STUDY ON THE AIR QUALITY BENEFITS TO THE PORT OF VANCOUVER BY ADOPTING LNG AS A MARINE FUEL

For the consideration of Tilbury Jetty Limited Partnership and FortisBC

APRIL 2022

Affinity (Shipping) LLP, 44th Floor,
The Leadenhall Building, 122 Leadenhall Street,
London, EC3A 8EE, United Kingdom

Glossary

Abbreviations

- **BC** – Black carbon
- **CO_2** - Carbon dioxide
- **CO_2e** - Carbon dioxide equivalent
- **DWT** – Deadweight tonnes
- **ECA** – Emission Control Area
- **GHG** – Greenhouse gas
- **GWP** – Global warming potential
- **ICCT** - International Council on Clean Transportation
- **IMO** – International Maritime Organisation
- **LNG** – Liquified natural gas
- **MGO** – Marine gas oil
- **N_2O** – Nitrogen oxide
- **NMVOCs** - Non-methane volatile organic compounds
- **NOx** – Nitrogen Oxides
- **PM** - Particulate matter
- **RNG** – Renewable natural gas
- **SCR** – Selective catalytic reduction (or selective catalytic reductor)
- **SOx** - Sulphur oxides

Definitions

- **Breakbulk** – Cargo that is not suitable for containers or easily fitted into the hulls of tankers and dry bulk carriers, so is transported in large quantities, often unpackaged. Examples include machinery, steel girders, and separate bags or barrels.
- **Carbon dioxide equivalent**– A measure of comparison between various greenhouse gases on the basis of their global warming potential, by converting gases into a common unit that reflects the atmospheric heating potential of that gas in carbon dioxide terms.
- **Global warming potential** – The heat absorbed by a greenhouse gas in the atmosphere, as a multiple of the heat that would be absorbed by the same mass of carbon dioxide. Because gas concentrations decay at different rates, the global warming potential of a gas depends on the time frame applied.
- **Lifecycle basis** – An emission accounting approach involving the evaluation of the environment impact of a product from the extraction of the raw material to the point of final use. Also known as lifecycle assessment.
- **On-shore power** – The provision of electrical power to a ship at birth while its main and auxiliary engines are shut down. Also known as cold-ironing, shore supply or shore power.
- **Ro-Ro** – A roll-on/roll-off vessel is a cargo ship designed to carry wheeled cargo, such as cars, trailers and rolling stock. Similarly, a RoPax vessel is designed to carry wheeled cargo and contains passenger facilities, including accommodation.
- **Tank-to-wake** – A measure of emissions produced by the on-board combustion of fuel.
- **Well-to-tank** - A measure of emissions from producing, processing, transporting and loading fuel into a ship.
- **Well-to-wake** – The summation of tank-to-wake and well-to-wake emissions.

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Executive Summary

The purpose of this study is to assess the real-world air quality benefits to the Port of Vancouver area if one million tonnes per annum (**1MMTPA**) of liquefied natural gas (**LNG**) provided by FortisBC was substituted into the maritime fuel mix of vessels servicing that area, thereby replacing oil-based maritime fuel.

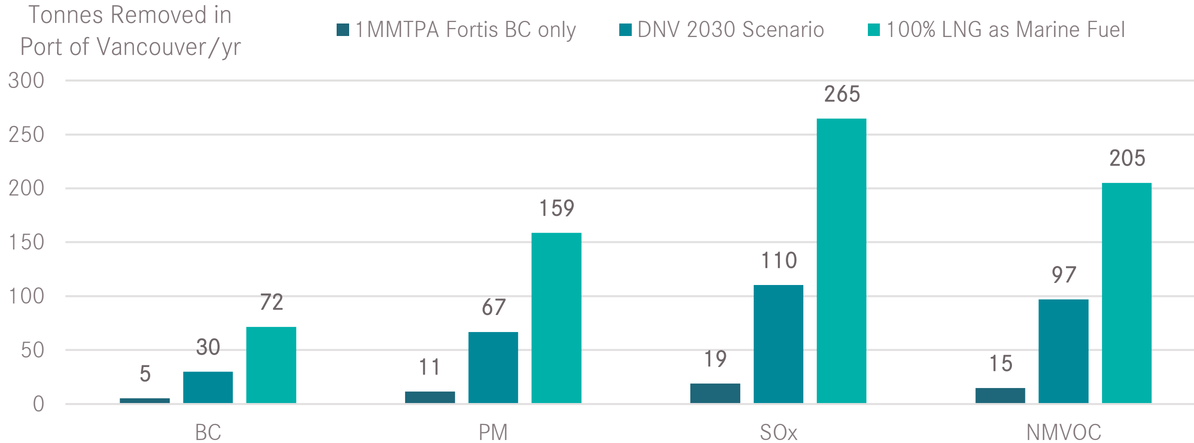
The study shows significant improvements can be made to the air quality of the Port of Vancouver airshed by fuel-switching LNG for marine gas oil (**MGO**).

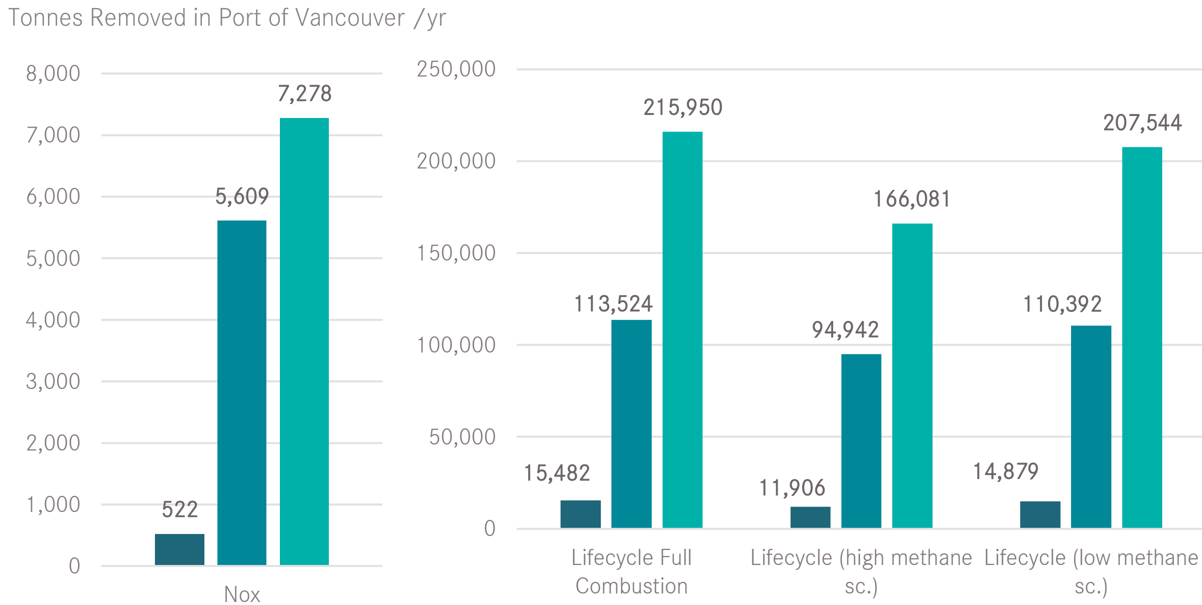
For example, we calculate that (in 2019) 177 tonnes of particulate matter (**PM**) were emitted in the Port of Vancouver Area. We estimate that this would be reduced by 11 tonnes per year if ships were to use only 1MMTPA of FortisBC LNG and reduced by 159 tonnes per year if LNG fully substituted MGO. The mid-case, which follows DNV's projection of LNG being ~37% of the maritime fuel-mix by 2030, sees a reduction of 67 tonnes of PM per year.

The lifecycle carbon intensity of FortisBC LNG is around 14% below that of the International Council on Clean Transportation's (**ICCT**) assessment of US-based LNG.[1] If 1MMTPA of FortisBC LNG were to be substituted into the maritime fuel mix, there would be a global annual reduction between 980k and 1.2MM tonnes of CO2e on a lifecycle basis.

The uptake of LNG as a marine fuel is a key element of shipping's decarbonisation journey, with Bio-LNG and Synthetic LNG as low carbon future versions of the fuel. LNG Bunkering in the Port of Vancouver would offer significant near-term air quality improvements for the local airshed whilst also encouraging the wider shipping industry to decarbonize.

Air Quality Benefits under different LNG as a marine fuel Scenarios





1 ICCT & British Columbia Low Carbon Fuel Standard

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Introduction

Emissions from ships are a major source of air pollutants and greenhouse gases, all of which can have either serious health impacts or adversely affect the climate. Due to the industry's reliance on oil-based fuels, the share of shipping emissions in global anthropogenic emissions has increased from 2.76% in 2012 to 2.89% in 2018.[2] Populations living in proximity to ports have been found to be exposed to particularly high levels of air pollution.[3]

At present, the area of Port of Vancouver (**Port**) is included in both SOx and NOx Emission Control Areas (ECAs). To comply with the SOx ECA, vessels must use fuel with a sulphur content of 0.1% or less - for oil-based fuels, this grade is known as marine gas oil (**MGO**).

The purpose of this study is to assess the real-world air quality benefits to the Port of Vancouver area if one million tonnes per annum **(1MMTPA)** of liquefied natural gas (**LNG**) provided by FortisBC was substituted into the maritime fuel mix of vessels servicing that area, thereby replacing oil-based maritime fuel.

LNG as a Marine Fuel

In recent years, liquefied natural gas (**LNG**) has been gaining traction as a replacement fuel for ships. LNG offers significant benefits to human health by virtually eliminating local air pollutants. This is especially important for ports and populated coastal areas. When dealt with efficiently, LNG offers important reductions in greenhouse gases in both the combustion phase and across the lifecycle of the fuel.

Pollutants Assessed

To assess the air quality benefits of substituting LNG into the fuel mix of vessels calling at the Port of Vancouver, we have assessed the following pollutants and greenhouse gases:

- ✓ Nitrogen oxides (**NOx**);
- ✓ Black carbon (**BC**);
- ✓ Particulate matter (**PM**);
- ✓ Sulphur oxides (**SOx**);
- ✓ Non-methane volatile organic compounds (**NMVOCs**);
- ✓ Carbon dioxide (**CO_2**);
- ✓ Carbon dioxide equivalents (**CO_2e**) (all greenhouse gases);
- ✓ **GHG Lifecycle-basis** – i.e., the greenhouse gas emissions associated with the production, transportation and final combustion of the fuel.

All these pollutants and greenhouse gases stand to be significantly reduced if LNG were brought into the fuel mix.

Conclusions: Air Quality and GHG Benefits for Local Airshed

If, for example, all the MGO/MDO burned by vessels in the Port was substituted for LNG, there would be benefits to the Port of Vancouver Airshed of:

- 84% reduction in **NOx** (7,311 tonnes/yr)
- 96% reduction in **BC** (72 tonnes/yr)
- 90% reduction in **PM** (159 tonnes/yr)
- 98% reduction in **SOx** (265 tonnes/yr)
- 43% reduction in **NMVOCs** (205 tonnes/yr)
- 22% reduction in **CO_2e** (164k tonnes/yr) in a high-methane scenario
- 27% reduction in **CO_2e** (206k tonnes/yr) in a low-methane scenario

The reduction in pollutants would notably improve the air quality in the Port of Vancouver and would consequently offer health benefits to the local population.

Note on Engine Technology

The tank-to-wake reductions in greenhouse gases are most effective when the LNG is used in high-pressure diesel engines, as opposed to low-pressure otto cycle engines (both medium and slow-speed).

In the analysis that follows, we therefore include a "methane sensitivity" – i.e. a range of added CO_2e that results from uptakes of differing LNG engine technologies across the fleet. Our "high methane scenario" includes passenger ships using 4-stroke medium speed Otto-cycle engines and all other ships using high-pressure 2-stroke and low-pressure 2-stroke engines in equal measures. In our "low methane scenario", all vessels use high-pressure 2-stroke engines.

From a life-cycle basis, FortisBC LNG has an approved carbon intensity of 65.09gCO_2e/MJ.[4] We then include methane slip values, according to engine type, as per the FuelEU Maritime.[5] We assume a 100-yr GWP for methane.

2 Fourth IMO Greenhouse Gas Study 3 Merico et al., 2017 4 British Columbia Ministry of Energy, Mines and Low Carbon Innovation 5 FuelEU Maritime Proposal

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Background: Development of LNG as a Marine Fuel

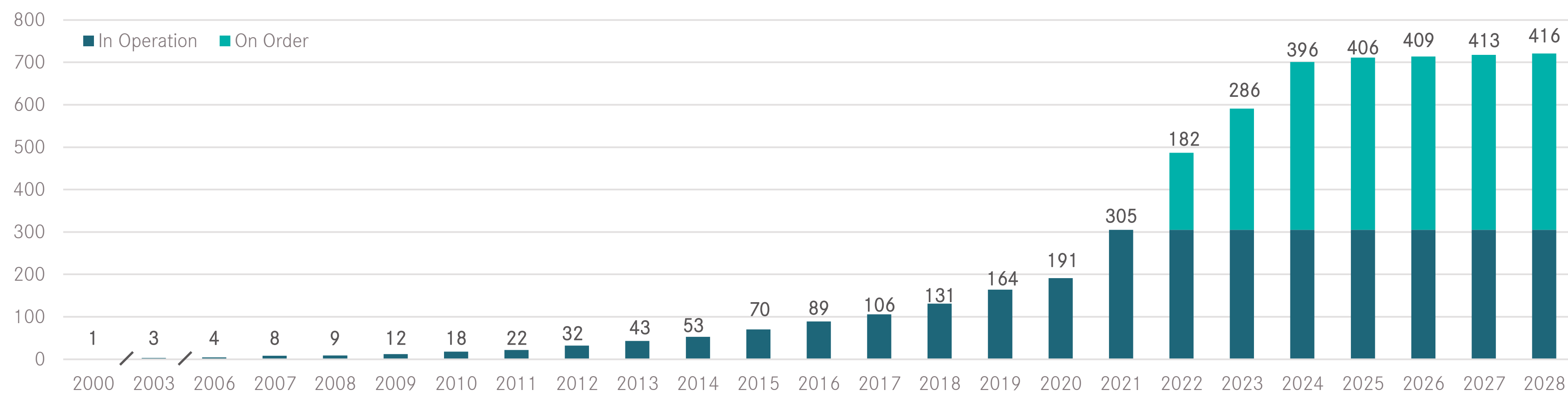
Demand for LNG marine fuel has accelerated over the past ten years, driven by the increased scrutiny placed on the shipping industry with regards to its environmental footprint. Shipping has experienced several waves of regulatory changes over the past half century, a process which has hastened in the past five years with the introduction of regulation of ballast water treatment and local air quality. Now, the focus is on carbon intensity and the level of atmospheric pollution generated by shipping. The reduction in emissions of carbon dioxide, NOx, particulate matter and other pollutants offered by LNG, and its increased density and energy content over traditional fuel oils, has made it the leading candidate amongst the various alternative fuel options.

DNV, the world's largest classification society, predict that the global maritime fuel mix will shift rapidly away from fuel-oil towards LNG, which will soon be the dominant fuel and will remain so until at least 2050. By 2030, 37% of energy consumed on-board by the global fleet will be provided by natural gas. This will increase to 42% by 2050, even as maritime energy demand declines (due to improvements in energy efficiency) [6]. The orderbook is filling up with LNG fueled vessels, of which 209 were ordered in 2021, more than the previous seven years combined. At the latest count, 37 orders have been placed so far this year [7].

The largest fuel oil bunkering hubs were the first to develop LNG bunkering and today contain the most advanced facilities. Rotterdam and Singapore lead the way in this regard, with Japan, the US Gulf Coast, and the Western Mediterranean (especially Spain) serving as regional hubs. As such, the immediate benefits in air quality derived from substituting LNG for fuel oil are concentrated in areas where LNG infrastructure already exists in ports along the cross-Suez route. Bunkering stations suitable for trans-Pacific routes are being developed in Australia, China, Indonesia, the ports of Long Beach and Seattle, Singapore and Japan (where a second LNG bunkering vessel will commence operations later this year).

Therefore, it is likely that the air quality improvements experienced in Vancouver by substituting FortisBC LNG into the local fuel mix will be multiplied by the cumulative impact of LNG bunker developments across the Pacific Rim. The availability of LNG marine fuel in Vancouver is likely to attract a greater number of LNG-fueled vessels, now confident they can complete a round voyage by refueling in Vancouver. Although DNV estimate that 37% of the marine fuel mix will be derived from LNG in 2030, it would be reasonable to assume that the LNG-fueled fleet will be concentrated on routes where bunkering infrastructure is sufficiently developed (namely trans-Pacific, cross-Suez and intra-European routes), and therefore the effective proportion of LNG in Vancouver's marine fuel mix might be greater than DNV's estimated figure for global LNG fuel consumption.

Cumulative Number of LNG Fueled Vessels in Global Fleet



6 DNV Energy Transition Outlook 2021 7 Affinity Research

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Path to Low Emission LNG

FortisBC LNG achieves a significant improvement in carbon intensity versus existing supplies of LNG. This is primarily due to the use of power generated by hydroelectricity plants in the production, processing and liquefaction of LNG. Furthermore, since no LNG carrier transport is required, the greenhouse gas intensity of the supply of LNG into the Port of Vancouver is reduced considerably. FortisBC LNG offers a 29.3% reduction versus the ICCT assessment (adjusted for AR5 GWP values) of MGO and a 14.3% reduction in well to wake carbon emissions over the ICCT assessment for LNG. By 2030, FortisBC LNG should have a 30% lower carbon intensity compared with global average LNG due to the uptake of Renewable Natural Gas (RNG), an expanded electric delivery system, and increased energy efficiency across the extraction, processing and transportation operations.

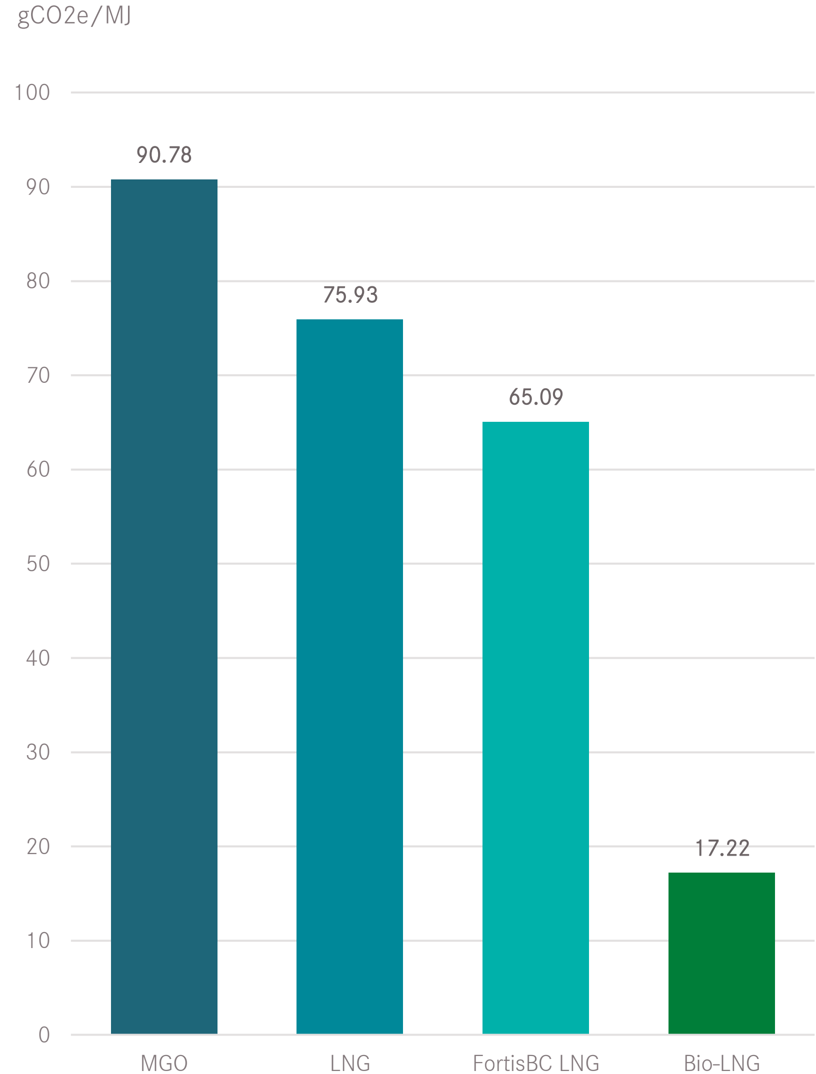
Additionally, it is possible to produce 'Green LNG' in the form of e-methane or bio-methane, a carbon-based yet low emissions fuel[4]. E-methane is a synthetic fuel resulting from electrolysis of water with renewable electricity and combining it with carbon dioxide to create methane. Bio-methane is typically produced by removing carbon dioxide from biogas or gasification of solid biomass followed by methanation, using renewable electricity. All these methods offer a dramatically lower lifecycle emissions factor compared to modern day LNG ('Grey LNG').

One of the advantages of the transition to Green LNG is that the fuel has the same molecular structure as existing LNG, and so would not require any changes to existing LNG infrastructure and can be easily blended into the fuel mix. This is dissimilar to competing alternative fuels such as ammonia and hydrogen which would require the construction of expensive and complex infrastructure and necessitates separation from fuels presently in use.

Previous studies performed by Sphera have modelled a 'Canada – CleanBC 2030' scenario resulting from reductions in emissions produced in the upstream segment of FortisBC's, which showed a 28.5% reduction in the well to tank emission intensity of FortisBC LNG relative to existing levels.[8] Again, this is attributable to the continued utilization of British Columbia's renewable electricity production capabilities, but also to Canadian regulations that reduce methane emissions from upstream oil and natural gas facilities (for example, the tracking and maintenance of fugitive methane leaks and introduction of venting limits).

The materialization of the Canada – CleanBC 2030 scenario, coupled with the rollout of Green LNG over the coming decades which can be easily input into the existing natural gas network, would allow for continual improvements in the greenhouse gas intensity and air quality benefits of the adoption of LNG as a marine fuel in the Port of Vancouver.

Lifecycle (Ful Combustion) Emission Factor Comparison *



8 Life Cycle GHG Emissions of the LNG Supply at the Port of Vancouver

* These emissions factors do not include methane slip in the engine. As mentioned in the Note on Engine Technology on Page 4, we include methane slip values when assessing particular vessels and engine types.

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Air Quality Benefits Resulting from the Adoption of LNG as a Marine Fuel – Port of Vancouver Area

Aim

To quantify the air quality benefits affecting the Port of Vancouver area, resulting from the adoption of FortisBC LNG as a marine fuel.

Methodology

1. Quantify the 2019 (i.e "non-Covid" year) air pollution levels in the Port of Vancouver area that resulted from maritime emissions and calculate the scope for air quality benefits if marine gas oil were to be fully substituted for liquefied natural gas.

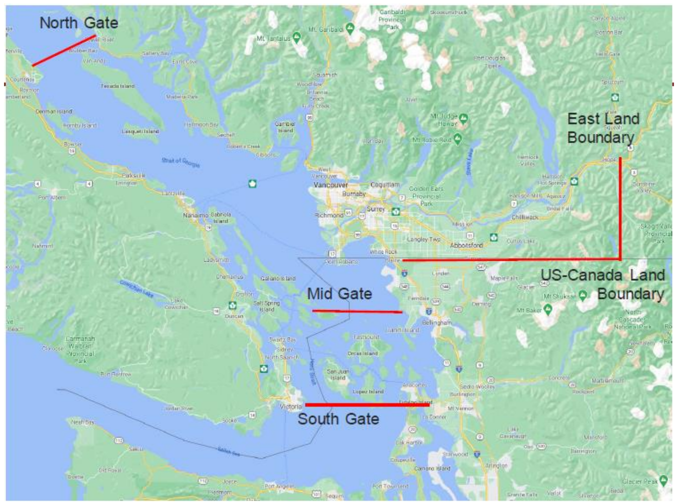
2. Categorize the industrial ships that entered ports in the Vancouver area during the year 2019 into size and age range (including bulk carriers, containerships, tankers, passenger ships, general cargo ships and Ro-Ros). Estimate the total annual fuel consumption for the vessels calling in the Port of Vancouver based on actual ship call data for 2019.

3. Calculate (as a percentage) the amount of the annual fuel consumption which could be switched with Fortis LNG. Apply that percentage "potential for fuel-switching" to the marine-based energy consumption in the Port of Vancouver during 2019 to quantify the amount that would be replaced by the fuel switch.

4. Apply internationally recognised fuel emissions factors to both the quantity of bunker fuel being replaced, and the LNG that the bunker fuel is being replaced with, to find potential pollution and emission reductions in the Port of Vancouver.

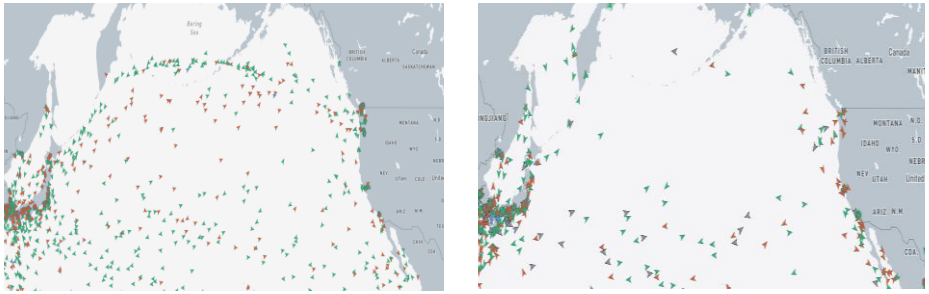
5. Estimate pollutant reductions in the territorial limit of Canada (12 nautical miles from the western land of Canada).

Initial Area Assessed



Areas between North Gate and South Gate are assessed

Snapshot of Bulkers and Tankers in North Pacific and Vancouver area



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Vessels Identified Using Port of Vancouver Data

Using IMO numbers supplied by the Port of Vancouver, we can see that of the ships that called at the Port of Vancouver in 2019:

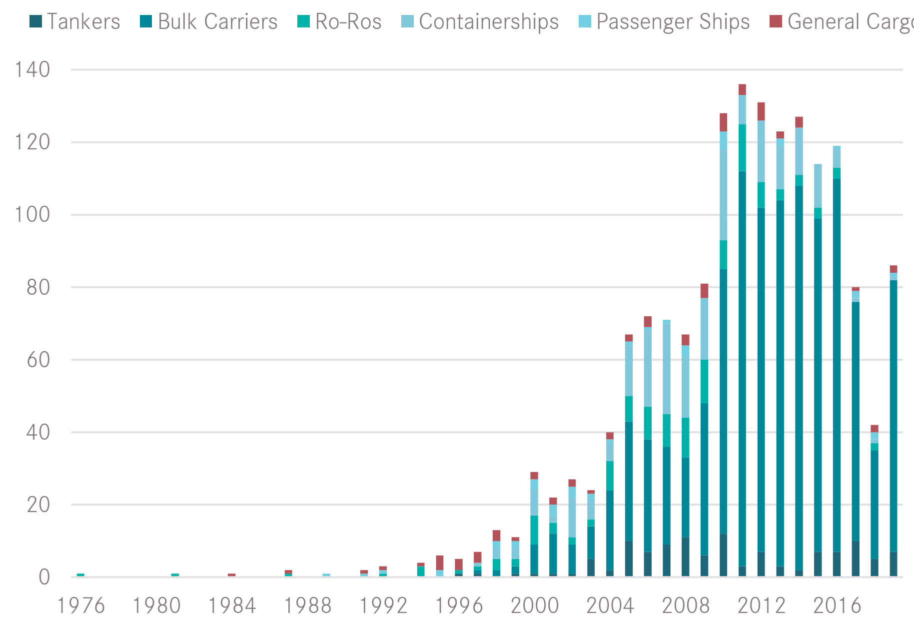
- 1,068 were bulk carriers
- 226 were containerships
- 119 were tankers
- 127 were Ro-Ros.
- 63 were general cargo carriers
- 40 were passenger ships

Using the IMO numbers of these vessels, we can find, for each vessel class, the average age of the ships and the average deadweight of the ships. Consequently, we can find the average daily consumptions using real-world vessel specifications.

Assuming ships spend 80% of the year sailing and 20% either idle or in port, we can estimate the total annual fuel consumption of all the vessels that serviced the Port of Vancouver in 2019.

As an estimate, we find that the total annual fuel consumption for the vessels that serviced Vancouver in the year 2019 is 16.6 MMTPA.

Age Range for Vessel Types



Ship Type	:	Bulk Carrier	Containership	Tanker	Ro-Ro	General Cargo	Passenger Ships
Avg. Dwt	*deadweight*	75,475	87,952	46,194	18,211	36,026	7,357
Corresponding Vessel Class	:	Panamax	8,000 TEU	Handysize	-	-	-
Avg. Build year	#	2010	2008	2010	2006	2004	2005
Sailing Consumption (1)	*tpd*	25	71	29	35	18	64.50
Port Consumption (1)	*tpd*	3.5	11.7	4.2	5	3	0
Number of Ships	#	1,068	226	119	127	63	40
Annual Estimated Consumption	*tonnes*	8,069,274	4,878,459	1,044,177	1,344,295	344,925	753,403

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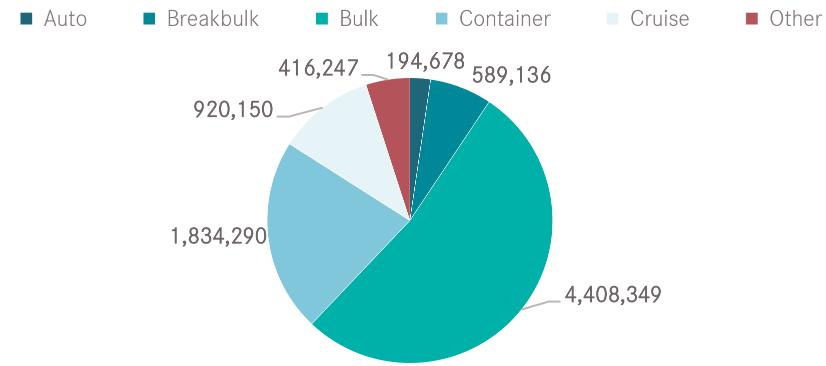
2019 Levels of Air Pollution in the Port of Vancouver Area

During 2019, a total of 196,854 tonnes of marine fuel was burned in the Port of Vancouver area (see map on Page 6) [9].

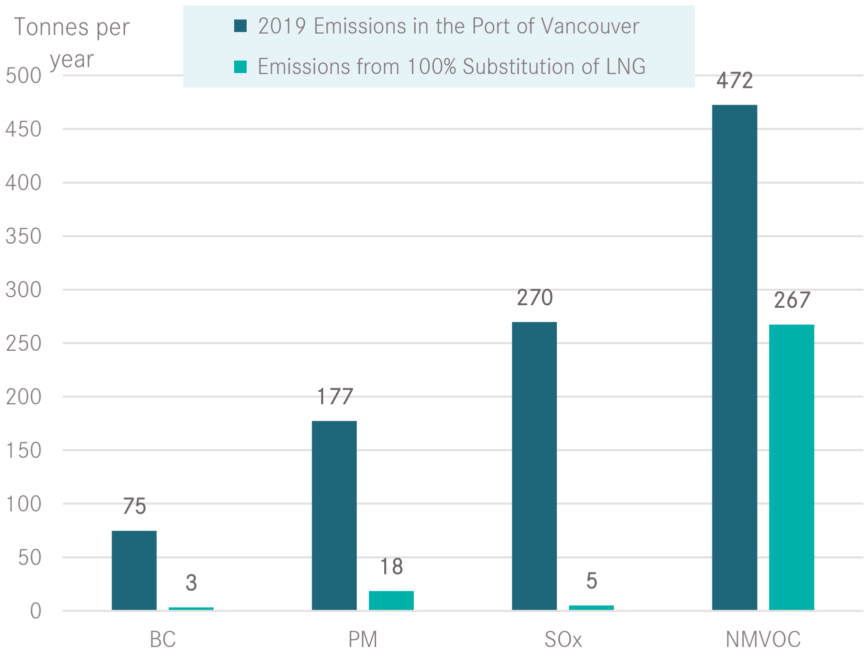
Using this figure, we can quantify pollutants and greenhouse gases emitted in the Port using industry standard emissions factors. These are obtained from the IMO, ICCT, and the British Columbia Ministry of Energy, Mines and Low Carbon Innovation.

In the graphs below, we have illustrated the pollutants and greenhouse gases released in the Port of Vancouver as a result of burning 196,854t of oil-based marine fuel. To demonstrate the potential long-term benefits of LNG as a marine fuel, we have also illustrated the emissions that would result from substituting that entire fuel-mix with LNG.

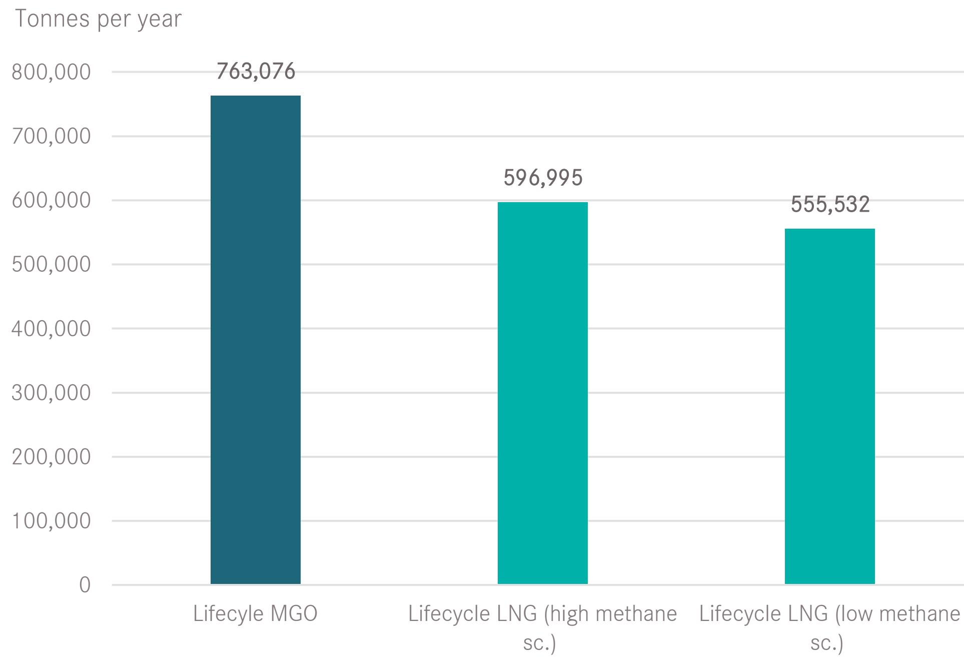
2015 Port Marine-based Energy Consumption by Vessel Class (GJ) [9]



Local Pollutant Emissions from 100% Substitution of LNG



Greenhouse Gases Emissions from 100% Substitution of LNG



9 Data provided by the Port of Vancouver

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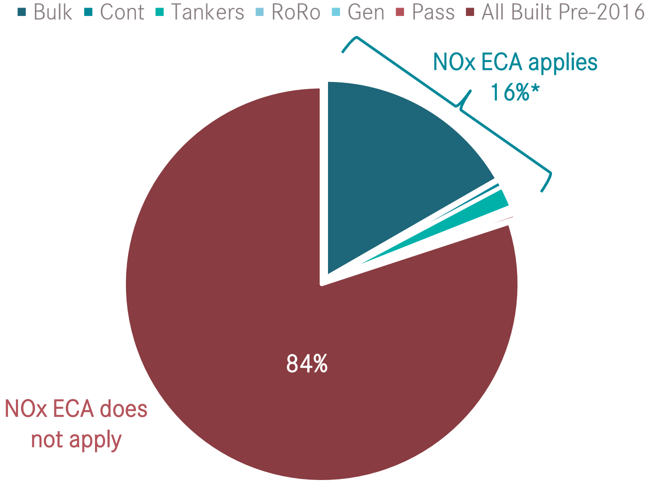
NOx Emissions in the Port of Vancouver

Since the 1st January 2016, a NOx emissions control area (ECA) has been in operation in the North American ECA and the US Caribbean Sea ECA. The NOx ECA prescribes different levels (Tiers) of control based on the ship construction date. While operating in an ECA established to limit NOx emissions, certain vessels must comply with Tier III controls. Since the 1st January 2016, a marine diesel engine that is installed on a ship constructed on or after the 1st January 2016 and operating in North American and US Caribbean Sea ECAs must comply with the Tier III NOx standard.

To comply, MGO-fueled vessels use selective catalytic reductors (SCRs), which reduce NOx emissions by ~80% [10]. This results in an emissions factor of 1.13kg of NOx per MJ of fuel.[1] However, according to 2019 data, only 16% of vessels arriving at the Port of Vancouver were built during or after the year 2016 [11].

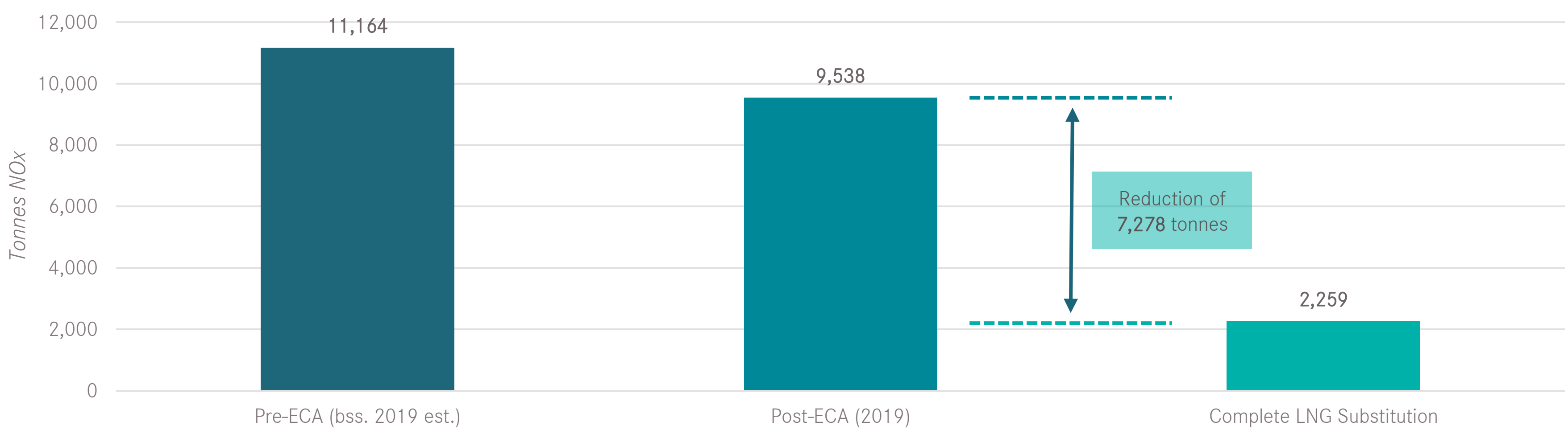
As such, we have considered three possible NOx scenarios. Firstly, the NOx emissions (based on 2019 consumption figures) for the Port without an ECA. Secondly, the NOx emissions assuming ~16% of the vessels arriving at the Port (which is equal to ~18% of the energy used in the Port) are built during or after the year 2016. Thirdly, that MGO is completely substituted for LNG.

Ships calling at Port (2019) built during or after 1st January 2016



* Equal to 18% of energy used in PoV in 2019

Estimate NOx Emissions in Port of Vancouver under different reduction scenarios



10 US EPA 11 Port of Vancouver – 2015 Emissions Inventory Report

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Potential For Fuel Switching in the Port of Vancouver

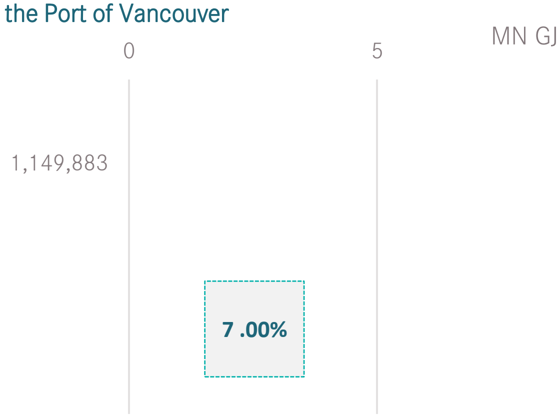
Having calculated the estimated total fuel consumption for the ships calling at the Port of Vancouver at 16.6MMTPA (or **702MN GJ**), we now look for the *percentage potential for fuel-switching*. The 1MMTPA of LNG from FortisBC (on an energy demand basis) would make up ~**7% of the annual fuel demand** for the vessels calling at the Port of Vancouver. On this methodology, we assume, therefore, that a minimum of ~7% of the marine-based energy consumption in the Port of Vancouver has the potential to be replaced with LNG.

According to data from the Port of Vancouver, the total marine-based energy consumption in port during the year of 2019 was ~**8.46MN GJ** (this energy is currently being produced from oil-based marine fuels). The fuel switching potential is therefore 7% of 8.46MN GJ which is **0.59 MN GJ**.

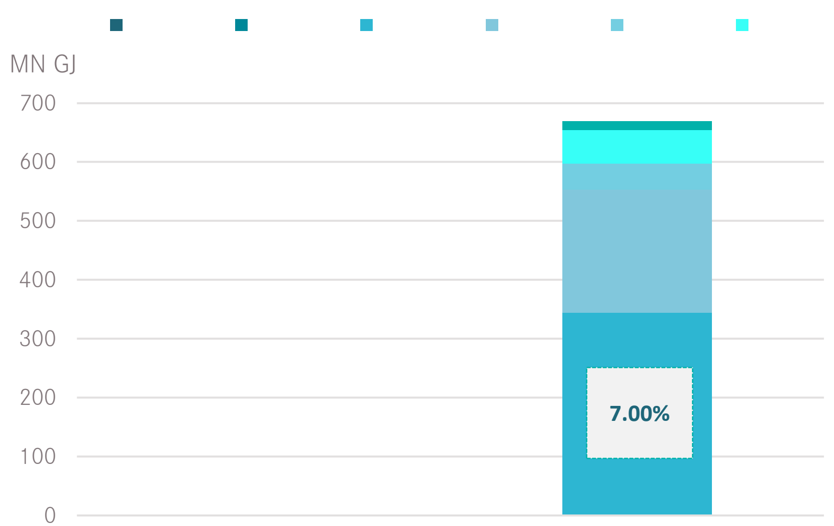
0.59 MN GJ converts to **~13.9k tonnes of marine gas oil**: therefore, scope for fuel switching is **~12k tonnes of LNG.**

It should be noted that the 8% potential for fuel-switching assumes that these ships can only bunker LNG in the Port of Vancouver. However, as LNG bunkering develops globally, ships will be able to bunker LNG in various other ports. This will make FortisBC LNG available for fuel-switching on more vessels. As such, the 7% should be seen as a base-case.

Scope for Fuel Switching in the Port of Vancouver



Estimated Vessel Consumption vs. Fortis Annual LNG Production



Port of Vancouver Application	
Total Marine-based Energy Consumption in Port	8,464,742 GJ
Scope for Fuel Switching	588,077 GJ
MGO Conversion Factor	42.7 GJ/t
MGO – Switch Potential	**13,870 tonnes**
LNG Conversion Factor	48 GJ/t
LNG – Switch Potential	**12,062 tonnes**

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Initial Results from FortisBC LNG Fuel-Switching Potential in the Port of Vancouver Area

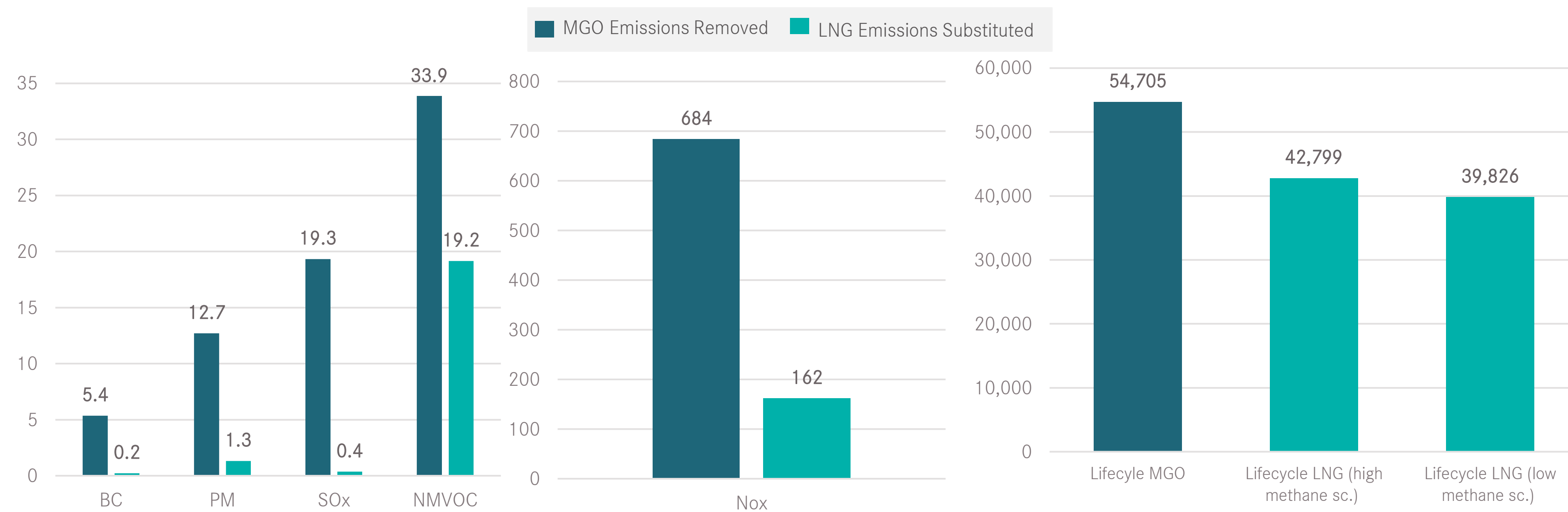
The next step is to assess the air quality benefits associated with a substitution of **~12kt of LNG** for **~13.9kt of MGO.** Using emissions factors provided by the **IMO**, the **ICCT** and the **British Columbia Ministry of Energy, Mines and Low Carbon Innovation**, we can quantify the amount of each pollutant or greenhouse gas that is saved by the fuel-switching substitution.

Further, we are able to calculate the air quality benefits as a percentage of the air pollution levels quantified on page 8. The percentage savings, along with absolute savings over a 25-year period, are displayed in the table to the right. The annual absolute savings are illustrated in the graphs below.

The greatest savings are felt in some of the most damaging pollutants. We estimate that the Port of Vancouver area will benefit from an **annual reduction** of over **11 tonnes of particulate matter**, around **19 tonnes of SOx** and around **5 tonnes of black carbon**.

Pollutant / Greenhouse Gas	1MMTPA LNG: Port Reductions	1 MMTPA LNG: 25-yr Period Savings
NOx	5.5%	13,045t
Black Carbon	6.9%	128t
PM	6.4%	284t
SOx	7.0%	474t
NMVOC	3.1%	368t
GHG Lifecycle (High Methane Scenario)	1.5%	297,660t
GHG Lifecycle (Low Methane Scenario)	1.9%	371,973t

Tonnes of Pollutants and Greenhouse Gases Saved in the Port of Vancouver Annually



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Air Quality Benefits within the Territorial Limit of Canada

In order to assess the air quality benefits that affect the area within 12nm of the Port of Vancouver, we use the daily fuel consumptions assigned to the average ship in each vessel class (see page 9) and correct for 12nm.

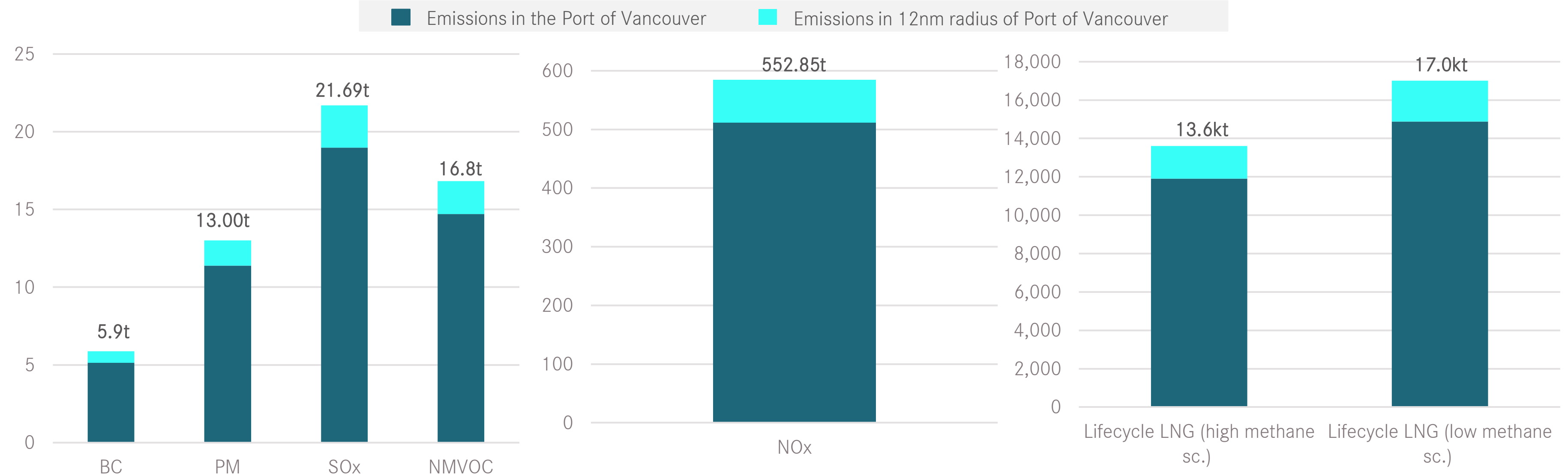
Using the known number of ships that called at the Port of Vancouver, we can estimate **the total fuel consumption from the South Gate of the Port of Vancouver to the 12nm territorial limit of Canada on a NE Pacific Route to China**. This is a ~84.5nm route. Assuming ships both arrive and leave, this figure is **~28,348 tonnes**.

We then assume the same percentage fuel-switching potential as identified previously: ~**7%**.

The result is that, on the 84.5nm route from the 12nm territorial limit to the South Gate, we estimate that **~1,983t of MGO** could be replaced with **~1,725t of LNG**. As previously, we then use the IMO, ICCT and British Columbia emissions factors to calculate the air quality benefits of this fuel-switching.

12nm Territorial Limit of Canada

Tonnes of Pollutants and Greenhouse Gases Saved Annually in the Port of Vancouver + 12nm



Data label figure reflects the total emissions saved from the journey between the 12nm territorial limit of Canada and the South Gate of the Port of Vancouver

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DNV 2030 Maritime Fuel Mix Scenario

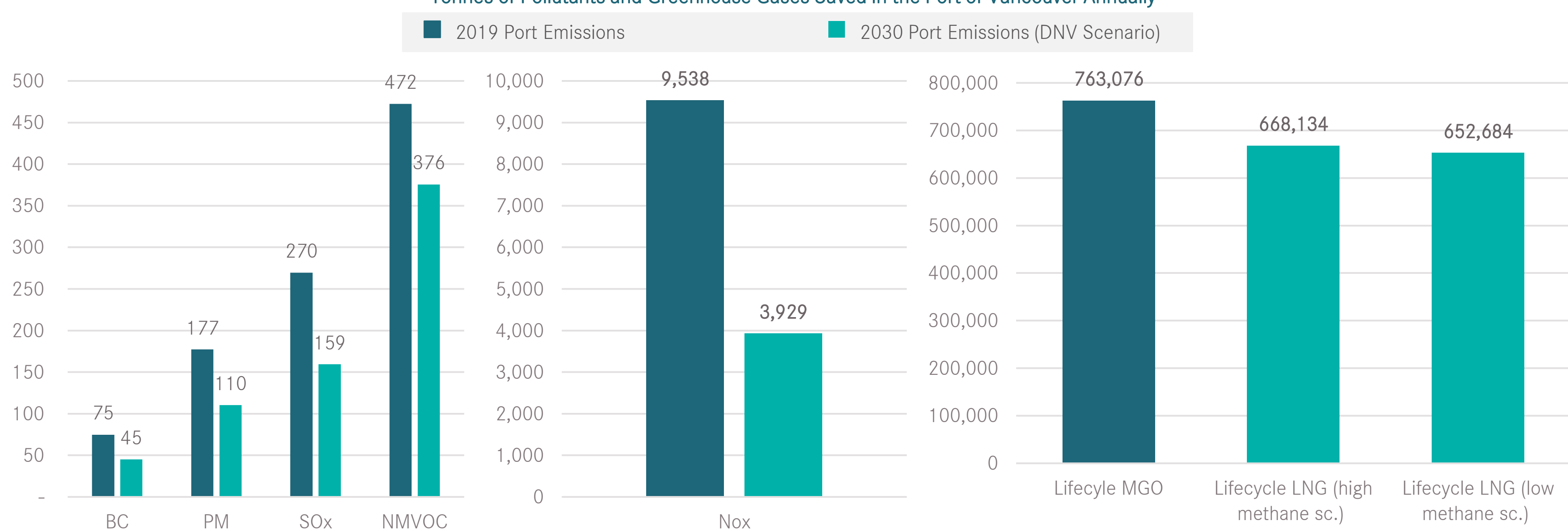
DNV's maritime fuel mix scenario for 2030 sees a sharp uptake in LNG as a marine fuel. By 2030, DNV predicts that ~37% of maritime energy demand will come from LNG, with 58% coming from oil-based fuels and 5% coming from bio-energy and electrification.

37% of maritime energy demand will require a significant roll-out of LNG-bunkering infrastructure, which FortisBC would contribute to. With LNG-bunkering available in key areas around the Pacific, the Port of Vancouver would most likely be one of the main beneficiaries of the air quality benefits associated with a large-scale switch to LNG.

The table to the right, and the graphs below, show the results from comparing 2019 Port of Vancouver emissions to the emissions associated with a DNV 2030 fuel-mix scenario.

Pollutant / Greenhouse Gas	1MMTPA LNG: Port Reductions	1 MMTPA LNG: 25-yr Period Savings
Nox	5.5%	13,045t
Black Carbon	6.9%	128t
PM	6.4%	284t
SOx	7.0%	474t
NMVOC	3.1%	368t
GHG Lifecycle (High Methane Scenario)	1.6%	297,660t
GHG Lifecycle (Low Methane Scenario)	1.9%	371,973t

Tonnes of Pollutants and Greenhouse Gases Saved in the Port of Vancouver Annually



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Results Table

Pollutant / GHG	Port 2019 Emissions	Port Emissions Savings (1MMTPA LNG)	Port Percentage Emissions Savings (1MMTPA LNG)	Port Emissions Savings (100% LNG)	Port Percentage Emissions Savings (100% LNG)	Global Emissions Savings (1MMTPA LNG)
NOx	**9,538t**	522t	5.5%	7, 278t	76%	43,295t
Black Carbon	**75t**	5.13t	6.9%	71.61t	96%	426t
PM	**177t**	11.38t	6.4%	158.68t	90%	944t
SOx	**270t**	18.97t	7.0%	264.65t	98%	1,574t
NMVOC	**472t**	14.71t	3.1%	205.15t	43%	1,220t
GHG Lifecycle (High Methane Scenario)	**763,076t**	11,909t	1.6%	166,081t	22%	987,907
GHG Lifecycle (Low Methane Scenario)	**763,076t**	14,879t	1.9%	207,544t	27%	1,234,548t

Total emission reductions in the Port of Vancouver from fuel substitution to LNG is expected to be somewhere between the High Methane Scenario and the Low Methane Scenario, based on the following scenarios:

1) The provision of 1MMTPA of LNG from FortisBC to the local bunkering market, which would be sufficient to replace 7% of the existing fuel mix used on-board ships arriving at the Port of Vancouver. Under a High Methane Scenario, this would result in a **1.7% reduction in greenhouse gas emissions** on a lifecycle assessment. Under a Low Methane Scenario, this would result in a **1.9% reduction in greenhouse gas emissions** on a lifecycle assessment. Both methane sensitivity scenarios would result in **an 5.5% reduction in nitrogen oxides**; an **6.4% reduction in particulate matter**; an **6.9% reduction in black carbon**; and a **7.0% reduction in sulphur oxides**.

2) Most ships calling at the Port of Vancouver are travelling between ports where additional LNG supply is being developed. Access to LNG in other ports is likely to increase the number of LNG-fueled ships that call to Vancouver. This would result in additional emission savings in the Port of Vancouver. Our second scenario models the complete substitution of fuel oils used on-board vessels in the Port of Vancouver with LNG, as a best-case scenario outlook for future emissions savings. Under a High Methane Scenario, this would result in a **22% reduction in greenhouse gas emissions** on a lifecycle assessment. Under a Low Methane Scenario, this would result in a **27% reduction in greenhouse gas emissions** on a lifecycle assessment. Both methane sensitivity scenarios would result in an **76% reduction in nitrogen oxides**; an **90% reduction in particulate matter**; an **96% reduction in black carbon**; and a **98% reduction in sulphur oxides**.

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Additional Sources

Emissions Factors Used

Pollutant	g/kg-MGO	g/kg-LNG	Source(s)
NOx	48.45	13.44	International Maritime Organisation 4th GHG Study
Black Carbon	0.38	0.02	International Maritime Organisation 4th GHG Study
PM	0.90	0.11	International Maritime Organisation 4th GHG Study
SOx	0.03	0.03	International Maritime Organisation 4th GHG Study
NMVOC	1.59	1.59	International Maritime Organisation 4th GHG Study
CO_2	3.87	3.25	International Maritime Organisation 4th GHG Study
CO_2e	3.87	3.55	FuelEU Maritime (European Union)
Well-to-Wake	3.87	3.30	CH4: FuelEU Maritime (European Union) ; LNG: British Columbia Government

Fuel Constants Used

LNG	*GJ/t*	50	ICCT
LNG	*M^3/t*	0.45	International Gas Union Conversion Pocketbook
MGO	*GJ/t*	42.70	ICCT
Sulphur content of LNG	*%*	0.004%	North P&I Club – LNG as a Marine Fuel
Sulphur Content of ECA-zone fuel oil	*%*	0.10%	International Maritime Organisation 4th GHG Study
IMO Sulphur equation (*S)	#	1.95506	International Maritime Organisation 4th GHG Study

Port of Vancouver – Marine-based Energy Consumption 2015

Auto	*GJ*	194,678	Port of Vancouver – 2015 Emissions Inventory Report
Breakbulk	*GJ*	589,136	
Bulk	*GJ*	4,408,349	
Container	*GJ*	1,834,290	
Cruise	*GJ*	920,150	
Other	*GJ*	416,247	
Total	*GJ*	8,362,649	
Total Less Cruises	*GJ*	7,442,700	

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