98	0.98	0.98	0.98	0.99	0.99	0.92
70%	0.99	0.93	0.82	0.99	0.99	0.99	0.99	0.99	0.99	0.99	0.93
71%	0.99	0.95	0.79	0.99	1.00	1.00	1.00	1.00	0.99	0.99	0.95
72%	0.99	0.96	0.76	0.99	1.01	1.01	1.01	1.01	0.99	0.99	0.96
73%	0.99	0.98	0.74	0.99	1.02	1.02	1.02	1.02	0.99	0.99	0.98
74%	0.99	0.99	0.71	0.99	1.03	1.03	1.03	1.03	0.99	0.99	0.99
75%	0.99	1.00	0.69	0.99	1.04	1.04	1.04	1.04	0.99	0.99	1.00

Table B.4 (continued): Load Adjustment Factors for MAN 2-Stroke Propulsion Engines with Slide Valves

Load	NO_x	HC	CO	SO_2	PM	$PM_{2.5}$	DPM	Black Carbon	CO_2	N_2O	CH_4
76%	0.99	1.02	0.66	0.99	1.05	1.05	1.05	1.05	0.99	0.99	1.02
77%	0.99	1.03	0.64	0.99	1.06	1.06	1.06	1.06	0.99	0.99	1.03
78%	0.99	1.05	0.63	0.99	1.07	1.07	1.07	1.07	0.99	0.99	1.05
79%	0.99	1.06	0.61	0.99	1.09	1.09	1.09	1.09	0.99	0.99	1.06
80%	0.99	1.08	0.60	0.99	1.10	1.10	1.10	1.10	0.99	0.99	1.08
81%	0.99	1.09	0.58	0.99	1.11	1.11	1.11	1.11	0.99	0.99	1.09
82%	0.99	1.10	0.57	0.99	1.12	1.12	1.12	1.12	0.99	0.99	1.10
83%	0.98	1.12	0.57	0.99	1.13	1.13	1.13	1.13	0.99	0.98	1.12
84%	0.98	1.13	0.56	0.99	1.14	1.14	1.14	1.14	0.99	0.98	1.13
85%	0.98	1.15	0.56	0.99	1.15	1.15	1.15	1.15	0.99	0.98	1.15
86%	0.98	1.16	0.56	0.99	1.16	1.16	1.16	1.16	0.99	0.98	1.16
87%	0.97	1.18	0.56	0.99	1.18	1.18	1.18	1.18	0.99	0.97	1.18
88%	0.97	1.19	0.57	0.99	1.19	1.19	1.19	1.19	0.99	0.97	1.19
89%	0.96	1.20	0.58	0.99	1.20	1.20	1.20	1.20	0.99	0.96	1.20
90%	0.96	1.22	0.59	0.99	1.21	1.21	1.21	1.21	0.99	0.96	1.22
91%	0.95	1.23	0.61	1.00	1.22	1.22	1.22	1.22	1.00	0.95	1.23
92%	0.95	1.24	0.63	1.00	1.23	1.23	1.23	1.23	1.00	0.95	1.24
93%	0.94	1.25	0.65	1.00	1.25	1.25	1.25	1.25	1.00	0.94	1.25
94%	0.93	1.27	0.67	1.00	1.26	1.26	1.26	1.26	1.00	0.93	1.27
95%	0.93	1.28	0.70	1.00	1.27	1.27	1.27	1.27	1.00	0.93	1.28
96%	0.92	1.29	0.73	1.00	1.28	1.28	1.28	1.28	1.00	0.92	1.29
97%	0.91	1.30	0.77	1.00	1.29	1.29	1.29	1.29	1.00	0.91	1.30
98%	0.90	1.31	0.81	1.00	1.31	1.31	1.31	1.31	1.00	0.90	1.31
99%	0.89	1.32	0.85	1.00	1.32	1.32	1.32	1.32	1.00	0.89	1.32
100%	0.88	1.34	0.90	1.00	1.33	1.33	1.33	1.33	1.00	0.88	1.34

Table B.5: Load Adjustment Factors for MAN 2-Stroke Propulsion Engines with Conventional Valves

Load	NO_x	HC	CO	SO_2	PM	$PM_{2.5}$	DPM	Black Carbon	CO_2	N_2O	CH_4
1%	1.91	2.53	1.38	1.11	0.84	0.84	0.84	0.84	1.11	1.91	2.53
2%	1.86	2.45	1.36	1.11	0.83	0.83	0.83	0.83	1.11	1.86	2.45
3%	1.82	2.37	1.34	1.10	0.83	0.83	0.83	0.83	1.10	1.82	2.37
4%	1.77	2.30	1.33	1.10	0.82	0.82	0.82	0.82	1.10	1.77	2.30
5%	1.72	2.23	1.31	1.10	0.82	0.82	0.82	0.82	1.10	1.72	2.23
6%	1.68	2.16	1.29	1.09	0.81	0.81	0.81	0.81	1.09	1.68	2.16
7%	1.64	2.10	1.28	1.09	0.81	0.81	0.81	0.81	1.09	1.64	2.10
8%	1.60	2.03	1.26	1.09	0.80	0.80	0.80	0.80	1.09	1.60	2.03
9%	1.56	1.97	1.25	1.08	0.80	0.80	0.80	0.80	1.08	1.56	1.97
10%	1.52	1.91	1.24	1.08	0.79	0.79	0.79	0.79	1.08	1.52	1.91
11%	1.49	1.86	1.22	1.08	0.79	0.79	0.79	0.79	1.08	1.49	1.86
12%	1.45	1.80	1.21	1.07	0.78	0.78	0.78	0.78	1.07	1.45	1.80
13%	1.42	1.75	1.20	1.07	0.78	0.78	0.78	0.78	1.07	1.42	1.75
14%	1.39	1.70	1.19	1.07	0.78	0.78	0.78	0.78	1.07	1.39	1.70
15%	1.36	1.65	1.18	1.06	0.77	0.77	0.77	0.77	1.06	1.36	1.65
16%	1.33	1.61	1.17	1.06	0.77	0.77	0.77	0.77	1.06	1.33	1.61
17%	1.30	1.56	1.16	1.06	0.77	0.77	0.77	0.77	1.06	1.30	1.56
18%	1.28	1.52	1.15	1.06	0.77	0.77	0.77	0.77	1.06	1.28	1.52
19%	1.25	1.48	1.14	1.05	0.76	0.76	0.76	0.76	1.05	1.25	1.48
20%	1.23	1.44	1.13	1.05	0.76	0.76	0.76	0.76	1.05	1.23	1.44
21%	1.20	1.41	1.13	1.05	0.76	0.76	0.76	0.76	1.05	1.20	1.41
22%	1.18	1.37	1.12	1.05	0.76	0.76	0.76	0.76	1.05	1.18	1.37
23%	1.16	1.34	1.11	1.04	0.76	0.76	0.76	0.76	1.04	1.16	1.34
24%	1.14	1.31	1.10	1.04	0.75	0.75	0.75	0.75	1.04	1.14	1.31
25%	1.12	1.28	1.10	1.04	0.75	0.75	0.75	0.75	1.04	1.12	1.28

Table B.5 (continued): Load Adjustment Factors for MAN 2-Stroke Propulsion Engines with Conventional Valves

Load	NO_x	HC	CO	SO_2	PM	$PM_{2.5}$	DPM	Black Carbon	CO_2	N_2O	CH_4
26%	1.11	1.25	1.09	1.04	0.75	0.75	0.75	0.75	1.04	1.11	1.25
27%	1.09	1.22	1.08	1.04	0.75	0.75	0.75	0.75	1.04	1.09	1.22
28%	1.07	1.20	1.08	1.03	0.75	0.75	0.75	0.75	1.03	1.07	1.20
29%	1.06	1.17	1.07	1.03	0.75	0.75	0.75	0.75	1.03	1.06	1.17
30%	1.05	1.15	1.07	1.03	0.75	0.75	0.75	0.75	1.03	1.05	1.15
31%	1.03	1.13	1.06	1.03	0.75	0.75	0.75	0.75	1.03	1.03	1.13
32%	1.02	1.11	1.06	1.03	0.75	0.75	0.75	0.75	1.03	1.02	1.11
33%	1.01	1.09	1.05	1.02	0.75	0.75	0.75	0.75	1.02	1.01	1.09
34%	1.00	1.08	1.05	1.02	0.75	0.75	0.75	0.75	1.02	1.00	1.08
35%	0.99	1.06	1.04	1.02	0.76	0.76	0.76	0.76	1.02	0.99	1.06
36%	0.98	1.05	1.04	1.02	0.76	0.76	0.76	0.76	1.02	0.98	1.05
37%	0.98	1.04	1.03	1.02	0.76	0.76	0.76	0.76	1.02	0.98	1.04
38%	0.97	1.02	1.03	1.02	0.76	0.76	0.76	0.76	1.02	0.97	1.02
39%	0.96	1.01	1.02	1.01	0.76	0.76	0.76	0.76	1.01	0.96	1.01
40%	0.96	1.00	1.02	1.01	0.76	0.76	0.76	0.76	1.01	0.96	1.00
41%	0.95	0.99	1.01	1.01	0.77	0.77	0.77	0.77	1.01	0.95	0.99
42%	0.95	0.99	1.01	1.01	0.77	0.77	0.77	0.77	1.01	0.95	0.99
43%	0.94	0.98	1.01	1.01	0.77	0.77	0.77	0.77	1.01	0.94	0.98
44%	0.94	0.97	1.00	1.01	0.78	0.78	0.78	0.78	1.01	0.94	0.97
45%	0.94	0.97	1.00	1.01	0.78	0.78	0.78	0.78	1.01	0.94	0.97
46%	0.94	0.96	0.99	1.01	0.78	0.78	0.78	0.78	1.01	0.94	0.96
47%	0.94	0.96	0.99	1.00	0.79	0.79	0.79	0.79	1.00	0.94	0.96
48%	0.93	0.96	0.98	1.00	0.79	0.79	0.79	0.79	1.00	0.93	0.96
49%	0.93	0.96	0.98	1.00	0.79	0.79	0.79	0.79	1.00	0.93	0.96
50%	0.93	0.96	0.98	1.00	0.80	0.80	0.80	0.80	1.00	0.93	0.96

Table B.5 (continued): Load Adjustment Factors for MAN 2-Stroke Propulsion Engines with Conventional Valves

Load	NO_x	HC	CO	SO_2	PM	$PM_{2.5}$	DPM	Black Carbon	CO_2	N_2O	CH_4
51%	0.94	0.95	0.97	1.00	0.80	0.80	0.80	0.80	1.00	0.94	0.95
52%	0.94	0.95	0.97	1.00	0.81	0.81	0.81	0.81	1.00	0.94	0.95
53%	0.94	0.95	0.96	1.00	0.81	0.81	0.81	0.81	1.00	0.94	0.95
54%	0.94	0.95	0.96	1.00	0.82	0.82	0.82	0.82	1.00	0.94	0.95
55%	0.94	0.96	0.96	1.00	0.82	0.82	0.82	0.82	1.00	0.94	0.96
56%	0.94	0.96	0.95	1.00	0.83	0.83	0.83	0.83	1.00	0.94	0.96
57%	0.95	0.96	0.95	1.00	0.84	0.84	0.84	0.84	1.00	0.95	0.96
58%	0.95	0.96	0.95	1.00	0.84	0.84	0.84	0.84	1.00	0.95	0.96
59%	0.95	0.96	0.94	1.00	0.85	0.85	0.85	0.85	1.00	0.95	0.96
60%	0.95	0.97	0.94	0.99	0.86	0.86	0.86	0.86	0.99	0.95	0.97
61%	0.96	0.97	0.93	0.99	0.86	0.86	0.86	0.86	0.99	0.96	0.97
62%	0.96	0.97	0.93	0.99	0.87	0.87	0.87	0.87	0.99	0.96	0.97
63%	0.96	0.98	0.93	0.99	0.88	0.88	0.88	0.88	0.99	0.96	0.98
64%	0.97	0.98	0.93	0.99	0.89	0.89	0.89	0.89	0.99	0.97	0.98
65%	0.97	0.98	0.92	0.99	0.89	0.89	0.89	0.89	0.99	0.97	0.98
66%	0.98	0.99	0.92	0.99	0.90	0.90	0.90	0.90	0.99	0.98	0.99
67%	0.98	0.99	0.92	0.99	0.91	0.91	0.91	0.91	0.99	0.98	0.99
68%	0.98	0.99	0.91	0.99	0.92	0.92	0.92	0.92	0.99	0.98	0.99
69%	0.99	1.00	0.91	0.99	0.93	0.93	0.93	0.93	0.99	0.99	1.00
70%	0.99	1.00	0.91	0.99	0.94	0.94	0.94	0.94	0.99	0.99	1.00
71%	0.99	1.00	0.91	0.99	0.94	0.94	0.94	0.94	0.99	0.99	1.00
72%	1.00	1.01	0.91	0.99	0.95	0.95	0.95	0.95	0.99	1.00	1.01
73%	1.00	1.01	0.91	0.99	0.96	0.96	0.96	0.96	0.99	1.00	1.01
74%	1.00	1.01	0.91	0.99	0.97	0.97	0.97	0.97	0.99	1.00	1.01
75%	1.01	1.01	0.90	0.99	0.98	0.98	0.98	0.98	0.99	1.01	1.01

Table B.5 (continued): Load Adjustment Factors for MAN 2-Stroke Propulsion Engines with Conventional Valves

Load	NO_x	HC	CO	SO_2	PM	$PM_{2.5}$	DPM	Black Carbon	CO_2	N_2O	CH_4
76%	1.01	1.01	0.90	0.99	0.99	0.99	0.99	0.99	0.99	1.01	1.01
77%	1.01	1.01	0.90	0.99	1.00	1.00	1.00	1.00	0.99	1.01	1.01
78%	1.01	1.01	0.91	0.99	1.01	1.01	1.01	1.01	0.99	1.01	1.01
79%	1.02	1.01	0.91	0.99	1.03	1.03	1.03	1.03	0.99	1.02	1.01
80%	1.02	1.01	0.91	0.99	1.04	1.04	1.04	1.04	0.99	1.02	1.01
81%	1.02	1.01	0.91	0.99	1.05	1.05	1.05	1.05	0.99	1.02	1.01
82%	1.02	1.01	0.91	0.99	1.06	1.06	1.06	1.06	0.99	1.02	1.01
83%	1.02	1.01	0.92	0.99	1.07	1.07	1.07	1.07	0.99	1.02	1.01
84%	1.02	1.00	0.92	0.99	1.08	1.08	1.08	1.08	0.99	1.02	1.00
85%	1.02	1.00	0.92	0.99	1.10	1.10	1.10	1.10	0.99	1.02	1.00
86%	1.02	0.99	0.93	0.99	1.11	1.11	1.11	1.11	0.99	1.02	0.99
87%	1.02	0.99	0.93	0.99	1.12	1.12	1.12	1.12	0.99	1.02	0.99
88%	1.02	0.98	0.94	0.99	1.13	1.13	1.13	1.13	0.99	1.02	0.98
89%	1.01	0.97	0.95	0.99	1.15	1.15	1.15	1.15	0.99	1.01	0.97
90%	1.01	0.97	0.95	0.99	1.16	1.16	1.16	1.16	0.99	1.01	0.97
91%	1.01	0.96	0.96	0.99	1.17	1.17	1.17	1.17	0.99	1.01	0.96
92%	1.00	0.94	0.97	0.99	1.19	1.19	1.19	1.19	0.99	1.00	0.94
93%	1.00	0.93	0.98	0.99	1.20	1.20	1.20	1.20	0.99	1.00	0.93
94%	0.99	0.92	0.99	0.99	1.22	1.22	1.22	1.22	0.99	0.99	0.92
95%	0.99	0.91	1.01	0.99	1.23	1.23	1.23	1.23	0.99	0.99	0.91
96%	0.98	0.89	1.02	0.99	1.24	1.24	1.24	1.24	0.99	0.98	0.89
97%	0.97	0.87	1.03	1.00	1.26	1.26	1.26	1.26	1.00	0.97	0.87
98%	0.97	0.86	1.05	1.00	1.28	1.28	1.28	1.28	1.00	0.97	0.86
99%	0.96	0.84	1.07	1.00	1.29	1.29	1.29	1.29	1.00	0.96	0.84
100%	0.95	0.82	1.08	1.00	1.31	1.31	1.31	1.31	1.00	0.95	0.82

Auxiliary Engine Emission Factors

The adjusted auxiliary engine emission factors using 0.1% S MDO, based on ENTEC 2002 and IVL 2004, are presented in Table B.7. Vessel specific NO_x emission factors from EIAPP certificates collected from VBP data were utilized. Vessels that did not have EIAPP NOx emission factors used the default NO_x emission factors. Similar to the propulsion engine emission factors, the 2.7% sulfur HFO base emission factors are multiplied by the appropriate pollutant FCF to calculate the 0.1% S MDO emission factors. PM_{10} and SO_x emission factors are based on equations 3.5 and 3.6 described in earlier sections. In 2016, it is assumed that all of the auxiliary engines used 0.1% S fuel due to the ECA requirement.

Table B.7: Auxiliary Engine Emission Factors, g/kW-hr

Engine Category	Model Year Range	NO_x	HC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon
Medium speed auxiliary (Tier 0)	1999 and older	13.8	0.4	1.1	0.44	0.24	0.23	0.24	0.0138
Medium speed auxiliary (Tier 1)	2000 to 2011	12.2	0.4	1.1	0.44	0.24	0.23	0.24	0.0138
Medium speed auxiliary (Tier 2)	2011 to 2016	10.5	0.4	1.1	0.44	0.24	0.23	0.24	0.0138
Medium speed auxiliary (Tier 3)	2016 +	2.6	0.4	1.1	0.44	0.24	0.23	0.24	0.0138
High speed auxiliary (Tier 0)	1999 and older	10.9	0.4	0.9	0.44	0.24	0.23	0.24	0.0138
High speed auxiliary (Tier 1)	2000 to 2011	9.8	0.4	0.9	0.44	0.24	0.23	0.24	0.0138
High speed auxiliary (Tier 2)	2011 to 2016	7.7	0.4	0.9	0.44	0.24	0.23	0.24	0.0138
High speed auxiliary (Tier 3)	2016 +	2.0	0.4	0.9	0.44	0.24	0.23	0.24	0.0138

Engine Category	Model Year Range	CO_2	N_2O	CH_4
Medium speed auxiliary (Tier 0)	1999 and older	686	0.029	0.008
Medium speed auxiliary (Tier 1)	2000 to 2011	686	0.029	0.008
Medium speed auxiliary (Tier 2)	2011 to 2016	686	0.029	0.008
Medium speed auxiliary (Tier 3)	2016 +	686	0.029	0.008
High speed auxiliary (Tier 0)	1999 and older	656	0.029	0.008
High speed auxiliary (Tier 1)	2000 to 2011	656	0.029	0.008
High speed auxiliary (Tier 2)	2011 to 2016	656	0.029	0.008
High speed auxiliary (Tier 3)	2016 +	656	0.029	0.008

Auxiliary Engine Defaults

The primary data source for auxiliary load data is from the VBP program where vessels are boarded at various ports and data is collected on vessel operations by mode. Vessel data for sister- ships of the boarded vessels are also collected and utilized. This inventory had 158 vessels with VBP data, accounting for 37% of inbound calls. VBP operational data is important for auxiliary engine emission estimates because the Lloyd's database contains very limited installed power information for auxiliary engines and no information on use by mode. VBP data relating to auxiliary engine use is acquired by vessel type, emission source, and by mode of operation. When estimating auxiliary engine emissions, VBP operational data is first applied on a vessel by vessel basis if the vessel was boarded or it is a sister-ship to a boarded vessel. If the vessel is not in the VBP data, average auxiliary engine load defaults are derived from the VBP data and applied by vessel type. For this inventory, defaults were developed from a straight average of compiled VBP data by vessel type and mode. For certain vessel types, if the VBP data was limited or not found, auxiliary engine default loads from the Port of Los Angeles 2016 Emissions Inventory[10], which was also based on VBP data, was utilized. The default loads used in the last PSEI update were compared to default utilized in other emissions inventories and it was determined that these default loads would be suitable surrogates when VBP data is not available.

Vessels do not use the total auxiliary engine installed power when at sea, during hoteling (e.g. at berth) and during maneuvering. For each mode and vessel type, a different number of auxiliary engines may be used and at varying loads depending on several factors, such as temperature and number of reefers onboard.

- Hoteling load is primarily what is needed to meet the power needs of the lights, heating/ventilation/air conditioning systems, communications, computers, ship cranes, pumps, reefer load, and various other power demands while the vessel is at dock. This load is met via the use of auxiliary engine load.
- Maneuvering generally requires the highest auxiliary load mode for OGVs in order to provide power to the bow thrusters that are used intermittently. The only exception is tankers, where the auxiliary load during loading at berth is at its highest.
- Transit periods, or "at sea mode," generally requires the lowest auxiliary loads, as additional auxiliary power is not required for maneuvering. Many vessels also have shaft generators and exhaust turbine generators that help provide power to the ship with greater fuel efficiency than auxiliary generators.

[10] Port of Los Angeles, Air Emissions Inventory (2016),
See: *www.portoflosangeles.org/pdf/2016_Air_Emissions_Inventory.pdf*

Table B.8 summarizes the total power and load defaults used for this study by vessel subtype.

Table B.8: 2016 Auxiliary Engine Load Defaults, kW

Vessel Type	Transit	Maneuvering	Berth Hotelling	Anchorage Hotelling
Auto Carrier	590	1,224	996	622
Bulk	266	384	376	253
Bulk - Heavy Load	462	1,223	272	253
Bulk - Self Discharging	305	807	179	305
Container - 1000	892	1,275	558	1,000
Container - 2000	1,280	1,911	644	1,012
Container - 3000	888	1,685	710	694
Container - 4000	1,499	2,528	980	1,200
Container - 5000	1,444	2,458	979	967
Container - 6000	1,598	2,665	928	1,645
Container - 7000	1,332	2,675	1,758	1,000
Container - 8000	1,497	2,550	1,018	986
Container - 9000	1,495	2,576	980	968
Container - 10000	1,662	2,130	1,104	1,129
Container - 11000	1,250	2,450	1,500	2,000
Container - 17000	1,500	1,750	1,000	1,000
General Cargo	471	1,096	829	180
ATB	79	208	102	79
Miscellaneous	834	820	300	200
Reefer	1,247	1,168	1,033	630
RoRo	132	396	229	132
Tanker - Chemical	417	583	1,271	402
Tanker - Handysize	560	600	900	560
Tanker - Panamax	488	600	797	379
Tanker - Aframax	556	628	909	474
Tanker - Suezmax	858	1,289	2,902	773

Cruise ships typically have one of two configurations. The most common is 'full' diesel-electric in which all of the power for the ship's propulsion and auxiliary systems comes from a common set of diesel-electric generators. All of the cruise ships calling Ports in this study are full diesel-electric configured cruise ships.

The auxiliary engine load defaults for cruise ships were derived from VBP data and interviews with the cruise vessel industry contacts. A straight average of cruise ship VBP data was calculated by passenger capacity range. There were 12 vessels with VBP data in this inventory, accounting for 79% of cruise ship arrivals. For cruise ship sizes that had limited or no VBP data available, published defaults from the Port of Los Angeles Air Emissions Inventory (2016)[11] were used. The cruise defaults, by mode, vary based on passenger capacity ranges. Cruise ship auxiliary defaults by mode are listed in Table B.9.

Table B.9: 2016 Cruise ShipAuxiliary Engine Load Defaults, kW

Passenger Range	Transit	Maneuvering	Berth Hotelling
<1,499	5,733	6,800	3,267
1,500 < 1,999	7,000	9,000	5,613
2,000 < 2,499	11,000	11,350	6,900
2,500 < 2,999	9,781	8,309	6,089
3,000 < 3,499	8,313	10,116	8,313
3,500 < 3,999	9,934	11,764	10,600
4,000 < 4,499	12,500	14,000	12,000
4,500 < 4,999	13,000	14,500	13,000
5,000 < 5,499	13,500	15,500	13,500
5,500 < 5,999	14,000	16,000	14,000
6,000 < 6,499	14,500	16,500	14,500
6,500+	15,000	17,000	15,000

[11] Port of Los Angeles, Air Emissions Inventory (2016), See: *www.portoflosangeles.org/environment/studies_reports.asp*

Auxiliary Boilers

In addition to the auxiliary engines that are used to generate electricity for on-board uses, most OGVs have one or more auxiliary boilers used for fuel heating and for producing hot water and steam. Table B.10 shows the adjusted emission factors used for the auxiliary boilers based on ENTEC 2002 and IVL 2004 studies. Mirroring the propulsion and auxiliary engine emission factors, the 2.7% sulfur HFO base emission factors are multiplied by the appropriate FCF to calculate the 0.1% S MDO emission factors. The diesel particulate matter (DPM) emission factor is zero for fuel fired boilers since boilers do not meet the EPA definition for origin of DPM (ie. it is not a combustion engine).

Table B.10: Auxiliary Boiler Emission Factors, g/kW-hr

Engine Category	Model Year Range	NO_x	HC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon
Steam main engine and boiler	All	2.0	0.1	0.2	0.60	0.16	0.15	0.00	0.0089

Engine Category	Model Year Range	CO_2	N_2O	CH_4
Steam main engine and boiler	All	922	0.075	0.002

The auxiliary boiler fuel consumption data collected from vessels during VBP was converted to kilowatts using specific fuel consumption (SCF) factors from the ENTEC 2002 study[12]. The average kW for auxiliary boilers was calculated using the following equation.

Equation 7

$$\textbf{Average kW} = ((\textbf{daily fuel}/24)\,\textbf{x}\,1,000,000)/305$$

Where:
Average kW = average energy output of auxiliary boilers, kW
daily fuel = auxiliary boiler fuel consumption, tonnes per day

As with auxiliary engines, the primary source of load data is VBP. Vessel and mode specific auxiliary boiler loads are utilized for vessels boarded and their sister ships. There is no auxiliary boiler load data available in IHS. For vessels with no or limited VBP data, defaults loads were developed based on a straight average of compiled boiler VBP data by vessel class and mode.

[12] ENTEC, *Quantification of Emissions from Ships Associated with Ship Movements between Ports in the European Community, Final Report*, July 2002. See: *ec.europa.eu/environment/air/pdf/chapter2_ship_emissions.pdf*

During transit, auxiliary boilers are not typically used when the main engine load is greater than approximately 20% due to waste heat recovery systems that are used to produce heat while the ship is underway. If the main engine load is less than or equal to 20%, the auxiliary boiler is considered to be utilized and the auxiliary boiler load by mode, either from VBP or the default, is applied. Similar to auxiliary engine load defaults, auxiliary boiler defaults were developed from a straight average of compiled VBP data by vessel type and mode. Auxiliary boiler defaults used for each vessel type and mode, in kilowatts, are presented in Table B.11.

Table B.11: 2016 Auxiliary Boiler Load Defaults, kW

Vessel Type	Transit	Maneuvering	Berth Hotelling	Anchorage Hotelling
Auto Carrier	87	184	314	305
Bulk	35	94	125	125
Bulk - Heavy Load	35	94	125	125
Bulk - Self Discharging	44	103	132	132
Container - 1000	106	213	273	270
Container - 2000	141	282	361	358
Container - 3000	164	328	420	416
Container - 4000	195	371	477	472
Container - 5000	247	473	579	572
Container - 6000	182	567	615	611
Container - 7000	259	470	623	619
Container - 8000	228	506	668	673
Container - 9000	381	613	677	675
Container - 10000	384	458	581	581
Container - 11000	330	575	790	790
Container - 17000	216	485	647	647
General Cargo	56	124	160	160
ATB	0	0	0	0
Miscellaneous	33	65	96	96
Reefer	104	237	304	304
RoRo	67	148	259	251
Tanker - Chemical	59	136	568	255
Tanker - Handysize	144	144	2,586	144
Tanker - Panamax	167	351	3,421	451
Tanker - Aframax	179	438	5,030	375
Tanker - Suezmax	144	191	5,843	503
Diesel Electric Tankers	0	145	220	220

The auxiliary boiler loads for diesel-electric tankers are lower than non-diesel-electric tankers, because they have been adjusted for the energy needed to provide the house load and not associated with cargo movements.

Large diesel-electric cruise ships typically utilize waste heat recovery (heat recovered from engine exhaust) to provide steam needed during vessel operations. Based on VBP data, typically auxiliary boilers in diesel-electric cruise ships are off during transiting, maneuvering, and hoteling modes of operations, unless otherwise specified during VBP data collection. Data collected from diesel-electric cruise ships for this inventory indicated that some cruise ships use their auxiliary boilers during operations; however, the majority of the cruise ships indicated that their operations are consistent with the boiler off assumption. The only time the auxiliary boiler is considered to be used while hoteling is when the ship is connected to an on-shore power supply, as the heat recovery systems are not effective because their heat source (the auxiliary engines) are turned off. Vessel specific auxiliary loads were available in VBP for all of the cruise ships that used shore power in this inventory. The boiler defaults for non-diesel-electric cruise ships are listed in Table B.12.

Table B.12: 2016 Auxiliary Boiler Load Defaults for Cruise Ships (non-diesel-electric), kW

Vessel Type	Transit	Maneuvering	Berth Hotelling	Anchorage Hotelling
Cruise	282	361	306	612

APPENDIX C: COMMERCIAL HARBOR AND GOVERNMENT VESSELS EMISSIONS ESTIMATING METHODOLOGY

Commercial Harbor and Government Vessels Emissions Estimating Methodology

Emission Equations

The basic equation used to estimate harbor vessels emissions is:

Equation 1

$$E = kW \times Act \times LF \times EF \times FCF$$

Where:
E = emission for a given calendar year, tons per year
kW = rated power of the engine, kilowatts
Act =hours of operation in the Puget Sound per year, hours per year
LF = load factor (ratio of average engine load required to perform its operating task to
full engine load at maximum rated horsepower,), dimensionless
EF = emission factor, g per kW-hr
FCF = fuel correction factor, dimensionless

The emission inventory only includes hours of operation within the Puget Sound. The calculated emissions were converted to tons per year by dividing the emissions by 907,200 (which is 2,000 lb/ton x 453.6 g/lb).

Emission Factors for Diesel Engines

The emission factors for harbor vessels are based on marine engine standards (i.e., Tier 0 to Tier 4) and their respective EPA engine categories. EPA marine engine standards are based on the model year and horsepower of the harbor craft engines. Most commercial harbor vessels have Category 1 engines, except for some of the larger tugboats and larger commercial fishing vessels, which have Category 2 engines. In Puget Sound, approximately 94% of the diesel-powered harbor vessels inventoried had EPA Category 1 engines. The other 6% had EPA Category 2 engines. The use of a specific emission factor is dependent on engine power, engine model year, and engine cylinder displacement.

The majority, 74%, of the diesel marine engines in 2016, had Tier 0 unregulated engines; the rest of the engines meet Tier 1, Tier 2 or Tier 3 engine standards. The emission factors used for this study are listed in Table C.1 and C.2 for diesel-fueled main propulsion and auxiliary engines. The source of emission factors includes:

- 1999 EPA RIA[13] for uncontrolled engines, except for GHG
- 2002 Entec[14] for GHG
- IMO for NO_x EF for Tier 1 engines
- 40 Code of Federal Register Part 90, Table 1 of 1042.101[15]

[13] Final Regulatory Impact Analysis: Control of Emissions from Marine Diesel Engines; EPA420-R-99-026, November 1999

[14] European Commission, Quantification of emissions from ships associated with ship movements between ports in the European Community, Final Report, July 2002, Entec UK Limited

[15] *www.ecfr.gov,* Title 40, Part 1042, Control of Emissions from New and In-use Nonroad Compression-ignition Engines

Please note that CO emission factors are higher for newer engines. EPA has set higher bounding values for CO for engines to allow for the control of NO_x and PM which have an inverse relationship to CO during fuel combustion.

Table C.1: Commercial Harbor and Government Vessel Emission Factors for Category 1 Diesel Engines, g/kW-hr

kW Range	Year Range	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2	N_2O	CH_4
Tier 0 engines												
0 to 8	<2000	10.23	0.27	8.0	1.3	1.00	0.92	1.00	0.7084	690	0.031	0.01
8 to 19	<2000	9.23	0.27	6.6	1.3	0.80	0.74	0.80	0.5698	690	0.031	0.01
19 to 37	<1999	9.23	0.27	6.6	1.3	0.80	0.74	0.80	0.5698	690	0.031	0.01
37 to 76	<2000	10.0	0.27	1.7	1.3	0.40	0.37	0.40	0.2849	690	0.031	0.01
76 to 131	<2000	10.0	0.27	1.5	1.3	0.40	0.37	0.40	0.2849	690	0.031	0.01
131 to 226	<2000	10.0	0.27	1.5	1.3	0.80	0.74	0.80	0.5698	690	0.031	0.01
226 to 1,001	<2000	10.0	0.27	1.5	1.3	0.30	0.28	0.30	0.2156	690	0.031	0.01
1,000+	<2000	13.0	0.27	2.5	1.3	0.30	0.28	0.30	0.2156	690	0.031	0.01
Tier 1 engines												
0 to 8	2000-2005	10.23	0.27	8.0	1.3	0.90	0.83	0.90	0.6391	690	0.031	0.01
8 to 19	2000-2005	9.23	0.27	6.6	1.3	0.80	0.74	0.80	0.5698	690	0.031	0.01
19 to 37	1999-2004	9.23	0.27	6.6	1.3	0.80	0.74	0.80	0.5698	690	0.031	0.01
37 to 76	2000-2004	9.8	0.27	1.7	1.3	0.40	0.37	0.40	0.2849	690	0.031	0.01
76 to 131	2000-2004	9.8	0.27	1.5	1.3	0.40	0.37	0.40	0.2849	690	0.031	0.01
131 to 1,001	2000-2004	9.8	0.27	1.5	1.3	0.30	0.28	0.30	0.2156	690	0.031	0.01
1,000+	2000-2007	9.8	0.27	2.5	1.3	0.30	0.28	0.30	0.2156	690	0.031	0.01
Tier 2 engines												
0 to 8	2005-2009	7.3	0.20	5.0	1.3	0.80	0.74	0.80	0.5698	690	0.031	0.01
8 to 19	2005-2009	7.3	0.20	5.0	1.3	0.80	0.74	0.80	0.5698	690	0.031	0.01
19 to 37	2004-2009	7.3	0.20	5.0	1.3	0.60	0.55	0.60	0.4235	690	0.031	0.01
37 to 76	2004-2009	7.0	0.2	5.0	1.3	0.2	0.184	0.2	0.1386	690	0.031	0.01
76 to 131	2004-2013	7.0	0.2	5.0	1.3	0.2	0.184	0.2	0.1386	690	0.031	0.01
131 to 1,001	2004-2013	7.0	0.20	5.0	1.3	0.20	0.18	0.20	0.1386	690	0.031	0.01
1,000+	2007-2013	7.0	0.20	5.0	1.3	0.20	0.18	0.20	0.1386	690	0.031	0.01
Tier 3 engines												
0 to 8	2009+	7.3	0.20	5.0	0.0065	0.40	0.37	0.40	0.2849	690	0.031	0.01
8 to 19	2009+	7.3	0.20	5.0	0.0065	0.40	0.37	0.40	0.2849	690	0.031	0.01
19 to 37	2009-2014	7.3	0.20	5.0	0.0065	0.30	0.28	0.30	0.2156	690	0.031	0.01
37 to 76	2009-2014	7.3	0.20	5.0	0.0065	0.30	0.28	0.30	0.2156	690	0.031	0.01
76 to 561	2013-2040	5.2	0.20	5.0	0.0065	0.12	0.11	0.12	0.0847	690	0.031	0.01
561-1,001	2013-2017	5.2	0.20	5.0	0.0065	0.12	0.11	0.12	0.0847	690	0.031	0.01
1,001-1,400	2013-2017	5.2	0.20	5.0	0.0065	0.12	0.11	0.12	0.0847	690	0.031	0.01
1,400-2,000	2013-2016	5.2	0.20	5.0	0.0065	0.12	0.11	0.12	0.0847	690	0.031	0.01
2,000-3,701	2013-2040	5.2	0.20	5.0	0.0065	0.12	0.11	0.12	0.0847	690	0.031	0.01
3,701+	2013-2016	5.2	0.20	5.0	0.0065	0.12	0.11	0.12	0.0847	690	0.031	0.01
Tier 4 engines												
19 to 37	2014-2040	4.5	0.20	5.0	0.0065	0.30	0.28	0.30	0.2156	690	0.031	0.01
37 to 76	2014-2040	4.5	0.20	5.0	0.0065	0.30	0.28	0.30	0.2156	690	0.031	0.01
561-1,001	2017-2040	1.8	0.19	5.0	0.0065	0.04	0.04	0.04	0.0037	690	0.031	0.01
1,001-1,400	2017-2040	1.8	0.19	5.0	0.0065	0.04	0.04	0.04	0.0037	690	0.031	0.01
1,400-2,000	2016-2040	1.8	0.19	5.0	0.0065	0.04	0.04	0.04	0.0037	690	0.031	0.01

Table C.2: Commercial Harbor and Government Vessel Emission Factors for Category 2 Diesel Engines, g/kW-hr

kW Range	Year Range	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2	N_2O	CH_4
Tier 0 engines												
1,400-2,000	0-2000	13.2	0.50	1.1	1.3	0.72	0.66	0.72	0.5082	690	0.031	0.01
2,000-3,701	0-2000	13.2	0.50	1.1	1.3	0.72	0.66	0.72	0.5082	690	0.031	0.01
3,701+	0-2000	13.2	0.50	1.1	1.3	0.72	0.66	0.72	0.5082	690	0.031	0.01
Tier 1 engines												
1,400-2,000	2000-2007	9.8	0.50	1.1	1.3	0.72	0.66	0.72	0.5082	690	0.031	0.01
2,000-3,701	2000-2007	9.8	0.50	1.1	1.3	0.72	0.66	0.72	0.5082	690	0.031	0.01
3,701+	2000-2007	9.8	0.50	1.1	1.3	0.72	0.66	0.72	0.5082	690	0.031	0.01
Tier 2 engines												
1,400-2,000	2007-2014	8.2	0.50	5.0	1.3	0.5	0.46	0.5	0.3542	690	0.031	0.01
2,000-3,701	2007-2016	9.3	0.50	5.0	1.3	0.5	0.46	0.5	0.3542	690	0.031	0.01
3,701+	2007-2016	9.3	0.50	5.0	1.3	0.5	0.46	0.5	0.3542	690	0.031	0.01
Tier 3 engines												
1,400-2,000	2014-2016	6.5	0.19	5.0	0.0065	0.34	0.31	0.34	0.0040	690	0.031	0.01
Tier 4 engines												
1,400-2,000	2016-2040	1.8	0.19	5.0	0.0065	0.04	0.04	0.04	0.0040	690	0.031	0.01
2,000-3,701	2016-2040	1.8	0.19	5.0	0.0065	0.34	0.31	0.34	0.0310	690	0.031	0.01
3,701+	2016-2040	1.8	0.19	5.0	0.0065	0.06	0.06	0.06	0.0060	690	0.031	0.01

Fuel Correction Factors for Diesel Engines

Fuel correction factors, shown in Table C.3, were applied to the Tier 0-2 engines using ULSD. The diesel emission factors used for this study are based on use of EPA non-road diesel fuel and thus need to be adjusted to account for the use of ULSD at 15 ppm[16]. Tier 3 and Tier 4 engine emission factors were based on vessels using ULSD.

Table C.3: Fuel Correction Factors for Tier 0 to 2 Engines

Fuel	NO_x	VOC	CO	SO_2	PM	CO_2	N_2O	CH_4
ULSD	1.00	1.00	1.00	0.005	0.86	1.00	1.00	1.00

Emission Factors for Gasoline Engines

Approximately 7% percent of the commercial harbor and government vessels are powered with gasoline engines. These are mainly government vessels, such as patrol boats with outboard gasoline engines. The emission factors for gasoline engines are different than those described previously for diesel engines. The emission factor for harbor crafts using gasoline engines are obtained by running the NONROAD module of MOVES2014a emissions estimating model. The MOVES2014a model (model) incorporates the functions of the NONROAD2008 model that was the standard stand- alone emissions estimating model for non-road equipment for many years. It uses region specific vessel activity data and fleet age distribution assumptions, corresponding emission factors, for a given calendar

[16] EPA, *Highway and Nonroad, Locomotive, and Marine (NRLM) Diesel Fuel Sulfur Standards*, EPA-420-B-16-005, March 2016. See: *www.epa.gov/emission-standards-reference-guide/epa-standards-fuel-sulfur*

year to estimate emissions. The model has series of post processing queries available. One of the post processing queries is an output of emission factors in grams/hp-hr. Emission factors in grams per hour by horse power groups and model year group similar to gasoline outboard engine emission standards from this query were used as input to harbor craft emissions calculation model. Emission factors in g/bhp-hr were converted to g/kW-hr as shown in Table C.4.

Table C.4: Commercial Harbor and Government Vessel Emission Factors for Gasoline Engines, g/kW-hr

Power (kW)	Year Range	Stroke	NO_x	VOC	CO	SO_2	PM	Black Carbon	CO_2	N_2O	CH_4
4 to 9	0-1999	2	2.09	251	418	0.46	5.21	0.48	1,994	0.06	5.52
4 to 9	1999-2003	2	4.97	117	352	0.43	2.29	0.21	1,833	0.06	3.94
4 to 9	2003-2010	2	6.21	56	319	0.41	0.98	0.09	1,760	0.05	3.2
4 to 9	2010-2040	2	5.65	13	294	0.40	0.08	0.01	1,716	0.05	2.46
9 to 13	0-1999	2	1.90	214	368	0.46	4.47	0.41	1,980	0.04	4.63
9 to 13	1999-2003	2	4.92	98	304	0.43	1.96	0.18	1,835	0.04	3.09
9 to 13	2003-2010	2	6.15	48	274	0.42	0.88	0.08	1,773	0.03	2.41
9 to 13	2010-2040	2	6.81	10	250	0.41	0.08	0.01	1,728	0.03	1.84
13 to 20	0-1999	2	1.87	170	321	0.47	3.57	0.33	2,034	0.04	3.66
13 to 20	1999-2003	2	3.13	131	295	0.46	2.75	0.25	1,955	0.04	3.11
13 to 20	2003-2010	2	5.27	65	249	0.43	1.31	0.12	1,818	0.03	2.15
13 to 20	2010-2040	2	4.34	11	207	0.40	0.08	0.01	1,687	0.03	1.98
20 to 31	0-1999	2	1.87	164	320	0.40	3.44	0.32	1,709	0.04	3.53
20 to 31	1999-2003	2	4.28	93	253	0.39	1.93	0.18	1,687	0.04	2.47
20 to 31	2003-2010	2	5.54	56	226	0.38	1.14	0.10	1,639	0.03	1.95
20 to 31	2010-2040	2	5.74	9	191	0.39	0.08	0.01	1,655	0.03	1.62
31 to 38	0-1999	2	1.81	158	322	0.38	3.34	0.31	1,636	0.04	3.4
31 to 38	1999-2003	2	3.90	102	264	0.37	2.15	0.20	1,598	0.04	2.49
31 to 38	2003-2010	2	4.91	76	237	0.37	1.59	0.15	1,563	0.03	2.02
31 to 38	2010-2040	2	5.98	8	169	0.37	0.08	0.01	1,580	0.03	1.48
38 to 57	0-1999	2	1.87	142	320	0.37	2.91	0.27	1,589	0.04	3.05
38 to 57	1999-2003	2	4.30	83	255	0.36	1.69	0.16	1,539	0.04	2.16
38 to 57	2003-2010	2	6.20	37	212	0.34	0.74	0.07	1,456	0.03	1.44
38 to 57	2010-2040	2	5.47	8	171	0.34	0.08	0.01	1,464	0.03	1.47
57 to 76	0-1999	2	1.80	143	322	0.37	2.95	0.27	1,590	0.04	3.07
57 to 76	1999-2003	2	4.07	86	251	0.37	1.75	0.16	1,562	0.04	2.16
57 to 76	2003-2010	2	5.99	43	212	0.34	0.86	0.08	1,465	0.03	1.44
57 to 76	2010-2040	2	5.47	8	171	0.34	0.08	0.01	1,464	0.03	1.47
76 to 132	0-1999	2	1.83	142	321	0.31	2.93	0.27	1,319	0.04	3.05
76 to 132	1999-2003	2	3.65	96	253	0.30	1.93	0.18	1,304	0.04	2.18
76 to 132	2003-2010	2	5.85	44	191	0.30	0.86	0.08	1,263	0.03	1.31
76 to 132	2010-2040	2	5.07	8	175	0.30	0.08	0.01	1,290	0.03	1.46
132+	0-1999	2	1.90	140	317	0.27	2.89	0.27	1,145	0.04	3.01
132+	1999-2003	2	4.29	77	206	0.27	1.5	0.14	1,154	0.04	1.67
132+	2003-2010	2	5.49	44	164	0.27	0.81	0.07	1,158	0.03	1.13
132+	2010-2040	2	3.73	9	139	0.28	0.08	0.01	1,209	0.03	1.63

Fuel Correction Factors for Gasoline Engines

The SO_2 emission factor, derived from MOVES, is based on S content of 340 ppm. In 2016, the average S content of the gasoline fuel was 30 ppm[17]. Therefore, a fuel correction factor of 0.088 was applied to SO_x emission factors output from MOVES2014a.

Engine Load Factors

Engine load factors represent the load applied to an engine or the percentage of rated engine power that is applied during the engine's operation. Table C.5 summarizes the annual average engine load factors that were used for propulsion and auxiliary engines of different vessel types.

Table C.5: Commercial Harbor and Government Vessel Load Factors

Harbor Vessel Type	Propulsion Engine	Source	Auxiliary Engine	Source
Assist and Escort	0.31	2001 POLA EI[18]	0.43	EPA NONROAD[19]
Harbor Tug	0.31	2001 POLA EI	0.43	EPA NONROAD
Ocean Tug	0.68	EPA NONROAD	0.43	EPA NONROAD
Commercial Fishing	0.30	EPA NONROAD	0.30	EPA NONROAD
Ferry	0.34	WSF 2011 data[20]	0.43	EPA NONROAD
Excursion	0.42	EPA NONROAD	0.43	EPA NONROAD
Government	0.51	EPA NONROAD	0.43	EPA NONROAD
Pilot Boat	0.51	EPA NONROAD	0.43	EPA NONROAD
Tank Barge	na	na	0.43	EPA NONROAD
Workboat	0.38	CARB[21]	0.32	CARB

[17] EPA, *Gasoline Sulfur Standards*, EPA-420-B-16-004, March 2016. See: *www.epa.gov/emission-standards-reference-guide/epa-standards-fuel-sulfur*
[18] *Port of Los Angeles Baseline Air Emissions Inventory,* 2001, Starcrest Consulting Group, LLC
[19] EPA, *Median Life, Annual Activity, and Load Factor Values for Nonroad Engine Emissions Modeling*, December 2002.
[20] *Puget Sound Emissions Inventory*, 2011, Starcrest Consulting Group, LLC
[21] CARB, *Emissions Estimation Methodology for Commercial Harbor Craft Operating in California, Appendix B*

Appendix D: Recreational Vessels Emissions Estimating Methodology

Recreational Vessels Emissions Estimating Methodology

Table D.1 lists the public marinas associated with public port authorities included in this study. For purposes of estimating vessel numbers and calculating emissions, slip count was considered to be the same as vessel count, although in actuality a slip may moor more than one vessel, also slips are sometimes unoccupied.

Table D.1: 2016 Public Marina Vessel Counts by Associated Port and County

Marina	County	Associated Port	Total Vessel Count
John Wayne Marina	Clallam	Port of Port Angeles	280
Port Angeles Boat Haven	Clallam	Port of Port Angeles	520
North Marina	Snohomish	Port of Everett	156
South/Central Marina	Snohomish	Port of Everett	1,812
Cap Sante Marina	Skagit	Port of Anacortes	1,000
Blaine Harbor	Whatcom	Port of Bellingham	629
Squalicum	Whatcom	Port of Bellingham	1,415
Bremerton	Kitsap	Port of Bremerton	45
Port Orchard	Kitsap	Port of Bremerton	375
Port of Brownsville	Kitsap	Port of Brownsville	335
Coupeville Wharf	Island	Port of Coupeville	340
Edmonds Marina	Snohomish	Port of Edmonds	292
Friday Harbor	San Juan	Port of Friday Harbor	500
Keyport Marina	Kitsap	Port of Keyport	28
Cove Marina	Kitsap	Port of Kingston	300
Swantown	Thurston	Port of Olympia	700
Point Hudson	Jefferson	Port of Port Townsend	45
Boat Haven	Jefferson	Port of Port Townsend	475
Herb Beck Marina	Jefferson	Port of Port Townsend	50
Poulsbo Marina	Kitsap	Port of Poulsbo	400
Fishermen's Terminal	King	Port of Seattle	165
Harbor Island	King	Port of Seattle	65
Shilshole Bay Marina	King	Port of Seattle	1,411
Bell Harbor Marina	King	Port of Seattle	45
Shelton Marina	Mason	Port of Shelton	100
La Conner Marina	Skagit	Port of Skagit	460
Port of South Whidbey Harbor	Island	Port of South Whidbey	32
Total vessel count			**11,975**

Table D.2 lists the marinas owned by private and other non-port, public entities included in this study. The slip count included permanent slips, transient slips, moorage balls, and transient dock space.

Table D.2: 2016 Private Marinas and Other Non-Port Public Entities Vessel Counts by County

Marina	Location	County	Total Vessel Count
La Push Marina	La Push	Clallam	92
Makah Marina	Neah Bay	Clallam	200
Mason's Resort	Sekiu	Clallam	200
Van Ripers Resort	Sekiu	Clallam	140
Cornet Bay County Park	Oak Harbor	Island	40
Deception Pass Marina	Oak Harbor	Island	70
Oak Harbor Marina	Oak Harbor	Island	404
Home Port Marina in Pleasant Harbor	Brinnon	Jefferson	92
Pleasant Harbor Marina	Brinnon	Jefferson	312
Point Hudson Marina	Port Townsend	Jefferson	150
Port Hadlock Marina	Port Hadlock	Jefferson	164
Port Hadlock Marina	Hadlock	Jefferson	160
Port Ludlow Marina	Port Ludlow	Jefferson	353
Bainbridge Island Marina & Yacht Club	Bainbridge Is.	Kitsap	173
Bay Marine	Poulsbo	Kitsap	20
Eagledale Mooring Marina	Bainbridge Is.	Kitsap	36
Eagledale Moorings	Bainbridge Is.	Kitsap	36
Harbour Marina	Bainbridge Is.	Kitsap	50
Kitsap Marina	Port Orchard	Kitsap	26
Liberty Bay Marina	Poulsbo	Kitsap	177
Port Orchard Yacht Club	Port Orchard	Kitsap	78
Seabeck Marina	Seabeck	Kitsap	125
Williamson Landing Marina	Bainbridge Is.	Kitsap	24
Winslow Wharf Marina	Bainbridge Is.	Kitsap	239
Fair Harbor Marina	Grapeview	Mason	70
Hood Canal Marina	Hoodsport	Mason	35
Jarrell's Cove Marina	Shelton	Mason	20
Port of Hoodsport	Hoodsport	Mason	14
Ballard Mill Marina	Seattle	King	130
Canal Marina	Seattle	King	86
Carillon Point's Marina	Kirkland	King	200
City of Bellevue Yacht Basin	Bellevue	King	30

Table D.2: 2016 Private Marinas and Other Non-Port Public Entities Vessel Counts by County (cont'd)

Marina	Location	County	Total Vessel Count
City of Des Moines Marina	Des Moines	King	915
City of Seattle, Lakewood Moorage	Seattle	King	140
Eagle Harbor Marina	Bainbridge Is.	King	107
Elliott Bay Marina	Seattle	King	1,200
Ewing Street Moorage	Seattle	King	60
Fairview Marina	Seattle	King	157
Gasworks Park Marina	Seattle	King	71
Gene Coulon Memorial Beach Park	Renton	King	30
Harbour Village Marina	Kenmore	King	137
Hood Canal Marina (Alderbrook)	Union	King	100
Jim Clark Marina	Seattle	King	90
Kenmore Marina (Air Harbor)	Kenmore	King	80
Lake Union Waterworks	Seattle	King	61
Lake Union Yacht Harbor	Seattle	King	62
Lee's Landing	Seattle	King	38
Leschi Sailboat Moorage	Seattle	King	200
Leschi Yacht Basin	Seattle	King	108
Lockhaven Marina Inc.	Seattle	King	140
McGinnis Marine Service	Seattle	King	80
Meydenbauer Bay Yacht Club	Bellevue	King	105
Nautical Landing	Seattle	King	5
Newport SkyLaunch Marina	Bellevue	King	91
Newport Yacht Basin	Bellevue	King	416
North Lake Washington Marina	Kenmore	King	140
Northlake Marina	Seattle	King	57
Northlake Wharf	Seattle	King	12
Parkshore Marina	Seattle	King	183
Port Washington Marina	Bremerton	King	81
Quartermaster Marina	Burton	King	110
Sagstad Marina	Seattle	King	40
Salmon Bay Marina	Seattle	King	168
Seattle Marina	Seattle	King	145
Seattle SkyLaunch Marina	Seattle	King	110
South Park Marina	Seattle	King	160
Stimson Marina	Seattle	King	250

Table D.2: 2016 Private Marinas and Other Non-Port Public Entities Vessel Counts by County (cont'd)

Marina	Location	County	Total Vessel Count
Tillicum Marina	Seattle	King	28
Westlake Marina	Seattle	King	50
Yarrow Bay Marina	Kirkland	King	120
Youngquist Marina	Seattle	King	40
Arabella's Landing	Gig Harbor	Pierce	108
Breakwater Marina	Tacoma	Pierce	123
Chinook Landing Marina	Tacoma	Pierce	210
Crow's Nest Marina	Tacoma	Pierce	109
Day Island Yacht Club	Tacoma	Pierce	80
Day Island Yacht Harbor	Tacoma	Pierce	180
Delin Docks Marina	Tacoma	Pierce	130
Dock Street Marina	Tacoma	Pierce	82
Fair Harbor Marina	Grapeview	Pierce	78
Foss Harbor Marina	Tacoma	Pierce	417
Foss Waterway Marina	Tacoma	Pierce	50
Gig Harbor Marina	Gig Harbor	Pierce	115
Harborview Marina	Gig Harbor	Pierce	49
Hylebos Marina	Tacoma	Pierce	144
Longbranch Marina	Longbranch	Pierce	86
Longbranch Marina	Lakebay	Pierce	44
Lucas Landing	Gig Harbor	Pierce	18
Murphy's Landing	Gig Harbor	Pierce	85
Narrows Marina	Tacoma	Pierce	26
Narrows Marina	Tacoma	Pierce	85
Peninsula Yacht Basin	Gig Harbor	Pierce	100
Pleasure Craft Marina	Gig Harbor	Pierce	61
Point Defiance Boathouse Marina	Tacoma	Pierce	25
Port of Allyn	Allyn	Pierce	10
Steilacoom Marina	Steilacoom	Pierce	76
Tacoma Yacht Club	Tacoma	Pierce	290
Tiderunner Inc.	Gig Harbor	Pierce	28
Tyee Marina	Tacoma	Pierce	750
West Shore Marina	Gig Harbor	Pierce	80

Table D.2: 2016 Private Marinas and Other Non-Port Public Entities Vessel Counts by County (cont'd)

Marina	Location	County	Total Vessel Count
Blakely Island Marina	Blakely Island	San Juan	45
Brandt's Landing Marina	Eastsound	San Juan	60
Cayou Quay Marina	Deer Harbor	San Juan	103
Deer Harbor Marina	Deer Harbor	San Juan	125
Islands Marina Center	Lopez Island	San Juan	100
Little Portion Store & Marina	Shaw Island	San Juan	20
Lopez Islander Resort & Marina	Lopez Island	San Juan	110
Quartermaster Yacht Club	Burton	San Juan	65
Roche Harbor Resort & Marina	Roche Harbor	San Juan	377
Rosario Resort Marina	Eastsound	San Juan	35
Shipyard Cove	Friday Harbor	San Juan	185
Skyline Marina	Anacortes	San Juan	600
Snug Harbor Marina Resort	Friday Harbor	San Juan	72
Stuart Island		San Juan	83
Sucia Island		San Juan	95
West Beach Resort & Marina	Eastbound	San Juan	55
West Sound Marina	Orcas Island	San Juan	157
Anchor Cove Marina	Anacortes	Skagit	166
Lovric's Landing	Anacortes	Skagit	87
Pioneer Point Marina	La Conner	Skagit	15
Shelter Bay Marina	LaConner	Skagit	330
Skyline Marina	Anacortes	Skagit	500
Geddes Marine Service	Marysville	Snohomish	78
Hat Island Marina	Everett	Snohomish	115
Meadowdale Marina	Edmonds	Snohomish	6
Seacrest Marina	Everett	Snohomish	9
Tulalip Marina	Marysville	Snohomish	65
Boston Harbor	Olympia	Thurston	105
Boston Harbor Marina	Olympia	Thurston	110
East Bay Marina	Olympia	Thurston	65
Fiddlehead Marina	Olympia	Thurston	75
Martin Marina	Olympia	Thurston	82
Percival Landing	Olympia	Thurston	50
West Bay Marina	Olympia	Thurston	420
Zittles Marina	Olympia	Thurston	200
Fisherman's Cove Marina	Bellingham	Whatcom	58
Point Roberts Marina	Point Roberts	Whatcom	1,048
Semiahmoo Marina	Blaine	Whatcom	300

The methodology used to estimate emissions for the recreational vessel emissions was same as for gasoline harbor craft emissions calculation described above. Since for this category only average horsepower by recreational vessel type shown in table D3 below were know, NONROAD module of EPA's MOVES2014a model was used to output average emission factors in grams per horsepower hour by vessel types. Evaporative emissions from the gasoline engines are included in the VOC emissions estimates. The average horsepower, listed in Table D.3, was used for each engine type for recreational vessels in 2016. Since there is no actual data on the engine power, the assumptions as shown in Table D.3 are the same as those used PSEI reports.

Table D.3: 2016 Recreational Vessel Fuel and Average Horsepower by Vessel Type

Vessel Type	Fuel	Power (hp)
Vessel outboard engines, runabouts	Gasoline	40
Vessel inboard engines, cabin boats	Gasoline	150
Vessels inboard engines	Gasoline	70
Vessel inboard Engines	Diesel	400
Sailboat auxiliary outboard engines	Gasoline	6
Sailboat auxiliary inboard engines	Diesel	34

Table D.4 shows the recreational vessel emission factors in g/hp-hr, except for VOC evaporative emission factors which are in g/vessel/day.

Table D.4: 2016 Recreational Vessel Emission Factors

Vessel Type	Engine Type	HP	Fuel Type	NO_x g/hp-hr	VOC g/hp-hr	Evap VOC g/vessel/day	CO g/hp-hr	SO_2 g/hp-hr	PM_{10} g/hp-hr	BC g/hp-hr	CO_2 g/hp-hr	N_2O g/hp-hr	CH_4 g/hp-hr
Vessels w/Outboard Engines	G2	40	Gasoline	5.960	0.897	6.770	133.58	0.026	0.975	0.090	1,242	0.035	1.526
Sailboat Auxiliary Outboard Engines	G2	6	Gasoline	4.470	2.135	5.732	237.62	0.029	2.321	0.213	1,424	0.045	3.575
Vessels w/Inboard Engines	G4	70	Gasoline	6.465	0.063	6.518	102.02	0.018	0.069	0.006	884	0.023	0.613
Vessels w/Outboard Engines	G4	150	Gasoline	6.676	0.063	14.055	103.50	0.018	0.069	0.006	885	0.023	0.623
Vessels w/Inboard Engines	D	400	Diesel	5.363	0.158	0.000	1.03	0.004	0.085	0.122	530	0.013	0.019
Sailboat Auxiliary Inboard Engines	D	34	Diesel	4.283	0.437	0.000	2.40	0.005	0.363	0.336	588	0.015	0.032

APPENDIX E: CARGO-HANDLING EQUIPMENT EMISSIONS ESTIMATING METHODOLOGY

Cargo-handling Equipment Emissions Estimating Methodology

Cargo-handling equipment emissions are estimated using the NONROAD module of MOVES2014a emissions estimating model[22]. The MOVES2014a model (model) incorporates the functions of the NONROAD2008 model that was the standard stand-alone emissions estimating model for non-road equipment for many years. It uses region specific equipment activity data and fleet age distribution assumptions, corresponding emission factors, and sulfur assumptions in the fuel for each calendar year to estimate emissions. The model has series of post processing queries available. One of the post processing queries is an output of emission factors in grams/hp-hr. Equipment specific emission factors in grams per hour by fuel type, by horse power groups and model year from this query were used as input to CHE emissions calculation model.

As an overview, CHE emissions calculation model estimated emissions using the following equation:

Equation 1

$$E_{MY} = EF \times HP \times LF \times A \times CF$$

Where:
E_{MY} = emissions from a given model year of equipment, tons per year
EF = emission factor in grams/hp-hour (MOVES2014a output by fuel, equipment, fuel and model year)
HP = maximum rated horsepower, hp
LF = load factor, dimensionless
A = activity, hours of use per year
CF = control factor for emission reduction technologies or on-road engines. Control factors represent the remaining emissions after a control has been added to an engine. For example, if a control technology provides a 20% reduction in emissions the CF = 0.8.

Per equation 1 above, CHE emissions in tons per year from each piece of equipment are calculated using data collected from the port terminals (including model year, horsepower rating, and annual hours of operation) as well as equipment-specific load factor assumptions shown in table E.1.

The MOVES2014a model accommodates a wide range of off-road equipment types including cargo handling equipment uses at the marine ports terminals. The cargo-handling equipment identified by port terminals is categorized into the most closely corresponding MOVES2014/NONROAD equipment type, shown in Table E.1, which presents equipment types by Source Classification Code (SCC), load factor, and NONROAD category common name.

[22] EPA, *www.epa.gov/otaq/models/moves/*

Table E.1: NONROAD Engine Source Categories

Equipment Type	SCC	Load Factor	NONROAD Category
Backhoe	2270002066	0.21	Tractors/Loaders/Backhoe
Car Loader, diesel	2265003050	0.43	Other Industrial Equipment
Car Loader, gasoline	2270003040	0.54	Other Industrial Equipment
Car Loader, propane	2265003040	0.54	Other Industrial Equipment
Compressor, diesel	2270006015	0.43	Air compressor
Compressor, gasoline	2265006015	0.56	Air compressor
Crane	2270002045	0.43	Crane
Forklift, diesel	2270003020	0.59	Forklift
Forklift, gasoline	2265003020	0.3	Forklift
Forklift, propane	2267003020	0.30	Forklift
Generator, diesel	2270006005	0.43	Generator
Generator, gasoline	2265006005	0.68	Generator
Light Tower	2270002027	0.43	Signal Boards/Light plant
Loader, diesel	2270002060	0.59	Rubber Tired Loader
Skid Steer Loader, diesel	2270002072	0.21	Skid Steer Loader
Skid Steer Loader, propane	2267002072	0.58	Skid Steer Loader
Manlift, diesel	2270003010	0.21	Aerial Lifts
Manlift, gasoline	2265003010	0.46	Aerial Lifts
Manlift, propane	2267003010	0.46	Aerial Lifts
Reach Stacker	2270003020	0.59	Forklift
Side Handler	2270003020	0.59	Forklift
Top Handler	2270003020	0.59	Forklift
RTG Crane	2270003050	0.21	Other Material Handling Equipment
Straddle Carrier	2270003050	0.21	Other Material Handling Equipment
Sweeper, diesel	2270003030	0.43	Sweeper / scrubber
Sweeper, propane	2267003030	0.71	Sweeper / scrubber
Truck, diesel	2270002051	0.59	Non-road Truck
Truck, propane	2265002051	0.70	Non-road Truck
Welder	2265006025	0.21	Welder
Yard Tractor	2270003070	0.39	Terminal Tractor

The MOVES2014a model takes into account characteristic of the non-road fuel available in each calendar year[23] and the change in engine emissions (emissions deterioration) as the engines get older and less efficient. In 2016, all diesel equipment used ULSD fuel with 15 ppm sulfur content, while in 2005, fuels with varying sulfur content were used. Adjustments to MOVES2014a default PM and SO_x emissions factors were done if the fuel assumed in MOVES2014a in a specific CY was different than the actual fuel used. The following equations were used:

Equation 2

$$\boldsymbol{SPMadj = BSFC \times 453.6 \times 7.0 \times soxcnv \times 0.01 \times (soxbas - soxdsl)}$$

Where:
SPMadj = SPM adj corrects PM emissions from the default fuel sulfur level to the
episodic fuel sulfur level. SPMadj is subtracted from the default MOVES 2014a PM output
BSFC = brake-specific fuel consumption (lb fuel/hp-hrHP = maximum rated horsepower, hp
453.6 = conversion from lb to grams
7.0 = grams PM sulfate/grams PM sulfur
soxcnv = 0.02247 grams PM sulfur/grams fuel sulfur consumed
0.01= conversion from percent to fraction
soxbas = default fuel sulfur weight percent used in MOVES 2014a output
soxdsl = actual fuel sulfur weight percent used

Default SO_x emissions factors are multiplied by the sulfur content ratio as shown in equation 3 below:

Equation 3

$$\boldsymbol{SO_x\ adj = \frac{Actual\ fuel\ sulfur\ weight\ percent\ used}{default\ fuel\ sulfur\ weight\ percent\ used\ in\ MOVES\ 2014a\ output}}$$

Equipment with zero hours of operational use in 2016, due to new purchases or other reasons, as well as electric equipment, are included in the inventory count, but do not have emissions associated with them.

[23] EPA 420-R-10-018, NR 009d, July 2010; "Exhaust and Crankcase Emission Factors for Nonroad Engine Modeling Compression-Ignition", Table 2

Emission Control Factors

Control factors are applied to equipment that have an emissions control device or technology applied that reduces emissions. Control factors represent the remaining emissions after a control has been added to an engine. For example, if a control technology provides a 40% reduction in emissions the CF = 0.6.

Table E.2 summarizes the emission control factors used for emission control technologies implemented at the major Puget Sound ports.

Table E.2: Emission Control Factors for CHE Retrofits

Technology or Fuel	NO_x	VOC	CO	SO_2	PM	BC
Diesel Oxidation Catalyst (DOC)	1.00	0.30	0.30	1.00	0.70	0.70
Diesel Particulate Filter (DPF)	1.00	1.00	1.00	1.00	0.15	0.02
On-Road	0.44	0.33	1.00	1.00	0.73	0.73
DOC, On-Road	0.44	0.10	0.30	1.00	0.51	0.51

Emission control factors were applied to cargo-handling equipment with on-road engines, such as yard tractors and trucks with on-road engines that operate at the terminals. The control factors were developed based on a yard tractor test study conducted by the Ports of Los Angeles and Long Beach.

APPENDIX F: LOCOMOTIVES EMISSIONS ESTIMATING METHODOLOGY

Locomotives Emissions Estimating Methodology

Emission estimation methodologies for port-related locomotive activities are summarized below, and emission factors are discussed and listed at the end of this section.

Switching Emissions

Switching emission estimates are based primarily on each locomotive's annual fuel consumption and date of construction or reconstruction. The fuel use provides an estimate of activity that is converted to horsepower-hours (hp-hrs) using a brake-specific fuel consumption (BSFC) factor of 15.2 horsepower-hours per gallon of fuel published by EPA.[24] The date of construction or reconstruction provides the basis for assigning emission factors provided by the same EPA document. The conversion of fuel consumption to horsepower-hours uses the following equation:

Equation 1

$$\textbf{Annual Energy}\left(\frac{hp-hrs}{year}\right) = \textbf{Fuel use}\left(\frac{gallons}{year}\right)\ x\ \textbf{EPA's BSFC}\left(\frac{hp-hrs}{gallons}\right)$$

The annual emissions, in tons per year, are calculated for each locomotive using the emission factor specific to the locomotive's year, which determined its engine tier level, and the following equation:

Equation 2

$$\textbf{Emissions} = \textbf{Annual Energy}\left(\frac{hp-hr}{year}\right) \times \textbf{EF}\left(\frac{g}{hp-hr}\right) \Big/ \left(453.59\left(\frac{g}{lb}\right) \times 2{,}000\left(\frac{lbs}{ton}\right)\right)$$

Since most switching fleets are captive fleets that do not vary much, if at all, over the course of a year most switching operators are able to provide the detailed information needed to estimate emissions using these equations. The Class 1 railroads often vary the switchers assigned to specific railyards so more general assumptions are made for them. Fleet descriptions were provided by the railroads to the PSCAA and made available for this emissions inventory. These descriptions indicate that the locomotives are generally in the range of pre-Tier 0 to Tier 0+. The methodology to estimate fuel consumption and hp-hrs was to calculate the ratio of 2016 throughput to 2011 throughput for each rail yard and multiply that ratio by the 2011 fuel consumption estimate and the BSFC value as shown in equation 3. Emissions were estimated from the hp-hr values in the same way as the other switching locomotives using equation 2.

[24] EPA, *Emission Factors for* Locomotives, EPA-420-F-09-025. April 2009.

Equation 3

$$Annual\ Energy\left(\frac{hp-hrs}{year}\right) = \frac{2016\ throughput}{2011\ thrughput}\ x\ 2011\ Fuel\ use\left(\frac{gallons}{year}\right)\ x\ EPA's\ BSFC\ \left(\frac{hp-hrs}{gallons}\right)$$

Table F.1 presents information on the switchers included in the emissions inventory. This list covers the captive fleets operated by terminals and small railroads, and includes a "snapshot" of switchers operated by the Class 1 railroads because their fleets are rotated periodically among the railroad's many facilities so the number and age of switchers at their locations are not static.

Table F.1: Switching Locomotive Tier Levels

Port	Distribution of Switching Locomotives									
	Pre-Tier 0	**Tier 0**	**Tier 0+**	**Tier 1**	**Tier 1+**	**Tier 2**	**Tier 2+**	**Tier 3**	**Tier 4**	**Total**
NWSA North Harbor	0	0	0	0	0	0	0	0	0	0
NWSA South Harbor	4	6	0	0	0	2	0	4	0	16
Port of Seattle	2	0	0	0	0	0	0	0	0	2
Port of Tacoma	3	1	0	0	0	0	0	0	0	4
Olympia	10	0	0	0	0	0	0	0	0	10
Class 1 Seattle	4	7	4	0	0	0	0	0	0	15
Class 1 Tacoma	3	8	5	0	0	0	0	0	0	16
Total	**19**	**7**	**0**	**0**	**0**	**2**	**0**	**4**	**0**	**32**

Line Haul Emissions – On-Port and Adjacent Rail Yards

For line-haul locomotives operating on port or within the adjacent rail yards, fuel consumption and hp-hr estimates were developed using equations 2 and 3 described above and emission factors expressed in terms of mass of emissions per hp-hr were used to estimate emissions. This ratio technique was used because the railroads did not provide specific information on their line haul activities in 2016. The basic calculation underlying the estimation of line haul fuel consumption and hp-hrs uses the following terms and equation:

- Number of trains per year
- Average number of locomotives per train
- Average locomotive rated horsepower
- Average in-use locomotive load factor
- Average on-port time per train

The equation can be summarized as:

Equation 4

$$\textbf{Annual Energy}\left(\frac{hp-hrs}{year}\right)=\frac{trains}{year}\times\frac{locomotives}{train}\times HP\times LF\times hours$$

Where:
Annual energy = activity, hp-hr/year
HP = average rated horsepower of a single locomotive
LF = load factor, unitless average power level related to full rated power

Fuel consumption is calculated from the hp-hr estimate using the line haul BSFC value of 20.8 horsepower-hours per gallon of fuel[25] (hp-hr/gal) by dividing hp-hr by hp-hr/gal.

As discussed in subsection 6.4 in the 2016 PSEI report, average locomotive horsepower was assumed to be 4,300, with four locomotives assigned to eastbound trains and three locomotives assigned to westbound trains. It was further assumed, consistent with the 2011 emissions inventory, that eastbound trains spend an average of two hours within the terminal or rail yard and westbound trains spend an average of one hour within the terminal or rail yard.

Locomotives seldom operate at their peak horsepower ratings, so the horsepower-hours of activity were calculated using an estimate of average in-use horsepower of the locomotives. The horsepower-hour units are consistent with the emission factors, which are expressed in units of mass of emissions per horsepower-hour. Starting with the 2005 emissions inventory, information from a Regulatory Support Document (RSD) published by EPA in support of rulemaking[26] was used to estimate an average locomotive load factor of 28% in normal operation. This assumption is less than ideal and is likely to be conservatively high because it represents the average of normal overall line-haul locomotive activity, which includes cross-country travel as well as the low-speed activity at each end of a trip, so the percentages of time in each notch setting may not accurately represent rail yard or port terminal activity. These averages have been used in lieu of locally specific information or information specifically representing the activities at each end of a line-haul trip.

The resulting hp-hr value is multiplied by pollutant-specific emission factors in terms of grams of pollutant per horsepower-hour (g/hp-hr) and divided by 453.59 g/lb x 2,000 pounds [lbs]/ton to calculate emissions in tons per year.

Equation 5

$$\textbf{Emissions} = \textbf{Annual Energy}\left(\frac{hp-hr}{year}\right)\times EF\left(\frac{g}{hp-hr}\right)\Big/\left(453.59\left(\frac{g}{lb}\right)\times 2{,}000\left(\frac{lbs}{ton}\right)\right)$$

[25] EPA, *Emission Factors for Locomotives*, EPA-420-F-09-025. April 2009.

[26] EPA, *Regulatory Impact Analysis: Control of Emissions of Air Pollution from Locomotive Engines and Marine Compression Ignition Engines Less than 30 Liters Per Cylinder,* EPA 420-R-08-001, March 2008.

Line Haul Emissions - Airshed

Port-related locomotive emissions within the airshed and outside the rail yards have been estimated using 2016 fleet composite emission factors published by EPA and discussed below. Emission estimates for port-related locomotive activity were developed using fuel consumption estimates converted to horsepower-hours and the fleet composite emission factors using equation 5 provided above. The railroads did not provide detailed information for this inventory. As a result, fuel consumption estimates developed for the 2011 PSEI were updated for port throughput changes on a terminal-specific basis using equation 3 with an additional step for the improvements in operating efficiency achieved by the railroads, as reflected in information provided by the railroads to the federal government in reports known as R-1 reports.[27]

The R-1 reports include detailed information on freight movements and fuel consumption that allow changes in overall fuel efficiency to be evaluated and tracked over time. Each Class 1 railroad submits a Form R-1 for each calendar year after the conclusion of the year, to the Surface Transportation Board (STB) of the U.S. Department of Transportation. The forms are posted on the STB's website as noted below in the footnote. The forms include total fuel consumption (Table 750) and total gross ton-miles (GTM, Table 755), from which an overall fuel consumption figure of gallons per GTM is calculated (gallons divided by gross ton-miles). This provides an overall figure for each Class 1 railroad that is not location specific but does provide a comparison of improvements in the railroads' fuel efficiency over time and so can be valuable in evaluating changes over time. The average difference for UP and BNSF between 2011 and 2016 was a modest 0.6% improvement in fuel consumption expressed as gallons per GTM. This improvement is incorporated into the 2016 fuel consumption and hp-hr estimates by multiplying the initial result of equation 3 by the result of (2016 R-1 factor) divided by (2011 R-1 factor) or specifically 0.993 gals per 1,000 GTM /0.999 gals per 1,000 GTM = 0.994.

Emission Factors

The emission factors for most pollutants (NO_x, PM, VOCs, CO) come from an EPA publication[28] issued in support of locomotive rulemaking. The emission factors are published for each engine tier level and also (for NO_x, PM, and VOCs) for annual fleet composites representing EPA's projection of fleet turnover and the makeup of the nationwide locomotive fleet annually through calendar year 2040. Tier-specific switching locomotive emission factors were used for the switching emission estimates while the fleet composite emission factors for calendar year 2016 were used for the line haul estimates instead of the tier-specific emission factors because information on the tier levels of the locomotives calling in the inventory area during 2016 is not available.

[27] Publicly available online from: *https://www.stb.gov/stb/industry/econ_reports.html*

[28] "Emission Factors for Locomotives," EPA-420-F-09-025, Office of Transportation and Air Quality, April 2009

Emission factors for SO_2 and CO_2 have been developed using a mass balance approach based on the typical amounts of sulfur and carbon in diesel fuel. The SO_2 emission factor assumed diesel fuel sulfur content of 15 ppm in 2016. The emission factors for N_2O and CH_4 were obtained from an EPA publication on greenhouse gases.[29] Emission factors for line haul and switching locomotives are presented in Table F.2.

Table F.2: Locomotive Emission Factors

Locomotive Tier Levels	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$ g/bhp-hr	DPM	BC	CO_2	N_2O	CH_4
Line haul locomotives											
CY 2016	5.82	0.25	1.28	0.005	0.15	0.14	0.15	0.11	484	0.012	0.038
Switching locomotives											
Pre-tier	17.4	1.01	1.83	0.006	0.44	0.40	0.44	0.31	662	0.017	0.052
Tier 0	12.6	1.01	1.83	0.006	0.44	0.40	0.44	0.31	662	0.017	0.052
Tier 0+	10.6	0.57	1.83	0.006	0.23	0.21	0.23	0.16	662	0.017	0.052
Tier 1	9.9	1.01	1.83	0.006	0.43	0.40	0.43	0.31	662	0.017	0.052
Tier 1+	9.9	0.57	1.83	0.006	0.23	0.21	0.23	0.16	662	0.017	0.052
Tier 2	7.3	0.51	1.83	0.006	0.19	0.17	0.19	0.13	662	0.017	0.052
Tier 2+	7.3	0.26	1.83	0.006	0.11	0.10	0.11	0.08	662	0.017	0.052
Tier 3	4.5	0.26	1.83	0.006	0.08	0.07	0.08	0.05	662	0.017	0.052
Tier 4	1.0	0.08	1.83	0.006	0.015	0.014	0.015	0.001	662	0.017	0.052

[29] Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990 – 2014; April 2016; Table A- 109: Emission Factors for CH_4 and N_2O Emissions from Non-Highway Mobile Combustion (g gas/kg fuel).

APPENDIX G: HEAVY-DUTY VEHICLES EMISSIONS ESTIMATING METHODOLOGY

Heavy-Duty Vehicle Emissions Estimating Methodology

The MOVES2014a model was used to calculate emission factors for HDVs, with the model being run for the truck type "combination short haul truck" and, for cruise terminal bus idling emissions, for the vehicle type "transit bus." This is the latest version of the model released by the U.S. EPA to assist in developing mobile source emission estimates.[30] It should be noted that the previous PSEIs (2011 and 2005) were prepared using the older EPA MOBILE series of models. The MOVES2014a model is based on newer data and provides greater flexibility to evaluate project-level emissions than the MOBILE model. Estimates produced by MOVES can differ considerably from estimates produced using the MOBILE model versions. Therefore, the 2011 and 2005 emissions have been re-estimated using MOVES2014a to allow comparison of the three inventories. The 2011 and 2005 emissions presented in this report are not the same as the emissions originally reported in the 2011 and 2005 PSEI reports, but represent the latest science with respect to vehicle emissions.

EPA's switch from MOBILE to MOVES marked a fundamental change in the vehicle emission estimating methodology, moving from an assessment of a vehicle's average emissions per mile in MOBILE6.2 to estimating emissions as a function of a vehicle's power output, or vehicle specific power in MOVES, allowing the model to be run for a wider variety of activity types. In addition, improvements have been made to other areas of the modeling methodology to modernize the observational data used to develop emission estimates and to base certain emission types on their underlying physical processes (such as evaporative emissions).

EPA has released information on the differences in estimates produced by the two models for some pollutants.[31] While the differences will vary by vehicle type, fuel type, and other modeling specifics, EPA has reported that the MOVES model produced higher estimates of NO_x and $PM_{2.5}$ emissions than the MOBILE6.2 in their comparison runs. Such differences do not reflect actual emission increases and are why the prior inventory years were rerun using the new model. EPA has also released additional information on the MOVES model, differences between MOVES and MOBILE6.2, and between the earlier versions of MOVES (which were not used in prior PSEI reports) and the current MOVES2014a.[32]

The MOVES2014a model runs were used to develop estimates of vehicle emission factors in terms of grams per mile for driving emissions and grams per hour for idling emissions. These estimates are specific to the vehicles' model year and can also be run for specific speeds and for idling, or for typical on-road travel in a specified county. Emission factors were developed for the average on-terminal speed of 15 miles per hour, for idling on-terminal or at the cruise terminal unload/load areas, and for on-road driving conditions in the inventory area outside of the terminals. On-road idling emissions (such as traffic signals) are included in the on-road emission factors. Composite emission factors were developed

[30] Information available at: https://*www.epa.gov/moves*
[31] See: *https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P1005ZAJ.pdf*
[32] See: *https://crcao.org/reports/recentstudies2011/E-68a/Final%20CRC%20E-68a%20Report_V6.pdf*
https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100NNR0.txt
https://nepis.epa.gov/Exe/ZyPDF.cgi?Dockey=P100JWJ5.pdf

for trucks using the by-model-year emission factors and the truck model year distribution information provided by the NWSA that reflect the local mixture of model years among the trucks serving the Ports included in the inventory. Emission factors for cruise terminal bus idling reflect the general age distribution of buses in King County, obtained from the MOVES model by not specifying the "by model year" option in the run specifications. These emission factors are presented in Table G.1.

Table G.1: HDV Emission Factors, g/hour and g/mile

Activity Component	Units	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	BC	CO_2	N_2O	CH_4
		g/hour and g/mile										
Bus Idling	g/hr	156.6	14.067	32.563	0.068	1.907	1.755	1.907	6.758	7,780	0.025	0.393
Truck Idling	g/hr	81.5	10.597	23.779	0.068	3.988	3.669	3.988	1.910	7,792	0.014	0.349
15 mph	g/mi	17.1	1.286	5.790	0.022	0.823	0.758	0.823	0.395	2,506	0.005	0.054
On-road	g/mi	9.5	0.396	2.267	0.016	0.444	0.408	0.444	0.147	1,845	0.002	0.045

The general form of the equation for estimating vehicle emissions is:

Equation 1

$$\boldsymbol{E} = (\boldsymbol{EF} \times \boldsymbol{A})$$

Where:
E = mass of emissions per defined period
EF = emission factor (g/mile or g/hr)
A = activity (miles driven or hours of idling during the defined period)

Emissions from on-terminal operations were estimated by multiplying the miles driven and hours idling provided by each terminal by the relevant emission factor. Emissions from on-road driving throughout the airshed were estimated by the Puget Sound Regional Council staff using vehicle miles of travel (VMT) estimated with their Travel Demand Model, which simulates all the travel in their 4-county region within the airshed (Snohomish, King, Kitsap, and Pierce) on an average weekday, to develop the annual on-road port-related truck VMT for 2016. To extrapolate from daily to annual VMT the daily mileage figures were multiplied by 310, which represent 6 day-per-week operation. The model includes speed and distance components and the PSRC's on-road gram-per-mile emission factors reflect the modeled average speeds, which ranged from 24 to 40 miles per hour.

The two largest ports in the Puget Sound region, the Northwest Seaport Alliance and Port of Everett (King, Pierce, and Snohomish Counties) have the highest off-terminal port-related HDV activity levels in the study area and were the focus of the PSRC's modeling efforts, which represent the best data within the inventory domain. The VMT for each of these ports were 119,520/day for the NWSA North Harbor, 125,540/day for the NWSA South Harbor, and 16,910/day for the Port of Everett, covering King, Kitsap, Pierce, and Snohomish Counties.

The PSRC estimated emissions from heavy-duty vehicles using their travel demand model to estimate VMT and MOVES2014a to develop emission factors for the following pollutants:

NO_x, VOC, CO, SO_2, PM_{10}, $PM_{2.5}$, CO_2, N_2O, and CH_4. DPM estimates were not directly calculated by the model, but are considered equal to the PM_{10} values because all particulate matter emitted from diesel engines is DPM. Black carbon emissions were estimated using a relationship with $PM_{2.5}$ emissions, with pre-2007 trucks (without DPF) emitting black carbon at 77% of $PM_{2.5}$ while 2007 and newer trucks (equipped with a DPF) emitting at 10% of $PM_{2.5}$.[33]

Consistent with the 2005 and 2016 emissions inventory methodologies, emissions from truck activities in other counties in the inventory area were extrapolated from the Puget Sound region emissions using the ratios of port-related HDV to total HDV emissions to develop scaling factors. For example, if VOC emissions from port-related HDVs in the Puget Sound region area made up 7% of all HDV emissions in the Puget Sound Region area, then each county's overall VOC emissions (from HDVs) would be multiplied by 7% to estimate the county-level VOC emissions from port-related HDVs. The overall county-specific HDV emissions used in developing the county-level extrapolations are from the 2014 National Emissions Inventory,[34] which consists of information provided to EPA by the Washington DoE. This data represents the most recent complete set of county-level HDV emissions.

[33] EPA, "*Black Carbon Emissions Inventory Methods and Comparisons*", Appendix 2, pages 276 to 278, EPA's report to Congress; no longer available on EPA website

[34] *https://www.epa.gov/air-emissions-inventories/2014-national-emissions-inventory-nei-data*

APPENDIX H: FLEET VEHICLES EMISSIONS ESTIMATING METHODOLOGY

Fleet Vehicles Emissions Estimating Methodology

The MOVES2014a model was used to calculate emission factors for the on-road fleet vehicles. It should be noted that the previous PSEIs (2011 and 2005) were prepared using versions of the previous EPA model for on-road mobile sources known as the MOBILE series of models (MOBILE2010 being the last version released). The MOVES model was developed using the latest information available to EPA and produces estimates that can differ considerably from estimates produced using the MOBILE model versions. As a result, 2011 and 2005 emissions have been re-estimated using MOVES2014a to allow comparison of the three inventories. The 2011 and 2005 emissions presented in this report are not the same as the emissions originally reported in the 2011 and 2005 PSEI reports, but represent the latest science with respect to vehicle emissions.

Similar to the HDV emission estimates, the general form of the equation for estimating emissions is:

Equation 1

$$\boldsymbol{E} = (\boldsymbol{EF} \times \boldsymbol{A})$$

Where:
E = mass of emissions per defined period
EF = emission factor (g/mile or g/hr)
A = activity (miles driven or hours of idling during the defined period)

The model was run by model year for gasoline and diesel fuels and for vehicle types passenger car, passenger truck, light commercial truck, transit bus, single-unit short-haul truck, and combination short-haul truck. Vehicle types were run for both fuels except for passenger cars run only for gasoline and combination short-haul trucks run only for diesel. Emission factors were developed for 15-mph and 25-mph travel and for idling. The vehicles reported in the fleet vehicles category were classified by fuel type and as one of these vehicle types. The MOVES emission factors were modified to reflect emission factors for the few alternatively-fueled vehicles reported (alternative fuels in the fleet are B20 biodiesel blend and CNG). B20 adjustment factors consistent with the 2011 PSEI that were used to modify the corresponding diesel emission factors are presented in Table H.1. Given that MOVES does not provide emission factors for CNG engines for most vehicle types, and that they meet the same emission standards as gasoline engines, the same emission factors were used for the two reported CNG vehicles as for gasoline vehicles.

Emission factors by model year, fuel type, speed, and vehicle type were matched to the model year of each discrete vehicle in the dataset. The model year distribution of the cruise terminal passenger vehicles is not known, so fleet average emission factors were developed for each pollutant for these vehicles in aggregate. The new vehicles processed through the automobile terminal were modeled as 2016 model year vehicles.

Emissions were estimated by multiplying the miles driven and hours idling on each terminal by the relevant emission factor, matched for vehicle type, fuel, model year, and speed based on the reported information.

Table H.1: B20 Adjustment Factors

Pollutant:	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	BC	CO_2	N_2O	CH_4
Adjustment factors	1.015	1.00	1.00	0.80	0.85	0.85	0.68	1.00	0.46	1.00	1.00

APPENDIX I: POLLUTANT DESCRIPTION TABLE

Table I.1: Pollutant and Greenhouse Gases Description

Pollutant	Sources	Health & Environmental Effects
Oxides of nitrogen (NO_x) is the generic term for a group of highly reactive gases; all of which contain nitrogen and oxygen in varying amounts.	NO_x forms when fuel is burned at high temperatures, as in a combustion process. The primary manmade sources of NO_x are motor vehicles, electric utilities, and other industrial, commercial, and residential sources that burn fuels.	NO_x can react with other compounds in the air to form tiny particles adding to PM concentrations. NO_x is an ozone precursor and is also associated with respiratory health effects.
Particulate matter (PM) refers to tiny, discrete solid or aerosol particles in the air. Dust, dirt, soot, and smoke are considered particulate matter. Two types of PM are included in this emissions inventory: **PM_{10}**, which consists of particles measuring up to 10 micrometers in diameter; and **$PM_{2.5}$**, which consists of fine particles measuring 2.5 micrometers in diameter or smaller.	Vehicle exhaust (cars, trucks, buses, among others) are the predominant sources of fine particles in urban areas. In rural areas, land-clearing burning and backyard burning of yard waste contribute to particulate matter levels.	Fine particles are a concern because their very tiny size allows them travel more deeply into lungs, increasing the potential for health risks. Exposure to $PM_{2.5}$ is linked with respiratory disease, decreased lung function, asthma attacks, heart attacks and premature death.
Volatile organic compounds (VOC) are included in the emissions inventory because they are an ozone ingredient.	VOCs come from the transportation sector: cars and light trucks, marine vessels, and heavy-duty diesel vehicles.	In addition to contributing to the formation of ozone, some VOC are air toxics which can contribute to a wide range of adverse health effects.
Carbon monoxide (CO) is a colorless, odorless, toxic gas commonly formed when carbon-containing fuel is not burned completely.	CO forms during incomplete combustion of fuels. The majority of CO comes from on and off road vehicle engine exhaust.	CO combines with hemoglobin in red blood cells and decreases the oxygen-carrying capacity of the blood. CO weakens heart contractions, reducing the amount of blood pumped through the body. It can affect brain and lung function.
Black Carbon (BC) is a sooty black material emitted from gas and diesel engines, coal-fired power plants, and other sources that burn fossil fuel.	BC is non-anthropogenic and anthropogenic as a result of the incomplete combustion of fossil fuels. Primary sources are diesel engines.	BC is a short-term climate change pollutant that has negative implications for human health such as respiratory and cardiovascular disease, cancer and birth defects.

Table I.1: Pollutant and Greenhouse Gases Description (cont'd)

Pollutant	Sources	Health & Environmental Effects
Sulfur dioxide (SO_2) is a colorless, corrosive gas produced by burning fuel containing sulfur, such as coal and oil, and by industrial processes such as smelters, paper mills, power plants and steel manufacturing plants.	SO_2 emissions are primarily a result of combustion fuels in cars, trucks, vessels, locomotives and equipment. Over the past decade, levels of sulfur in diesel and gasoline fuels have decreased dramatically due to federal regulations set by the EPA, which resulted in decreasing SO_2 emissions.	SO_2 is associated with a variety of respiratory diseases. Inhalation of SO_2 can cause increased airway resistance by constricting lung passages. Some of the SO_2 become sulfate particles in the atmosphere adding to measured PM levels.
Diesel particulate matter (DPM) is a significant component of PM. Diesel exhaust also includes more than 40 substances that are listed as hazardous pollutants. Because of their microscopic size, DPM can become trapped in the small airways of the lungs.	Sources of diesel emissions include diesel-powered trucks, buses and cars (on-road sources); diesel-powered marine vessels, construction equipment, trains and aircraft support equipment (non-road sources).	DPM is linked with health effects typical of all PM, including heart problems, aggravated asthma, chronic bronchitis and premature death.
Greenhouse gases (GHG) included in this emissions inventory are carbon dioxide, methane, and nitrous oxide. Additional gases that are not significantly emitted by maritime-related sources or included in this inventory also contribute to climate change.	GHG come from both natural processes and human activities, although increases of human-made GHG are most responsible for disrupting the balance of the atmosphere. Most GHG come from transportation and electricity generation.	Climate change, also referred to as global warming, occurs when excessive amounts of GHG accumulate in our atmosphere. These gases trap heat, causing the temperature of the earth to rise.
Ozone (O_3) is a pungent-smelling, colorless gas produced in the atmosphere when NO_x and VOC chemically react under sunlight. The highest O_3 levels occur on hot summer afternoons. This inventory does not include O_3 because it is not directly emitted; this inventory does include the O_3 precursors NO_x and VOC compounds.	Most O_3 causing NO_x and VOCs come from the transportation sector: cars and light trucks, marine vessels, and heavy-duty diesel vehicles. Other sources include gasoline-powered yard equipment, gasoline refueling, industrial solvents, and auto-body paint shops, among others.	Exposure to ground-level O_3 can reduce lung function, cause respiratory irritation, aggravate asthma symptoms, and weaken the immune system. O_3 has environmental impacts as well; studies show that O_3 can damage agricultural crops and forests.

Appendix J: Commercial Harbor and Government Vessel Characteristics Comparison Tables

Table J.1: Commercial Harbor and Government Vessel Average Operational Hours Comparison for Propulsion Engines

Type	2005 (hours)	2011 (hours)	2016 (hours)	2016 vs 2005 % Change	2016 vs 2011 % Change
Assist/Escort	2,673	3,135	3,135	17%	0%
Commercial fishing	49	49	49	-1%	0%
Derrick barge	na	na	na	na	na
Excursion	851	857	879	3%	3%
Ferry	3,845	4,337	4,420	15%	2%
Government	826	832	838	1%	1%
Harbor tug	1,529	1,788	1,540	1%	-14%
Ocean tug	498	657	498	0%	-24%
Pilot boat	2,675	799	799	-70%	0%
Tank barge	na	na	na	na	na
Workboat	553	570	840	52%	47%

Table J.2: Commercial Harbor and Government Vessel Average Operational Hours Comparison for Auxiliary Engines

Type	2005 (hours)	2011 (hours)	2016 (hours)	2016 vs 2005 % Change	2016 vs 2011 % Change
Assist/Escort	3,644	3,122	3,081	-15%	-1%
Commercial fishing	49	49	48	-2%	-1%
Derrick barge	na	820	472	na	-42%
Excursion	600	684	707	18%	3%
Ferry	2,212	2,080	2,207	0%	6%
Government	716	633	186	-74%	-71%
Harbor tug	1,034	1,669	1,842	78%	10%
Ocean tug	439	457	900	105%	97%
Pilot boat	1,000	342	342	-66%	0%
Tank barge	455	1,087	990	118%	-9%
Workboat	574	na	224	-61%	na

Table J.3: Commercial Harbor and Government Vessel Average Propulsion Engine Horsepower by Engine and Vessel Type, hp

Type	2005 (hp)	2011 (hp)	2016 (hp)	2016 vs 2005 % Change	2016 vs 2011 % Change
Assist/Escort	2,123	2,616	2,682	26%	3%
Commercial fishing	762	718	776	2%	8%
Derrick barge	na	na	na	na	na
Excursion	404	400	385	-5%	-4%
Ferry	1,809	1,914	2,028	12%	6%
Government	990	1,007	1,010	2%	0%
Harbor tug	849	854	961	13%	13%
Ocean tug	2,156	2,316	2,394	11%	3%
Pilot boat	1,100	1,100	1,100	0%	0%
Tank barge	na	na	na	na	na
Workboat	384	463	298	-22%	-36%

Table J.4: Commercial Harbor and Government Vessel Average Auxiliary Engine Horsepower by Engine and Vessel Type, hp

Type	2005 (hp)	2011 (hp)	2016 (hp)	2016 vs 2005 % Change	2016 vs 2011 % Change
Assist/Escort	134	203	214	60%	5%
Commercial fishing	316	304	326	3%	7%
Derrick barge	na	326	309	na	-6%
Excursion	42	42	37	-12%	-12%
Ferry	377	363	341	-10%	-6%
Government	402	431	653	62%	52%
Harbor tug	85	98	99	16%	1%
Ocean tug	133	147	157	18%	7%
Pilot boat	47	47	47	0%	0%
Tank barge	188	228	249	32%	9%
Workboat	174	na	58	-67%	na

Table J.5: Commercial Harbor and Government Vessel Average Propulsion Engine Model Year by Vessel Type

Type	2005 Year	2011 Year	2016 Year	2005 Age	2011 Age	2016 Age
Assist/Escort	1986	1994	1993	19	17	23
Commercial fishing	1973	1976	1974	32	35	42
Derrick barge	na	na	na	na	na	na
Excursion	1992	1992	1996	13	19	20
Ferry	1994	1996	1999	11	15	17
Government	1991	1993	2000	14	18	16
Harbor tug	1978	1988	1993	27	23	23
Ocean tug	1981	1983	1992	24	28	24
Pilot boat	2000	2000	2000	5	11	16
Tank barge	na	na	na	na	na	na
Workboat	1981	1982	2009	24	29	7

Table J.6: Commercial Harbor and Government Vessel Average Auxiliary Engine Model Year by Vessel Type

Type	2005 Year	2011 Year	2016 Year	2005 Age	2011 Age	2016 Age
Assist/Escort	1985	1999	2003	20	12	13
Commercial fishing	1973	1976	1975	32	35	41
Derrick barge	na	1988	1995	na	23	21
Excursion	1987	1992	1997	na	19	19
Ferry	1996	1997	2002	9	14	14
Government	1999	1969	1987	6	42	29
Harbor tug	1977	1986	1998	28	25	18
Ocean tug	1982	1984	1995	23	27	21
Pilot boat	2000	2000	2000	5	11	16
Tank barge	1987	2000	2008	18	11	8
Workboat	1976	na	2001	29	na	15

Appendix K: Cargo-handling Equipment Characteristics By Port

The following tables present for each port, the 2016 CHE characteristics. For fields with "na", it means that data is not available, and for electric equipment, it also means horsepower is not applicable since electric equipment have zero-emission engines. For electric equipment, only the count is included in this emissions inventory, therefore no other data was requested or received for electric equipment.

Table K.1: Port of Anacortes 2016 CHE Characteristics

Equipment	Engine Type	Count	Power (hp)			Model Year			Annual Hours		
			Min	Max	verage	Min	Max	verage	Min	Max	verage
Forklift	Diesel	1	200	200	200	1982	1982	1982	78	78	78
Skid steer loader	Diesel	2	150	150	150	1991	2012	2002	42	95	69
Forklift	Propane	4	50	200	117	1970	2008	1988	3	51	21
Total		**7**									

Table K.2: Port of Port Angeles 2016 CHE Characteristics

Equipment	Engine Type	Count	Power (hp)			Model Year			Annual Hours		
			Min	Max	verage	Min	Max	verage	Min	Max	verage
Forklift	Diesel	2	95	99	97	1973	2014	1994	132	273	203
Log stacker	Diesel	2	400	400	400	1986	1999	1993	825	825	825
Total		**4**									

Table K.3: Port of Olympia 2016 CHE Characteristics

Equipment	Engine Type	Count	Power (hp)			Model Year			Annual Hours		
			Min	Max	verage	Min	Max	verage	Min	Max	verage
Crane	Diesel	2	100	1135	618	1994	1994	1994	10	341	176
Forklift	Diesel	7	85	159	109	2001	2013	2008	112	358	229
Loader	Diesel	6	197	415	379	1989	2000	1995	131	1,678	876
Log Stacker	Diesel	21	197	500	340	1994	2015	2005	500	2,000	1,357
Skid steer loader	Diesel	2	100	200	150	1994	1998	1996	20	250	135
Sweeper	Diesel	2	210	230	220	1999	2010	2005	105	157	131
Tractor	Diesel	1	33	33	33	2006	2006	2006	500	500	500
Truck	Diesel	3	250	460	370	1972	1995	1986	50	350	217
Yard tractor	Diesel	4	275	275	275	2006	2013	2011	10	62	25
Forklift	Propane	1	120	120	120	1993	1993	1993	100	100	100
Manlift	Propane	1	87	87	87	1997	1997	1997	211	211	211
Sweeper	Propane	1	130	130	130	2002	2002	2002	23	23	23
Total		**51**									

For Port of Everett, the characteristics are presented entity. In 2016, there were only three entities that owned and/or operated cargo-handling equipment at the Port which includes two stevedores and port-owned equipment.

Table K.4: Port of Everett 2016 CHE Characteristics by Entity

Entity	Equipment	Engine Type	Count	Power (hp)			Model Year			Annual Hours		
				Min	Max	Average	Min	Max	Average	Min	Max	Average
PSE010	Backhoe	Diesel	1	63	63	63	1988	1988	1988	300	300	300
PSE010	Compressor	Gasoline	1	50	50	50	1978	1978	1978	250	250	250
PSE010	Crane	Diesel	1	250	250	250	2000	2000	2000	280	280	280
PSE010	Forklift	Propane	5	93	93	93	1982	1982	1982	300	300	300
PSE010	Forklift	Diesel	9	85	220	136	1974	2014	1996	197	465	288
PSE010	Forklift	Gasoline	3	76	175	109	1968	1974	1970	200	250	217
PSE010	Generator	Diesel	2	210	602	406	2000	2006	2003	50	100	75
PSE010	Light tower	Diesel	1	25	25	25	1991	1991	1991	300	300	300
PSE010	Loader	Diesel	2	101	101	101	1970	1974	1972	200	200	200
PSE010	Manlift	Gasoline	1	82	82	82	1998	1998	1998	300	300	300
PSE010	Rail pusher	Diesel	1	215	215	215	2013	2013	2013	200	200	200
PSE010	Reach stacker	Diesel	5	261	335	291	2006	2014	2011	299	655	506
PSE010	Sweeper	Diesel	1	36	36	36	1987	1987	1987	300	300	300
PSE010	Truck	Diesel	1	210	210	210	1992	1992	1992	350	350	350
PSE010	Welder	Gasoline	1	76	76	76	1968	1968	1968	250	250	250
Total PSE010			**35**									
PSE030	Forklift	Diesel	4	75	150	113	1984	1990	1986	1	21	9
PSE030	Top handler	Diesel	1	200	200	200	1993	1993	1993	0	0	0
PSE030	Yard tractor	Diesel	4	175	175	175	1986	1988	1987	0	145	70
Total PSE030			**9**									
PSE040	Forklift	Diesel	6	75	150	138	1987	1995	1991	200	200	200
PSE040	Forklift	Propane	3	na	na	na	na	na	na	200	200	200
PSE040	Reach stacker	Diesel	1	200	200	200	2000	2000	2000	400	400	400
PSE040	Yard tractor	Diesel	10	175	175	175	1984	2005	1993	200	200	200
Total PSE040			**20**									
Total Port			**64**									

Table K.5: Rail Yards 2016 CHE Characteristics

Equipment	Engine Type	Count	Power (hp)			Model Year			Annual Hours		
			Min	Max	Average	Min	Max	Average	Min	Max	Average
Loader	Diesel	4	355	355	355	1997	2005	2001	455	455	455
Side handler	Diesel	5	250	250	250	1991	2000	1994	816	816	816
Top handler	Diesel	13	250	335	278	1970	2014	1996	0	4,285	1,295
Yard tractor	Diesel	12	148	160	156	2003	2008	2007	1177	1,300	1,259
RMG crane	Electric	4	na	na	na	na	na	na	na	na	na
Manlift	Gasoline	1	30	30	30	1987	1987	1987	25	25	25
Forklift	Propane	1	45	45	45	1989	1989	1989	24	24	24
Total		**40**									

In 2015, the Port of Seattle and Port of Tacoma entered into a partnership for their marine cargo operations to manage the container, breakbulk, auto and some bulk terminals. Each port retains some lines of business that are outside of the NWSA boundaries. Therefore, for this inventory, the Port of Seattle and Port of Tacoma include only those facilities that are excluded from the NWSA. The Port of Seattle (non-NWSA) entities that owned and/or operated equipment in 2016 include a bulk terminal, cruise terminal, and Port-owned equipment.

Table K.6: Port of Seattle 2016 CHE Characteristics by Entity

Entity	Equipment	Engine Type	Count	Power (hp) Min	Max	Average	Model Year Min	Max	Average	Annual Hours Min	Max	Average
PSS010	Backhoe	Diesel	2	na	na	na	2011	2016	2014	750	750	750
PSS010	Forklift	Electric	1	na	na	na	1995	1995	1995	na	na	na
PSS010	Forklift	Propane	13	100	100	100	1988	2016	2009	50	1,500	221
PSS010	Forklift	Gasoline	4	35	150	96	1988	1993	1990	20	200	94
PSS010	Forklift	Diesel	10	150	200	193	1961	2016	1989	1	700	191
PSS010	Generator	Diesel	3	210	364	287	2001	2003	2002	28	102	58
PSS010	Generator	Gasoline	2	5	20	13	2005	2005	2005	5	5	5
PSS010	Golf cart	Electric	4	na	na	na	2000	2012	2008	na	na	na
PSS010	Manlift	Diesel	4	na	na	na	2006	2015	2010	100	215	159
PSS010	Manlift	Electric	1	na	na	na	2015	2015	2015	0	0	0
PSS010	Roller	Diesel	2	84	84	84	2013	2015	2014	25	50	38
PSS010	Tractor	Diesel	1	na	na	na	2009	2009	2009	85	85	85
Total PSS010			**47**									
PSS020	Crane	Diesel	8	130	130	130	1992	1998	1997	60	720	484
PSS020	Forklift	Electric	3	na	na	na	na	na	na	na	na	na
PSS020	Forklift	Propane	24	85	85	85	1987	2014	1999	480	610	518
PSS020	Forklift	Diesel	3	85	150	107	1991	1995	1992	20	60	47
PSS020	Pallet jack	Electric	24	na	na	na	na	na	na	na	na	na
Total PSS020			**62**									
PSS040	Forklift	Diesel	1	100	100	100	1995	1995	1995	1,000	1,000	1,000
Total PSS040			**1**									
Total Port			**110**									

The Port of Tacoma (non-NWSA) facilities include a grain terminal.

Table K.7: Port of Tacoma 2016 CHE Characteristics

Equipme	Engine Type	Count	Power (hp) Min	Max	Average	Model Year Min	Max	Average	Annual Hours Min	Max	Average
Forklift	Propane	1	77	77	77	2002	2002	2002	660	660	660
Total		**1**									

The NWSA North Harbor facilities include Terminal 18, Terminal 30, Terminal 46, and Terminal 115. Terminal 5 was closed for renovation in 2016 and did not operate equipment.

Table K.8: North Harbor 2016 CHE Characteristics

Entity	Equipment	Engine Type	Count	Power (hp)			Model Year			Annual Hours		
				Min	Max	Average	Min	Max	Average	Min	Max	Average
PSS030	Forklift	Propane	2	90	90	90	1997	2001	1999	127	825	476
PSS030	Forklift	Diesel	18	100	335	233	1993	2017	2005	20	2,586	1,139
PSS030	Forklift	Electric	12	na	na	na	2014	2015	2015	208	1,014	692
PSS030	Reach stacker	Diesel	2	335	335	335	2008	2010	2009	128	1,292	710
PSS030	Yard tractor	Diesel	2	200	200	200	2015	2015	2015	469	730	600
Total PSS030			**36**									
PSS050	Crane	Electric	10	na	na	na	na	na	na	na	na	na
PSS050	Forklift	Diesel	16	85	200	127	1982	2006	2002	0	391	342
PSS050	RTG crane	Diesel	6	620	947	838	1995	2005	2002	0	1,577	1,051
PSS050	Side handler	Diesel	4	200	205	204	2001	2011	2007	768	1,690	1,332
PSS050	Top handler	Diesel	29	335	335	335	2004	2007	2006	609	2,181	1,427
PSS050	Yard tractor	Diesel	63	173	173	173	2005	2008	2006	42	2,639	1,231
Total PSS050			**128**									
PSS060	Crane	Electric	6	na	na	na	na	na	na	na	na	na
PSS060	Forklift	Diesel	3	85	190	120	2004	2005	2004	260	372	303
PSS060	Side handler	Diesel	1	200	200	200	2001	2001	2001	420	420	420
PSS060	Top handler	Diesel	10	260	335	290	2001	2005	2004	676	1,853	1,257
PSS060	Yard tractor	Diesel	23	173	174	174	2002	2005	2003	210	1,141	849
Total PSS060			**43**									
PSS070	Crane	Electric	5	na	na	na	na	na	na	na	na	na
PSS070	Forklift	Propane	4	100	100	100	1994	2007	2000	30	300	233
PSS070	Forklift	Diesel	9	100	175	127	1970	2005	1996	70	1,675	342
PSS070	Side handler	Diesel	1	152	152	152	1995	1995	1995	350	350	350
PSS070	Sweeper	Diesel	1	185	185	185	2016	2016	2016	2,500	2,500	2,500
PSS070	Top handler	Diesel	24	250	250	250	1995	2008	2002	0	1,200	1,004
PSS070	Yard tractor	Diesel	38	174	240	186	1994	2007	2003	260	950	932
Total PSS070			**82**									
Total Port			**289**									

The NWSA South Harbor facilities include APM Terminal, Pierce County Terminal, Husky Terminal, Olympic Container Terminal, TOTE Terminal, Washington United Terminals, and port-owned equipment.

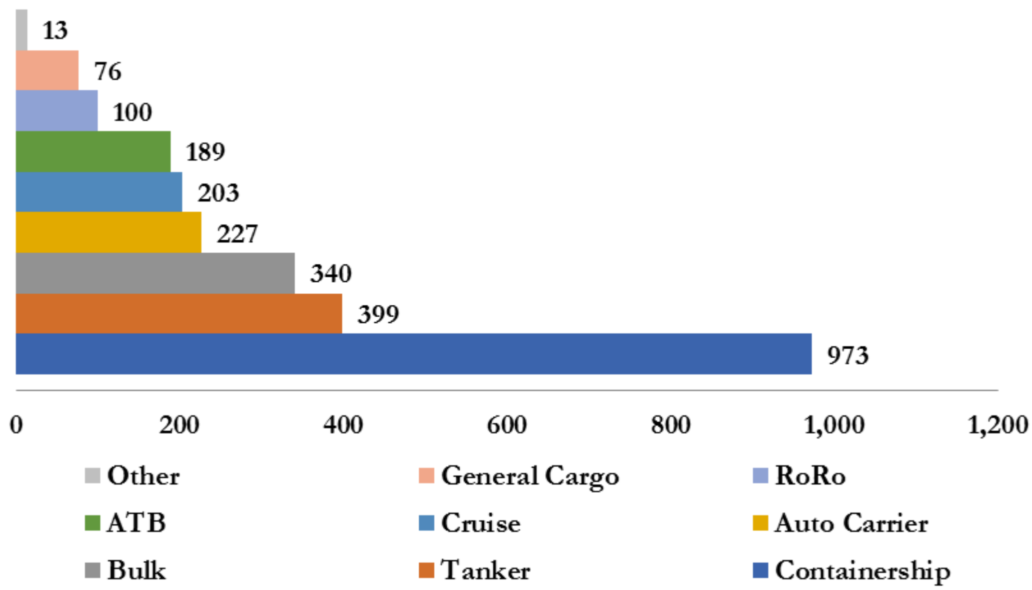
Table K.9: South Harbor 2016 CHE Characteristics

Entity	Equipment	Engine Type	Count	Power (hp) Min	Power (hp) Max	Power (hp) Average	Model Year Min	Model Year Max	Model Year Average	Annual Hours Min	Annual Hours Max	Annual Hours Average
PST010	Backhoe	Diesel	2	350	350	350	1985	1998	1992	65	271	168
PST010	Compressor	Gasoline	4	10	10	10	1996	2001	1999	253	253	253
PST010	Compressor	Diesel	6	10	10	10	1977	2004	1989	4	61	27
PST010	Forklift	Diesel	22	174	375	202	1978	2011	1994	1	497	91
PST010	Forklift	Propane	14	60	80	70	1977	2004	1986	15	109	49
PST010	Generator	Gasoline	2	60	100	80	1999	2007	2003	401	1,264	833
PST010	Generator	Diesel	3	36	237	170	2012	2013	2013	10	10	10
PST010	Manlift	Propane	2	50	60	55	2000	2008	2004	8	218	113
PST010	Manlift	Diesel	2	185	185	185	2006	2011	2009	54	146	100
PST010	Manlift	Gasoline	3	50	60	57	1984	2004	1994	52	226	110
PST010	Straddle carrier	Diesel	32	185	368	201	1991	2014	2002	147	2,330	1,316
PST010	Sweeper	Diesel	3	50	250	158	1994	2016	2005	82	930	410
PST010	Sweeper	Propane	1	50	50	50	1989	1989	1989	8	8	8
PST010	Tractor	Diesel	1	50	50	50	2012	2012	2012	200	200	200
PST010	Truck	Diesel	8	180	450	214	1984	2016	1996	4	203	68
PST010	Truck	Gasoline	2	130	130	130	1999	2003	2001	47	1,665	856
PST010	Yard tractor	Gasoline	1	110	110	110	2003	2003	2003	65	65	65
PST010	Yard tractor	Diesel	2	110	110	110	1987	1991	1989	16	43	30
Total PST010			**110**									
PST020	Crane	Electric	7	na	na	na	na	na	na	na	na	na
PST020	Forklift	Propane	6	155	155	155	2005	2005	2005	152	282	239
PST020	Forklift	Diesel	2	180	180	180	2005	2005	2005	134	269	202
PST020	Side handler	Diesel	8	210	210	210	2005	2006	2005	648	1,066	786
PST020	Straddle carrier	Diesel	50	455	455	455	2004	2005	2004	378	1,805	1,363
PST020	Yard tractor	Diesel	4	180	180	180	2005	2006	2005	189	1,116	544
Total PST020			**77**									
PST030	Crane	Electric	4	na	na	na	na	na	na	na	na	na
PST030	Forklift	Diesel	5	57	156	116	1982	2006	2000	41	2,100	1,007
PST030	RTG crane	Diesel	5	300	300	300	2005	2012	2006	800	800	800
PST030	Top handler	Diesel	15	300	350	320	2002	2015	2008	2,666	2,666	2,666
PST030	Yard tractor	Diesel	40	173	174	173	2004	2015	2009	569	2,017	1,490
Total PST030			**69**									
PST040	Yard tractor	Diesel	33	210	250	242	1993	2016	2012	400	800	788
Total PST040			**33**									
PST050	Crane	Electric	5	na	na	na	na	na	na	na	na	na
PST050	Forklift	Diesel	6	120	185	142	2003	2006	2004	33	479	298
PST050	Forklift	Propane	1	120	120	120	1988	1988	1988	27	27	27
PST050	Manlift	Diesel	1	185	185	185	2005	2005	2005	99	99	99
PST050	Reach stacker	Diesel	3	335	335	335	2006	2006	2006	371	804	574
PST050	Sweeper	Diesel	1	205	205	205	2000	2000	2000	415	415	415
PST050	Yard tractor	Diesel	30	174	245	234	2000	2005	2004	149	1,417	911
PST055	Forklift	Propane	13	55	55	55	1988	2014	2000	352	1,225	748
PST055	Forklift	Diesel	9	50	100	70	1976	2009	1992	73	854	371
PST055	Top handler	Diesel	2	330	330	330	2007	2014	2011	1,220	1,271	1,246
PST055	Yard tractor	Diesel	12	174	174	174	2006	2006	2006	817	1,500	874
Total PST050 and PST055			**83**									
PST060	Crane	Electric	6	na	na	na	na	na	na	na	na	na
PST060	Forklift	Diesel	2	130	130	130	1964	1999	1982	30	54	42
PST060	Reach Stacker	Diesel	5	375	375	375	2012	2012	2012	na	na	na
PST060	RTG crane	Diesel	6	972	972	972	2012	2012	2012	na	na	na
PST060	Side handler	Diesel	6	166	185	182	2012	2013	2013	na	na	na
PST060	Top handler	Diesel	9	343	365	363	2011	2012	2012	na	na	na
PST060	Yard tractor	Diesel	75	173	215	176	1998	2013	2008	263	2,550	1,198
Total PST060			**109**									
PST070	Crane	Electric	4	na	na	na	na	na	na	na	na	na
PST070	Forklift	Propane	1	86	86	86	2015	2015	2015	144	144	144
PST070	Forklift	Diesel	14	75	194	124	1992	2015	2009	35	827	242
PST070	Side handler	Diesel	3	200	200	200	2001	2001	2001	650	682	671
PST070	Top handler	Diesel	2	350	350	350	2014	2014	2014	1,275	1,399	1,337
PST070	Yard tractor	Diesel	14	174	215	192	2001	2016	2009	14	1,720	514
Total PST070			**38**									
PST120	Backhoe	Diesel	1	65	65	65	1991	1991	1991	2,080	2,080	2,080
PST120	Loader	Diesel	15	51	440	274	1987	2011	2001	2,080	2,080	2,080
PST120	Truck	Diesel	1	210	210	210	1995	1995	1995	350	350	350
Total PST120			**17**									
Total Port			**536**									

APPENDIX L: OCEAN GOING VESSELS CHARACTERISTICS AND EMISSIONS BY PORT

Information gathered during the data collection process is summarized in this subsection. Figure L.1 shows the inbound vessels that visited the Puget Sound study area in 2016 by vessel type.

Figure L.1: 2016 OGV Inbound Calls by Vessel Type



Although the study is for all maritime facilities, the following data findings are summaries by port. The average vessel characteristics listed in the tables were not used for estimating emissions since actual values were used on a per engine and vessel basis. The purpose of the average vessel characteristic tables included in this subsection is to summarize the data for the reader.

Port of Anacortes Data Findings

Table L.1 summarizes the vessel movements for Port of Anacortes in 2016.

Table L.1: Port of Anacortes 2016 OGV Movements

Vessel Type	Inbound	Outbound	Shift	Movements
Bulk	5	14	10	29
General Cargo	1	1	0	2
ATB	5	2	8	15
Total	**11**	**17**	**18**	**46**

Table L.2 presents the average vessel and engine characteristics by vessel type for those vessels that called at the Port of Anacortes in 2016.

Table L.2: Port of Anacortes 2016 OGV Type Characteristics

Vessel Type	Year Built	Age	DWT (tons)	Speed (knots)	Main Engine Power (kW)	Aux Engine Power (kW)
Bulk	2011	5	49,240	14.4	8,279	na
General Cargo	2008	8	12,668	14	5,400	1,185
ITB	2009	7	656	na	7,626	na

Table L.3 presents the 2016 port emissions by hoteling and maneuvering for Port of Anacortes.

Table L.3: Port of Anacortes 2016 OGV Port Emissions by Mode, tpy

Mode	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
Hotelling	14.3	0.50	1.36	0.73	0.34	0.32	0.29	0.02	1,152
Maneuvering	0.1	0.01	0.01	0.00	0.00	0.00	0.00	0.00	7
Total	**14.5**	**0.51**	**1.37**	**0.74**	**0.35**	**0.32**	**0.29**	**0.02**	**1,159**

Port of Port Angeles Data Findings

Table L.4 presents the vessel movements for Port of Port Angeles in 2016.

Table L.4: Port of Port Angeles 2016 OGV Movements

Vessel Type	Inbound	Outbound	Shift	Movements
Bulk - Heavy Load	0	1	1	2
ATB	3	0	3	6
Tanker - Chemical	0	0	2	2
Tanker - Aframax	0	1	1	2
Tanker - Suezmax	5	8	4	17
Total	**8**	**10**	**11**	**29**

Table L.5 presents the average vessel and engine characteristics by vessel type for those vessels that called at the Port of Port Angeles in 2016.

Table L.5: Port of Port Angeles 2016 OGV Type Characteristics

Vessel Type	Year Built	Age	DWT (tons)	Speed (knots)	Main Engine Power (kW)	Aux Engine Power (kW)
Bulk - Heavy Load	2009	7	2,779	10	2,985	na
ATB	2010	6	806	na	7,395	na
Tanker - Chemical	2009	7	46,734	14.6	8,700	2,400
Tanker - Aframax	2009	7	114,824	15	11,525	na
Tanker - Suezmax	2004	12	167,394	15.9	23,647	13,751

Table L.6 presents the 2016 port emissions by hoteling and maneuvering for Port of Port Angeles.

Table L.6: Port of Port Angeles 2016 OGV Port Emissions by Mode, tpy

Mode	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
Hotelling	125.1	4.34	11.83	5.40	2.77	2.61	2.58	0.16	8,482
Maneuvering	0.7	0.03	0.05	0.03	0.01	0.01	0.01	0.00	41
Total	**125.8**	**4.36**	**11.89**	**5.43**	**2.79**	**2.62**	**2.59**	**0.16**	**8,524**

Port of Everett Data Findings

Table L.7 presents the vessel movements for Port of Everett in 2016. The number of inbound and outbound trips does not match due to vessel shifts from another dock or terminal within the port instead of arriving from the sea or another port or maritime facility.

Table L.7: Port of Everett 2016 OGVMovements

Vessel Type	Inbound	Outbound	Shift	Movements
Bulk	6	8	2	16
Container - 1000	0	1	1	2
Container - 2000	33	9	0	42
General Cargo	40	15	1	56
ATB	3	1	4	8
Total	**82**	**34**	**8**	**124**

Table L.8 presents the average vessel and engine characteristics by vessel type for those vessels that called at the Port of Everett in 2016.

Table L.8: Port of Everett 2016 OGV Type Characteristics

Vessel Type	Year Built	Age	DWT (tons)	Speed (knots)	Main Engine Power (kW)	Aux Engine Power (kW)
Bulk	2010	6	32,816	14.4	6,446	na
Container - 1000	2001	15	8,441	18.4	7,200	na
Container - 2000	2009	7	32,794	19.9	17,872	5,760
General Cargo	2007	9	30,422	15.9	9,981	3,780
ATB	2012	4	402	na	7,768	na

Table L.9 presents the 2016 port emissions by hoteling and maneuvering for Port of Everett.

Table L.9: Port of Everett 2016 OGV Port Emissions by Mode, tpy

Mode	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
Hotelling	24.5	0.84	2.27	1.27	0.58	0.55	0.47	0.03	1,997
Maneuvering	1.0	0.07	0.11	0.03	0.02	0.02	0.02	0.00	54
Total	**25.6**	**0.91**	**2.38**	**1.30**	**0.60**	**0.57**	**0.49**	**0.03**	**2,051**

Port of Olympia Data Findings

Table L.10 presents the vessel movements for Port of Olympia in 2016.

Table L.10: Port of Olympia 2016 OGV Movements

Vessel Type	Inbound	Outbound	Shift	Movements
Bulk	22	26	4	52
General Cargo	3	3	0	6
Reefer	1	1	0	2
Total	**26**	**30**	**4**	**60**

Table L.11 presents the average vessel and engine characteristics by vessel type for those vessels that called at the Port of Olympia in 2016.

Table L.11: Port of Olympia 2016 Average OGV Type Characteristics

Vessel Type	Year Built	Age	DWT (tons)	Speed (knots)	Main Engine Power (kW)	Aux Engine Power (kW)
Bulk	2007	9	35,904	14.2	7,032	na
General Cargo	2014	2	42,258	14.6	8,085	na
Reefer	1993	23	11,733	20	12,500	3,900

Table L.12 presents the 2016 port emissions by hoteling and maneuvering for Port of Olympia.

Table L.12: Port of Olympia 2016 OGV Port Emissions by Mode, tpy

Mode	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
Hotelling	25.5	0.87	2.33	1.26	0.59	0.55	0.49	0.03	1,983
Maneuvering	0.3	0.02	0.03	0.01	0.01	0.01	0.01	0.00	12
Total	**25.7**	**0.89**	**2.37**	**1.27**	**0.60**	**0.56**	**0.50**	**0.03**	**1,996**

Port of Seattle Data Findings

Table L.13 presents the vessel movements for Port of Seattle in 2016. In 2016, the Port of Seattle terminals included cruise terminals and the Pier 86 grain facility. The North Harbor data findings are shown separately. Per the inbound definition used for the emissions estimation model, the zero for inbound for some of the vessel types in the table means the vessel that called the port shifted from another berth, terminal or port. It did not arrive to the berth directly from the sea.

Table L.13: Port of Seattle 2016 OGV Movements

Vessel Type	Inbound	Outbound	Shift	Movements
Bulk	0	58	69	127
Cruise	203	203	0	406
Miscellaneous	0	1	1	2
Total	**203**	**262**	**70**	**535**

Table L.14 presents the average vessel and engine characteristics by vessel type for those vessels that called at the Port of Seattle in 2016.

Table L.14: Port of Seattle 2016 OGV Type Characteristics

Vessel Type	Year Built	Age	DWT (tons)	Speed (knots)	Main Engine Power (kW)	Aux Engine Power (kW)
Bulk	2010	6	79,104	14.5	10,331	na
Cruise	2003	13	8,948	22.1	60,013	23,225
Miscellaneous	2014	2	1,556	11	4,476	1,912

Table L.15 presents the 2016 port emissions by hoteling and maneuvering for Port of Seattle.

Table L.15: Port of Seattle 2016 OGV Port Emissions by Mode, tpy

Mode	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
Hotelling	211.2	6.83	18.62	8.62	4.39	4.12	4.05	0.25	13,540
Maneuvering	17.0	0.56	1.46	0.61	0.33	0.31	0.32	0.02	962
Total	**228.1**	**7.39**	**20.08**	**9.24**	**4.72**	**4.43**	**4.37**	**0.27**	**14,502**

Port of Tacoma Data Findings

Table L.16 presents the vessel movements for Port of Tacoma in 2016. In 2016, the Port of Tacoma terminals include the auto terminal, log facility, and grain facility. The South Harbor data findings are shown separately. Per the inbound definition used for the emissions estimation model, the zero for inbound for the bulk vessels in the table means the vessel that called the port shifted from another berth, terminal or port. It did not arrive to the berth directly from the sea.

Table L.16: Port of Tacoma 2016 OGV Movements

Vessel Type	Inbound	Outbound	Shift	Movements
Bulk	0	62	70	132
Total	**0**	**62**	**70**	**132**

Table L.17 presents the average vessel and engine characteristics by vessel type for those vessels that called at the Port of Tacoma in 2016.

Table L.17: Port of Tacoma Average 2016 OGV Type Characteristics

Vessel Type	Year Built	Age	DWT (tons)	Speed (knots)	Main Engine Power (kW)	Aux Engine Power (kW)
Bulk	2010	6	77,888	14.5	9,947	na

Table L.18 presents the 2016 port emissions by hoteling and maneuvering for Port of Tacoma.

Table L.18: Port of Tacoma 2016 OGV Port Emissions by Mode, tpy

Mode	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
Hotelling	33.6	1.20	3.23	1.78	0.82	0.77	0.68	0.05	2,796
Maneuvering	1.6	0.07	0.10	0.04	0.02	0.02	0.02	0.00	65
Total	**35.1**	**1.27**	**3.34**	**1.82**	**0.84**	**0.79**	**0.70**	**0.05**	**2,861**

NWSA North Harbor Data Findings

Table L.19 presents the vessel movements for North Harbor terminals in 2016. The North Harbor terminals are the container terminals located in Seattle.

Table L.19: North Harbor 2016 OGV Movements

Vessel Type	Inbound	Outbound	Shift	Movements
Bulk - Heavy Load	2	3	1	6
Bulk - Self Discharging	0	1	1	2
Container - 1000	10	10	0	20
Container - 2000	17	16	0	33
Container - 3000	44	44	0	88
Container - 4000	65	66	2	133
Container - 5000	54	53	0	107
Container - 6000	43	45	3	91
Container - 8000	48	107	64	219
Container - 9000	28	28	0	56
Container - 10000	39	80	41	160
Container - 11000	2	2	0	4
Container - 17000	1	1	0	2
General Cargo	1	1	0	2
ATB	0	0	2	2
RoRo	0	1	1	2
Tanker - Chemical	0	0	1	1
Total	**354**	**458**	**116**	**928**

Table L.20 presents the average vessel and engine characteristics by vessel type for those vessels that called at the North Harbor in 2016.

Table L.20: North Harbor 2016 OGV Type Characteristics

Vessel Type	Year Built	Age	DWT (tons)	Speed (knots)	Main Engine Power (kW)	Aux Engine Power (kW)
Bulk - Heavy Load	2006	10	3,940	16	12,167	na
Bulk - Self Discharging	2010	6	29,827	13.5	7,999	na
Container - 1000	1979	37	25,517	20	23,538	4,178
Container - 2000	2005	11	35,689	21.6	20,994	na
Container - 3000	1993	23	37,803	22.3	28,812	7,500
Container - 4000	2005	11	59,011	23.6	39,240	6,988
Container - 5000	2006	10	67,770	24.2	43,139	7,916
Container - 6000	2006	10	79,161	25.5	60,748	11,504
Container - 8000	2009	7	102,978	25.4	69,268	11,604
Container - 9000	2011	5	111,788	23.5	58,637	12,040
Container - 10000	2011	5	117,620	24.3	64,082	12,778
Container - 11000	2010	7	131,534	24.5	72,159	na
Container - 17000	2015	1	185,070	18	63,909	18,000
General Cargo	2008	8	12,742	15	5,400	na
ATB	2009	7	786	na	7,999	na
RoRo	1976	40	16,144	22	22,067	na
Tanker - Chemical	2010	6	48,641	15	8,580	na

Table L.21 presents the 2016 port emissions by hoteling and maneuvering for North Harbor.

Table L.21: North Harbor 2016 OGV Port Emissions by Mode, tpy

Mode	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
Hotelling	239.2	8.35	22.18	14.34	6.13	5.75	4.47	0.35	22,589
Maneuvering	52.8	4.21	5.50	1.39	0.94	0.88	0.89	0.03	2,185
Total	**292.1**	**12.56**	**27.68**	**15.73**	**7.06**	**6.63**	**5.36**	**0.38**	**24,775**

NWSA South Harbor Data Findings

Table L.22 presents the vessel movements for the South Harbor in 2016. The South Harbor terminals are the container terminals located in Tacoma.

Table L.22: South Harbor 2016 OGV Movements

Vessel Type	Inbound	Outbound	Shift	Movements
Auto Carrier	212	218	32	462
Bulk	4	5	2	11
Bulk - Self Discharging	8	8	0	16
Container - 1000	102	103	2	207
Container - 2000	36	59	26	121
Container - 4000	59	70	13	142
Container - 5000	96	97	2	195
Container - 6000	61	60	1	122
Container - 7000	52	51	0	103
Container - 8000	109	54	7	170
Container - 10000	38	0	3	41
General Cargo	19	41	26	86
ATB	2	0	1	3
RoRo	98	99	6	203
Total	**896**	**865**	**121**	**1,882**

Table L.23 presents the average vessel and engine characteristics by vessel type for those vessels that called at the South Harbor in 2016.

Table L.23: South Harbor Average 2016 OGV Type Characteristics

Vessel Type	Year Built	Age	DWT (tons)	Speed (knots)	Main Engine Power (kW)	Aux Engine Power (kW)
Auto Carrier	2006	10	20,364	19.8	14,319	4,306
Bulk	2013	3	38,817	14.5	6,702	na
Bulk - Self Discharging	2008	8	70,921	14.7	13,161	na
Container - 1000	1984	33	22,067	20.5	18,495	6,400
Container - 2000	2006	10	33,621	21.7	20,466	5,760
Container - 4000	2004	12	62,059	23.7	43,447	7,050
Container - 5000	2002	14	66,533	25.1	54,578	8,380
Container - 6000	2006	10	77,272	24.9	55,246	10,371
Container - 7000	2006	10	78,684	25.3	54,928	12,284
Container - 8000	2008	8	101,279	25.6	68,454	11,944
Container - 10000	2011	5	120,620	24.6	66,434	14,000
General Cargo	2006	10	33,619	16.5	10,836	3,780
ATB	2012	4	402	na	7,768	na
RoRo	1991	25	20,637	22.8	37,133	3,600

Table L.24 presents the 2016 port emissions by hoteling and maneuvering for South Harbor.

Table L.24: South Harbor 2016 OGV Port Emissions by Mode, tpy

Mode	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
Hotelling	488.6	16.56	44.09	27.81	12.03	11.29	8.94	0.68	43,796
Maneuvering	109.9	8.18	11.44	3.02	2.00	1.88	1.90	0.07	4,745
Total	**598.4**	**24.75**	**55.53**	**30.83**	**14.02**	**13.17**	**10.85**	**0.75**	**48,542**

Other Facilities in Puget Sound

Table L.25 presents the vessel movements for vessels that called private petroleum facilities in Puget Sound in 2016.

Table L.25: Petroleum Facilities 2016 OGV Movements

Vessel Type	Inbound	Outbound	Shift	Movements
Bulk	11	8	29	48
ATB	142	166	298	606
Tanker - Chemical	145	169	188	502
Tanker - Handysize	7	8	13	28
Tanker - Panamax	19	14	33	66
Tanker - Aframax	27	19	54	100
Tanker - Suezmax	90	78	209	377
Total	**441**	**462**	**824**	**1,727**

Table L.26 presents the 2016 port emissions by hoteling and maneuvering for the petroleum facilities.

Table L.26: Petroleum Facilities 2016 OGV Port Emissions by Mode, tpy

Mode	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
Hotelling	602.4	22.0	58.2	38.7	16.3	15.3	11.6	0.92	60,938
Maneuvering	26.1	1.0	2.0	0.9	0.4	0.4	0.4	0.02	1,392
Total	**628.5**	**23.0**	**60.2**	**39.6**	**16.8**	**15.7**	**12.1**	**0.94**	**62,330**

Table L.27 presents the vessel movements for vessels that called other private facilities in Puget Sound in 2016.

Table L.27: Other Private Facilities 2016 OGV Movements

Vessel Type	Inbound	Outbound	Shift	Movements
Auto Carrier	15	10	10	35
Bulk	267	136	62	465
Bulk - Heavy Load	2	2	6	10
Bulk - Self Discharging	13	12	10	35
Container - 1000	3	2	0	5
Container - 2000	4	6	7	17
Container - 4000	13	1	1	15
Container - 5000	2	1	1	4
Container - 6000	2	2	2	6
Container - 7000	0	1	1	2
Container - 8000	8	4	6	18
Container - 10000	4	0	0	4
Cruise	0	1	1	2
General Cargo	12	15	12	39
ATB	34	21	69	124
Miscellaneous	5	4	1	10
Reefer	7	7	6	20
RoRo	2	0	4	6
Tanker - Chemical	54	28	19	101
Tanker - Handysize	3	3	2	8
Tanker - Panamax	11	16	17	44
Tanker - Aframax	10	17	14	41
Tanker - Suezmax	28	37	39	104
Total	**499**	**326**	**290**	**1,115**

Table L.28 presents the 2016 port emissions by hoteling and maneuvering for other private facilities.

Table L.28: Other Private Facilities 2016 OGV Port Emissions by Mode, tpy

Mode	NO_x	VOC	CO	SO_2	PM_{10}	$PM_{2.5}$	DPM	Black Carbon	CO_2e
Hotelling	315.4	11.00	29.41	17.67	7.83	7.35	6.04	0.44	27,805
Maneuvering	13.1	0.76	1.21	0.42	0.24	0.22	0.22	0.01	660
Total	**328.5**	**11.76**	**30.62**	**18.08**	**8.07**	**7.57**	**6.27**	**0.45**	**28,464**