Task 7/8 Working Group
June 2022

Project Summary

This project will investigate the feasibility, benefits and risks of the use of natural gas to replace some or all of the current diesel and heavy fuel oil (HFO) used in the Canadian Arctic, exploring if and how LNG fuel can provide a solution to:

- Reducing or eliminating the risk of **oil spills** in the Arctic
- Reducing **black carbon** emissions
- Eliminating **sulphur emissions**
- Reducing **greenhouse gas emissions**
- Reducing the **health and pollution risk to Arctic communities**
- Meeting the 2050 net zero **greening of government** targets

Who is participating?

- Original Equipment Manufacturers – marine engines and fuel systems
- Marine consultants
- Natural gas and LNG consultants
- Ship operators
- Gaseous fuels providers
- Federal Departments and Agencies
- Provincial and Territorial governments
- Arctic Communities and Economic interests
- Indigenous organizations
- Environmental non-governmental organizations

Perspectives Sharing Workshop

Tuesday, January 25 & Wednesday, January 26, 2022

A workshop aimed at sharing perspectives on the feasibility, benefits and risks of the use of natural gas (in the form of Liquefied Natural Gas or LNG) to replace some or all of the current diesel and heavy fuel oil (HFO) used in the Canadian Arctic.

Review presentations here:

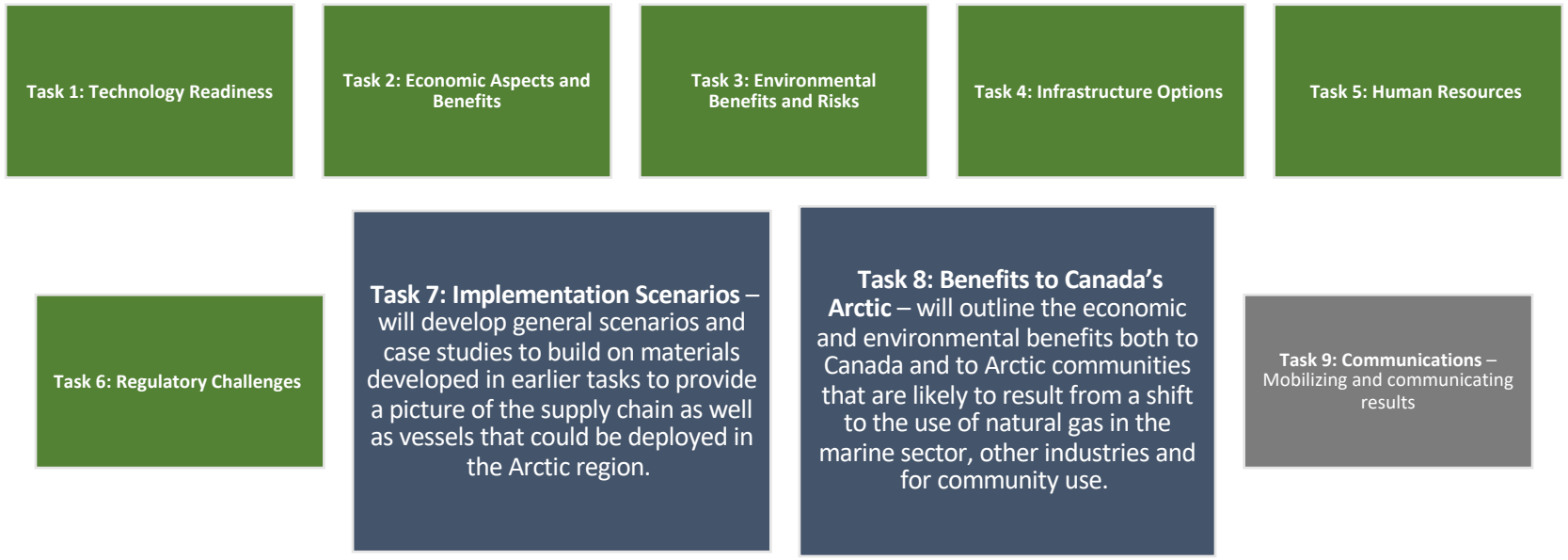
https://clearseas.org/en/research_project/arctic-marine-natural-gas-supply-chain-supply/

Featuring Special Guest Speakers including:

Lisa Koperqualuk
VP of International Affairs, Inuit Circumpolar Council Canada

Bryan Comer
Marine Program Lead, International Council on Clean Transportation

Task Teams


Task 1: Technology Readiness
Task 2: Economic Aspects and Benefits
Task 3: Environmental Benefits and Risks
Task 4: Infrastructure Options
Task 5: Human Resources
Task 6: Regulatory Challenges
Task 7: Implementation Scenarios – will develop general scenarios and case studies to build on materials developed in earlier tasks to provide a picture of the supply chain as well as vessels that could be deployed in the Arctic region.
Task 8: Benefits to Canada's Arctic – will outline the economic and environmental benefits both to Canada and to Arctic communities that are likely to result from a shift to the use of natural gas in the marine sector, other industries and for community use.
Task 9: Communications – Mobilizing and communicating results

Task 7 / 8 Outlines

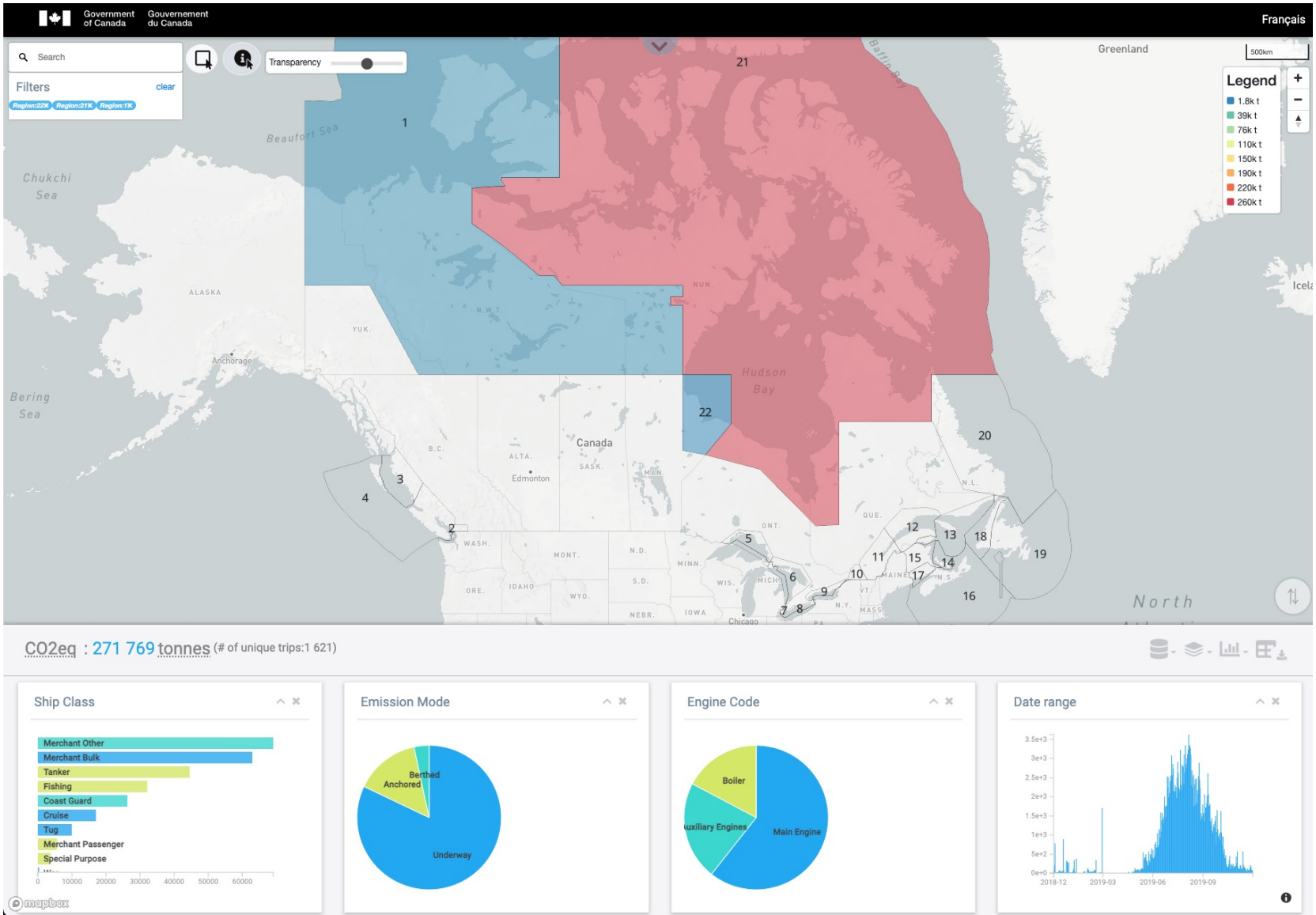
Task 7: Implementation Scenarios

1. Arctic Shipping Fuel Use and Emissions
2. Vessel Implementation Scenarios
   - Domestic commercial fleet
   - International shipping
   - Government
3. Summary of Emissions Impact
4. Supply Chain Options

Task 8: Benefits to Canada's Arctic

1. Environmental Impacts
   - Air pollution and health
   - Greenhouse gas
     1. CO2 and Black Carbon reduction
     2. Risk from methane
        - LPDF engines
        - Venting
   - Oil Spill Risk Reduction
2. Economic Impacts
   - Goods transportation cost
   - LNG sales
   - Infrastructure investment
   - Ship conversion/construction
   - Electricity cost

Marine Emissions Inventory Tool (MEIT)



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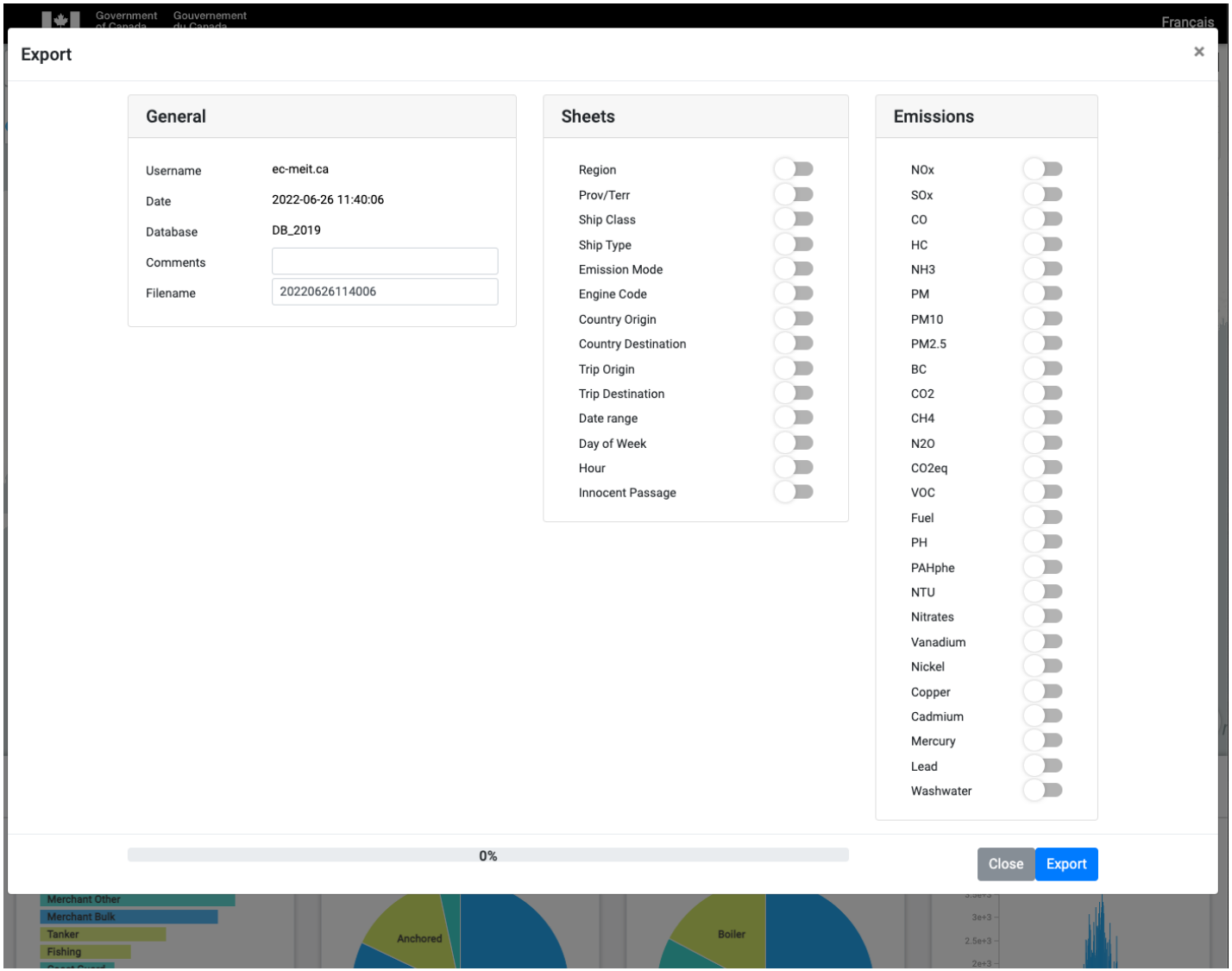
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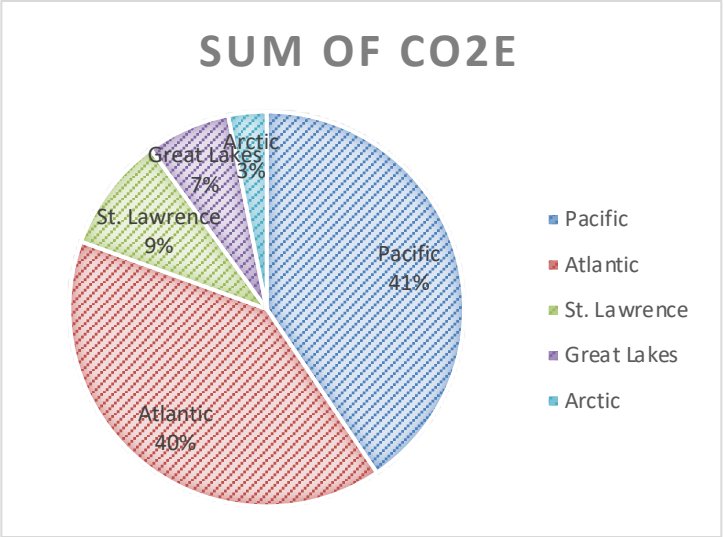
Nitrates
Vanadium
Nickel
Copper
Cadmium
Mercury
Lead
Washwater
0%
Close
Export
Merchant Other
Merchant Bulk
Tanker
Fishing
Anchored
Boiler

DRAFT – subject to change

Arctic Shipping Emissions in Context

2019 CO_2e Emissions*

Region	Co2e [GT]
Pacific	3.53
Atlantic	3.48
St. Lawrence	0.82
Great Lakes	0.60
Arctic	0.27
Total	**8.7**



*100-year IPCC GWP AR4 - excludes Black Carbon

Other values for comparison

Canada Domestic Marine Transport 2019:	4.4 GT
NU Territory 2019:	0.7 GT
Arctic Diesel Power Gen 2017:	0.9 GT

Arctic Shipping

2019 MEIT Raw Data Extract

Emissions By Vessel Type in Canadian Arctic for 2019 [t]														
Type	nox	sox	co	hc	pm	pm10	pm25	bc	co2	ch4	n2o	co2e	fuel_cons	Arctic LNG Study
Coast Guard Icebreaker	559.0	0.2	19.0	23.5	5.8	5.6	5.1	2.8	24,515.9	0.4	1.2	24,882.0	7,646,872,000	CCG Icebreaker
Coast Guard Rescue	1.5	0.0	0.1	0.1	0.0	0.0	0.0	0.0	89.2	0.0	0.0	90.6	27,817,370	Other
Coast Guard Supply	3.7	0.0	0.2	0.2	0.0	0.0	0.0	0.0	233.3	0.0	0.0	237.1	72,779,710	Other
Coast Guard Tender	17.9	0.0	1.0	0.9	0.2	0.2	0.2	0.1	1,066.1	0.0	0.1	1,084.4	332,518,400	Other
Cruise	285.9	158.3	10.5	9.9	18.8	18.0	16.6	1.7	16,807.6	0.2	0.8	17,048.5	5,397,440,000	Cruise
Factory Ship	105.4	0.1	4.9	4.1	0.3	0.3	0.3	0.1	5,581.6	0.1	0.3	5,681.1	1,740,972,000	Fishing Vessel
Fishing Vessel	293.2	0.2	10.7	9.3	1.5	1.4	1.3	0.7	20,172.3	0.2	1.1	20,492.3	6,292,056,000	Fishing Vessel
Merchant (Tanker)	274.1	160.6	9.3	9.6	15.7	15.1	13.9	0.4	12,131.0	0.2	0.6	12,328.5	3,895,624,000	Tanker
Merchant Bulk	1,416.8	866.9	53.1	59.0	107.0	102.7	94.5	2.8	61,901.6	1.0	3.4	62,936.9	19,878,480,000	Bulk Carrier
Merchant Chemical	66.9	45.4	2.2	2.1	3.2	3.0	2.8	0.1	3,263.4	0.0	0.2	3,314.2	1,047,987,000	Tanker
Merchant Chemical/Oil Products Tanker	318.5	230.3	12.1	11.9	21.5	20.6	19.0	0.8	15,999.1	0.2	0.9	16,259.2	5,137,790,000	Tanker
Merchant General	1,369.7	967.6	54.3	51.7	95.7	91.9	84.5	3.9	67,899.6	1.0	3.8	69,053.3	21,804,640,000	General Cargo
Merchant Ore/Bulk/Oil	205.3	171.9	8.3	7.1	9.5	9.1	8.4	0.8	12,479.8	0.2	0.6	12,671.5	4,007,629,000	I/B Bulk Carrier
Merchant Passenger	100.9	0.1	4.0	4.6	1.4	1.3	1.2	0.3	5,553.1	0.1	0.3	5,637.7	1,732,097,000	Other
Special Purpose Research VSL	4.9	0.0	0.3	0.3	0.1	0.1	0.1	0.0	297.3	0.0	0.0	302.3	92,737,070	Other
Special Purpose Supply VSL	52.6	0.0	3.2	3.3	0.9	0.9	0.8	0.3	3,404.4	0.1	0.2	3,462.0	1,061,869,000	Other
Trawler	112.8	0.1	5.4	5.1	0.9	0.8	0.8	0.3	5,839.2	0.1	0.3	5,942.7	1,821,349,000	Fishing Vessel
Tug	87.8	0.1	5.1	5.8	1.4	1.3	1.2	0.8	5,660.0	0.1	0.3	5,748.5	1,765,444,000	Tug
Tug Harbour	42.1	0.0	2.1	2.6	0.6	0.6	0.6	0.3	2,398.4	0.0	0.1	2,435.9	748,095,300	Tug
Tug Ocean	27.1	0.0	1.2	1.3	0.4	0.4	0.3	0.1	1,481.8	0.0	0.1	1,505.6	462,191,400	Tug
Tug Supply	5.3	0.0	0.2	0.2	0.1	0.1	0.1	0.0	260.8	0.0	0.0	264.3	81,333,810	Tug
Warship Surface	8.5	0.0	0.3	0.3	0.1	0.1	0.1	0.0	384.8	0.0	0.0	390.8	120,039,400	Other
	5,359.8	2,601.6	207.3	213.0	284.9	273.5	251.6	16.5	267,420.2	4.0	14.3	271,769.4	85,167,761,460	

Arctic Shipping

2019 MEIT Summary

Greenhouse Gas Emissions							
Row Labels	Sum of bc	Sum of co2	Sum of ch4	Sum of n2o	Sum of co2e	Sum of fuel_cons	
Bulk Carrier	2.8	61,901.6	1.0	3.4	62,937	19,878,480,000	**A7**
General Cargo	3.9	67,899.6	1.0	3.8	69,053	21,804,640,000	**A2**
Tanker	1.4	31,393.5	0.4	1.7	31,902	10,081,401,000	**A3**
I/B Bulk Carrier	0.8	12,479.8	0.2	0.6	12,671	4,007,629,000	**A6**
Fishing Vessel	1.1	31,593.1	0.4	1.7	32,116	9,854,377,000	
CCG Icebreaker	2.8	24,515.9	0.4	1.2	24,882	7,646,872,000	**A1**
Cruise	1.7	16,807.6	0.2	0.8	17,048	5,397,440,000	**A2**
Tug	1.3	9,801.0	0.2	0.5	9,954	3,057,064,510	
Other	0.8	11,028.2	0.2	0.6	11,205	3,439,857,950	
Grand Total	**17**	**267,420**	**4**	**14.3**	**271,769**	**85,167,761,460**	

Arctic Shipping

2010 – 2018 Unique Ship Counts Raw Data

Unique Ship Counts within NORDREG										
Vessel Type	2010	2011	2012	2013	2014	2015	2016	2017	2018	Arctic LNG Category
Bulk Carriers	23	19	18	24	21	20	21	27	36	Bulk Carrier + I/B Bulk Carrier
Fishing Vessels	24	25	23	22	24	24	21	30	32	Fishing Vessel
General Cargo	15	12	11	11	13	14	16	19	17	General Cargo
Government Vessels and Icebreakers	20	23	23	23	22	22	20	28	24	Other +. CCG Icebreaker
Oil/Gas Exploration/Exploitation		1	1							Other
Passenger Ships	11	8	6	10	9	11	12	12	10	Cruise
Pleasure Crafts	11	20	24	26	31	23	23	30	18	Other
Tanker Ships	13	15	11	11	11	10	11	13	14	Tanker
Tug/Barge	23	20	19	20	13	14	15	20	18	Tug
Grand Total	140	143	136	147	144	138	139	179	169	

Source: Environment, Society and Policy Group – University of Ottawa

Arctic Shipping

Unique Ship Count Summary

Vessel Type	Number of Vessels in 2018	Fuel Consumed in Arctic in 2019 [millions of tonnes]	
Bulk Carriers	33	19.9	A7
General Cargo	17	21.8	A2
Tanker	14	10.1	A3
I/B Bulk Carrier*	3	4.0	A6
Fishing Vessel	32	9.9	
CCG Icebreaker*	7	7.6	A1
Cruise	10	5.4	A4
Tug	18	3.1	
Other	35	3.4	
Total	**169**	**85.2**	

Source: ESPG, MEIT

* Industry data

Particulars/Profile– Icegoing Bulker

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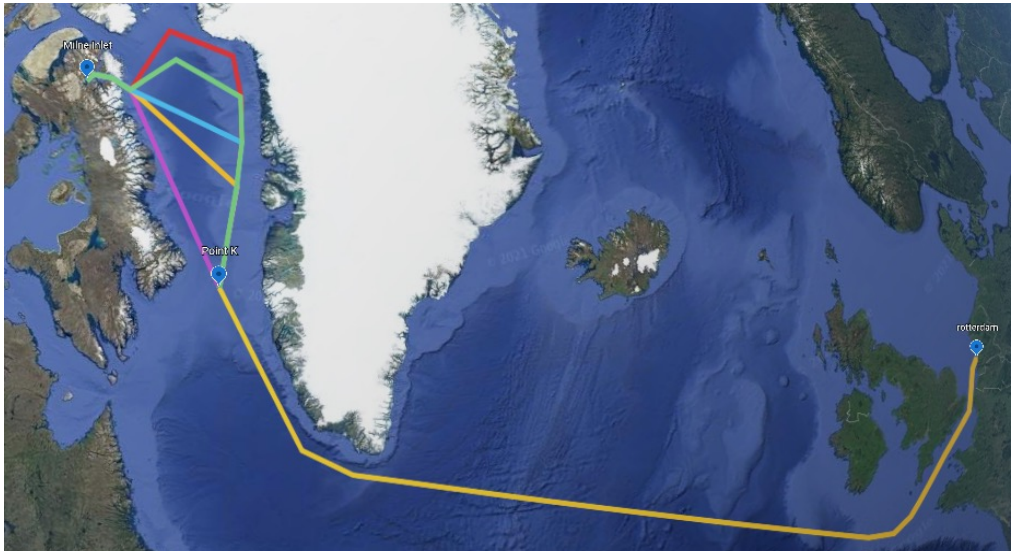
Vessel Particulars		A7
Cargo		Icegoing Bulker
Length	(m)	225.00
Breadth	(m)	32.00
Depth	(m)	20.00
Draft	(m)	14.50
Gross Tonnage	(MT)	40000
Deadweight	(MT)	75000
Speed	(kts)	13
Power	(kW)	14,500
Passenger Cap		n/a
Crew		20
Ice Class		PC 7
Engine Type		Slow speed
Fuel tank volume	(m^3)	2500



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Implementation Scenario

Bulk Carriers

Scenario: International bulk carriers burn LNG fuel instead of MDO because of HFO ban
Reference Case A7

Emissions Impact = MEIT (Region) x Factors from Task 3

Economic Impact = # vessels x Annual Savings $

Investment = # vessels x Conversion Cost

Fuel Demand = # vessels x consumption -> Europe

Particulars/Profile – General Cargo

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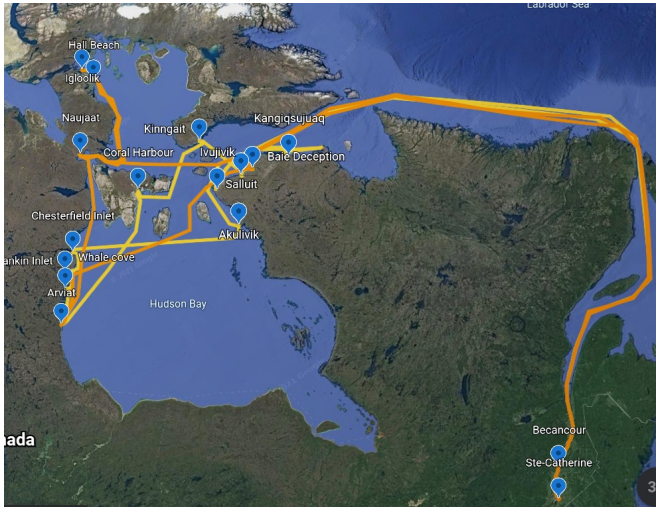
Vessel Particulars		A2
Cargo		General Cargo
Length	(m)	140.00
Breadth	(m)	21.00
Draft	(m)	8.00
Gross Tonnage	(MT)	10000
Deadweight	(MT)	15000
Speed	(kts)	15
Power	(kW)	6,000
Passenger Cap		n/a
Crew		25
Ice Class		PC 7
Engine Type		Slow Speed
Fuel tank volume	(m^3)	550



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Implementation Scenario

General Cargo

Scenario: Arctic sealift ships replaced with LNG-powered at replacement
Reference Case A2

Emissions Impact = MEIT (Region) x Factors from Task 3

Economic Impact = # vessels x Annual Savings $

Investment = # vessels x upgrade cost

Fuel Demand = # vessels x consumption -> QC

Notes:

- MEIT assumes HFO
- Methane emissions if MS-LPDF engines used instead = limited benefit
- No regional bunkering solution currently in QC

Particulars/Profile - Tanker

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Vessel Particulars		A3
Cargo		Tanker
Length	(m)	135.00
Breadth	(m)	23.50
Draft	(m)	8.00
Gross Tonnage	(MT)	12000
Deadweight	(MT)	15000
Speed	(kts)	14
Power	(kW)	5,500
Passenger Cap		n/a
Crew		20
Ice Class		PC 7
Engine Type		Slow Speed
Fuel tank volume	(m^3)	600

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Implementation Scenario

Tanker

Scenario: Arctic sealift ships replaced with LNG-powered at replacement
Reference Case A3

Emissions Impact = MEIT (Region) x Factors from Task 3

Economic Impact = # vessels x Annual Savings $

Investment = # vessels x upgrade cost

Fuel Demand = # vessels x consumption -> QC

Notes:

- MEIT assumes HFO
- Methane emissions if MS-LPDF engines used instead = limited benefit
- No regional bunkering solution currently in QC

Particulars/Profile– I/B Bulker

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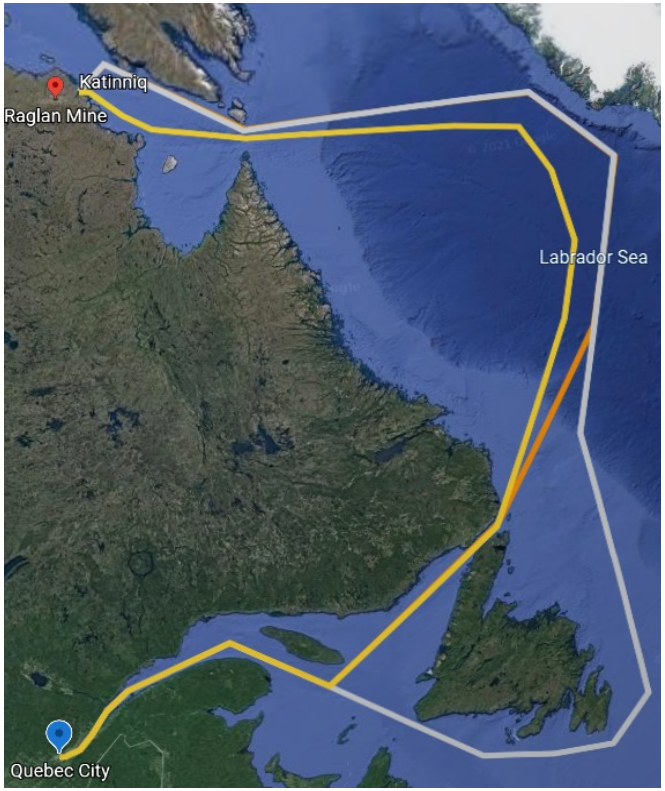
Vessel Particulars		A6
Cargo		I/B Bulker
Length	(m)	190.00
Breadth	(m)	26.50
Depth	(m)	18.00
Draft	(m)	12.00
Gross Tonnage	(MT)	22000
Deadweight	(MT)	32000
Speed	(kts)	13
Power	(kW)	22,000
Passenger Cap		n/a
Crew		20
Ice Class		PC 4
Engine Type		Slow speed
Fuel tank volume	(m^3)	2200



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Implementation Scenario

Icebreaking Bulk Carriers

Reference Cast A6

Emissions Impact = MEIT (Region) x Factors from Task 3

Economic Impact = # vessels x Annual Savings $

Investment = # vessels x Conversion Cost

Fuel Demand = # vessels x consumption -> QC

Particulars/Profile – CCG Icbreaker

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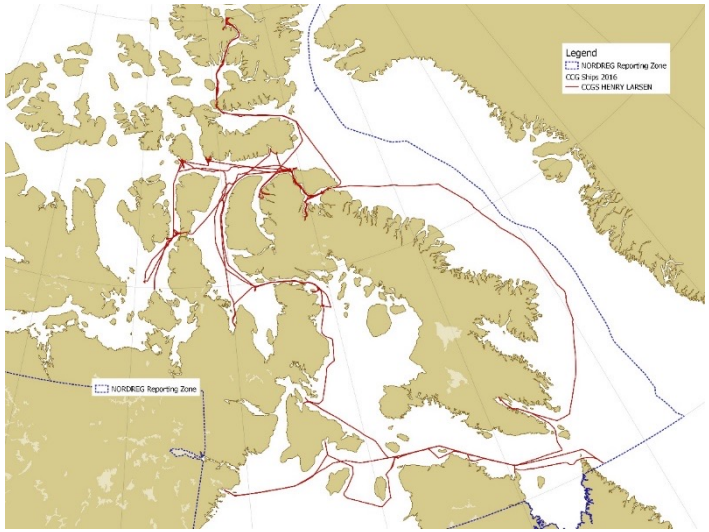
Vessel Particulars		A1
Cargo		As required
Length	(m)	110.00
Breadth	(m)	23.00
Draft	(m)	8.00
Gross Tonnage	(MT)	n/a
Deadweight	(MT)	3000
Speed	(kts)	16
Power	(kW)	20,000
Passenger Cap		n/a
Crew		50
Ice Class		PC 3
Engine Type		Medium speed, DE
Fuel tank volume	(m^3)	1500



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Implementation Scenario

CCG Icebreaker

Scenario: New CCG icebreakers are built with LNG power instead of diesel

Reference Case A1

Emissions Impact = MEIT (Region) x Factors from Task 3

Economic Impact = MT Fuel from MEIT x (ULSD – LNG Price from Task 4)

Investment = Unable to calculate

Fuel Demand = MEIT -> Arctic

Notes

- Diesel-electric configuration limits choice of engines to MS-LPDF => high methane emissions
- Range requirement necessitates refuelling in Arctic

Particulars/Profile– Cruise Ship

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Vessel Particulars		A4
Cargo		Cruise Ship
Length	(m)	138.00
Breadth	(m)	22.00
Draft	(m)	5.60
Gross Tonnage	(MT)	15500
Speed	(kts)	16
Power	(kW)	11,200
Passenger Cap		200
Crew		175
Ice Class		PC 6
Engine Type		Medium speed DE

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Implementation Scenario

Cruise Ship

Canadian-flagged LNG-fuelled cruise ships originating in Iqaluit replace current cruise fleet
Reference Case A4

Emissions Impact = MEIT (Region) x Factors from Task 3

Economic Impact = $ value of fuel purchased in Arctic: MEIT fuel x Task 4 cost $

Investment = # vessels x upgrade cost

Fuel Demand = MEIT forecast -> Arctic

Notes:

- Scenario requires in-region LNG
- Diesel-electric propulsion necessitates choice of LPDF emissions -> CH4 issues

Fuel Cost

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Fuel	Port	Current (%/MT)
MDO	Montreal	$800.00
ULSD (0.01% S)	Montreal	$888.00
HFO (0.5%)	Montreal	$559.00
HFO (0.5%)	Rotterdam	$488.00
LNG	Montreal	$720.00
LNG	Rotterdam	$801.37

LNG Iqaluit $941.90 (Task 4 Scenario 1)

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Annual Fuel Cost

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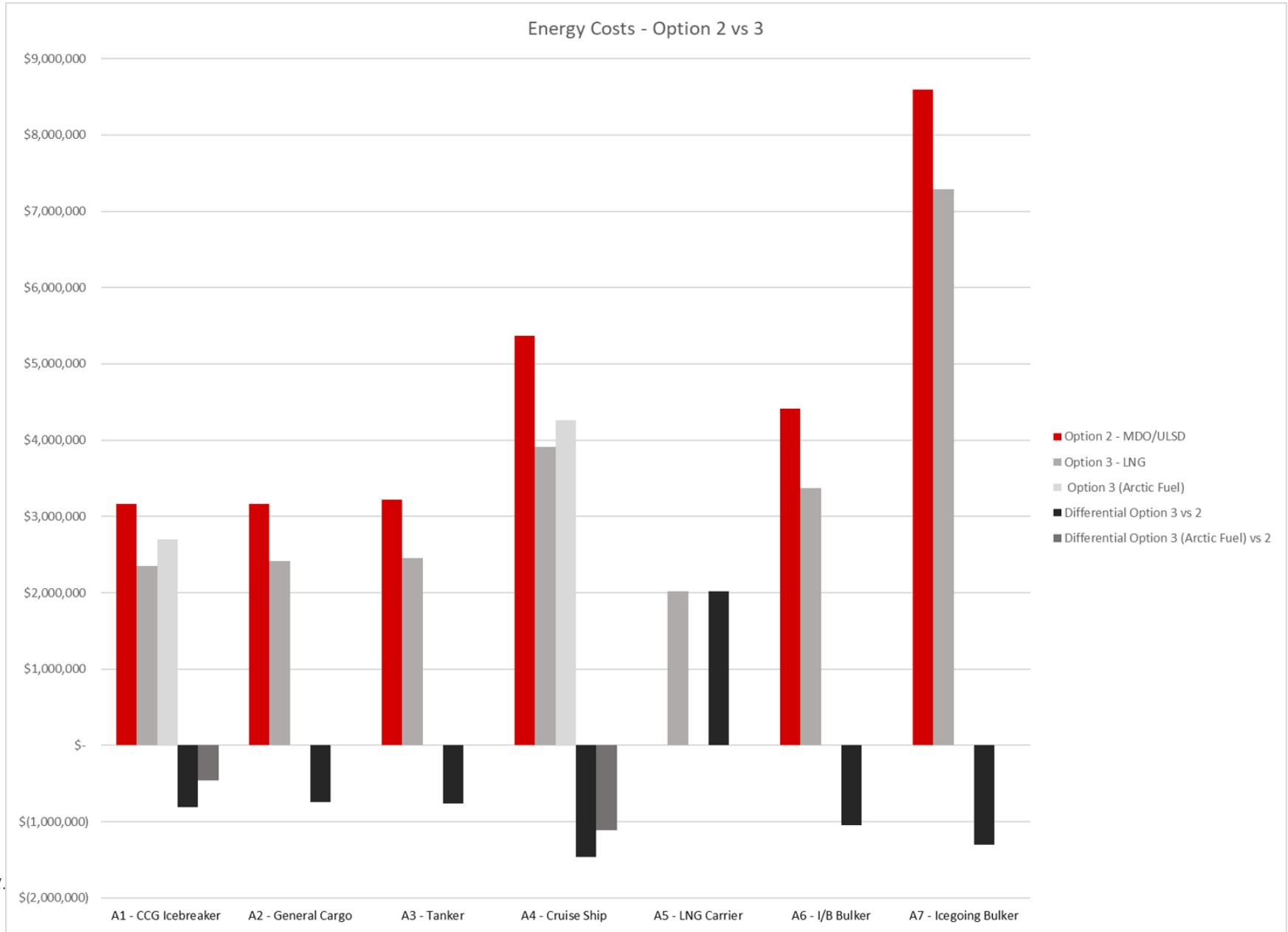

Payback Periods

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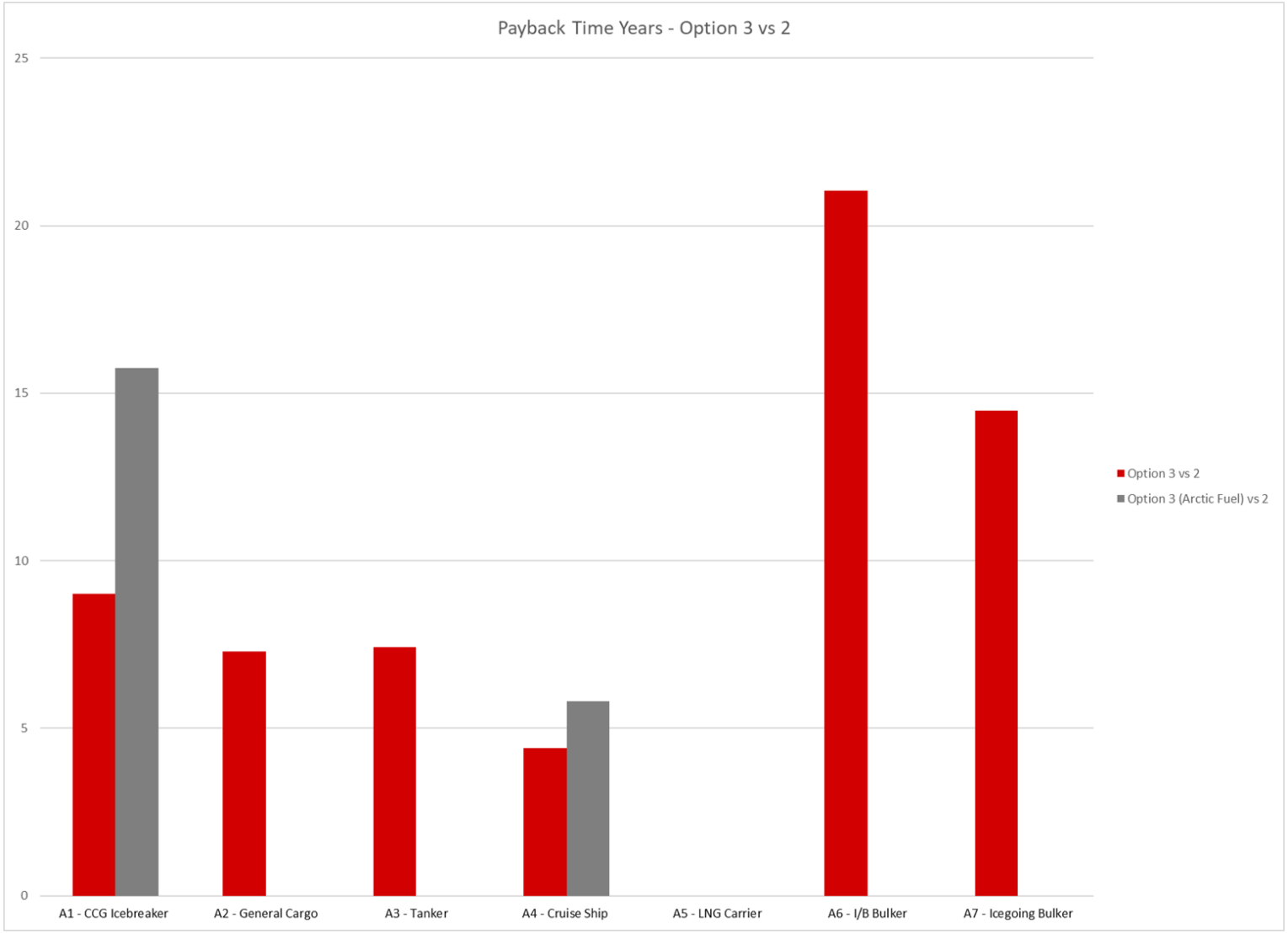

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Sensitivity Analyses

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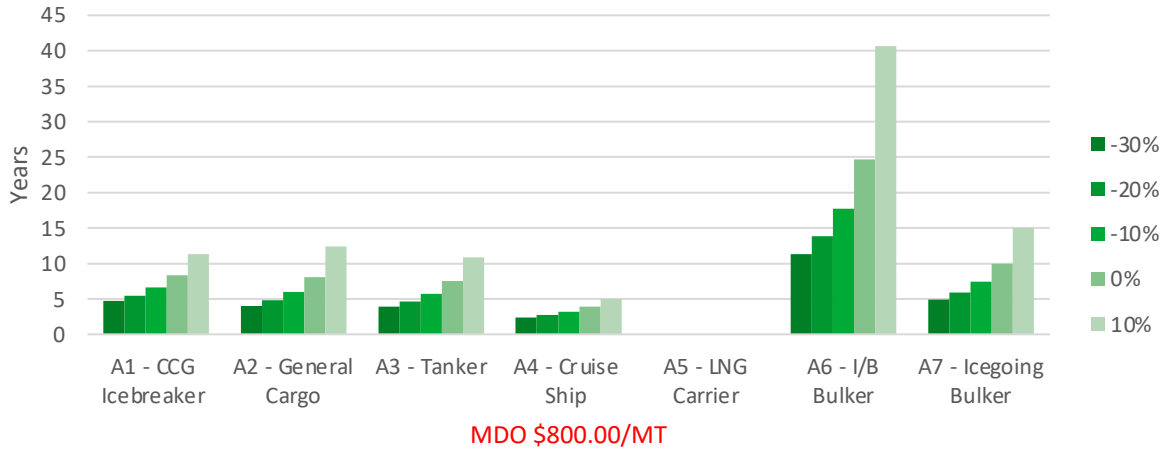
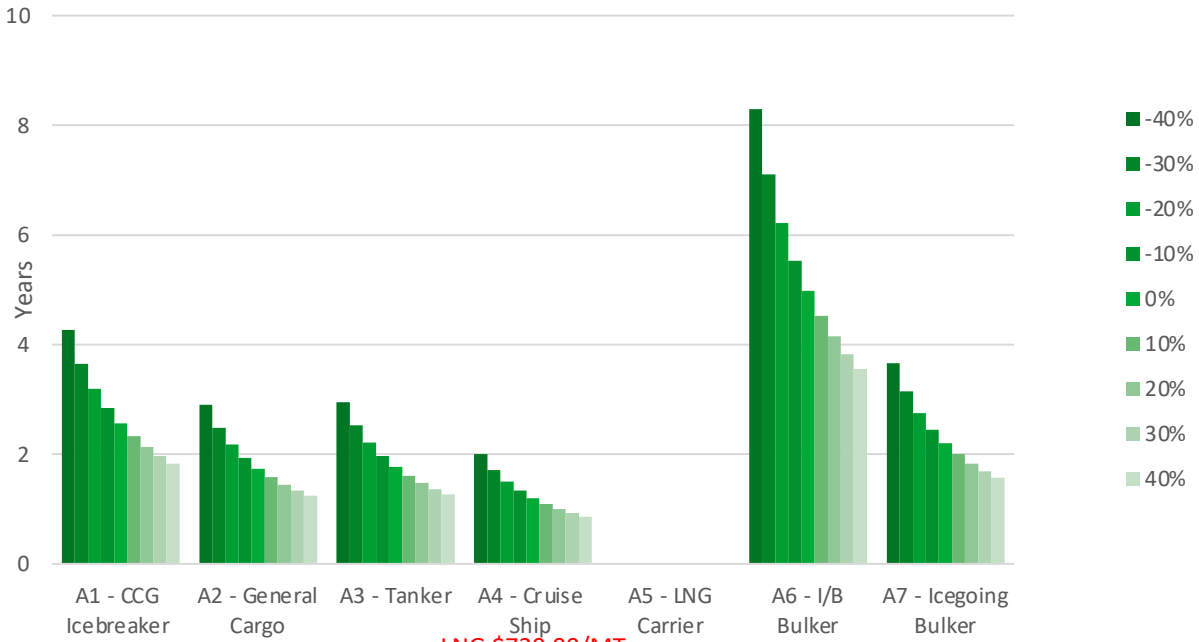


MDO $800.00/MT



LNG $720.00/MT

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Greenhouse Gas Impact

Impact on CO2 Emissions of Implementation Sceanrios [tonnes]					
		ULSD/MDO		LNG	
Vessel Type	Baseline	Change	Percent	Change	Percent
Bulk Carrier	61,901.6	(1,698.1)	-3%	(16,094.9)	-29%
General Cargo	67,899.6	(1,654.7)	-2%	(18,248.6)	-29%
Tanker	31,393.5	(724.9)	-2%	(8,561.6)	-30%
I/B Bulk Carrier	12,479.8	(354.1)	-3%	(3,209.9)	-29%
CCG Icebreaker	24,515.9	-	-	(5,238.5)	-21%
Cruise	16,807.6	(433.9)	-3%	(3,498.7)	-21%
Total	**214,998.0**	**(4,865.7)**		**(54,852.3)**	

Impact on BC Emissions of Implementation Sceanrios [tonnes]					
		ULSD/MDO		LNG	
Vessel Type	Baseline	Change	Percent	Change	Percent
Bulk Carrier	2.8	(2.1)	-74%	(0.6)	-94%
General Cargo	3.9	(2.5)	-63%	(1.2)	-94%
Tanker	1.4	(0.8)	-59%	(0.5)	-95%
I/B Bulk Carrier	0.8	(0.6)	-77%	(0.1)	-95%
CCG Icebreaker	2.8	-	-	(2.6)	-91%
Cruise	2.8	(1.9)	-68%	(0.8)	-95%
Total	**14.5**	**(7.9)**		**(5.8)**	

Impact on CH4 Emissions of Implementation Sceanrios [tonnes]			
		LNG	
Vessel Type	Baseline	Change	Percent
Bulk Carrier	1.0	19.4	1951%
General Cargo	1.0	18.7	1887%
Tanker	0.4	8.1	1903%
I/B Bulk Carrier	0.2	2.9	1945%
CCG Icebreaker	0.4	273.3	62391%
Cruise	0.2	98.0	52255%
Total	**3.2**	**420.5**	

- CO_2 Reduced
- Black Carbon Reduced
- Methane increased – worse with LPDF engines
- N2O reduced (not calculated)

Greenhouse Gas Impact

Impact of CO2-e GWP 100 Emissions of Implementation Scenarios [tonnes]			
		LNG Best Scenario	
Vessel Type	Baseline	Change	Percent
Bulk Carrier	64,459.8	(16,020.8)	-25%
General Cargo	71,456.1	(18,779.9)	-26%
Tanker	32,641.8	(8,757.5)	-27%
I/B Bulk Carrier	13,223.2	(3,250.1)	-25%
CCG Icebreaker	27,008.1	663.8	2%
Cruise	18,336.6	(1,315.3)	-7%
Total	**227,125.5**	**(47,459.9)**	**-21%**

- In region emissions only - Task 3 includes lifecycle
- Includes Black Carbon
- Excludes N_2O
- Requires use of HPDF engines to limit methane

Air Pollution Impact

Impact on NOx Emissions of Implementation Scenario					
Vessel Type	Baseline	Change	Percent		
Bulk Carrier	1,416.8	-	0%		
General Cargo	1,369.7	-	0%		
Tanker	659.4	-	0%		
I/B Bulk Carrier	205.3	-	0%		
CCG Icebreaker	559.0	(490.5)	-88%		
Cruise	285.9	(250.2)	-88%		
Total	**4,496.1**	**(740.6)**			

Impact on SOx Emissions of Implementation Sceanrios after IMO 2020 and HFO Ban					
		MDO/ULSD		LNG	
Vessel Type	Baseline	Change	Percent	Change	Percent
Bulk Carrier	866.9	(694.0)	-80%	(165.4)	-99%
General Cargo	967.6	(774.6)	-80%	(176.6)	-98%
Tanker	436.2	(336.8)	-77%	(92.0)	-98%
I/B Bulk Carrier	171.9	(138.5)	-81%	(32.1)	-99%
CCG Icebreaker	0.2	-	-	(0.2)	-81%
Cruise	158.3	(125.8)	-79%	(30.5)	-99%
Total	**2,601.1**	**(2,069.8)**		**(496.7)**	

Impact on PM Emissions of Implementation Sceanrios after IMO 2020 and HFO Ban					
		MDO/ULSD		LNG	
Vessel Type	Baseline	Change	Percent	Change	Percent
Bulk Carrier	107.0	(79.7)	-75%	(25.9)	-99%
General Cargo	95.7	(68.1)	-71%	(26.2)	-99%
Tanker	40.4	(28.9)	-71%	(11.5)	-100%
I/B Bulk Carrier	9.5	(7.1)	-75%	(2.3)	-99%
CCG Icebreaker	5.8	-	-	(5.1)	-88%
Cruise	18.8	(13.7)	-73%	(4.9)	-99%
Total	**277.1**	**(197.5)**		**(75.8)**	

- NOx reduction only from high methane LPDF engines
- Big SOx reduction from move to Ultra-Low Sulphur fuel due to HFO ban
- PM reduced

Supply Chain Options

Implementation Scenarios Fuel Demand			**Total LNG Required Annually (tonnes)**		
	LNG Fuel Per Season (tonnes)	**Number of Vessels**	**Europe**	**Quebec**	**Arctic**
Bulk Carriers	2,761	33	91,113		
General Cargo	440	17		7,480	
Tanker	434	14		6,076	
I/B Bulk Carrier*	4,013	3		12,039	
CCG Icebreaker*	3,171	7		11,099	11,099
Cruise	1,582	10			15,820
LNG Carrier	440	1		440	
Total		**85**	**91,113**	**37,134**	**26,919**

Task 7 / 8 Outlines

Task 7: Implementation Scenarios

1. Arctic Shipping Fuel Use and Emissions
2. Vessel Implementation Scenarios
   - Domestic commercial fleet
   - International shipping
   - Government
3. Summary of Emissions Impact
4. Supply Chain Options

Task 8: Benefits to Canada's Arctic

1. Environmental Impacts
   - Air pollution and health
   - Greenhouse gas
     1. CO2 and Black Carbon reduction
     2. Risk from methane
        - LPDF engines
        - Venting
   - Oil Spill Risk Reduction
2. Economic Impacts
   - Goods transportation cost
   - LNG sales
   - Infrastructure investment
   - Ship conversion/construction
   - Electricity cost