TANKER POLLUTANT LOADING TO THE PRINCE WILLIAM SOUND AIRSHED

PRINCE WILLIAM SOUND REGIONAL CITIZENS' ADVISORY COUNCIL

Prince William Sound RCAC Regional Citizens' Advisory Council

CONTRACT # 5575.14.02

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Prepared by:

STARCREST CONSULTING GROUP, LLC

ENVIRONMENTAL MANAGEMENT • AIR QUALITY • CLIMATE • SUSTAINABILITY

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AIS	automated information system
BSFC	brake specific fuel consumption
CF	control factor
CH_4	methane
CO	carbon monoxide
CO_2	carbon dioxide
CO_2e	carbon dioxide equivalent
D	distance
DPM	diesel particulate matter
DWT	deadweight tonnage
E	emissions
ECA	Emission control area
EEAI	Energy and Environmental Analysis, Inc.
EF	emission factor
EI	emissions inventory
EPA	U.S. Environmental Protection Agency
FCF	fuel correction factor
g/kW-hr	grams per kilowatt-hour
GIS	geographic information system
GHG	greenhouse gas
GWP	global warming potential
HC	hydrocarbons
HFO	heavy fuel oil
hp	horsepower
hrs	hours
IFO	intermediate fuel oil
IMO	International Maritime Organization
kW	kilowatt
kW-hr	kilowatt hour
LF	load factor
LLA	low load adjustment
Lloyd's	Lloyd's Register of Ships
LNG	liquefied natural gas
LPG	liquefied petroleum gas
MARPOL	Convention for the Prevention of Pollution from Ships
MCR	maximum continuous rating
MDO	marine diesel oil
MGO	marine gas oil
N_2O	nitrous oxide
nm	nautical miles
NO_x	oxides of nitrogen
OGV	ocean-going vessel
PM	particulate matter
PM_{10}	particulate matter less than 10 microns in diameter
$PM_{2.5}$	particulate matter less than 2.5 microns in diameter

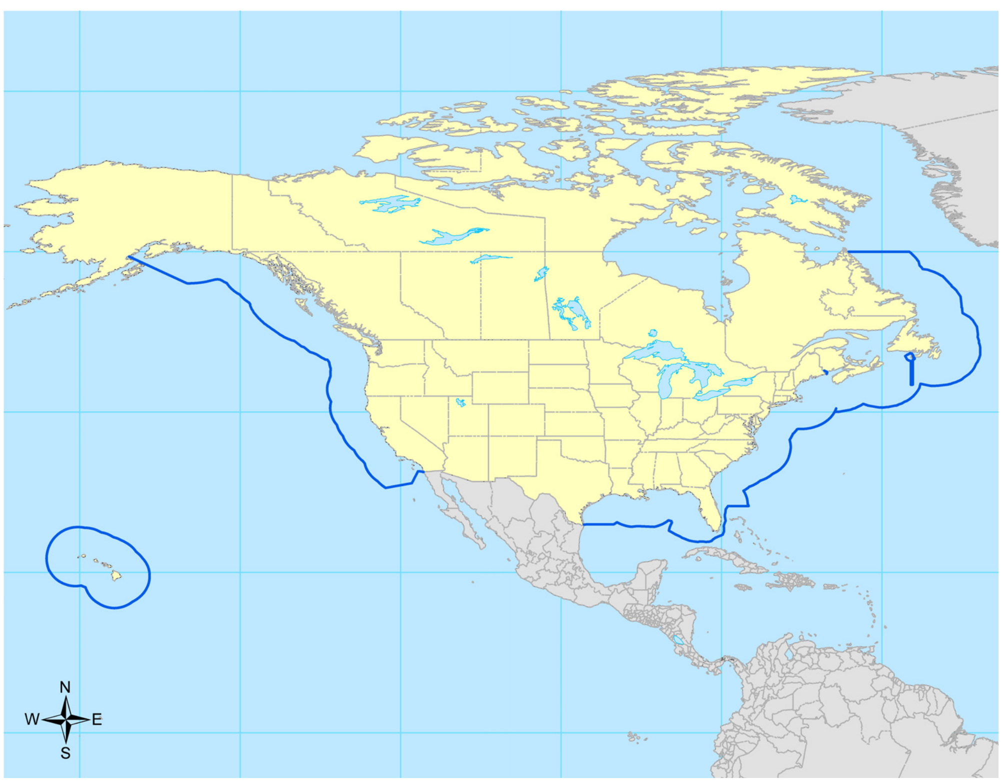
ppm	parts per million
RO	residual oil
S	sulfur
SFC	specific fuel consumption
SOx	oxides of sulfur
TEU	twenty-foot equivalent unit
tonnes	metric tons
tpy	tons per year
U.S.	United States
ULSD	ultra-low sulfur diesel

1.0 INTRODUCTION

The Prince William Sound Regional Citizens' Advisory Council (the Council) is an independent non-profit organization that promotes the environmentally safe operation of the Alyeska Pipeline marine terminal in Valdez and the oil tankers that use it. The stakeholders include the commercial fishing industry, aquaculture associations, Native Corporations, environmental organizations, recreational organizations, the Alaska State Chamber of Commerce, and the municipalities affected by the 1989 Exxon Valdez Oil Spill. The Council requested this study to understand how tanker ship air emissions will be reduced in the Prince William Sound airshed as a result of the promulgation of national and international marine pollution control regulations.

This study quantifies the reductions in crude tanker's air pollution emissions resulting from the implementation of federal and international regulations. The primary regulation that is reducing ship emissions in Prince Williams Sound is the International Maritime Organization (IMO) International Convention for the Prevention of Pollution from Ships Annex VI (MARPOL Annex VI) and its amendments, under which the North American Emissions Control Area (ECA) was established. Prince William Sound is within the North American ECA, which has both fuel sulfur content requirements and advanced oxides of nitrogen (NO_x) standards for marine diesel engines on ships with a keel laid date on or after 1 January 2016. In this study, the emissions reductions are estimated as a result of the lower sulfur fuel requirements and the NO_x marine diesel engine standards applicable to the fleet calling Prince Williams Sound. The figure below shows the boundary of the North American ECA.

Figure 1.0: North American Emissions Control Area



In addition, the Environmental Protection Agency (EPA) adopted engine standards that apply to marine engines installed on United States (US) flagged vessels. The EPA engine standards which are aligned with IMO standards may have an effect on future tankers as they turnover their fleet and acquire new tankers with new engines that comply with the latest EPA engine standards.

This study evaluates a number of emissions scenarios using the activity from 2014 calendar year. First, a baseline scenario was developed to simulate annual tanker emissions prior to the implementation of these regulations when ships were using, on average, heavy fuel oil (HFO) 2.7% sulfur fuel. The second scenario estimates annual tanker emissions based on the requirements to use fuel of HFO 1.0% sulfur content or less. The last scenario estimates annual tanker emissions based on the 2015 requirement to use a minimum of marine gas oil (MGO) 0.1% sulfur content fuel.

The report has the following components:

- Ship emissions regulations and policy review
- Air quality, environment and human health review
- Emissions inventory including baseline and forecasts

The emissions inventory presented in this report includes baseline (pre-ECA regulation) and forecast (post-ECA) emissions. The baseline and forecast emissions (in tons per year) are estimated for the following pollutants:

- Particulate matter (PM); (10-micron, 2.5-micron which is the portion of PM_{10})
- Diesel particulate matter (DPM); a significant component of PM formed during combustion of diesel fuel.
- Oxides of Nitrogen (NO_x)
- Sulfur oxides (SO_x)
- Hydrocarbons (HC); in general hydrocarbons are a combination of oxygenated (such as alcohols and aldehydes) and non-oxygenated (such as methane and ethane) hydrocarbons.
- Carbon monoxide (CO)
- Carbon dioxide (CO_2)
- Methane (CH_4)
- Nitrous oxide (N_2O)

The primary source of shipboard greenhouse gases (GHG) involves fuel combustion in the various engines and boilers, thus CO_2, CH_4, and N_2O are included in this inventory. Each greenhouse gas differs in its ability to absorb heat in the atmosphere. Estimates of greenhouse gas emissions are presented as carbon dioxide equivalents (CO_2e), which weights each gas, by its global warming potential (GWP) value. All pollutants except CO2e are reported in short tons. To be consistent with most commonly used units at international level, CO_{2e} values are reported in metric tons (tonnes). To normalize these values into a single greenhouse gas value, CO_2e, the three types of GHG emission are multiplied by the following values[1] and then added together. The GWPs include:

- CO_2 – 1
- CH_4 – 25
- N_2O – 298

Estimated tanker emissions include the following modes of operation:

- Hotelling – when a ship is stationary at the dock/berth or at an anchorage.
- Maneuvering and reduced speed zones - when a ship is traveling in restricted waters at lower speeds.
- Transit – when a ship is operating in open water at cruising speed/sea speeds.

Emissions are estimated for the following ship-related emission sources:

- Propulsion engines
- Auxiliary engines
- Auxiliary boilers

The geographical extent of the baseline inventory includes the inbound arrivals, at-berth, at-anchorage, and outbound departures from Cape Hinchinbrook through the 64-nautical mile (nm) transit to the Valdez Marine Terminal. The Knowles Head anchorage is also included in the geographical extent of this study. The five geographic regions in Prince William Sound are:

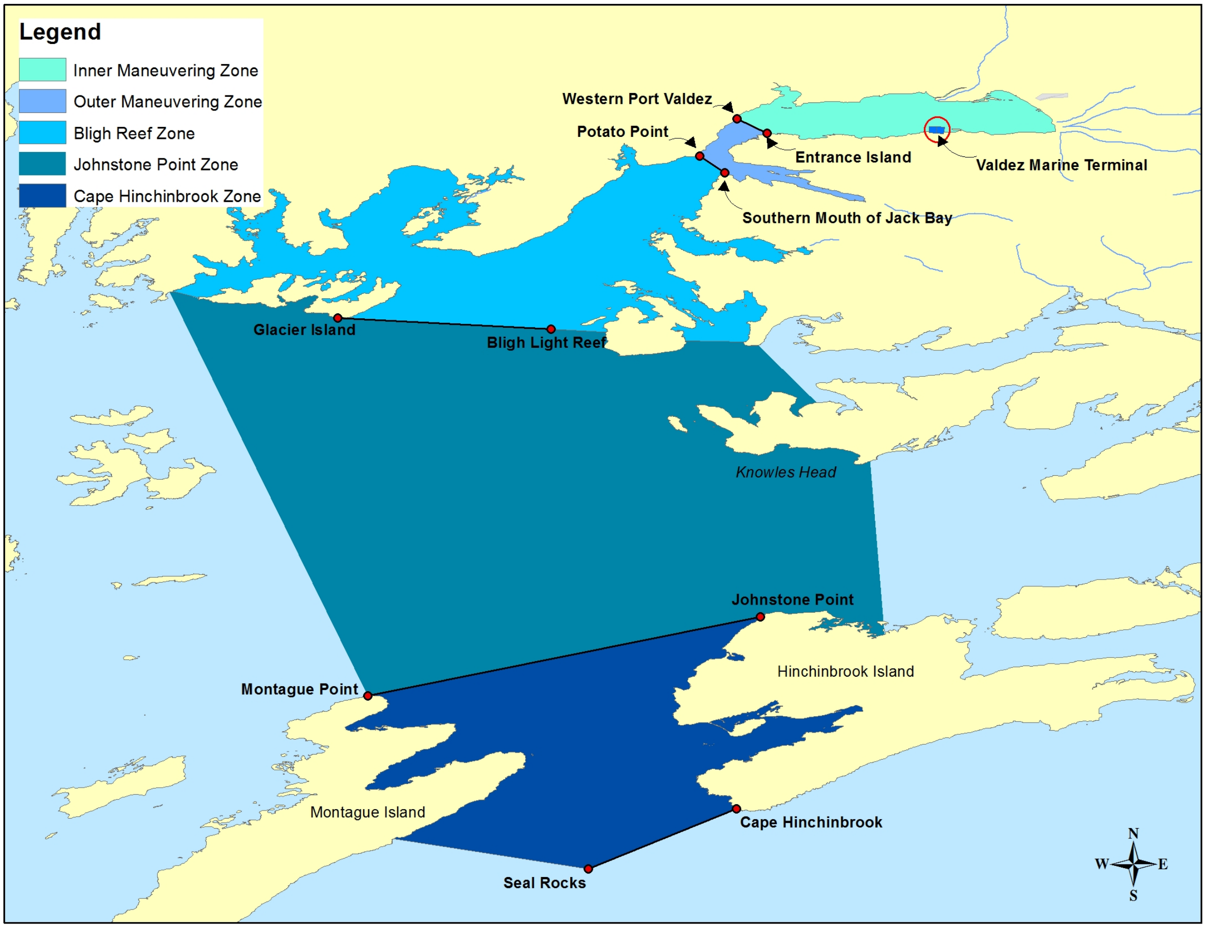
Table 1.0: Lines Delineating Geographic Regions in Prince William Sound

Region	Start	End
1	Seal Rocks	Cape Hinchinbrook
2	Montague Point	Johnstone Point
3	Glacier Island	Bligh Reef Light
4	Potato Point	Southern Mouth of Jack Bay
5	Western Port Valdez	Entrance Island

[1] EPA, *Inventory of US Greenhouse Gas Emissions and Sinks: 1990-2013*, April 2015.

Figure 1.1 shows the lines listed in the Table 1.0.

Figure 1.1: Geographic Regions in Prince William Sound



The Valdez Marine Terminal is located in the northeast corner of Prince William Sound and marks the end of the Trans Alaska Pipeline System. The terminal is used for the storage of crude oil prior to transportation and the loading of crude oil tankers, which then is sent to markets outside Prince William Sound. The tankers calling Valdez are operated by shipping companies who contract with producers to carry crude oil to market. The following vessels called at the Valdez Terminal in 2014.

Table 1.1: 2014 List of Vessels

Company	Vessel Name
Alaska Tanker Company	Alaskan Frontier
Alaska Tanker Company	Alaskan Explorer
Alaska Tanker Company	Alaskan Navigator
Alaska Tanker Company	Alaskan Legend
Polar Tankers	Polar Endeavour
Polar Tankers	Polar Resolution
Polar Tankers	Polar Discovery
Polar Tankers	Polar Adventure
Polar Tankers	Polar Enterprise
SeaRiver Maritime	Sierra
SeaRiver Maritime	Kodiak
SeaRiver Maritime	Liberty Bay
Tesoro	OS Boston
Tesoro	OS Nikiski
Tesoro	OS Martinez

2.0 SHIP EMISSIONS REGULATIONS AND POLICY REVIEW APPLICABLE TO TANKER FLEET THAT VISITS PRINCE WILLIAM SOUND

This section identifies and provides overview information of the pertinent international and federal regulations, standards, and policies that are related to ship air emissions, which lead to the reductions of pollutants emitted from the tanker fleet calling the Prince William Sound. Table 2.0 summarizes the various regulations and standards, and their respective discussions described in greater detail in the following pages. Both the IMO and EPA regulations listed will have an impact on Prince William Sound by lowering emissions through the use of cleaner fuels and newer cleaner engines. The regulation that has a current impact (2015) and reduction in SO_x, PM and NO_x emissions in Prince William Sound is the top regulation in Table 2.0, IMO Low Sulfur Fuel Requirements for Marine Engines when traveling in ECA area. In addition, in 2015, operations of two vessels equipped with pre-2011 (pre Tier 2) engines, part of 2014 fleet, were taken over by ships which have Tier 2 engines thus lowering NO_x emissions. Starting in 2016, ships with keel laid date of January 1, 2016 or later have to meet the more stringent Tier 3 NO_x standard as shown in table 2.0 which will lower NO_x emissions significantly.

Table 2.0: Ship Emission Regulations and Standards

Entity	Regulation/Standard	Pollutant Impact	When	Applicable Equipment	Responsible Party
IMO	Low Sulfur Fuel Requirements for Marine Engines	SO_x, PM, & NO_x	2012 – 1% for ECA 2015 – 0.1% for ECA	Propulsion, auxiliary engines, & boilers	Ship owner
IMO	Emission Standard for Marine Engines	NO_x	2011 – Tier 2 2016 – Tier 3 (only in ECA)	Propulsion & auxiliary engines	Engine manufacturer
EPA	Emission Standards for Marine Diesel Engines above 30 Liters per Cylinder (Category 3 Engines)	NO_x	2011 – Tier 2 2016 – Tier 3	Propulsion & auxiliary engines – aligns with IMO engine tiers above (applicable to US flag vessels)	Engine manufacturer

IMO Low Sulfur Fuel Requirements for Marine Engines

At the 58th Session (October 2008), the IMO's Marine Environmental Protection Committee (MEPC) adopted amendments to international requirements under MARPOL Annex VI, which placed a global limit on marine fuel sulfur content of 3.5% by 2013, which will be further reduced to 0.5% sulfur by 2020, or 2025 at the latest, pending a technical review anticipated in 2018. The North American ECA, which includes Prince Williams Sound and Valdez, is designated as a NO_x, SO_x, and PM ECA. In ECAs, sulfur content was limited to 1.0% beginning in August 2012, and was further reduced to 0.1% sulfur starting in January 2015. On March 26, 2010, the IMO officially designated waters within 200 miles of North American coasts as an ECA. From the effective date in August 2012 until 2015, sulfur content of the fuel used by all vessels operating in this area was 1.0%

or lower unless exempted for specific reasons such as safety or vessel going out of the service soon; it did not make sense to alter fuel tanks to accommodate low sulfur fuel for a short duration. The North American ECA directly impacts the fuel used by the tanker fleet in Prince William Sound reducing PM and SO_x emissions significantly, and reducing NO_x emissions to a lesser extent.

IMO allows use of alternative technologies such as approved exhaust gas cleaning system that can reduce the SO_x emissions from the ship to an equivalent level achieved by the fuel switch. Over recent years, several cruise lines have applied for flexibility under the IMO requirements to support the development of exhaust gas cleaning technology. In August 2013, Carnival Corporation received an approval from United States Coast Guard and EPA for a trial program under which 32 Carnival ships will be exempt from ECA low sulfur fuel requirement in support of development of exhaust gas cleaning technology that has potential to meet or exceed 2015 fuel sulfur standard ECA requirements, as well as provide additional benefits in the reduction of particulate matter and black carbon, at a lower cost than using lower sulfur fuel. The exhaust cleaning systems will be installed between 2014 and 2016 during a ship's scheduled dry-dock.

IMO Emission Standard for Marine Diesel Engines

At the International Conference of Parties to the MARPOL Convention, the MEPC adopted the Protocol of 1997 and adopted limits (Tier 1) for NOx in Annex VI to the International Convention for the Prevention of Pollution from Ships (MARPOL). The Conference also adopted the Technical Code on Control of Emissions of Nitrogen Oxides from Marine Diesel Engines (NO_x Technical Code), which is mandatory under MARPOL Annex VI. In October 2008, the IMO adopted amendments to international requirements under MARPOL Annex VI, which introduced new Tier 2 and Tier 3 engine emission rate limits for NOx for marine diesel engines installed on newly built ships. These NOx standards are applicable to engines over 130 kilowatts (kW) installed on vessels according to the keel laid date shown in Table 2.1 below. The current MARPOL Annex VI Tiers, in grams per kilowatt-hour (g/kW-hr), are summarized in Table 2.1 as follows:

Table 2.1: NO_x Limits for Marine Engines, g/kW-hr

Tier	Keel Laid Date	Engine Speed (n) in rpm		
		n<130	130 ≤ n < 2000	n ≥ 2000
Tier 1	2000–2010	17	$45 \times n^{-0.20}$	9.8
Tier 2	2011–2015	14.4	$44 \times n^{-0.23}$	7.7
Tier 3 (ECA only)	2016+	3.4	$9 \times n^{-0.20}$	2.0

Tier 1 and Tier 2 NO_x limits are achieved by use of engine-based controls, such as engine timing, engine cooling, and advanced electronic controls without the need for exhaust gas after treatment technologies. The Tier 2 standards will result in a 15 to 25 percent NOx reduction below the current Tier 1 levels. Tier 3 engines will require exhaust gas after treatment technologies such as Selective Catalyst Reduction (SCR) or Exhaust Gas Recirculation (EGR). Tier 3 standards will achieve 80% NO_x reduction from Tier 1 NO_x level. Engines installed on current tanker fleet that operated in 2014 in Prince Williams Sound and Valdez area consists of uncontrolled (Tier 0, oldest MY 1976) to Tier 2 (latest MY 2012).

EPA's Emission Standards for Marine Diesel Engines above 30 Liters per Cylinder (Category 3 Engines)

EPA is a member of the US delegation that participates in negotiations at the IMO with regard to amendments to Annex VI. As of December 2009, EPA has adopted Tier 1 to Tier 3 NO_x standards for Category 3 marine diesel engines installed on US flagged vessels as well as marine fuel sulfur limits that are equivalent to the amendments adopted in MARPOL Annex VI.[2]

Air Quality Control

Alaska adheres to all federal EPA emission standards, adoption by reference, for air pollutants, compliance dates, their rules, and implementation. The Alaska Department of Environmental Conservation, Division of Air Quality oversees the monitoring and compliance with the National Ambient Air Quality Standards (NAAQS). The Alaska's Marine vessel visible emission standard (18 AAC 50.070)[3] is one state rule that is pertinent to marine vessel operations in Prince William Sound. The rule requires: Within three miles of the Alaska coastline, visible emissions, excluding condensed water vapor, may not reduce visibility through the exhaust effluent of a marine vessel by more than 20 percent with some exceptions.

(1) While at berth or at anchor, visibility may be reduced by up to 100 percent for periods aggregating no more than
   (A) Three minutes in any one hour; and
   (B) An additional three minutes during initial startup of a vessel; for purposes of this subparagraph, "initial startup" includes the period during which a vessel is testing equipment in preparation to casting off or weighing anchor;

(2) During the hour immediately after weighing anchor or casting off, visibility may be reduced under one, but not both, of the following options:
   (A) Visibility may be reduced by up to 40 percent for that entire hour; or
   (B) Visibility may be reduced by up to 100 percent for periods aggregating no more than nine minutes during that hour;

(3) During the hour immediately before the completion of all maneuvers to anchor or make fast to the shore, visibility may be reduced under one, but not both, of the following options:
   (A) Visibility may be reduced by up to 40 percent for that entire hour; or
   (B) Visibility may be reduced by up to 100 percent for periods aggregating no more than nine minutes during that hour; and

(4) At any time not covered by (1) - (3) of this section, visibility may be reduced by up to 100 percent for periods aggregating no more than three minutes in any one hour.

The newly enacted international and federal regulations discussed previously in this section are not expected to affect the Alaska marine vessel visibility standards.

[2] 40 CFR part 1042 for marine compression-ignition engine standards and 40 CFR part 80 for regulations related to marine fuels

[3] *https://dec.alaska.gov/water/cruise_ships/reg/Alaska_Opacity&Excess_Emissions_Regulations.pdf*

Compliance and Enforcement

MARPOL Annex VI mandates that both the quantity of fuel bunkered and sulfur content be reported on Bunker Delivery Notes (BDN) site. IMO is not responsible to enforce its own regulations. Once the Annex is ratified by nations, it becomes that nations responsibility that appropriate agency ensure that the regulations are being implemented properly. The US Coast Guard and USEPA have a Memorandum of Understanding that allows both agencies to work together to enforce MARPOL Annex VI regulations.

3.0 AIR QUALITY, ENVIRONMENT AND HUMAN HEALTH REVIEW

Diesel engines, like many other mobile, stationary, and area sources, are significant generators of criteria pollutants, their precursors and toxic emissions. Excessive exposure to these pollutants can contribute to increased rates of lung cancer, chronic respiratory disease, impaired lung development in children, cardiovascular disease, and other health effects. Given these implications for public health, the reduction and minimization of these emissions are a priority of the EPA and the Council. This emission inventory will support the effort by increasing the understanding of the emission contributions from the maritime-related sources.

While the EPA has not yet officially designated diesel emissions as a hazardous air contaminant, and there are no established regulatory standards for diesel particulate emissions beyond inclusion in the PM_{10} and $PM_{2.5}$ ambient air standards, it is important to note that federal regulations are in place that require dramatically cleaner fuels and new diesel engines, as discussed in the prior section. Table 3.0 provides pollutant description by summarizing the ambient standard compliance status for the area and lists the health and environmental effect for each pollutant[4].

Prince William Sound airshed is in attainment with all EPA National Ambient Air Quality Standards (NAAQS)[5]. The only nonattainment area in the State of Alaska is the Fairbank area for $PM_{2.5}$ standard exceedance. On October 1, 2015, EPA revised the primary and secondary NAAQS for ground level ozone from 0.075 parts per million to 0.070 parts per million[6].

[4] Puget Sound Maritime Air Forum, *2011 Puget Sound Maritime Air Emissions Inventory*, May 2013
[5] EPA, *www3.epa.gov/airquality/greenbook/ancl3.html*
[6] EPA, *www3.epa.gov/ozonepollution/actions.html*

Table 3.0: Pollutant Description

Pollutant	Ambient Standard Compliance Status	Sources	Health & Environmental Effects
Ozone (O_3)* is a pungent-smelling, colorless gas produced in the atmosphere when nitrogen oxides (NO_x) and volatile organic compounds (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 ingredients nitrogen oxides and volatile organic compounds.	The O_3 levels are below federal standards in the region.	Most O_3-causing NO_x and VOC 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. Natural emissions from biogenic (vegetation) sources also contribute to O_3 formation.	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.
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. Most NO_x are colorless and odorless. **Nitrogen dioxide (NO_2)*** is one form of NO_x. NO_2, along with particles in the air can often be seen as a reddish-brown layer over many urban areas.	NO_2 levels are below federal air quality standards in the region. See information above for information about the role of NO_x in O_3 formation.	NO_x form 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. Other sources include industrial boilers and processes, home heaters, and gas stoves. NO_x can also be formed naturally.	Exposure to NO_2 has been connected to a range of respiratory diseases and infections. NO_2 plays an essential role in the photochemical reactions that produce O_3, the major component in smog. NO_x can react with other compounds in the air to form tiny particles adding to PM concentrations.

*** Indicates a criteria pollutant which National Ambient Air Quality Standards have been established by EPA.**

Table 3.0: Pollutant Description, cont'd

Pollutant	Ambient Standard Compliance Status	Sources	Health & Environmental Effects
Hydrocarbons (HC) HC are included in the emissions inventory because the reactive organic hydrocarbon components -VOC are an ozone ingredient, see ozone information above	No ambient standards. HC's are not classified as criteria pollutants but can contribute to the formation of ozone.	See ozone information above.	In addition to contributing to the formation of ozone, some HC are air toxics which can contribute to a wide range of adverse health effects.
Carbon monoxide (CO) Carbon monoxide is a colorless, odorless, toxic gas commonly formed when carbon-containing fuel is not burned completely. Motor vehicles are the predominant source of carbon monoxide in many urban regions.	CO levels are below federal standards in the region.	CO forms during incomplete combustion of fuels. The majority of CO comes from on and off road vehicle engine exhaust. Other contributing CO source categories include woodstoves and fireplaces, outdoor burning and industrial sources.	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. People with heart disease and pregnant women are especially at risk.
Sulfur dioxide (SO_2)* is a colorless, corrosive gas produced burning of fuel containing sulfur like coal and oil, and by industrial processes such as smelters, paper mills, power plants and steel manufacturing plants. Sulfur dioxide (SO_2) is one form of SO_x.	SO_x levels are below federal standards in the region.	Levels of sulfur in diesel and gasoline fuels are decreasing due to federal regulations set by the Environmental Protection Agency. Reductions in sulfur content for the fuel that tankers use decreased in 2014 due to ECA and continued to decrease further in 2015.	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_x become sulfate particles in the atmosphere adding to measured PM levels.
*** Indicates a criteria pollutant which National Ambient Air Quality Standards have been established by EPA.**			

Table 3.0: Pollutant Description, cont'd

Pollutant	Ambient Standard Compliance Status	Sources	Health & Environmental Effects
Particulate Matter (PM_{10} * & $PM_{2.5}$*) refers to tiny, discrete solid or aerosol particles in the air. Dust, dirt, soot, and smoke are considered particulate matter (PM). 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.	The region is in attainment with federal air quality standards for PM.	In the winter, most PM comes from wood burning in fireplaces and wood stoves particularly in residential neighborhoods. During the summer, 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 summer time levels. In Alaska, volcano ashes and forest fires also contribute significantly to PM spikes.	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. Some PM, such as diesel particulate matter and smoke from wood and waste burning, are classified as toxic due to the concentrations of harmful chemicals bound to the particles.
Diesel Particulate Matter (DPM) is a significant component of PM. Diesel exhaust also includes more than 40 substances that are listed as hazardous pollutants. DPM is considered a surrogate for the effects of both the PM and gaseous component of diesel exhaust. Because of their microscopic size, DPM can become trapped in the small airways of the lungs.	No ambient standards.	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 has been shown to contribute up to 80% of the carcinogenic health risk related to the portion of outdoor air pollutants classified as "toxics". DPM is linked with health effects typical of all PM, including heart problems, aggravated asthma, chronic bronchitis and premature death.
*** Indicates a criteria pollutant which National Ambient Air Quality Standards have been established by EPA.**			

Table 3.0: Pollutant Description, cont'd

Pollutant	Ambient Standard Compliance Status	Sources	Health & Environmental Effects
Greenhouse Gases (GHG) included in this emissions inventory are carbon dioxide, methane, and nitrous oxide. Additional gases that are not significantly emitted in by maritime-related sources or included in this inventory also contribute to climate change.	No ambient standards.	GHG come from natural processes as well as human activities, though 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.
*** Indicates a criteria pollutant for which National Ambient Air Quality Standards have been established by EPA.**			

4.0 2014 EMISSIONS INVENTORY

This study evaluates a number of emissions scenarios for fuel requirements using the activity from 2014 calendar year. Table 4.0 summarizes the effect of the various fuel sulfur contents due to the IMO's Low Sulfur Fuel Requirements for Marine Engines. In order to do a straight comparison, 2014 activity was used for these three scenarios:

- Baseline with vessels using HFO 2.7% sulfur fuel (prior to 2012)
- Vessels using HFO 1.0% sulfur fuel (ECA regulation requirement up to end of 2014)
- Vessels using MGO 0.1% sulfur fuel (ECA regulation requirement 2015 and the future years)

Table 4.0: Summary of Emissions

Activity Year	Fuel Type	PM_{10} tpy	$PM_{2.5}$ tpy	DPM tpy	NO_x tpy	SO_x tpy	CO tpy	HC tpy	CO_2e tonnes/yr
2014	HFO 2.7% S	51.7	41.3	47.4	475.3	442.8	40.4	17.1	21,879
2014	HFO 1.0% S	38.1	30.4	34.8	475.3	174.6	40.4	17.1	21,879
2014	MGO 0.1% S	8.8	8.3	8.1	446.8	16.4	40.4	17.1	20,782
% Change	**2.7% vs 1.0%**	**-26%**	**-26%**	**-27%**	**0%**	**-61%**	**0%**	**0%**	**0%**
% Change	**2.7% vs 0.1%**	**-83%**	**-80%**	**-83%**	**-6%**	**-96%**	**0%**	**0%**	**-5%**
% Change	**1.0% vs 0.1%**	**-77%**	**-73%**	**-77%**	**-6%**	**-91%**	**0%**	**0%**	**-5%**

One ton of $PM_{2.5}$ emission is equivalent to the same emissions generated from over 55,500 heavy-duty diesel trucks operating for an average work day.

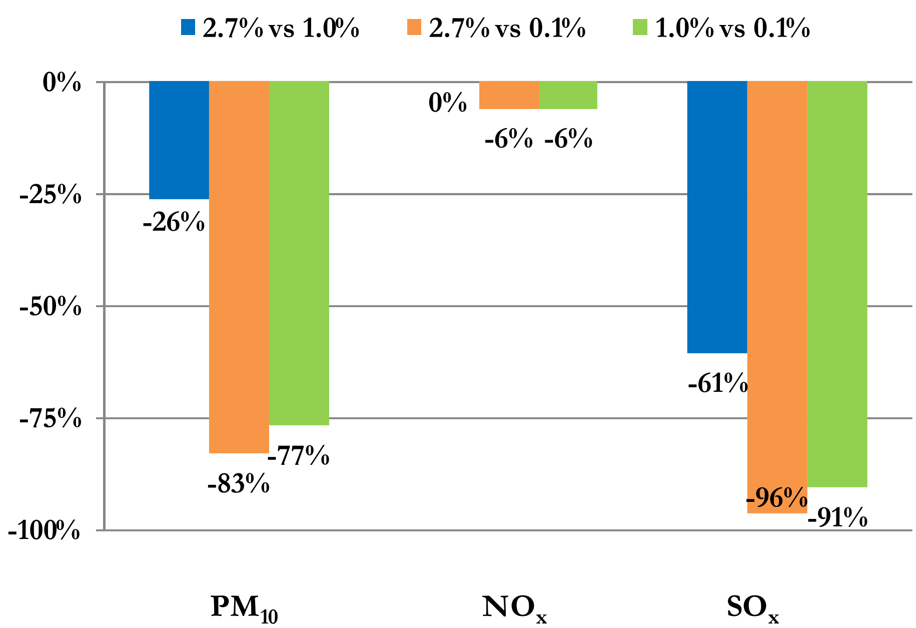
One ton of NO_x emission is equivalent to the same emissions generated from almost 800 heavy-duty diesel trucks operating for an average work day.

One ton of SO_x emission is equivalent to the same emissions generated from over 380,000 heavy-duty diesel trucks operating for an average work day.

One ton of CO_2e emission is equivalent to the same emissions generated from nearly 4 heavy-duty diesel trucks operating for an average work day.

Figure 4.0 shows the percent reductions of PM, NO_x and SO_x emissions due to the fuel switching regulation requirement. The green bar shows the reductions from 2014 (using 1.0% S) to 2015 (using 0.1% S) if the activity remained the same.

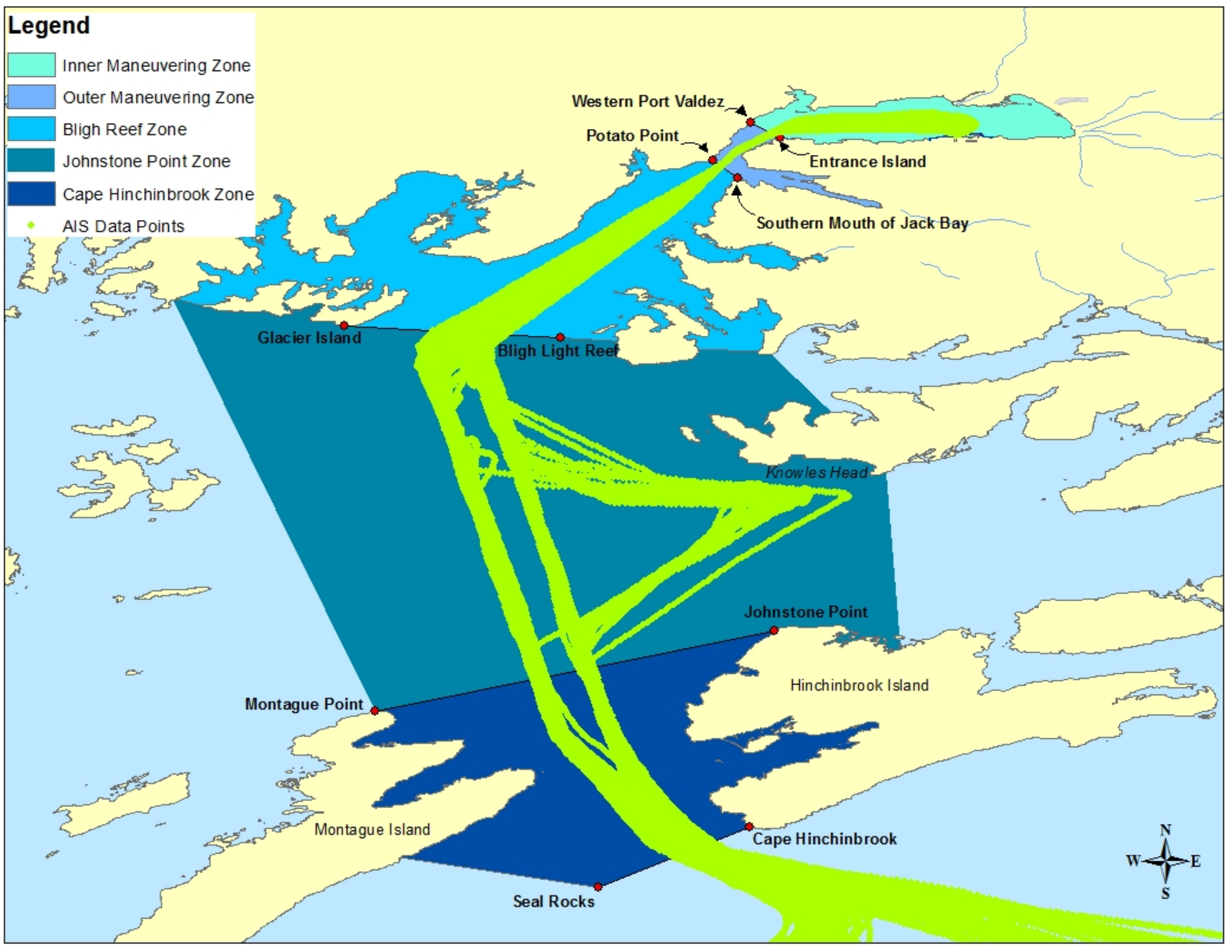
Figure 4.0: Emissions Reductions due to Fuel Switching



General Methodology

The OGV emission estimates presented in this report are primarily based on vessel activity data, vessel operational data, and vessel parameter data. AIS data was used for identifying vessels operating within the geographical domain and processed to determine discrete vessel activity parameters including speed over water. This data was collected by the US Coast Guard (USCG) AIS receiver network, and compiled into files comprised of unique AIS records. AIS data points contain vessel specific geographical and temporal information including, but not limited to: IMO number, MMSI number, geographic coordinates, speed over water, heading, date, and time. Figure 4.1 shows a spatial representation of the AIS data collected for this inventory.

Figure 4.1: AIS Data Processing Zones



The 2014 emissions estimates include operations of all vessels that called the Valdez Marine Terminal. These vessels are shown in Table 1.1.

Emission estimates have been developed for the three combustion emission source types associated with marine vessels: main (or propulsion) engines, auxiliary engines, and auxiliary boilers. Based on the geographical domain, the following vessel operational modes define the characteristics of a ship's operation within the emission inventory domain:

1. *Maneuvering* Ship movements inside the geographical boundary, including the approach zone for this inventory. Additional power is typically brought online since the ship is preparing to or traveling in restricted waters.
2. *At-Berth* When a ship is stationary at the dock/berth.
3. *Shift* When a ship moves from one berth to another or from anchor to berth within the geographical boundary.

In general, emissions are estimated as a function of vessel power demand with energy expressed in kW-hr multiplied by an emission factor, where the emission factor is expressed in terms of grams per kilowatt-hour (g/kW-hr).

Equations 4.1 and 4.2 report the basic equations used in estimating emissions by mode.

Equation 4.1

$$\boldsymbol{E_i = Energy_i \times EF \times FCF}$$

Where:

E_i = Emissions by mode
$Energy_i$ = Energy demand by mode, calculated using Equation 4.2 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 by mode is calculated using Equation 4.2:

Equation 4.2

$$\boldsymbol{Energy_i = Load \times Act}$$

Where:

$Energy_i$ = Energy demand by mode, kW-hr
Load = maximum continuous rated (MCR) power times load factor (LF) for propulsion engine power (kW); reported operational load of the auxiliary engine(s), by mode (kW); or operational load of the auxiliary boiler, by mode (kW)
Act = activity, hours

Further details on emissions estimating methodology can be found in section 3 of the 2013 Air Emissions Inventory report published by the Port of Long Beach[7].

[7] POLB, *http://www.polb.com/environment/air/emissions.asp*

Emission Factors

The emissions factors are based on residual fuel oil/ heavy fuel oil (HFO), which is intermediate fuel oil (IFO 380) or one with similar specifications, with average sulfur content of 2.7%. The emissions factors were corrected using fuel correction factors (FCFs) from the baseline HFO 2.7% S to HFO 1.0% S and marine gas oil (MGO) 0.1% S. Table 4.1 shows the fuel correction factors used.

Table 4.1: Fuel Correction Factors

Actual Fuel Used Content	Sulfur Content by weight %	PM_{10}	$PM_{2.5}$	DPM	NO_x	SO_x	CO	HC	CO_2	N_2O	CH_4
HFO	1%	0.73	0.73	0.73	1.00	0.370	1.00	1.00	1.00	1.00	1.00
MGO	0.1%	0.17	0.17	0.17	0.94	0.037	1.00	1.00	0.95	0.94	1.00

Tables 4.2 through 4.5 show the resulting emission factors for main engines, auxiliary engines and boiler. The $PM_{2.5}$ to PM_{10} ratio is 0.80 for HFO and 0.92 for MGO. DPM is equal to PM_{10} for both the propulsion and auxiliary engines using diesel fuel. Boilers do not have DPM, thus the DPM EF for boilers is zero.

Table 4.2: Main Engines Emission Factors at HFO 2.7 %S (g/kW-hr)

Engine Category	Model Year Range	PM_{10}	$PM_{2.5}$	DPM	NO_x	SO_x	CO	HC	CO_2	N_2O	CH_4
Slow Speed Main (Tier 0)	1999 and older	1.50	1.20	1.50	18.10	10.50	1.40	0.60	620	0.031	0.012
Slow Speed Main (Tier 1)	2000 to 2010	1.50	1.20	1.50	17.00	10.50	1.40	0.60	620	0.031	0.012
Slow Speed Main (Tier 2)	2011 to 2015	1.50	1.20	1.50	15.30	10.50	1.40	0.60	620	0.031	0.012
Slow Speed Main (Tier 3)	2016+	1.50	1.20	1.50	3.60	10.50	1.40	0.60	620	0.031	0.012
Medium Speed Main (Tier 0)	1999 and older	1.50	1.20	1.50	14.00	11.50	1.10	0.50	683	0.031	0.010
Medium Speed Main (Tier 1)	2000 to 2010	1.50	1.20	1.50	13.00	11.50	1.10	0.50	683	0.031	0.010
Medium Speed Main (Tier 2)	2011 to 2015	1.50	1.20	1.50	11.20	11.50	1.10	0.50	683	0.031	0.010
Medium Speed Main (Tier 3)	2016+	1.50	1.20	1.50	2.80	11.50	1.10	0.50	683	0.031	0.010
Gas Turbine	All	0.05	0.04	0.05	6.10	16.50	0.20	0.10	970	0.080	0.002
Steam Main and Boiler	All	0.80	0.64	0.00	2.10	16.50	0.20	0.10	970	0.080	0.002

Table 4.3: Adjusted Main Engines Emission Factors at HFO 1.0 %S (g/kW-hr)

Engine Category	Model Year Range	PM_{10}	$PM_{2.5}$	DPM	NO_x	SO_x	CO	HC	CO_2	N_2O	CH_4
Slow Speed Main (Tier 0)	1999 and older	1.10	0.88	1.10	18.10	3.89	1.40	0.60	620	0.031	0.012
Slow Speed Main (Tier 1)	2000 to 2010	1.10	0.88	1.10	17.00	3.89	1.40	0.60	620	0.031	0.012
Slow Speed Main (Tier 2)	2011 to 2015	1.10	0.88	1.10	15.30	3.89	1.40	0.60	620	0.031	0.012
Slow Speed Main (Tier 3)	2016+	1.10	0.88	1.10	3.60	3.89	1.40	0.60	620	0.031	0.012
Medium Speed Main (Tier 0)	1999 and older	1.10	0.88	1.10	14.00	4.26	1.10	0.50	683	0.031	0.010
Medium Speed Main (Tier 1)	2000 to 2010	1.10	0.88	1.10	13.00	4.26	1.10	0.50	683	0.031	0.010
Medium Speed Main (Tier 2)	2011 to 2015	1.10	0.88	1.10	11.20	4.26	1.10	0.50	683	0.031	0.010
Medium Speed Main (Tier 3)	2016+	1.10	0.88	1.10	2.80	4.26	1.10	0.50	683	0.031	0.010
Gas Turbine	All	0.04	0.04	0.04	6.10	6.11	0.20	0.10	970	0.080	0.002
Steam Main and Boiler	All	0.68	0.54	0.00	2.10	6.11	0.20	0.10	970	0.080	0.002

Table 4.4: Adjusted Main Engines Emission Factors at MGO 0.1 %S (g/kW-hr)

Engine Category	Model Year Range	PM_{10}	$PM_{2.5}$	DPM	NO_x	SO_x	CO	HC	CO_2	N_2O	CH_4
Slow Speed Main (Tier 0)	1999 and older	0.26	0.23	0.26	17.01	0.39	1.40	0.60	589	0.029	0.012
Slow Speed Main (Tier 1)	2000 to 2010	0.26	0.23	0.26	15.98	0.39	1.40	0.60	589	0.029	0.012
Slow Speed Main (Tier 2)	2011 to 2015	0.26	0.23	0.26	14.38	0.39	1.40	0.60	589	0.029	0.012
Slow Speed Main (Tier 3)	2016+	0.26	0.23	0.26	3.38	0.39	1.40	0.60	589	0.029	0.012
Medium Speed Main (Tier 0)	1999 and older	0.26	0.23	0.26	3.38	0.39	1.40	0.60	649	0.029	0.010
Medium Speed Main (Tier 1)	2000 to 2010	0.26	0.23	0.26	3.38	0.39	1.40	0.60	649	0.029	0.010
Medium Speed Main (Tier 2)	2011 to 2015	0.26	0.23	0.26	3.38	0.39	1.40	0.60	649	0.029	0.010
Medium Speed Main (Tier 3)	2016+	0.26	0.23	0.26	3.38	0.39	1.40	0.60	649	0.029	0.010
Gas Turbine	All	0.01	0.01	0.01	5.70	0.61	0.20	0.10	922	0.075	0.002
Steam Main and Boiler	All	0.14	0.13	0.00	2.00	0.61	0.20	0.10	922	0.075	0.002

Table 4.5: Auxiliary Engines Emission Factors (g/kW-hr)

Engine Category	Model Year Range	PM_{10}	$PM_{2.5}$	DPM	NO_x	SO_x	CO	HC	CO_2	N_2O	CH_4
2.7% S Fuel											
Medium Auxiliary (Tier 0)	1999 and older	1.50	1.20	1.50	14.7	11.98	1.10	0.40	722	0.031	0.008
Medium Auxiliary (Tier 1)	2000 to 2010	1.50	1.20	1.50	13.0	11.98	1.10	0.40	722	0.031	0.008
Medium Auxiliary (Tier 2)	2011 to 2015	1.50	1.20	1.50	11.2	11.98	1.10	0.40	722	0.031	0.008
Medium Auxiliary (Tier 3)	2016+	1.50	1.20	1.50	2.8	11.98	1.10	0.40	722	0.031	0.008
High Auxiliary (Tier 0)	1999 and older	1.50	1.20	1.50	11.6	11.98	0.90	0.40	690	0.031	0.008
High Auxiliary (Tier 1)	2000 to 2010	1.50	1.20	1.50	10.4	11.98	0.90	0.40	690	0.031	0.008
High Auxiliary (Tier 2)	2011 to 2015	1.50	1.20	1.50	8.2	11.98	0.90	0.40	690	0.031	0.008
High Auxiliary (Tier 3)	2016+	1.50	1.20	1.50	2.1	11.98	0.90	0.40	690	0.031	0.008
1.0% S Fuel											
Medium Auxiliary (Tier 0)	1999 and older	1.10	0.88	1.10	14.7	4.43	1.10	0.40	722	0.031	0.008
Medium Auxiliary (Tier 1)	2000 to 2010	1.10	0.88	1.10	13.0	4.43	1.10	0.40	722	0.031	0.008
Medium Auxiliary (Tier 2)	2011 to 2015	1.10	0.88	1.10	11.2	4.43	1.10	0.40	722	0.031	0.008
Medium Auxiliary (Tier 3)	2016+	1.10	0.88	1.10	2.8	4.43	1.10	0.40	722	0.031	0.008
High Auxiliary (Tier 0)	1999 and older	1.10	0.88	1.10	11.6	4.43	0.90	0.40	690	0.031	0.008
High Auxiliary (Tier 1)	2000 to 2010	1.10	0.88	1.10	10.4	4.43	0.90	0.40	690	0.031	0.008
High Auxiliary (Tier 2)	2011 to 2015	1.10	0.88	1.10	8.2	4.43	0.90	0.40	690	0.031	0.008
High Auxiliary (Tier 3)	2016+	1.10	0.88	1.10	2.1	4.43	0.90	0.40	690	0.031	0.008
0.1% S Fuel											
Medium Auxiliary (Tier 0)	1999 and older	0.26	0.23	0.26	13.8	0.44	1.10	0.40	686	0.029	0.008
Medium Auxiliary (Tier 1)	2000 to 2010	0.26	0.23	0.26	12.2	0.44	1.10	0.40	686	0.029	0.008
Medium Auxiliary (Tier 2)	2011 to 2015	0.26	0.23	0.26	10.5	0.44	1.10	0.40	686	0.029	0.008
Medium Auxiliary (Tier 3)	2016+	0.26	0.23	0.26	2.6	0.44	1.10	0.40	686	0.029	0.008
High Auxiliary (Tier 0)	1999 and older	0.26	0.23	0.26	10.9	0.44	0.90	0.40	656	0.029	0.008
High Auxiliary (Tier 1)	2000 to 2010	0.26	0.23	0.26	9.8	0.44	0.90	0.40	656	0.029	0.008
High Auxiliary (Tier 2)	2011 to 2015	0.26	0.23	0.26	7.7	0.44	0.90	0.40	656	0.029	0.008
High Auxiliary (Tier 3)	2016+	0.26	0.23	0.26	2.0	0.44	0.90	0.40	656	0.029	0.008

2014 Distribution of Barrels of Crude and Vessel Calls by Company

Since the emissions for HFO 2.7% S, HFO 1.0% S and MGO 0.1% S scenarios are based on actual 2014 activity, the figures below are distributions of actual activity in 2014. Figure 4.2 shows the percentage of barrels of crude moved by company in 2014. Figure 4.3 shows the vessel movement distribution by company.

Figure 4.2: 2014 Barrels of Crude by Company

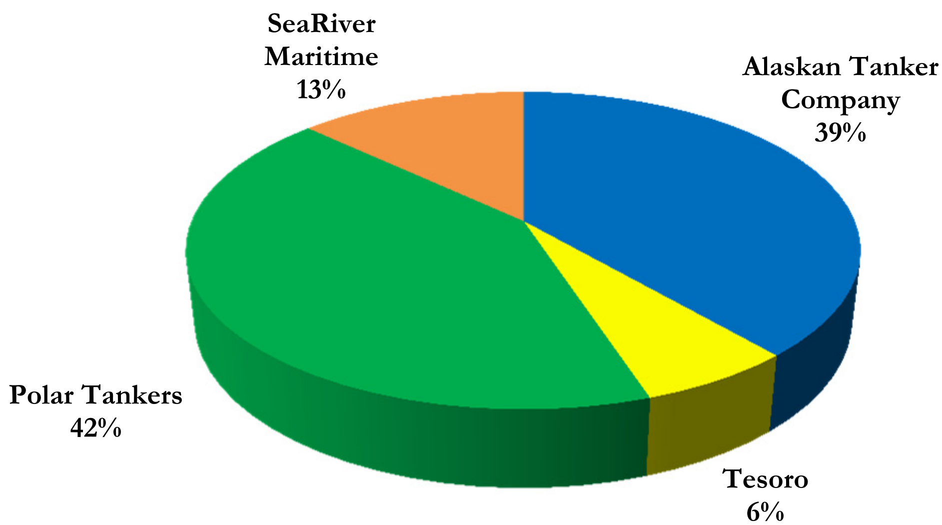
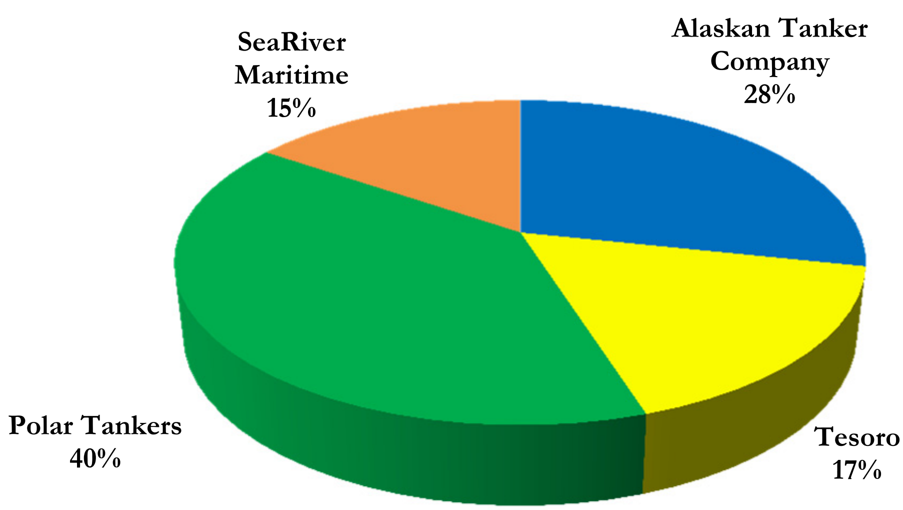


Figure 4.3: 2014 Vessel Calls by Company



2014 Emissions using HFO 2.7% S Fuel

The following two tables show the emissions for 2014 activity using HFO 2.7% S fuel which was the fuel predominantly used prior to the North American ECA. Table 4.6 shows the emissions by mode and engine type.

Table 4.6: Emissions by Mode and Engine Type Using HFO 2.7% S Fuel

Engine Type	PM_{10} tpy	$PM_{2.5}$ tpy	DPM tpy	NO_x tpy	SO_x tpy	CO tpy	HC tpy	CO_2e tonnes/yr
Auxiliary Engine	7.1	5.6	7.1	61	58	5.2	1.9	2,836
Auxiliary Boiler	0.6	0.5	0.0	2	13	0.2	0.1	627
Main Engine	10.4	8.3	10.4	90	80	7.6	3.5	3,962
Alaska Tanker Company	**18.1**	**14.5**	**17.5**	**153**	**150**	**13.0**	**5.4**	**7,425**
Auxiliary Engine	8.0	6.4	8.0	73	66	5.9	2.1	3,231
Auxiliary Boiler	0.7	0.5	0.0	2	14	0.2	0.1	688
Main Engine	13.9	11.1	13.9	158	92	13.6	6.2	4,581
Polar Tankers	**22.6**	**18.1**	**21.9**	**233**	**172**	**19.7**	**8.4**	**8,501**
Auxiliary Engine	1.8	1.4	1.8	17	15	1.3	0.5	719
Auxiliary Boiler	0.4	0.3	0.0	1	8	0.1	0.0	381
Main Engine	3.9	3.2	1.6	22	58	2.2	1.0	2,891
SeaRiver Maritime	**6.1**	**4.9**	**3.4**	**41**	**81**	**3.6**	**1.5**	**3,991**
Auxiliary Engine	1.6	1.3	1.6	14	13	1.2	0.4	650
Auxiliary Boiler	0.3	0.2	0.0	1	6	0.1	0.0	301
Main Engine	3.0	2.4	3.0	34	20	2.9	1.3	1,011
Tesoro	**4.9**	**3.9**	**4.6**	**48**	**40**	**4.2**	**1.8**	**1,962**
Total	**51.7**	**41.3**	**47.4**	**475**	**443**	**40.4**	**17.1**	**21,879**

2014 Actual Emissions using HFO 1.0% S Fuel

The following two tables show the actual emissions for 2014 using 2014 activity and HFO fuel with 1.0% S content. In 2014, the vessels in the North American ECA are required to use HFO fuel with 1.0% S. Table 4.7 shows the emissions by mode and engine type.

Table 4.7: Emissions by Mode and Engine Type Using HFO 1.0% S Fuel

Engine Type	PM_{10} tpy	$PM_{2.5}$ tpy	DPM tpy	NO_x tpy	SO_x tpy	CO tpy	HC tpy	CO_2e tonnes/yr
Auxiliary Engine	5.2	4.1	5.2	61	21	5.2	1.9	2,836
Auxiliary Boiler	0.4	0.4	0.0	2	5	0.2	0.1	627
Main Engine	7.6	6.1	7.6	90	29	7.6	3.5	3,962
Alaska Tanker Company	**13.2**	**10.6**	**12.7**	**153**	**56**	**13.0**	**5.4**	**7,425**
Auxiliary Engine	5.9	4.7	5.9	73	24	5.9	2.1	3,231
Auxiliary Boiler	0.5	0.4	0.0	2	5	0.2	0.1	688
Main Engine	10.1	8.1	10.1	158	34	13.6	6.2	4,581
Polar Tankers	**16.5**	**13.2**	**16.0**	**233**	**64**	**19.7**	**8.4**	**8,501**
Auxiliary Engine	1.4	1.1	1.4	17	8	1.3	0.5	719
Auxiliary Boiler	0.3	0.2	0.0	1	4	0.1	0.0	381
Main Engine	3.0	2.4	1.2	22	29	2.2	1.0	2,891
SeaRiver Maritime	**4.8**	**3.8**	**2.6**	**41**	**41**	**3.6**	**1.5**	**3,991**
Auxiliary Engine	1.2	0.9	1.2	14	5	1.2	0.4	650
Auxiliary Boiler	0.2	0.2	0.0	1	2	0.1	0.0	301
Main Engine	2.2	1.8	2.2	34	8	2.9	1.3	1,011
Tesoro	**3.6**	**2.9**	**3.4**	**48**	**15**	**4.2**	**1.8**	**1,962**
Total	**38.1**	**30.4**	**34.8**	**475**	**175**	**40.4**	**17.1**	**21,879**

2014 Emissions using MGO 0.1% S Fuel

The following two tables show the emissions for 2014 activity using MGO 0.1% S fuel which is the fuel required for the North American ECA starting in January 2015. Table 4.8 shows the emissions by mode and engine type.

Table 4.8: Emissions by Mode and Engine Type Using MGO 0.1% S Fuel

Engine Type	PM_{10} tpy	$PM_{2.5}$ tpy	DPM tpy	NO_x tpy	SO_x tpy	CO tpy	HC tpy	CO_2e tonnes/yr
Auxiliary Engine	1.2	1.1	1.2	58	2.1	5.2	1.9	2,694
Auxiliary Boiler	0.1	0.1	0.0	2	0.5	0.2	0.1	596
Main Engine	1.8	1.7	1.8	85	2.9	7.6	3.5	3,763
Alaska Tanker Company	**3.1**	**2.9**	**3.0**	**144**	**5.6**	**13.0**	**5.4**	**7,053.1**
Auxiliary Engine	1.4	1.3	1.4	69	2.4	5.9	2.1	3,069
Auxiliary Boiler	0.1	0.1	0.0	2	0.5	0.2	0.1	654
Main Engine	2.4	2.2	2.4	149	3.4	13.6	6.2	4,352
Polar Tankers	**3.8**	**3.6**	**3.7**	**219**	**6.4**	**19.7**	**8.4**	**8,074**
Auxiliary Engine	0.3	0.3	0.3	16	0.5	1.3	0.5	683
Auxiliary Boiler	0.1	0.1	0.0	1	0.3	0.1	0.0	362
Main Engine	0.7	0.6	0.3	21	2.2	2.2	1.0	2,746
SeaRiver Maritime	**1.0**	**1.0**	**0.6**	**38**	**3.0**	**3.6**	**1.5**	**3,791**
Auxiliary Engine	0.3	0.3	0.3	13	0.5	1.2	0.4	617
Auxiliary Boiler	0.1	0.0	0.0	1	0.2	0.1	0.0	286
Main Engine	0.5	0.5	0.5	32	0.8	2.9	1.3	961
Tesoro	**0.8**	**0.8**	**0.8**	**46**	**1.5**	**4.2**	**1.8**	**1,864**
Total	**8.8**	**8.3**	**8.1**	**447**	**16.4**	**40.4**	**17.1**	**20,782**

5.0 FORECAST EMISSIONS

As part of this study, the Council also requested a forecasted emissions inventory using a default of 0.1% sulfur fuel based on projected future tanker fleet growth, decline, or replacement within the next 5-10 years. As the State of Alaska Department of Revenue - Tax Division forecasts the volume of Alaskan North Slope crude oil production at regular intervals, the production forecast contained in their Revenue Sources Book for 2015 spring was used as the basis of determining the future vessel calls to the Valdez Marine Terminal (VMT) for 2015, 2020 and 2024[8].

The spring 2015 production forecast shows an overall decline in the volume of oil available for transport via crude oil tanker from the VMT during our forecast period, therefore no fleet growth is expected during this period. The vessel Eagle Bay replaced the Sierra during the forecast period (2015) and that has been factored in to the forecast.

To estimate the emissions for the forecast period, a ratio of the current number of ship trips used to load the 2014 actual barrels at the VMT was applied to the volume forecasts for the years 2015, 2020 and 2024 to determine the amount of ship trips required to transport the crude oil production out of the VMT in 2015, 2020 and 2024. As the existing fleet currently supports four individual North Slope producers and has the capacity to transport the oil to the various customers in the West Coast market, including Hawaii, the 2014 ratio provides a representation of the average volumes/ship that can be applied throughout the forecast period resulting in a consistent basis for emissions comparison. Additionally, the 2014 percentage of oil volume per shipper was also held constant throughout the forecast period.

Table 5.0: State of Alaska Spring 2015 Production Forecast

Forecast year	barrels (bbl)/day	Total Annual (bbl/day*365)	Number of trips
2015	508,000	185,420,000	244
2020	440,100	160,636,500	212
2024	320,300	116,909,500	154

Table 21 summarizes the forecast emissions for years 2015, 2020 and 2024.

Table 5.1: Summary of Forecast Emissions

Activity Year	PM_{10} tpy	$PM_{2.5}$ tpy	DPM tpy	NO_x tpy	SO_x tpy	CO tpy	HC tpy	CO_2e tonnes/yr
2015	12.0	11.0	11.6	545.9	24.4	50.4	21.5	22,678
2020	10.8	9.8	10.5	484.6	22.0	44.9	19.2	19,621
2024	8.5	7.7	8.3	365.7	18.0	33.8	14.5	14,664

[8] *www.tax.alaska.gov/programs/documentviewer/viewer.aspx?1143r*

Figures 5.0 shows the actual 2014 emissions (1.0% S) and the 2015, 2020, and 2024 forecasted emissions (0.1% S) for PM, NO_x and SO_x. These three pollutants were chosen because they are the pollutants impacted by the North American ECA fuel regulation. As can be seen, SO_x emissions dropped significantly in 2015 and subsequent years due to the change in fuel.

Figure 5.0: Actual and Forecasted Emissions for PM, NO_x and SO_x

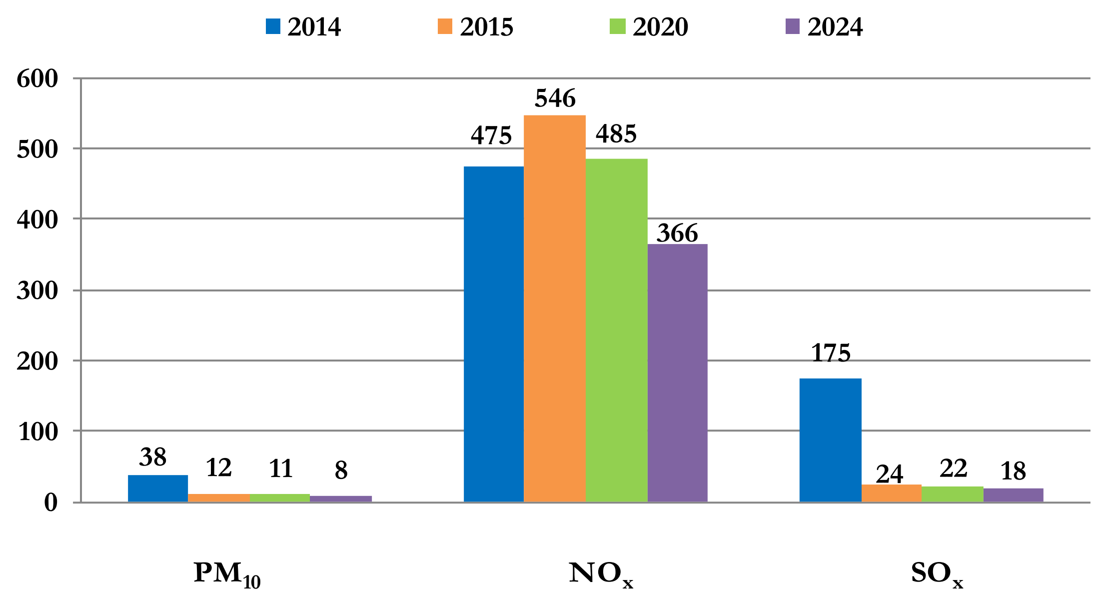
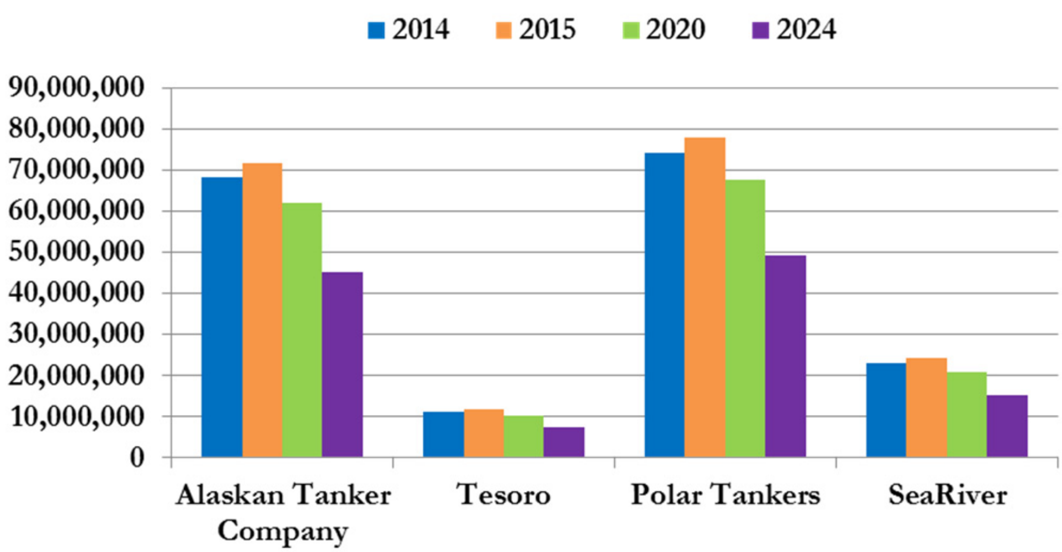


Figure 5.1 shows the actual and forecasted barrels of crude by company. The increased crude in 2015 explains the increased NO_x emissions shown in Figure 5.0 for 2015 as compared to 2014.

Figure 5.1: Actual and Forecast Barrels of Crude by Company



2015 Forecast Emissions

The following two tables show the forecast emissions for 2015 using 0.1% S fuel which is the fuel required for the North American ECA starting in January 2015. Table 5.2 shows the emissions by mode and engine type.

Table 5.2: 2015 Forecast Emissions by Mode and Engine Type

Engine Type	PM_{10} tpy	$PM_{2.5}$ tpy	DPM tpy	NO_x tpy	SO_x tpy	CO tpy	HC tpy	CO_2e tonnes/yr
Auxiliary Engine	1.3	1.2	1.3	61.0	2.3	5.5	2.0	2,857
Auxiliary Boiler	0.1	0.1	0.0	1.6	0.5	0.2	0.1	632
Main Engine	1.9	1.8	1.9	89.8	3.1	8.1	3.7	3,990
Alaska Tanker Company	**3.3**	**3.1**	**3.1**	**152.4**	**5.9**	**13.7**	**5.8**	**7,479**
Auxiliary Engine	1.4	1.4	1.4	72.8	2.6	6.2	2.3	3,237
Auxiliary Boiler	0.1	0.1	0.0	1.8	0.5	0.2	0.1	690
Main Engine	4.1	3.6	4.1	157.2	10.1	14.2	6.4	4,589
Polar Tankers	**5.7**	**5.0**	**5.5**	**231.7**	**13.2**	**20.6**	**8.8**	**8,515**
Auxiliary Engine	0.3	0.3	0.3	11.8	0.5	1.2	0.4	604
Auxiliary Boiler	0.1	0.1	0.0	0.9	0.3	0.1	0.0	339
Main Engine	1.9	1.8	1.8	100.0	2.9	10.4	4.7	3,734
SeaRiver Maritime	**2.2**	**2.1**	**2.1**	**112.7**	**3.7**	**11.6**	**5.1**	**4,676**
Auxiliary Engine	0.3	0.3	0.3	14.2	0.5	1.3	0.5	665
Auxiliary Boiler	0.1	0.1	0.0	0.8	0.2	0.1	0.0	308
Main Engine	0.6	0.5	0.6	34.1	0.8	3.1	1.4	1,035
Tesoro	**0.9**	**0.8**	**0.8**	**49.0**	**1.6**	**4.5**	**1.9**	**2,008**
Total	**12.0**	**11.3**	**11.6**	**545.9**	**24.4**	**50.4**	**21.5**	**22,678**

2020 Forecast Emissions

The following two tables show the forecast emissions for 2020 using 0.1% S fuel which is the fuel required for the North American ECA starting in January 2015. Table 5.3 shows the emissions by mode and engine type.

Table 5.3: 2020 Forecast Emissions by Mode and Engine Type

Engine Type	PM_{10} tpy	$PM_{2.5}$ tpy	DPM tpy	NO_x tpy	SO_x tpy	CO tpy	HC tpy	CO_2e tonnes/yr
Auxiliary Engine	1.1	1.0	1.1	52.3	1.9	4.7	1.7	2,450
Auxiliary Boiler	0.1	0.1	0.0	1.4	0.4	0.1	0.1	542
Main Engine	1.6	1.5	1.6	77.0	2.7	6.9	3.1	3,420
Alaska Tanker Company	**2.8**	**2.6**	**2.7**	**130.6**	**5.1**	**11.8**	**4.9**	**6,412**
Auxiliary Engine	1.2	1.2	1.2	62.2	2.2	5.3	1.9	2,770
Auxiliary Boiler	0.1	0.1	0.0	1.5	0.5	0.2	0.1	590
Main Engine	3.8	3.3	3.8	139.7	9.7	12.6	5.7	4,072
Polar Tankers	**5.2**	**4.6**	**5.1**	**203.5**	**12.3**	**18.0**	**7.7**	**7,433**
Auxiliary Engine	0.2	0.2	0.2	8.9	0.4	0.9	0.3	483
Auxiliary Boiler	0.0	0.0	0.0	0.7	0.2	0.1	0.0	275
Main Engine	1.8	1.7	1.8	98.9	2.6	10.3	4.6	3,298
SeaRiver Maritime	**2.1**	**1.9**	**2.0**	**108.5**	**3.2**	**11.3**	**5.0**	**4,056**
Auxiliary Engine	0.3	0.2	0.3	12.2	0.5	1.1	0.4	570
Auxiliary Boiler	0.0	0.0	0.0	0.7	0.2	0.1	0.0	264
Main Engine	0.5	0.4	0.5	29.2	0.7	2.7	1.2	887
Tesoro	**0.8**	**0.7**	**0.7**	**42.0**	**1.4**	**3.8**	**1.6**	**1,720**
Total	**10.8**	**9.8**	**10.5**	**484.6**	**22.0**	**44.9**	**19.2**	**19,621**

2024 Forecast Emissions

The following two tables show the forecast emissions for 2024 using 0.1% S fuel which is the fuel required for the North American ECA starting in January 2015. Table 5.4 shows the emissions by mode and engine type.

Table 5.4: 2024 Forecast Emissions by Mode and Engine Type

Engine Type	PM_{10} tpy	$PM_{2.5}$ tpy	DPM tpy	NO_x tpy	SO_x tpy	CO tpy	HC tpy	CO_2e tonnes/yr
Auxiliary Engine	0.8	0.7	0.8	37.5	1.4	3.4	1.2	1,756
Auxiliary Boiler	0.1	0.1	0.0	1.0	0.3	0.1	0.0	388
Main Engine	1.2	1.1	1.2	55.2	1.9	5.0	2.3	2,452
Alaska Tanker Company	**2.0**	**1.9**	**1.9**	**93.7**	**3.6**	**8.4**	**3.5**	**4,596**
Auxiliary Engine	0.9	0.9	0.9	46.5	1.6	4.0	1.4	2,069
Auxiliary Boiler	0.1	0.1	0.0	1.1	0.3	0.1	0.1	441
Main Engine	3.4	2.9	3.4	112.6	9.0	10.1	4.6	3,272
Polar Tankers	**4.4**	**3.8**	**4.3**	**160.3**	**11.0**	**14.2**	**6.1**	**5,783**
Auxiliary Engine	0.2	0.2	0.2	6.7	0.3	0.7	0.3	362
Auxiliary Boiler	0.0	0.0	0.0	0.5	0.2	0.1	0.0	206
Main Engine	1.3	1.3	1.3	74.2	2.0	7.7	3.5	2,473
SeaRiver Maritime	**1.5**	**1.4**	**1.5**	**81.4**	**2.4**	**8.4**	**3.7**	**3,042**
Auxiliary Engine	0.2	0.2	0.2	8.8	0.3	0.8	0.3	412
Auxiliary Boiler	0.0	0.0	0.0	0.5	0.1	0.0	0.0	191
Main Engine	0.3	0.3	0.3	21.1	0.5	1.9	0.9	640
Tesoro	**0.6**	**0.5**	**0.5**	**30.3**	**1.0**	**2.8**	**1.2**	**1,243**
Total	**8.5**	**7.7**	**8.3**	**365.7**	**18.0**	**33.8**	**14.5**	**14,664**

Forecast 2015-2024 Trends

Figures 5.2 through 5.9 show the forecast emissions in tons for each pollutant from 2015 to 2024. The figures also include the 2014 actual emissions with an emission reduction arrow to the right. The predominant driver for lower emissions in the forecasted years is the reduction in forecasted tanker activity and use of low sulfur (0.1%) fuel.

Figure 5.2: PM_{10} Forecast 2015-2014, tons

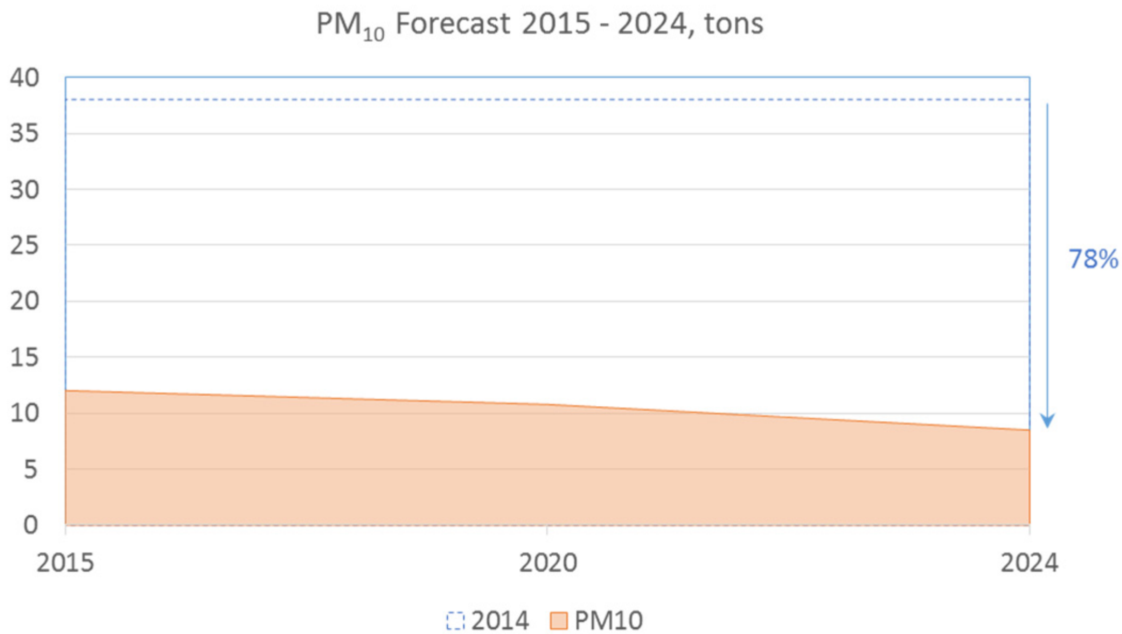


Figure 5.3: $PM_{2.5}$ Forecast 2015-2014, tons

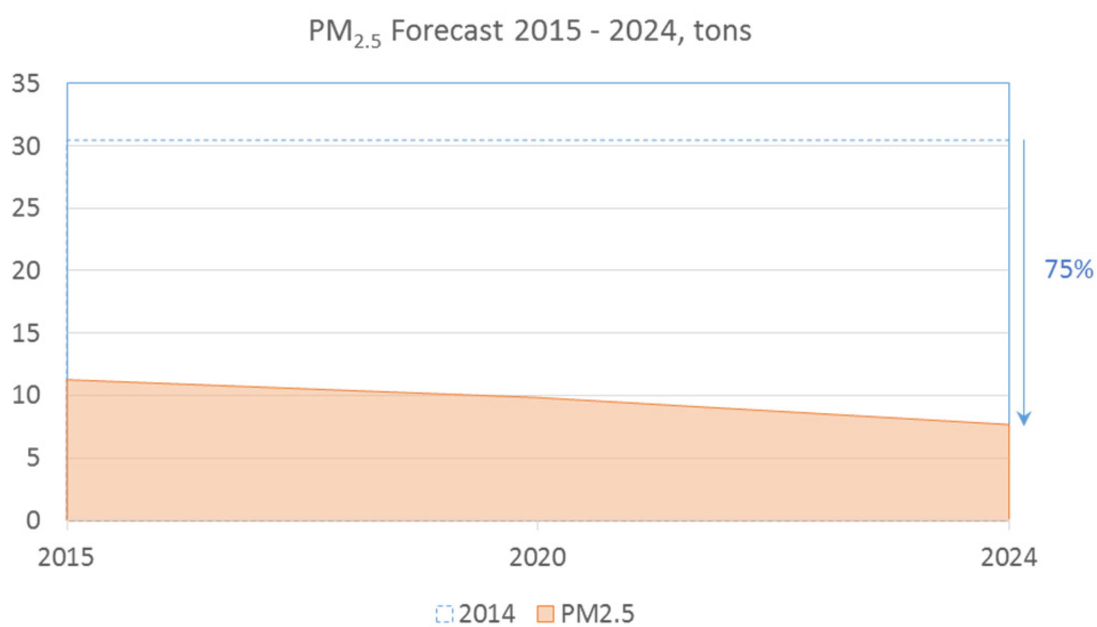


Figure 5.4: DPM Forecast 2015-2014, tons

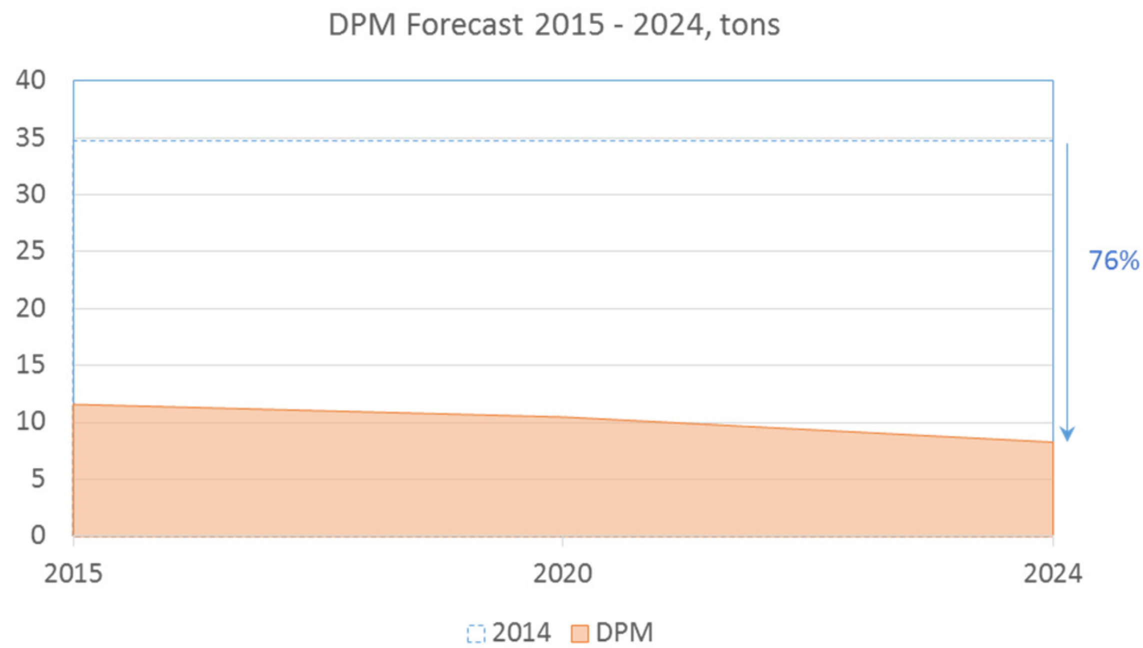


Figure 5.5: NO_x Forecast 2015-2014, tons

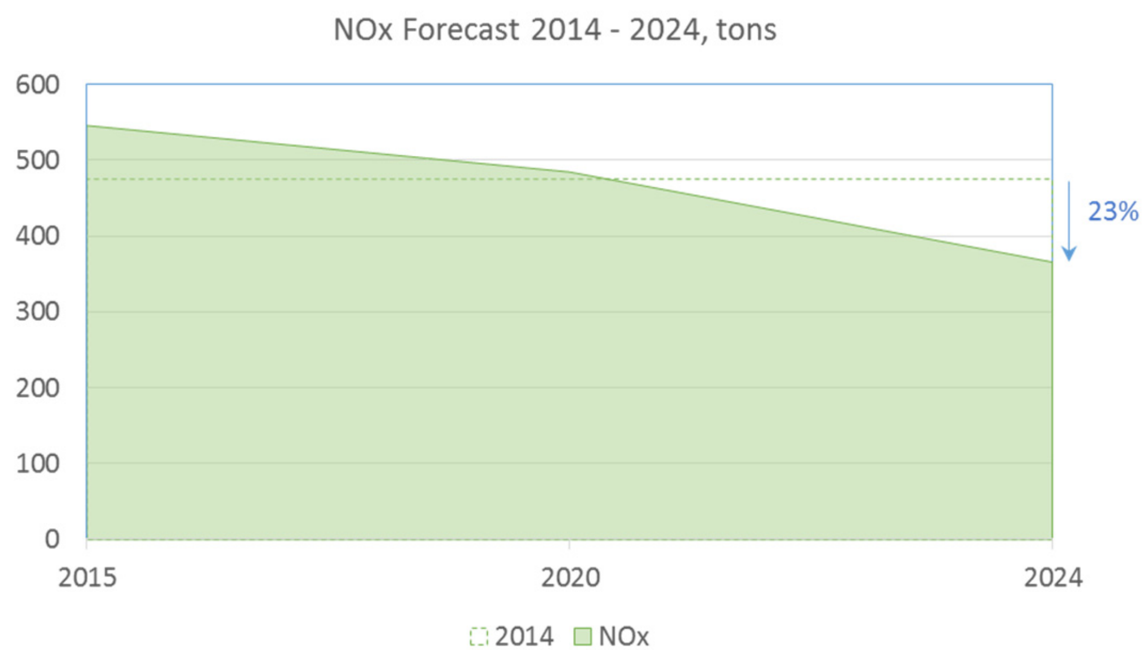


Figure 5.6: SO_x Forecast 2015-2014, tons

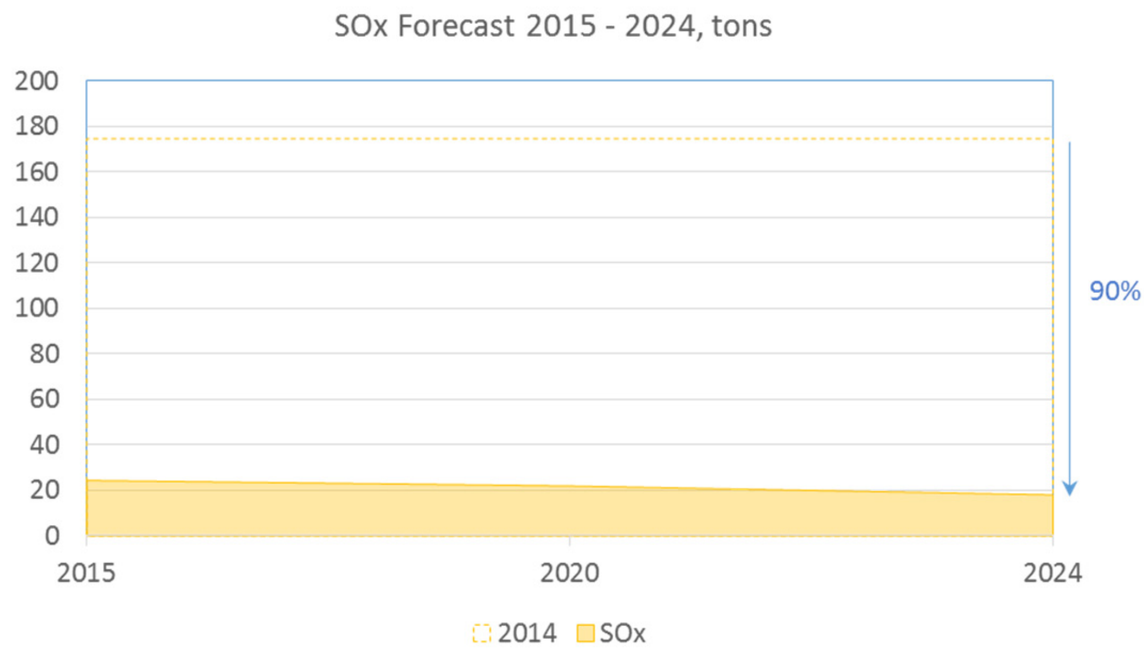


Figure 5.7: CO Forecast 2015-2014, tons

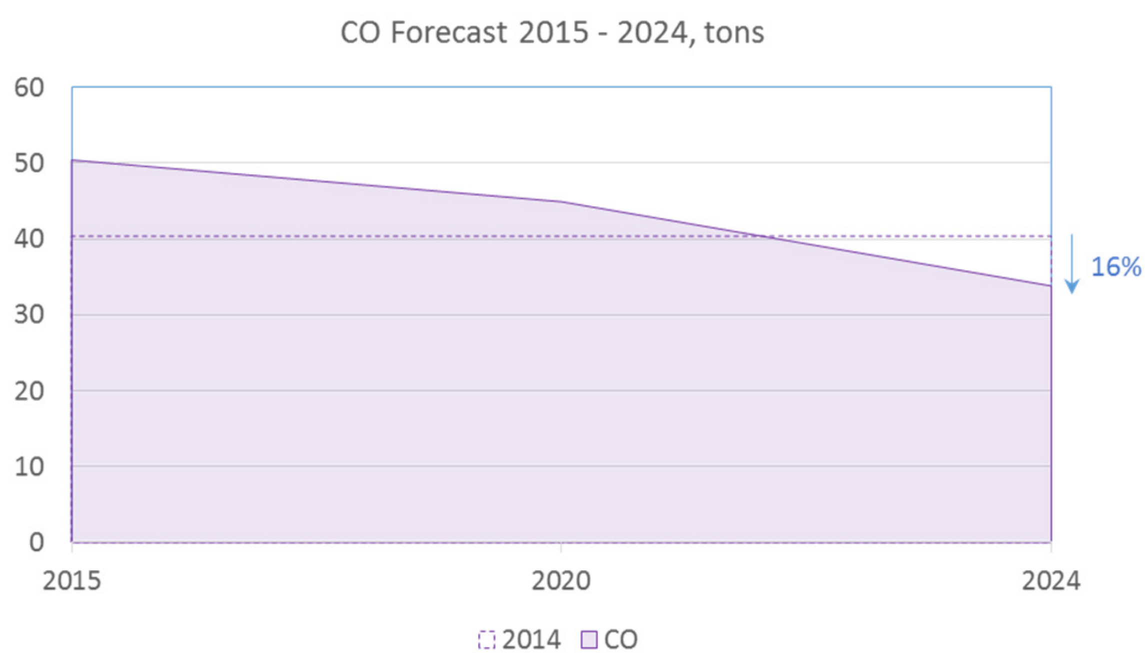


Figure 5.8: Hydrocarbon Forecast 2015-2014, tons

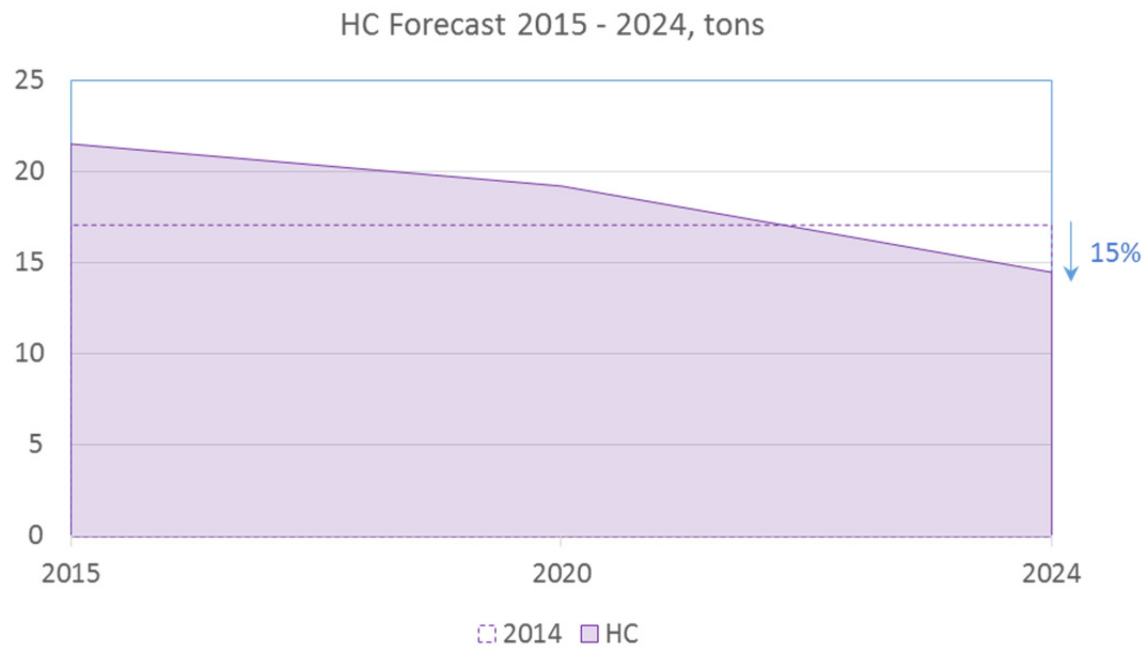
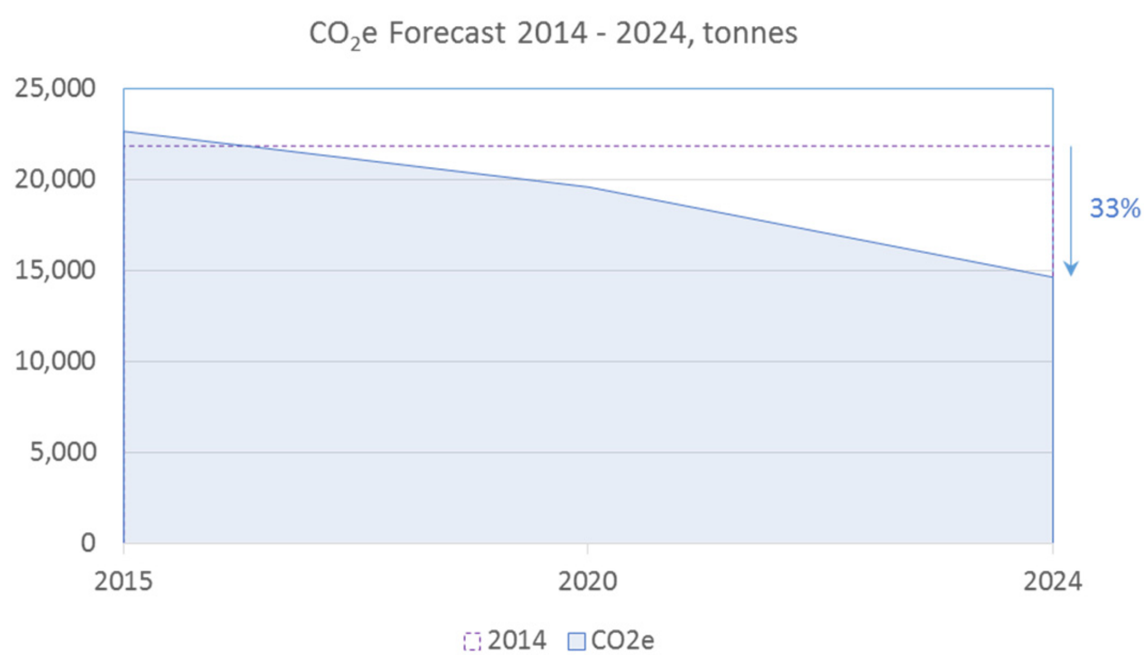


Figure 5.9: CO_{2e} Forecast 2015-2014, tonnes



6.0 CONCLUSION

Studies have shown that sulfur content of the fuel has significant effect on PM and SO_x emissions which led to IMO MARPOL Annex VI regulation requiring low sulfur fuel to be used by ships. Therefore, as seen in Table 4.0, the emissions estimation analysis shows that using 2014 vessel fleet and activity in the Prince Williams Sound, there is a 26% reduction in PM and 61% reduction in SO_x for a fuel switch between 2.7% S HFO fuel and 1% S HFO fuel. Further, using 2014 vessel activity in the Prince Williams Sound, an 83% reduction in PM and 96% reduction in SO_x will occur for a fuel switch between 2.7% S HFO fuel and 0.1% S MGO fuel. The NO_x emissions are also reduced slightly when switching from HFO fuel to MGO due to change in composition of the fuel. In future years, there may be further reductions in NO_x when the ships equipped with IMO NO_x Tier 0 and Tier 1 engines in the current fleet are replaced with ships with IMO NO_x Tier 2 and Tier 3 engines.