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FAST Track to Clean and Carbon-Neutral WATERborne Transport

Deliverable 7.1

Report on methanol supply, bunkering guidelines, and infrastructure

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Executive Summary

The FASTWATER (FAST Track to Clean and Carbon-Neutral WATERborne Transport through Gradual Introduction of Methanol Fuel) project aims to start a fast transitionary path to move waterborne transport away from fossil fuels, and reduce its pollutant emissions to zero impact, through the use of methanol fuel. FASTWATER will develop and demonstrate a path for marine methanol technology, both for retrofit and next generation systems. Specifically, the project will demonstrate feasibility on three vessels running on methanol fuel: a harbour tug, a pilot boat, and a coast guard vessel. A conversion concept for a river cruise ship using methanol-driven propulsion will also be developed and a universal, scalable retrofit kit for converting diesel-fuelled ships to methanol use for a wide power range (200 kW-4 MW) will be validated.

The work within the FASTWATER project also extends to investigating methanol supply, bunkering, and infrastructure needs to facilitate the use of renewable methanol in the marine transport sector. This deliverable report includes a description of the current status of renewable methanol production and supply; gives an overview of bunkering guidelines; and describes developments and work underway for the FASTWATER vessel demonstrations. Recommendations for future development are given.

Problem definition

The purpose of this document is to provide a summary of the current status regarding renewable methanol supply and infrastructure for the marine sector, and of methanol bunkering guidelines and current practices. Development of bunkering plans and infrastructure needs for the FASTWATER demonstrators are also described.

Approach and scope

Information was collected from published articles and project reports and from direct contact with participants in ongoing and recent projects where methanol was used as a marine fuel. Information was also generated through direct discussions with FASTWATER demonstration partners to collect information on the specific needs for their vessels, and from project partners' ongoing activities in methanol supply and bunkering. The focus was to some extent on smaller vessels used in European coastal and inland waterways and demonstrated in the FASTWATER project, although a wider perspective was taken for some topics to provide examples for other ship types.

Conclusions and recommendation

Experience with methanol supply and bunkering for the marine sector has been developing rapidly in recent years. Truck to ship, terminal to ship, and barge to ship bunkering pathways have all been safely demonstrated for methanol, although to a limited extent. A methanol bunkering reference document is now available and a standard is under development. The Swedish pilot boat will be the first FASTWATER demonstrator to bunker methanol, and it will be the first vessel known to bunker methanol from a quayside dispensing station. Further work in the FASTWATER project on bunkering includes an investigation on the use of a bunker barge for a river cruise vessel. It is expected that the demonstrators within the FASTWATER project will contribute to further knowledge within the area of marine methanol supply and bunkering by providing feedback to standards development and sharing experiences from practical operation.

CONTENTS

List of symbols and abbreviations

AAGR	Average Annual Growth Rate
ADN	European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways
CAGR	Compound Annual Growth Rate
CEN	European Committee for Standardization
CESNI	European Committee for drawing up Standards in the field of Inland Navigation
ES-TRIN	European Standard laying down Technical Requirements for Inland Navigation vessels
IGF Code	International Code of Safety for Ship Using Gases or Other Low-flashpoint Fuels
IMO	International Maritime Organization
ISO	International Organization for Standardization
MTO	Methanol-to-Olefins
PPE	Personal Protective Equipment
REACH	European Union regulation concerning the Registration, Evaluation, Authorisation and restriction of CHemicals
SBC	Safe dry break-away coupling
Stem	Term used in bunkering to describe the supply of fuel on one occasion

1 INTRODUCTION

The FASTWATER project aims to demonstrate the feasibility of using renewable methanol as a marine fuel on three different vessel types and to create a detailed design and feasibility study for a fourth. In addition to developing the technology and on-board installations to burn methanol as a fuel for propulsion, the logistics and procedures for providing methanol fuel to the vessels are being investigated and demonstrated. The FASTWATER project is thus investigating the complete renewable methanol supply chain from producers to transporters to port-based infrastructure and finally to the bunkering of ships. For each demonstrator vessel in the FASTWATER project, plans for safe and efficient supply and bunkering within a port environment are in development.

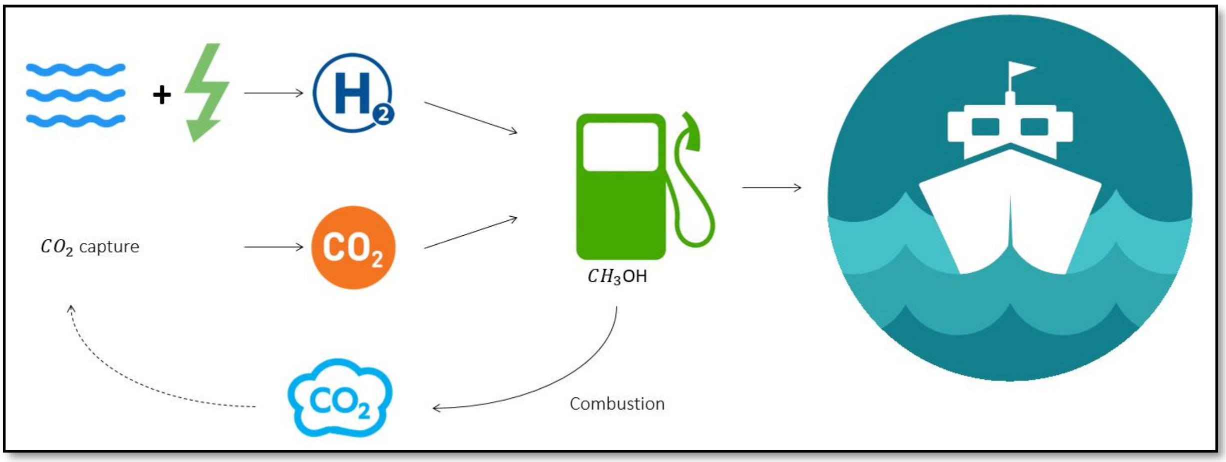

Figure 1: The FASTWATER project covers the link from production of renewable methanol to supply as a vessel fuel) (Source: FASTWATER consortium)

1.1 Background

Methanol is widely available and is one of the top five chemical commodities shipped globally (Methanex, 2020). Methanol has been shipped, handled, and used in a variety of industries for over 100 years (Anderson and Marquez-Salazar, 2015). As a commodity, methanol is available in over 100 ports worldwide (Methanol Institute, 2021), including in 88 out of the top 100 ports (Martin, 2021). Although supply of methanol as a commodity is well established, the provision and use of methanol as a marine fuel is quite limited as of 2021.

Fuel supply and bunkering facilities are important considerations for ship operators when considering a switch to new fuels – uncertainties regarding availability and lack of bunkering facilities can be a barrier to uptake of alternative fuels (Chryssakis et al., 2014). Transitioning to a new fuel will be facilitated by developing and demonstrating a range of bunkering possibilities to suit different vessel types and operational profiles.

1.2 Purpose

FASTWATER project Task 7.1, "Methanol Fuel Supply Chain", has the overall objective of investigating and proposing recommendations concerning fuel supply, logistics, and bunkering. The purpose of this report, Deliverable D7.1 "Report on methanol supply, bunkering guidelines, and infrastructure", is to investigate and describe the status of methanol supply procedures and guidelines for marine vessels, with the aim of giving guidance and recommendations for the demonstrators within the FASTWATER project. The intent of the report is also to give a wider view of the status and developments of marine methanol fuel supply, which may be useful for many other vessel types and sizes, and for the waterborne transport sector in general. The report should provide the state of the art on current methanol supply, bunkering and logistics for methanol fuelled vessels. Guidelines and regulations available or under development for methanol bunkering will also be investigated and described. Missing or weak links in the supply chain and logistics for provision of methanol as a marine fuel will be identified and recommendations made for further development and support needs.

1.3 Scope and Approach

Although the focus of the FASTWATER project is on smaller vessels used in European coastal and inland waterways, this investigation took a wider perspective to include all current and previous methanol fuelled vessels during the information collection phase, as the number of vessels currently bunkering methanol is limited. As of 2020, there were only12 vessels reported to be fuelled by methanol, as reported in the IMO's 4th GHG study (Faber et al., 2020).

The approach was to collect information from published articles and project reports and from direct contact with participants in ongoing and recent projects where methanol was used as a marine fuel. Information on methanol bunkering guidelines development was obtained from project partners Lloyd's Register and the Methanol Institute, which have been involved in the recent development of guidelines. Information was also generated through direct discussions with FASTWATER demonstration partners to collect information on the specific needs for these vessels.

2 METHANOL AS A MARINE FUEL – PROPERTIES AND OVERVIEW

Methanol (CH_3OH) is the simplest of alcohols and is a colourless, flammable liquid at ambient temperatures. Also known as methyl alcohol or wood alcohol, it is an oxygenated hydrocarbon that is used widely in the chemical industry as a feedstock for producing chemicals such as formaldehyde, acetic acid and plastics. These chemicals are a building block for many of the products used in daily life such as paints, adhesives, and building materials.

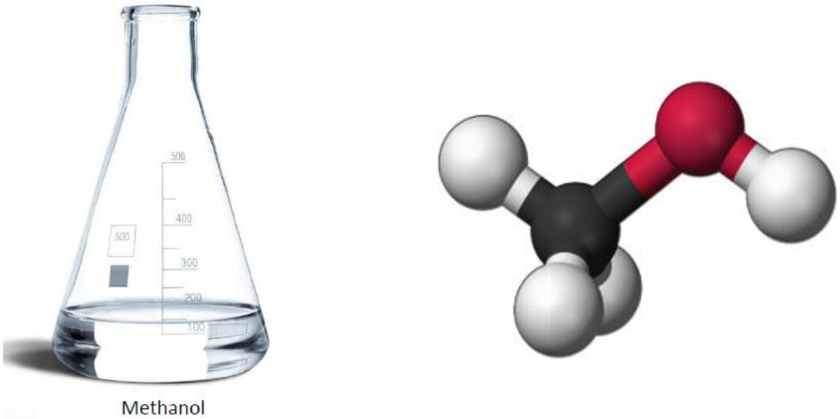

Figure 2: Methanol (CH_3OH)

Methanol is also used as a fuel either by itself in vehicles, ships, or for cooking, or as a blend with other fuels such as gasoline. Methanol's history as a fuel began at the time of the second world war, when methanol produced from coal was used in Germany (Netzer et al., 2015). It was used extensively in California in the 1980s and 1990s in an M85 fuel (85% methanol, 15% gasoline) trial that was initiated primarily for air quality considerations (Verhelst et al., 2019). There has recently been an increase in interest in the use of methanol as a fuel and its use for this purpose has grown rapidly since the mid-2000s (IRENA, 2021).

2.1 Properties and safe handling

Methanol is a clear, colourless liquid that is soluble in water and biodegradable. Selected properties of methanol are shown in Table 1.

Table 1: Selected properties of methanol (of IMPCA quality: 99.85 % purity by weight) (source: Methanol Institute "Methanol Technical Data Sheet")

Molecular Weight	32.04 g/mol
Specific Gravity (20/20°C)	0.7910 – 0.7930
Freezing Point	-97.8°C
Boiling Point	64.6°C
Flash Point (closed cup, 1 atm.)	12°C
Explosive limits in air	6% - 36%
Solubility: Methanol in Water/Water in Methanol	100%/100%

Additional information about methanol is provided in the Methanol Institute Technical Data Sheet included in Annex B.

The hazards of methanol are flammability (liquid and vapour) and toxicity (by ingestion, skin contact, and inhalation), according to the harmonised classification and labelling (CLP00) approved by the European Union (see Figure 3).

Figure 3. Hazard symbols for methanol as shown on the European Chemicals Agency website substance card for methanol (ECHA, 2021).

The following points are key to consider when handling methanol:

- *Methanol is a flammable, easily ignited liquid*
- *Methanol vapour has a density that is slightly higher than that of air (molecular weight of 32 versus 28 grams per mole). Depending on the circumstances of a release, methanol vapour may migrate near the ground and collect in confined spaces and low-lying areas. As it is near neutral buoyancy, it will readily dissipate in ventilated areas. In areas where it accumulates, it may flash back to the source if ignited.*
- *In some specific circumstances, methanol vapour may explode rather than burn on ignition and methanol containers are subject to Boiling Liquid Expanding Vapour Explosion (BLEVE) when externally heated.*
- *Methanol is a toxin; ingestion of even small amounts (approximately 10 to 30 millilitres) may be fatal. It is also toxic by inhalation and skin absorption.*
- *Methanol is completely miscible in water but retains flammability at relatively high dilutions – a 75% v water and 25% v methanol solution is still considered a flammable liquid.*

(summarized from the Methanol Institute Safe Handling Manual (Methanol Institute, 2019).

2.2 Benefits of using methanol as a marine fuel

Methanol has many potential benefits for ship operators aiming to reduce their environmental impact. Methanol can be extremely clean burning, as it contains no sulphur, and with a single carbon atom it does not easily form carbonaceous particulate matter (Verhelst et al., 2019). Thus it provides immediate benefits in terms of pollutant emissions. When produced from low carbon feedstock such as waste or biomass and renewable electricity, life cycle climate impacts in terms of greenhouse gas emissions are very low (Martin, 2021). These renewable feedstocks offer a pathway for methanol to meet future emissions and GHG reductions targets without requiring additional shipboard installations or investment. Methanol also has the benefits of ease of handling and onboard storage, as it is a liquid at ambient shipboard conditions.

For marine spill events, methanol is classified as a "dissolver that evaporates" according to the Standard European Behaviour Classification (HNS-MS, 2021). It is fully miscible with water, meaning it will dissolve completely if spilled in water, with some fraction evaporating depending on the temperature. According to the Joint Group of Experts on the Scientific Aspects of Marine Environmental Protection hazard procedure system (GESAMP, 2019), methanol is fully biodegradable with no potential to bioaccumulate (See https://www.hns-ms.eu/result/72). Methanol spilled to ground is expected to biodegrade over time, with an estimated half-life in soil and groundwater of one to seven days (Pirnie, 1999).

The EU's Joint Research Centre's study on alternative fuels for shipping states that methanol is one of the most promising options to decarbonise the shipping sector (Moirangthem, 2016). In recent years the interest in methanol-fuelled vessels has been steadily increasing. In addition to the twelve commercial vessels operating on methanol in 2020 (Faber et al., 2020), many additional vessels are on order. Stena and energy company Proman have partnered to develop three methanol-ready tankers, with the first scheduled for delivery in early 2022 (Ship Technology, 2021). In July 2021, Maersk signed a contract for a feeder container vessel to operate on a Baltic Sea shipping route, with delivery planned for 2023. In August 2021, Maersk announced the order of eight new container vessels that they plan to run on carbon neutral methanol (Jacobsen, 2021).

Further evidence of emissions reductions for both end of pipe and across the fuel life cycle, specifically for smaller vessels operating in coastal and inland waterways in Europe, will be demonstrated in other work packages in the FASTWATER project.

3 METHANOL SUPPLY

Methanol is a globally traded, large platform fuel and chemical, produced at multiple locations across the globe. Over 100 methanol plants now in operation have a combined capacity of about 140 million metric tons. According to Globe Newswire, the global methanol market reached a value of USD 34 billion in 2020 (Globe Newswire, 2021). Figure 4 illustrates methanol trading hubs and volume traded on an annual basis.

Figure 4. Methanol Trading Hubs (volumes in thousand tonnes) (courtesy Methanol Institute)

Methanol demand is expected to grow at an average annual growth rate of 3.5% towards 2025 (see Figure 5), with new capacity planned to come online in North America, Russia, Iran and China in coming years (Business Wire, 2019). In China, the largest geographical market for methanol, growing demand for methanol is highly attributed to the methanol-to-olefins sector, but there is also increasing demand in the automotive and construction end-use industries. Some forecasts have reported an expected growth at a compound annual growth rate (CAGR) of 7.4% by 2023 (Business Wire, 2019). New methanol capacity is expected to come online in 2021 and 2022, mostly in North America but also in Central Asia, the Middle East and in China.

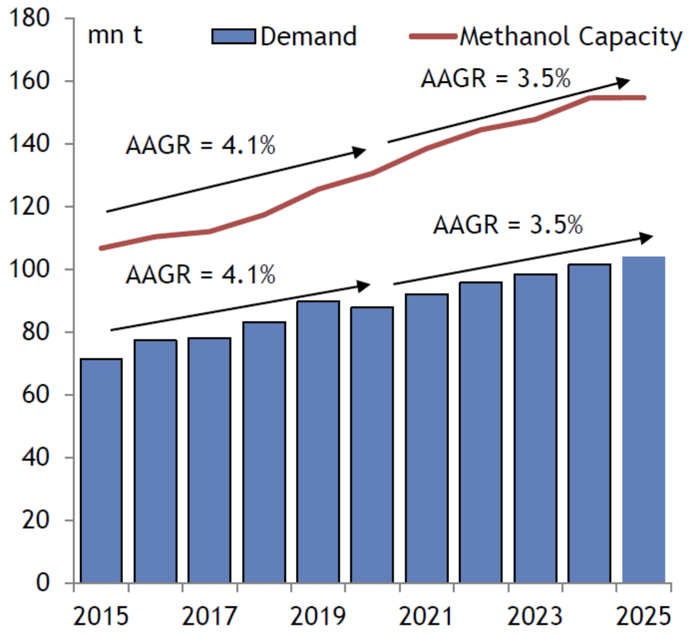

Figure 5. Methanol capacity and demand (Courtesy Argus Media)

In 2020, about 30% of world demand by end use was represented by energy applications and 70% by chemical applications in terms of volume, as shown in Figure 6, while in terms of value, energy applications exceeded chemicals.

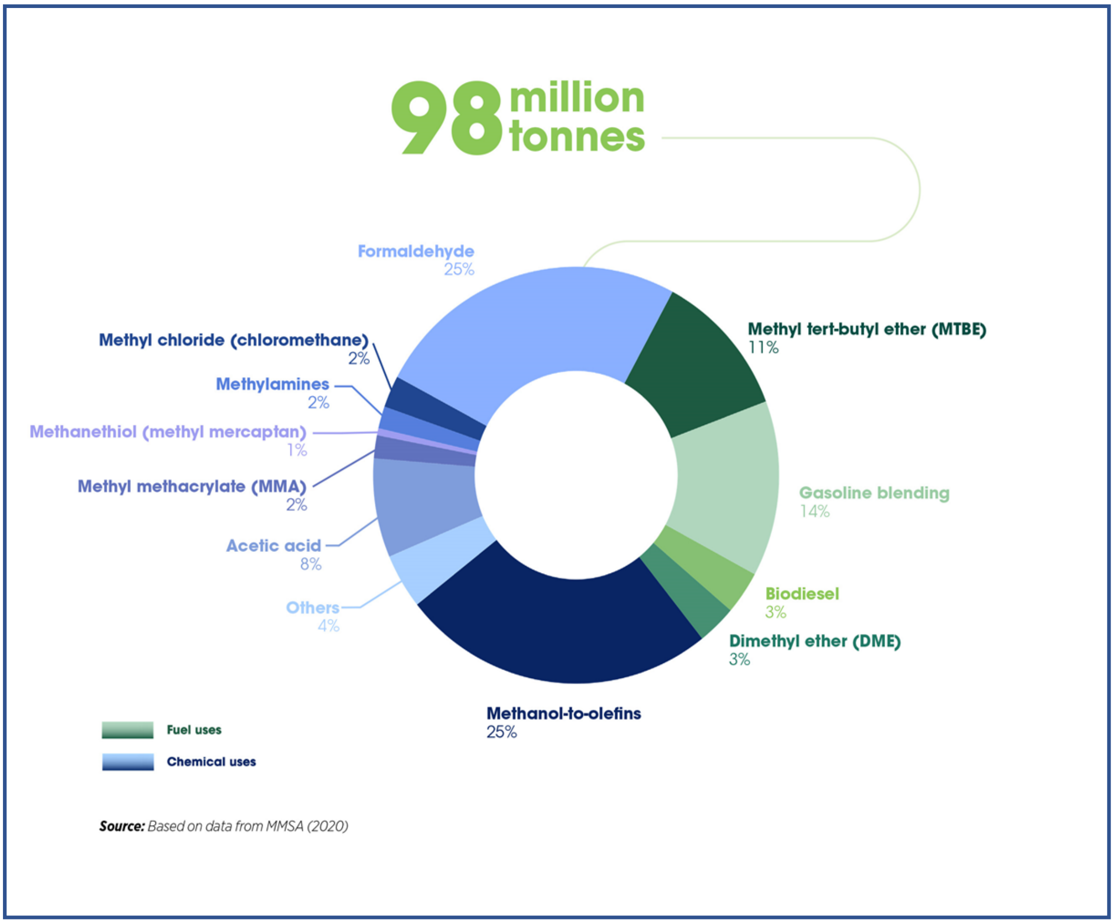

Figure 6. Methanol use by application (Reproduced from IRENA and Methanol Institute, 2021, © IRENA)

An overview of examples of methanol use in derivative chemicals, products, and fuel uses is shown in Figure 7.

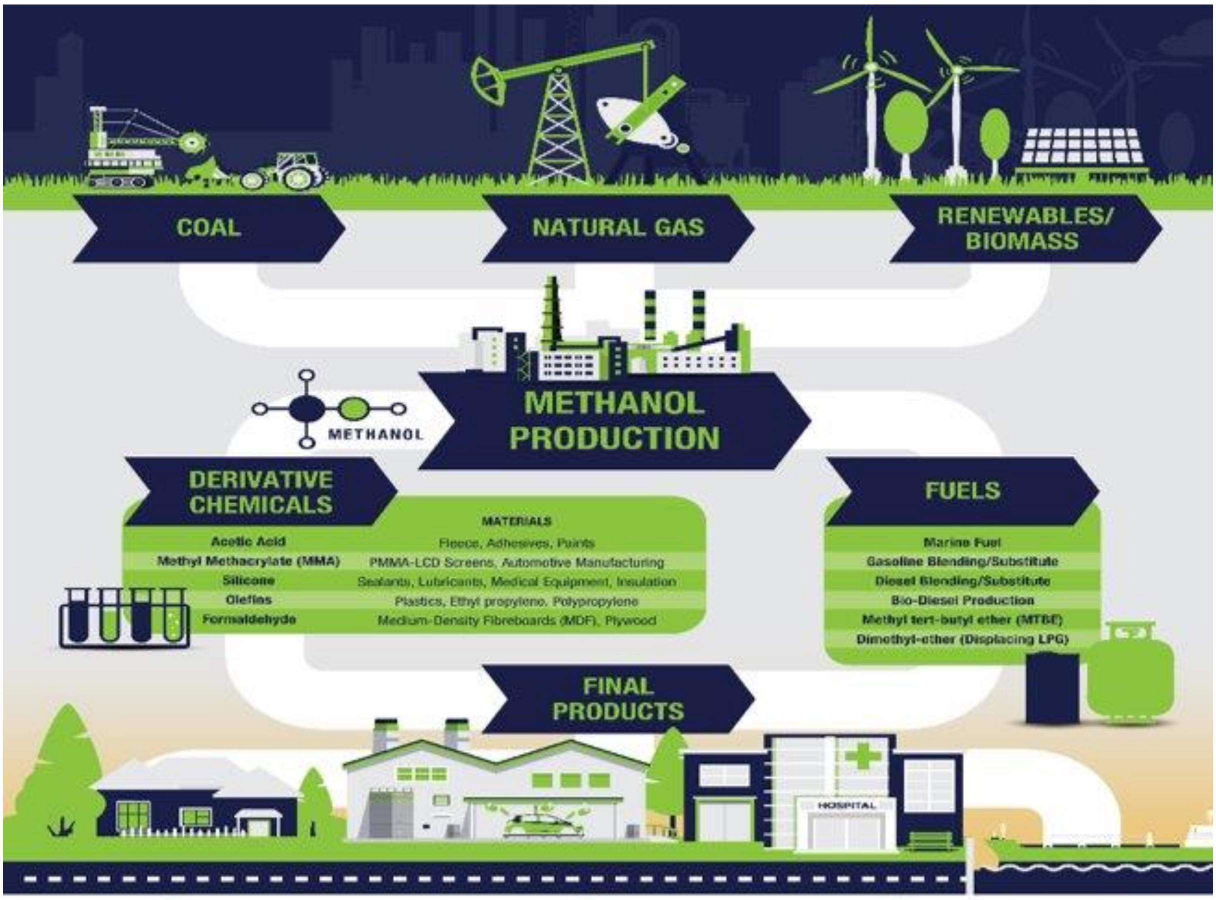

Figure 7. Methanol production pathways and end uses. Figure courtesy of the Methanol Institute

While demand growth in coming years is piloted by the Chinese MTO sector, the need to replace traditional fuels in the automotive and marine sectors with alternative fuels is poised to become a large demand segment in the global methanol segment. As an emerging renewable energy resource, methanol has gained traction as a transition fuel capable of delivering climate benefits in the near term and carbon neutrality in the long term. Increasingly loud calls for policymakers to enact legislation, such as the proposed extension of the Emissions Trade System (ETS) to maritime transport in the European Union (EU), and discussions at the International Maritime Organization (IMO) concerning the adoption of a global fuel levy, to address energy transition of mobility, indicate a prominent role for methanol as a marine fuel. In fact, its integration into the global bunker fuel mix has already started, with S&P Global Platts having launched daily methanol bunker fuel price assessments and market analytics agency IHS Markit projecting methanol bunker availability to have reached about a million tons by 2025.

3.1 Methanol global distribution and availability in ports

A report assembled by Infiniti Research in 2019, which identified and validated suppliers of methanol capable of selling and delivering at major ports across the world, found that methanol may be available at over 100 ports across the globe.

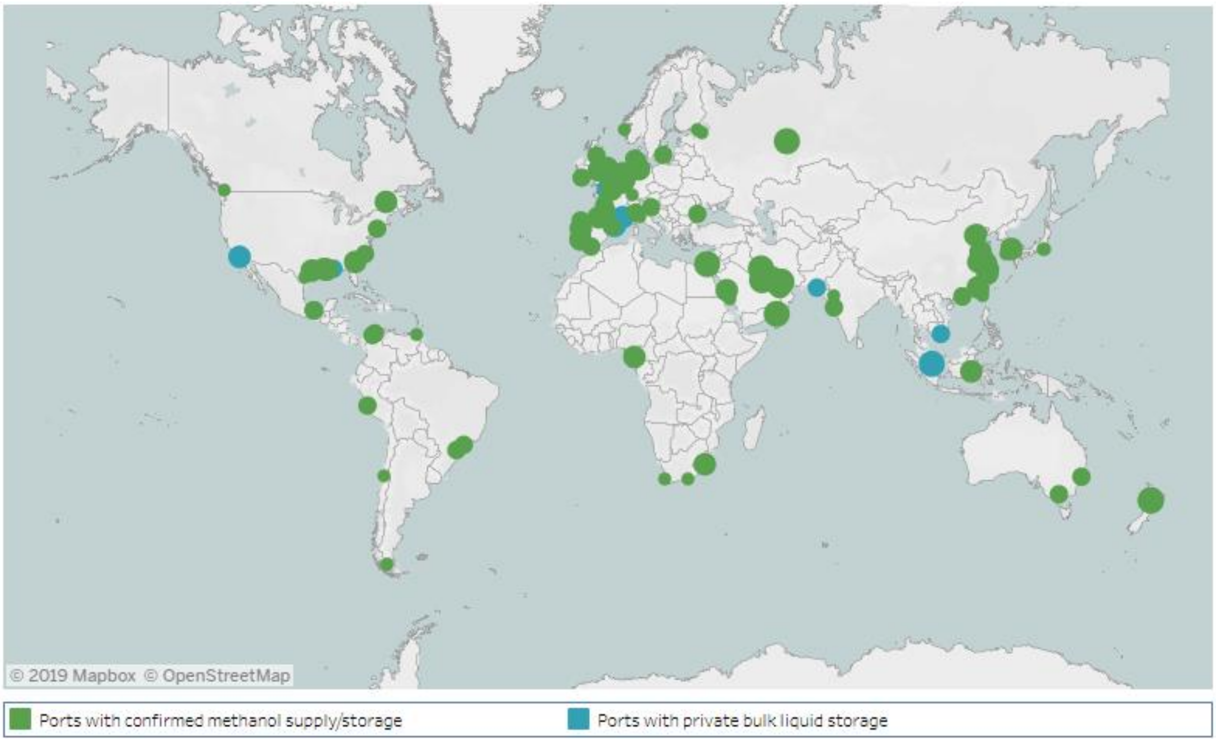

Figure 8. Methanol availability in port (courtesy of the Methanol Institute)

Figure 8 shows the global distribution of ports with methanol supply or storage, demonstrating availability of methanol along all major trade routes.

3.2 Carbon-Neutral Methanol Availability and Development

While most methanol is produced by steam reforming natural gas, production of renewable methanol derived from a variety of sustainable feedstocks, such as biomass, waste and captured CO_2 and hydrogen has become increasingly prominent in the methanol sector. This is due to the increasingly apparent need to address the threat of climate change, by shifting towards low carbon and eventually net carbon neutral fuels and chemicals to power our societies. Renewable methanol, derived from renewable energy and renewable feedstocks, is fundamentally produced via two routes, as shown in Figure 9. Sustainable methanol production routes (courtesy of the Methanol Institute).Figure 9: biomethanol, sourced from biomass, and e-methanol, obtained by generating hydrogen by electrolysis of water, combining it with captured CO_2 emissions and catalytically converting it into methanol.

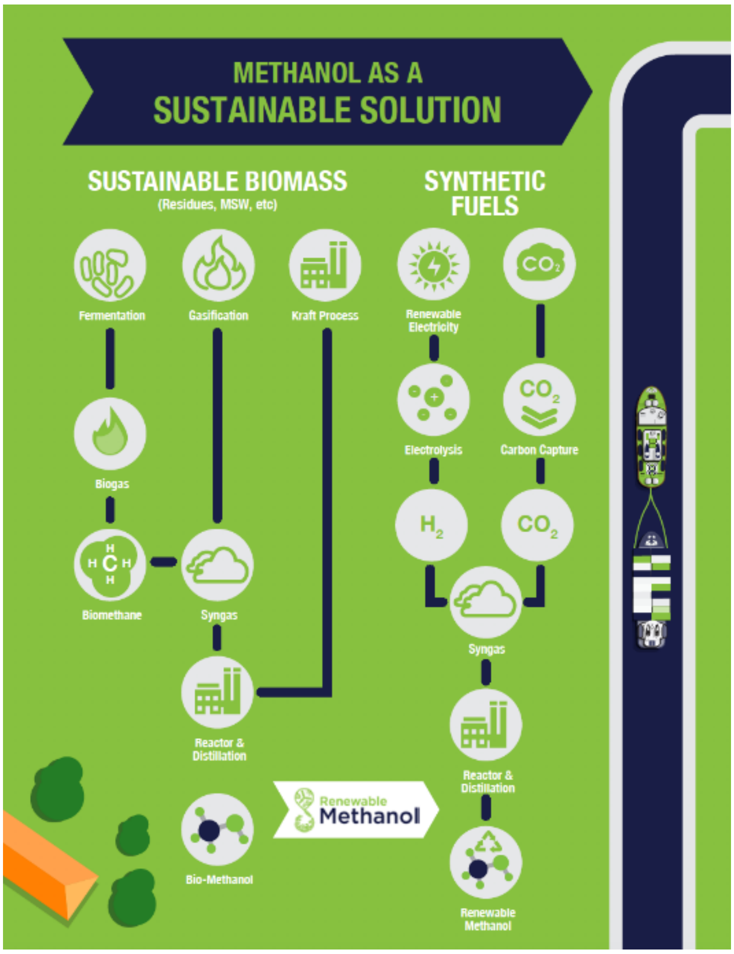

Figure 9. Sustainable methanol production routes (courtesy of the Methanol Institute).

A report compiled by the International Renewable Energy Agency (IRENA) and the Methanol Institute in 2021 found that world demand for methanol may increase fivefold, to 500 million tonnes by 2050. As illustrated by the chart in Figure 10, IRENA projects that 80% of the global production will be from renewable sources.

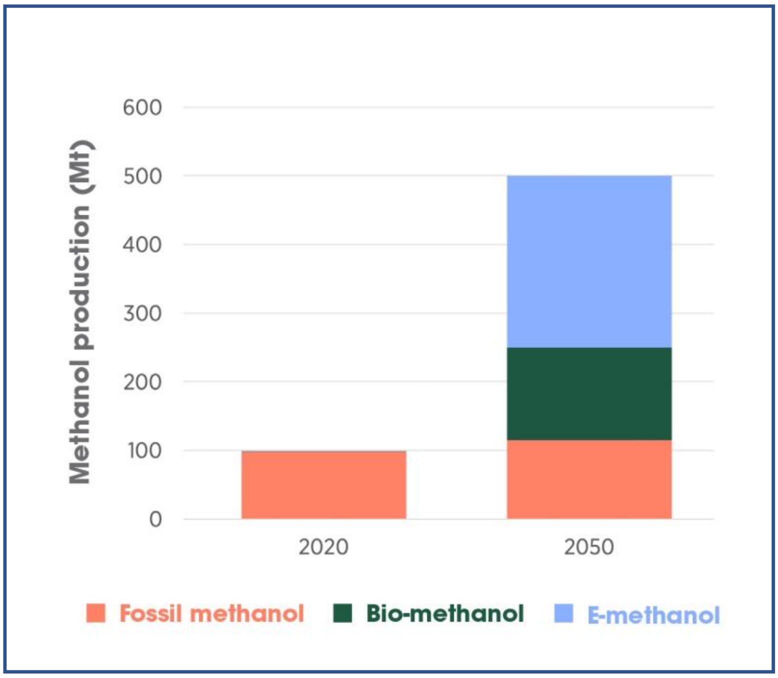

Figure 10: Current and future methanol production by source (Reproduced from IRENA and Methanol Institute, 2021, © IRENA)

The key variable explaining the extensive projected growth of methanol production from sustainable feedstocks is the dramatic cost reductions of key cost drivers, as illustrated in Figure 11. In the case of bio-methanol, these are attributed to more mature production costs and feedstock availability. In the case of e-methanol, to more affordable renewable electricity and advancements in the field of water electrolysis. In the long term, the report finds that cost of renewable methanol will be on par with current petroleum-based fuels by 2050.

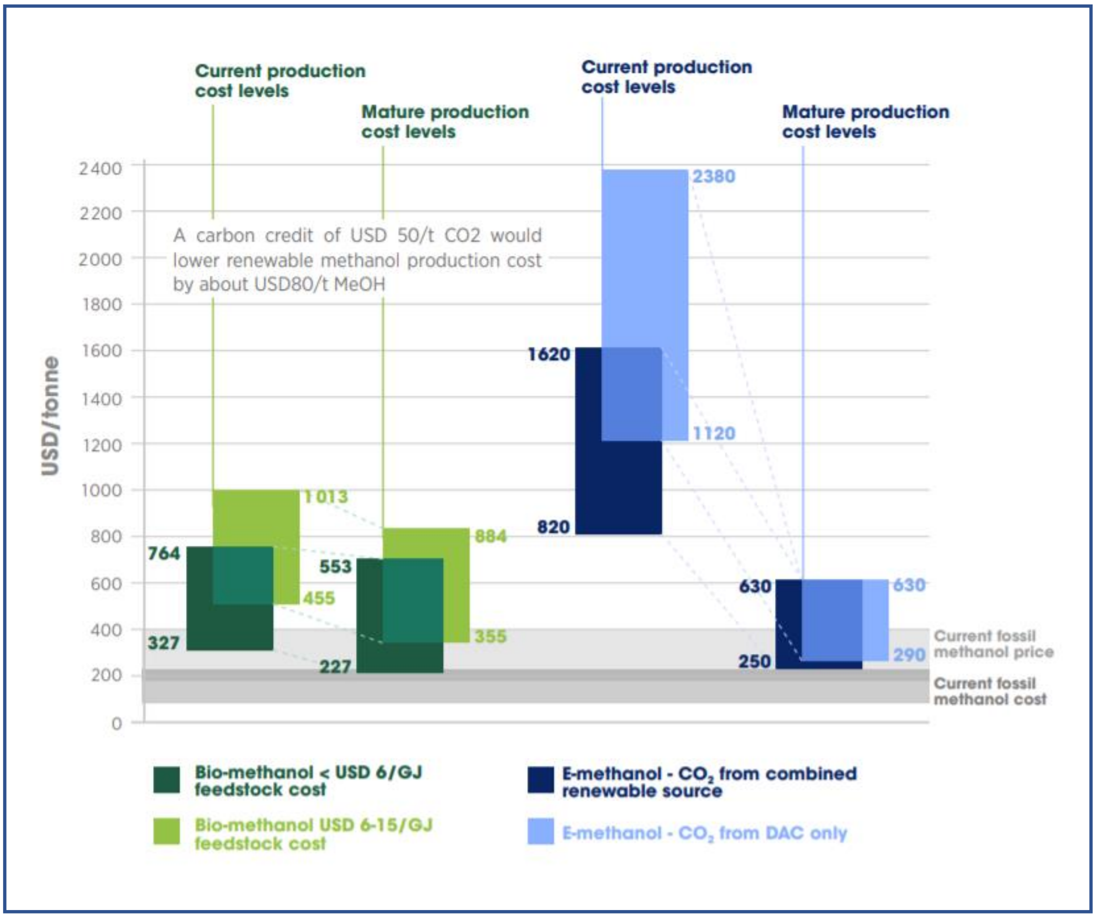

Figure 11. Current and future production costs of bio- and e-methanol (Reproduced from IRENA and Methanol Institute 2021, © IRENA)

4 TRANSFER and BUNKERING

Much experience and knowledge from the routine transport and transfer of methanol product can be applied for safe transfer of methanol to a ship's bunker tanks. As described in Chapter 3, methanol is a globally traded chemical, widely transported, and available in many ports around the world. It is transported by ship, road, and rail, and there are regulations and best practices for transferring methanol from carriers in each of these transport modes. For loading and unloading methanol from ships, for example, the Methanol Institute has published a technical bulletin on safe handling and safe berthing (Methanol Institute, 2018). For inland navigation, the *International Safety Guide for Inland Navigation Tank-barges and Terminals* (CCNR and OCIMF, 2010) was published with the aim of improving safe transport of dangerous goods at the interface of inland tank barges with other vessels or shore facilities. For road transport, regulations regarding transport of dangerous goods apply. There are also best practice guidance documents such as the Methanol Institute's Technical Bulletin *Precautions for Loading, Unloading, Transporting, and Storing Methanol*.

Transferring of methanol as bunker fuel to a ship has been carried out for a number of cases, as described in the following text. Available guidance and regulations to be followed when developing bunkering procedures for a specific case are also described.

4.1 Bunkering methods

The main methods of bunkering liquid fuel to ships are as follows:

- *Truck to ship bunkering using a road tanker*
- *Ship to ship bunkering (delivery by bunker vessel)*
- *Land storage tank to ship bunkering, using a pipe or hose connection.*

All of these methods are also suitable for bunkering methanol and have been tested in actual use cases, as described in following sub-sections. Providing fuel in portable tanks that are transferred to the vessel is another option that could be used by some smaller vessel applications for specific fuels or applications, such as for fuel cells.

4.1.1 Truck to ship bunkering

Truck to ship bunkering is the most common method of bunkering methanol that has been used to date for vessels other than methanol tanker vessels. As methanol is widely used, there is considerable experience with transporting it to a variety of consumers by road. In Europe it is transported according to ADR dangerous goods transport regulations as a class 3 flammable liquid with UN number 1230.

Many of the methanol-fuelled vessels using truck to ship bunkering have been using methanol on a test basis in research projects or pilot studies. As methanol is quite new as a marine fuel, there has not been a big enough demand in specific areas to establish a methanol bunker barge service yet.

Vessels that have been bunkered with methanol by truck include the following:

- *The Wallenius car carrier MV Undine, which bunkered methanol from a tanker truck located on the quay to a tank located on deck. Methanol was used in a test of a solid oxide fuel cell during 2010 (Fort, 2011).*
- *The Stena Scanrail, a ropax ferry, bunkered methanol from a tanker truck located on the deck of the vehicle to a tank located on deck. This was carried out as part of the SPIRETH project (Ellis et al., 2014) during 2013-2014.*

- *The ropax ferry Stena Germanic, has been bunkering methanol since 2015 for use in its dual-fuel main engines. Bunkering is carried out from the quayside (see Figure 12) using a specially built bunkering facility (see Section 5.3). Methanol is bunkered to integral tanks on board the vessel.*
- *The Viking Mariella bunkers methanol by truck using a standard hose arrangement (Chatterton, 2021). The ropax ferry has a methanol fuel cell installation providing 90 kW of auxiliary power.*

Figure 12: Stena Germanica bunkering methanol from a tanker truck with trailer (photo: J.Ellis)

4.1.2 Ship to ship bunkering

"Ship to ship" bunkering, also referred to as "barge to ship" bunkering, may be carried out while a ship is alongside at port or while at anchor. Fuel is provided from a bunker supply ship, tanker, or barge to the receiving vessel. Most large vessels use this method of bunkering, although it may also be appropriate for smaller vessels in some cases.

A demonstration of methanol ship to ship bunkering was carried out in Rotterdam in May, 2021. The Waterfront Shipping methanol tanker *Takaroa Sun* was bunkered by the barge *MTS Evidence* (Ovcina, 2021) (see Figure 13).

Figure 13: Methanol barge to ship bunkering in Rotterdam at the VOPAK Botlek terminal (photo courtesy Methanex).

The goal of the exercise was to carry out an operational test of ship-to-ship bunkering procedures of methanol and to demonstrate the simplicity of bunkering methanol using existing infrastructure. Mooring and signalling was done according to ADN (European Agreement concerning the International Carriage of Dangerous Goods by Inland Waterways) requirements (Boon, 2021). A transfer of 300 metric tonnes of methanol was successfully completed (Chatterton, 2021). It was concluded from the operation that methanol could be bunkered safely as a regular operation, although some further development of procedures was expected for different ship types.

4.1.3 Land storage tank (or terminal) to ship bunkering

Bunkering from a land storage tank or terminal may be a suitable solution for vessels operating out of a home port, such as the pilot boat and tugboat vessels that are being converted and operated as demonstrators within the FASTWATER project. It may also be suitable for vessels operating on fixed routes that bunker from the same port. For larger vessels, the transferring will be similar to procedures for loading small methanol tankers. All of the methanol dual fueled tankers of Waterfront Shipping bunker from terminals during cargo loading activities.

Bunkering from a methanol terminal may also be a solution for other vessel types, but pipe sizes and delivery pressures will need to be compatible with the ship's equipment. This is likely only feasible for vessels receiving larger volumes of methanol, unless modifications or new equipment is installed at the terminal.

For smaller vessels that have on-board bunker pipe sizes that are incompatible with terminal equipment, a more appropriate solution could be to install a small tank or dispensing station at the home port. For vessels that bunker volumes that are less than that carried by a tanker truck (which typically carry a minimum of 30 m^3), this could be a more economical solution than truck delivery for every bunkering occasion. The Swedish Maritime Administration's methanol-fuelled pilot boat developed as one of the FASTWATER project demonstrators will be bunkered from a small purpose-built dispensing station at the Oxelösund pilot boat station (see Figure 14 and Figure 17). Pilot boats operated on marine gas oil are currently fuelled from tanks installed at the pilot boat station. Thus it was considered feasible for the methanol-fuelled pilot boat to be bunkered in a similar way.

Figure 14. Swedish Maritime Administration methanol-fuelled pilot boat with methanol M97 dispensing station shown on the right (see Figure 18 for complete view of methanol M97 bunkering station)(Photo: J.Ellis).

4.1.4 Portable tanks

Transport of methanol in a portable tank and bunkering from the tank to the vessel is a possible solution for bunkering smaller volumes of methanol. The MS Innogy, which has a 330 litre methanol tank on board to power fuel cells (Maritime Knowledge Centre et al., 2018), bunkered methanol from a portable tank that was towed to the jetty. For the GreenPilot project a similar method was used for bunkering. The pilot boat was only operated for a limited time during the project for testing and development purposes – it was not used in regular operations. Thus a portable tank on a trailer was an appropriate solution.

4.2 Guidelines and Recommendations

Bunkering of methanol, like bunkering of any other type of fuel, brings with it some risks that should be managed by following safe procedures and practices. Specific properties and hazards of methanol should be considered when developing procedures for the particular application. The main hazards associated with methanol and examples of measures for managing these during bunkering operations are shown in Table 2.

Table 2. Methanol main hazards and examples of safeguards during bunkering

Hazard	Examples of Safeguards
Flammability	• Elimination of ignition sources in zones near bunkering hoses and equipment (no smoking, no cell phones, etc.) • Use of Ex classed equipment such as bunker pump, gas detectors, etc. • Vapour detection • Bunker connections should be in open areas such as on deck • Anti-static measures such as grounding and bonding (ensuring there is no potential difference between the supplier and the receiver, and that cannot be developed during flow through a hose or pipe) Elimination or minimisation of leakage or spill through: • Use of drip-free couplings • Use of breakaway couplings • High level alarm • Automatic shutdown of pump when "high high" level is reached in the receiving tank • Emergency shut down equipment
Toxicity	• Personal protective equipment (PPE) fit for the task • Portable gas detector for monitoring exposure • Spill/leakage minimisation measures as above
Corrosivity	• Use of materials compatible with methanol • Spill trays in areas near pipe/hose connections • Use of drip-free couplings to prevent release

Hazard identification and HAZOP studies for the particular case under consideration should cover bunkering procedures and identify applicable safeguards.

Guidelines and recommendations for bunkering methanol that have been published or are under development include a technical reference produced by Lloyds Register and the Methanol Institute, and a workshop agreement produced by the European Committee for Standardisation.

4.2.1 Methanol Bunkering Reference

A methanol bunkering technical reference was published by Lloyd's Register and the Methanol Institute in 2020. The purpose of this document was to provide an accessible user-oriented document to be used by those supplying and loading methanol as a bunker fuel (Lloyd's Register, 2020). The bunkering reference uses a checklist approach and covers three different routes for supplying methanol to the receiving vessel:

- *Bunker vessel*
- *Terminal*
- *Truck*

A set of checklists is provided for each of the above routes, plus for the receiving ship (Lloyd's Register, 2020). The checklists cover the following phases of the bunkering process:

- *Preparation in advance of delivery*
- *Readiness to bunker*
- *Delivery/loading process.*

4.2.2 ISO Standard Development

The European Committee for Standardisation (CEN) developed a workshop agreement, "CWA 17540:2020 Ships and marine technology – Specification for bunkering of methanol fuelled vessels", which is available from CEN Members National Standards Bodies. The workshop agreement covers the following four elements:

- *"Guidelines for usage of hardware and transfer system*
- *Operational procedures*
- *Requirement for the methanol provider to provide a bunker delivery note*
- *Training and qualification of personnel involved."*

(European Committee for Standardisation, 2020).

The workshop agreement is not yet an official standard, but the European Commission has requested that it be developed further to this level.

5 INFRASTRUCTURE

International shipping consumed the equivalent of about 300 million tonnes heavy fuel oil in 2018; methanol accounted for an estimated 160 000 tonnes of this (Faber et al., 2020). Fuel availability consistently ranks as one of the most important factors to shipowners looking to invest in new fuel technologies. Methanol has been shown to be available globally along all major trade routes, albeit not necessarily available as a marine fuel. However, only minor and relatively inexpensive modifications to the existing oil storage and distribution infrastructure are required to handle methanol compared to gaseous or cryogenic fuels (IRENA, 2021). Any existing tank currently used for gasoline can quickly and readily be adapted for methanol delivery and storage (Netzer et al., 2015). For ship bunkering, specific transfer and safety equipment will be needed. Requirements will vary depending on the ship's methanol storage and supply system and the bunkering method, as described in the following sections.

5.1 Infrastructure currently existing for methanol supply – overview and applicability for marine use

Storage capacity and infrastructure for methanol, shown in Figure 4, is built to supply the current demand for chemical and energy applications. For utilization as a marine fuel, it is likely that more or larger terminals would be needed to accommodate the greater demand.

There are only a few instances around the world where methanol is supplied to ships as a marine fuel. Nevertheless loading, carriage, discharge and handling of methanol is a practice well familiar to terminals, truck, and barge operators under the same fundamental principles as with a cargo intended for industrial use – to transfer an intended quantity safely without leakage, spillage, or any other hazard (Lloyd's Register, 2020).

5.2 Ship to ship bunkering infrastructure

The practice of unloading to or receiving methanol from a storage tank at a terminal is well established. Before a transfer can begin a pre-meeting is to be held to confirm the details of the operation. This involves product confirmation, quantity to be transferred, flow rate, pumping pressure, transfer sequence, and more. It should also include information on applicable safety arrangements and restrictions (Methanol Institute, 2018).

Bunker vessels must comply with relevant parts of IBC Code, rules issued by the Classification Society, port authorities and other relevant authorities (Lloyd's Register, 2020). The world's first methanol bunkering using a barge was conducted in the Port of Rotterdam by the "MTS Evidence" (Royal Volpak) in May 2021 (Schuler, 2021).

Terminal to barge transfers can be conducted using the barge's regular manifold flange, connected with ASTM approved flanges, gaskets, and bolts (Methanol Institute, 2018), or consider a safe dry break-away coupling (SBC) in a risk assessment (European Committee for Standardisation, 2020). Barge to ship transfers (bunkering) should connect with the receiving ship using an SBC (IMO, 2020). There shall also be an emergency shut down system (ESD) in place, activated by either sensors or an operator, designed to stop the methanol transfer pumps and close the ESD valves (IMO, 2020).

5.3 Truck to ship bunkering infrastructure

Truck to ship bunkering operations are suitable for smaller vessels and quantities or when a bunker vessel is unavailable. Infrastructure requirements for mobile facilities (tanker trucks, rail tank cars, and portable tanks) are primarily related to personnel and fire safety, and environmental protection. As such, these facilities must conform to national standard bodies and local terminal codes for handling methanol. At the very least, materials in the transfer system should not be degraded by methanol. The IMO's interim guidelines for methanol state that the receiving ship should be connected using an SBC (IMO, 2020). Quayside facilities for tanker trucks may be quite simple for bunkering smaller quantities, with equipment such as pumps on the road tanker truck being sufficient for the transfer, as was done for the *MV Undine* and *Stena Scanrail* pilot projects described previously.

For regular bunkering of larger volumes, more equipment such as larger pumps may be required and the construction of a quayside facility may be warranted. For example, the *Stena Germanica* regularly bunkers large volumes of methanol from tanker trucks, as its integral methanol fuel tanks have a capacity of 400 m^3 (Stojcevksi et al., 2016). A purpose-built bunkering facility was constructed on the quayside where the *Stena Germanica* berths in Gothenburg, Sweden. as shown in Figure 15.

Figure 15: Stena Germanica bunkering facility. The blue enclosure in the left photo houses pumps (middle photo) and some of the safety equipment, including the shower and eyewash station (photo on the right). A water spray system over the truck parking area is visible in the photo on the left (photos J. Ellis).

Some of the main features of this facility include:

- *Enclosure housing pumps with a capacity of 2000 litres/minute (Stojcevksi et al., 2016) to facilitate a quick refuelling time*
- *Eyewash and shower facility for emergency use*
- *Water spray system over the tanker truck parking area*
- *Spill containment facility to collect possible spill from the truck*
- *Truck grounding (earthing) connection*
- *Emergency shut down capability*
- *Platform to support hose and facilitate connection to the ship bunkering connection (see Figure 16).*

Figure 16: Stena Germanica bunker station enclosure (left photo) and platform for hose connection (right photo). The bunker hose is connected to the ship's system using drip-free connections. (Photos: J. Ellis)

The first methanol bunkering of the *Stena Germanica* took place in 2015, and as of 2020, 400 stems (occasion where fuel is supplied) of methanol had been carried out (Methanol Institute, 2020).

Any bunkering installation on the quayside should comply with requirements from the competent authority or port regulatory body.

5.4 Fuelling station – "self fuelling" from small storage tank

For small vessels such as a pilot boat or pleasure craft, self-fuelling stations with on site storage can be used. These are often found in marinas and are nearly identical to stations dispensing gasoline and diesel fuel to cars. In most cases, methanol can use the same storage tanks after a proper cleaning and change of gaskets, fuelling lines, seals, and other components to accommodate for methanol (IRENA, 2021).

National and local regulations will determine the additional safety equipment that is required, likely in conjunction with a risk assessment. The fuelling station may need to be fitted with suitable fire extinguishers such as alcohol resistant foam or dry powder, spill containment, absorbent, provision of water, emergency shower and eyewash station at the quayside, and more.

For the FASTWATER pilot boat demonstrator case, a small fuel dispensing station with an integral above ground storage tank (7.19 m^3) for methanol, as shown in Figure 17, was constructed by Malte Fuel & Wash. Fuel additives (ignition improver and lubricant) will be dosed during dispensing to bunker a fuel referred to as MD97, consisting of 97% methanol. The pilot boat methanol tank capacity is 1.3 m^3 so can be bunkered from the station several times between truck deliveries of methanol. In Sweden, construction and operation of fuel dispensing installations are governed by national regulations pertaining to handling and storage of flammable and explosive substances. A permit is required for the installation and a risk analysis should be submitted for the permit application. In addition, EU ATEX directives on identification and classification on hazardous zones and equipment and protective systems in identified zones must be followed.

Figure 17. Methanol (M97) refuelling facility at the Swedish Maritime Adminstration's Oxelösund pilot boat (Photo: J.Ellis)

Some of the main features of the methanol dispensing station installed at the Oxelösund pilot boat station include:

- Inner methanol tank with volume of 7.19 m^3; Beraid additive tank with volume of 2.5 m^3
- Secondary containment capable of holding 110% of the inner tank volume. The interstitial space is fitted with a leak detection system
- Ex-classed pumps: the pump for bunkering the methanol to the pilot boat has a maximum flow rate of 80 litres/minute and a maximum pressure of 3.5 bar; the pump for transferring the methanol from the tanker truck to the dispensing station will use a flow rate of 350 litres/minute
- Grounding connection for the tanker truck
- Drip-free connector for the hose connection at the pilot boat.
- Bunker station pump safety connection to the pilot boat methanol tank "high high" level indicator, with automatic shut off of the pump when the level is reached.

5.5 Pipeline to ship infrastructure

Bunkering through a pipeline is uncommon for oil-based fuels. One example is however the Swedish icebreakers operating in the Gulf of Bothnia and the Baltic Sea. Waterfront Shipping is bunkering methanol for their dual-fuelled methanol tankers using shore cargo pipelines near Methanex's production facilities (Schuler, 2021). A temporary elbow connection is installed to redirect some of the cargo to the ship's bunker tanks, a setup requiring at least Flag state approval but may also be subject to local port restrictions (Lloyd's Register, 2020). Existing shore facilities may possibly be used to bunker other vessel types – likely larger ships bunkering larger quantities. An evaluation of compatibility with system pressures and the need for specific adaptations should be evaluated on a case-by-case basis.

6 CONCLUSIONS AND RECOMMENDATIONS

Methanol produced from conventional fossil fuel feedstocks, primarily natural gas, is widely available and there is a well-developed supply chain in place. It is available in over 100 ports worldwide as a commodity. Although the provision of methanol as a marine fuel has been quite limited to date, demand is growing and it is now being included in marine bunker fuel assessments. Availability of methanol produced from renewable feedstock is currently small but is expected to grow and considerably exceed production from fossil feedstock by 2050. Process improvements for bio-methanol production and advancements in water electrolysis and renewable electricity production for e-methanol are expected to result in renewable methanol prices being within the range of current petroleum-based fuels by 2050.

Storage capacity and infrastructure for methanol to supply the current demand for chemical and energy applications is widely available, internationally and in Europe. To supply growing demand such as for marine fuel, additional infrastructure will likely be required. In many cases it is possible to convert existing infrastructure for petroleum products to methanol storage and distribution with minor modifications. For the final distribution step to a vessel's bunker tanks, specific transfer and safety equipment will be needed. Requirements will vary depending on the ship's methanol storage and supply system and the bunkering method.

Bunkering of methanol as ship fuel has been carried out safely for several vessels. The first cases used truck to ship bunkering. Terminal to ship bunkering via pipeline is carried out regularly for methanol dual-fuel tankers. Barge to ship bunkering of methanol was demonstrated in 2021, using an existing methanol barge to bunker a tanker. This was the first example of ship to ship bunkering of methanol. Further development of procedures is expected for other vessel types.

The FASTWATER project will be investigating the use of a bunker barge for an inland waterways river cruise vessel, which will be reported in future deliverable reports. Within the FASTWATER project, the first demonstration of bunkering methanol from a quayside methanol dispensing station will be carried out for a pilot boat in late 2021. This method is suitable for smaller vessels that bunker quantities less than a full tanker truck load.

A technical reference for methanol bunkering was published by Lloyd's Register and the Methanol Institute in 2020. The European Committee for Standardisation (CEN) has published a workshop agreement specification for bunkering of methanol fuelled vessels, which is expected to be developed further to a standard. The recent publications and demonstrations have been helpful references for the development of the FASTWATER demonstrators' bunkering procedures. It is expected that the demonstrators within the FASTWATER project will contribute to further knowledge within this area by using and providing feedback on the standards for different vessel types and sharing experiences from practical operation.

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8 ANNEXES

8.1 Annex A: Methanol Technical Data Sheet

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METHANOL TECHNICAL DATA SHEET

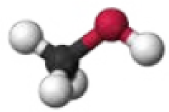
FOR PRODUCED METHANOL

METHANOL INSTITUTE

CHEMICAL FORMULA:	CH_3OH
CAS No:	67-56-1
SYNONYMS:	METHYL ALCOHOL, WOOD ALCOHOL
DESCRIPTION:	*METHANOL IS A CLEAR, COLORLESS LIQUID THAT IS SOLUABLE IN WATER AND IS BIODEGRADABLE.*

APPLICATIONS:

- **CHEMICAL FEEDSTOCK** - *FORMALDEHYDE, ACETIC ACID, MTBE, DME, BIODIESEL, OLEFINS.*
- **FUEL & FUEL ADDITIVE** - *VEHICLES, SHIPS, COOKING, HEATING*
- **HYDROGEN CARRIER FOR METHANOL FUEL CELLS**
- **WINDSHIELD WASHER FLUID**
- **WASTEWATER DENITRIFICATION**



TYPICAL PROPERTIES:

Moluecular Weight:	32.04 g/mol
Purity:	99.85 %wt min
Water (impurity)	0.100 %wt max
Acetone (impurity)	30mg/kg max
Ethanol (impurity)	50 mg/kg max
Chloride (impurity) as Cl^-	0.5 mg/kg max

Specific Gravity (20/20°C)	0.7910 - 0.7930
Freezing Point:	-97.8°C / -144°F
Boiling Point:	64.6°C / 148°F
Flash Point (closed cup, 1 atm):	12°C / 54°F
Explosive limits in air	6% - 36%
Solubility: Methanol in Water/ Water in Methanol	100% / 100%

PRODUCTION SPECIFICATIONS:

Methanol is typically produced to meet the methanol specificationsof the International Methanol Producers and Consumers Association (IMPCA), which reviews and updates the specifications approximately every two years. For the current IMPCA methanol specifications, refer to the IMPCA website at http://www.impca.eu/IMPCA/Technical/IMPCA-Documents

HAZARDS & PRECAUTIONS:

FLAMMABLE	Methanol is flammable and burns with a clear blue flame that is mokeless and difficult to see in daylight. Keep away from sources of ignition including heat, sparks, flames, and hot surfaces. Keep containers tightly closed when not in use. Containers should be stored in well-ventilated and cool areas.
HEALTH	Methanol can be toxic if swallowed, inhaled, or contacts the skin, although skin absorption is a slower process than ingestion or inhalation. Avoid breathing vapors or mist. When handling methanol, wear chemical-resistant gloves and appropriate PPE. Depending on the activity, respiratory protection may be required. If swallowed, immediately seek medical attention.

For detailed PPE and safe handling and storage requirements, refer to the Methanol Institute's Methanol Safe Handling Manual and to the manufacturer's or supplier's Safety Data Sheet for methanol.

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