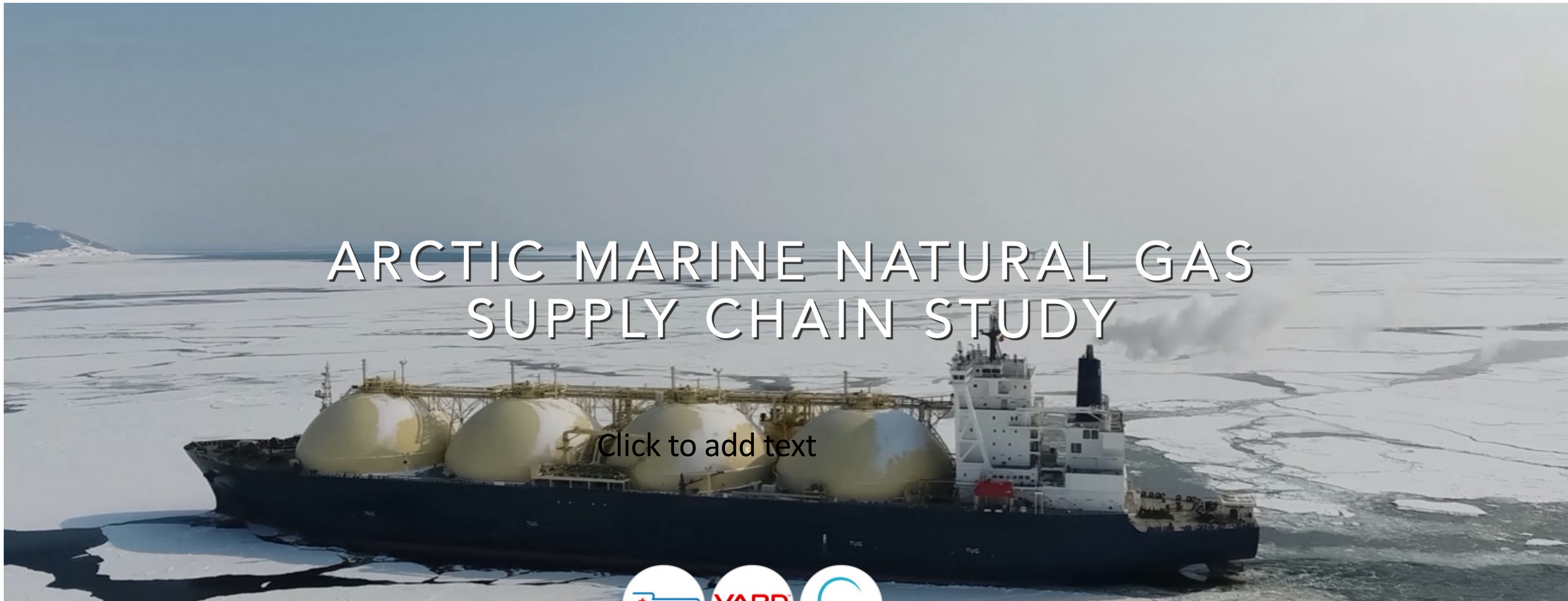

LNG as a Ship Fuel for the Arctic: Results Tasks 1 & 2

Andrew Kendrick
Vard Marine

Agenda

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- Overview of Project Tasks
- Results to date:
  - Technology Readiness
  - Economics
  - Environmental Considerations
  - Implementation Approaches
  - Human Resources
  - Regulations
- Ongoing and Future Work

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Project Tasks

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- Task 1: Technology Readiness Review
- Task 2: Economic Aspects and Benefits
- Task 3: Environmental Benefits
- Task 4: Infrastructure Options
- Task 5: Human Resources
- Task 6: Regulatory Challenges
- Task 7: Implementation Scenarios
- Task 8: Benefits to Canada's Arctic
- Task 9: Communications

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Task 1: Technology Readiness

- Inherent characteristics of natural gas and variations in gas properties;
- Liquefaction and bulk storage systems;
- Distribution systems such as bulk cargo and feeder vessels, barges, rail and road vehicles, local tanks, etc.;
- Bunkering systems;
- Onboard storage and fuel distribution technologies;
- Engine technologies for various types of dual-fuel and pure natural gas engines;
- The integration of natural gas engines into propulsion;
- Safety technologies associated with transportation of natural gas and use as fuel;
- Technical standards available for certification of equipment using LNG; and
- Ongoing research and development activities associated with all of the above.

State-of-the-art

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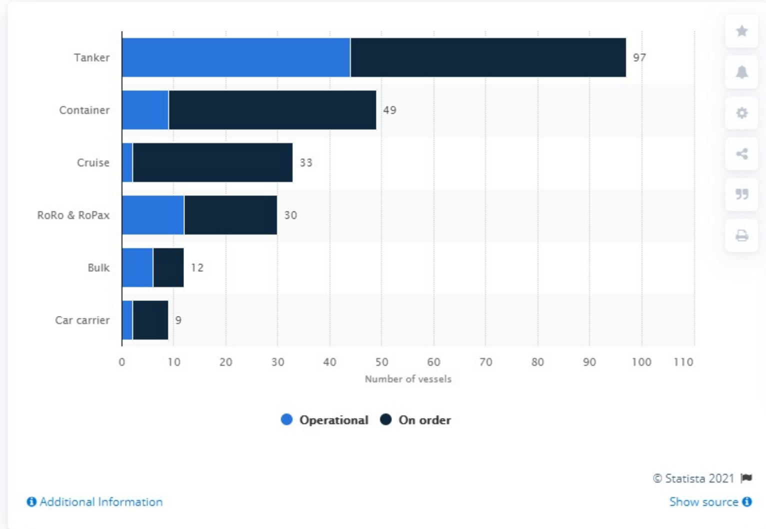
- LNG propulsion is now mature technology, being applied in many ship types including a variety in Arctic service.

Number of LNG-fueled vessels worldwide in 2019, by type



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Achievements

- Safety record of LNG-fuelled vessels is excellent, with no significant incidents to date;
- A wide range of standards and guidelines have been developed for equipment and operations;
- Medium and small scale LNG production enables ship and other transportation fuel uses;
- LNG bunkering technologies for small, medium and large scale ship refuelling have advanced rapidly, with new small-scale LNG carriers as bunkering vessels

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Issues

- Availability of LNG for bunkering (ship refuelling) remains patchy in most parts of the world;
- Capital cost is a barrier to adoption, though investments can pay back for many ship types;
- LNG tanks are difficult to install in some smaller/high density ship types, due to lower energy density and containment safety requirements;
- Environmental impacts will be of increasing concern, though methane slip from newer installations is much reduced.

Arctic LNG

- LNG production, storage and distribution requires cryogenic temperatures – Arctic conditions are beneficial!
- Building infrastructure is always challenging.
- Russian large-scale LNG is developing rapidly.

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Task 2 - Economics

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- Considers a set of scenarios for LNG-fuelled vessels in the Canadian Arctic
- Scenario choice based on traffic patterns and initial screening of ship types:
  - Small vessels; e.g. tugs, private yachts, fishing vessels pose major challenges and have not been included at this time.
- Scenarios are used in both economic and environmental impact analysis in Tasks 2 and 3.

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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)

Particulars/Profile - Cargo

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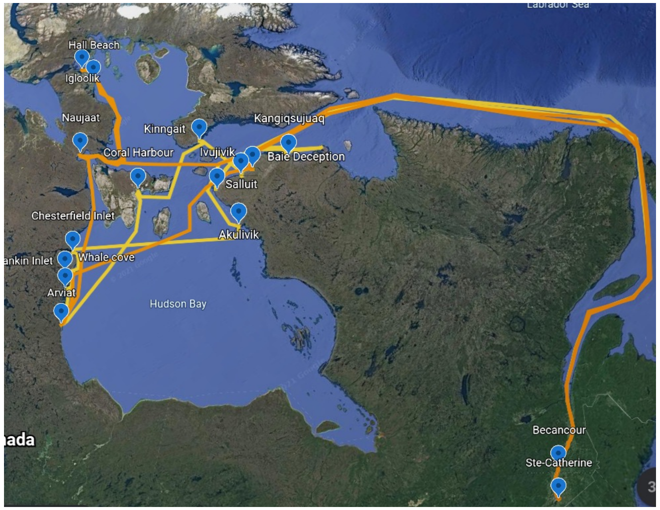
Vessel Particulars		A2
Cargo		General Cargo
Length	(m)	140.00
Breadth	(m)	21.00
Draft	(m)	8.00
Gross Tonnage	(MT)	10000
Deadweight	(MT)	15000
Speed	(kts)	15
Power	(kW)	6,000
Passenger Cap		n/a
Crew		25
Ice Class		PC 7
Engine Type		Slow Speed
Fuel tank volume	(m³)	550



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Particulars/Profile - Tanker

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

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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Particulars/Profile– LNG Carrier

Vessel Particulars		A5
Cargo		LNG Carrier
Length	(m)	134
Breadth	(m)	22
Depth	(m)	15
Draft	(m)	5.66
Gross Tonnage	(MT)	10000
Net Tonnage	(MT)	
Deadweight	(MT)	7000
Speed	(kts)	13
Power	(kW)	8,000
Passenger Cap		n/a
Crew		20
Ice Class		PC 6
Engine Type		Medium speed DE

Particulars/Profile– I/B Bulker

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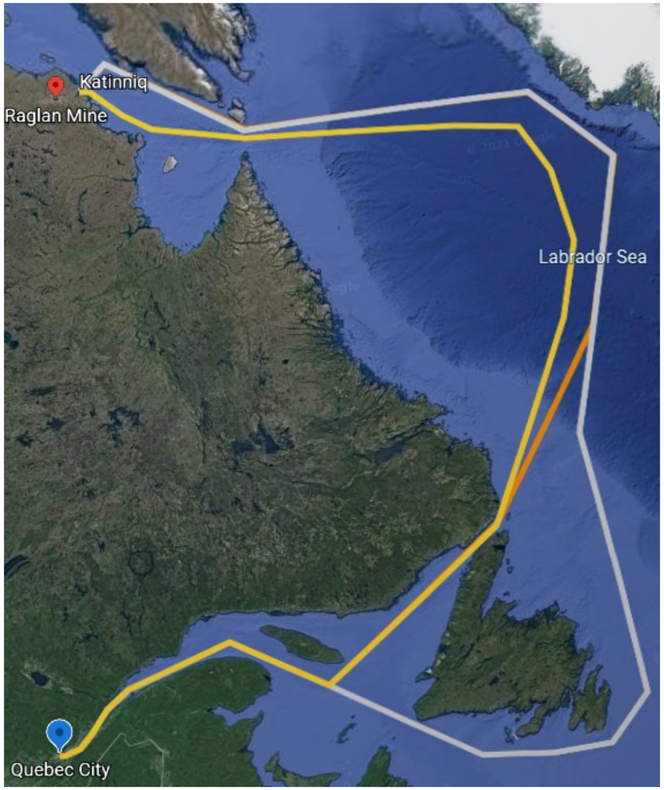
Vessel Particulars		A6
Cargo		I/B Bulker
Length	(m)	190.00
Breadth	(m)	26.50
Depth	(m)	18.00
Draft	(m)	12.00
Gross Tonnage	(MT)	22000
Deadweight	(MT)	32000
Speed	(kts)	13
Power	(kW)	22,000
Passenger Cap		n/a
Crew		20
Ice Class		PC 4
Engine Type		Slow speed
Fuel tank volume	(m^3)	2200



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Particulars/Profile– Icegoing Bulker

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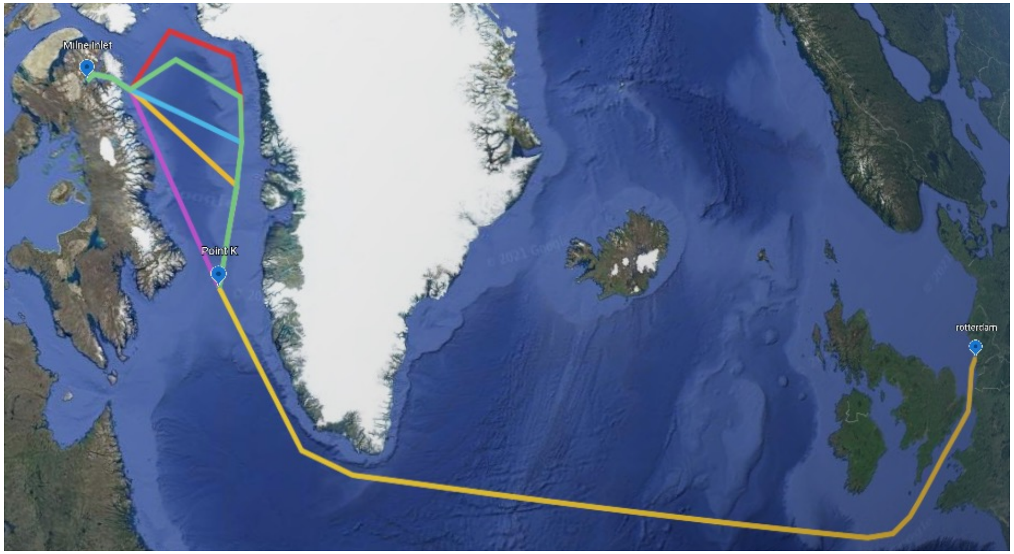
Vessel Particulars		A7
Cargo		Icegoing Bulker
Length	(m)	225.00
Breadth	(m)	32.00
Depth	(m)	20.00
Draft	(m)	14.50
Gross Tonnage	(MT)	40000
Deadweight	(MT)	75000
Speed	(kts)	13
Power	(kW)	14,500
Passenger Cap		n/a
Crew		20
Ice Class		PC 7
Engine Type		Slow speed
Fuel tank volume	(m^3)	2500



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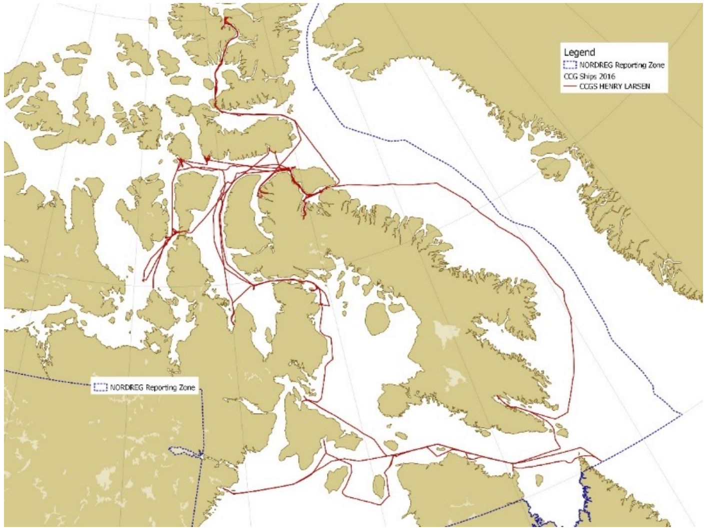
Particulars/Profile – CCG Icbreaker

Vessel Particulars		A2
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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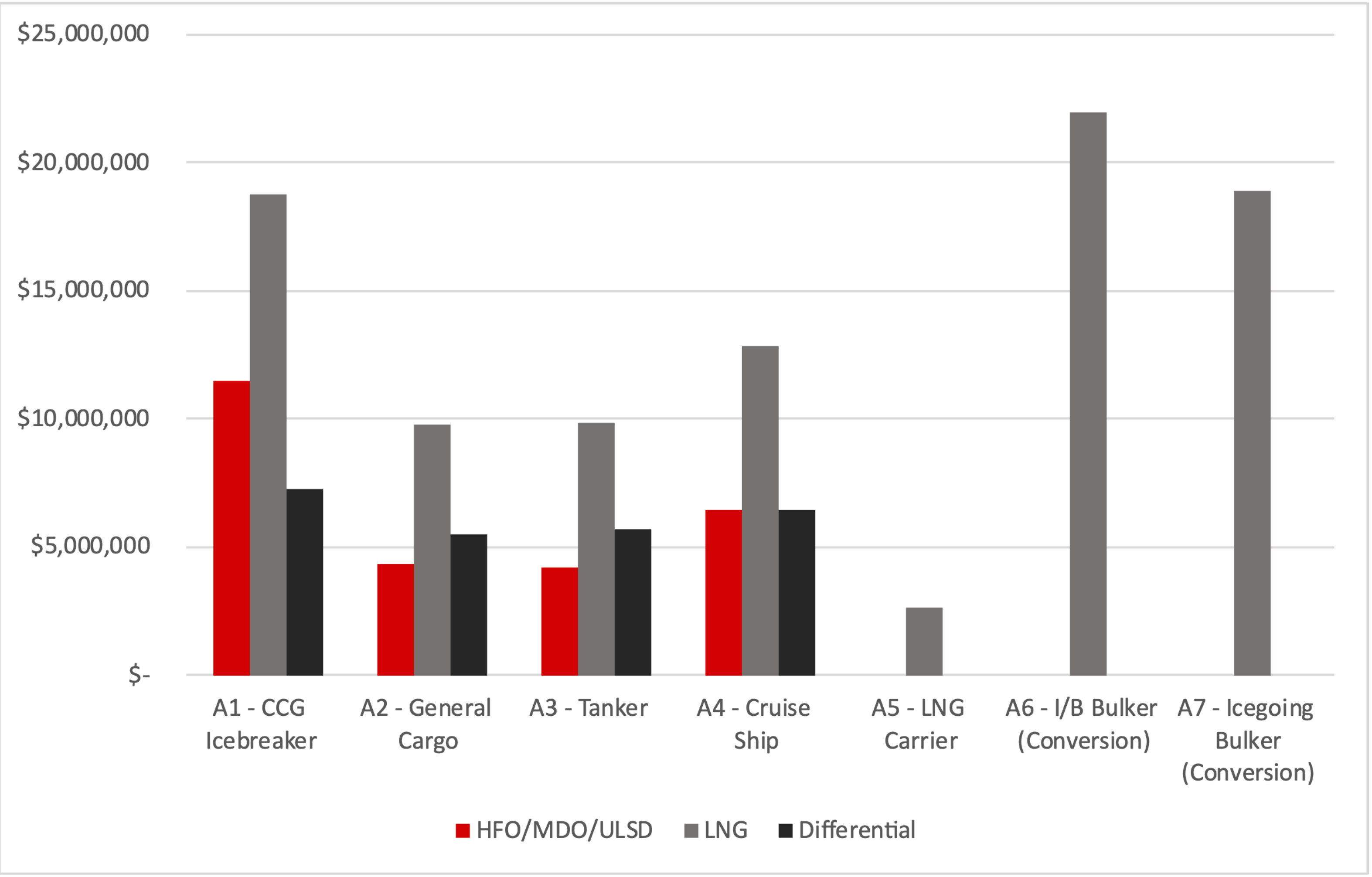
Propulsion System Capital Cost



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Fuel Use and Engine Assumptions

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Base (Case 1)

	Fuel	Sulphur	Engine Type
A1 - CCG Icebreaker	ULSD	0.015%	Medium Speed Diesel 4 Stroke
A2 - General Cargo	HFO	0.50%	Slow Speed Diesel 2 Stroke
A3 - Tanker	HFO	0.50%	Slow Speed Diesel 2 Stroke
A4 - Cruise Ship	MDO	0.10%	Medium Speed Diesel 4 Stroke
A5 - LNG Carrier	-	-	-
A6 - I/B Bulker	HFO	0.50%	Slow Speed Diesel 2 Stroke
A7 - Icegoing Bulker	HFO	0.50%	Slow Speed Diesel 2 Stroke

Future (Case 2)
Diesel – no HFO

	Fuel	Sulphur	Engine Type
A1 - CCG Icebreaker	ULSD	0.015%	Medium Speed Diesel 4 Stroke
A2 - General Cargo	MDO	0.10%	Slow Speed Diesel 2 Stroke
A3 - Tanker	MDO	0.10%	Slow Speed Diesel 2 Stroke
A4 - Cruise Ship	MDO	0.10%	Medium Speed Diesel 4 Stroke
A5 - LNG Carrier	-	-	-
A6 - I/B Bulker	MDO	0.10%	Slow Speed Diesel 2 Stroke
A7 - Icegoing Bulker	MDO	0.10%	Slow Speed Diesel 2 Stroke

Future (Case 3)
LNG

	Fuel	Engine Type
A1 - CCG Icebreaker	LNG	Medium Speed Otto 4 Stroke Dual Fuel
A2 - General Cargo	LNG	Slow Speed Diesel 2 Stroke Dual Fuel
A3 - Tanker	LNG	Slow Speed Diesel 2 Stroke Dual Fuel
A4 - Cruise Ship	LNG	Medium Speed Otto 4 Stroke Dual Fuel
A5 - LNG Carrier	LNG	Medium Speed Diesel 2 Stroke Dual Fuel
A6 - I/B Bulker	LNG	Slow Speed Diesel 2 Stroke Dual Fuel
A7 - Icegoing Bulker	LNG	Slow Speed Otto 4 Stroke Dual Fuel

Assumptions: No fuel switching and no scrubbers.

Specific Fuel Consumption (SFC) (g/kWh)

- All engine SFC ratings to come from Fourth IMO GHG Study 2020

Table 19 – *The SFC_{base} given in g/kWh for different engine and fuel types, and year of built*

Engine Type	Fuel Type	Before 1983	1984-2000	2001+
SSD	HFO	205	185	175
	MDO	190*	175*	165*
	MeOH**	N/A	N/A	350*
MSD	HFO	215	195	185
	MDO	200*	185*	175*
	MeOH**	N/A	N/A	370*
HSD	HFO	225	205	195
	MDO	210*	190*	185*

Engine Type	Fuel Type	Before 1983	1984-2000	2001+
LNG-Otto (dual-fuel, medium-speed)*	LNG	N/A	173*	156*
LNG-Otto (dual-fuel, slow-speed)*	LNG	N/A	N/A	148 LNG + 0.8 MDO (pilot)*
LNG-Diesel (dual-fuel)*	LNG	N/A	N/A	135 LNG + 6.0 MDO (pilot)*
LBSI*	LNG	N/A	156*	156*
Gas Turbines**	HFO	305	305	305
	MDO	300	300	300
	LNG	N/A	N/A	203*
Steam Turbines (and boilers)**	HFO	340*	340*	340*
	MDO	320*	320*	320*
	LNG	285*	285*	285*
Auxiliary engines	HFO	225	205*	195*
	MDO	210*	190*	185*
	LNG	N/A	173*	156*

* Refer to a change from the *Third IMO GHG Study 2014*.

** The conversion of SFC_{base} between fuels was done using the following assumed energy densities: For HFO is 40,200 kJ/kg; MDO uses 42,700 kJ/kg; LNG uses 48,000 kJ/kg and Methanol is assigned 19,900 kJ/kg (International Maritime Organization, 2018).

The resultant main engine SFC empirical equation, which is as well used in this study, is given as follows:

$$SFC_{ME,i} = SFC_{base} \cdot (0.455 \cdot Load_i^2 - 0.710 \cdot Load_i + 1.280) \qquad (10)$$

Fuel Cost

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

Annual Fuel Cost, baseline

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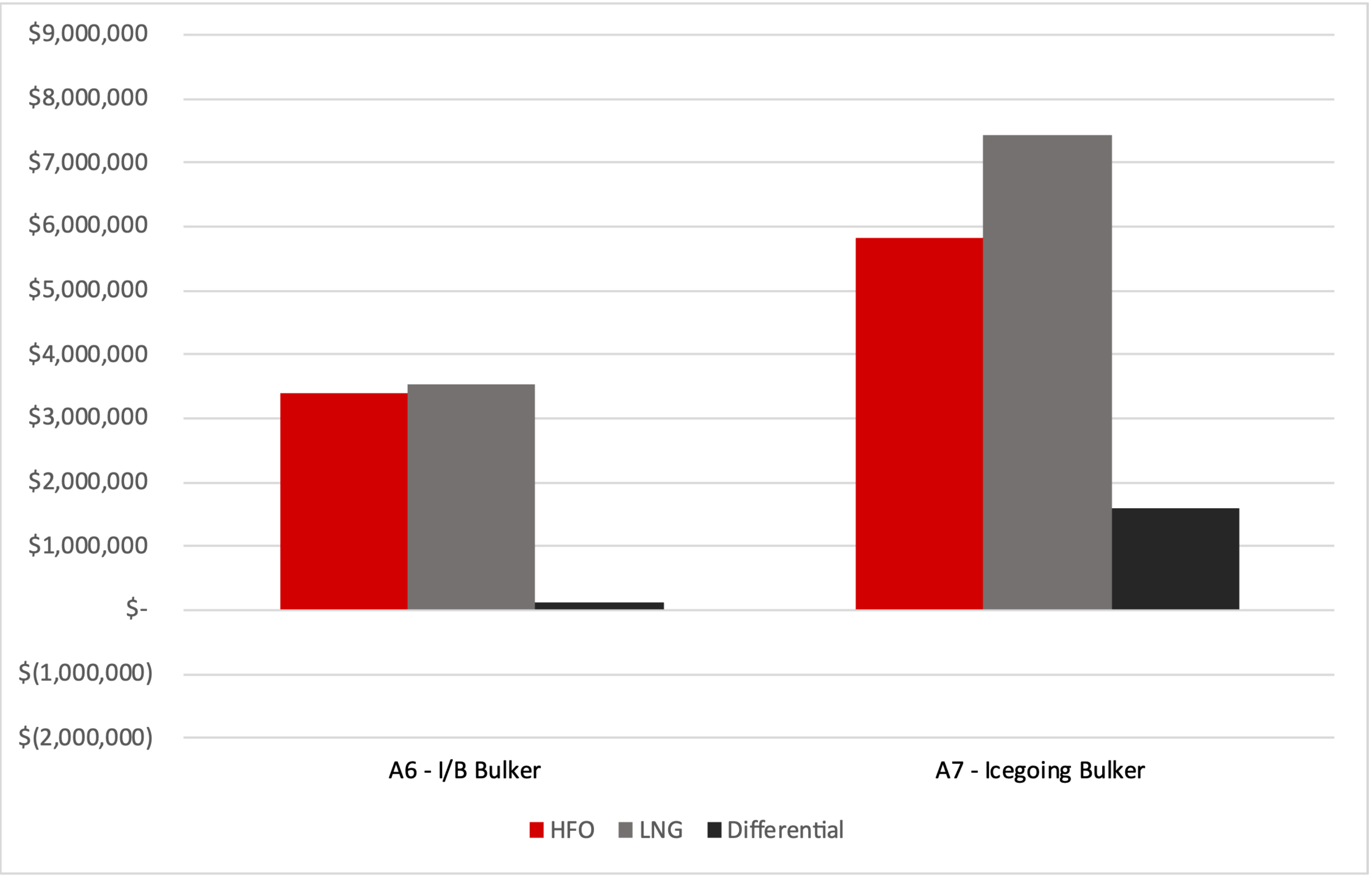

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Annual Fuel Cost vs MDO

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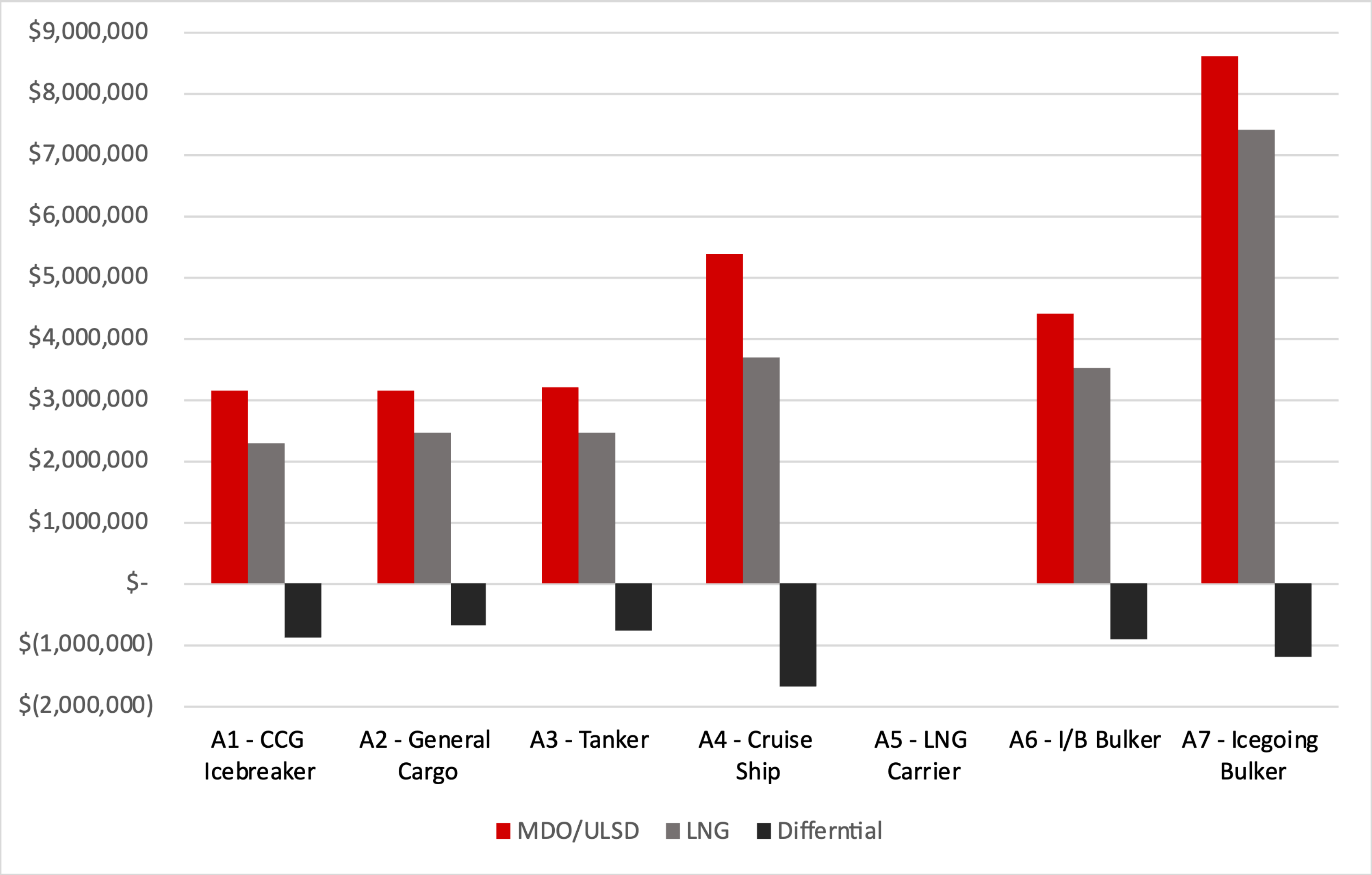

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Payback Periods

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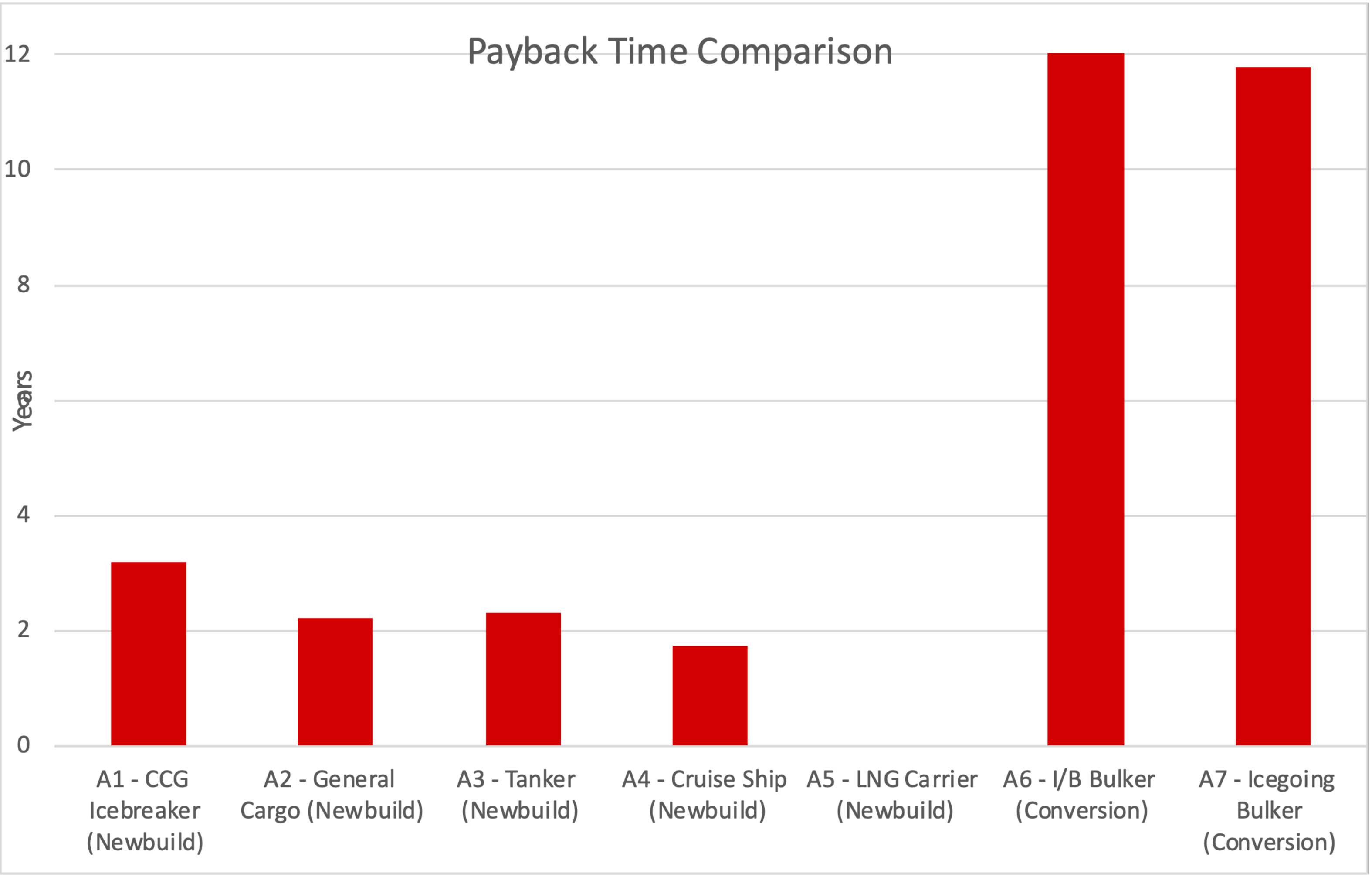

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Sensitivity Analyses

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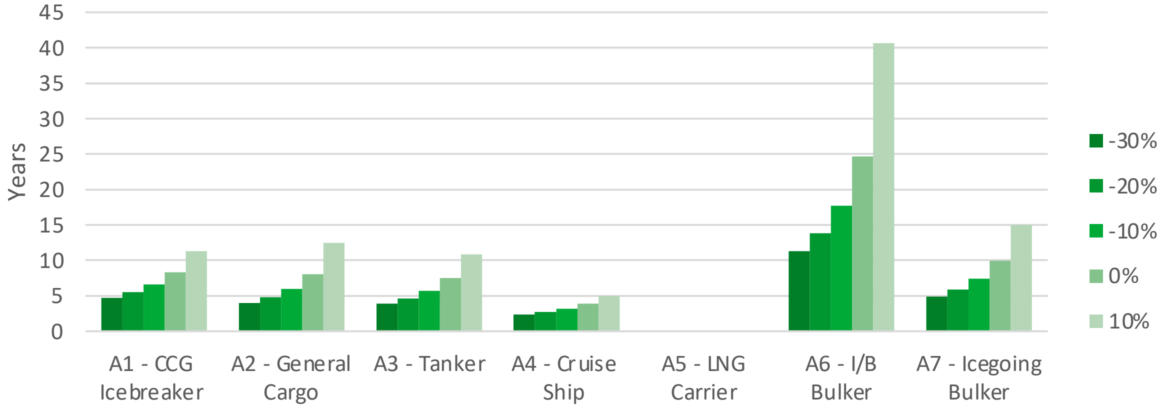
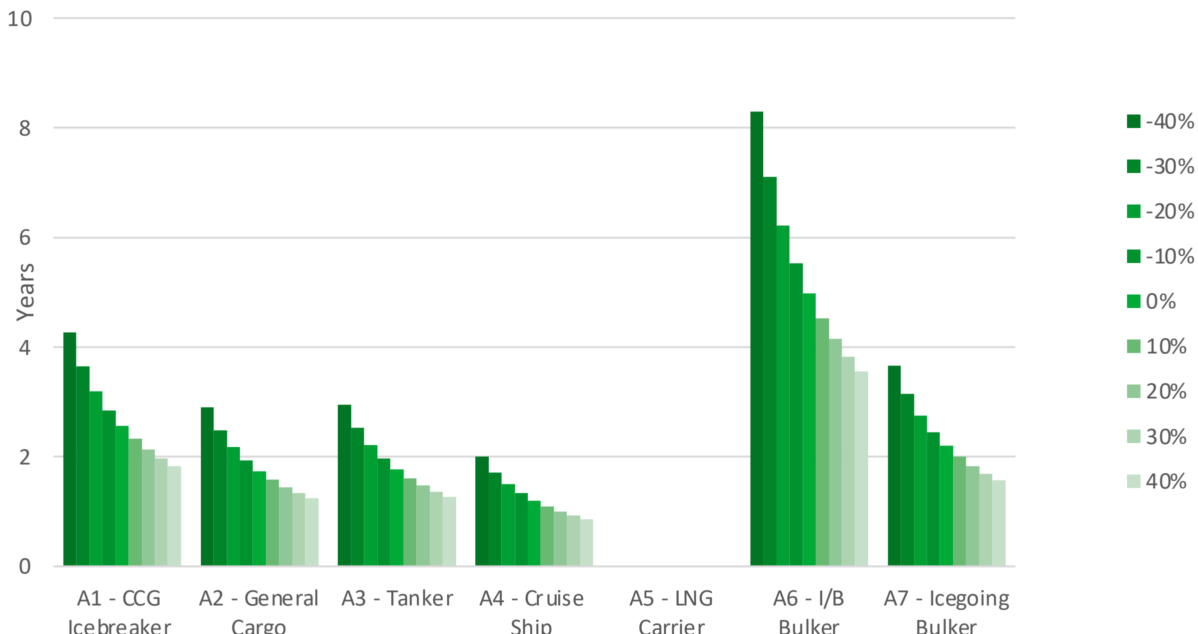


MDO $800.00/MT



LNG $720.00/MT

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Conclusions – Task 2

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- All base case analyses based on current LNG “spot” prices, which are historically high due to energy crunch.
- LNG is still reasonably attractive as a newbuild option for many ship types operating on MDO, with fuel savings offsetting capital cost.
- HFO is currently a lower cost option, but use in the Arctic will not be possible after 2029.
- Future changes in fuel cost, including impacts of differentiated carbon taxes may improve the attractiveness of LNG options.

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