The UUPO project – New fuels for maritime logistics as drivers of green transition and blue growth

Fuel Info Package: Methanol

samk
Satakunta University of Applied Sciences

SATAKUNTALIITTO
Regional Council of Satakunta

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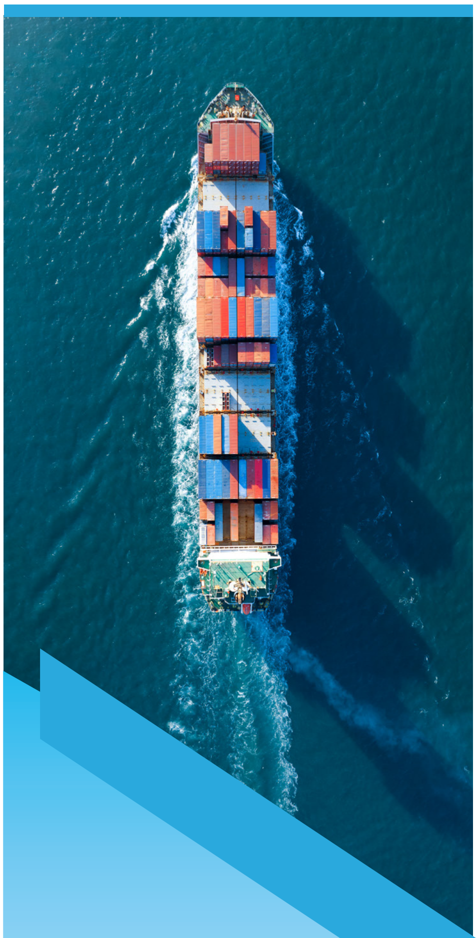
Basic information



Methanol

Methanol (CH_3OH) is a carbon-based compound belonging to the alcohol group, consisting of one carbon atom, three hydrogen atoms, and one hydroxyl group (-OH). At normal temperature and pressure, it is a colorless, easily flammable liquid with an odor characteristic of other alcohols. Methanol is also known as methyl alcohol or wood spirit.

Methanol was produced as a byproduct of the wood industry as early as the first half of the 1800s and was used for various purposes, including lighting, cooking, and heating. The wood industry was the only source of industrial-scale methanol until the 1920s, when methanol began to be produced directly from coal. Two decades later, methanol also began to be produced from natural gas. Today, methanol can be produced in numerous ways, and depending on the production method and the raw materials used, it is categorized into different classes or colors. Typically, these colors are gray, brown, blue, and green. Most of the methanol currently produced is used in the chemical industry for the production of various chemicals, such as formaldehyde. Chemicals made from methanol are critical for various industrial sectors, including the wood and plastics industries. [1]

In maritime applications, methanol is seen as a promising alternative to traditional fossil fuels because it potentially generates lower carbon dioxide emissions. There are already ships operating on methanol, and this number is expected to grow rapidly in the coming years. According to DNV's 2023 assessment, approximately 150 methanol-fueled vessels were on order. [2]

Important notes:

1. Methanol is already in use in the maritime industry

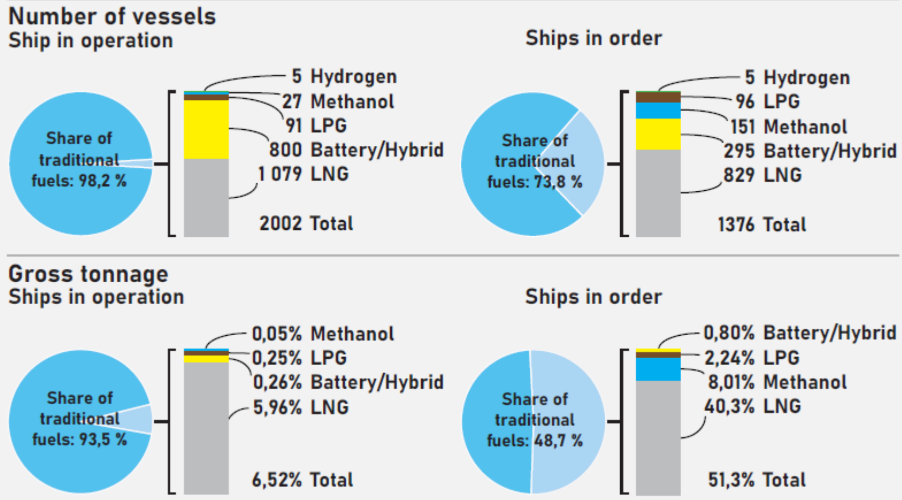
2. Methanol is the fastest-growing alternative fuel after LNG and other methane-based fuels

3. Methanol is a carbon-based fuel, meaning its use results in CO_2 emissions

4. The lifecycle emissions of grey methanol are higher than those of low-sulfur fuel oil (LSHFO)

5. Existing fuel infrastructure can be adapted for methanol use with only minor modifications

Figure 1. Adoption of alternative fuels in the global fleet by the number of vessels (top) and by gross tonnage (bottom), July 2023



Production methods

Methanol can be produced in various ways, but the most common methods are based either on the utilization of syngas or on a reaction where methanol is produced from carbon dioxide and hydrogen.

Gray methanol

The production of gray methanol is based on the steam reforming of natural gas. In the steam reforming process, natural gas is heated with steam in the presence of a catalyst, causing the natural gas and steam to react with each other. The reaction results in the formation of syngas, which mainly consists of carbon monoxide and hydrogen. [3] Methanol is obtained from the syngas by feeding it into a methanol reactor. In the reactor, carbon monoxide and hydrogen react under high pressure and temperature, forming methanol. [4]

In 2021, approximately 65% of the world's methanol was produced from natural gas. [5]

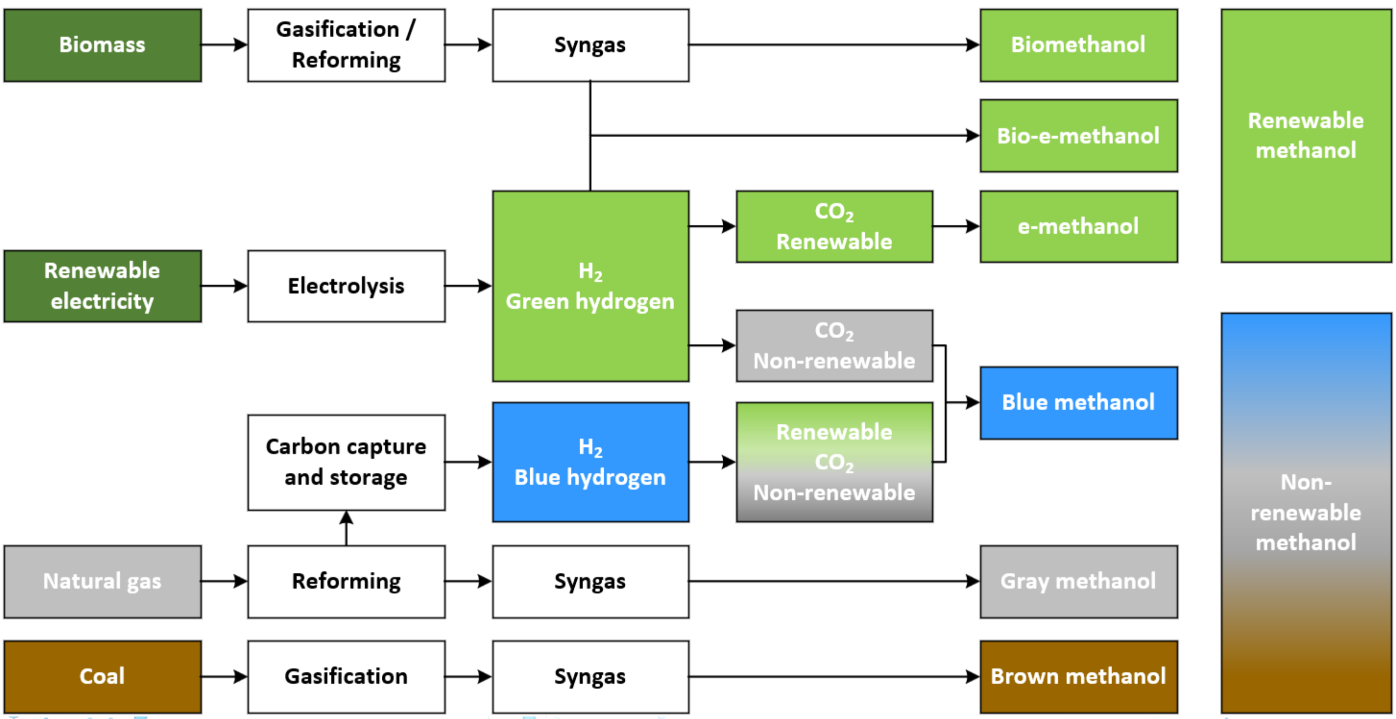
Brown methanol

Brown methanol is produced similarly to gray methanol from fossil raw materials, but instead of natural gas, brown methanol is produced using coal. The production of methanol begins with a coal gasification process, where coal is heated to high temperatures in the presence of oxygen, air, or steam. As a result, the carbon in coal reacts with oxygen, partially oxidizing and producing syngas. [6] In 2021, nearly 35% of the world's methanol was produced from coal. The largest producer of brown methanol in the world is China, which has large coal reserves. Brown methanol is the most environmentally burdensome of all methanol production methods, as its production generates large amounts of greenhouse gas emissions. [7]

Blue methanol

Blue methanol is produced from carbon dioxide and hydrogen. The sources of these raw materials can vary significantly. Typically, blue methanol can be produced in three different ways.

Figure 2. The main methods for producing methanol



Citations: [3], [4], [5], [6], [7], [Figure 2]

Production methods

In the first production method, green hydrogen and carbon dioxide sourced from fossil fuels are utilized. In the second and third methods, blue hydrogen, which is hydrogen produced from fossil raw materials but using greenhouse gas emission reduction technologies such as carbon dioxide capture, is used. The difference between the second and third production methods lies in the source of carbon dioxide used. In the second, lower-emission method, the carbon dioxide is renewable and sourced, for example, from biomass that has absorbed atmospheric carbon dioxide. In the third method, the carbon dioxide is sourced from fossil sources, which is a more environmentally harmful option. The life cycle emissions of blue methanol therefore strongly depend on how the raw materials used for its production are sourced. [8]

Green methanol

Like blue methanol, green methanol can be produced in several different ways. Depending on the production method and raw materials, green methanol is classified as biomethanol, bio-e-methanol, or e-methanol.

Biomethanol is produced from syngas, which can be produced using similar processes to those used for gray and brown methanol. The difference between biomethanol and the syngas used for gray and brown methanol is that the syngas for biomethanol is sourced from some biomass. The biomass can include, for example, municipal waste or lignocellulose generated from agriculture and the forestry industry. The syngas for biomethanol can also be produced by digesting wet biomass. E-methanol, on the other hand, is synthesized from green hydrogen and renewable carbon dioxide. Methanol produced from syngas derived from biomass and green hydrogen is called bio-e-methanol. In 2021, the share of green methanol in the world's total methanol production was only 0.2%, the majority of which was biomethanol. [9]

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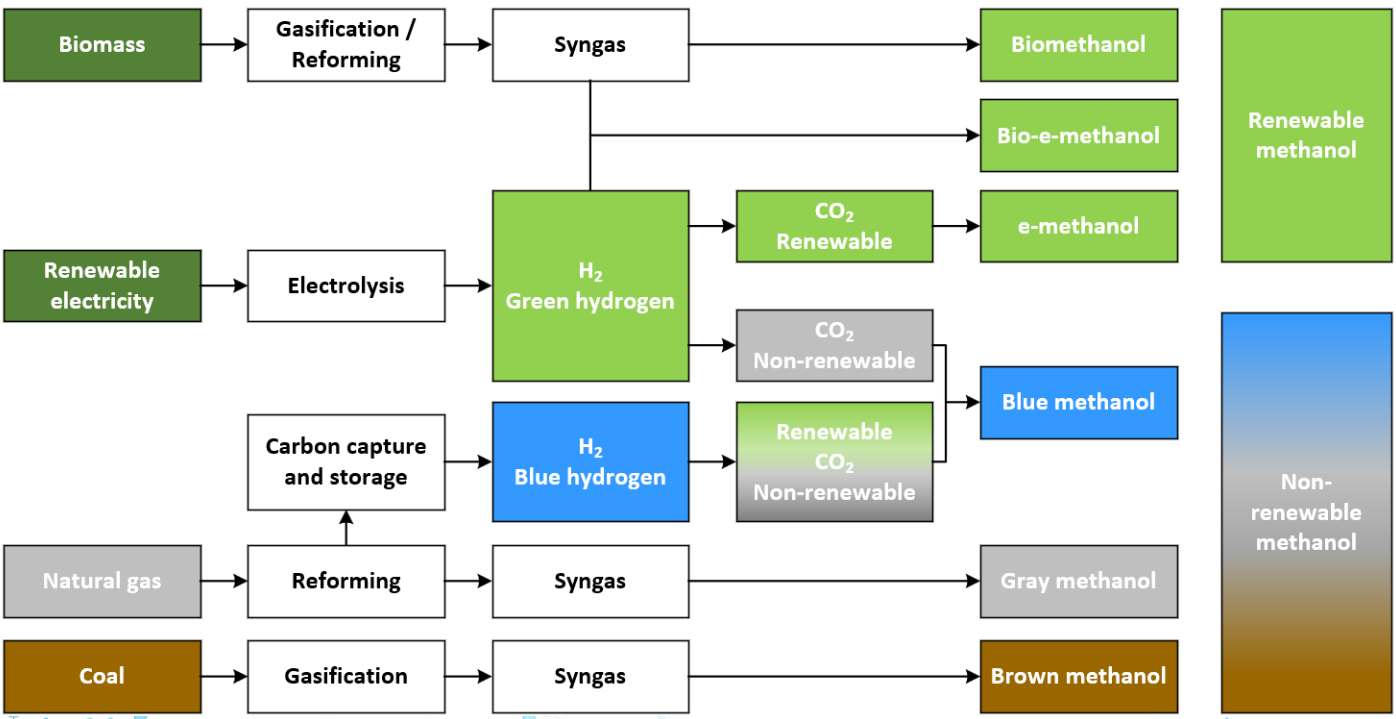

Properties and safety aspects

Fuel properties

Compared to traditional fossil fuels, methanol (MeOH) has a relatively low calorific value. When comparing the energy densities of fuels, the difference between methanol and conventional fuels increases further due to methanol's low density. As a result, methanol requires approximately 2,5 times the volume to store the same amount of energy as heavy fuel oil.

When using pure methanol as fuel for ships, pilot fuels may be utilized in combustion engines. This works by having the pilot fuel ignite first due to the rising temperature and pressure in the combustion chamber. The energy released from the pilot fuel then ignites the methanol present in the chamber. The choice of pilot fuel and its proportion in the overall fuel quantity depends on the type of combustion engine. [10]

Methanol can also be used in various blending ratios with other fuels, typically comprising 5–30 % methanol. [11]

Safety aspects

Methanol is, of course, toxic to humans when ingested or inhaled, and it can also be absorbed through the skin, leading to methanol poisoning. Mild symptoms of methanol poisoning include nausea, diarrhea, visual disturbances, abdominal pain, confusion, and decreased consciousness. In cases of greater exposure, symptoms can be more severe, including unconsciousness, blindness, kidney damage, and, in the worst cases, death. [12]

Methanol poses several fire and explosion hazards that must be considered in various situations. Due to methanol's wide flammability range and low flash point, it is crucial to implement appropriate safety measures during its handling and storage. Furthermore, the combustion process of methanol occurs at low temperatures, and it does not produce smoke, which can make its flame difficult to detect in bright lighting conditions. [13]

Guidelines and standards related to the use of methanol in maritime applications include ISO/AWI 6583 and SOLAS Chapter II. [14]

	Energy and storage					Flammability		
Fuel	Density [kg/m^3]	Lower heating value [MJ/kg]	Energy density [MJ/m^3]	Boiling point [°C]	Fuel volume requirement vs. LSHFO	Autoignition temperature in air [°C]	Flashpoint [°C]	Flammability limits in air [%]
LSHFO	993	40,5	40 217	> 180	-	230	> 60	0,6 - 7,5
MDO	819	40,5	33 170	> 180	1,21	210	> 60	0,6 - 7,5
LNG	450	49,1	22 095	-162	1,82	540	-188	5,0 - 15,0
MeOH	**792**	**19,9**	**15 761**	**65**	**2,55**	**464**	**12**	**6,7 - 36,0**
EtOH	789	26,8	21 145	78	1,90	365	17	3,3 - 19,0
L NH_3	680	18,6	12 648	-33	3,18	651	132	15,0 - 28,0
L H_2	70	120	8 400	-253	4,79	585	-	4,0 - 75,0
FAME	880	37,2	32 736	> 180	1,23	261	> 61	0,6 - 7,5
HVO	780	44	34 320	> 180	1,17	204	> 61	0,6 - 7,5
FT-Diesel	785	43,2	33 912	> 180	1,19	204	89	0,6 - 7,5

Citations: [10], [11], [12], [13], [14], [Table]

Production

Global production
Methanol production has steadily increased in recent years. In 2017, approximately 88 million tons of methanol were produced, which rose to 111 million tons by 2022. [15] The global production capacity is currently estimated at around 165 million tons. [16]

The International Renewable Energy Agency (IRENA) has projected that methanol production could reach approximately 500 million tons by 2050. According to this estimate, some of this methanol will be produced using natural gas or coal, but about 250 million tons would be e-methanol and 135 million tons biomethanol. To meet these production levels, around 280 e-methanol and 135 biomethanol production plants would be needed. E-methanol production facilities will require an environmentally friendly source of carbon dioxide, as well as a substantial amount of renewable electricity, while biomethanol facilities will need a sustainable biomass source. The construction of these production plants will therefore require significant investments in various sectors. [17]

As of 2023, there were approximately 90 methanol production facilities worldwide. [18]

Future outlooks in Finland and Satakunta
There are plans for several billion euros' worth of green hydrogen projects in Finland. This hydrogen can be used to produce various synthetic fuels, including methanol. In addition to hydrogen projects, several methanol production facilities are in the planning and construction stages throughout Finland. For example, the French energy production company Total Eren's subsidiary TEH2, along with Pietarsaari-based Aliceco Energy, plans to construct a methanol production plant in Kokkolan. The plant's annual production capacity is expected to be about 400 000 tons and is anticipated to begin operations in 2029. [19]

In Haapavesi, Liquid Wind, Kanteleen Voima, and Piipsan Tuulivoima are considering building a methanol production plant that would primarily produce methanol for maritime use. The project is still in the planning stage, so it is uncertain whether the area will have one or two plants with an annual production capacity of 100 000 tons each. [20]

Additionally, a methanol production project is planned for Ranua, which could produce about 100 000 tons of green methanol annually using wind power. The produced methanol would be transported by truck to ports in the Bothnian Bay, where it could be utilized for maritime traffic. [21]

Satakunta has excellent opportunities to initiate green methanol production, as the region currently produces significantly more electricity than it consumes. [22] Electricity production is expected to further increase, as several renewable energy projects are planned both on land and at sea. [23] The region also benefits from the green hydrogen production facility in Harjavalta, which supports hydrogen and synthetic fuel expertise and production. In addition to these advantages, Satakunta has a substantial industrial sector whose emissions could be utilized in methanol production. [24]

Citations: [15], [16], [17], [18], [19], [20], [21], [22], [23], [24]

Technical aspects

Infrastructure

Methanol is already produced in large quantities, which has led to the establishment of existing transportation methods and built infrastructure. However, broader use of methanol as fuel in various sectors will require significantly more infrastructure. Methanol has low viscosity and is corrosive to some materials, meaning it is not suitable for current fuel distribution infrastructure without modifications. However, with minor changes, it could be integrated into existing infrastructure. [25] Modifications may include material choices, as for example, carbon steels can suffer from stress corrosion when in contact with methanol, leading to material degradation and potential serious structural damage. [26] Methanol is also not compatible with all plastic, resin, or rubber materials. [27]

The chemical industry has extensive experience in the handling, transportation, and storage of methanol, which can facilitate its adoption in maritime logistics. [28]

From a maritime logistics perspective, bunkering options are crucial when considering the wider adoption of a new fuel. Various bunkering methods for methanol have already been tested and proven effective. For instance, since 2015, the Stena Germanica ferry has been bunkered with methanol using tank trucks. In 2021, the world's first ship-to-ship bunkering occurred in the Port of Rotterdam when the methanol tanker Takaroa Sun was bunkered using the barge MTS Evidence. In 2022, three methanol tankers were bunkered directly from a shore-based bunkering station. [29]

Transportation and storage

For shorter distances and smaller quantities, methanol is transported by tank trucks and rail. About one-third of all produced methanol is exported and primarily transported by sea. There are approximately 120 ports worldwide through which this seaborne methanol is shipped. These ports serve as crucial hubs for methanol transport, enabling efficient movement from production sites to various parts of the world. [30]

In terms of storage, one of methanol's significant advantages is its relatively high boiling point (about 65 °C) compared to other new fuels like hydrogen (-252 °C), liquefied natural gas (-162 °C), or ammonia (-33 °C). This property allows methanol to remain in liquid form at normal temperature and pressure, making its storage and transport significantly easier and cheaper than these other fuels. Due to its liquid state, methanol can be utilized in existing storage systems for liquid fuels like heavy fuel oil and MGO, provided necessary modifications are made to accommodate methanol. Since heavy fuel oil and MGO are already widely used in maritime operations, integrating methanol into maritime logistics could proceed relatively smoothly, cost-effectively, and quickly. [31]

However, it is essential to note that while methanol can potentially be stored in traditional fuel tanks, the energy content in the tank will be significantly lower due to its energy density. In the case of ships, this means either more space must be allocated for fuel tanks or ships must be bunkered more frequently.

Citations: [25], [26], [27], [28], [29], [30], [31]

Technical aspects

Use as fuel

Although methanol shares some properties with traditional fuels, it cannot be used directly in conventional combustion engines without modifications. Changes may relate to the fuel injection system and associated components and devices. [32]

Methanol can also be used in fuel cells, where the energy from methanol is converted directly into electricity. However, this technology is still in early development stages, and large-scale commercial solutions are not yet available. [33]

Compared to hydrogen or ammonia, methanol technology is in a more mature state in maritime transport. The engine manufacturer MAN Energy Solutions has had commercially available two-stroke engines for ships that can use either traditional fuels or methanol since 2016. [34] The company also signed an agreement with Alfa Laval in December 2023, under which Alfa Laval will supply the fuel supply system to convert MAN Energy Solutions' four-stroke engines to run on methanol. [35]

Many other marine engine manufacturers also have methanol-capable engines. For example, the South Korean engine manufacturer Hyundai Heavy Industries has several orders for engines that operate on both methanol and traditional fuels. Additionally, mtu Solutions, a subsidiary of Rolls-Royce, is expected to launch a methanol engine by 2026 and aims to introduce a methanol fuel cell system by 2028. [36]

Unlike many other marine engine manufacturers, Wärtsilä has a long history of developing methanol engines. For example, the Stena Germanica vessel has used Wärtsilä's four-stroke methanol engine since 2015. However, the vessel was not built in 2015, instead its engines were modified to enable methanol use. In the summer of 2023, Wärtsilä announced it would continue its collaboration with Stena Line, the owner of Stena Germanica. This collaboration will include modifications to other Stena Line vessels to enable methanol fuel use as well. [37]

At the end of 2023, Wärtsilä also announced plans to expand its range of methanol engines with four new models. Deliveries of these new engines are expected to begin in 2025. [38]

The growth of methanol in maritime transport is also reflected in new ship orders, as the proportion of methanol-powered vessels has rapidly increased in recent years. The primary reason for this is, of course, the need for emissions reduction, but part of it is also due to the fact that one of the world's largest maritime logistics companies, Maersk, decided to order the world's first methanol-powered container ship in 2021. Since then, the number of methanol-powered vessels on order has significantly increased, and currently, there are over 100 new methanol vessels on order globally. [39]

Citations: [32], [33], [34], [35], [36], [37], [38], [39]

Environmental aspects

As a fuel, methanol has the potential to produce significantly fewer emissions compared to heavy fuel oil or MGO, which are currently widely used in maritime transport. This explains the reason why methanol has seen substantial growth and interest in maritime logistics in recent years.

Greenhouse gas emissions

The use of methanol in combustion engines generates carbon dioxide emissions. Additionally, various greenhouse gas emissions such as methane and nitrous oxide may be produced during the production of methanol. The emissions generated from methanol and their magnitude are highly dependent on how the methanol itself is produced. The life cycle emissions of methanol produced from natural gas are approximately 103 gCO_2eq/MJ, which is more than the corresponding emissions from heavy fuel oil or MGO, which are around 90 gCO_2eq/MJ. In contrast, the life cycle emissions of bio-methanol and e-methanol are significantly lower. The life cycle emissions of e-methanol can be around 5 gCO_2eq/MJ, while the emissions from bio-based methanol range from 10 to 40 gCO_2eq/MJ depending on the origin of the biomass used. Furthermore, the life cycle emissions of bio-gas can even be negative, for example, if it is produced from cow manure, as the methane emissions generated from manure can be utilized in the fuel production instead of being released into the atmosphere. [40]

Nitrogen oxides emissions

Like other fuels, methanol also produces nitrogen oxides when used in combustion engines. However, the emissions are relatively low, as methanol produces up to 80 % less NOx emissions compared to MGO. These emissions can further be reduced by adding water to the fuel, making methanol suitable for use in nitrogen oxide control areas. However, adding water to methanol may affect the combustion properties of the fuel, which may require the use of pilot fuels. [41]

Sulfur oxides emissions

Methanol does not contain sulfur, which is why the emissions of sulfur oxides are practically nonexistent. However, small amounts of SOx emissions may arise from impurities that may be present in the fuel. In addition to impurities, sulfur oxides may be produced from pilot fuels if such fuels are used. Due to the low sulfur oxide emissions, methanol is an excellent fuel alternative for sulfur oxide control areas. [42]

Other emissions

The use of methanol generates very small amounts of particulate matter emissions. Compared to heavy fuel oil, these particulate emissions are produced in about 95 % lesser quantities. [43]

Incomplete combustion may also cause emissions of methanoic acid and formaldehyde. [44]

Fuel spills

In general, the management of methanol leaks is easier than that of LNG, hydrogen, or ammonia leaks because methanol does not vaporize and disperse into the air in case of a leak. This makes the collection and containment of methanol technically simpler.

Compared to other fuel leaks, methanol leaks are not nearly as harmful in terms of water pollution. Methanol mixes completely with water, diluting and partially neutralizing the associated risks. In aquatic environments, the LD50 value of methanol for fish is about 15 400 mg/l, while the corresponding value for heavy fuel oil is 79 mg/l. This means that a methanol leak would have to be approximately 200 times larger than a heavy fuel oil leak to have the same impact on fish populations. [45]

Citations: [40], [41], [42], [43], [44], [45]

Summary

Methanol has become an attractive alternative to traditional fossil fuels in shipping due to its numerous advantages. This is evident in the number of vessels on order and the attitude of major shipping companies such as Maersk towards methanol.

Its use as fuel offers significant environmental benefits and can be produced from various renewable sources, such as biomass or agricultural waste. Additionally, methanol can contribute to reducing sulfur oxide and nitrogen oxide emissions, which are key targets in maritime regulations. These reductions make methanol particularly appealing in emission control areas.

Furthermore, the handling and storage of methanol are significantly easier than many other alternative fuels. The standards and practices related to the use of methanol have also progressed much further than many other alternative fuels, facilitating its wider adoption.

However, it is essential to note that most of the methanol currently produced is derived from fossil raw materials. As a result, the life cycle emissions of methanol are typically higher than even those of fossil maritime fuels. However, change is on the horizon, as substantial investments are being made in Finland and elsewhere around the world in the construction of various green methanol production facilities. These will enable a more environmentally friendly future for shipping.

By transitioning to green methanol, the shipping industry can further align with global sustainability goals and reduce its carbon footprint.

Strengths

+ Methanol is already in use in shipping
+ The life cycle emissions of methanol as a fuel can be over 90% lower than those of fossil fuels
+ The infrastructure for fossil fuels can be utilized for methanol with minor modifications
+ Energy density is better than, for example, hydrogen or ammonia
+ Methanol is easier to handle and store than many other alternative fuels
+ Extremely low NOx, SOx, and particulate matter emissions
+ The impacts of methanol leaks are relatively small compared to other fuels

Weaknesses

- Most of the current methanol is gray or brown methanol, whose life cycle emissions are higher than those of fossil fuels
- The energy density is lower than that of fossil fuels, so storage requires significantly more space
- Methanol cannot be used directly in existing marine engines without modifications
- Methanol is a carbon-based fuel and thus produces greenhouse gas emissions when burned
- Methanol is widely used in various industries, which may affect the availability of methanol

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