SNAME MARITIME 2022 CONVENTION
26-29 September | Houston, TX

Arctic LNG

Environmental Trade-offs & Supply Chain Infrastructure

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Introduction

With Arctic marine shipping expected to increase in the coming years, many stakeholders are interested in the impact that this will have on the environment. Additionally what options there are to reduce the impact this increased marine traffic will have on the environment.

Since Natural Gas (NG/LNG) is the cleanest burning fossil fuel there is significant interest in exploring its feasibility as a marine fuel in the Canadian Arctic.

Agenda

- **Project background**
- **Environmental**
    - **Emissions**
        - Emission types, engine technologies and fuel types
        - Arctic vessel case studies
        - Emissions modeling results
    - **Spill risk**
- **Economics & Supply Chain**
- **Conclusions**

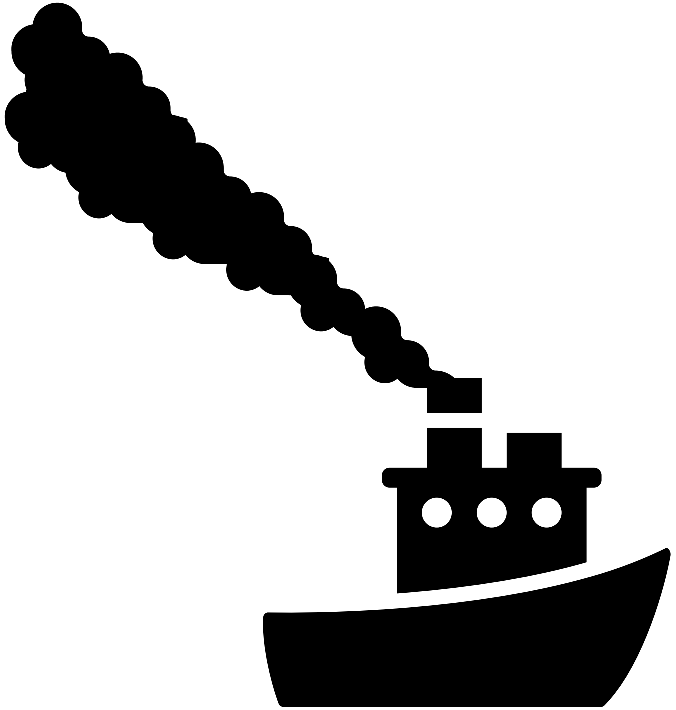
Project Background

The parent project for this presentation studied 8 areas pertaining to LNG as a marine fuel in the Arctic;

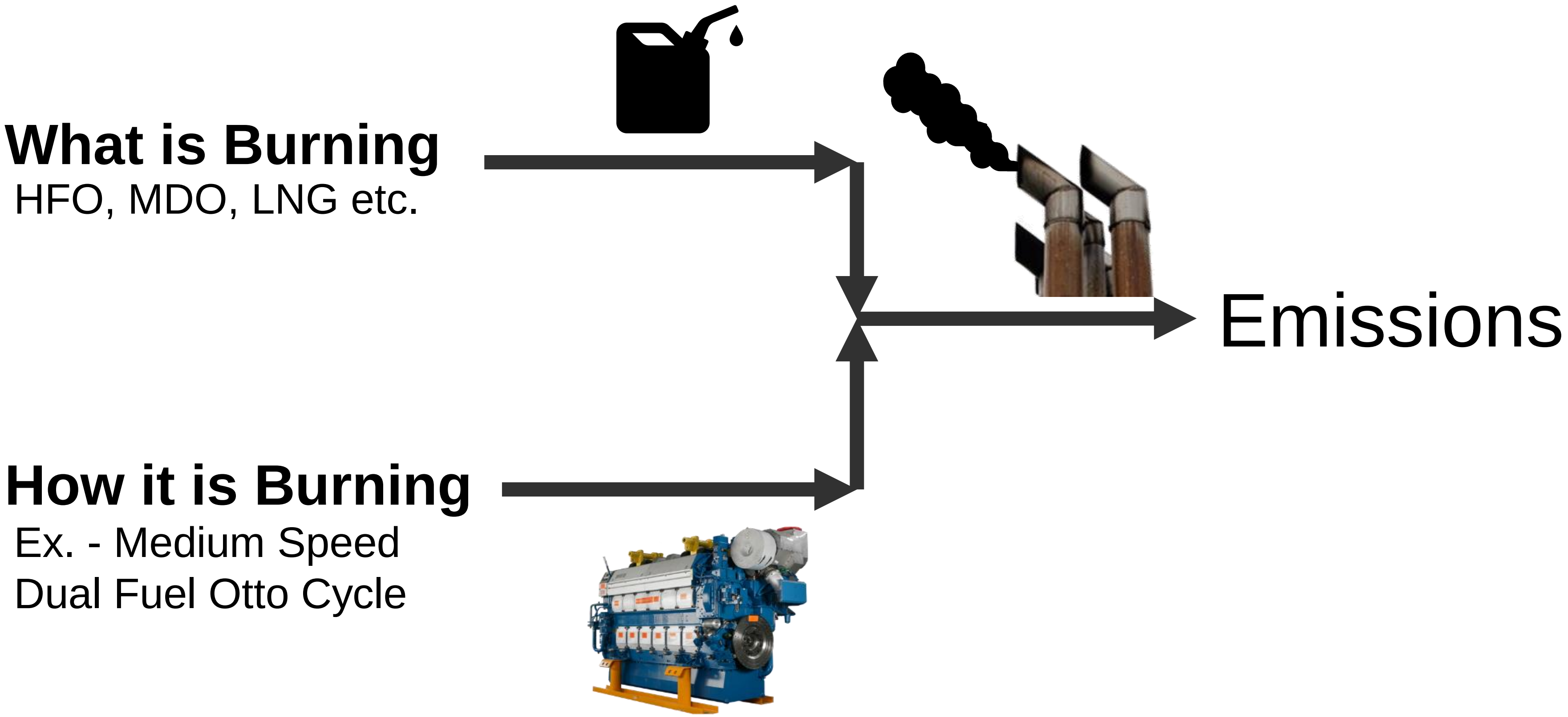
- Technology Readiness
- Economics
- Environmental trade-offs
- Infrastructure
- Human Resources
- Regulations
- Implementation Scenarios
- Benefits to Canadian Arctic

DISCUSSION TODAY

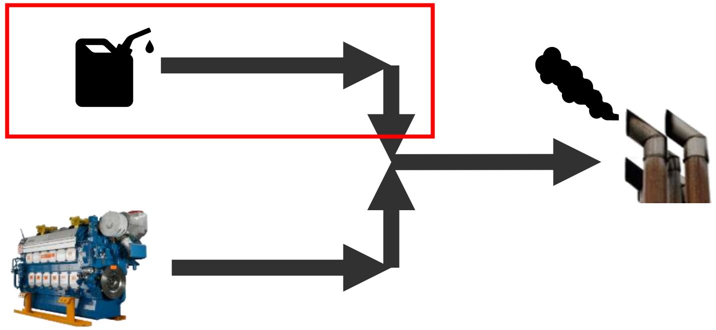
EMISSIONS



Engine Emissions – The Basics



Marine Fuels



Heavy Fuel Oil (HFO)

Marine Distillates (MDO & MGO)

Natural Gas (LNG)

Marine Fuels - HFO

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

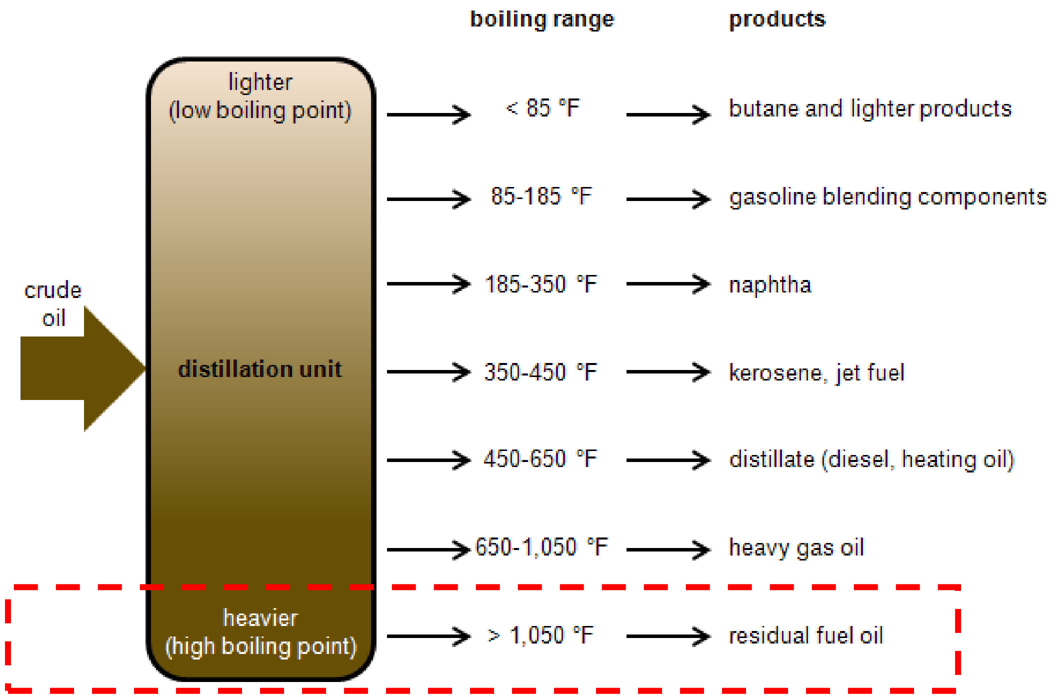
Aluminum

Silicon

Sodium

Sediment

Asphaltenes



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)

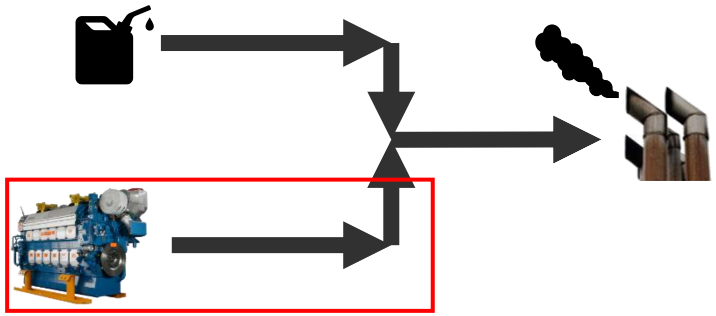
- MGO is similar to MDO in that it is a distillate fuel, derived from crude oil by distillation. However MGO will not contain any HFO or residual fuels.

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



Fuel Oil Engines

They can be categorized as slow, medium and high-speed coupled with two and four stroke designs. Most of these engines will operate on the diesel cycle.

Slow Speed

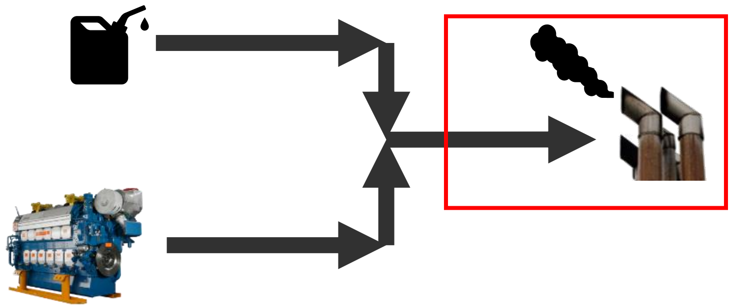
Medium Speed

Natural Gas Engines

Three technologies are typically 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 - Regulated

Three types of internationally regulated marine exhaust emissions:

- **CO_2** – Significant greenhouse gas (Ex. - IMO EEDI)
- **NO_X** – Contributes to the formation of smog as well as acid rain (Ex. -Tier I/II/III)
- **SO_X** – Contributes to the formation acid rain (Ex. – Sulphur Limits)

Somewhat regulated by function of SO_X & NO_X;

- **Particulate Matter (PM)** – Harmful to humans

Exhaust Emissions - Unregulated

There are two additional types of exhaust emissions that are of particular interest when reviewing LNG applications in the Arctic:

- **Black Carbon (Black Carbon)** – Damaging to polar icecaps
- **Methane (CH_4)** – Very potent greenhouse gas from methane slip in LNG fueled engines

Both of these are considered Short Lived Climate Pollutants (SLCPs) which remain in the atmosphere for a shorter duration than CO_2.

Exhaust Emissions – Methane

Emitted from all natural gas burning engines through a process called methane slip.

Methane is a greenhouse gas;

GWP = 30 on a 100 year timescale

GWP = 84 on a 20 year timescale

Global Warming Potential (GWP) = is a measure of how much energy the emissions of 1 ton of a gas will absorb over a given period of time, relative to the emissions of 1 ton of carbon dioxide (CO_2)

A higher fraction of methane slips in engines operating on the Otto cycle and in engines operating at lower loads.

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DIESEL

LOW METHANE SLIP

OTTO

HIGH METHANE SLIP

Exhaust Emissions – Black Carbon

- Black Carbon is a type of particulate matter and is damaging to human health and the environment. (lung/heart disease)
- Black Carbon emitters in the Arctic are especially damaging due to the impact that Black Carbon has on glaciers and polar icecaps.
- The effects of Black Carbon are still not completely characterized both within the lower latitudes and the Arctic.

Properties:

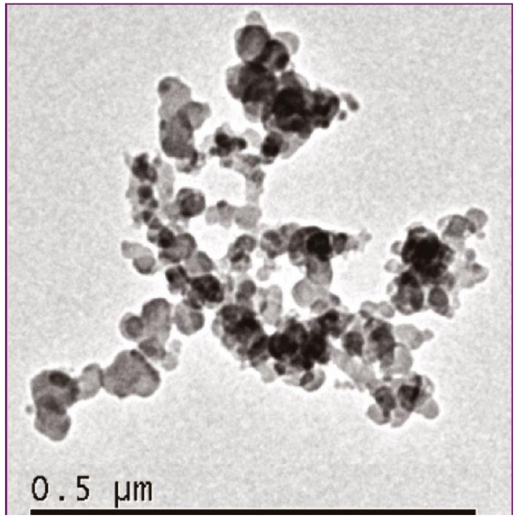
Strongly absorbs physical light

Vaporization temperature near 4000k

Exists as small aggregate spheres

Insoluble in water and other organic solvents

100 year GWP for Black Carbon is 900



Exhaust Emissions – Black Carbon

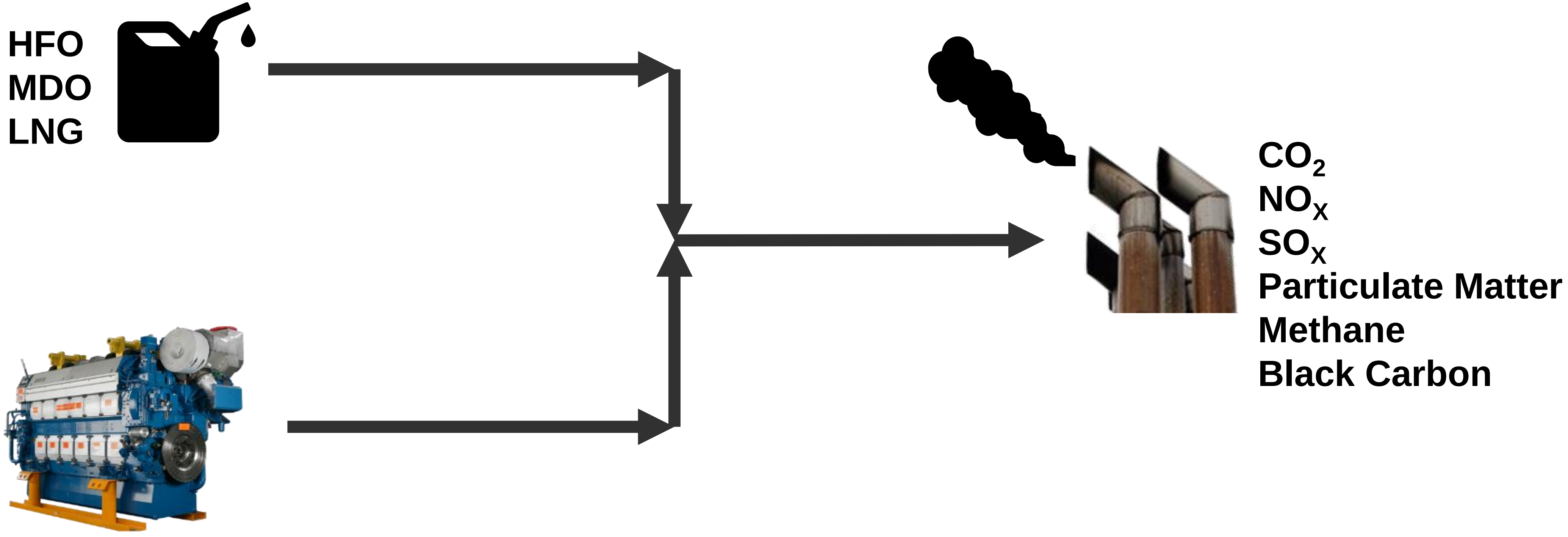
- Black Carbon is **not** a greenhouse gas, however it does have a Global Warming Potential (GWP);

  GWP = 900 on a 100 year timescale

  GWP = 3200 on a 20 year timescale

- Black Carbon warms the atmosphere by absorbing large amounts of solar radiation.
- When Black Carbon lands on an icecap, it melts ice caps by absorbing large amounts of solar radiation. (Note that water is a worse solar reflector than ice.)
- It is estimated that Black Carbon emitted within the Arctic warms arctic surface temperatures **five times more** than more midlatitudes.

Quick Recap



Fuel Oil - Diesel
LNG – Dual Fuel Otto Cycle Engines
LNG – Direct Injection Diesel Engines

Vessel Case Studies

Vessel Case Studies – Objective

- Seven vessel case studies were selected as a representative cross section of ships operating within or making port calls on Canada's Arctic Coast.

  Vessel types not well suited to being LNG fueled in the Arctic were not considered. (ex. Tugs or Fishing Vessels)

- The case studies were analyzed to determine the CO_2, CO_2 –E, SO_X, NO_X, CH_4, Black Carbon, and PM produced on an annual basis when operating within the Arctic.

- The results presented are intended to be generally reflective of the performance that is available from different prime mover types, ship applications and fuel choices.

Vessel Case Studies – Approach

Basis for emissions modeling is the Fourth IMO GHG 2020 Study bottom-up 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

Economic

- Capital cost for each option
- Annual operating costs
- Payback period

Environmental

- Upstream emissions
- Operating emissions
- Oil carriage

Outputs (MT/year)

- CO_2
- SO_X
- NO_X
- Particulate Matter (PM)
- CH_4
- Black Carbon (Black Carbon)
- CO_2-eq (CH_4, Black Carbon, CO_2 & Upstream)

Case 2 – General Cargo (example)

Define Vessel →

Type	General Cargo
Overall Length (m)	140.00
Beam (m)	21.00
Draft (m)	8.00
Gross Tonnage	10,000
Deadweight (t)	15,000
Speed (kts)	15
Power (kW)	6,000

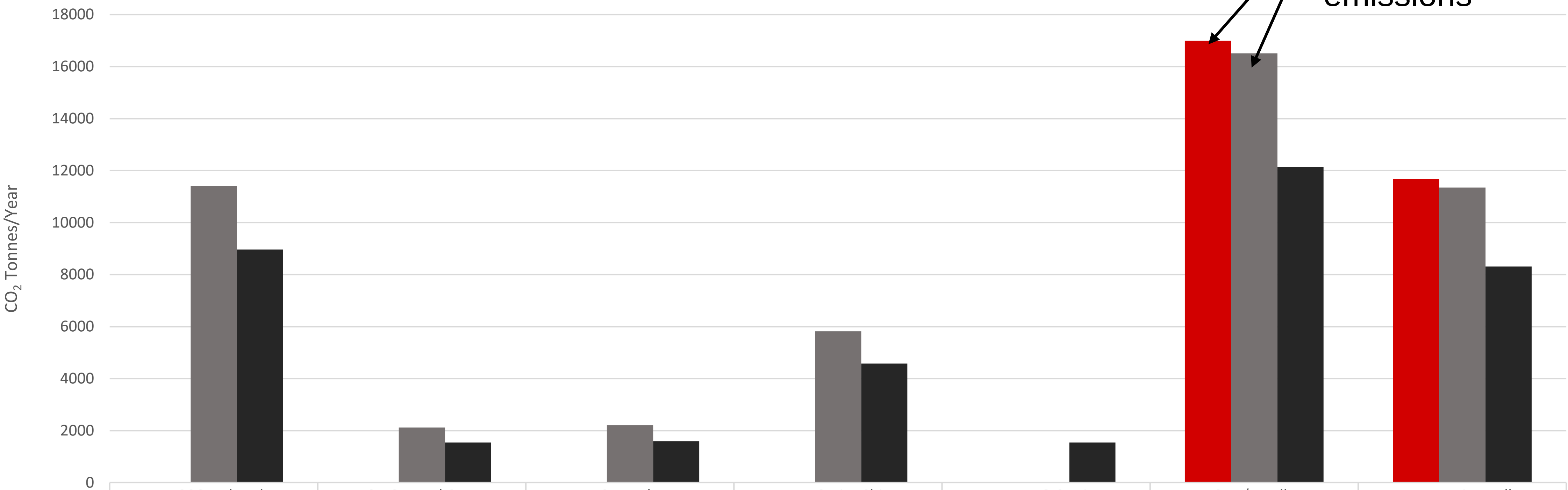
Define Route →

Vessel Case Studies – Overview

	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

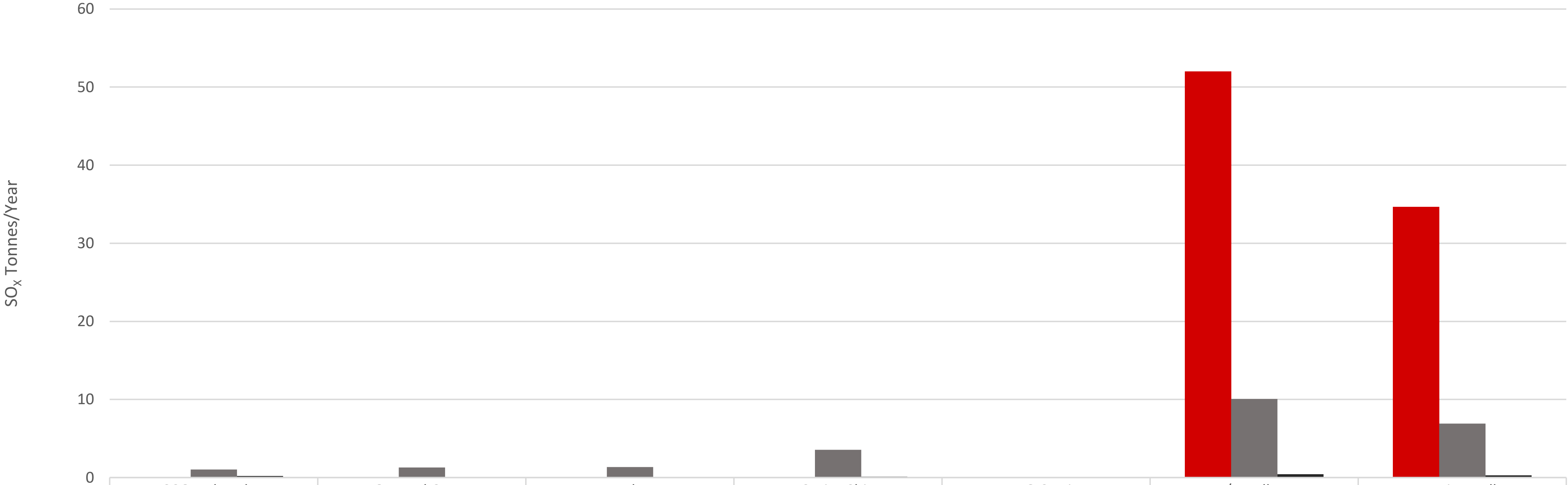
Vessel Case Studies – CO_2

HFO & MDO have similar CO_2 emissions



	A1 - CCG Icebreaker	A2 - General Cargo	A3 - Tanker	A4 - Cruise Ship	A5 - LNG Carrier	A6 - I/B Bulker	A7 - Icegoing Bulker
HFO						16994	11665
MDO/ULSD	11405	2120	2203	5820		16509	11345
LNG	8968	1536	1588	4576	1537	12144	8312

Vessel Case Studies – SO_X

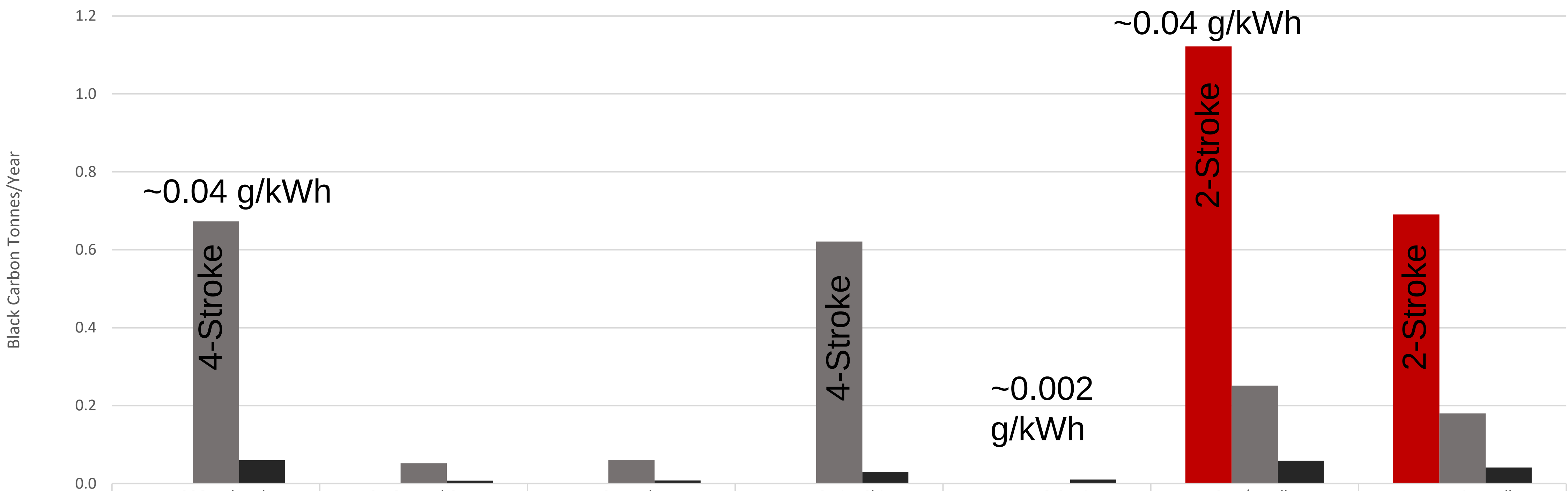


	CCG Icebreaker	General Cargo	Tanker	Cruise Ship	LNG Carrier	I/B Bulker	Icegoing Bulker
HFO						52.0	34.6
MDO/ULSD	1.043	1.3	1.3	3.5		10.1	6.9
LNG	0.202	0.1	0.1	0.1	0.030	0.4	0.3



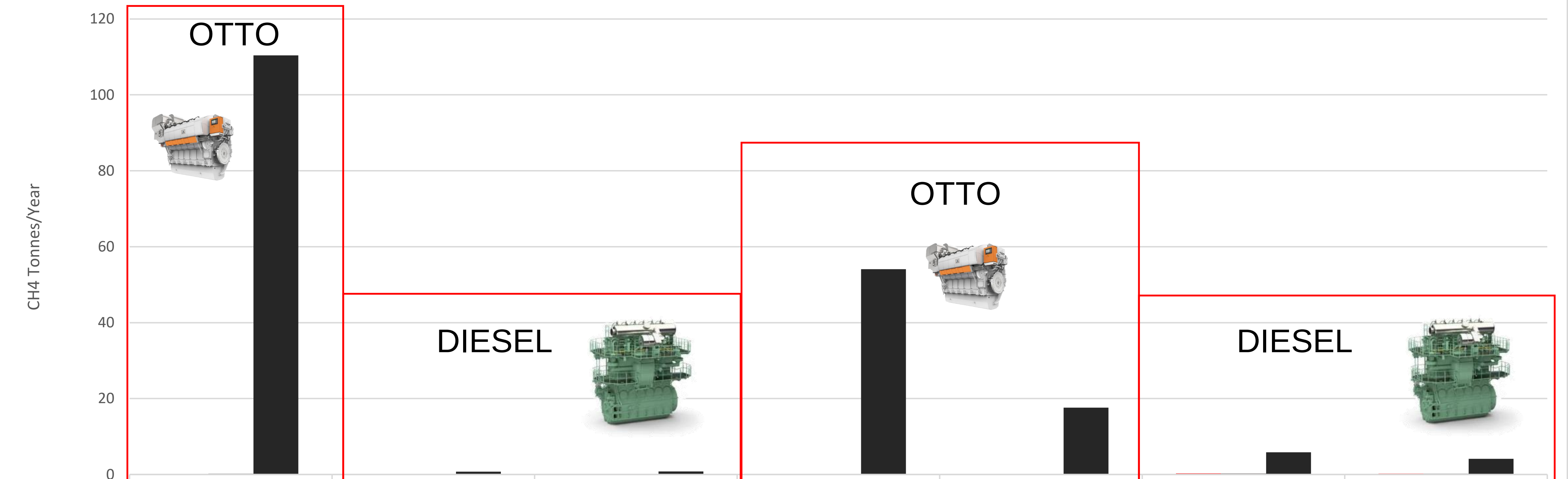



Vessel Case Studies – Black Carbon



	A1 - CCG Icebreaker	A2 - General Cargo	A3 - Tanker	A4 - Cruise Ship	A5 - LNG Carrier	A6 - I/B Bulker	A7 - Icegoing Bulker
HFO						1.122	0.691
MDO/ULSD	0.673	0.052	0.061	0.621		0.251	0.180
LNG	0.060	0.008	0.008	0.030	0.010	0.058	0.041

Vessel Case Studies – CH_4



	A1 - CCG Icebreaker	A2 - General Cargo	A3 - Tanker	A4 - Cruise Ship	A5 - LNG Carrier	A6 - I/B Bulker	A7 - Icegoing Bulker
HFO						0.3	0.2
MDO/ULSD	0.20	0.0	0.03904	0.1		0.3	0.2
LNG	110.40	0.8	0.78082	54.1	17.6	5.8	4.1

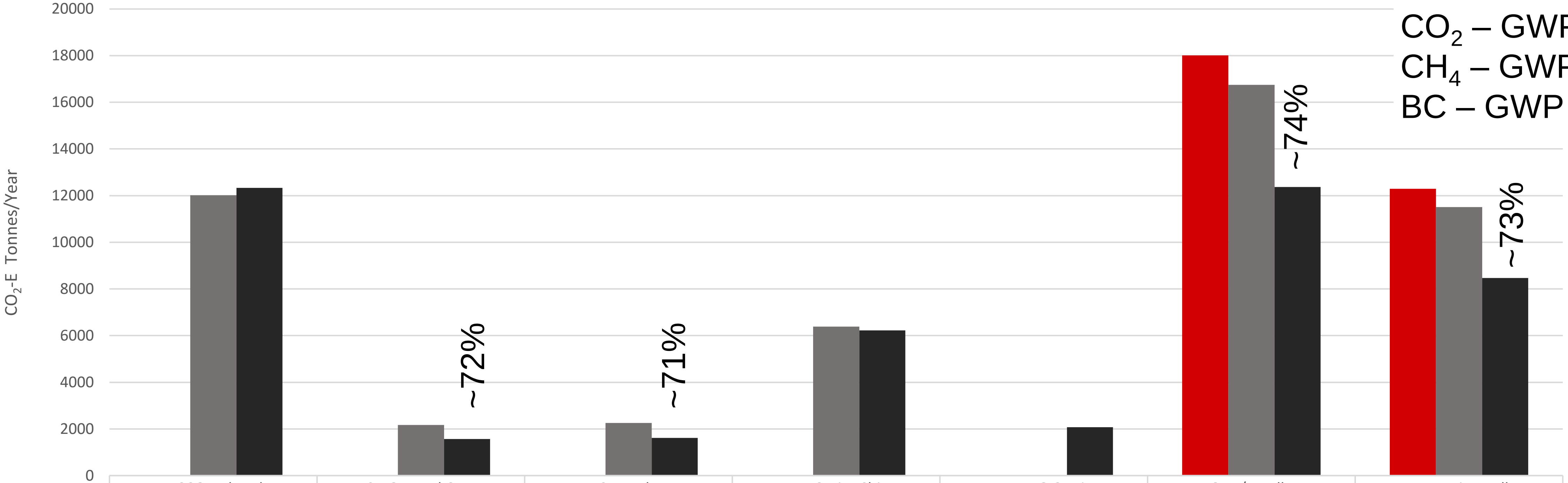






Vessel Case Studies – CO_2 – Equivalent

CO_2 – GWP 1
CH_4 – GWP 30
BC – GWP 900

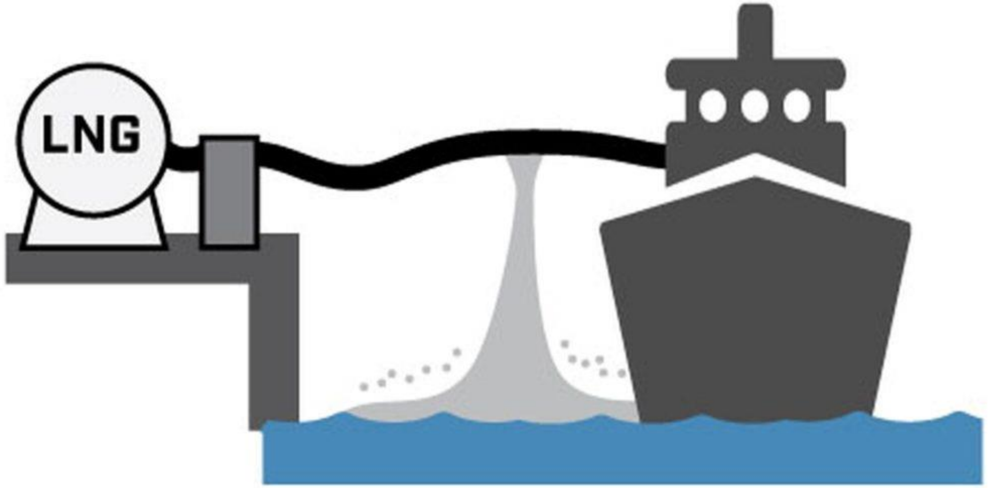


	A1 - CCG Icebreaker	A2 - General Cargo	A3 - Tanker	A4 - Cruise Ship	A5 - LNG Carrier	A6 - I/B Bulker	A7 - Icegoing Bulker
HFO						18012	12293
MDO/ULSD	12016	2168	2258	6382		16744	11513
LNG	12334	1565	1619	6226	2075	12372	8474



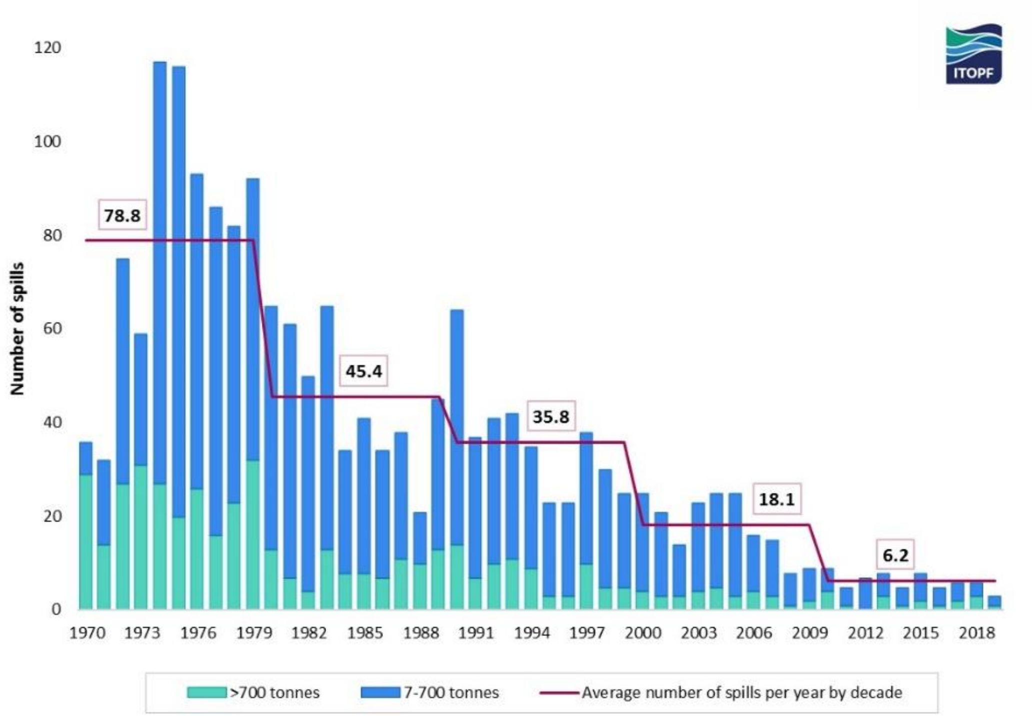



ACCIDENTAL POLLUTION SCENARIOS



Accidental Pollution Scenarios - Hydrocarbons

- 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.

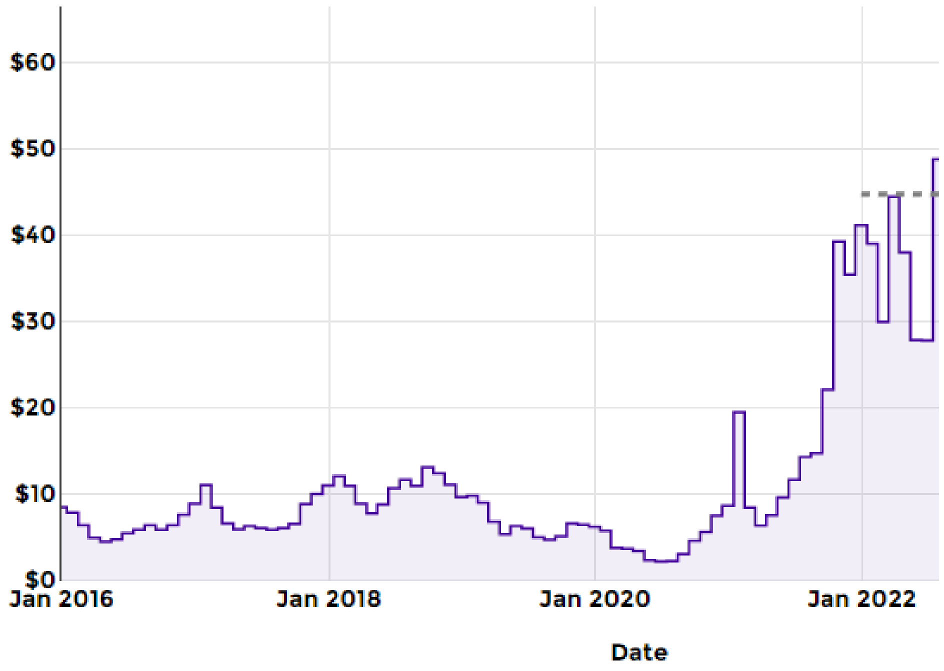


Accidental Pollution Scenarios - LNG

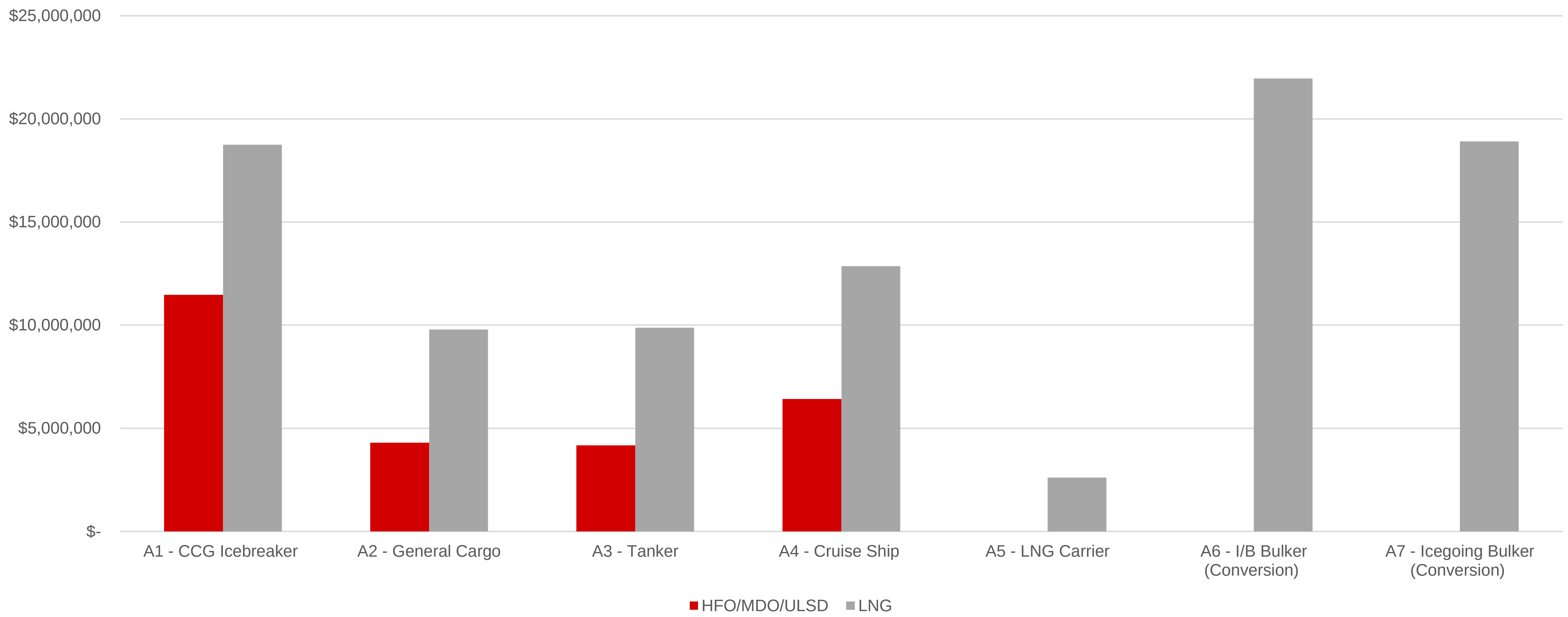
- LNG is lighter than water, so in the event of a release, it will float on the surface of the water
- LNG will immediately start to vaporize after a release and disperse rapidly depending on the local wind conditions
- No clean-up effort will be required in the event of an LNG release
- If an ignition 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%.

ECONOMICS


POLARIS LNG


$60
$50
$40
$30
$20
$10
$0
Jan 2016
Jan 2018
Jan 2020
Jan 2022
Date

Vessel Case Studies – Propulsion System Cost

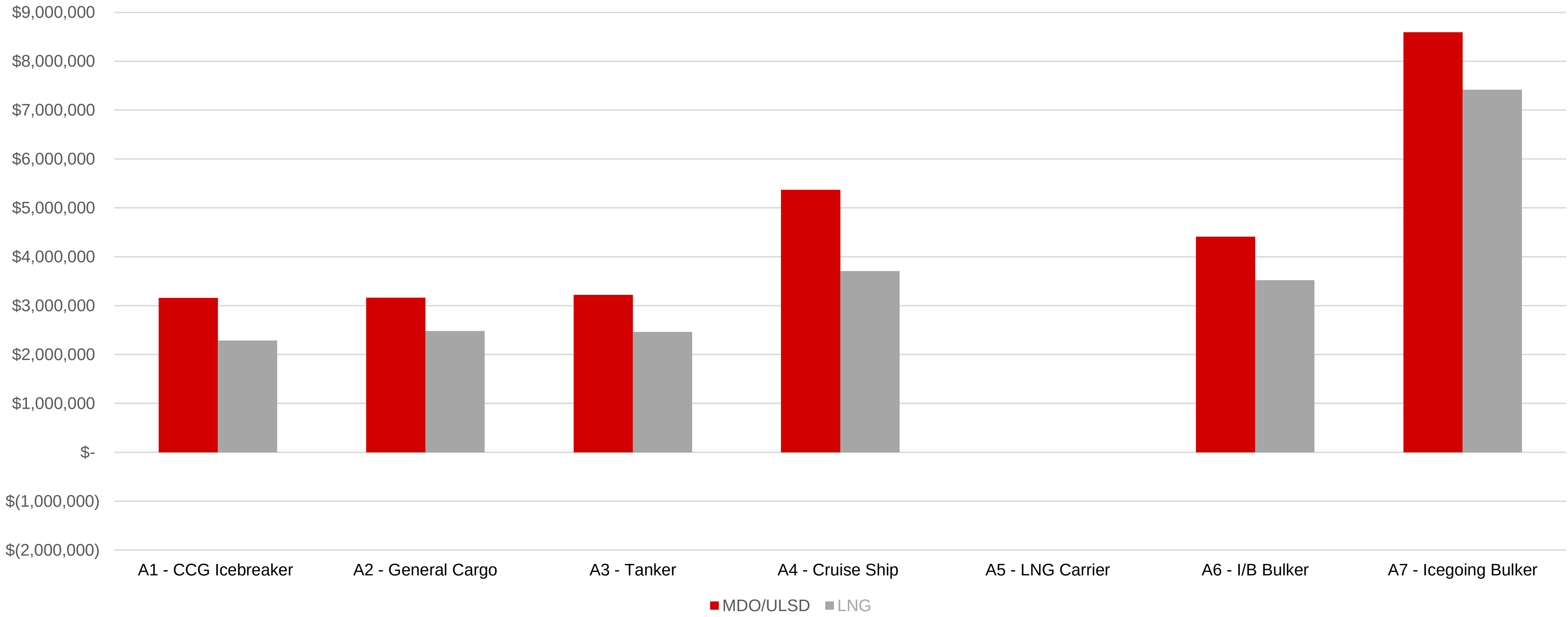








Vessel Case Studies – Annual Energy Costs



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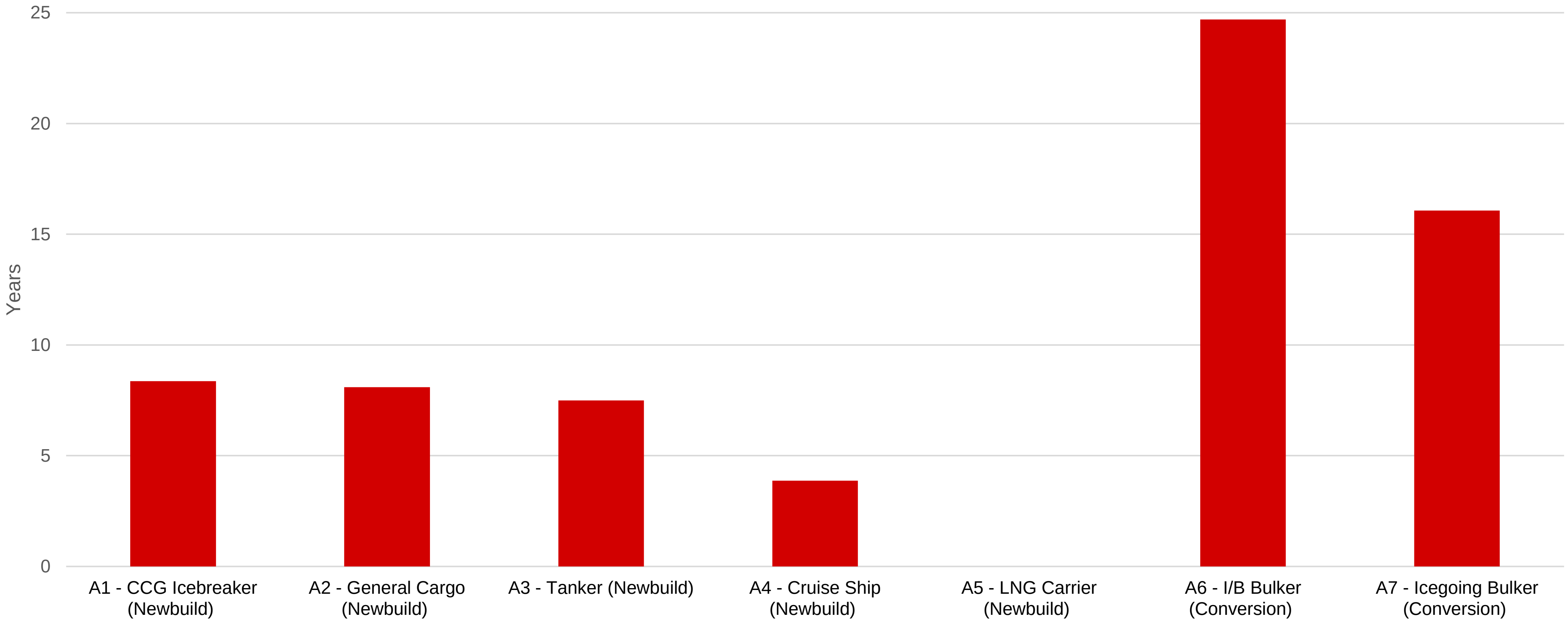
Vessel Case Studies – Payback Period





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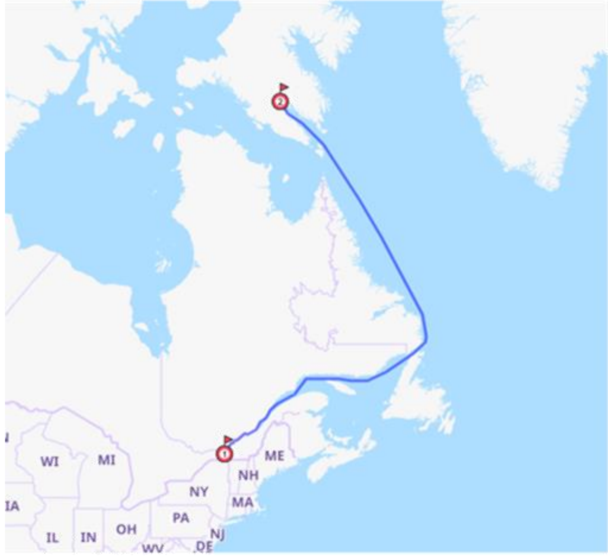
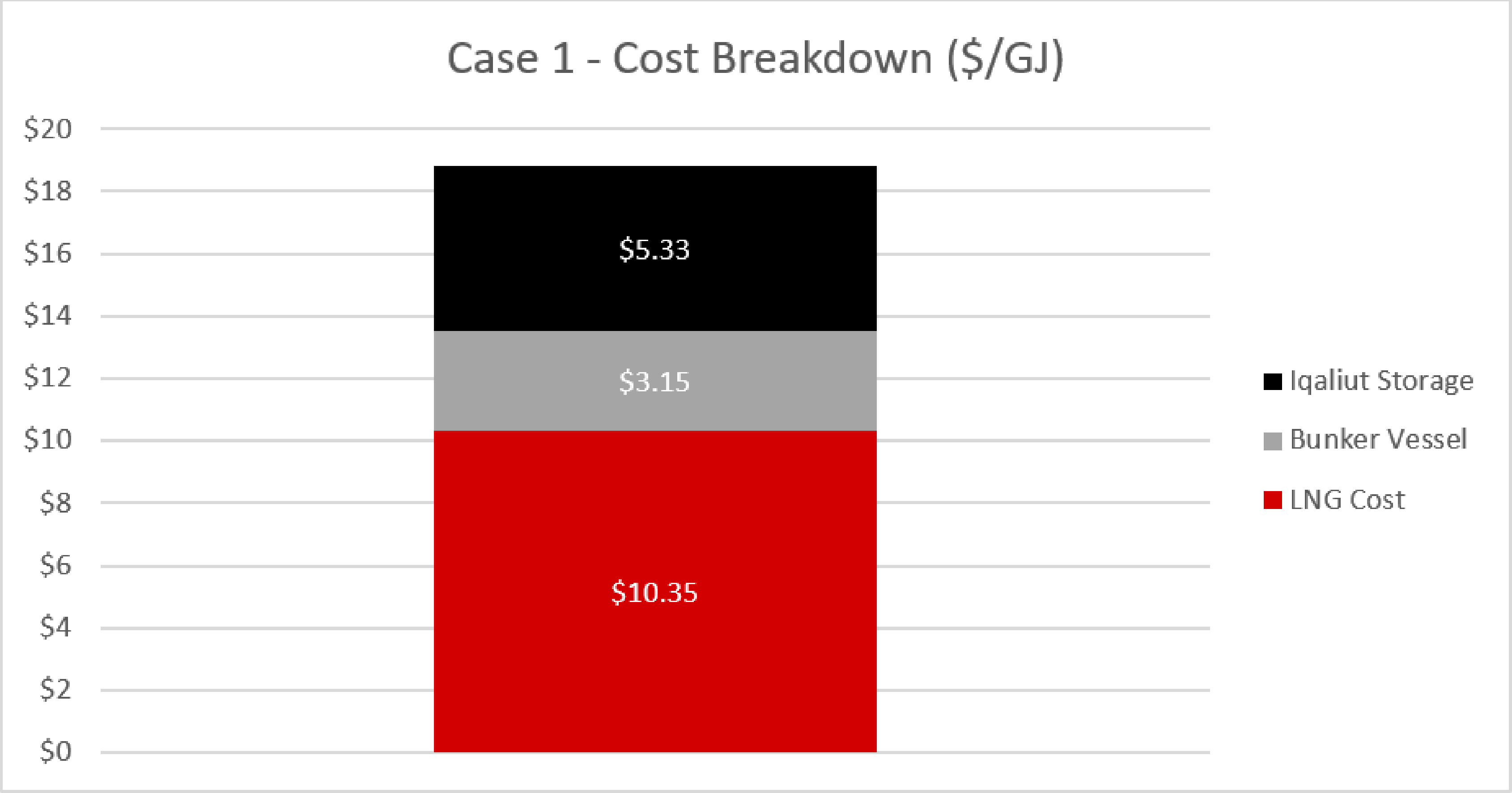
SUPPLY CHAIN

Case Study 1 - Summary

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



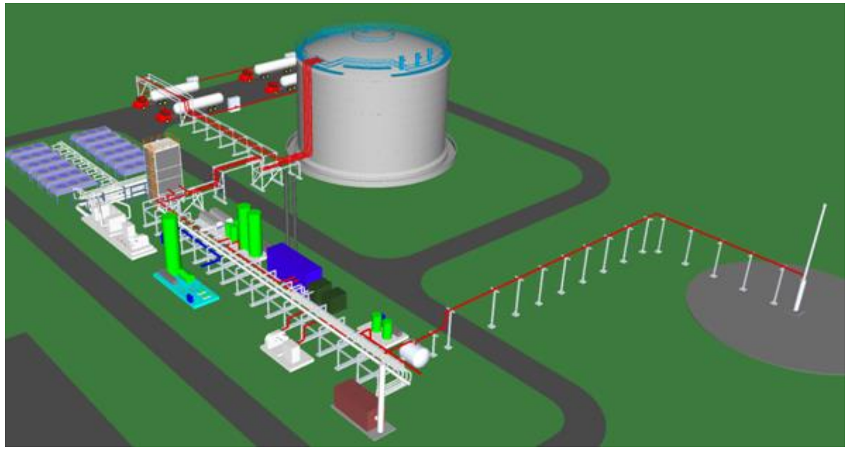
Case Study 1 - Results



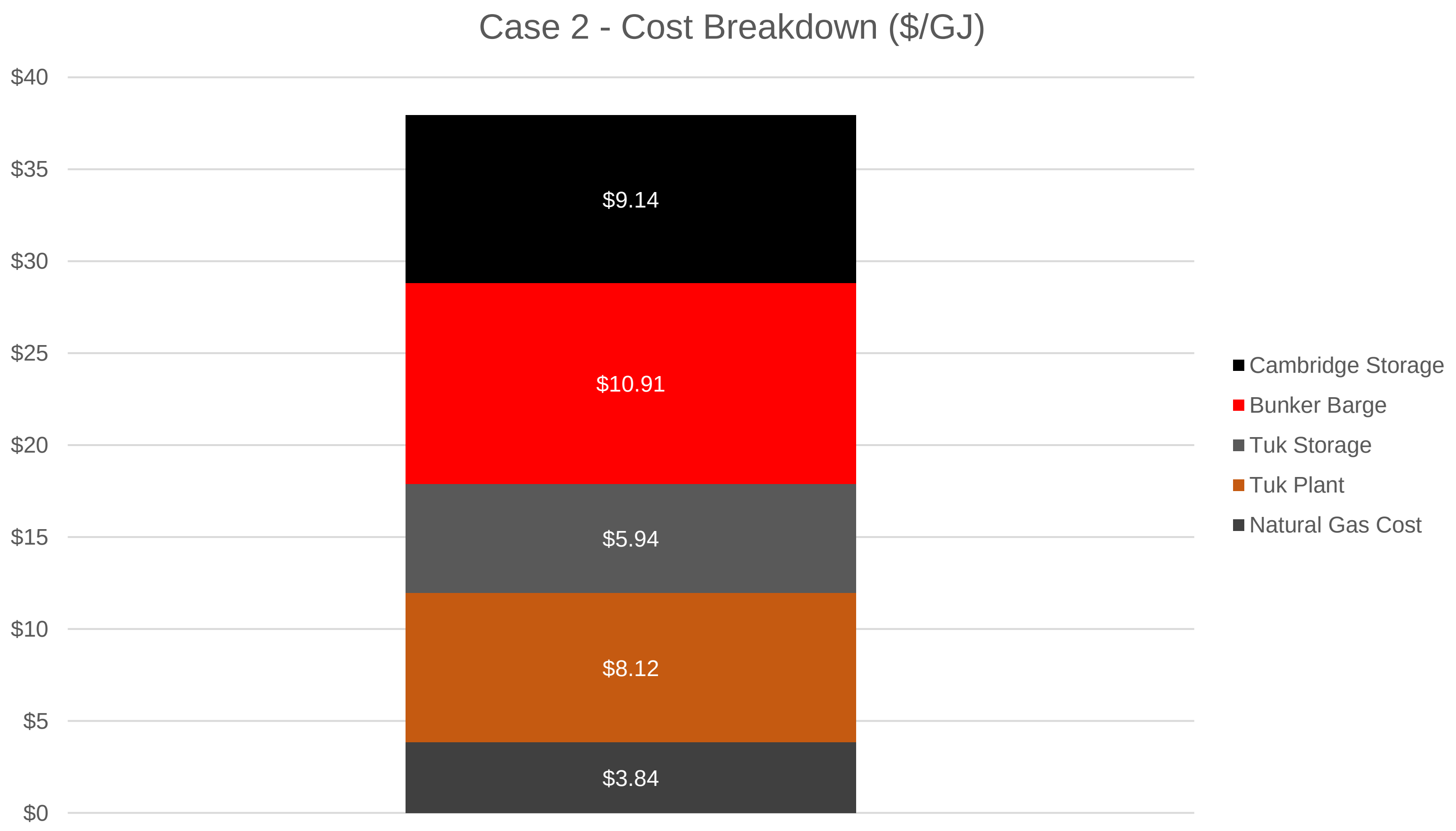
~$0.69 Diesel Liter Equivalent

Case Study 2 - Summary

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

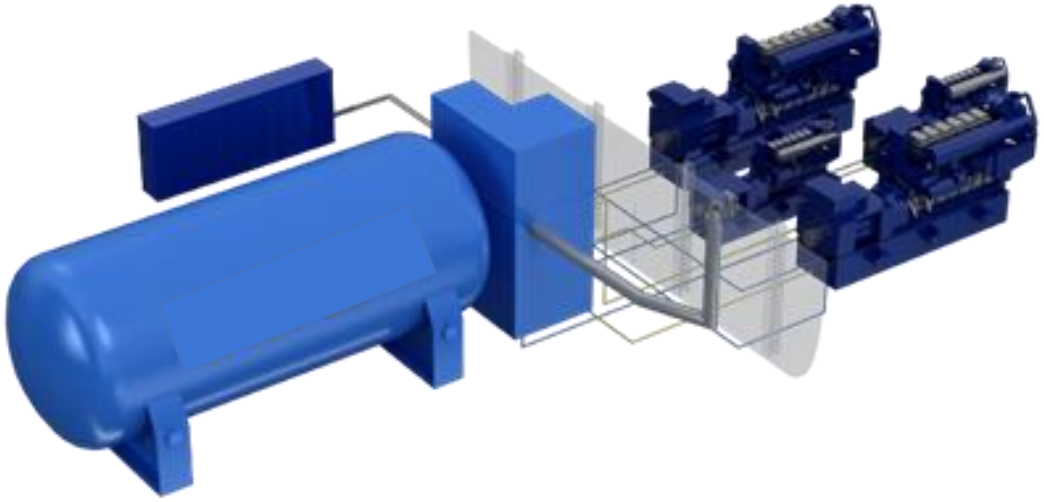


Case Study 2 - Results



~$1.39 Diesel Liter Equivalent

Summary



Conclusions

- The environmental benefits of LNG can include a reduction in CO_2, SO_X, PM, BC and NO_X emissions
- 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
- Until future fuels being to see more implementation on a commercial scale, Arctic marine traffic will continue to be operated on traditional fuel oils or to a lesser extent LNG.
- The economics of LNG as a marine fuel are just as important as emissions reduction in driving take-up of LNG
- Fossil based LNG is not the answer to net zero, but it can be a scalable transition fuel on a pathway to net zero.

Thank you for your attention this concludes the presentation

Questions?