Methanol as a Marine Fuel

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Accelerating climate change has brought about huge changes in the shipping industry. Various alternative fuels are rising for the reduction of GHG (greenhouse gas) emissions, and currently Methanol is receiving great attention as an environmentally-friendly alternative fuel. The main reasons for the current attention to Methanol are as follows:

1. Green Methanol having low GHG emissions intensity, such as bio-Methanol and e-Methanol, can be produced and supplied.
2. Methanol is a liquid at atmospheric pressure and temperature, so the existing facilities and infrastructures can be used without major modifications.
3. Methanol engines have high TRL levels, so Methanol-fueled ships are already viable commercially.

On the other hand, Methanol is a flammable and toxic material, so it should be handled carefully, and the required systems are not identical to LNG-fueled ships. This article aims to describe the characteristics of Methanol as a next-generation alternative fuel for ships and deliver key differences between Methanol and other fuels.

While safety precautions are needed, methanol stands as a next-generation alternative marine fuel.

Blue Methanol and Green Methanol

The GHG emissions intensity of Methanol has a wide range of values depending on feedstocks and production methods. The TtW (Tank-to-Wake) GHG emissions intensity of Methanol is lower than that of fossil fuels. If Methanol is produced from fossil fuels such as natural gas, however, the WtW (Well-to-Wake) GHG emissions intensity, including the production of Methanol, is 100.4 gCO2eq/MJ, which is even higher than that of HFO (Heavy Fuel Oil), as shown in Table 1. That is, Methanol produced from fossil fuels cannot be an environmentally-friendly alternative fuel.

As for Hydrogen, a color classification can be applied according to the production pathway (Fig. 1). Among them, Blue and Green Methanol have lower GHG emissions intensity compared to Methanol from fossil fuels. Green Methanol can be classified into bio-Methanol and e-Methanol. Bio-Methanol refers to Methanol produced from biomass, absorbing CO_2 for growth. E-Methanol refers to Methanol produced by synthesizing renewable CO_2 and Green Hydrogen obtained by electrolyzing water through renewable energy. It should be noted that Methanol produced from non-renewable CO_2 may not be admitted as Green Methanol even when it is synthesized with Green Hydrogen, because the WtW GHG emissions intensity of Methanol produced from non-renewable CO_2 may not be low enough to satisfy the threshold.

In July 2023, MEPC80 selected the concept of a threshold for bio-fuels, so now only bio-fuels reducing more than 65% of WtW GHG intensity can be admitted as a bio-fuel, compared to the WtW GHG intensity of IMO fossil fuel reference, 94 gCO2eq/MJ. In other words, only fuels having a WtW GHG emissions intensity lower than 32.9 gCO2eq/MJ can be admitted as bio-fuels. The discussions for e-fuels are not concluded yet, but when checking the specifications for synthetic fuels in RFNBO (Renewable Fuel of Non-Biological Origin) in FuelEU maritime/REDII, it requires at least 70% reduction of WtW GHG emissions intensity compared to the intensity of the reference fossil fuel. If IMO also adopts the same threshold of 70% reduction for e-fuels, only synthetic fuels having WtW GHG intensity lower than 28.2 gCO2eq/MJ will be able to be admitted as an e-fuel.

If Methanol is synthesized from Green Hydrogen and non-renewable CO_2 or Blue Hydrogen and renewable CO_2, it can be classified as Blue Methanol. Blue Methanol cannot satisfy the threshold WtW GHG intensity required for Green Methanol, but has lower GHG intensity than Grey Methanol. Because the production capacity of Green Methanol is not enough to meet worldwide needs yet, mixed use of Blue/Green Methanol with Grey Methanol is expected in the future, to satisfy the target of GHG reduction.

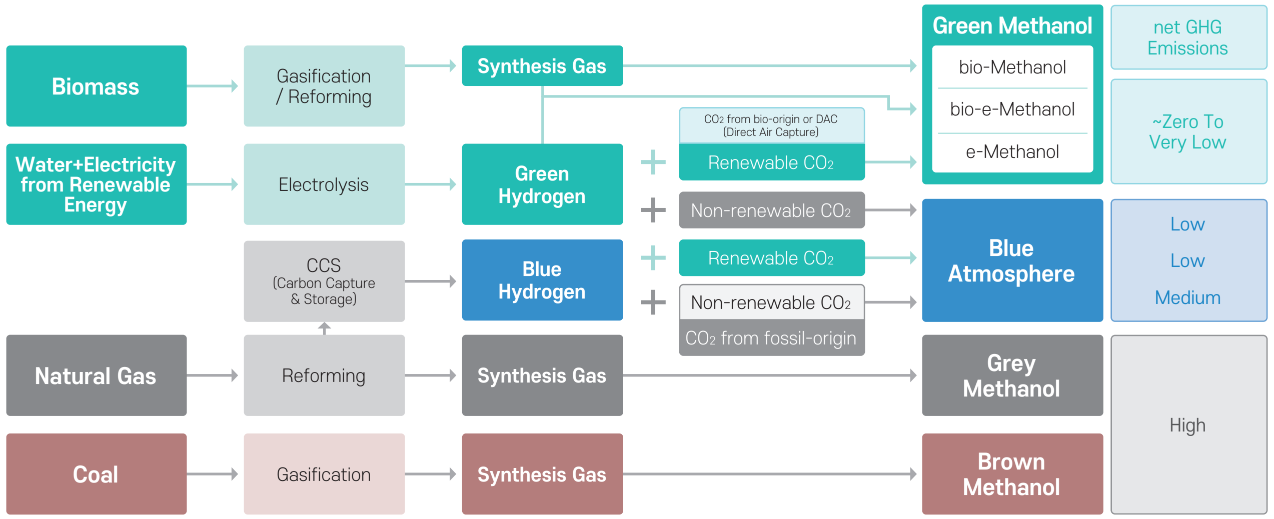
WtW GHG Emissions Intensity of Various Fuels for Ships (Based on REDII/FuelEU Maritime)

LHV: Lower Heating Value; ICE: Internal Combustion Engine; DFMS: Dual Fuel Medium Speed;DFSS: Dual Fuel Slow Speed; OPS: On-shore Power Supply; ILUC: Indirect Land Use Change

Fuel Class	Pathway Name	LHV (MJ/g)	WtT Intensity (g_{CO2eq}/MJ)	Fuel Consumer Unit Class	TtW Intensity (g_{CO2eq}/MJ)	WtW Intensity (g_{CO2eq}/MJ) 1)	Source
Fossil	HFO (ISO 8217 Grades RME to RMK)	0.0405	13.5	All ICEs	78.2	91.7	FuelEU Maritime (EU, 2023)
	LFO (ISO 8217 Grades RMA to RMD)	0.041	13.2		78.2	91.4	
	MDO/MGO (ISO 8217 DMX to DMB)	0.0427	14.4		76.4	90.8	
	LNG (Liquified Natural Gas)	0.0491	18.5	LNG Otto(DFMS)	70.7	89.2	
				LNG Otto(DFSS)	64.4	82.9	
				LNG Diesel(DFSS)	57.6	76.1	
	LPG (Liquified Petroleum Gas)	0.046	7.8	ICE (Butane)	65.9	73.7	
				ICE (Propane)	65.2	73.0	
	H_2 (from Natural Gas)	0.12	132.0	ICE/Fuel Cells	0.0 2)	132.0	
	NH_3 (from Natural Gas)	0.0186	121.0	ICE/Fuel Cells	0.0 2)	121.0	
	Methanol (from Natural Gas)	0.0199	31.3	ICE	69.1	100.4	
Biodiesel	Crop Biodiesel	0.0372	-61.7 to -0.9	All ICEs	76.6	44.7 ~ 50.1	
	Oil Crop Biodiesel					51.6 ~ 75.7	
	Waste Cooking Oil Biodiesel					14.9	
	Animal Fats from Rendering Biodiesel					20.8	
	Fischer-tropsch Diesel	0.044	-54.2 to -47.7		64.4	11.7 ~ 18.2	
Biomethanol	Waste Wood Methanol in Free-standing Plant	0.02	-55.3	All ICEs	68.8	10.4	
	Farmed Wood Methanol in Free-standing Plant		-52.6			13.5	
	Methanol from Black-liquor Gasification		-58.4			16.2	
RFNBO Renewable Fuels of NonBiological Origin (e-fuels)	e-diesel	0.0427	-48.2 or less	ICE	76.4	28.2 or less (based on 70% reduction) 3)	RED II (EU, 2018) / FuelEU Maritime (EU, 2023)
	e-methanol	0.0199	-40.9 or less	ICE	69.1		
	e-LNG	0.0491	-42.5~-29.4 or less	LNG Otto/Diesel	57.6 ~ 70.7		
	e-H_2	0.12	28.2 or less	ICE/Fuel Cells	0.0 2)		
	e-NH_3	0.0186	28.2 or less	ICE/Fuel Cells	0.0 2)		

1) Currently the baseline of IMO fossil fuel WtW GHG intensity (94 gCO2eq/MJ) is not the same as the baseline of FuelEU maritime (91.2 gCO2eq/MJ).
2) Impact of GHGs other than CO2 (CH4, N2O) is not included, but may be revised later.
3) E-fuel qualification criteria is 70% reduction compared to IMO fossil fuel WtW intensity, and biofuel qualification criteria is 65% reduction.

Color Classification Based on Methanol Production Pathway



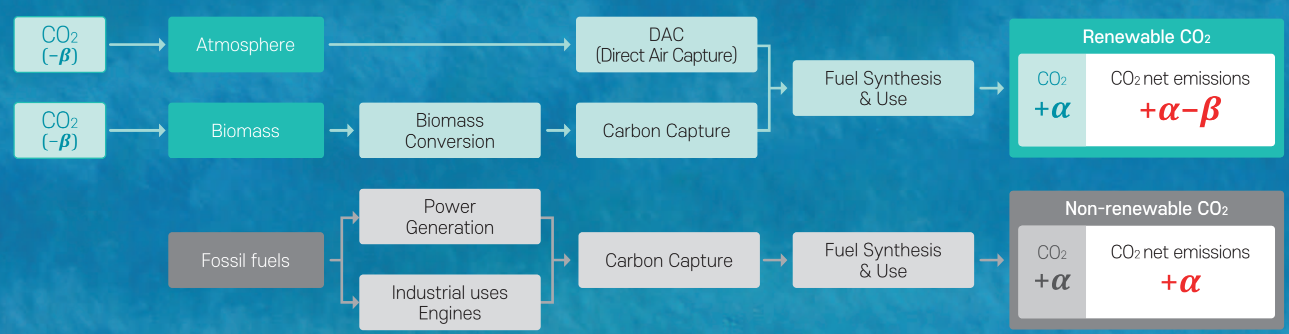
Methanol Engines and Storage

Currently, major engine manufacturers are developing, or have developed, Methanol dual-fuel engines (Table 2). Clarksons Research Services (CRS) reported that 43 Methanol-fueled vessels and 22 Methanol-ready ships were ordered in 2022.

Methanol is a volatile liquid having a boiling point of 64.7°C at atmospheric pressure. It exists as a stable liquid at atmospheric temperature, so there is no need to use low-temperature steel. However, it can be corrosive to some materials, so careful consideration must be given to material selection for tanks and pipes, seals, and other components. The special paint applied to the cargo handling system for a chemical tanker can be also applied to a methanol fuel tank, and then the methanol fuel tank can be manufactured with general shipbuilding steels (AH grade, A grade, etc.). When coating the tank with zinc silicate, the outer structure and the inside of the tank must have flat surfaces without sharp edges. For the special coating, it is important that no support member should be located inside the tank, and outfitting should be minimized for access to the cargo tank.

The energy density of Methanol is lower than that of LNG, but there is no additional requirement for cryogenic insulation and bottom space can be used. Accordingly, the relative size of fuel storage space for Methanol is estimated similar to the required space for LNG, which is around 2.3 times larger than that of MDO/MGO (Table 3) even considering cofferdam. This is about half of the required fuel storage space for liquid Ammonia, and ~30% of the space required for liquid Hydrogen. Several literatures reported that the cargo capacity would be reduced by 1.5 – 4.0 % when a ship using HFO as a fuel is converted to a Methanol-fueled ship. To reduce the loss, it is necessary to prepare the structural elements and systems for Methanol conversion.

Concept of Renewable and Non-renewable CO_2



The Status of Methanol Engine by Engine Developers

Anglo Belgian Corporation (ABC)	Developed the DZD Methanol engine family, consisting of 6- and 8-cylinder inline engines and 12- and 16-cylinder V-engines with outputs ranging from 955 kW to 3,536 kW.
Caterpillar	Cat® 3500E Series engines can be converted to Methanol-fueled propulsion engines.
CSSC Power Research Institute, Anqing CSSC Diesel Engine, and Hudong Heavy Machinery	Developed the M320DM Methanol-fueled engine, which can be applied to a wide range of vessels up to 20,000 GT.
Hyundai Heavy Industries Engine & Machinery Division (HHI-EMD)	Developed a 5,400-hp Methanol dual-fuel power generation engine and received orders for more than 50 engines (as of October 2022).
MAN Energy Solutions	Completed development of ME-LGIM, a two-stroke Methanol dual-fuel engine (accumulated over 145,000 operating hours) and is developing a four-stroke Methanol engine.
mtu Marine solutions (by Rolls-Royce)	Will launch a Methanol engine based on the MTU Series 4000 in 2026 and a Methanol fuel cell in 2028.
Nordhavn Power Solutions A/S	Partnered with ScandiNAOS to offer 13L/6-cylinder and 16L/8-cylinder Methanol engines.
Wärtsilä	Completed development of ZA40S and W32 Methanol engines based on Methanol engine operation experience accumulated since 2015. It will also develop W20 and W46 Methanol engines.
WinGD and HSD Engine	Will complete Methanol engine development in 2024 through a joint development project.

Characteristics of Marine Fuels for Storage

Fuel	LHV (MJ/kg)	Energy Density (GJ/m^3)	Storage Pressure (bar)	Storage Temperature(℃)	Relative Fuel Storage Space*
MDO/MGO	42.7	36.6	1	20	1
LNG	55.6	25.0	1	-162	2.3
Methanol	19.9	15.8	1	20	2.3
Liquid Ammonia	18.6	12.7	1	-34	4.1
			10	20	
Liquid Hydrogen	120.0	8.5	1	-253	7.6

* Relative space is estimated based on a Handymax bulk carrier with a cruising range of 1,000 nm

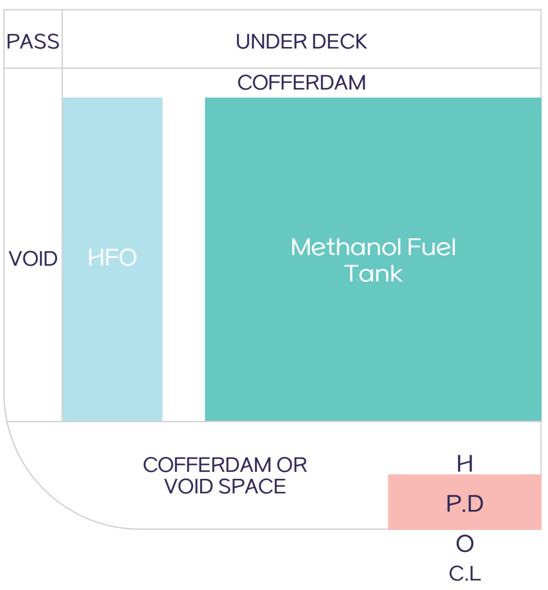
Hazards and Safety of Methanol

Methanol is a corrosive, flammable, and toxic substance, requiring very careful handling. Methanol can be absorbed into the body through ingestion, inhalation, and skin contact. Once absorbed, Methanol is oxidized and changed to Formaldehyde, which becomes Formic Acid by alcohol dehydrogenase, and is finally oxidized and decomposed to water and Carbon Dioxide. However, the decomposition rate of Methanol is very slow, leading to the accumulation of toxic substances such as Formaldehyde in the body, and consequently damage to the human body. The incomplete combustion of Methanol may also form Formaldehyde. Formaldehyde is distributed to various tissues of the body, including cerebrospinal fluid, blood, and urine, and is especially damaging when it is absorbed into the ocular and vitreous humor fluid. It causes atrophy of the optic nerve and retina, leading to blindness. According to the standard of NIOSH (US National Institute for Occupational Safety & Health), the TWA(Time Weighted Average) exposure limit for Methanol is 200 ppm and the STEL (Short-Term Exposure Limit) is 250 ppm for a one-day work period.

To prevent accidents, a Methanol fuel tank should be sealed and isolated from heat and ignition sources. The fuel tank must be electrically grounded, and equipped with spark/explosion-proof equipment, ventilation, and exhaust systems. It should be used outdoors or in an area with ventilation systems and personal protective equipment should be worn if direct contact is required. If swallowed, one should wash the mouth and seek immediate medical attention. If Methanol is in contact with skin or hair, one should immediately take off all contaminated clothing and flush the skin with water. Contaminated clothing should be washed before reuse. When inhaled, one should move to a place with fresh air and take a rest. Fomepizole (or 4-Methylpyrazole) is available for the treatment of Methanol poisoning in the WHO Essential Medicines List.

For Methanol-fueled ships, the IMO's Interim Guidelines for the Safety of Ships Using Methyl/Ethyl Alcohol as Fuel (MSC.1/Circular.1621) is applied and KR applies Appendix 5: Requirement for Ships Using Methyl/Ethyl Alcohol As Fuel in KR Rules for Ships Using Low-flashpoint Fuels. The regulations are based on the IGF Code, but there are differences with LNG because Methanol has clearly different characteristics. Since Methanol exists as a liquid at atmospheric temperature and pressure, cryogenic insulation and a secondary barrier designed to prevent brittle fracture are not required. As a result, unlike LNG or Ammonia fuel tanks, Methanol tanks can be deployed as integral fuel tanks where part of the hull structure belongs to the tank. However, due to the toxicity, a protective cofferdam is required around the Methanol tank (Fig. 3) and should be inerted at all times during normal operation. Fuel piping that passes through enclosed spaces in the ship should be enclosed in a pipe or duct that is gas and liquid tight. Drip trays should be fitted where leakage and spill may occur, and each tray should be provided with means to safely drain spills or transfer spills to a dedicated holding tank.

Example of Methanol Fuel Tank a Arrangement



Price Estimation for Methanol

The price volatility of alternative fuels is very high depending on the period, regions, and feedstocks, making it difficult to draw comparisons. As of 2021, the estimated price of Grey LNG was around \$17.6/GJ, and that of Grey Methanol was around \$20/GJ. However, for a certain period of time, the price of LNG increased more than twice that of Grey Methanol.

Bio-Methanol can be produced from biomass or MSW (Municipal Solid Waste), and the price is estimated at around \$30/GJ, which is relatively low among Green Methanol. On the other hand, the production price of e-Methanol is estimated quite high, at around \$66, and the price increases to more than \$80/GJ in the case of using carbon dioxide from DAC (Direct Air Capture). The cost of electricity from renewable energy has the most significant impact on the production cost of e-Methanol. By achieving high technology readiness of renewable power generation and water electrolysis in the future, the production cost of e-Methanol is expected to gradually decrease. For bio-Methanol, due to the increased demand for biomass, even with mature technology in the future, the decrease in production cost is not expected to be large. Fig. 4 shows the expected change in fuel price for bio-/e-Methanol and other fuels.

Conclusion: Methanol as a Marine Fuel

Methanol is a liquid fuel, so has the advantage of being able to utilize existing liquid storage facilities and infrastructure without major modifications. Methanol engines are already commercialized so Methanol-fueled ships are viable now. Also, Blue Methanol and Green Methanol, having lower GHG intensity, can be produced and used with Grey Methanol to satisfy the regulation for GHG emissions reduction. Currently, the price of bio-Methanol is relatively low, so the demand for bio-Methanol would be high for a considerable period of time. The production cost of e-Methanol would decrease with advanced technologies, then e-Methanol would be able to compete with other alternative fuels.

Methanol is a toxic substance that can be absorbed into the body through ingestion, inhalation, and skin contact, so should be handled very carefully. Distinguished safety regulations such as cofferdams and double-walled pipes need to be applied. Safety education on Methanol for seafarers are not provided sufficiently yet, education and training programs are needed to be prepared.

Fuel Price Forecast for bio-/e-LNG, blue/e-Ammonia, and bio-/e-Methanol