



**GREEN MARITIME METHANOL**

# **GREEN MARITIME METHANOL**

**A CALL TO ACTION**



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# Contents

<b>1</b>	<b>Introduction</b>	<b>4</b>
<b>2</b>	<b>The shipping sector must lower its greenhouse gas emissions</b>	<b>6</b>
<b>3</b>	<b>Methanol is a low-emission marine fuel</b>	<b>8</b>
3.1	Greenhouse gas emissions	8
3.2	Other harmful emissions	9
3.3	Rules and regulations for maritime greenhouse gas emissions	9
<b>4</b>	<b>Methanol-powered ship technology is ready for large-scale adoption</b>	<b>11</b>
4.1	Building methanol-powered ships	11
4.2	Shipowners' perspective	12
<b>5</b>	<b>Summary</b>	<b>17</b>
<b>6</b>	<b>Call to action</b>	<b>18</b>
	<b>Appendices</b>	<b>22</b>
A	What is 'green' methanol?	22
B	Emissions from methanol ship engines	28
C	Impact on ship design and operations	32
	<b>References</b>	<b>36</b>

# 1 INTRODUCTION

The maritime sector must do its part to limit global climate change caused by emission of greenhouse gases. The International Maritime Organization, in its 2018 Initial IMO GHG strategy, agreed to a 40% reduction of carbon intensity of international shipping by 2030 compared to 2008 levels [1]. The European Union sets ambitious greenhouse gas emission reduction targets for maritime transport under its FuelEU Maritime program, undergoing final approval by legislators at the time of writing (Q4 2022).

Shipping emissions are mainly caused by combustion of fossil fuels in ship engines. Several stakeholders are working on the development of new alternative maritime fuels in order to reduce greenhouse gas emissions. In the **Green Maritime Methanol** project, a consortium of Dutch and international maritime companies and knowledge institutes have joined forces to investigate the application of renewable methanol as a maritime fuel.

The first stage of the project ran between 2018 and 2020. In our follow-up Green Maritime Methanol 2.0 (GMM 2.0), the consortium continues its cooperation to research safety aspects, engine development, development of ship designs for three additional vessel types and long-term availability and business case development. The GMM 2.0 project is supported by TKI Maritime and the Netherlands Ministry of Economic Affairs.

This report describes the greenhouse gas emission reduction challenge for the maritime industry and the role renewable methanol can play in meeting this challenge. Based on the experience and viewpoints of members of the Green Maritime Methanol consortium that are currently investing in methanol powered vessels, we present drivers and barriers in further implementation of methanol. Finally, the paper contains a call to action.

The following partners participate actively in the consortium:



1 Compared to the total emissions from maritime transport in 2008. For details, please refer to the IMO website [1].

## 2 THE SHIPPING SECTOR MUST LOWER ITS GREENHOUSE GAS EMISSIONS

Greenhouse gas emissions from shipping are growing every year. Exhaust from ship combustion engines caused 1.1 billion tons of CO<sub>2</sub>eq emissions in 2018, which is roughly 3% of all global greenhouse gas emissions [2]. The International Maritime Organization (IMO) predicts that without intervention, emissions in 2050 could reach 1.5 billion tons per year (see Figure 1). Dr. Bryan Comer, an expert on maritime emissions and co-author of the fourth IMO Greenhouse gas study, estimates that if we want to keep global warming well below 1.5 degrees, the remaining carbon budget for shipping is roughly 10 billion tons. Therefore, the shipping sector must lower its greenhouse gas emissions. That is why both the IMO and the European Union have set greenhouse gas emission reduction goals.

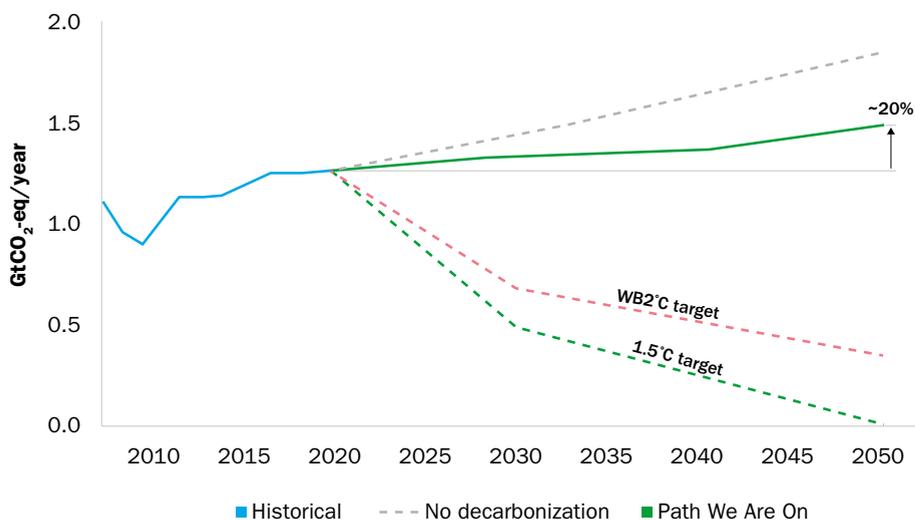


Figure 1: Emission reduction targets and some maritime emissions pathways.

Source: Mærsk McKinney Møller Center for Zero Carbon Shipping [3]

The IMO has agreed on a set of measures to reduce emissions [4]. Design changes, operational measures (for example slow steaming) and increasing operational efficiency can reduce the GHG emissions from ships significantly by reducing fuel consumption. However, to reach a (net-)zero emissions shipping sector, (net-)zero emissions marine propulsion methods are required. This maritime energy transition will consist of the gradual introduction of sustainable technologies in various ship segments, replacing fossil fuels with sustainable alternatives.

Most likely, there will not be a single solution to decarbonise all types of ships. [5] [6] [7]. Just like in the current situation, a sustainable future maritime sector will use a mix of different fuels. Nevertheless, it is desirable to limit the total number of fuels because each fuel will need a supply infrastructure. Multiple options are being considered, most prominently methanol, ammonia and hydrogen. Currently, there is no consensus yet on which 'green' fuel(s) will become widely available and affordable alternatives for HFO and MGO. Recent scenario studies reach different conclusions on the likely development and uptake of these fuels in the longer term.

According to industry partners in the consortium, methanol stands out in three ways compared to other sustainable maritime fuels:

- Methanol can be used in existing engine platforms with few modifications and significantly lower CAPEX when compared to other available alternative fuels.
- Methanol can be used in dual-fuel engines which can also run on diesel fuel. Fossil methanol can also be blended with renewable methanol as production of the latter is scaling up to power a 100% methanol-burning engine. Both practices create a scalable decarbonisation pathway as low-carbon and renewable methanol production increases year-on-year. A fossil – renewable methanol blend can be used to replace traditional marine fuels immediately, while ensuring compliance with new emission reduction laws.
- Methanol is easy to manage and inexpensive to store, handle and transport, unlike other alternative low-emission fuels which require costly cooled or cryogenic and/or pressurised storage

Methanol is already produced and traded globally, and available in more than 100 ports worldwide.

In short, methanol is a proven fuel ready for use in today's maritime sector. There are proven low- and zero-emission production pathways. That is why several leading ship operators have made large investments in methanol-powered ships. In the following section, the main reason for using methanol as a maritime fuel will be elaborated – the role it can play in the reduction of maritime greenhouse gas emissions.

# 3 METHANOL IS A LOW-EMISSION MARINE FUEL

## 3.1 GREENHOUSE GAS EMISSIONS

To reduce maritime greenhouse gas emissions, we must look at the entire life cycle of maritime fuels, a so-called 'well-to-wake' approach. Rather than only looking at exhaust emissions (a method also known as 'tank-to-wake'), greenhouse gas emission during production, transportation and use of a fuel should be counted too.

Methanol contains carbon, which is emitted when it is burned. Renewable methanol can be produced by combining carbon and hydrogen from renewable sources (e-methanol). It can also be produced from various types of biomass (biomethanol). Burning renewable ('green') methanol does not contribute to global warming, since it does not lead to a net increase in the amount of carbon in our atmosphere.

Greenhouse gas emissions from 'green' methanol are much lower than those for traditional marine fuels. Depending on the production method and feedstocks used, renewable methanol can save between 80% and 99% of well-to-wake greenhouse emissions compared to marine

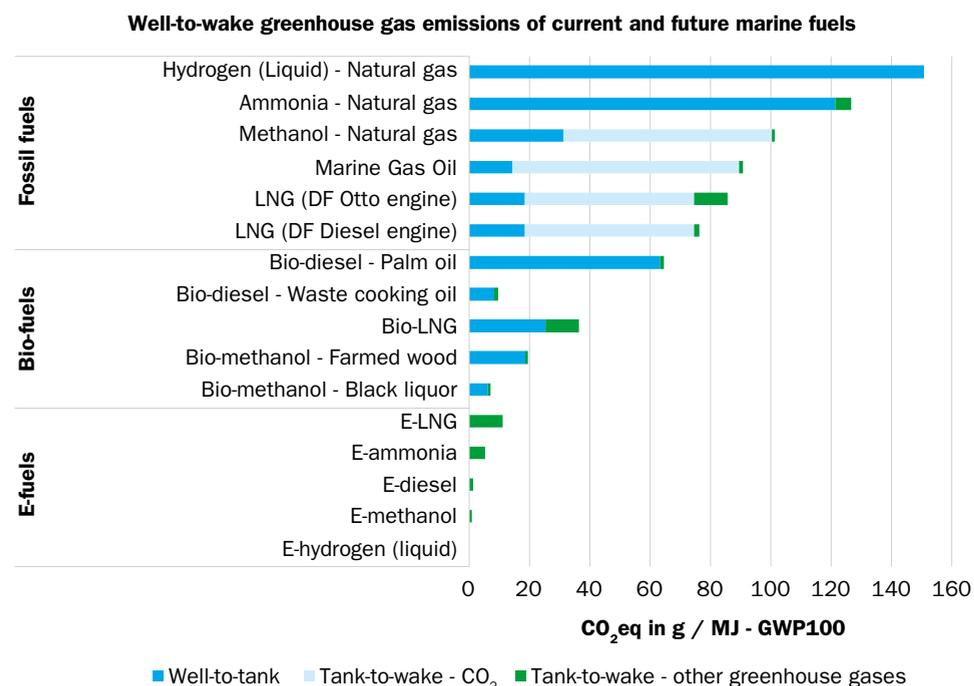


Figure 2: Well-to-wake emissions from various marine fuels in grams per MJ. These are based on default emission values taken from [8] and [9]. Individual certified values can differ. GWP for 100 years. See **Table 3** in annex B for details.

gas oil. A comparison between greenhouse emissions from current and potential future marine fuels is shown in Figure 2. A detailed summary of available research on this topic is attached to this report as Annex B.

## 3.2 OTHER HARMFUL EMISSIONS

Apart from greenhouse gases, ship engines also emit other substances than can adversely affect human health and the environment. These emissions include:

- Nitrogen (NO<sub>x</sub>),
- Sulphur (SO<sub>x</sub>),
- Particulate matter (PM), and
- Black Carbon.

Using methanol leads to a reduction of sulphur oxide emissions proportional to the amount of methanol used in dual-fuel engines. Nitrogen oxide emissions are reduced by approximately 60% (compared to Tier II) [10] [11]. It also reduces black carbon and particulate matter emissions. For ships sailing in IMO emission-controlled areas (ECA), methanol-powered marine engines are a way to comply with low-sulphur marine fuel requirements. Tier III NO<sub>x</sub> level can be achieved via several emission control technologies such as SCR, water blending or EGR.

This makes methanol an excellent fuel for improving air quality and reducing pollution near ports, waterways and shipping lanes. It should be noted that initial trials suggest methanol engines can have significant aldehyde emissions [12]. It would be good to investigate possible effects on air quality and health and if needed to introduce limit values.

## 3.3 RULES AND REGULATIONS FOR MARITIME GREENHOUSE GAS EMISSIONS

Rules and regulations cover the use of marine fuels and its emissions. These rules also force or incentivize ship owners to reduce greenhouse gas emissions from maritime transport. For European parties the most important regulatory bodies for shipping emissions are the International Maritime Organization (IMO) and the EU.

In this paper we identify five policy packages which will have an impact on the introduction of renewable methanol. Policies that have well-to-wake emissions as their scope incentivise the use of sustainable feedstocks. Policies that use tank-to-wake emissions as a scope do not make a distinction between the use fossil-based methanol and methanol from sustainable feedstocks, because they only consider the direct emissions from combustion. However, for design guidelines for new build vessels (such as EEDI), the WTT emissions of the fuel that will be used by the vessel are unknown. The use of tank-to-wake emission figures is therefore a logical approach.

Important legislative packages are:

### EEDI / EEXI

EEDI (Energy Efficiency Design Index) and EEXI (Energy Efficiency eXisting ship Index) are design standards. They apply respectively to newbuilt and existing ships. The standards provide a calculation of the standard CO<sub>2</sub> emissions (gram per ton/nautical mile) based on the technical characteristics of a ship. Depending on the propulsion method and design of the vessel, there are minimum ratings a vessel must attain in order to be approved. Ships must receive EEXI or EEDI approval once during their lifetime.

**CII / SEEMP**

The Carbon Intensity Indicator (CII) rates the operational performance of a vessel. The vessel is compared to a reference within its size class and is given a rating from A to E. The threshold for the different labels will become increasingly stringent towards 2030, forcing ship owners to decrease carbon emissions. Ship owners must draft a plan to improve the CII, and therefore the vessel's operational energy efficiency, for the next three years as part of the Ship Energy Efficiency Management Plan (SEEMP).

**Renewable Energy Directive (RED II)**

The RED is an EU Directive which contains a target for renewable energy use. The RED contains emissions factors used to calculate standardized emission figures for various maritime fuels, taking their production method into account. It also sets threshold values fuels must meet to be classified as 'renewable' and targets for the percentage of renewable fuel that must be used in transport in the EU.

**FuelEU Maritime**

FuelEU Maritime is a European Commission proposal. It contains greenhouse gas intensity targets for ships that are tightened over time.

**EU ETS**

The Emissions Trading Scheme is a system where companies emitting greenhouse gases in the EU need a certificate to do so. The number of available certificates decreases slowly, forcing companies to reduce their emissions. By making the certificates tradeable, the scheme aims to reduce emissions in the most cost-effective areas first.

Some inconsistencies exist between the different legislative packages. Main inconsistencies are use of tank-to-wake or well-to-wake emissions, and whether they include all greenhouse gas emissions or just at CO<sub>2</sub>. See Table 1 below for a summary. For more information on regulations please see annex A.

Table 1: important regulations for GHG emission reduction and green maritime fuels by the IMO and the EU

Name	Scope	Emissions scope
IMO	EEDI / EEXI	Tank-to-wake
	CII	Tank-to-wake
EU	Renewable Energy Directive (RED)	Well-to-wake
	FuelEU Maritime	Well-to-wake
	EU Emissions Trading System	Tank-to-wake

The IMO policy packages, as well as EU ETS, have tank-to-wake emissions as their scope. On the short term, these will favour the use of fossil feedstocks over green feedstocks, since the price of fossil fuels is much lower. This aspect will be further elaborated in chapter 6.

<sup>2</sup> This legislation is still a work in progress. The EC proposal includes only CO<sub>2</sub>, the text agreed by member states includes CO<sub>2</sub>, N<sub>2</sub>O and CH<sub>4</sub>.

# 4 METHANOL-POWERED SHIP TECHNOLOGY IS READY FOR LARGE-SCALE ADOPTION

**4.1 BUILDING METHANOL-POWERED SHIPS**

Many shipyards can build ships powered by methanol. Large marine engine manufacturers already sell marine engines that run on methanol. New build methanol vessels are available for sale for a variety of different uses such as tankers, container ships, work vessels, pilot boats and ferries.

Converting existing engines to run on methanol is also possible. This involves modifications to the ship engine, fuel supply lines, pumps and storage tanks. Retrofitting existing vessels is possible if an engine conversion kit is available for the ship's engine. This is currently not the case for many engine models, but large manufacturers have started programmes with the aim of converting existing ships to run on methanol generally with a dual-fuel engine (using marine diesel to start the combustion of methanol). Caterpillar, for instance, announced in September 2022, that their 3500E-series marine engines can be modified to run as methanol dual fuel engines.

According to Maersk, conversions to methanol are not always feasible because the need for larger fuel tanks will reduce the cargo space available on an existing ship. However, often alternatives are possible that leave the amount of cargo space unchanged. Conversion may also put more strain on a ship's hull due to installation of methanol tanks and cofferdams. For these reasons, conversion to methanol propulsion may not be feasible for all ship types. However, some ship engines can already be converted to methanol and successful examples of conversion (like the Stena Germanica, a ferry converted in 2015) show that renewable methanol can be used to decarbonise the existing fleet. This is important, because the lifetimes of oceangoing vessels can often exceed 30 years, while significant reduction of maritime emissions is needed to meet the Initial IMO GHG Strategy in 2030.

For more information on the building, conversion and use of methanol-powered vessels, please see Annex C.

## 4.2 SHIPOWNERS' PERSPECTIVE

Four different shipowners were asked about their reasons for choosing methanol as a future or current marine fuel.

### 4.2.1 Maersk – container ships



Figure 3: 16,000 TEU Methanol fuelled container ship by Maersk

In December 2021, Maersk has ordered 12 new container vessels from Hyundai Heavy Industries. The ships will have dual-fuel engines that can operate on methanol or on low-sulphur fuel oil and a capacity of 16,000 TEU. For Maersk, this is a first major step towards reducing greenhouse gas emissions caused by large container ships.

Maersk feels an obligation to act now to reduce the emissions of greenhouse gases caused by their shipping operations. Methanol is their fuel of choice for three main reasons:

- Maersk chose renewable methanol due to three reasons: speed, optionality, and cost. The technology for methanol as a fuel for shipping is ready, renewable methanol allows Maersk to make an impact on GHG reduction already this decade, and renewable methanol is feasible to scale up from a cost perspective. Maersk has entered into offtake partnerships with seven leading companies with the intent of sourcing more than 900,000 tons per year by end 2025.
- Methanol is relatively safe and easy to handle and store.
- The required technology (engines, bunkering and storage) is ready and commercially available.

Renewable methanol is a good way for Maersk to realize emission reduction quickly. That is why Maersk invests in methanol-powered ship engines now.

Maersk thinks scaling up its use of methanol will be challenging but will gain speed in the second half of this decade. The cost of renewable methanol (as well as other green fuels) is still relatively high, and the supply is currently limited. Bunkering of renewable methanol is not widely available so Maersk will rely on tankers and bunker barges at first. There is still work to be done on standardization of bunkering equipment and protocols. Maersk hopes that, by being a first mover, it can create the conditions for these barriers to be overcome by creating sizeable and continuous demand for renewable methanol and associated goods and services.

### 4.2.2 Van Oord – jack-up vessel Boreas

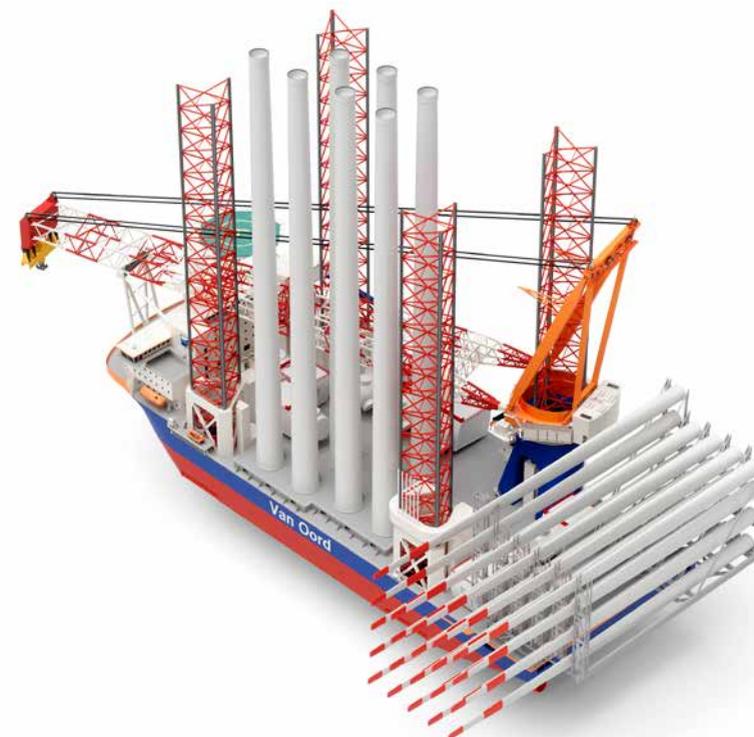


Figure 4: Jack-up vessel powered by methanol and ordered by Van Oord.

Van Oord has ordered a jack-up vessel powered by methanol. The vessel will be delivered in 2024. The vessel will be used to build offshore wind parks. Because those wind parks will be used to generate green energy, clients demand sustainable construction practices as well. Currently, Van Oord views renewable methanol as the most promising way of reducing GHG emissions on such vessels. Van Oord also explores other options for reducing its GHG emissions, such as LNG-powered vessels. Since marine vessels usually have a life span of between 15 and 30 years, making changes now is necessary to achieve Van Oord's goal of becoming carbon net zero in 2050.

Implementing of a methanol propulsion system does not influence the main ship dimensions or operational profile and therefore is a feasible option.

#### 4.2.3 Proman and Stena Bulk – Methanol-fuelled tankers



Figure 5: The Stena Pro Patria at its launch in late 2021. Photo: Proman

The transportation of Proman's products has until 2022 been carried out by a dedicated fleet of eleven ocean-going time-chartered vessels.

Proman, the second largest methanol producer in the world, has committed to transitioning to a more sustainable shipping fleet by building an initial six state of the art methanol-fuelled vessels – three of which will be jointly owned with its joint venture partner Stena Bulk – to replace existing vessels which are coming to the end of their lease periods. In time, Proman expects its entire fleet to be replaced with next-generation methanol-fuelled vessels. There are several reasons for Proman to choose methanol, as outlined in chapter 2. It delivers immediate and significant GHG emissions and has a demonstrated net-zero pathway, with commercially viable large-scale renewable production via several production routes. This means methanol-fuelled ships are effectively future-proofed, since greater volumes of very low-carbon and renewable methanol can be blended into the maritime fuel pool as production capacity increases. This will allow such ships to meet every current and expected future emissions reduction target.

Dual fuel engines can run on diesel fuel or on methanol (with diesel pilot) creating a highly scalable decarbonisation pathway as low-carbon and renewable methanol production increases year-on-year. Methanol is one of the most effective and safest hydrogen carriers, with four hydrogen atoms per molecule – making it highly complementary to the emerging role of hydrogen in the energy transition.

Moreover, methanol is easy to manage and inexpensive to handle and transport, unlike other alternative low-emission fuels which require costly cryogenic and/or pressurised storage. Methanol infrastructure is already established, meaning lower costs are associated with building up the fuel infrastructure.

Methanol runs well in existing engine technology with few modifications and significantly lower CAPEX when compared to other available alternative fuels and is already available in more than 120 ports worldwide. It has an established infrastructure. Therefore, few costs are associated with building up the fuel infrastructure.

Four vessels, the 49,900 DWT Stena Pro Patria, Stena Pro Marine, Stena Promise and Stena Prosperous, have already been delivered in 2022, with two further vessels due by early 2024. All four vessels are fully operational and running on methanol. They have loaded methanol fuel in Rotterdam, Ulsan and Trinidad, with further global bunkering hubs to follow in 2023, proving methanol's widespread availability. Even using conventional methanol from natural gas, operating the initial fleet of six methanol-powered ships will save approximately 45,000 tonnes of CO<sub>2</sub> per year. For Proman, methanol is a key fuel to help meet IMO and EU greenhouse gas emissions and air quality targets.

In addition to transporting its own products, Proman will make a number of its new vessels available globally for the shipping of chemicals and clean petroleum products, enabling third-party charterers to gain experience with methanol as a marine fuel.

#### 4.2.4 Acta Marine – Construction Service Operating Vessels for the offshore industry



Figure 6: Acta Marine Methanol-powered CSO vessel

Acta Marine has ordered construction service operating vessels with a dual-fuel engine, capable of running on methanol and diesel blend (up to 85% methanol and 15% diesel). The CSOVs measure 89 metres in length, 19 metres in width and accommodate up to 135 people in 85 cabins.

The vessels are equipped with two types of fuel tanks and supply systems, for HVO/diesel and methanol. It is possible to convert them to methanol-only in the future. However, if methanol cannot be supplied, the vessels can also sail using traditional marine diesel or bio-based fuel such as HVO.

For Acta, methanol vessels are a 'green' vessel with relatively low additional CAPEX compared to traditional vessels. The methanol fuel tanks are relatively easy to incorporate into the ship's design because no pressurized or circular tanks are needed. Other alternatives for sustainable propulsion (batteries, fuel cells, ammonia) are either not technologically mature, do not deliver a long enough range, or are too expensive compared to methanol at this stage.

The supply of renewable methanol for Acta's vessels still has to be arranged and is currently not available in the market. Bio-methanol is currently available in ports such as Hull, close to the main operational bases of some of the offshore wind farms on the East coast of the UK and locations that are visited frequently by the Acta Marine vessels. Methanol can be delivered to Acta's vessels by a tank wagon, however a reliable supply and bunkering of renewable methanol from barges would be preferred.

## 5 SUMMARY

The main reasons for choosing methanol as a marine fuel are:

- 🔹 **Reduction of maritime greenhouse gas emissions** Using renewable methanol causes little or no emission of greenhouse gases. Multiple sustainable production methods exist, both bio-based and synthetic (E-fuel).
- 🔹 **Improved air quality** Methanol engines emit less sulphur oxides, particulate matter and nitrogen oxides
- 🔹 **Methanol technology is available** While you are reading this report, methanol-powered vessels are already operational. New methanol-powered vessels are being built and existing vessels have successfully been retrofitted with methanol engines.
- 🔹 **Methanol is a convenient marine fuel** Because methanol is liquid at ambient pressure and temperature, it has minor impact on ship design at manageable volumetric energy density. Methanol is relatively easy to store, handle and move, making it a convenient fuel compared to alternatives like ammonia and hydrogen. Only minor adjustments to current bunkering and storage infrastructure are required to make these systems suitable for methanol.
- 🔹 **Availability of dual-fuel engines** make it possible to use renewable methanol where it is available and MGO (or biodiesel) in other locations. This allows ship owners to get started with the energy transition immediately, rather than waiting for sustainable fuels to become available in all ports relevant to them. Furthermore, it will stimulate the production of renewable methanol.

There are also barriers to adoption of methanol as a marine fuel (these apply to other alternative maritime fuels too):

- 🔹 **Unclear long term (EU) policy embedding** of methanol, mainly in the ETS and RED, is causing uncertainty on the extent to which methanol will be supported by governments and the EU as a 'green' fuel.
- 🔹 **Regulations are still being developed** Although rapidly maturing, emissions regulations, safety and fuel standards must still be further developed and optimized for large scale adoption.
- 🔹 **Uncertain supply of sustainably produced feedstock and energy** Both bio-methanol and e-methanol require sufficient available sustainable source materials and energy. The supply of feedstock for bio-methanol and/or bio-based carbon for E-methanol are limited, and there is growing demand from other sectors for these materials too. Sustainable electricity production will take time to scale up. Supply of carbon from end-of-pipe capture or direct air capture is limited at the moment. It is uncertain if this supply will increase and if the price will make methanol production from those sources competitive.
- 🔹 **Uncertainty about the future maritime energy mix** Will methanol become a widely available and 'mainstream' maritime fuel, or a niche product available in select locations?
- 🔹 **Bunker price development** Because of the uncertainties listed above, the expected price of renewable methanol as a bunker fuel is hard to predict.

## 6 CALL TO ACTION

The maritime sector considers transition to low carbon technologies as one of the most important challenges for the coming decade. A main challenge is to overcome the so-called “Valley of Death” between scientific innovation and commercial adoption. With combined efforts the barriers to adoption of methanol as a marine fuel can be reduced, enhancing the business case for renewable methanol and accelerating the reduction of greenhouse gas emissions from shipping.

### FIRST MOVERS RISK HIGH COST IN CASE OF DISAPPOINTING UPTAKE OF METHANOL AS A MARINE FUEL

Using methanol as a marine fuel enables emission reduction in the short term. A main challenge to overcome however is the so-called “valley of death” between scientific innovation and commercial adoption. Early adaptors that implement methanol will face relatively high additional costs and operational uncertainties. This can slow down large-scale adoption, which in turn will reduce investments of technology providers and scaling up of production of renewable methanol. This is a problem, because a quick energy transition is required to meet the goals in the Paris Agreement and the IMO decarbonisation goals.

#### Action: Re-invest ‘carbon tax’ revenues to support early adopters

Financial support to pilot projects and early adaptors can reduce the costs of zero-emission ships both through development and increased market demand. Supporting early adopters can help maritime methanol cross the so-called ‘valley of death’. The revenues from the EU ETS and or the IMO carbon tax could be used to incentivize early adopters, especially small and medium sized companies that do not have large investment and R&D budgets. The EU has taken an important step in this direction by establishing the Ocean Fund, which will use 75% of the maritime ETS revenues to accelerate the energy transition.

#### Action: Fund research and development on easily convertible maritime engines

To reduce a risk of a lock-in, vessels and their components should be designed to be flexible with regards to fuel type. This would decrease the costs for switching between different fuels over the lifetime of the vessel. In order to enhance flexibility, knowledge needs to be developed both on the ship design level and on underlying systems and components.

### USE WELL-TO-WAKE EMISSION FACTORS IN NEW POLICIES

For viability of methanol as a sustainable marine fuel, clear and coherent international rules are necessary. Both IMO and the European Union have implemented policies that can improve the business case for investing in sustainable fuels. Good examples are the European proposal to include shipping in the emissions trading system or the recent IMO proposal to put a price on maritime greenhouse gas emissions. Such measures can accelerate uptake of sustainable fuels.

However, stakeholders should have sufficient options to implement CO<sub>2</sub>-reduction measures. As discussed in chapter 3, policies such as ETS for maritime transport and CII do currently not distinguish between the difference of fossil-based methanol and methanol from sustainable feedstocks, because they only consider the direct emissions from combustion. On the short term, this will favour the use of fossil feedstocks over green feedstocks, since the price of fossil fuels is much lower.

In order to clarify the impact of the use of Tank-to-Wake emissions in ETS for an individual ship, Wagenborg Shipping made an example calculation for one of their freight vessels based on MRV data for the year 2021. For calculating the costs of ETS, an allowance rate of 80€ per metric ton CO<sub>2</sub> was assumed. All voyages within the EU were fully taken into account as well as 50% of the CO<sub>2</sub> of voyages between EU and non-EU ports.

The total costs of ETS for this vessel using MGO would be 1.3 million euro. Switching to grey methanol will reduce ETS costs for this vessel by 9%. Under the current ETS proposition however using bio-methanol or e-methanol will not give any additional benefits. Using the IPCC calculation methodology, the GHG emissions for bio- and e-methanol would be net-zero, which would result in a large incentive for ship owners to use sustainable feedstocks. Alternatively, considering the well-to-wake emissions in ETS would also result in a large reduction (and perhaps fairer price).

Table 2: ETS calculation options for an example short sea freight vessel, based on a CO<sub>2</sub> rate of 80€ per metric ton

Energy carrier	GHG emission Gram CO <sub>2</sub> per MJ		ETS costs per year for example vessel using different calculation methods		
	Tank-to-wake - CO <sub>2</sub>	Well-to-wake	TTW only	TTW - netzero for green fuels	WTW
Marine Gas Oil (MGO)	75.1	89.5	€ 1,290,000	€ 1,290,000	€ 1,540,000
Grey methanol - Natural gas	69.1	100.4	€ 1,190,000	€ 1,190,000	€ 1,730,000
Bio-methanol - Farmed wood	0	18.6	€ 1,190,000	€ 0	€ 320,000
Bio-methanol - Black liquor	0	6.2	€ 1,190,000	€ 0	€ 110,000
E-methanol	0	0	€ 1,190,000	€ 0	€ 0

In the current proposals, investments in renewable methanol will thus not contribute to a reduction of the costs of ETS for ship owners. Ship owners will therefore be very reluctant in making long term investments for their vessels. This also challenges necessary investments in alternative fuel infrastructure in ports and the development of production capacity of sustainable fuels.

**Action: Use well-to-wake emissions factors when assessing maritime fuels**

The ETS (and other policies regulating maritime emissions) should accurately consider the climate impact of the whole life cycle of maritime fuels, including production and distribution, whenever possible. This can be done by using well-to-wake emission factors, like those used in FuelEU Maritime. This creates consistency between policies and encourages the use of truly 'green' fuels, rather than the movement of emissions outside the scope of legislation (for example, using grey hydrogen as a marine fuel).

**SAFETY AND FUEL STANDARDS REGULATION**

Development of clear rules and guidelines is required for large scale implementation of methanol. This will decrease the design and implementation costs of methanol ships. The most important topics are the safety regulations for bunkering and storage of methanol and the standards for methanol as a marine fuel.

The current safety standards regulations and procedures are a good starting point for the first methanol vessels. New guidelines and equivalent safety standards for methanol are under development at IMO [13] and CESNI. This is done in parallel with improvements to safety standards which are energy carrier specific, such as rules on storage above the water line. Progress is made and aligns with the sectoral ambitions.

For smaller vessels (such as inland vessels, patrol vessels, yachts), current safety requirements can be difficult to implement in designs. For example, the requirement that cofferdams need to be placed around the fuel tanks. Therefore, further development of safety solutions that reduce space and cost of implementation of methanol in smaller vessels is required.

Current fuel standards cover mainly fossil based maritime fuels (for instance in ISO 8217). These standards are currently not yet applicable and/or available for alternative fuels such as methanol, especially not when it includes bio-elements from different feedstocks.

**Action: Support further development of rules and regulations**

Support further development of rules and regulations for vessels and bunkering. This applies in particular to specific vessel types (e.g., small craft, yachts, inland vessels etc.)  
Support development of fuel standards for alternative green fuels for maritime applications.

**UNCERTAIN SUPPLY OF 'GREEN' METHANOL**

The short-term availability of renewable methanol, and the development of the price, are still very uncertain. This leads to hesitation for shipowners and maritime suppliers to invest in development of methanol vessels and equipment. The absence of a demand for methanol in turn will delay investment in production of renewable methanol, creating a vicious cycle. In order to accelerate developments on both side we propose the following actions:

**Action: Develop supply of renewable methanol**

Large companies, such as Maersk, can secure supply of renewable methanol for themselves by working with large producers directly. Smaller companies can't follow this example. To make investment in methanol ships/ engines possible, they need methanol production volumes to rise and bunker supply to exist at locations where they are active.

National and regional governments can support creation of maritime methanol supply by creating demand. This can be done directly, by converting publicly owned vessels. This option is currently being investigated by the Dutch Royal Navy and the 'Rijksrederij'. Governments can also create demand indirectly by inclusion of environmental preconditions in tenders for public works, such as coastal and waterway maintenance and the installation of wind farms.

**AVAILABILITY OF BUNKERING FACILITIES**

Widespread availability of bunkering facilities of methanol throughout Europe is an important precondition for a large adaptation by the sector. In some energy ports, there are existing methanol storage facilities available (for instance in the Dutch ports of Amsterdam and Rotterdam). These facilities can be used for distribution and supplying neighbouring ports. For wider roll-out, especially for small or more remote ports, the following actions are proposed

**Action: Development of solutions for bunkering alternative fuels**

Just as with investments by ship owners, investments in bunkering infrastructure can be costly for (bunkering operators in) ports, since it is still uncertain what the bunkering demand will be for different energy carriers. Therefore, there is a need for flexible and adaptive solutions as well as innovative and operational procedures with marine renewable energies and alternative fuels, given the varied range of fuels and a large assortment of engines technically possible. Port stakeholders, fuel suppliers and research institutes can take the lead in development. The topic is included in the Zero Emission Waterborne Transport Partnership as part of the Horizon Europe programme.

**Action: Development of a roll-out strategy**

Flexible bunkering solutions need to be complemented with a Europe wide roll-out strategy for alternative maritime fuels. On a national level, the development of such strategies is foreseen in the Alternative Fuel Infrastructure Regulation (as part of Fit for 55). For maritime shipping, these national strategies should be complemented with an overall strategy on a TEN-T corridor level.

**Action: Standardisation of bunkering equipment and procedures**

The AFIR also calls for the development of technical standards for bunkering facilities (i.e., nozzles and hoses). The consortium supports this action.

# A WHAT IS 'GREEN' METHANOL?

## REGULATIONS

Many regulations and rules influence the maritime fuels market. Below is a short list of main regulation packages from the EU and the IMO that are the main influences on the maritime energy transition.

### EU regulations

In 2020, the EU adopted the 'Fit For 55' plan which contains the ambition to reduce greenhouse gas emissions by 55% in 2030, compared to a 1990 baseline emissions figure. It also states the EU aims to be carbon neutral in 2050. While we are writing this report, negotiations are ongoing on how to implement this ambition into the many EU regulations and directives governing emissions for shipping. The section below should be read with this important caveat in mind.

### Renewable Energy Directive

The use of alternative fuels in transport is primarily regulated in the Renewable Energy Directive (RED II), European Renewable Energy Directive For the transport industry and the upcoming revision RED III). RED II sets goals for the amount of renewable energy and fuels member states must use. Recently, the European Commission has published the 'Fit for 55' package, adapting existing climate and energy legislation to meet the new EU objective of a minimum 55 % reduction in greenhouse gas (GHG) emissions by 2030.

The RED II, and the proposed revision as part of the "Fit For 55" programme, distinguishes several types of sustainable fuels and sets requirements for their share in the energy mix:

- **Biofuels produced from food or feed crops.** Biofuels from food or feed crops are separated into low Indirect Land-Use Change (ILUC) risk biofuels and high ILUC risk biofuels. High ILUC biofuels are to be phased out, and low ILUC biofuels (conventional biofuels) are limited to a maximum of 7% of total energy used in the transport sector.
- **Waste based biofuels** which are made from feedstock listed in Annex IX, b Examples include UCO (used/waste cooking oil) and animal fat. The share of this source needs to be limited to 1.7% of total energy used.
- **Advanced Biofuels and -gasses** This category includes fuels based on raw materials such as household waste, industrial waste and agricultural residues, and algae. For this category, there is a minimum share in 2030 of 2.2%.
- **Renewable fuels of non-biological origin (RFNBO)** such as hydrogen and E-fuels produced via electrolysis powered by renewable electricity. Fuels in this category needs to be at least 2.6% of the fuel mix in 2030.
- **Recycled Carbon Fuels** that are produced from recycled (fossil) wastes or from gaseous waste CO<sub>2</sub>.

The RED-II (Annex V) contains emissions factors used to calculate standardized emission figures for various maritime fuels, taking their production method into account. It also sets threshold values fuels must meet to be classified as 'renewable' and targets for the % of renewable fuel that must be used. Renewable fuels of non-biological origin, such as renewable methanol, must reduce the greenhouse gas emissions by at least 70% compared to fossil fuel equivalents to be classified as 'renewable'.

It is up to the Member States to determine how they want to achieve the targets set by the RED. Member States can implement different measure such as blending mandates, emission quota or tax incentives.

Recently, the European Commission has published the 'Fit for 55' package, adapting existing climate and energy legislation to meet the new EU objective of a minimum 55 % reduction in greenhouse gas (GHG) emissions by 2030. Currently, the European Parliament, Commission and Council are in the process of revising the RED. The new version (RED-III) aims to bring the directive in line with the 'Fit For 55' programme.

### FuelEU Maritime

FuelEU Maritime is a European Commission proposal. It contains greenhouse gas intensity targets for ships that are tightened over time. These targets apply to all ships calling at EU ports, except for warships, fishing vessels, wooden ships of a primitive build, ships not propelled by mechanical means, or government ships used for non-commercial purposes. The targets are for reduction of Well-to-Wake GHG emissions (not only CO<sub>2</sub> but also other GHGs like CH<sub>4</sub> and N<sub>2</sub>O). There will be a penalty for non-compliance. Marine fuels must be certified following the RED guidelines, otherwise they will be counted using the least favourable fossil fuel pathway emission factor for this type of fuel.

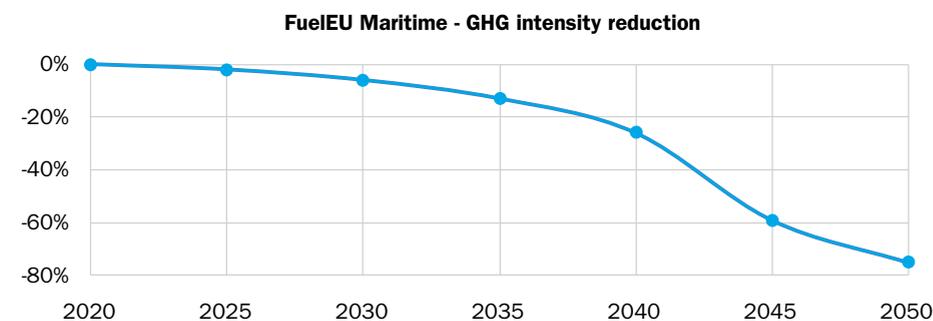


Figure 7: Proposed reduction of GHG intensity for maritime transport under FuelEU Maritime

**Alternative Fuel Infrastructure Regulation (AFIR)** aims to stimulate the supply of alternative fuels and power sources to kickstart the energy transition in transportation. It forces main EU ports to create supply of shoreside electricity and LNG. Other sustainable marine fuels like methanol are not included the AFIR.

#### EU-MRV

EU-MRV is a system for Monitoring, reporting and verification of emissions. Starting in 2018, ships over 5,000 gross tonnage loading or unloading cargo in the European Economic Area must monitor and report their related CO<sub>2</sub> emissions and other relevant information. The EU-MRV uses a set of default tank-to-wake emission factors [14] from the IMO, the same once used in the EEDI/EEXI system (see below). The emissions recorded under the MRV scheme are used for other EU schemes, such as the ETS.

**Emissions Trading System (EU ETS)** If this legislation package is finalized, the shipping sector will be included in the emissions trading system (ETS). This means they vessels above 5,000 DWT must purchase emission rights and have a financial incentive to reduce their greenhouse gas emissions. The proposal includes a 4-year phase-in period during which only a percentage of reported emissions must be compensated for (see Figure 8).

The commission proposal includes default emission factors [15] in to compute tank-to-wake emissions. These are in line with default IMO emission factors [16]. It is still uncertain if only CO<sub>2</sub> or also N<sub>2</sub>O and CH<sub>4</sub> will be included in the final version of the legislation. The emissions recorded under the EU-MRV scheme are used to calculate how many emission allowances ship owners must purchase.

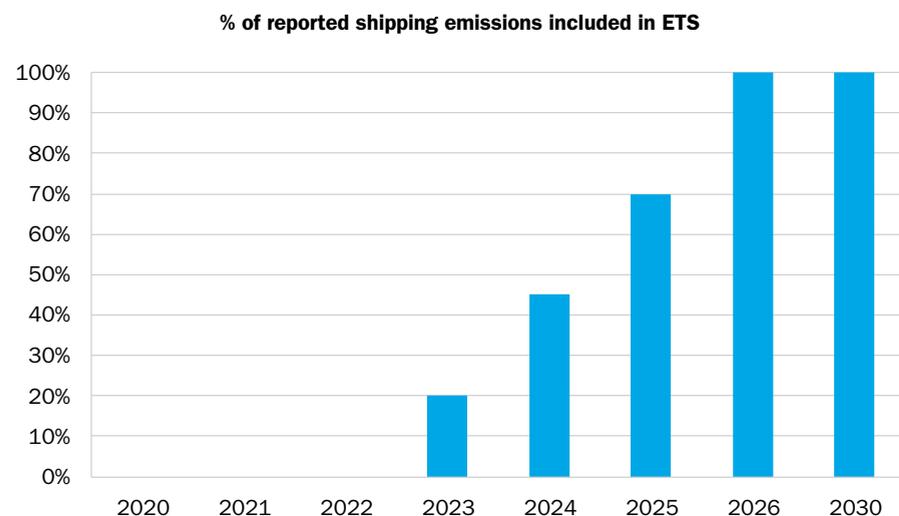


Figure 8: Phase-in period for ETS for ships over 5,000 DWT

At the time of writing, the European Parliament, Commission, and the Council of the European Union have adopted different versions of the proposal to include shipping in the ETS. These proposals differ on key issues, for example the % of emissions for voyages between EU and non-EU ports to be included in the ETS requirement. Agreement between the three parties is expected by the end of 2022.

**Energy Tax Directive (ETD)** Ship bunker fuel will be taxed under the EU ETD scheme, starting in 2023. The Directive includes a 10-year phase in period. Methanol and other sustainable fuels would not be taxed under this scheme.

#### IMO Regulations

Regulations set out by IMO apply to all ships globally. IMO will introduce a set of indices both on technical design of the vessel (EEXI) and on operational results (CII). The **EEDI** and **EEXI** are design guidelines. They provide a calculation of the standard CO<sub>2</sub> emissions (grams per ton/NM) based on the technical characteristics of a ship. The index uses static input such as standard speeds and the payload capacity. EEDI is for new-built ships, while EEXI applies to the existing fleet. The IMO's **Carbon Intensity Indicator (CII)** rates the operational performance of the vessel. CII measures how efficiently a vessel transports goods or passengers and is given in grams of CO<sub>2</sub> emitted per cargo-carrying capacity and nautical mile. The vessel is compared to a reference ship of a similar type and size and is given a rating from A to E. The threshold for the different labels will become increasingly stringent towards 2030. From 2023, the CII requirements will take effect for all cargo, RoPax and cruise vessels above 5,000 GT and trading internationally. While EEXI and EEDI are one-time certification based on a ship's design, the CII is based the actual CO<sub>2</sub> emissions during operation. There is no IMO system of sanctions for ships with low ratings, though the IMO encourages administrations, port authorities and other stakeholders to provide incentives to ships rated A or B (the highest possible ratings).

Currently, EEDI/EEXI and CII calculations are based on Tank-to-Wake CO<sub>2</sub> emission factors. This means that well-to-tank emissions and emissions of other greenhouse gases are currently not included.

In October 2022, the International Council on Clean Transportation published a working paper on EEDI compliance of two example vessels [17]. The paper analyses the EEDI of a large container carrier and a cruise ship using several fuels engine types. The paper concludes that both vessels would be compliant with the current EEDI regulations if they were equipped with methanol engines. Even if non-CO<sub>2</sub> greenhouse gas emissions were included in the EEDI, both methanol vessels would still be compliant.

#### AVAILABILITY OF FEEDSTOCKS AND PRICE FORECASTS

##### Biofuels - feedstock availability and pricing

The energy transition in the maritime sector is a huge challenge. Therefore, all measures that reduce emissions must be taken into consideration. The Dutch Social and Economic Council identified the maritime industry as a hard-to-abate sector for which use of biomass for feedstocks is acceptable. However, the availability of biomass for use in methanol production is not a given.

In a study by the international energy agency in 2021 [18], the authors calculated there is enough potential supply of biomass to produce significant quantities of bio-methanol, provided the biomass is used for methanol production and not for other purposes. An advantage of methanol is that it can be produced sustainably via multiple production pathways based on different feedstocks (see Figure 10). This makes methanol relatively robust to price shocks or supply problems compared to single-feedstock fuels.

In a study performed by IEA in 2021 [18] an extensive analysis was performed on expected cost levels for different types of biofuels, based on different production processes and feedstocks. The authors expect prices of new built plants to decrease due to technological improvements. Increasing production volumes is expected to lead to lower financing risk and costs, further lowering bio-methanol prices. The study found that some bio-methanol production pathways could already be cost-competitive with current MGO and VLSFO prices in 2020, and that prices were expected to decrease until at least 2050.

#### E-fuels - feedstock availability and pricing

The production of sustainable e-methanol depends on the production of the feedstocks: electricity, hydrogen and carbon dioxide. With water being an abundant resource, sustainable hydrogen production by electrolysis depends primarily on the price and availability of renewable electricity. The uptake of renewable energy in Europe is expected to increase significantly in the coming years. However, there will also be a growing demand for sustainable electricity from other sectors.

CO<sub>2</sub> can come from the air via Direct Air Capture (DAC) or via biomass to achieve net-zero emissions. Alternatively CO<sub>2</sub> can be re-used from end-of-pipe capture elsewhere. Both carbon capture and use (CCU) and DAC are still developing technologies and it is unknown if and when they will be available at large scale and competitive prices.

In 2021, the International Renewable Energy Agency (IRENA) conducted a study to predict prices for methanol [18]. The authors expect bio-methanol to be the cheapest way of producing methanol, at somewhere between 300 and 1000 USD / ton [18], meaning it could be cost-competitive with MGO at current price levels. E-methanol using DAC is expected to be more costly (between 800 and 1600 USD per ton), at least in the short term, because the production technologies for DAC and green hydrogen are still developing. If technology improves, however, these prices could come down to similar levels as those for bio-methanol.

#### ADAPTATION TO RENEWABLE METHANOL IN THE SHORT TERM

To use renewable methanol as a maritime energy carrier on the short to medium term, three things must be available:

- Production capacity
- Distribution capacity
- Methanol bunkering in most ports.

Currently, production capacity of renewable methanol is limited. Figure 9 shows current initiatives in development of both bio- and e-methanol in Europe (either already in production or planned). The initiatives contribute to over 2.5 million metric tons of renewable methanol production by the year 2025 in Europe.



Figure 9: Announced production facilities for bio-methanol (orange) and e-methanol (green) in Europe [19]

From these production locations, methanol needs to be distributed towards bunkering ports. There is already a well-established global methanol market with a total consumption of around 100 million tons annually [18]. Currently, Europe imports most of its methanol from (among others) Russia, Trinidad, the US, Venezuela and Equatorial Guinea. There is a well-established market for maritime methanol carriers. Import terminals for storage and handling of methanol are available in ports throughout Europe. Ports in the Netherlands are large hubs in the current methanol trade, with a share of 35% of European imports (according to the EU's COMEXT database).

Bunkering methanol requires relatively minor adjustments to existing bunkering infrastructure, contrary to those required for other alternative fuels such as LNG. The additional measures include (among others) specific safety equipment, training and certification. In different pilot projects, experience is being gained with bunkering methanol and safety procedures are being established. For instance, the port of Rotterdam has successfully executed a ship-to-ship methanol bunkering procedure in 2021 and is currently developing safety procedures and regulations to make methanol bunkering part of their standard operations. Stena and Proman completed two successful ship-to-ship bunkering operations in August 2022 in Rotterdam and Ulsan. On European level, standardized safety procedures are being developed too.

# B EMISSIONS FROM METHANOL SHIP ENGINES

## CALCULATING GREENHOUSE GAS EMISSIONS FROM MARINE FUELS

To reduce carbon emissions from shipping, new fuels are needed that cause lower greenhouse gas emissions than current common marine fuels such as marine gas oil (MGO) and diesel.

Emissions from marine fuels are divided into two main categories:

- Well-to-tank (WTT) emissions caused during production, distribution and storage of the fuel.
- Tank-to-wake (TTW) emissions caused by consumption of the fuel.

To determine the emission reductions that can be achieved by using alternative shipping fuels, emission calculations must be based on the so-called **'well-to-wake'** emission data. A well-to-wake emissions number combines WTT and TTW emission calculations to estimate the total amount of greenhouse gas emissions emitted by production, distribution, and combustion of a fuel.

A well-to-wake calculation takes into account the possible carbon sequestration by plants or recycling of waste carbons (CCU) or potentially carbon sinks (manure). Doing so is in line with IPCC methodologies and incentivizes changes in market behaviour contributing to reducing global carbon emissions.

## WELL-TO-TANK EMISSIONS FROM METHANOL

Direct emissions from combustion of methanol are based on the molecular content of methanol. Depending on the feedstock used, following the IPCC / EU calculation methodologies, the greenhouse gas emissions from methanol combustion can be net zero. Depending on the production process, more or less greenhouse gases are emitted during the production of the methanol. There are three main methods for producing methanol based on different types of feedstocks, as shown in Figure 10.

**'Grey' methanol** is produced from natural gas (roughly 2/3rds of current global production) or coal (the remaining 1/3rd, mainly produced in China). Grey methanol is made from carbon monoxide and hydrogen, which react over a catalyst to form methanol [18].

**Bio-methanol** is produced from biogenic feedstock. Multiple biomass streams can be used, including biogenic waste streams, such as the biogenic fraction of municipal solid waste, biogenic industrial wastes (such as black liquor), agricultural wastes or manure [18].

**E-methanol**, produced from renewable electricity which is converted into hydrogen and reacted with CO and or CO<sub>2</sub>. If the hydrogen is produced using green electricity, the methanol produced is according to European legislation (RED 2) considered a renewable fuel of non-biogenic origin. The well-to-tank emissions from renewable e-methanol will depend on other processing emissions and or use of transport for intermediate products and raw materials and distribution of the end fuel. [9]

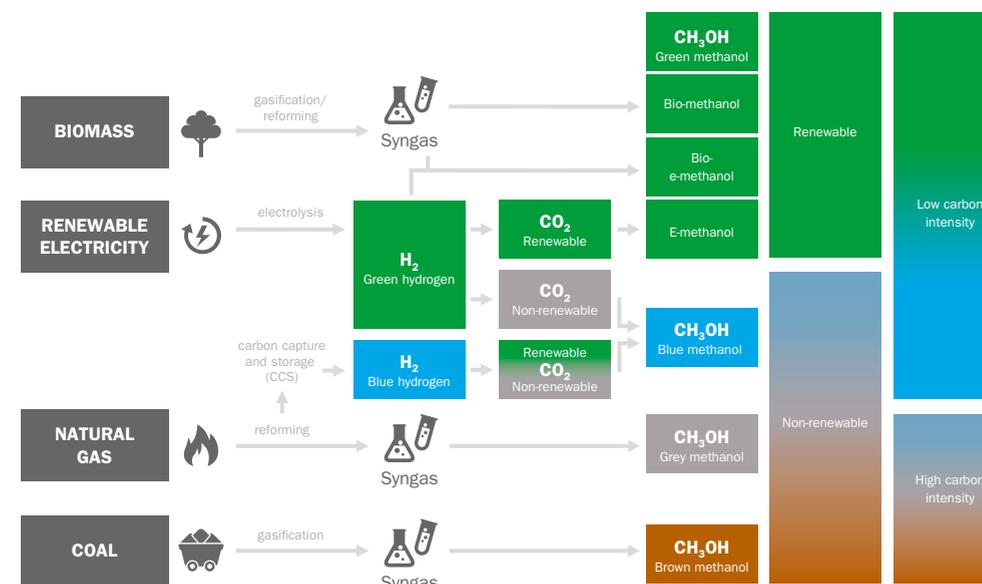


Figure 10: High-level overview of methanol production methods. Source: [18]

Grey: fossil; blue: carbon-recycled; green: renewable

## TANK-TO-WAKE GREENHOUSE GAS EMISSIONS FROM METHANOL

Methanol contains carbon, which is released into the atmosphere when it is burned. However, these emissions are net-zero if that CO<sub>2</sub> was also captured from the atmosphere, directly or through biomass. Burning methanol also creates small quantities of other greenhouse gases [8]. These are the sole tank-to-wake greenhouse gas emissions for 'green' methanol.

## WELL-TO-WAKE GREENHOUSE GAS EMISSIONS OF ALTERNATIVE MARINE FUELS COMPARED

The well-to-wake GHG emission estimates for various marine fuels are shown in Figure 11 and in Table 3. Some alternative low-emission marine fuels are included in the figure for context. These total numbers include well-to-tank and tank-to-wake emissions and take into account the greenhouse gases CH<sub>4</sub> (methane) and N<sub>2</sub>O (laughing gas). The values shown are based on default emission figures and on assumptions. Individual certified values can differ.

### DEFAULT EMISSION VALUES, ASSUMPTIONS AND ESTIMATES USED

The main source for Table 3 and Figure 11 is a research paper by Dr Lindstad et al called “Reduction of maritime GHG emissions and the potential role of E-fuels“ [8]. Biofuels are not included in the overview by Lindstad et al, so we used well-to-tank emission values from the JEC well-to-tank report version 5 [9] for those. Although that last report describes well-to-tank emissions for road transport fuels, the production pathways and emission estimates are very similar to those of marine fuels. There are dozens of different fuel production and distribution pathways – this report contains a selection of options deemed to be relevant to the maritime sector.

For bio-methanol and biodiesel, the production pathways chosen are those with the lowest and highest CO<sub>2</sub>-equivalent emissions according to JEC reference values. Other production pathways will have CO<sub>2</sub>-equivalent emissions somewhere in between those values.

The tank-to-wake emissions of CH<sub>4</sub> and N<sub>2</sub>O emissions listed here are estimates. For both methanol-fuelled engines [20] and ammonia-fuelled engines [21] [22] those emissions have been measured in real-world tests, but exact amounts are to be determined. For Bio- and E-LNG, CH<sub>4</sub> emissions are assumed to be equal to default values for regular LNG. Potential mitigation methods for CH<sub>4</sub> and N<sub>2</sub>O emissions (e.g., a Selective Catalytic Reduction System) are not considered.

For e-fuels, we assume the fuels are produced using 100% wind power, which (according to the JEC) produces no greenhouse gas emissions during power generation. We assume there are no other WTT emissions during the production and distribution of e-fuels. Although technically

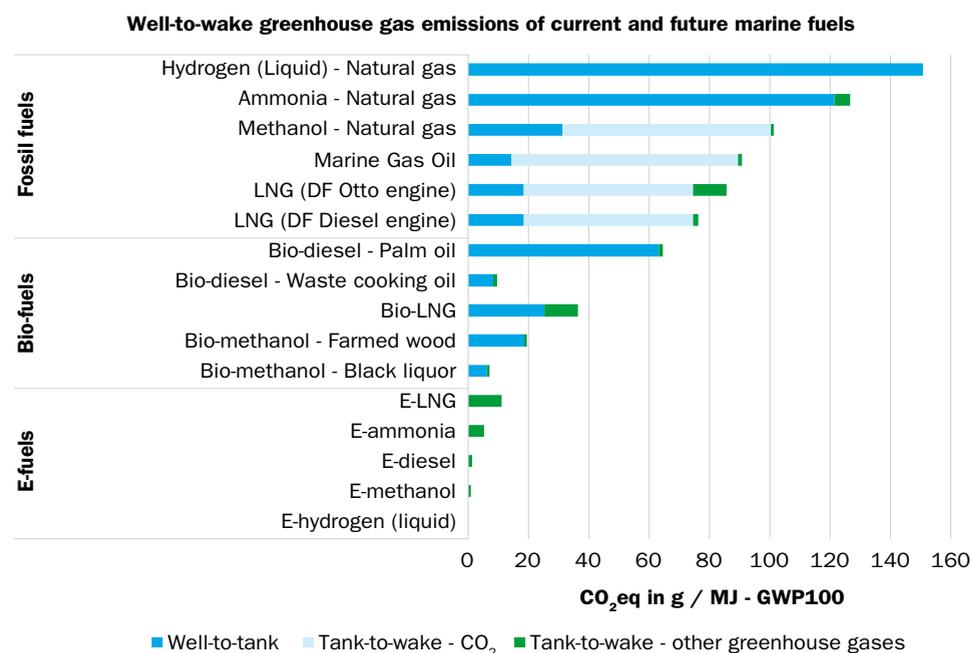


Figure 11: Well-to-wake CO<sub>2</sub>-equivalent emissions in g per MJ for different energy carriers with 100-year Global Warming Potential.

possible, it will take significant efforts to decarbonise entire marine fuel supply chains from end to end. These zero-emission assumptions therefore do not reflect the current situation but are intended to show the possibilities for zero-emission marine fuels.

Table 3: Greenhouse gas emission values in grams CO<sub>2</sub>-equivalent per MJ (GWP 100). The codes in the ‘source’ field refer to standardized production and distribution pathways for biofuels– see [9] for details.

	Well-to-tank	Tank-to-wake - CO <sub>2</sub>	Tank-to-wake - other ghg	Tank-to-wake - CH <sub>4</sub>	Tank-to-wake - N <sub>2</sub> O	Source
<b>E-hydrogen (liquid)</b>	0	0	0	0	0	[8]
<b>E-methanol</b>	0	0	0,9	0,2	0,7	[8]
<b>E-diesel</b>	0	0	1,3	0,2	1,1	[8]
<b>E-ammonia</b>	0	0	5,3	0	5,3	[8]
<b>E-LNG</b>	0	0	11,1	10,4	0,7	[8]
<b>Bio-methanol - Black liquor</b>	6,2	0	0,9	0,2	0,7	[8], [9] - BLME1a
<b>Bio-methanol - Farmed wood</b>	18,6	0	0,9	0,2	0,7	[8], [9] - WFME1b
<b>Bio-LNG</b>	25,3	0	11,1	10,4	0,7	[8], [9] - WWLG2
<b>Bio-diesel - Waste cooking oil</b>	8,3	0	1,3	0,2	1,1	[8], [9] - WOFA3
<b>Bio-diesel - Palm oil</b>	63,3	0	1,3	0,2	1,1	[8], [9] - POFA3c
<b>LNG (DF Diesel engine)</b>	18,5	56,1	1,7	1	0,7	[8]
<b>LNG (DF Otto engine)</b>	18,5	56,1	11,1	10,4	0,7	[8]
<b>Marine Gas Oil</b>	14,4	75,1	1,3	0,2	1,1	[8]
<b>Methanol - Natural gas</b>	31,3	69,1	0,9	0,2	0,7	[8]
<b>Ammonia - Natural gas</b>	121,4	0	5,3	0	5,3	[8]
<b>Hydrogen (Liquid) - Natural gas</b>	150,8	0	0	0	0	[8]

### AIR POLLUTANTS

Apart from greenhouse gases, ships also emit other substances than can adversely affect human health or the environment. These emissions include:

- Nitrogen (NO<sub>x</sub>),
- Sulphur (SO<sub>x</sub>),
- Particulate matter (PM), and
- Black Carbon.

Using methanol leads to a reduction of sulphur oxide emissions proportional to the amount of methanol used in dual-fuel engines. Nitrogen oxide emissions are roughly 40% lower (compared to Tier II) [10] [11]. It also reduces black carbon and particulate matter emissions. For ships sailing in IMO emission-controlled areas (ECA), methanol-powered marine engines are a way to comply with low-sulphur marine fuel requirements. Tier III NO<sub>x</sub> level can be achieved via several emission control technologies such as SCR, water blending or EGR).

# C IMPACT ON SHIP DESIGN AND OPERATIONS

There are many different types of marine vessels with very different designs, depending on their technical and operational profile. Choosing an alternative 'green' maritime fuel can impact the technical lay-out of the vessels (tanks, engines, piping), compliance with safety regulations, and/or the operational range of the vessel.

## ENERGY DENSITY

'Energy density' is the amount of energy per unit of volume of a fuel. Figure 12 shows the energy density for various fuels and the density including packaging (the size of the storage tanks, secondary barriers and cofferdams). The energy density of methanol is less than that of MGO - to store the same energy as is contained in 1 litre of marine gas oil, one needs 2.3 litres of methanol. Diesel, MGO and HFO have a relatively high energy density compared to the alternative fuel types. Methanol has a significantly lower density than diesel, but higher than the other fuels in the comparison, especially when taking packaging into account.

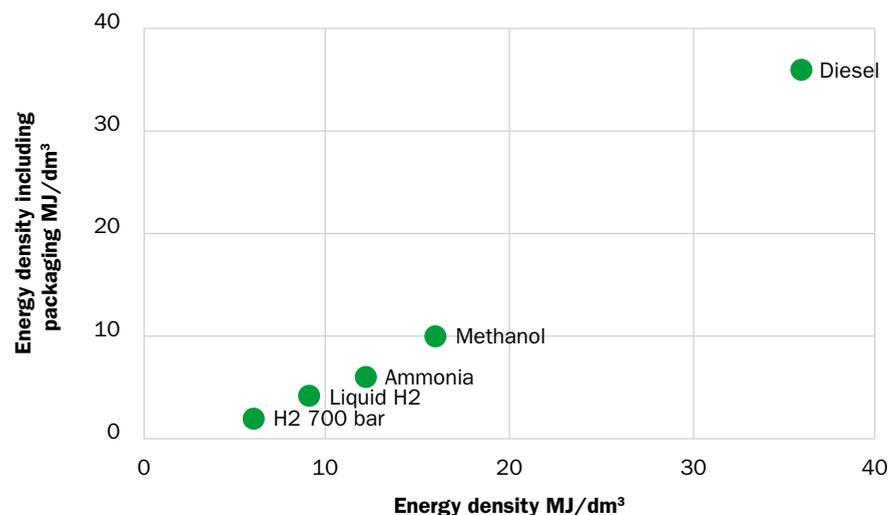


Figure 12: Energy density of marine fuels [23]

## DOES SWITCHING TO METHANOL RESTRICT MARITIME OPERATIONS?

According to a previous study by TNO, many vessels can complete their normal journeys using methanol without additional bunkering [23]. Based on data analysis of vessel arrival data in the ports of Rotterdam and Amsterdam, sailing on methanol seems applicable for most midrange shipping markets. The often over-dimensioned tank capacity allows them to bunker methanol without serious adjustments to the bunker frequency, sailing pattern, or tank capacity/ship design. This is particularly the case for shortsea shipping markets and shipping markets with point-to-point sailing patterns, including inland shipping. Others will need to reduce speed, increase tank/ship size or bunker more often to achieve the same range as an MGO-fuelled vessel.

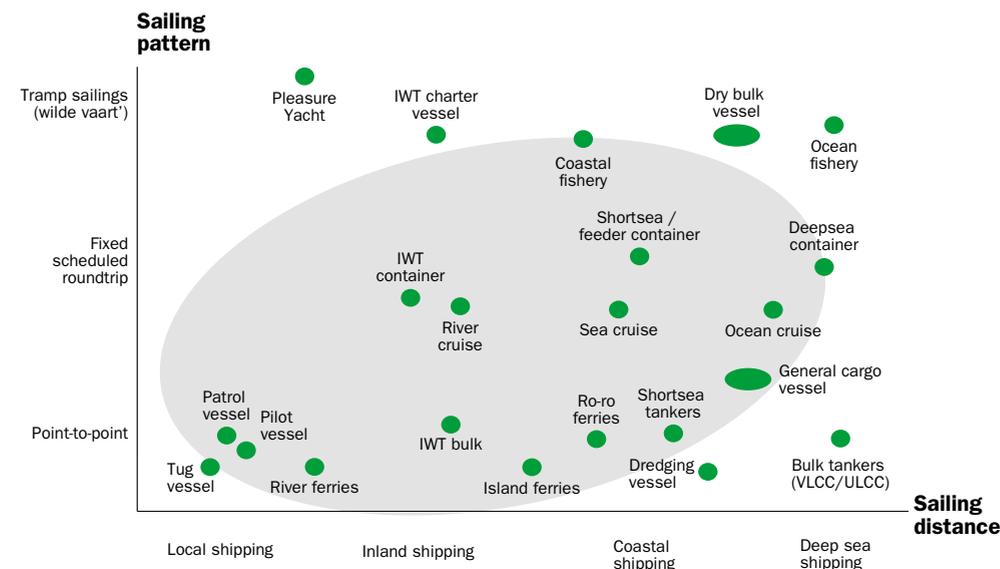


Figure 13: Ship types thought to be suitable for methanol propulsion

As part of the JIP ZERO initiative, MARIN performed an analysis of the technical and operational suitability of introduction of a wide range of alternative energy carriers for eight different ship types. The analysis took several aspects into account, including volume of the on-board storage and power system, effects on the operational profile and the effects on CAPEX and OPEX. The analysis concludes that especially for vessels with a relatively large power demand or with a relative high autonomy (6 out of 8 use cases), methanol was considered as one of the most suitable alternatives.



Figure 14: Bunkering of the Takaroa Sun with methanol in the port of Rotterdam

### BUNKERING METHANOL

Methanol vessels can receive their fuel in a variety of ways. Usually, ships are fuelled by pipelines from a shore-based installation. However, shore-to-ship methanol bunkering installations are still rare. The Stena Germanica has been supplied via truck-to-ship bunkering since 2015. In May 2021, the first barge-to-ship methanol bunkering operation took place in the Port of Rotterdam (see Figure 14), where the tanker Takaroa Sun was fuelled. Both bunkering methods are seen as safe and practical by Waterfront Shipping, the charterer of the Takaroa Sun.

Because methanol is liquid at ambient temperatures and pressure, existing storage and bunkering facilities only require minor modification in order to be able to handle it. This enables a rapid adaptation of existing facilities to methanol bunkering if the demand is there.

### AVAILABILITY OF RENEWABLE METHANOL FOR BUNKERING

Methanol is currently available in 100 ports worldwide, of which 47 currently store with large quantities. However, much of this methanol is currently produced from either natural gas or coal. Annual production of methanol was roughly 100 million tons in 2021, of which only 0.2 million tons were produced in a sustainable manner [18].

Emissions reduction in the shipping sector will be a gradual process. Blending green and grey methanol, while gradually increasing the share of renewable methanol, could reduce the GHG emissions of methanol ship engines in line with the targets set by the IMO and EU.

### SAFETY

Methanol is a hazardous substance because of its volatility, flammability, toxicity and vapour density (heavier than air). It has a low flashpoint (12 degrees Celsius), so safety measures must be taken to prevent fires and explosions. The main risks associated with methanol are:

- leaked vapours (mixed with air) catching fire or exploding.
- intoxication of people handling the fuel due to imbibing, prolonged skin contact, or excessive exposure to methanol vapour.

Fortunately, the chemical and shipping industries are familiar with methanol and possess a wealth of knowledge of and experience with safe storage and handling. Methanol ships are already in operation and have provided ample real-world experience with risk management and safe handling of methanol as a marine fuel. This knowledge is currently being consolidated in the International Code of Safety for Ships using Gases or other Low-Flashpoint Fuels (IGF CODE) for methanol and ethanol [24].

Methanol is not considered an acute danger to the environment. If methanol leaks into the ocean, it is rapidly decomposed by microorganisms that are widely present in the marine environment [25]. Methanol is soluble in water and unlike traditional marine fuels, it will therefore not form floating pools. This limits the danger of pool fires when methanol is spilt in the water.

Cofferdam requirements for methanol differ from those for MGO. A methanol tank does not require a cofferdam to the water because it is not toxic to aquatic life. However, above the waterline and within the ship, cofferdams are required. Fuel tanks that comply with both MGO and methanol will take up more space than tanks designed for a single fuel. [26] [8]

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