Environmentally Superior LNG-Fueled Vessels

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With increasing demand for environmental protection and improvements in marine vessel operations, the International Maritime Organization (IMO) has adopted the Energy Efficiency Design Index (EEDI) for the control of emissions of nitrogen oxide (NO_X) and sulfur oxide (SO_X), as well as carbon dioxide (CO_2) per ton mile. As one of the promising solutions for the reduction of exhaust emissions from vessels, switching from conventional heavy fuel oils to liquefied natural gas (LNG) is being studied and pursued. This article describes concept vessels that use LNG fuels to reduce environmental impact, as developed by Mitsubishi Heavy Industries, Ltd. (MHI).

1. Introduction

The IMO Tier III limits on NO_X, which come into effect in 2016, are considered difficult to achieve even with an 80-percent reduction from the Tier I standard and further technological improvements in inner engine combustion. As such, the adoption of a combination of various technologies or a different approach is required. Furthermore, the EEDI requirements on CO_2 conflict with NO_X-reduction technology. In terms of SO_X regulations, the sulfur content of fuel oil within Emission Control Areas (ECAs) will be reduced to no more than 0.1 percent, effective in 2015, followed by a global 0.5 percent fuel sulfur limit coming into force in 2020. This will require technological innovation such as a transition to low-sulfur fuels and the implementation of desulfurization equipment.

As one effective solution to meeting such reduction limits, switching from conventional heavy fuel oils to LNG can potentially enable a significant reduction in NO_X emissions. In addition, LNG does not contain sulfur and is thus free of SO_X emissions. LNG fuels are also very promising due to the fact that CO_2 emissions during combustion are becoming quite low. After reviewing the issues surrounding the use of LNG fuels in vessels, MHI has developed LNG-fueled ROPAX (roll on/roll off passenger) and VLCC (very large crude carrier) vessels that significantly reduce environmental impact.

2. IMO environmental regulations

2.1 ECA

At the 53rd session of the IMO Marine Environment Protection Committee (MEPC) in 2005, portions of the Baltic Sea and the North Sea were designated as ECAs. At MEPC 59 in 2009, areas within 200 nautical miles of U.S. and Canadian shores were also included. The ECA designation will be further extended and the phased introduction of tighter standards is being implemented. In particular, Tier III NO_X limits taking effect in 2016 will target an 80-percent reduction from the Tier I standard within ECAs (**Figure 1**). In terms of SO_X regulations, the sulfur content of fuel oil within ECAs will be reduced to no more than 0.1 percent, effective 2015 (**Figure 2**).

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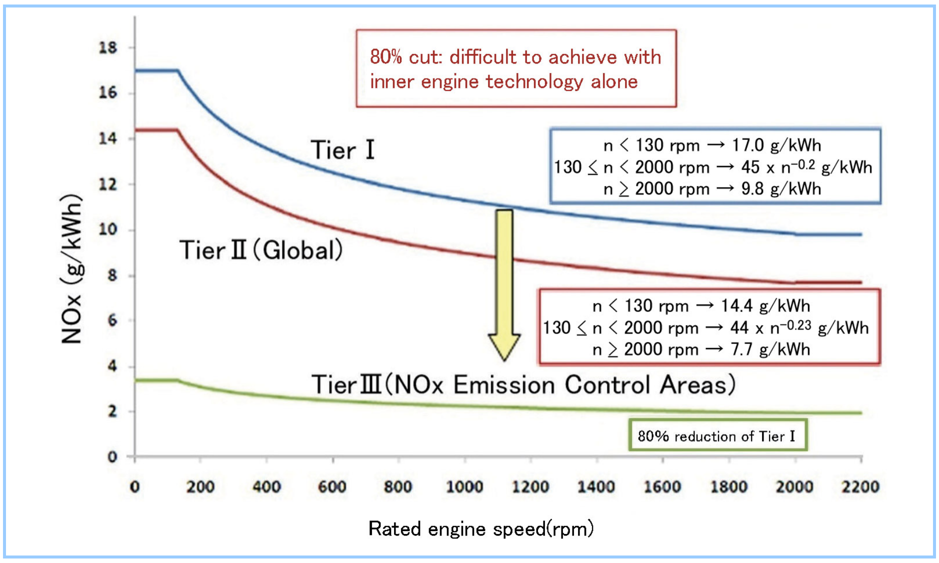


Figure 1　IMO NO_X standards

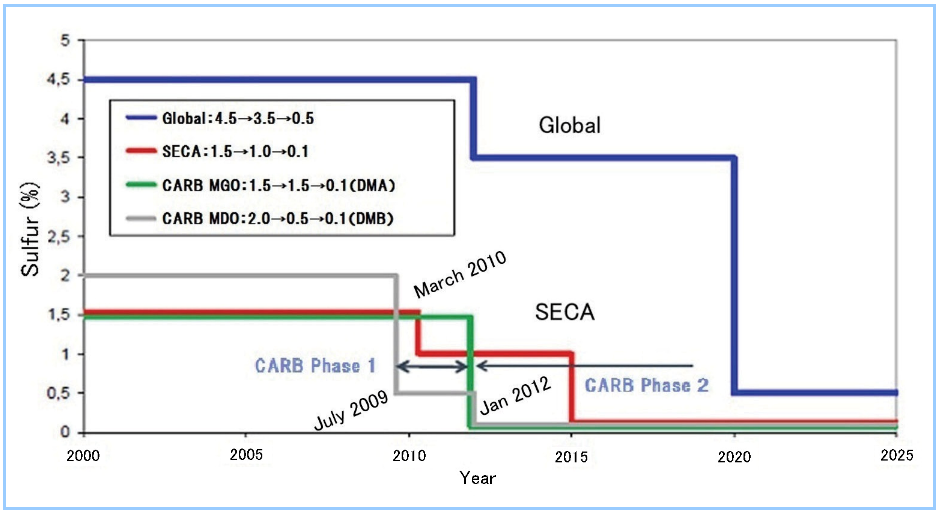


Figure 2　Fuel sulfur standards of IMO and CARB

2.2　ECA compliance through use of fuel oil

Several fuel oil-related methods are being examined by engine manufacturers to accommodate the ECA standards. SO_X limits can be addressed through the use of low-sulfur fuel oils. Also being pursued and put to use is a device that cleans the exhaust gas with sea water or fresh water (injected with neutralizing agents) and thus reduces the SO_X content to the regulated level (**Figure 3**).

Meanwhile, NO_X emission reduction involves a wide range of issues and approaches depending on the engine model. Technologies being examined include exhaust gas denitration equipment (**Figure 4**) and an exhaust gas re-circulation system (**Figure 5**).

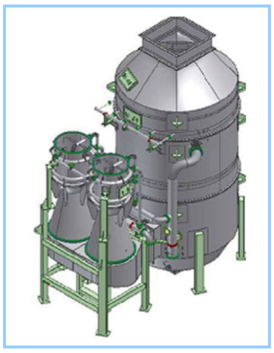


Figure 3 Exhaust gas desulfurization equipment

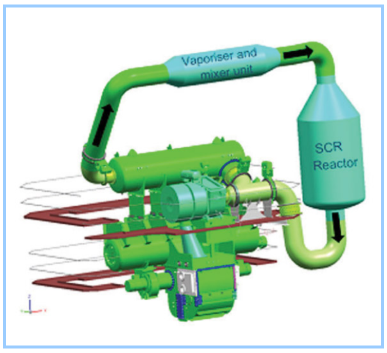


Figure 4　Exhaust gas denitration equipment

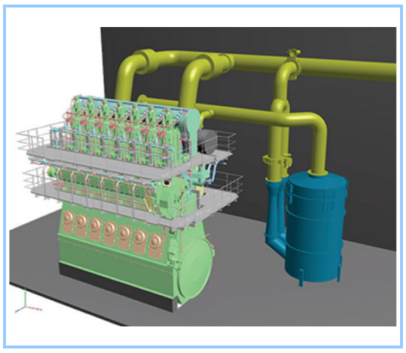


Figure 5　Exhaust gas re-circulation system

2.3 ECA compliance through use of LNG fuel

Switching from fuel oils to LNG fuels, especially in a 4-cycle engine, has proven not only to achieve compliance with the most stringent regulations, but also to result in environmental performance that far exceeds such standards. In spark-ignition gas engines in particular, SO_X and particulate matter (PM) in the exhaust gas can be reduced by almost 100 percent, while also reducing NO_X and CO_2 by more than 90 percent and 20 percent, respectively (**Figure 6**). A major issue with current 4-cycle engines, however, is methane slip of 1-2 percent (emissions of unburned methane, which has a Global Warming Potential (GWP) 25 times that of CO_2). The development of methane slip reduction technology is ongoing.

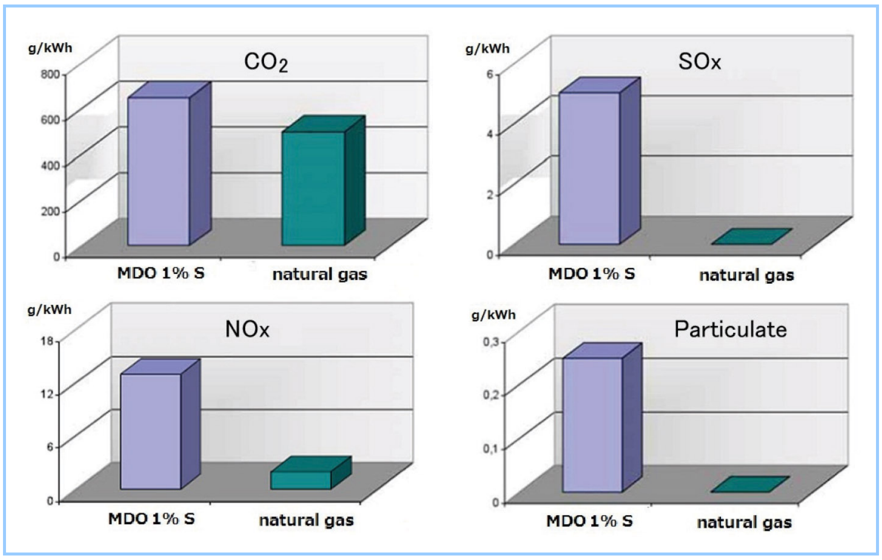


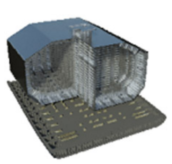
Figure 6 4-Cycle engine emissions comparison between marine diesel oil (MDO) and LNG

3. Issues in LNG-fueled vessels

3.1 LNG tank system

Tanks are categorized in five shapes and types as shown in **Table 1**. Each has advantages and disadvantages and requires widely different ancillary facilities. As such, an appropriate tank system must be selected based on multiple requirements such as mode of operation, fuel consumption and LNG tank space.

Table 1 LNG tank system

Tank type	Prismatic tank	Spherical tank	Cylindrical tank		Tank truck
					
IMO type	B	B or C	C		
Heat insulation	External		External	Vacuum	Vacuum
Max. pressure	0.7 bar	1 bar	10 Bar		10 Bar
Space efficiency	High	Low	Medium		Low/Medium
Gas delivery	Pumping Out		Pressure Built-Up Type		
Design cost	High	Medium	Low	Low	-
BOG treatment	Necessary		Not Necessary		
Suitable cap.	>5,000m^3	>5,000m^3	30-1,000m^3	30-1,000m^3	<100m^3
Cost	High	High	Medium	Medium	Low/Medium

3.2 LNG-fueled propulsion plant

LNG-fueled engines include gas-only, dual-fuel (2-cycle low-speed and 4-cycle mid-speed), and steam turbine systems as shown in **Table 2**. In general commercial vessels, the use of a turbine plant is unlikely. When fitted with a gas-only engine system, the IMO International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk Code (IGF Code) requires the installation of a backup LNG tank and propulsion system, neither of which is required with a dual-fuel engine system. **Figure 7** shows a comparison of the environmental impact of DF low-speed and mid-speed engines and LNG-fueled re-heat steam turbines versus a heavy oil-fueled low-speed diesel engine, which is the most fuel-efficient system currently available. The comparison indicates that the fuel-efficient DF low-speed diesel engine performs best in terms of CO_2 emissions. By contrast, emissions from the steam turbine are near zero, with the exception of a slightly elevated CO_2 Emissions level.

Table 2 LNG fueled engine

	Gas Engine 4 Cycle	Dual Fuel diesel 4 Cycle	Dual Fuel diesel 2 Cycle	Steam Turbine
Pilot fuel	Spark igniter	Micro pilot fuel	Micro pilot fuel	--
LNG Tank required	2-tanks or more	1-Tank		
NO_X-Tier III	Meet	Meet	Additional treatment unit	Meet
Stand-by propulsion	Needs	--	--	--
Emergency	Change over to stand-by propulsion	Change over to H.F.O.	Change over to H.F.O.	Change over to H.F.O.
Remarks	Methane slip 1~2%	Methane slip 1~2%	Gas burning >20% load	Limited operator

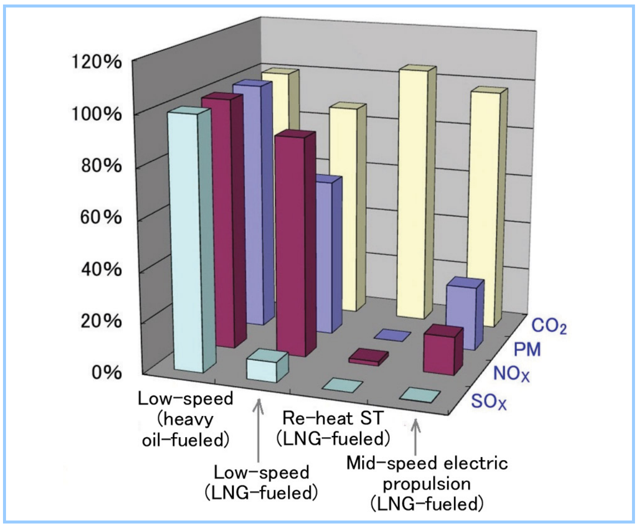


Figure 7 LNG-fueled engine emissions comparison

4. Concept design of LNG-fueled vessel: ROPAX

The concept design of the LNG-fueled ROPAX vessel is described as follows:

Passenger capacity: 600/ Trailer capacity: 150/ Normal speed: 23 knots (Cruising range: 450 nautical miles)

4.1 Selection of LNG tank system

Due to the mode of operation, fuel consumption and restricted LNG tank space of a coastal ROPAX vessel, vacuum-insulated pressure vessels have been adopted for the LNG tank system. The pressure vessel design enables LNG fuels to be supplied to the main engine via a pressure build-up unit. In addition, as the system does not require a boil-off gas (BOG) treatment device, the overall design is simpler compared to other tank systems. From a safety perspective, the desirable location for the tank system is the exposed deck on the stern, away from the passenger area. On the coastal ROPAX vessel used this time, however, the total weight of the LNG tanks and the electric propulsion system (described in the next section) is around several hundred tons. Therefore, in order to maintain stability and trim and to minimize the impact on propulsion performance, the tank system is fitted below deck in the area adjacent to the forward side of the engine room at the middle of the ship (**Figure 8**).

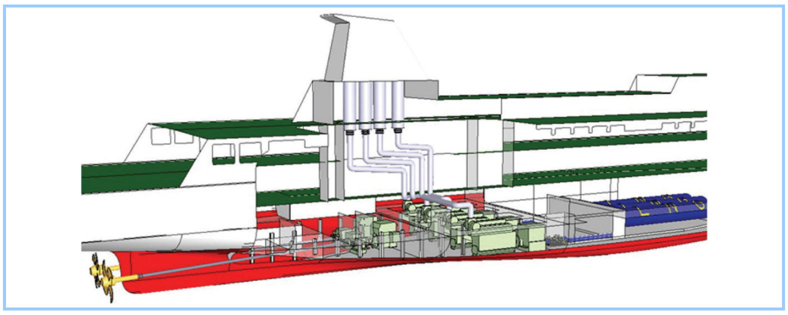


Figure 8 ROPAX: Arrangement of LNG- fueled propulsion plant

4.2 LNG-fueled propulsion plant

In order to accommodate the ROPAX vessel's engine room location requirements and to avoid knocking due to engine load fluctuations while cruising, as well the risk of gas trip, the plant combines a dual-fuel 4-cycle mid-speed engine and a dual-shaft electric propulsion system (**Figure 9**). **Table 3** shows a comparison of the environmental impact of the concept vessel and an existing ROPAX vessel. By switching from the heavy-oil fueled, mid-speed direct-drive diesel dual-shaft propulsion plant to the LNG-fueled dual-fuel mid-speed diesel dual-shaft electric propulsion plant, a 25-percent CO_2 reduction, an 87-percent NO_X reduction, and a 98-percent SO_X reduction were achieved, even with the decrease in fuel efficiency due to electric conversion loss. These reductions are far below the IMO limits, thus indicating superior environmental performance.

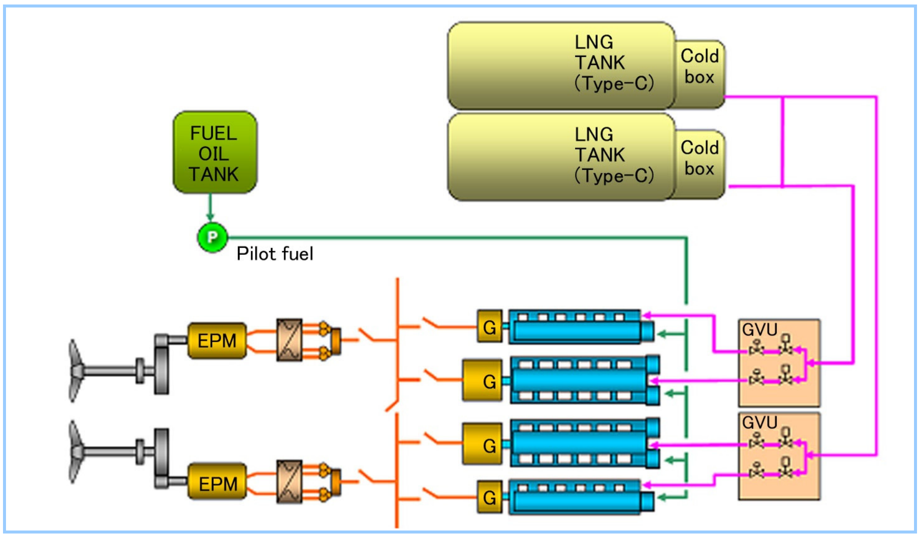


Figure 9 ROPAX: LNG-fueled propulsion plant

Table 3 ROPAX emission comparison

ROPAX emission calculation

(HFO.:3% S, MDO:0.5%)

		Conventional twin CPP diesel driven	4Cyc. DFDE with LNG as fuel	
PAX		600		
Trailers / Cars	12m Trailers	155		
	Cars	50	--	
Vessel speed		23 kts		
Main propulsion eingine		12,000 kw x 2sets	--	
Main generator		--	8,400 kw x 2sets	
Auxiliary generator		1,270 kw x 3sets	5,400 kw x 2sets	
Operation hours / Voyage		19.5 hrs		
Voyage days / year		300 days		
Fuel consumption / year	FO. (k-ton/y)	26	0.2	
	LNG (k-ton/y)	--	23	
Emission	CO_2 (k-ton/y)	82	62	-25%
	NO_X (ton/y)	1,398	233	-83%
	SO_X (ton/y)	1,432	28	-98%

Tier III NO_X and SO_X regulations all satisfied with use of LNG fuel

5. Concept design of LNG-fueled vessel: VLCC

The concept design of the LNG-fueled VLCC is described as follows (**Figure 10**).

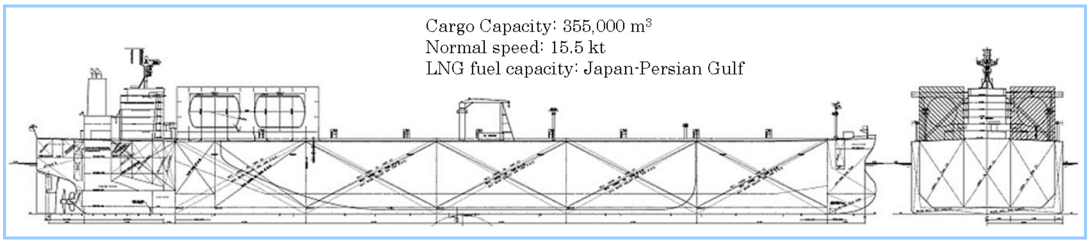


Figure 10 LNG-Fueled VLCC vessel general arrangement

5.1 Selection of LNG tank system

Based on a Japan-Persian Gulf roundtrip, VLCC vessels require large LNG tanks with a capacity exceeding 8,000m^3, thus the vacuum insulated system is not applicable. As the exposed upper deck has no particular space restrictions for the tanks, horizontally-placed cylindrical Type-C tanks with exterior insulation were selected.

5.2 LNG-fueled propulsion plant

Based on the propulsion power, fuel efficiency and waste heat recovery power plant required for VLCC vessels, the DF low-speed diesel engine was selected. The LNG is pressurized and raised to the normal temperature in high-pressure pumps before being supplied as fuel. The auxiliary boiler that supplies steam for turbine-driven cargo pumps is run on dual-fuels. The BOG from the LNG tanks is supplied via the gas heater and burned in the boiler. The turbine generator then uses steam generated by this process to run and generate power, which is recovered as auxiliary propulsion drive via the shaft drive motor (**Figure 11**).

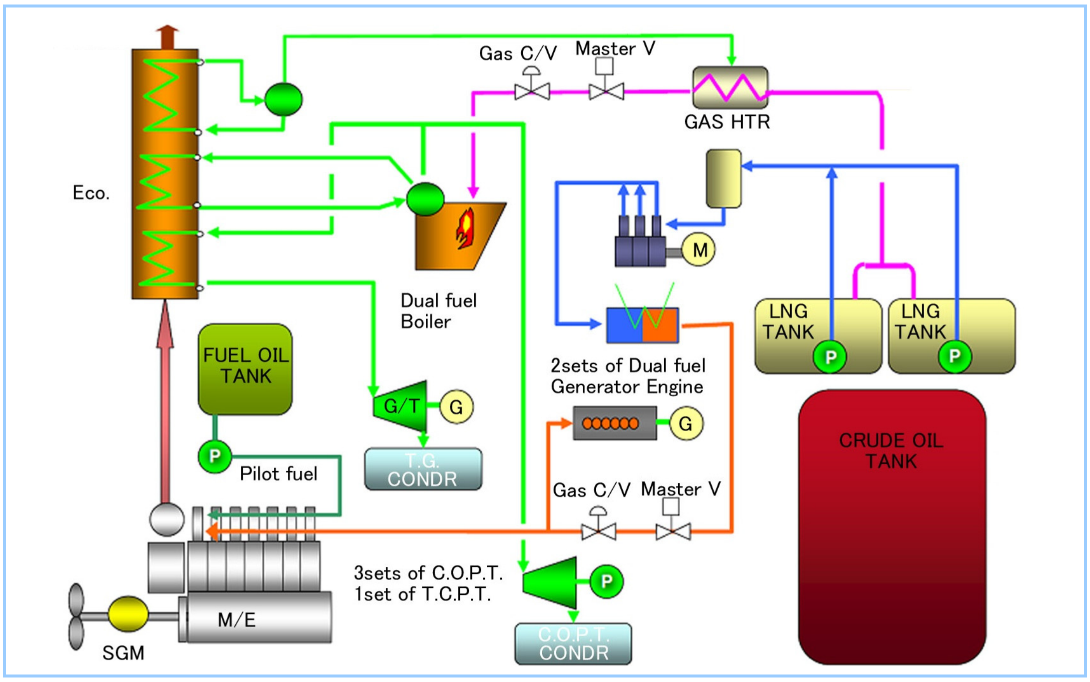


Figure 11 VLCC: LNG-Fueled Propulsion Plant

Table 4 shows a comparison of the environmental impact of the concept vessel and an existing VLCC vessel. By switching from the heavy-oil fueled, low-speed diesel propulsion plant to the LNG-fueled propulsion plant (Plant-A), a 14.4-percent CO_2 reduction, a 12.6-percent NO_X reduction and a 92-percent SO_X reduction were achieved. In addition, when incorporating the latest propulsion capability, the concept vessel is able to further improve its environmental performance with a 29.5-percent CO_2 reduction, a 19.1-percent NO_X reduction and a 92.6-percent SO_X reduction (Plant-B). Other technologies such as EGR must also be combined in order to meet the IMO Tier III NO_X limits.

Table 4 VLCC Emission Comparison

VLCC Emission calculation

H.F.O.:3% S, MDO:0.5% S

Main Propulsion		Slow-speed Diesel (H.F.O)	DF Slow-speed Diesel (LNG) Plant-A		DF Slow-speed Diesel (LNG) Plant-B	
Vessel speed		15.5 kt				
Propusion power		27,000 kw x 76 rpm			25,000 kw x 63 rpm	
Electric. Gene.	T/G	1,100 kw x 1set	2,000 kw×1set		--	
	STG	--	--		2,000 kw x 1set	
	D/G	1,100 kw x 2sets	1,400 kw x 2sets		1,400 kw x 2sets	
	SGM		1,000 kw x 1set		1,000 kw x 1set	
Cargo capacity		355,000	326,000		326,000	
Voyagedays / year		300 days				
Fuel consumption	FO. (ton/day)	90	5.2		5.5	
	LNG (ton/day)	--	81.8		66	
Emission	CO_2 (k-ton/y)	84,605	72,401	-14.4%	59,649	-29.5%
	NO_X (ton/y)	1,913	1,672	-12.6%	1,548	-19.1%
	SO_X (ton/y)	1,811	145	-92.0%	135	-92.6%

SSD-Gi will required additional treatment unit to meet NO_X Tier-III

6. Conclusion

The switch to LNG as a fuel source involves more than just changes in vessel specifications. It is a long process that requires a significant investment in areas such as infrastructure development to transport and supply LNG fuels. Meanwhile, fuel oils continue to face stricter environmental requirements, thus adding value to low-sulfur fuels. Combined with expected CO_2 surcharges, a significant price increase in fuel oils is predicted. As such, when considering the switch to LNG fuels, price trend predictions for fuel oils and LNG fuels become a key deciding factor. So far, the price of gas has followed a similar fluctuation to that of crude oil, while maintaining a certain price gap. In the future, the addition of even cheaper shale gas as another fuel option is likely to further promote the wider adoption of more popular LNG fuels in place of crude oil.