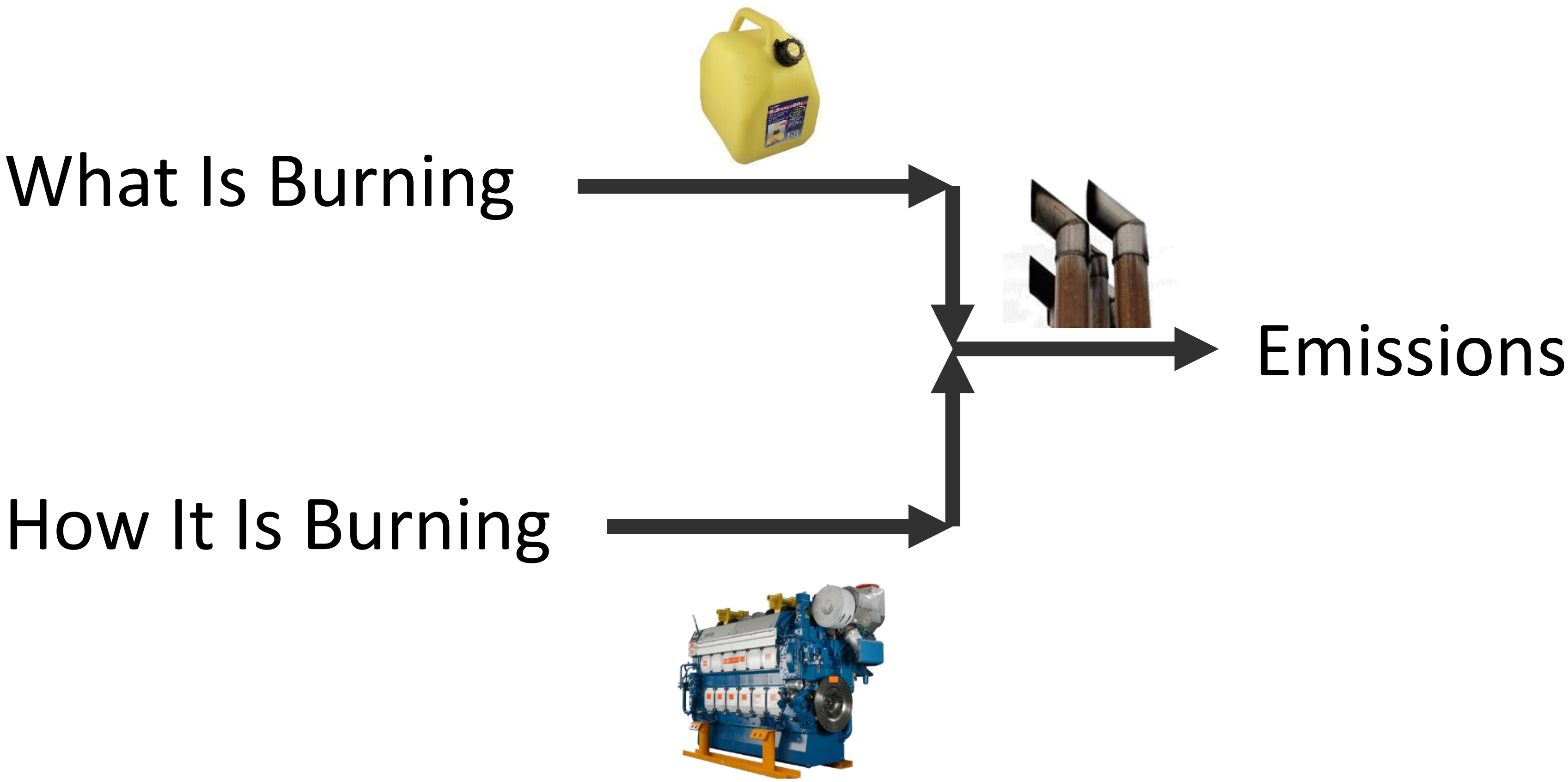

# Workshop Presentation, January 2022
## Task 3 – Environmental Tradeoffs

# Agenda

- Background information
- Types of emissions (atmospheric)
- Case studies
  - Fuel use and engine assumptions
  - Emissions modeling results to date
- Spill risk assessment

# Marine Emissions



# Marine Fuels

Heavy Fuel Oil (HFO)

Marine Distillates (MDO & MGO)

Natural Gas (LNG)

# Marine Fuels - HFO

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HFO is taken from what is left after more valuable components of stock crude oil have been extracted by some form of refining process. Often referred to as bunker or residual fuel.

Impurities:

- Ash
- Water
- Sulphur
- Vanadium
- Aluminum
- Silicon
- Sodium
- Sediment
- Asphaltenes



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# Marine Fuels – MDO/MGO

Marine distillates can be divided into two categories:

- Marine Diesel Oil (MDO)
  - Derived from crude oil by some form of a distillation (differential boiling) process
  - MDO will typically be a blend of distillates with a fractional amount of HFO
- Marine Gas Oil (MGO)
  - MGO is similar to MDO in that it is a distillate fuel, derived from crude oil by distillation. However MGO will not contain any HFO or residual fuels.

# Marine Fuels – Natural Gas



Natural gas must be either compressed (CNG) or liquefied (LNG) in order to be used as a transportation fuel due to its low energy density by volume

North American pipeline natural gas used to make either CNG or LNG has a relatively narrow range of chemical constituents and properties, making it a cleaner-burning fuel compared to oil-based fuels

# Marine Engines

# Diesel Engines



They can be categorized as slow, medium and high-speed coupled with two and four stroke designs.

Slow Speed

Medium Speed

# Natural Gas Engines



Three basic technologies are used in marine natural gas engines;

| | Lean burn spark ignition (SI) pure gas | Dual-fuel (DF) with diesel pilot | Direct injection (DI) with diesel pilot |
|---|---|---|---|
| Thermodynamic Cycle | Otto | Otto | Diesel |
| Fuel introduction | Pre-mixed in intake or port injection | Pre-mixed in intake | Direct in cylinder |
| Ignition source | Spark plug pre-chamber | Liquid fuel pilot | Liquid fuel pilot |

# Exhaust Emissions

# Exhaust Emissions - Overview



Three main types of emissions are created from the diesel combustion process depending on the fuel type used:

**$CO_2$** – Significant greenhouse gas

**$NO_X$** – Contributes to the formation of smog as well as acid rain

**$SO_X$** – Contributes to the formation acid rain

(Other emissions will be addressed on subsequent slides)

# Exhaust Emissions – $CO_2$



$CO_2$ is a greenhouse gas with a Global Warming Potential of 1.

$CO_2$ emissions are related to the carbon content of fuel and the amount of fuel consumed. Ways to reduce $CO_2$ emissions include;

- Creating more efficient engines
- Transitioning to fuels containing less carbon per unit energy
- Reducing energy demand

# Exhaust Emissions – $CH_4$ (Methane)



$CH_4$ is a greenhouse gas with a Global Warming Potential of 30.

Emitted from natural gas burning engines through a process called methane slip – a term to describe the fraction of natural gas that passes through the engine without burning.

Methane slip is more prevalent in engines operating on the Otto cycle.

# Exhaust Emissions – $SO_X$

Emitted from engines burning fuels that contain sulphur and is a direct function of the sulphur content of the fuel.

| | LNG | ULSD | MDO | RMG 180 (HFO) |
|---|---|---|---|---|
| Sulphur content (max) % m/m | 0.0 | 0.0015 | 0.1 | 3.5 |

# Exhaust Emissions – $NO_X$

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$NO_X$ is primarily a function of the combustion temperature. The higher the cylinder temperatures during combustion, the more $NO_X$ is produced.

$NO_X$ is not good for human health as it can have ill-effects on the respiratory system

| Tier | Ship Construction date on or after | Total weighted cycle emission limit (g/kWh) n = engine's rated speed (rpm) | | |
|---|---|---|---|---|
| | | n < 130 | 130 ≤ n < 2000 | n ≥ 2000 |
| Tier I | 1 January 2000 | 17.0 | $45 \times n^{-0.2}$ | 9.8 |
| Tier II | 1 January 2011 | 14.4 | $44 \times n^{-0.23}$ | 7.7 |
| Tier III | 1 January 2016* | 3.4 | $9 \times n^{-0.2}$ | 2.0 |



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# Exhaust Emissions – Particulate Matter



Particulate Matter (PM) emissions can be attributed to incomplete combustion of fuels. High cylinder temperatures and pressures can cause some of the fuel injected into a cylinder to break down rather than combust with the air in the cylinder space. This breakdown of the fuel can lead to carbon particles, sulphates and nitrate aerosols being produced.

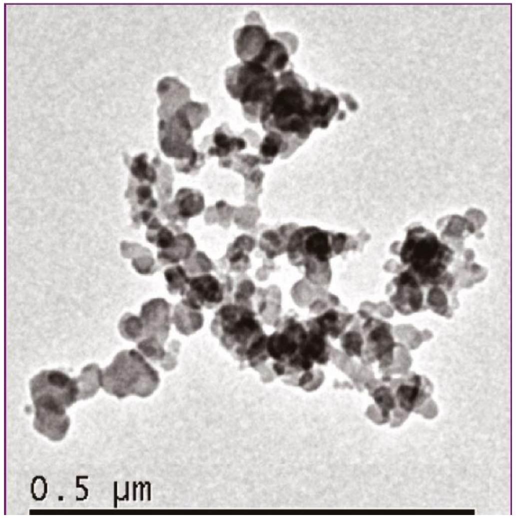
# Exhaust Emissions – Black Carbon



Black Carbon (BC) is not a greenhouse gas, however it does have a Global Warming Potential of 900.

Black Carbon (BC) by definition is a distinct type of carbonaceous material, formed primarily in flames during combustion of carbon-based fuels.

BC emitters in the Arctic are especially damaging due to the impact that BC has on glaciers and polar icecaps.



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# Exhaust Emissions – Summary

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**$CO_2$** – Significant greenhouse gas

**$NO_X$** – Contributes to the formation of smog as well as acid rain, bad for human health

**$SO_X$** – Contributes to the formation of acid rain, bad for human health

**$CH_4$** – Potent greenhouse gas (30 times more potent than $CO_2$)

**PM** – Carbon particles, sulphates and nitrate aerosols

**BC** – Especially damaging to glaciers and polar icecaps



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# Note About GWP

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- This study only focuses on **GWP100**
- As discussed yesterday, GWP100 could favor some short lived GHG's such as $CH_4$, and underestimate BC benefits, in the context of LNG engines

| | CO2-E Ratio (GWP20) | CO2-E Ratio (GWP100) |
|---|---|---|
| **CO2** | 1 | 1 |
| **CH4** | 86 | 30 |
| **BC** | 3200 | 900 |



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# Vessel Case Studies

# Vessel Case Studies – Objective

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- Seven vessel case studies were selected as a representative cross section of ships operating within or making port calls on Canada's Arctic Coast.
- The case studies were analyzed to determine the $CO_2$, $CO_2$ –E, $SO_X$, $NO_X$, $CH_4$, BC, and PM produced on an annual basis
- The results presented are intended to be generally reflective of the performance that is available from different prime mover types and ship applications



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# Vessel Case Studies – Approach



## Vessel Cases
- Particulars
  - Size
  - Engines
- Voyages **(Arctic only)**
  - Routes
  - Engine load profile
  - Fuels used
  - Fuel consumption
  - Seasonal utilization

## Data Inputs
- Fuel costs
- Equipment costs
- Engine emission
- Upstream emissions

## Task 2 - Economic
- Capital cost for each option
- Annual operating costs
- Payback period

## Task 3 - Environmental
- Upstream emissions
- Operating emissions
- Oil carriage

## Outputs (MT/year)
- $CO_2$
- $SO_X$
- $NO_X$
- Particulate Matter (PM)
- $CH_4$
- BC (Black Carbon)
- $CO_2$-eq ($CH_4$, BC, $CO_2$ & Upstream)

# Vessel Case Studies – Overview

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| No | Vessel | Power (kW) | Fuel Option 1 | Option 1 Engine | Fuel Option 2 | Option 2 Engine | Fuel Option 3 Engine (LNG only) |
|---|---|---|---|---|---|---|---|
| 1 | CCG Icebreaker | 20,000 | - | - | ULSD | Medium Speed Diesel 4 Stroke | Medium Speed Otto 4 Stroke Dual Fuel |
| 2 | General Cargo | 6,000 | - | - | MDO | Slow Speed Diesel 2 Stroke | Slow Speed Diesel 2 Stroke Dual Fuel |
| 3 | Tanker | 5,500 | - | - | MDO | Slow Speed Diesel 2 Stroke | Slow Speed Diesel 2 Stroke Dual Fuel |
| 4 | Cruise Ship | 11,200 | - | - | MDO | Medium Speed Diesel 4 Stroke | Medium Speed Otto 4 Stroke Dual Fuel |
| 5 | LNG Carrier | 8,000 | - | - | - | - | Medium Speed Otto 4 Stroke Dual Fuel |
| 6 | I/B Bulker | 22,000 | HFO | Slow Speed Diesel 2 Stroke | MDO | Slow Speed Diesel 2 Stroke | Slow Speed Diesel 2 Stroke Dual Fuel |
| 7 | Icegoing Bulker | 14,500 | HFO | Slow Speed Diesel 2 Stroke | MDO | Slow Speed Diesel 2 Stroke | Slow Speed Diesel 2 Stroke Dual Fuel |



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# Vessel Case Studies – $CO_2$

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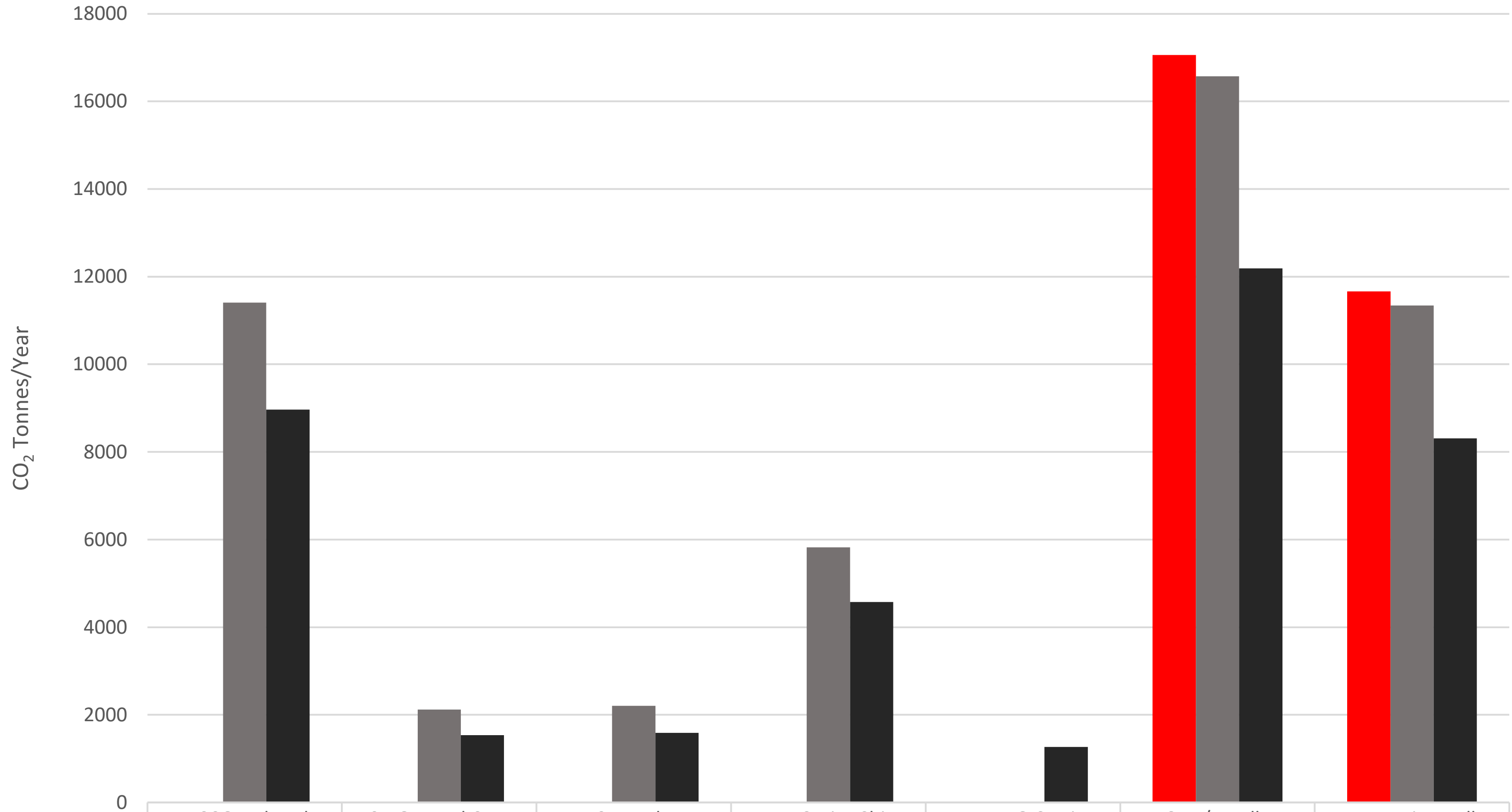


| | A1 - CCG Icebreaker | A2 - General Cargo | A3 - Tanker | A4 - Cruise Ship | A5 - LNG Carrier | A6 - I/B Bulker | A7 - Icegoing Bulker |
|---|---|---|---|---|---|---|---|
| HFO | 0 | 0 | 0 | 0 | 0 | 17060 | 11665 |
| MDO/ULSD | 11405 | 2120 | 2203 | 5820 | 0 | 16576 | 11345 |
| LNG | 8968 | 1536 | 1588 | 4576 | 1268 | 12188 | 8312 |



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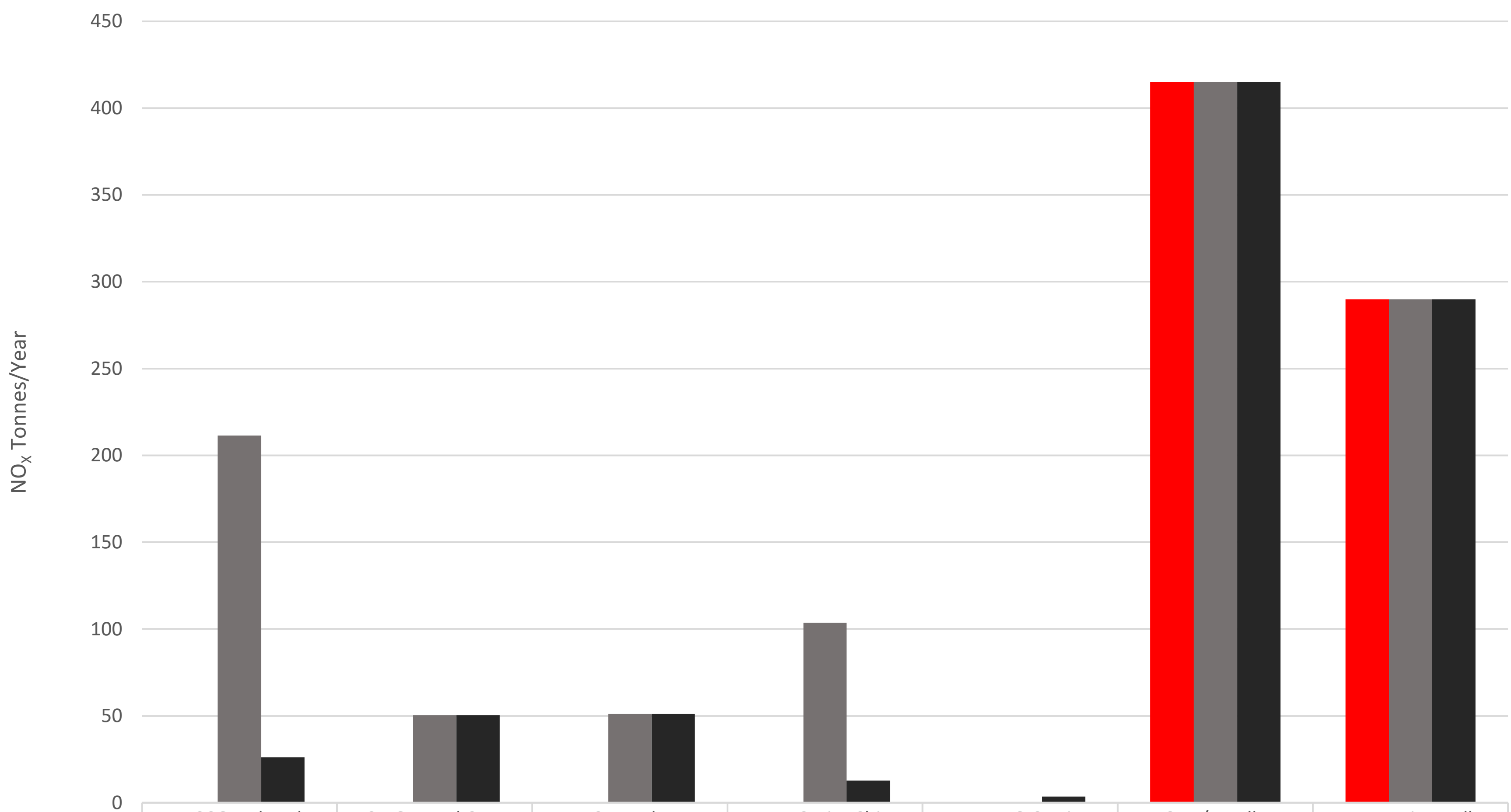
# Vessel Case Studies – $NO_X$




| | A1 - CCG Icebreaker | A2 - General Cargo | A3 - Tanker | A4 - Cruise Ship | A5 - LNG Carrier | A6 - I/B Bulker | A7 - Icegoing Bulker |
|---|---|---|---|---|---|---|---|
| HFO | 0 | 0 | 0 | 0 | 0 | 415 | 290 |
| MDO/ULSD | 212 | 50 | 51 | 104 | 0 | 415 | 290 |
| LNG | 26 | 50 | 51 | 13 | 4 | 415 | 290 |



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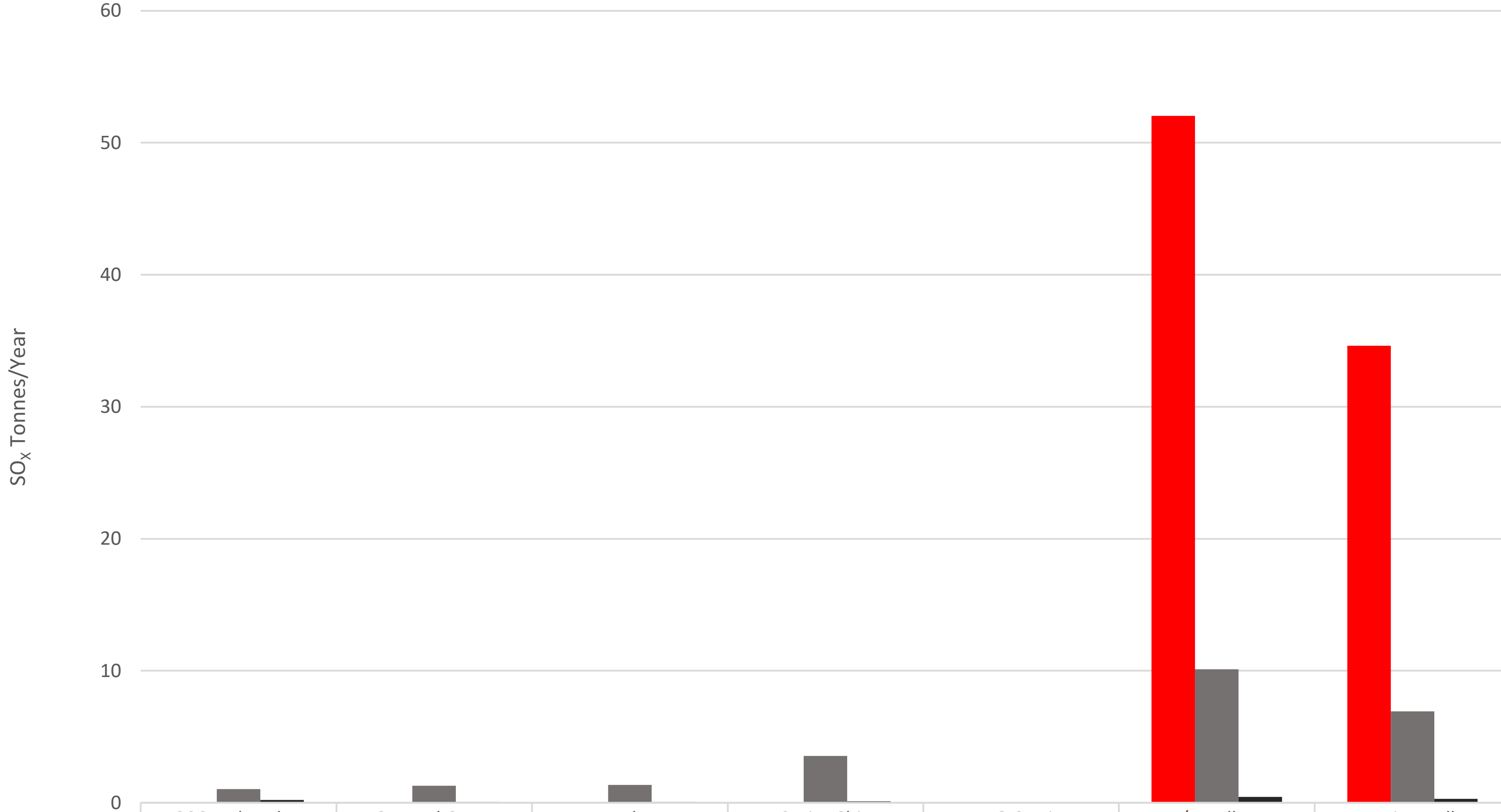
# Vessel Case Studies – $SO_X$




| | CCG Icebreaker | General Cargo | Tanker | Cruise Ship | LNG Carrier | I/B Bulker | Icegoing Bulker |
|---|---|---|---|---|---|---|---|
| HFO | 0 | 0 | 0 | 0 | 0.0 | 52.0 | 34.6 |
| MDO/ULSD | 1.043 | 1.3 | 1.3 | 3.5 | 0.0 | 10.1 | 6.9 |
| LNG | 0.202 | 0.1 | 0.1 | 0.1 | 0.0 | 0.4 | 0.3 |

# Vessel Case Studies – $CH_4$

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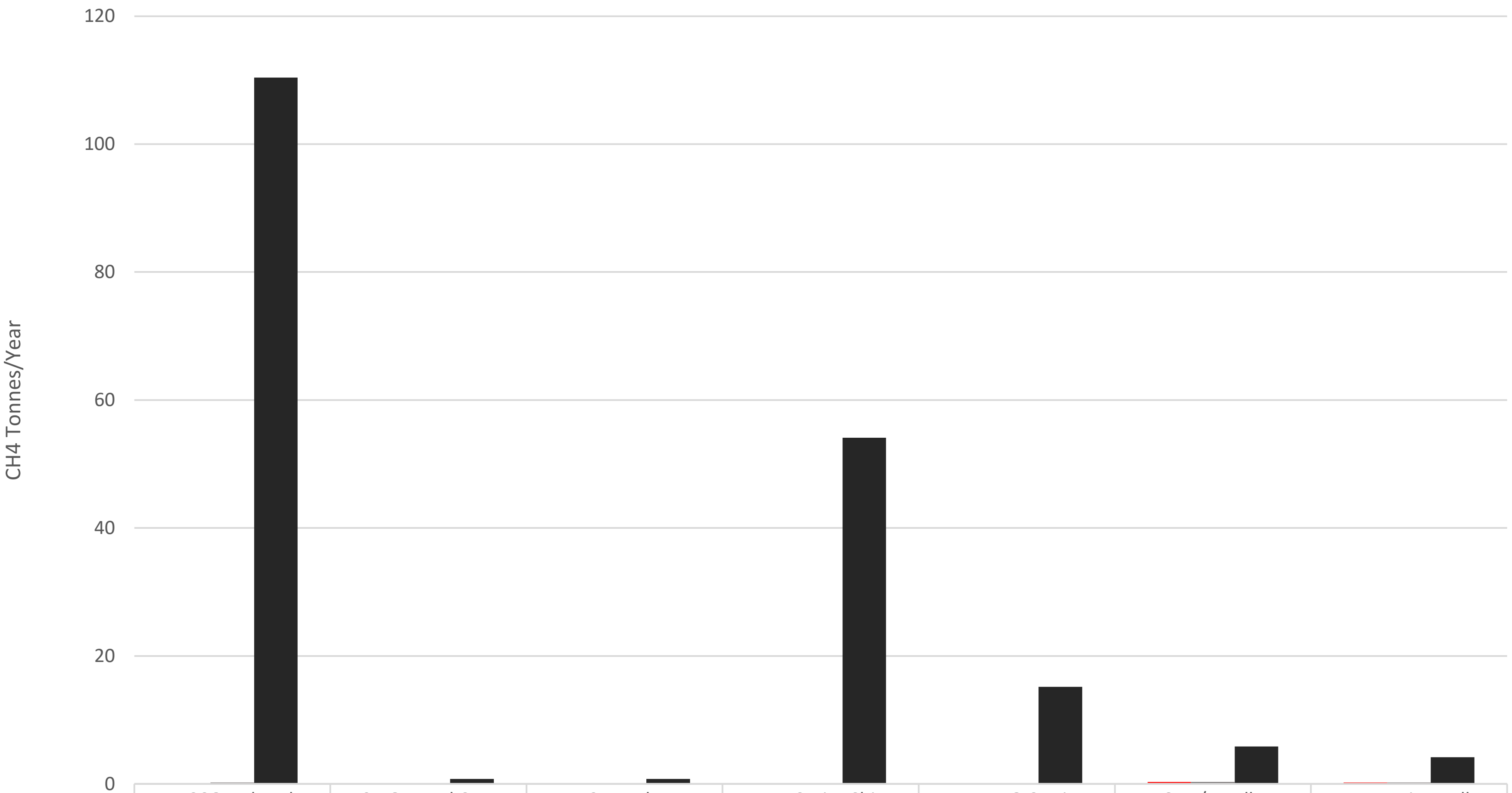


| | A1 - CCG Icebreaker | A2 - General Cargo | A3 - Tanker | A4 - Cruise Ship | A5 - LNG Carrier | A6 - I/B Bulker | A7 - Icegoing Bulker |
|---|---|---|---|---|---|---|---|
| HFO | 0 | 0 | 0 | 0 | 0.0 | 0.3 | 0.2 |
| MDO/ULSD | 0.20 | 0.0 | 0.03904 | 0.1 | 0.0 | 0.3 | 0.2 |
| LNG | 110.40 | 0.8 | 0.78082 | 54.1 | 15.2 | 5.9 | 4.1 |



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# Vessel Case Studies – PM

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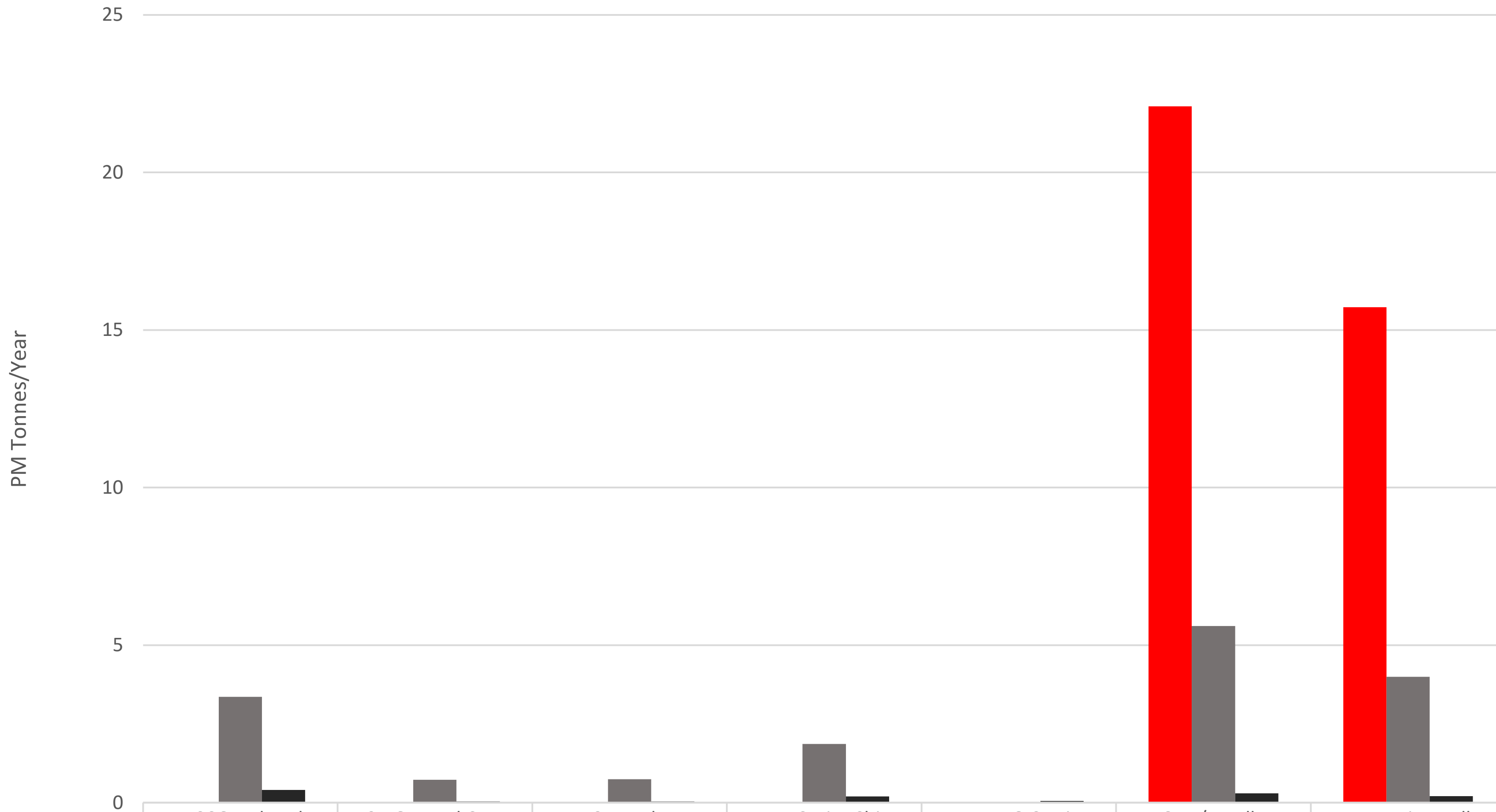


| | A1 - CCG Icebreaker | A2 - General Cargo | A3 - Tanker | A4 - Cruise Ship | A5 - LNG Carrier | A6 - I/B Bulker | A7 - Icegoing Bulker |
|---|---|---|---|---|---|---|---|
| HFO | 0 | 0 | 0 | 0 | 0.0 | 22.1 | 15.7 |
| MDO/ULSD | 3.4 | 0.7 | 0.7 | 1.9 | 0.0 | 5.6 | 4.0 |
| LNG | 0.4 | 0.0 | 0.0 | 0.2 | 0.1 | 0.3 | 0.2 |



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# Vessel Case Studies – BC

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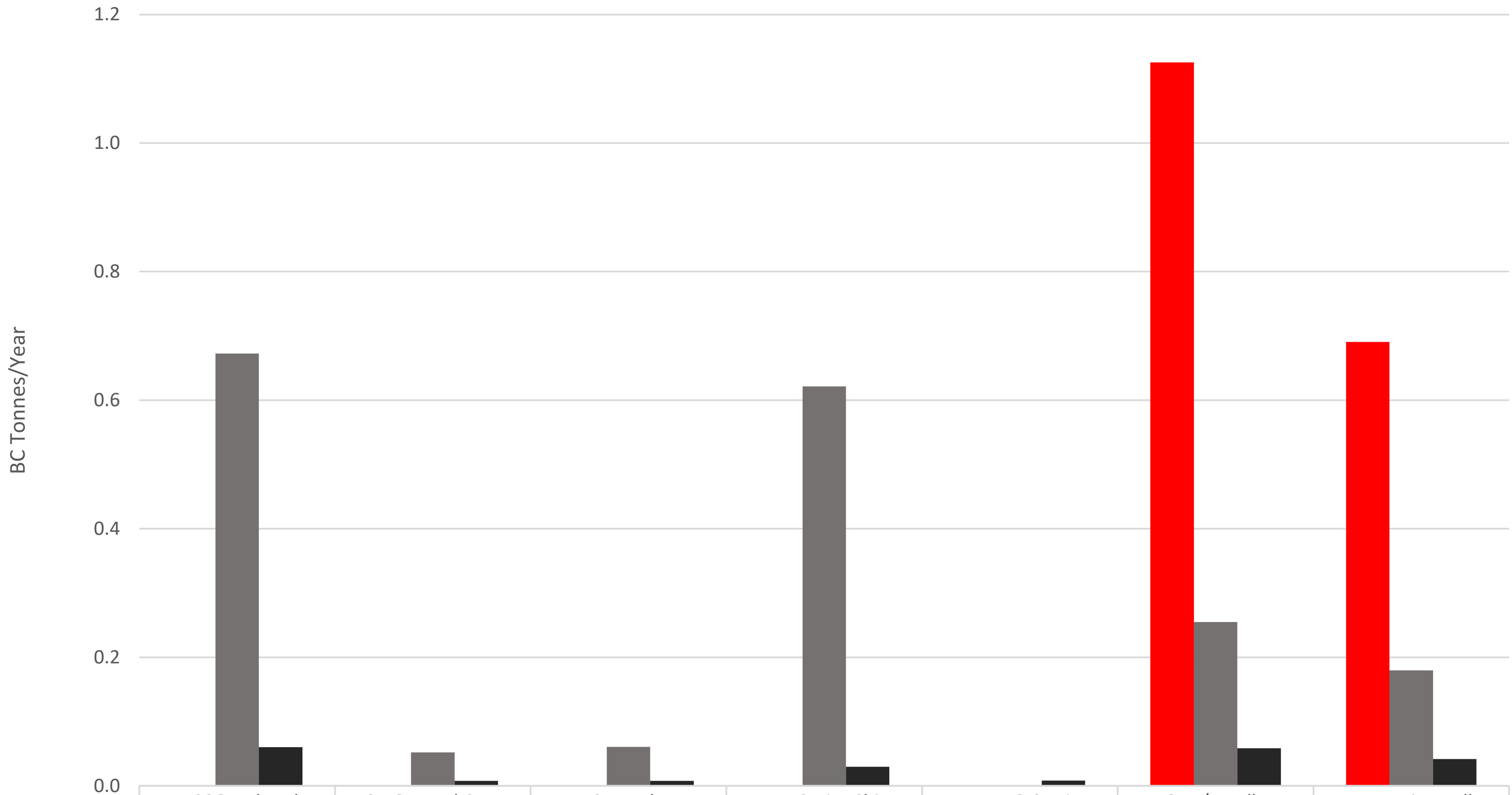


| | A1 - CCG Icebreaker | A2 - General Cargo | A3 - Tanker | A4 - Cruise Ship | A5 - LNG Carrier | A6 - I/B Bulker | A7 - Icegoing Bulker |
|---|---|---|---|---|---|---|---|
| HFO | 0 | 0 | 0 | 0 | 0.000 | 1.126 | 0.691 |
| MDO/ULSD | 0.673 | 0.052 | 0.061 | 0.621 | 0.000 | 0.255 | 0.180 |
| LNG | 0.060 | 0.008 | 0.008 | 0.030 | 0.008 | 0.059 | 0.041 |



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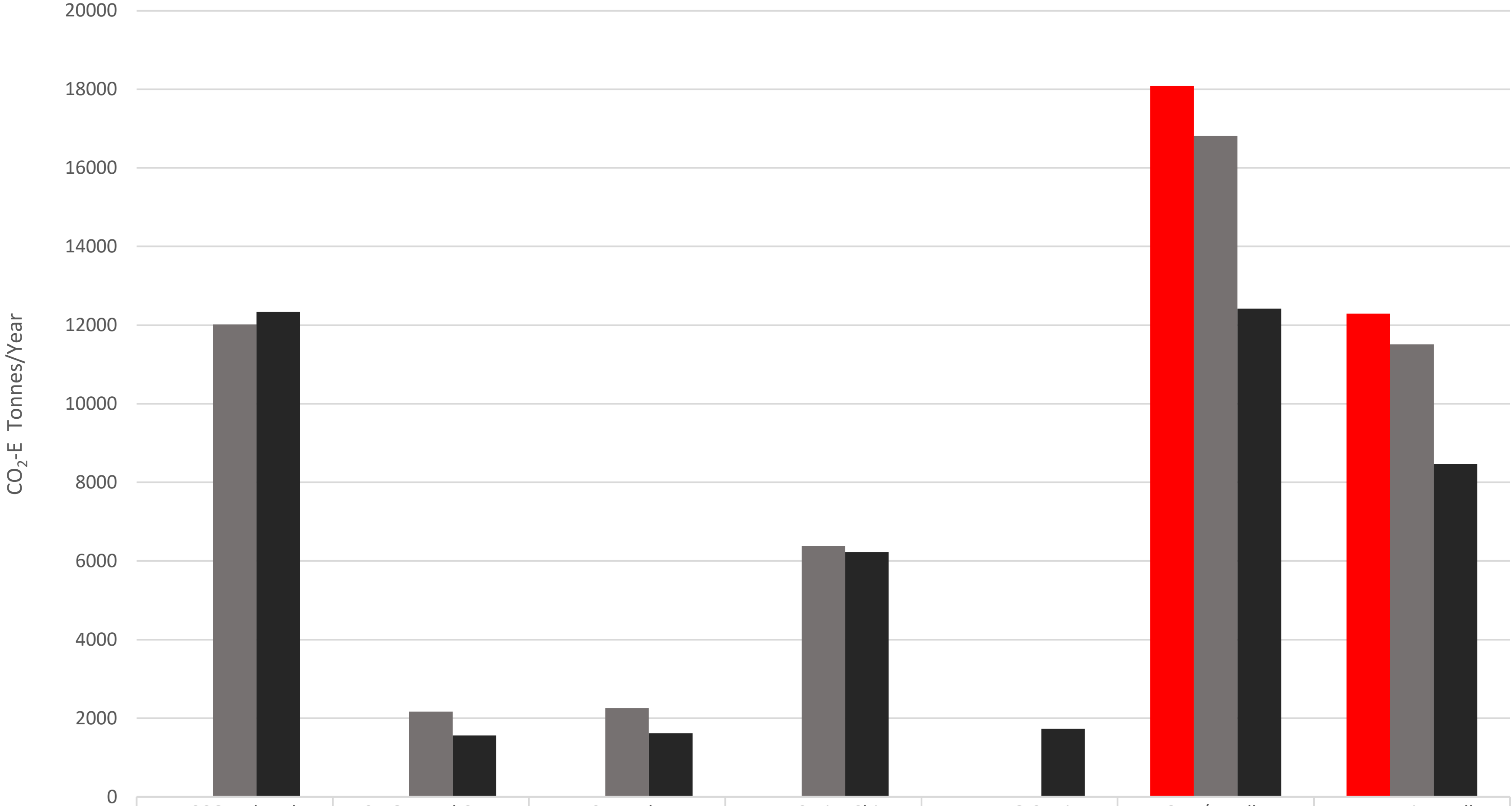
# Vessel Case Studies – $CO_2$ – Equivalent



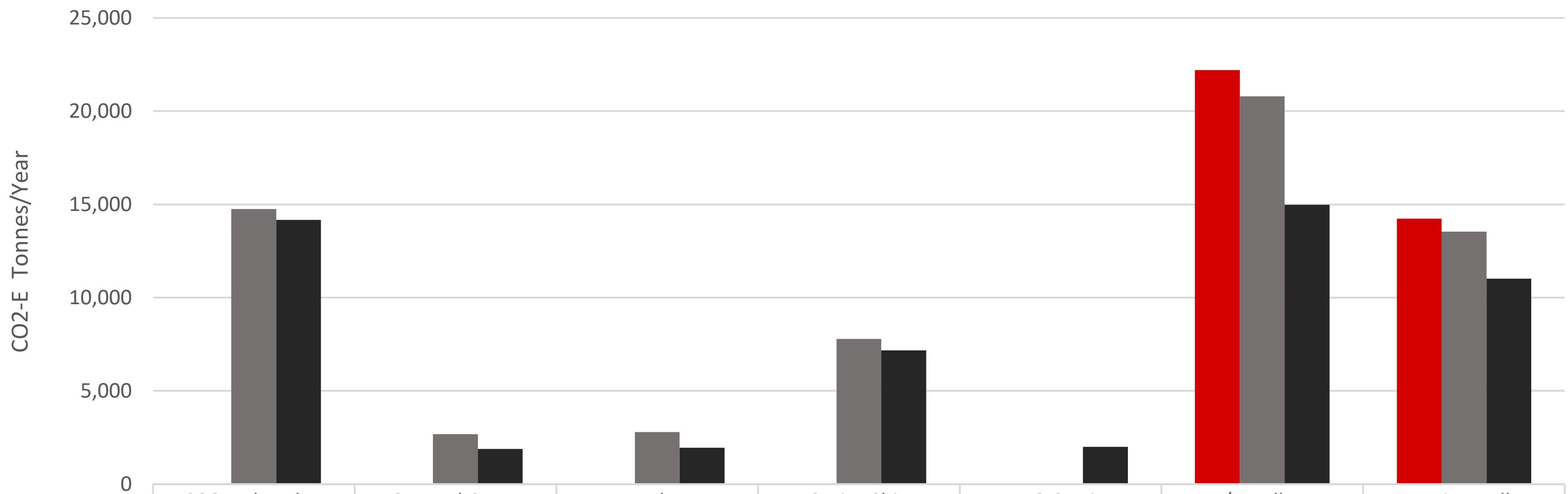



| | A1 - CCG Icebreaker | A2 - General Cargo | A3 - Tanker | A4 - Cruise Ship | A5 - LNG Carrier | A6 - I/B Bulker | A7 - Icegoing Bulker |
|---|---|---|---|---|---|---|---|
| HFO | 0 | 0 | 0 | 0 | 0 | 18082 | 12293 |
| MDO/ULSD | 12016 | 2168 | 2258 | 6382 | 0 | 16814 | 11513 |
| LNG | 12334 | 1565 | 1619 | 6226 | 1730 | 12417 | 8474 |

# Vessel Case Studies – Upstream Emissions

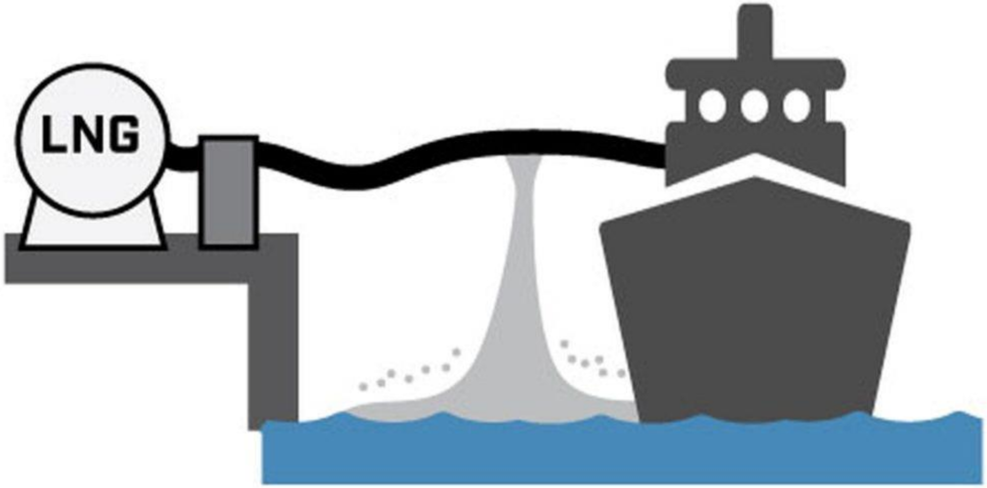


- Using the fuel production supply chain GHG emissions and total GHG produced at the ship level, the lifecycle GHG emissions can be calculated for each of the case studies




| | CCG Icebreaker | General Cargo | Tanker | Cruise Ship | LNG Carrier | I/B Bulker | Icegoing Bulker |
|---|---|---|---|---|---|---|---|
| HFO | 0 | 0 | 0 | 0 | 0 | 22,201 | 14,235 |
| MDO/ULSD | 14,754 | 2,677 | 2,787 | 7,779 | 0 | 20,794 | 13,537 |
| LNG | 14,160 | 1,888 | 1,953 | 7,180 | 1,996 | 14,982 | 11,016 |

# ACCIDENTAL POLLUTION SCENARIOS



# Accidental Pollution Scenarios - Hydrocarbons

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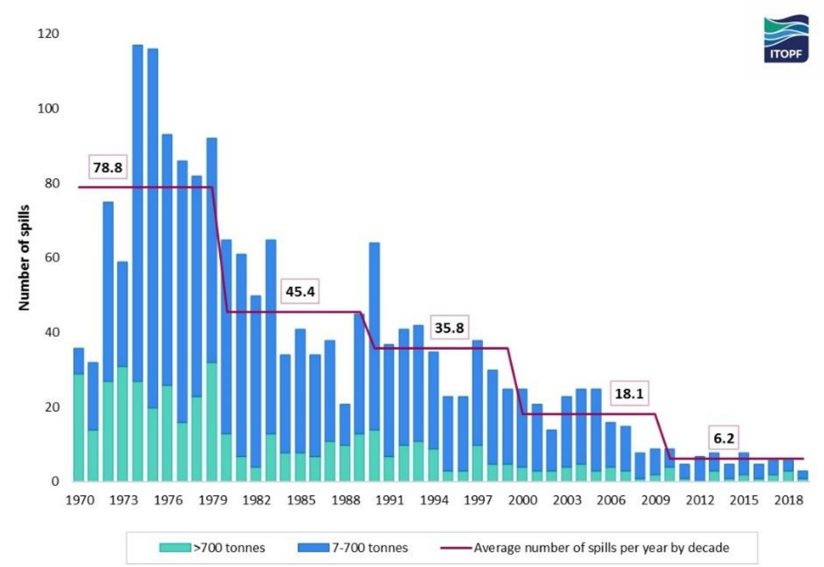
- Liquid hydrocarbons, whether fuel oils or cargoes, have always been the greatest concern for spills in all sea areas, due to their highly visible effects on the environment.
- HFOs are persistent where as distillate fuels evaporate and weather somewhat more rapidly.
- Both contain a range of toxic chemicals in addition to the hydrocarbons.



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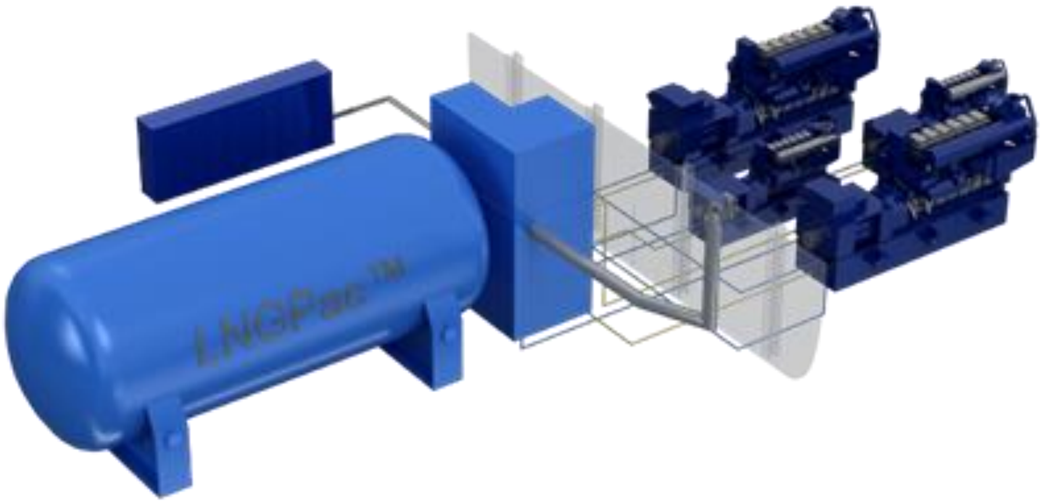
# Accidental Pollution Scenarios - LNG



- LNG is lighter than water, so in the event of a release, it will float on the surface of the water
- LNG will immediately start to vaporize after a release and disperse rapidly depending on the local wind conditions
- No clean-up effort will be required in the event of an LNG release
- If an ignition source is available, there is a risk that the natural gas at the edge of the vapour cloud could ignite and that a pool fire or an explosion could occur. The right conditions for a pool fire or explosion involve gas mixing with air in a ratio of 5-15%.

# Summary



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# Summary



- The environmental benefits of LNG can include a reduction in $CO_2$, $SO_X$, PM, BC, and $NO_X$ emissions (depending on the engine technology selected and on the source of the LNG)
- LNG engines can emit significant amounts of $CH_4$ (methane) if not managed correctly, which needs to be weighed against the environmental benefits of LNG
- LNG spills and other accidental releases of LNG are highly undesirable and do represent a safety risk, however from an environmental standpoint they are far more benign than either HFO or diesel oil spills


# Workshop Presentation, January 2022
# Task 4 – Infrastructure

# Agenda

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- Case study approach
- Inputs and results for two case studies
  - Montreal to Iqaluit
  - Tuktoyaktuk to Cambridge Bay



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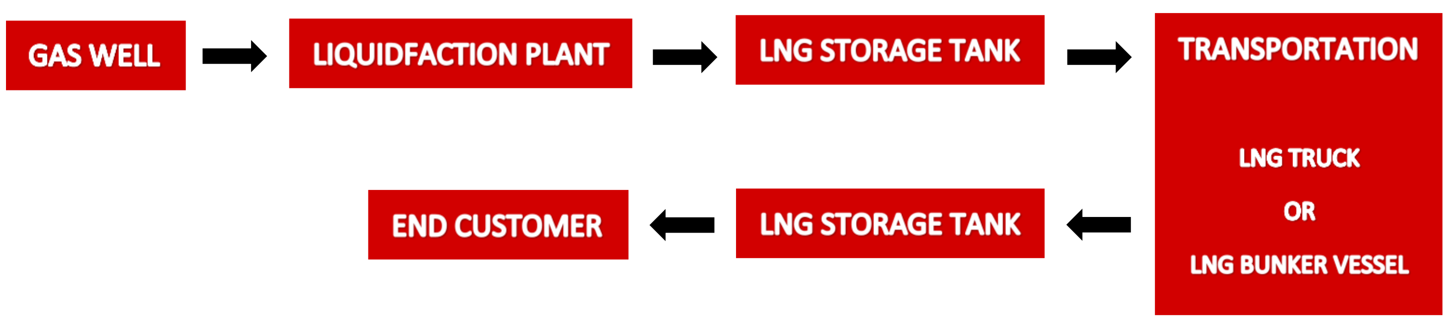
# Supply Chain



Currently the Canadian Arctic has a small and localized LNG supply chain in the West, and no supply chain in the East. This existing supply chain does not currently have the capacity to supply LNG as a marine fuel. As demand increases there will be a need to add new capacity to one or more elements of the chain, potentially including gas supply, liquefaction, distribution and storage.

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# Goal

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1. Define each section of the supply chain
2. Model the cost ($/GJ) at each step of the supply chain
3. Sum all costs together to determine the total cost of the supply chain

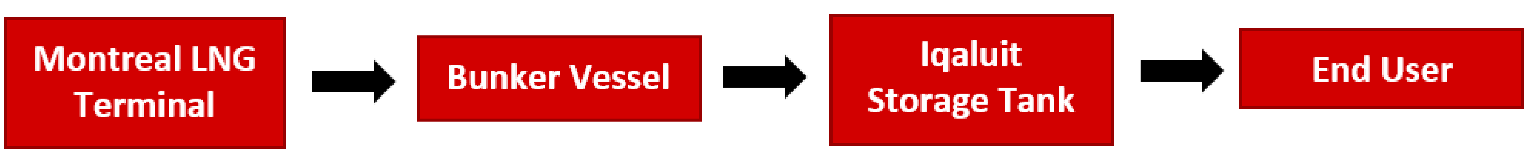
# Case Study 1 - Introduction



Iqaluit installs a 30,000 m3 LNG storage facility to offset the amount of diesel used by the town.

This storage facility can either supply ships with LNG via shore to ship bunkering during the summer months or provide natural gas to local residents throughout the year.

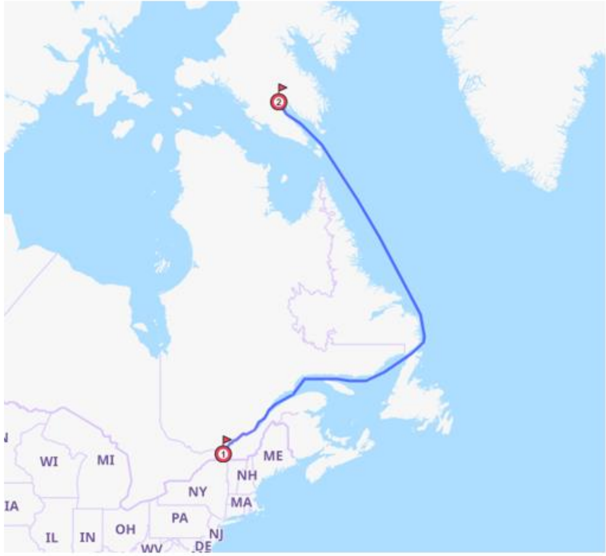
A 10,000 m3 ice class LNG bunkering vessel is built to deliver LNG to Iqaluit during the summer months (3) with 100% utilization.



# Case Study 1 - Inputs


| | |
|---|---|
| Type | LNG Carrier |
| Overall Length (m) | - |
| Beam (m) | - |
| Draft (m) | - |
| Gross Tonnage | 5,000 |
| Deadweight (t) | 4,000 |
| Speed (kts) | 13 |
| Power (kW) | 4,000 |

| Category | Value | Units |
|---|---|---|
| **LNG Storage Tank** | | |
| Capex | $50,000,000 | $ |
| Labor, Material and Other | 2% | %CAPEX/year |
| Lifespan | 20 | years |
| **Bunker Vessel** | | |
| Capex - Bunker Vessel | $100,000,000 | $ |
| Maintenance - Bunker Vessel | 3% | %CAPEX/year |
| Salvage Value - Bunker Vessel | 0 | $ |
| Estimated Life - Bunker Vessel | 20 | years |
| Annual Insurance | $100,000 | $/year |
| Fleet Overhead | $375,000 | $/year |
| Crew - Bunker Vessel | 24 | # |
| Feedstock LNG Price | $10.35 | $/GJ |



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# Case Study 1 - Results

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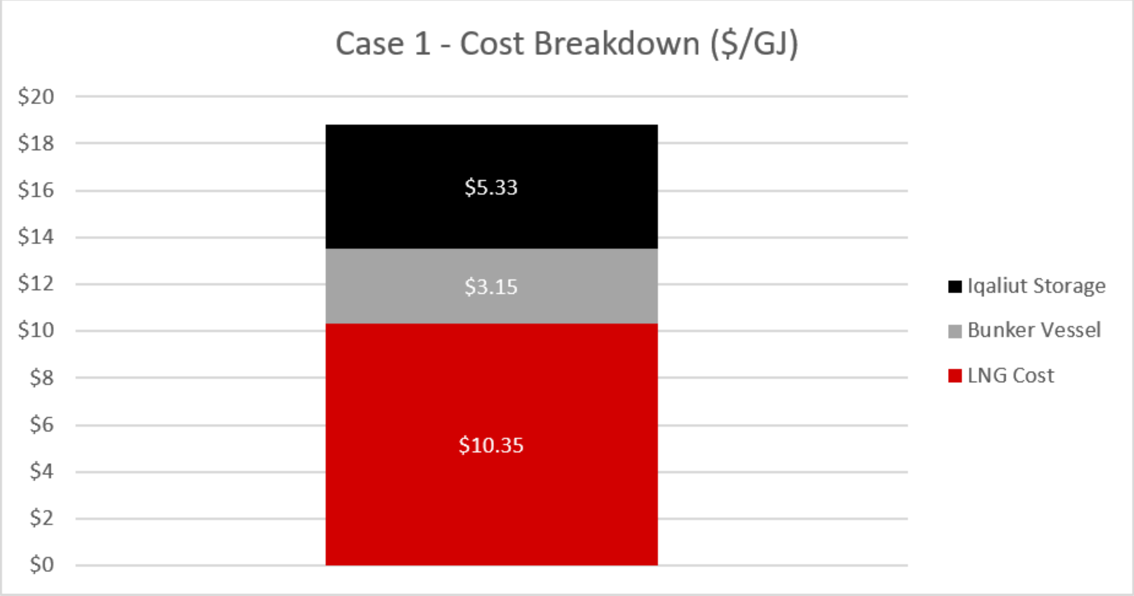
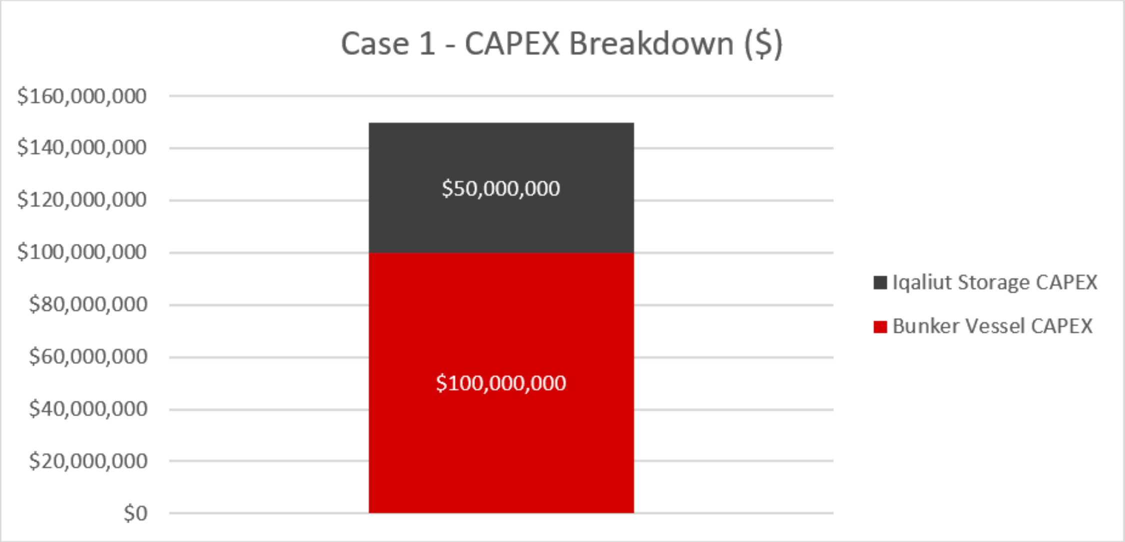



~$0.69 Diesel Liter Equivalent



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# Case Study 2 - Introduction

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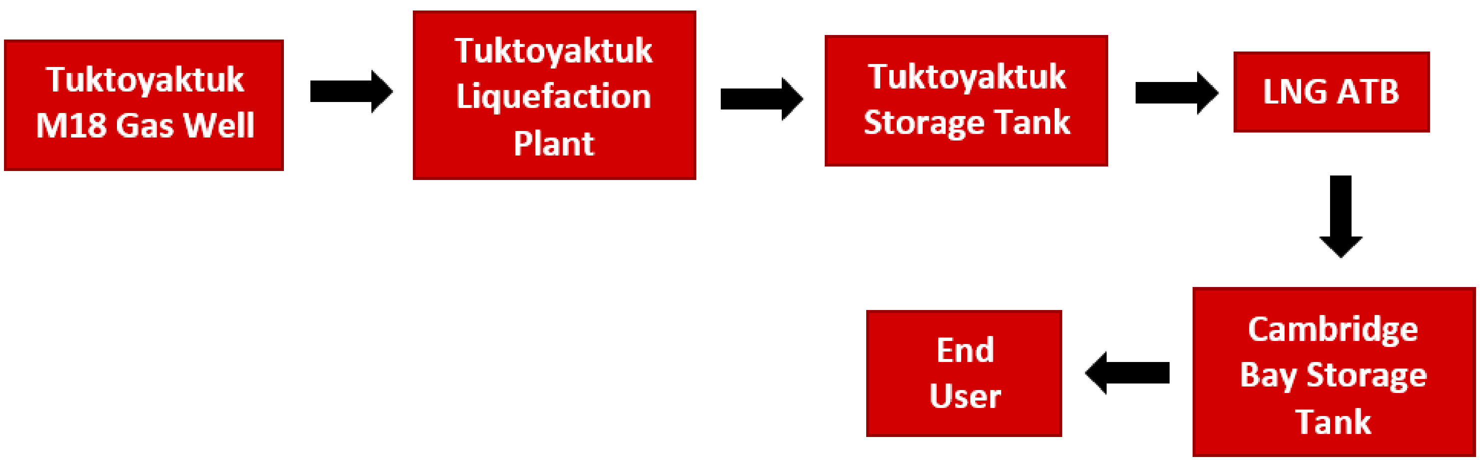
Tuktoyaktuk has installed an LNG liquefaction plant and storage tank for the M-18 natural gas well.

Located at Cambridge Bay is a 10,000 m3 LNG storage tank used to either supply ships with LNG via shore to ship bunkering during the summer months or provide natural gas to local residents throughout the year.

A 5,000 m3 LNG Articulated Tug Barge (ATB) is built to supply Cambridge Bay with LNG from Tuktoyaktuk.

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# Case Study 2 - Inputs

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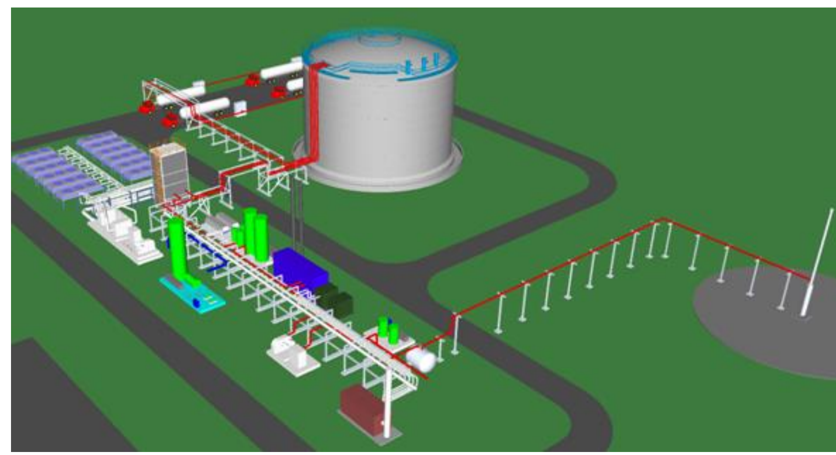
| Category | Value | Units |
| --- | --- | --- |
| **Small Scale LNG Plant** | | |
| Capex | $46,000,000 | $ |
| Labor, Maintenance and Other | 3% | %CAPEX/year |
| Lifespan | 20 | years |
| **LNG Storage Tank - Tuktoyaktuk** | | |
| Capex | $26,000,000 | $ |
| Labor, Material and Other | 2% | %CAPEX/year |
| Lifespan | 20 | years |
| **Bunker Barge** | | |
| Capex | $60,000,000 | $ |
| Maintenance | 3% | %CAPEX/year |
| Salvage Value | 0 | $ |
| Estimated Life | 20 | years |
| Annual Insurance | $50,000 | $/year |
| Fleet Overhead | $200,000 | $/year |
| Crew (Bunker Barge Only) | 2 | # |
| Tug Rental Rate | $25,000 | $/day |
| **LNG Storage Tank - Cambridge Bay** | | |
| Capex | $31,000,000 | $ |
| Labor, Material and Other | 2% | %CAPEX/year |
| Lifespan | 20 | years |


| | |
| --- | --- |
| Type | LNG ATB |
| Overall Length (m) | - |
| Beam (m) | - |
| Draft (m) | - |
| Gross Tonnage | 2,500 |
| Deadweight (t) | 2,000 |
| Speed (kts) | 6 |
| Power (kW) | Tug |





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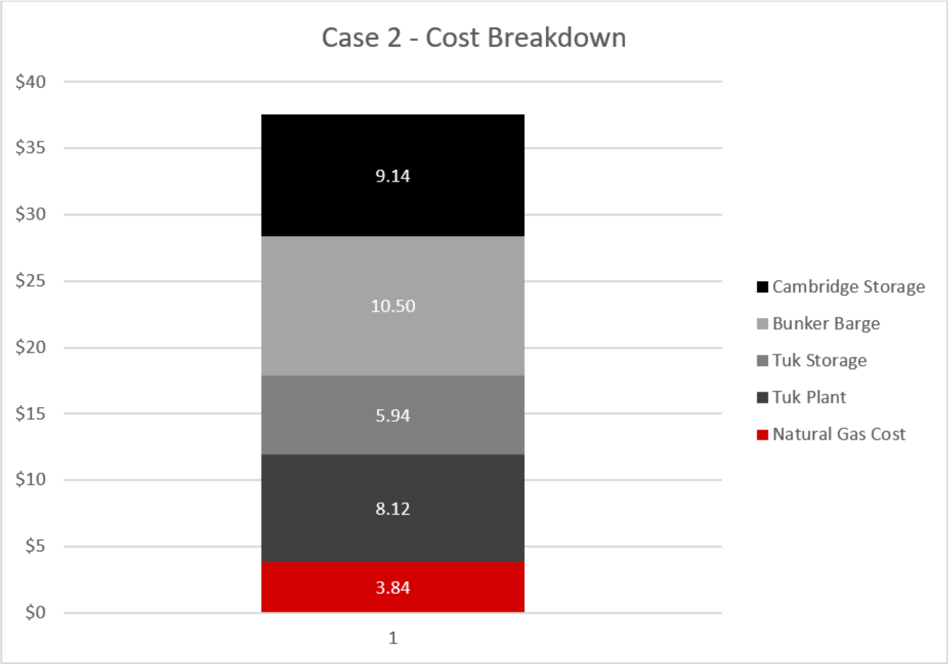
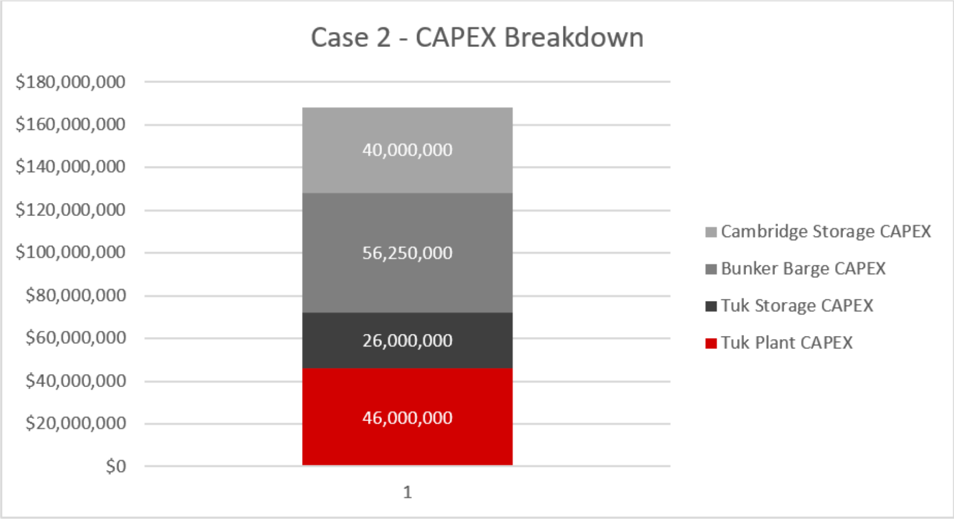
# Case Study 2 - Results




~$1.39 Diesel Liter Equivalent



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# Summary

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- An arctic LNG supply chain can look quite different from location to location
- The end user cost of LNG is quite variable depending on the complexity of the supply chain
- Case Study 2 could be used as an example of energy independence given that the whole supply chain is in the Arctic

High Level Estimates

LNG @ Iqaluit = $0.69 DLE

LNG @ Cambridge Bay = $1.39 DLE



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