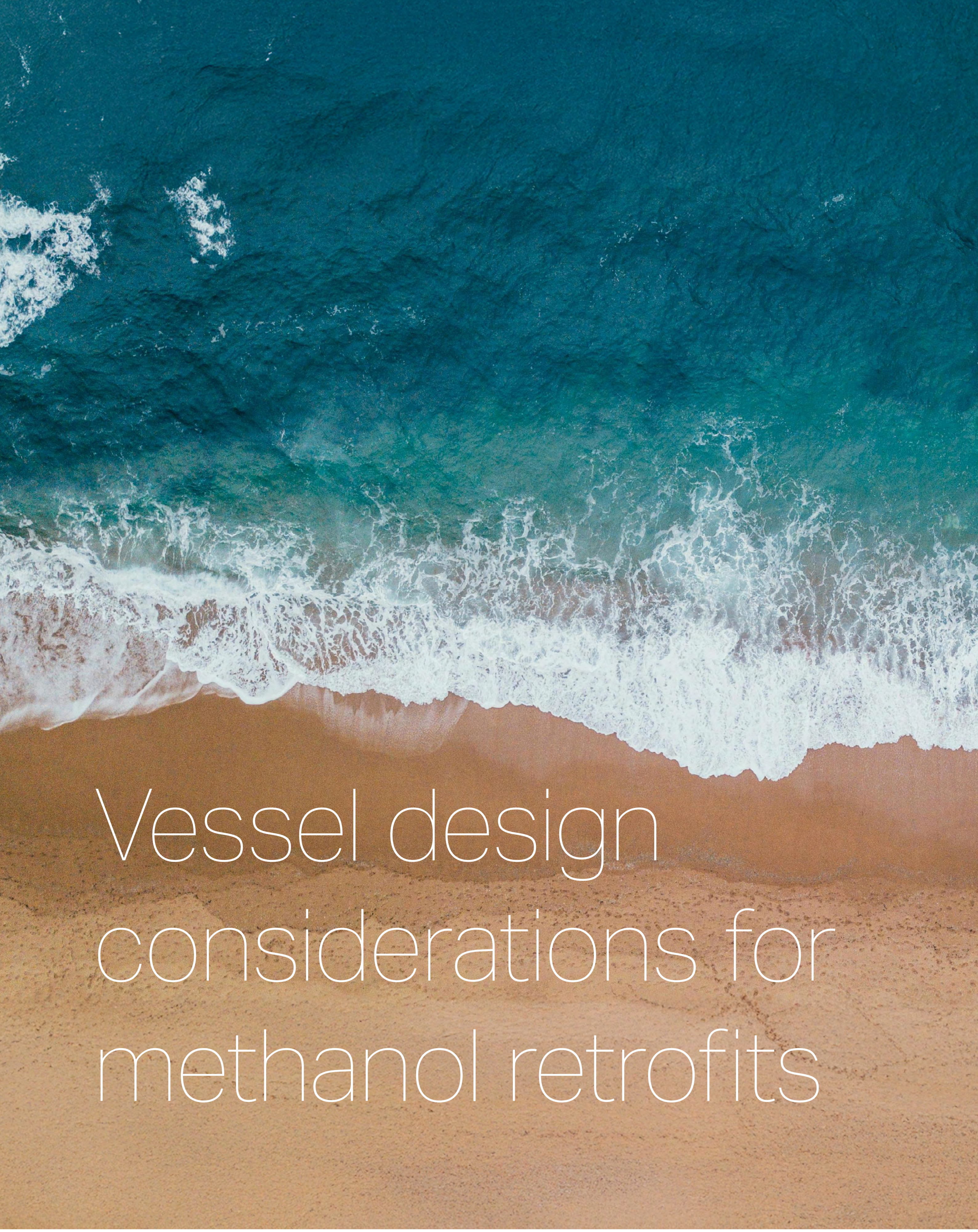

# Vessel design considerations for methanol retrofits

**Mærsk Mc-Kinney Møller Center**
for Zero Carbon Shipping

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# Executive summary

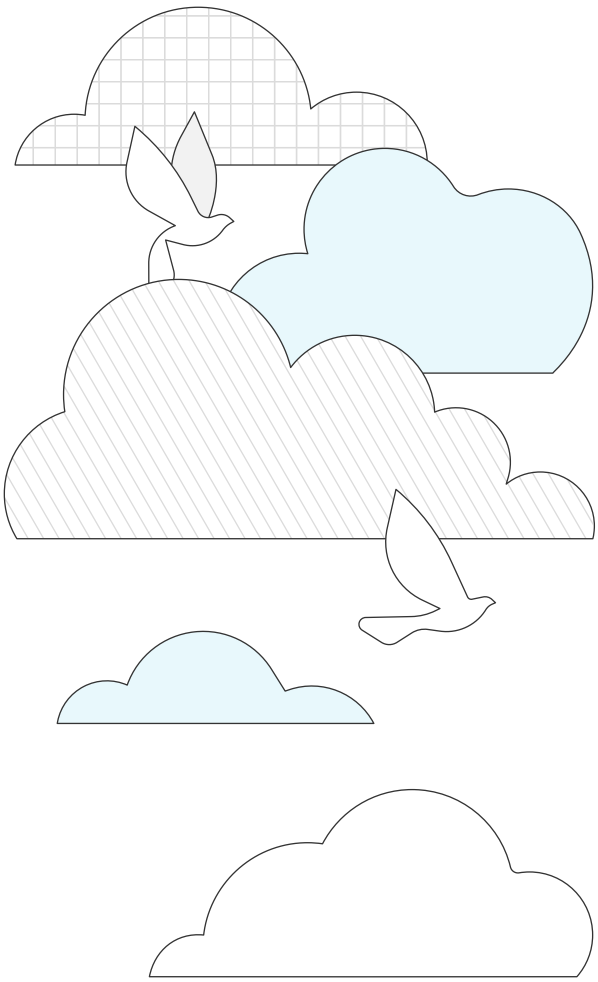
In 2023, the International Maritime Organization revised its greenhouse gas (GHG) emissions strategy, requiring international shipping to achieve net-zero emissions by or around 2050, with a 40% reduction in carbon intensity by 2030. To meet these targets, many owners will need to operate on alternative fuels. However, the capacity of shipyards to build new vessels powered by green energy is limited, making retrofitting existing vessels a critical solution to complement newbuilds.

Retrofitting allows shipowners to convert vessels to operate on alternative fuels like methanol, reducing GHG emissions and ensuring compliance with future regulations. Methanol is particularly promising due to its similarities with conventional fuels, which makes it easier to implement in retrofits than other alternatives like ammonia or liquefied natural gas. While methanol presents certain safety risks such as toxicity and flammability, these risks are lower than those from other alternative fuels if proper precautions are in place.

Retrofitting provides flexibility for shipowners to extend the operational life of vessels, especially those between 5-10 years old, while aligning with new environmental regulations. Studies show that methanol fuel retrofits can significantly reduce carbon emissions, especially when using e-methanol or bio-methanol.

The design and technical aspects of retrofitting must be carefully planned to optimize the methanol fuel system, bunkering station, tank arrangements, and overall vessel performance based on the operational requirement. Retrofitting methanol tanks presents several design options, including independent, integral, or on-deck tanks, depending on operational needs and budget constraints. Shipyards must be capable and prepared in handling specialized equipment, methanol-specific technical work, and safety standards related to methanol, while collaboration with engine manufacturers is crucial for successful engine conversions.

This report provides a comprehensive guide to shipowners, operators, ship designers, and shipyards on designing and planning a successful methanol retrofit, underscoring the main technical considerations while complying with regulatory requirements.



# 01 Introduction

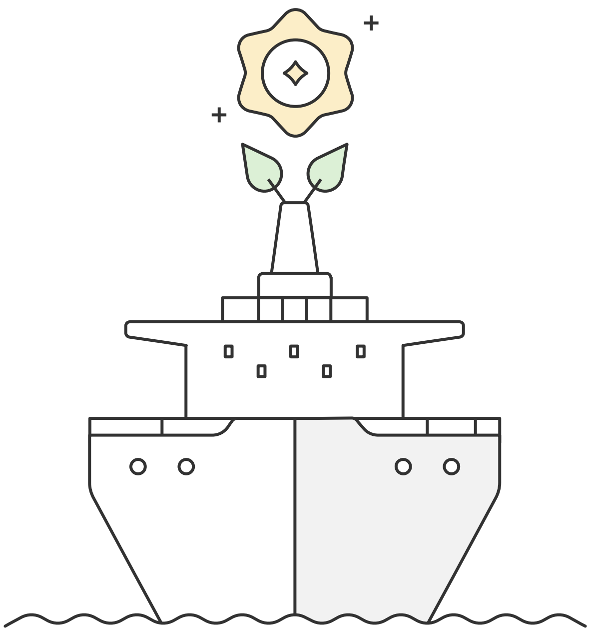
In 2023, the International Maritime Organization (IMO) revised and adopted a new greenhouse gas (GHG) emission strategy, governing emissions from international seagoing transport.[1] Under this strategy, GHG emissions from international shipping should peak as soon as possible and reach net zero by or around 2050, while reducing carbon intensity by at least 40% by 2030.[1] Vessel operation on alternative fuels with net-zero or near-net-zero GHG emissions will become increasingly important to ensure compliance with regulations that seek to reduce GHG emissions from shipping. Newbuild vessels designed for operation on alternative fuels and improvements in the energy efficiency of conventional fossil-fueled vessels are both crucial to fulfilling these regulatory ambitions. However, these measures alone are not sufficient to achieve net zero by 2050.[2]

The limited availability of newbuilding slots is a major challenge for shipping's decarbonization. The current newbuilding capacity is adjusted to replace retiring vessels and to deliver additional tonnage during periods of high demand. However, it would be difficult to increase the newbuilding capacity to align with the short-term increase in demand to immediately replace the fleet with new vessels powered by green energy.

A more realistic approach to decarbonization includes reducing GHG emissions from existing vessels. Sharing the load between newbuilding shipyards and retrofit yards provides a stronger chance for the sector to meet the 2050 net-zero targets, while retaining the operational value of the existing fleet. Retrofitting can also present an opportunity to leverage the effects of pooling from retrofitted vessels to de-risk the initial investment in new fuels under the FuelEU regulation.[3] Additionally, a review of the current newbuilding order book (2024) reveals that a substantial number of vessels (83.15%) under construction are single-fueled.[4] Given the long lifespan of those vessels, many of them will still be in service in 2030-2035. Without retrofitting, these vessels will continue to operate on heavy fuel oil (HFO), potentially hindering progress towards mid- and long-term emissions reduction goals.

From a shipowner's perspective, retrofits can offer viability to vessels aged 5-10 years, extending their operational life by ensuring compliance with emission regulations through operation on alternative fuels. Previous studies at the Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping (MMMCZCS) have demonstrated the beneficial impact on cost and GHG emissions of different preparation levels for a dual-fuel retrofit to methanol or ammonia.[3,5,6] Given the average age of the global fleet (12.6 years based on Clarksons' 2023 market review),[7] many vessels still have a substantial operational life ahead of them and will likely need to adapt to alternative fuels to maintain regulatory compliance and economic viability.

In summary, retrofits of existing vessels will play a critical role in meeting the short-term increase in demand for alternatively-fueled vessels as the industry transitions to a green future. Retrofitting, in addition to newbuilds, will become essential for ensuring compliance with IMO and EU GHG emissions reduction targets.

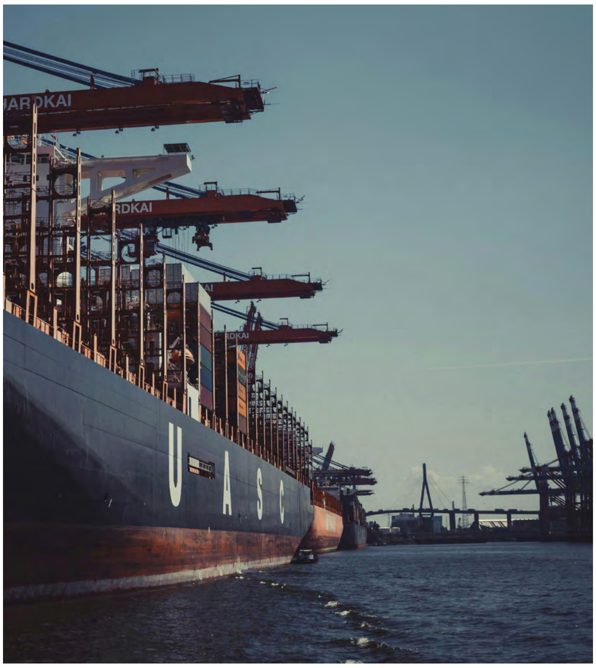


## 1.1 Methanol properties and suitability for retrofits

There are multiple alternative fuels that have the potential to help decarbonize shipping and reduce the $CO_2$ emissions of vessels, such as ammonia, methane, methanol, and hydrogen. However, the technical barriers to implementing methanol in a fuel retrofit of an existing vessel are easier to overcome because of the similarities between methanol and conventional fuel. For example, methanol is a liquid at room temperature and can use an existing fuel tank surrounded with a cofferdam. Figure 1 presents an overview of some of methanol's key chemical and safety properties.

The three main safety risks of methanol fuel are: toxicity at high concentrations, high flammability, and the poor visibility of a methanol flame in daylight (Figure 1). Methanol dissolves in water, rapidly reducing its flammability and neutralizing the risk. It may have a significant environmental impact if spilled in seawater at concentrations around 1,000 mg/L.[8] These risks mean that methanol does require specific safety precautions, but these are significantly simpler than those needed for liquefied natural gas (LNG) or ammonia.[9]

Depending on how methanol is produced and combusted onboard (well-to-wake, WTW), consuming methanol can potentially reduce vessel emissions associated with fuel use relative to using HFO. The ability of methanol to offer reductions in GHG emissions primarily relates to:




- The source of the carbon molecule (biogenic, atmospheric, or hydrocarbon-derived)
- Energy required to produce the fuel
- Transportation distances and energy use (fuel production to market distribution)
- Use of pilot oil
- Efficiency of fuel combustion

Comparing emissions from fuel use (tank-to-wake, TTW) for HFO and methanol shows that, while there can be a reduction in GHG emissions, specifically $CO_2$, the benefit is somewhat limited due to methanol's lower energy density. From a TTW perspective, methanol reduces $CO_2$ emissions by 8.4 kg$CO_2$/GJ relative to HFO. The climate benefits of replacing HFO with methanol rely on the well-to-tank (WTT) emissions reduction and depend on the source of $CO_2$ and the upstream emissions during fuel production.

From a near-term regulatory perspective, the emissions associated with fuel combustion (TTW) are crucial to incorporate into decision-making processes; however, from a long-term perspective, life-cycle emissions (WTW) become more relevant. This is due to the nature of developments at the IMO, specifically work on the IMO's life-cycle assessment (LCA) guidelines, which provide a framework for calculating the GHG intensity of fuel used by the maritime industry.

In summary, the full environmental benefits of methanol will only be realized when considering both TTW and WTW emissions, particularly as the IMO finalizes its LCA guidelines for the maritime sector. Retrofits to methanol can enable extension of the vessel service life by facilitating compliance with regulations that seek to reduce GHG emissions and/or promote alternative fuels.

Overall, considering the similarity in properties between methanol and conventional fuels, methanol is a promising substitute for conventional marine fuels in retrofits. Converting a vessel to run on methanol can reduce both its TTW and WTW GHG emissions if using low emission intensity methanol. Methanol conversion provides flexibility that can allow the vessel to remain compliant with GHG emissions reduction regulations over the coming decades.

Figure 1: Toxicity, corrosiveness, physical and chemical properties of methanol.[8,10]

### Low-flashpoint liquid

Liquid fuel having a flashpoint lower than otherwise permitted under paragraph 2.1.1 of SOLAS regulation II-2/4 [11]

### Toxic
at high concentrations

Skin contact causes irritation, dry skin and redness

In the vapor phase, the safe limit for human exposure is 200 ppm

### Corrosive
in the presence of aluminum and titanium alloys

### Relatively low energy density

Lower calorific value (LCV): 19.9 MJ/kg

(LCV of HFO is 2.02 times higher, 40.2 MJ/kg)

### Highly soluble in water
Reduces flammability

### Liquid fuel

Boiling point at 101.3 kPa: 64.5°C
Vapor pressure at 20°C: 12.9 kPa

### TTW carbon factor ($C_F$)

$C_F$ = 1.375

1.74 tonnes less $CO_2$ is emitted per tonne of methanol burned compared to HFO

### $CO_2$ emissions per 1 GJ of fuel burned

69.1 kg

(HFO emits 77.5 kg of $CO_2$)

### Retrofit advantages

Existing conventional fuel tank can be converted to methanol tank (separated by cofferdam)

Easy to prepare for combustion in the engine

### Highly flammable

Auto-ignition temperature: 440°C

Difficult to see the methanol flame in daylight

### Relative density at 16°C compared with water

(water=1): 0.79

### Environment

Toxic to aquatic life at concentrations above 1,000 mg/L[10]

SOLAS = International Convention for the Safety of Life at Sea, HFO = heavy fuel oil, TTW = tank-to-wake

## 1.2 About this document

This report is a collaboration between the MMMCZCS and our partner organizations Cargill, MAN Energy Solutions, Tsuneishi, Oldendorff, and ClassNK.

The IMO and some classification societies have previously published technical documents (Table1) to guide designers to develop a safe methanol retrofit design. However, there is no advice on optimal design configurations. This document can support the decision-making process for owners, operators, and shipyards when converting existing vessels to methanol operation.

The document aims to provide advice and considerations on the safety, technical, regulatory, and commercial aspects of a methanol fuel retrofit, covering everything from the concept design phases to critical items in specification development.

The main sections of the document are organized as follows:

- Regulatory assessment (Section 2)
- Methanol fuel system (Section 3)
- Impact on design and performance (Section 4)
- Design optimization (Section 5)
- Shipyard technical requirements and capabilities (Section 6)

The document will shed light on the technical requirements needed to plan and undertake a successful retrofit from a shipyard perspective. To aid in defining the fuel conversion, this guideline includes a framework in Appendix C for developing the conversion specification. Key chapters to be considered are listed along with brief explanations of the necessary information.

Costs associated with capital expenditure (CapEx) and operating expenses are not considered in this document, as these values will vary dramatically as methanol becomes more established as a shipping fuel. The MMMCZCS approach is to offer neutral insight into technology, which is thereafter verified through techno-economic studies.

# 02 Regulatory standards and assessment

Table 1 summarizes the current requirements and guidelines applicable to methanol-fueled vessels.

Currently, vessels using alternative fuels must comply with the International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels (IGF Code), which mainly focuses on the use of LNG (methane) as a fuel.[11] Although methanol is a low-flashpoint fuel, there is no specific methanol fuel regulation in the IGF Code. However, class guidelines have been developed to support vessel designers with regulatory requirements for methanol-fueled vessels, and the Maritime Safety Committee (MSC) under the IMO has adopted interim guidelines on methanol as a fuel (MSC.1/Circ.1621 – see Table 1) with an alternative ship design process based on the IGF Code.[12]

The International Code for the Construction and Equipment of Ships carrying Dangerous Chemicals in Bulk (IBC Code)[13] is well established for carrying methanol as cargo. However, compared to the IGF Code and MSC.1/Circ.1621, the IBC Code has significant relaxations in the storage requirements for methanol (see Appendix A).

The alternative design approval path for a vessel using methanol as fuel is MSC.1/Circ.1621 based on the IGF Code and the use of low-flashpoint fuels. However, if the vessel design cannot comply with MSC.1/Circ.1621,[12] the Guidelines for the Approval of Alternatives and Equivalents (MSC.1/Circ. 1455),[14] (see Table 1) should be followed instead, while also considering the application of the IBC regulation philosophy.[13]

The International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (the IGC Code)[15] is more onerous than the IBC Code, which relates to IGC regulations governing issues and difficulties when transporting gaseous chemicals. Further details are provided in Appendix A and Table 8.

The consideration of the retrofit as a major conversion will also impact on the requirements, and it is important to assess whether the planned scope of a methanol fuel conversion exceeds a threshold defining a major conversion. If the planned conversion triggers the requirements for a major conversion, the vessel must comply with the latest regulations, as opposed to the regulations applicable at the time the vessel was originally built. Therefore, a major conversion can potentially require substantial changes to other aspects of the vessel design.

The methanol safety concepts used in the IBC Code and the IGF Code (and MSC.1/Circ.1621) differ. The main difference for the tank arrangement is that MSC.1/Circ.1621 requires a cofferdam around a methanol fuel tank (except in specific cases, which will be discussed in Section 3),[12] whereas the IBC Code does not.[13] Another difference is that the IBC Code does not require inert gas blanketing for small methanol tanks.[13] As for the ventilation system, some requirements of the IBC Code are stricter than those in MSC.1/Circ.1621. Appendix A analyses the differences between the requirements for methanol fuel and methanol cargo tanks, and between the requirements for loading equipment for methanol bunkering and cargo loading, in greater detail.

Classification societies have prepared their own equivalent safety guidance to supplement MSC.1/Circ.1621. For retrofit designs, the main design-improving points are (1) relaxation of the cofferdam space requirement, and (2) use of the cofferdam space for ballast tanks.

Considering the limited space on existing vessel designs, along with the increased quantity of fuel needed for an equivalent endurance, the cofferdam size and arrangement is crucial to methanol-fueled vessel design. The IBC Code requirements[13] could be considered to support the technical justification for alternative designs deviating from the IMO guidelines.[12]

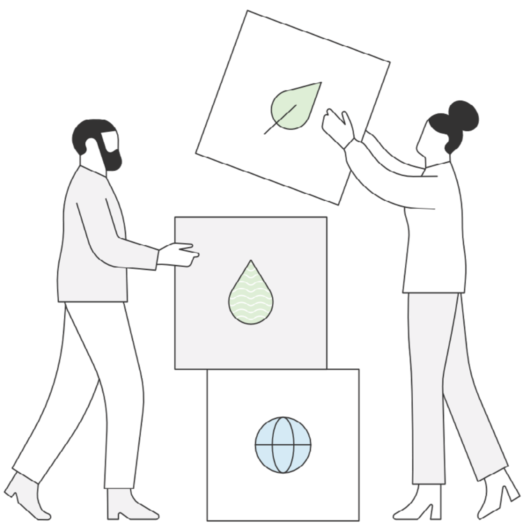


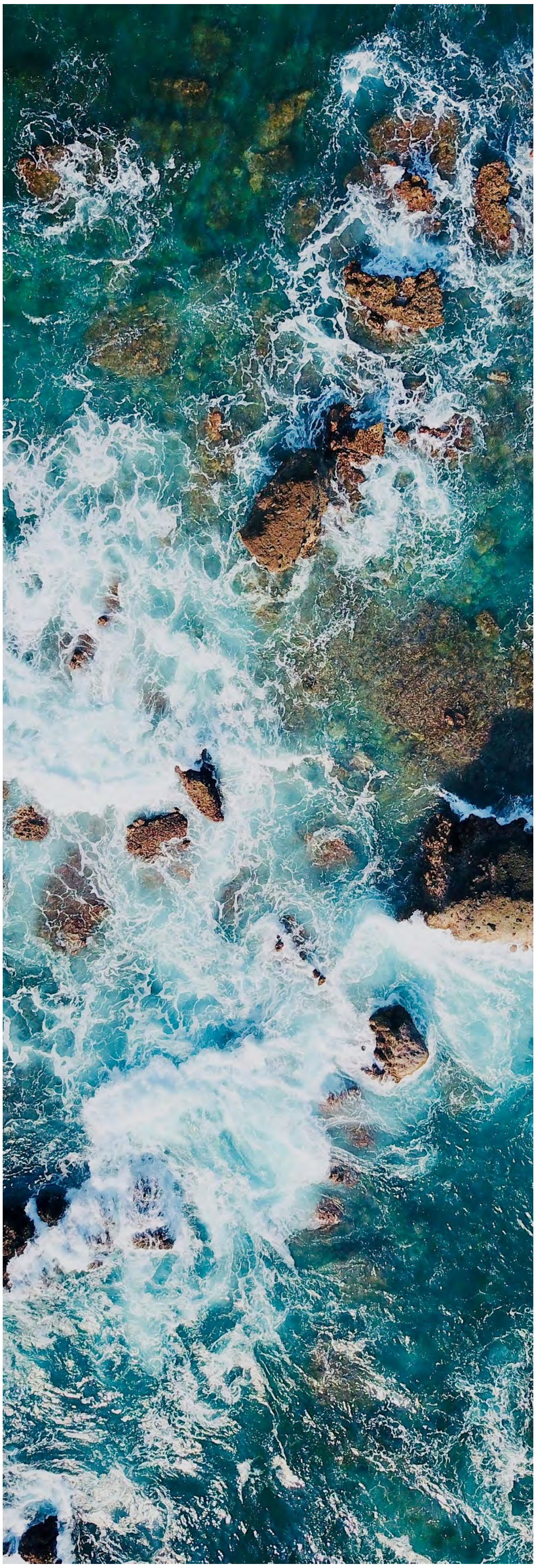
Table 1: Overview of class and IMO requirements and guidelines covering methanol. Links are current as of time of writing. Please note that some documents require an account for access.

| Organization* | Methanol requirements and guidelines |
|---|---|
| IMO | MSC.1/Circ.1621 Interim Guidelines for the Safety of Ships Using Methyl/Ethyl Alcohol as Fuel |
| IMO | MSC.1/Circ.1455 Guidelines for the Approval of Alternatives and Equivalents as Provided for in Various IMO Instruments |
| ABS | Requirements for Methanol and Ethanol Fueled Vessels |
| BV | Classification Rules covering methanol and ethanol fueled ships (NR 670) |
| Class NK | Guidelines for Ships Using Alternative Fuels |
| DNV | Ships (RU-SHIP) Part 6: Additional class notations, Ch 2: Propulsion, power generation and auxiliary systems, LFL fueled notation requirements. |
| KR | Guidelines for Ships Using Low-Flashpoint Fuels (LPG & Methyl/Ethyl Alcohol) |
| LR | Guidance Notes Proposal No.2024/GN06 |

LPG = liquefied petroleum gas

*Please refer to Abbreviations section for full names of organizations.

# 03 Methanol fuel system



The following section delineates the main elements of a methanol fuel system. Figure 2 shows an overview of a generic methanol fuel system.

If the main engine is retrofitted to a dual-fuel engine capable of running on methanol and conventional fuel, a low-flashpoint fuel supply system (LFSS) is needed to supply methanol. The LFSS will also supply pilot fuel (conventional fuel or biofuel) during operation on methanol. The LFSS supplies methanol to the main engine from a methanol service tank according to main engine requirements regarding transfer rate, pressure, and temperature. Before an engine changeover to conventional fuel operation, methanol in the engine will be transferred back to the methanol service tank and displaced with inert gas.

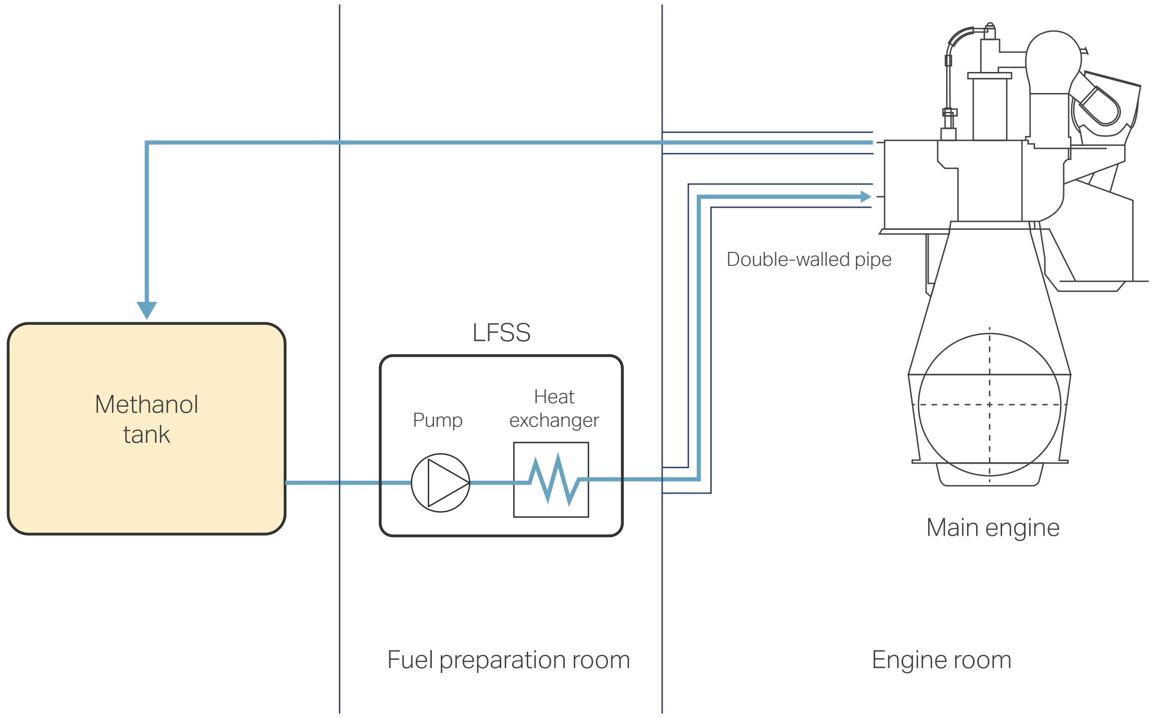
Since methanol is highly flammable (Figure 1), methanol-related equipment must be separated and marked as a hazardous zone. All pipes running through areas that must remain safe, such as the engine room and passageways, need to be double-walled and equipped with appropriate ventilation and gas detection systems as required by the IMO guidelines.[12]

Traditionally, the engine retrofit kit covers the conversion of the main engine, including the fuel valve train (FVT). In addition to the engine retrofit kit scope, a full conversion project consists of installation and integration of a methanol fuel bunker and storage system, methanol fuel service tank, LFSS, and nitrogen system for purging purposes (Figure 3).

In the next subsections, we provide a detailed breakdown of the following onboard systems:

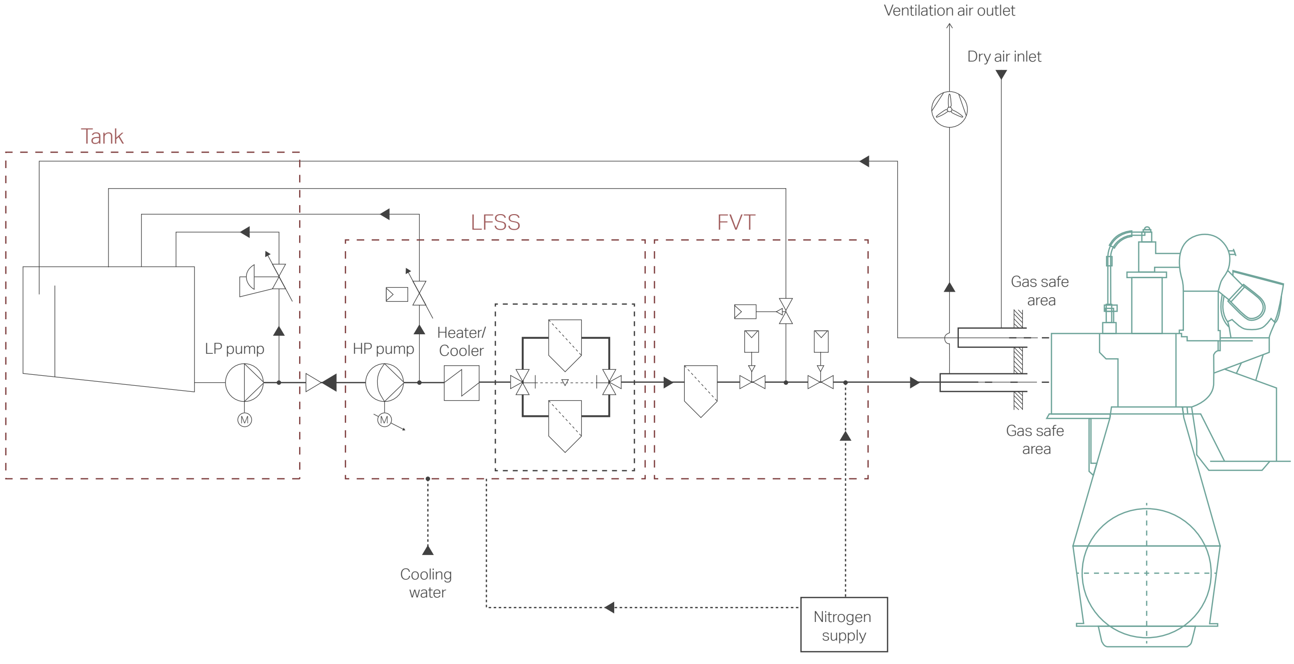
- storage
- fuel preparation room
- transfer pump
- bunker station
- tank connection space
- purging/inerting
- fuel tank vent outlet
- drainage and bilge for methanol drain tank
- dual-fuel engines

Figure 2: Typical methanol fuel system.




LFSS = low-flashpoint fuel supply system

Figure 3: Fuel auxiliary systems overview (MAN Energy Solutions, 2024).




LFSS = low-flashpoint fuel supply system, FVT= fuel valve train, LP = low-pressure, HP = high-pressure

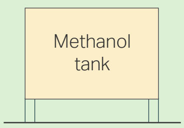
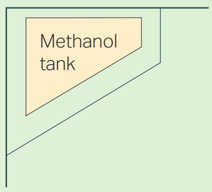
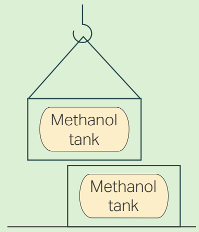
## 3.1 Storage

There are three aspects to consider during the design phase when choosing a methanol tank: tank type, material, and location.

### 3.1.1 Tank options

Traditionally, there are three types of methanol storage tanks. Table 2 shows the features of each type.

Table 2: Comparison of methanol tank types: independent, integral, and portable tanks.

| | Independent tanks | Integral tanks | Portable tanks | Notes |
|---|---|---|---|---|
| |  |  |  | |
| Prefabrication of the methanol tank before dry docking | Possible | Not applicable | Possible | Prefabrication can reduce the installation work and off-hire time. |
| Boundary wall between hull and methanol tank | Double | Single | Double | If an integral tank is selected, the hull structure can constitute the boundary wall of the methanol tank.<br>The maximum size of a portable tank is limited, and a large-capacity tank increases the added steel weight. |
| Replacement of the methanol tank for bunkering | Not applicable | Not applicable | Possible | Depending on the volume to transfer, the bunkering time may be reduced by exchanging an empty tank onboard with a prefilled tank onshore. |

### 3.1.2 Tank material

The tank material should be selected according to the IMO guidelines[12] and with consideration of fuel corrosiveness. Traditionally, there are two options: stainless steel and steel coated with inorganic zinc silicate.

#### Stainless steel

- Stainless steel is expensive and will significantly increase CapEx.
- Less maintenance required during construction and during operation as the tank is not painted.

#### Steel coated with zinc silicate

- Coating a tank with inorganic zinc silicate requires thorough cleaning and surface preparation, such as full blasting. This preparation is one of the challenges when converting an existing integrated tank with a complex structure, such as double-bottom tanks, to methanol.
- CapEx is lower than for a stainless-steel tank considering the installation work.

A prefabricated independent tank can be a suitable option for methanol storage when compared to the extensive preparation required before coating an existing integrated tank.

### 3.1.3 Location

During the feasibility stage of the ship design, three locations can be considered for the methanol tank: on the open deck, in the cargo holds, or integrated with existing double-bottom tanks, side tanks, and topside tanks. Table 3 describes the advantages, disadvantages, and design impact for each tank location.

Table 3: Advantages, disadvantages, and design impact of three tank locations: on open deck, in cargo holds, or as integrated tank solutions for double-bottom, side, and topside tanks.

| | Open deck | Cargo hold | Double-bottom, side, and topside tanks | Notes |
|---|---|---|---|---|
| Cofferdam | Not necessary [i] | Necessary | Necessary [ii] | [i] A cofferdam can eliminate water spray system, A-60 insulation, and drip tray. Refer to Figure 4.<br>[ii] Unnecessary if outer hull is underwater. Refer to Figure 5. |
| Tank connection space | Not necessary | Necessary [iii] | Necessary [iii] | [iii] If the connection point is in an enclosed space. |
| Visibility from wheelhouse | Should be checked [iv] | Same as original | Same as original | [iv] If the tanks interfere with the visibility. Refer to Figure 6. |
| Center of gravity | High | Middle | Low ~ High | Check the effect on the center of gravity, e.g., trim, stability, and longitudinal strength. |
| Advantages | - No need for a cofferdam structure and tank connection space<br>- Prefabricated tank<br>- No effect on cargo volume<br>- Easy installation | - Stability<br>- Large tank volume | - If the outer hull is underwater, there is no need for a cofferdam structure between the outer hull and the methanol tank<br>- Large tank volume<br>- No effect on cargo volume<br>- Relatively smaller deadweight reduction compared to open deck/ cargo hold options | |
| Disadvantages | - Increased instability due to higher center of gravity<br>- Area around the tank will be a hazardous zone<br>- Possibly limiting cargo operation due to tank arrangement and an additional hazardous zone in the cargo area (refer to Figure 7)<br>- Consideration of tank collision may be necessary in case cofferdam is not applied | - Reduced cargo volume<br>- May require difficult retrofit work | - Challenging retrofit work, especially in the case of tank coating<br>- Reduction of fuel oil or ballast water volume | |

Figure 4: Illustrations of a methanol retrofit using on-deck tanks without (left) and with (right) a cofferdam and water spray installation.

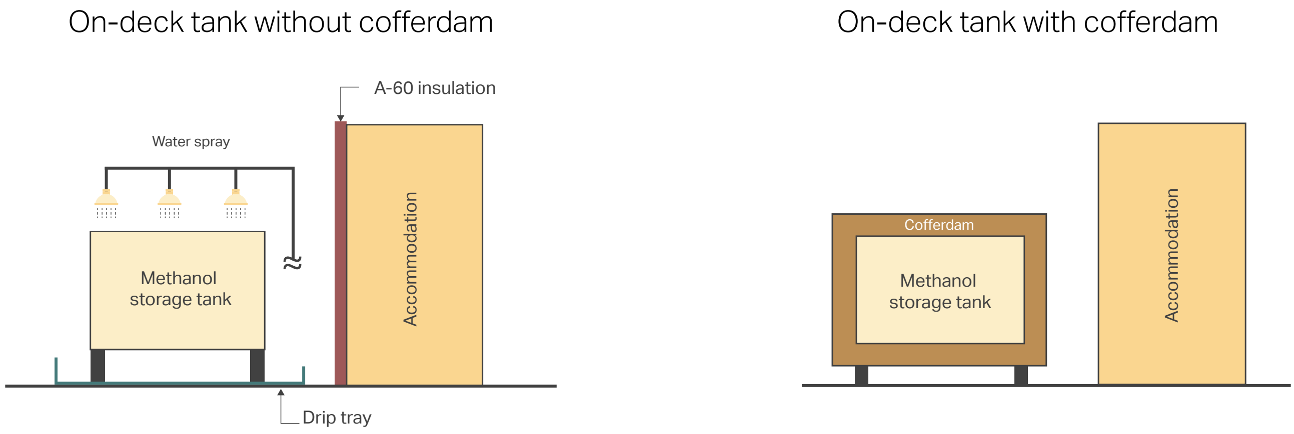



Figure 5: Example of a methanol retrofit arrangement for a bottom tank.

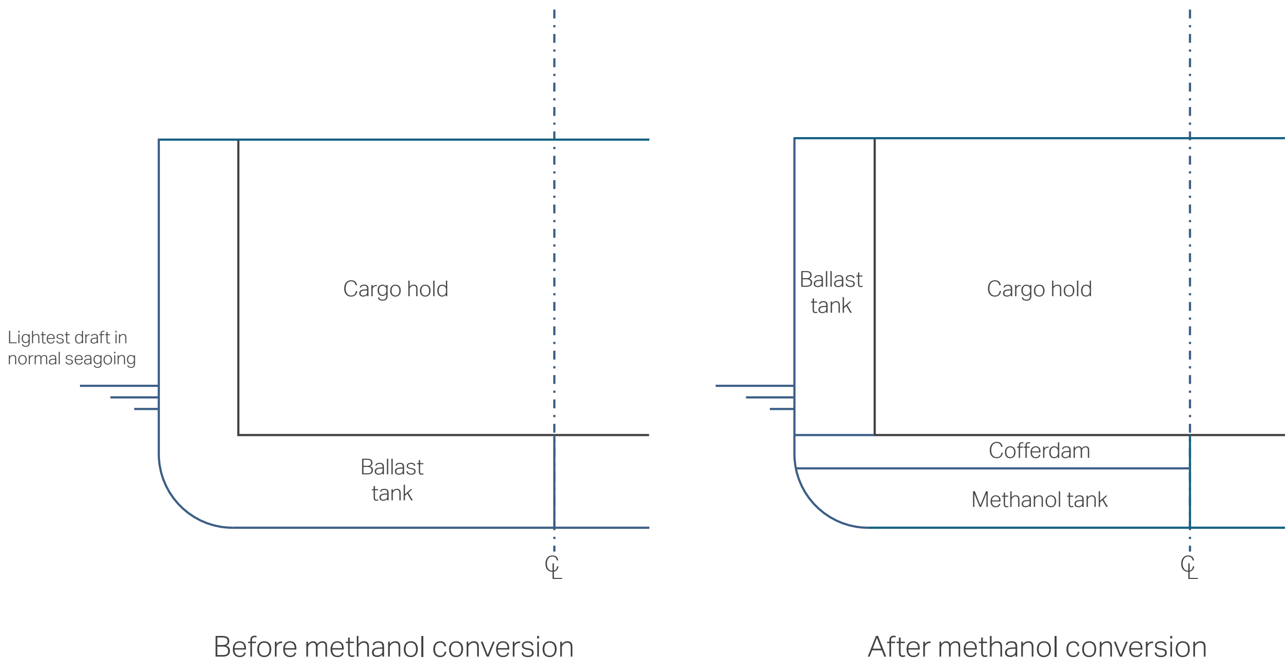
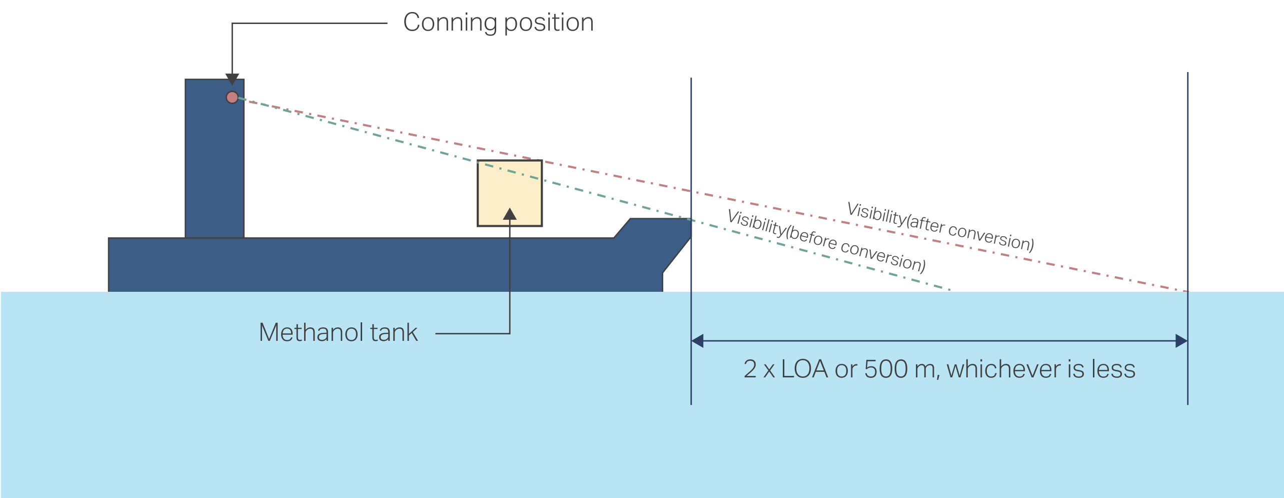
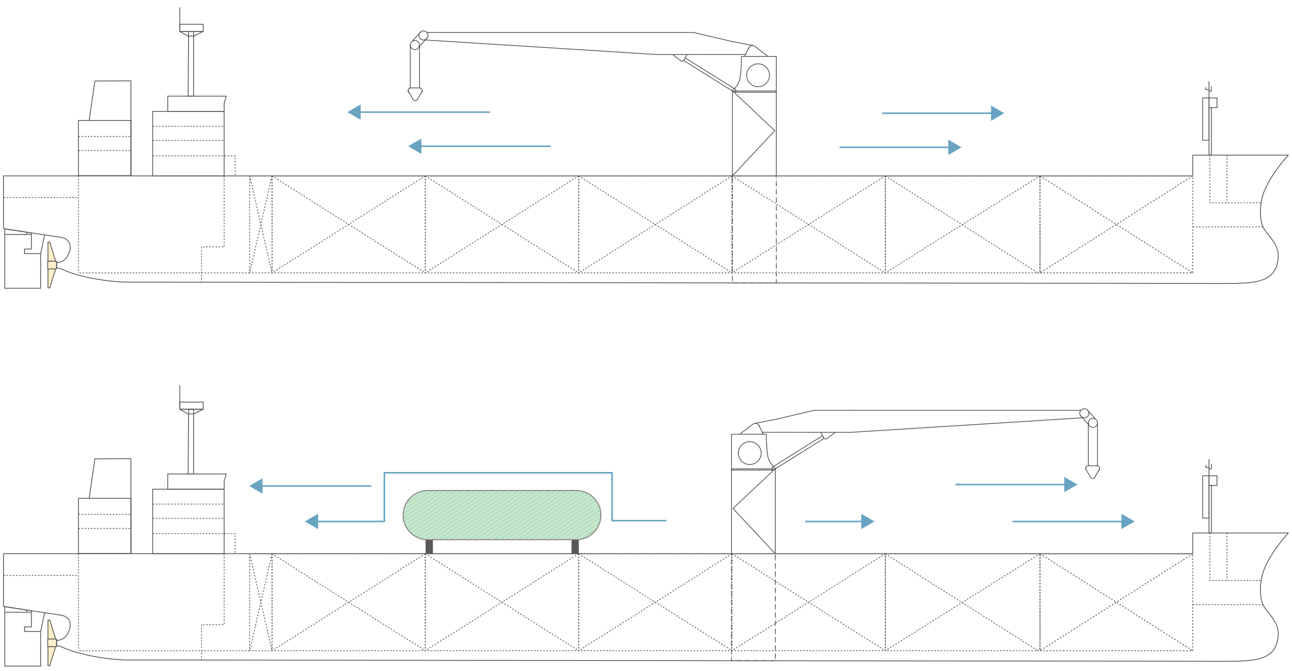


Figure 6: Illustration of the visibility from the bridge before and after an on-deck tank installation.




LOA= length overall

Figure 7: Cargo loader/unloader movement without (upper) and with (lower) an on-deck tank.



A potential tank location should be evaluated based on the advantages and disadvantages of the three potential locations in Table 3, and the vessel in question. In summary, on-deck tanks are easy to install; however, when deciding on the tank capacity, it is important to evaluate the impact of raising the center of gravity. Although tanks placed in hold can lower the center of gravity, they require an evaluation of the reduced cargo volume. Finally, double-bottom, side, and topside tanks provide large fuel volumes, but the complexity of the conversion work and internal tank structure must be taken into consideration.

## 3.1.4 Typical tank arrangements

The tank arrangement is a crucial consideration when converting a vessel to methanol. The tank arrangement depends on the availability of free space and the ship type. This section describes examples of tank arrangements for bulk carriers, container ships, and tankers.

### Bulk carriers

An on-deck tank arrangement does not require extensive installation work, but has limited capacity due to factors such as visibility from the wheelhouse and an increased center of gravity. By contrast, placing a methanol tank in an enclosed space allows for a larger capacity, though the retrofit becomes more challenging.

The optimal choice of tank location is determined by evaluating factors such as endurance, impact on cargo weight and volume, effect on ballast and fuel oil tank capacities, and the complexity of the retrofit work.

Figure 8 shows the different location options for a methanol tank arrangement on a bulk carrier.

### Container vessels

An evaluation of the methanol tank size and position for container vessels must be based on the vessel size and operational requirements. Since the on-deck space is used for cargo and due to the low metacentric height 'GM', the tank must be placed below the upper deck. However, placing the tank in the hold results in loss of TEU capacity and an increased slot cost (cost to transport a single container) of the design.

The low energy density of methanol means that a large tank is required to achieve even a modest endurance. Larger tanks improve the endurance and increase the flexibility of port bunkering, but reduce container capacity. In addition, the weight of the fuel will negatively impact the bending moment and trim. Installing the tanks towards midship reduces this impact; however, it requires significant modifications to the design.

Figures 9 and 10 show the different options for a methanol retrofit arrangement on a 15,000 TEU and a 10,000 TEU container vessel, respectively.

Figure 8: Options for methanol tank arrangement (on deck and in hold) on a bulk carrier. Green shapes represent methanol tanks and yellow represents cofferdams.

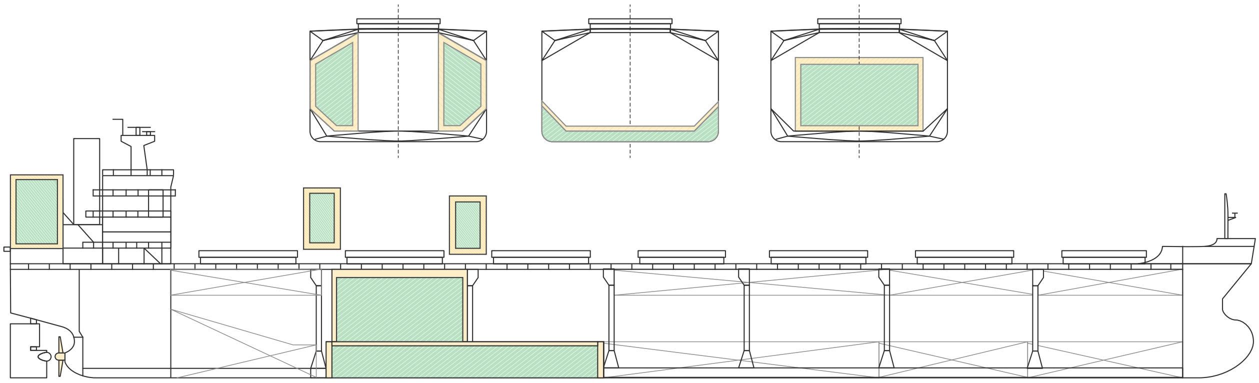
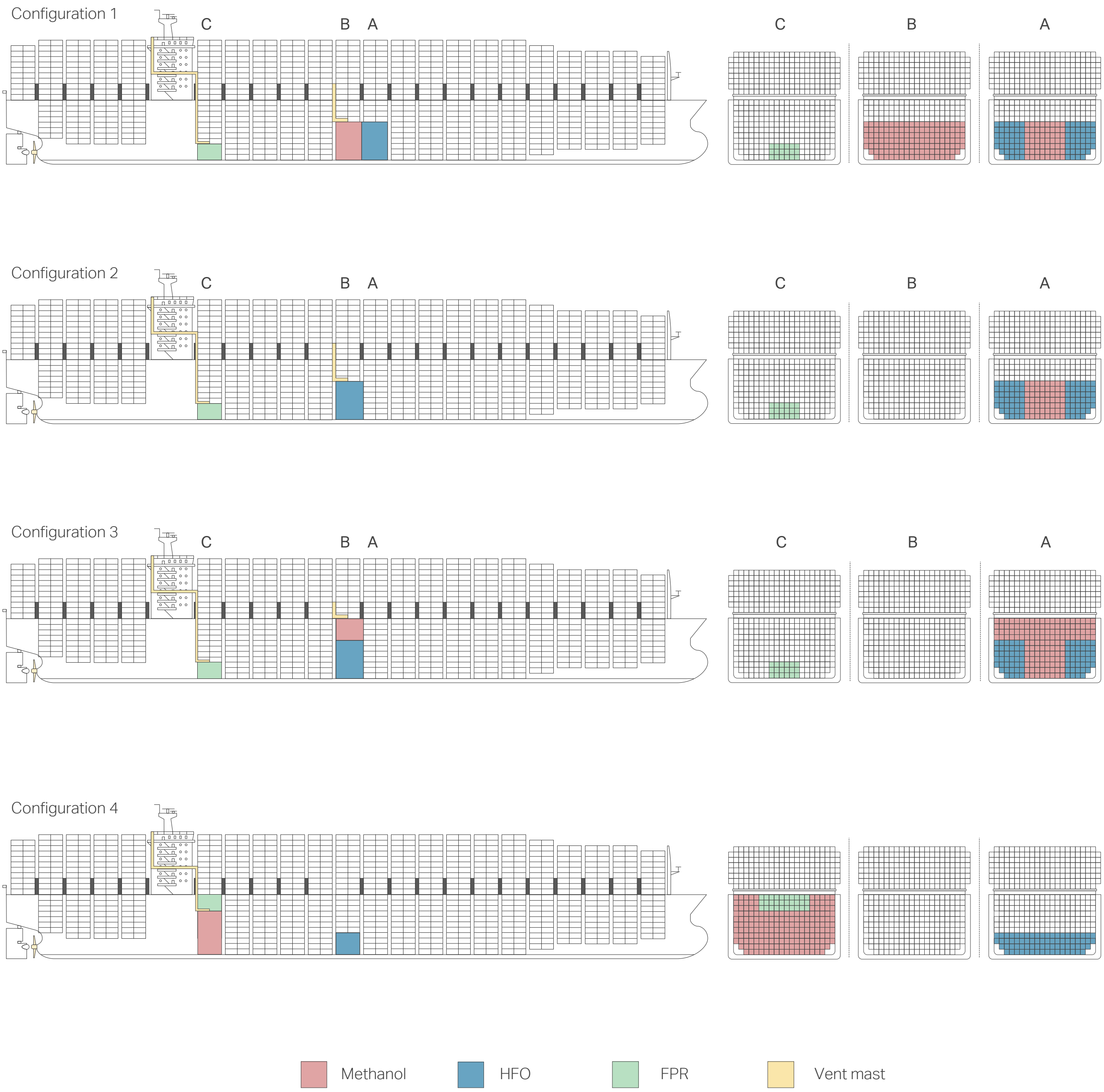


Figure 9: Three fuel system design alternatives for methanol retrofitting a 15,000 TEU container vessel (source: Seaspan).


FPR= fuel preparation room, HFO = heavy fuel oil

Figure 10: Four methanol retrofit design configurations for a 10,000 TEU container vessel (source: Seaspan).



## Tankers

Methanol tanks are more easily installed on-deck on tankers compared to bulk carriers. The MMMCZCS has previously carried out a case study of the tank space availability and the required methanol tank capacities of long-range 2 (LR2) tankers and very large crude carriers (VLCCs) for full and reduced ranges.[7] The values in Table 4 are based on this study. Note that the margin of the methanol fuel capacity (range) should be considered based on the original philosophy of FO tank margin.

After installing the tank on deck in a position not interfering with existing equipment, the following should be checked: visibility from the navigation bridge, stability, and hull longitudinal strength with the additional weight. Depending on the outcome, it may be necessary to reduce the methanol fuel tank capacity to mitigate the effect of the chosen tank size.

When installing fuel equipment systems on tankers, the rationale behind the concept applied for bulk carriers can be used.

Figure 11 shows the most typical design of the LR2 tanker introduced in Table 4 with an on-deck tank and a reduced range on methanol compared to fuel oil. As guidance for the specification of the methanol tanks for this tanker, we used the range of LNG-fueled Aframax and LR2 tankers built or ordered. An LNG storage capacity of 3,500 $m^3$ has become the standard accepted by major charterers and operators. When running on LNG, this storage capacity equates to a range of about 15,500 nautical miles (NM).[6] A similar range for methanol will require a methanol storage capacity of 4,300 $m^3$, which can be fulfilled by two prismatic on-deck tanks with internal dimensions of 18 m x 14 m x 8.5 m. An open type of methanol bunker station is located midship near the cargo and fossil fuel manifolds on both the port and starboard side.

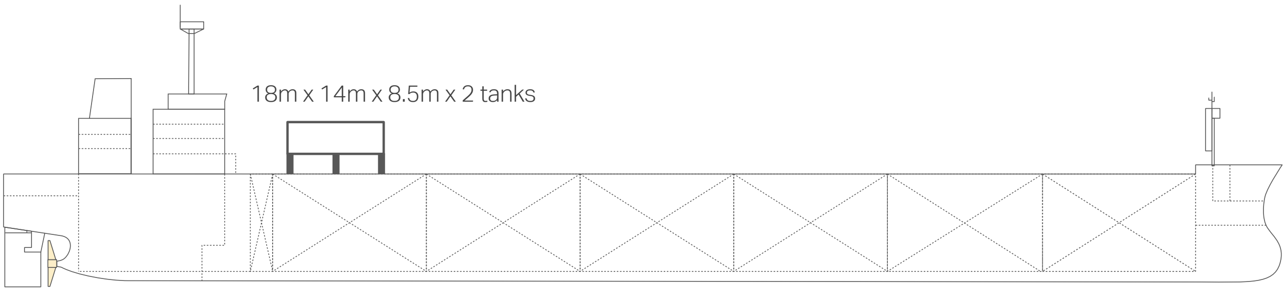
Table 4: Necessary fuel capacity and tank space availability for LR2 tankers and VLCCs for full and reduced ranges.

| Vessel size/fuel type | Range* | FO tank | Methanol tank | Methanol tank location |
|---|---|---|---|---|
| **LR2** Single-fuel (fuel oil) | 19,000 NM | 2,500 $m^3$ | N/A | N/A |
| **LR2** Methanol, dual-fuel (full range) | 19,000 NM | 2,500 $m^3$ | 5,400 $m^3$ | On deck only |
| **LR2** Methanol, dual-fuel (reduced range) | 15,500 NM | 2,500 $m^3$ | 4,300 $m^3$ | On deck only |
| **VLCC** Single-fuel (fuel oil) | 25,000 NM | 6,400 $m^3$ | N/A | N/A |
| **VLCC** Methanol, dual-fuel (full range) | 25,000 NM | 6,400 $m^3$ | 15,900 $m^3$ | On deck and in hold |
| **VLCC** Methanol, dual-fuel (reduced range) | 14,000 NM | 6,400 $m^3$ | 9,000 $m^3$ | On deck only |

LR = long-range, VLCC = very large crude carrier, FO = fuel oil, NM = nautical miles

*Range values are given for fuel oil operation for single-fuel designs and for methanol operation for dual-fuel designs.

Figure 11: On-deck prismatic tank installations (4,300 m³) for a dual-fuel LR2 tanker with reduced range on methanol.




## 3.2 Fuel preparation room

The fuel preparation room (FPR) contains all the necessary equipment for fuel preparation and supply purposes, including fuel supply pumps, transfer pumps, FVTs, heat exchangers, and filters. The IMO requires the FPR to be separated from the engine room. However, the FPR should be placed as close as possible to the main engine to reduce the length of the high-pressure fuel supply and return pipes.[12] There is the potential of prefabricating the FPR module onboard, which will reduce the lead time and integration complexity of a retrofit.

The FPR is categorized as hazardous area zone 1, and the areas surrounding the ventilation inlet and outlet, and the access door opening, are also categorized as hazardous zones.[12] Therefore, designing the fuel preparation arrangement requires an evaluation of the existing safety area opening, ventilation, and electrical equipment.

The FPR design must be able to contain potential methanol leakage and, therefore, must incorporate a fire extinguishing system using alcohol-resistant foam, gas detectors, a bilge system, etc. Furthermore, at least 50% of the capacity of two sets of mechanical exhaust ventilators is necessary to ensure an adequate ventilation capacity.

In summary, the FPR is one of the main hazardous areas, and the position of hazardous equipment around this room should be carefully scrutinized.

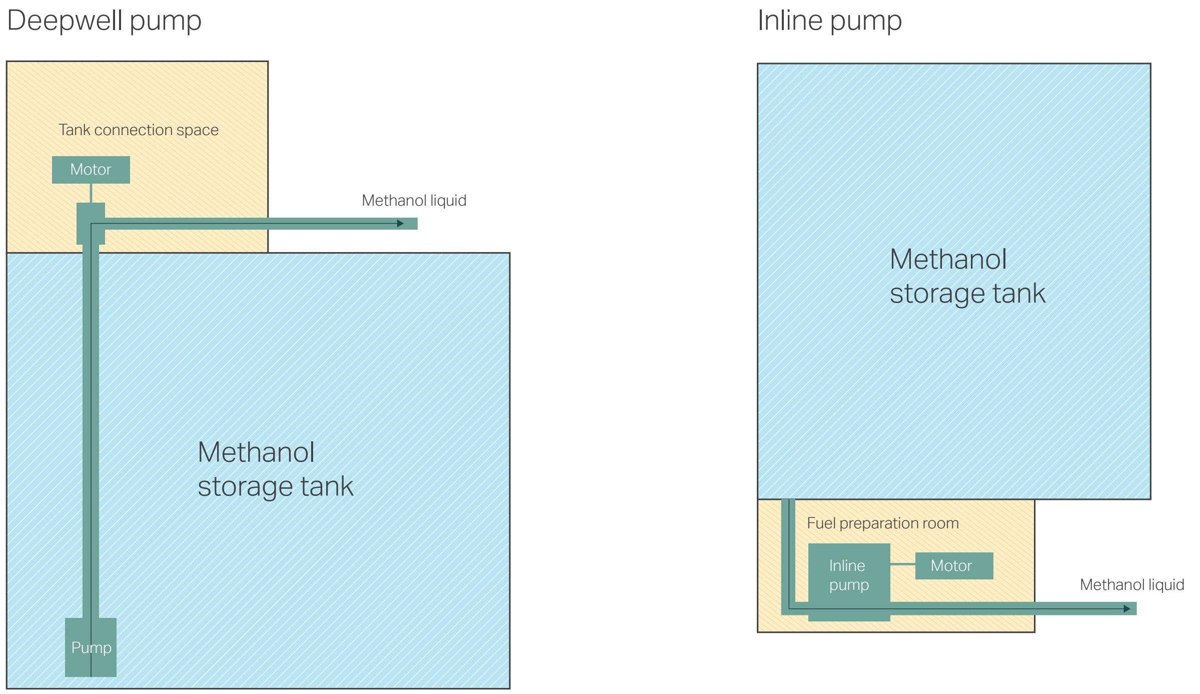
## 3.3 Fuel transfer pump

The fuel transfer pump transfers methanol from the storage tank to service tank or the fuel supply pumps in the FPR. The transfer pump can either be of an in-tank pump type (e.g., a deep-well pump) or an inline pump type mounted outside the tank (e.g., a gear pump) (Figure 12).

Normally, the pump head connection is defined as the tank connection for an in-tank pump. However, if the pump is placed in an enclosed space, this enclosed space is defined as the tank connection space (TCS).

When an inline pump is used, the pump needs to be placed near the bottom of the tank. The area where the pump is placed, including the pump, is categorized as the FPR. If possible, the inline pump should be placed in the FPR containing the LFSS.

Figure 12: Typical arrangements of the fuel transfer pump for a deep-well pump (left) and an inline (right) pump.




## 3.4 Bunker station

Normally, the bunker station has two interfaces (see Figure 13). The liquid line fills methanol into the storage tank, while the vapor line returns methanol vapor from the storage tank to shore or bunker vessel during methanol bunkering. These lines are also used for dry docking operations (i.e., receive inert gas from shore for inerting the methanol tank).

When bunkering liquid methanol, the methanol tank must be protected from overpressure. Installing a safety valve would cause methanol vapor to be released to the atmosphere when the valve is activated. To avoid this scenario, vapor lines are connected to the bunkering facility to return the displaced vapor.

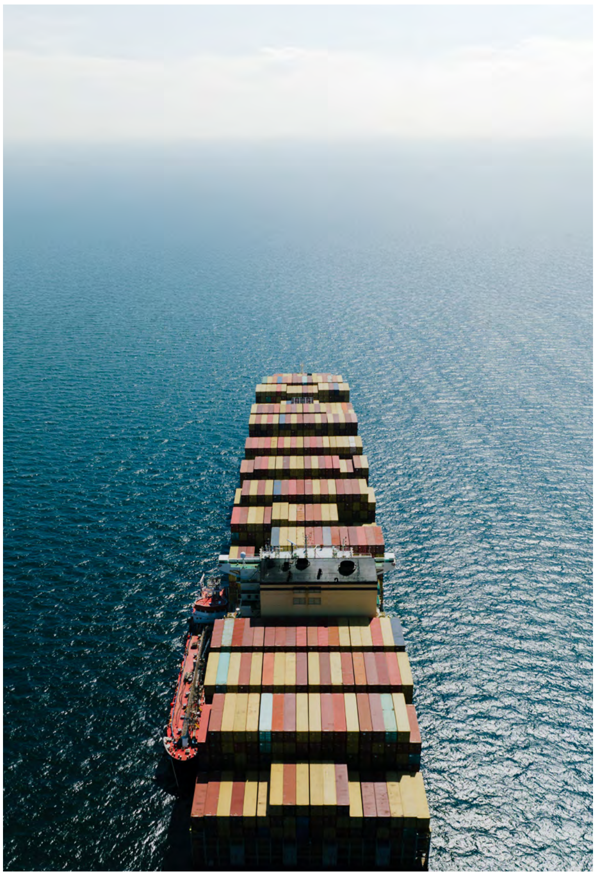
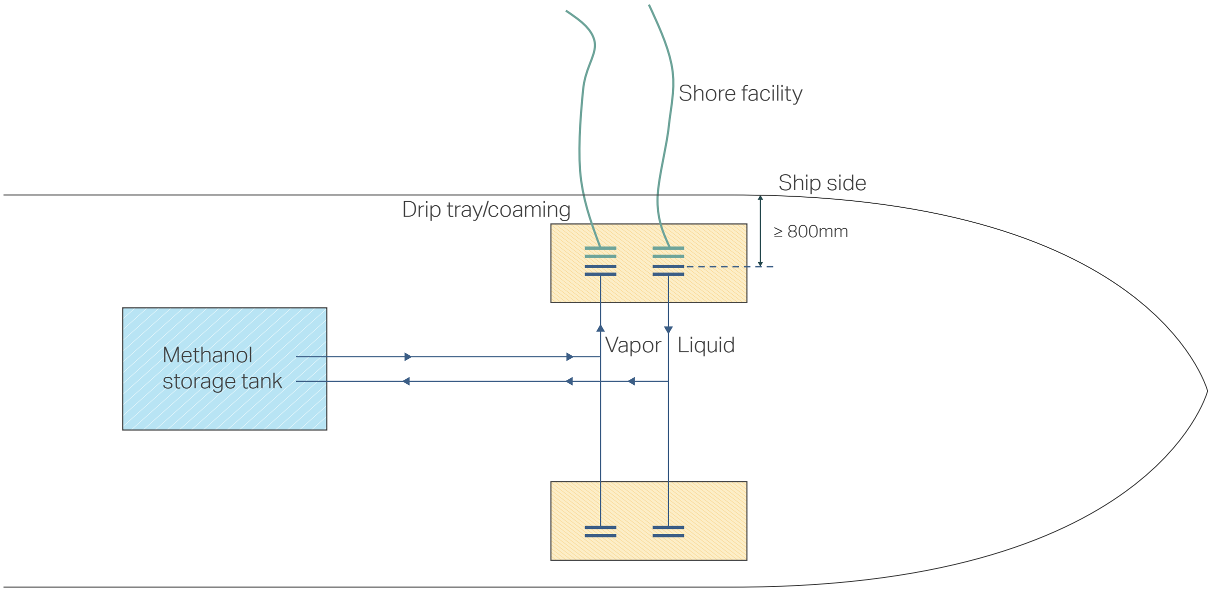


Figure 13: Typical bunker station layout.




## 3.4.1 Ship-to-ship transfer

For ship-to-ship transfer of methanol, a bunker station is best arranged around the flat-of-side area to stabilize the bunker vessel during the bunkering operation.

Further considerations:

- Fuel pipes should not be located less than 800 mm from the ship's side (Figure 13).
- If the bunker station is located on an open deck, ensure it does not face entrances, air inlets, and openings to accommodation areas, etc.
- If the bunker station is located in a closed or semi-closed space, implement countermeasures to prevent the accumulation of methanol gas.
- To operate hose handling, an additional davit may be necessary.

## 3.4.2 Compatibility study

A compatibility study is necessary when considering ship-to-ship or ship-to-shore transfer of methanol, including mooring arrangements, piping interface arrangements, supply pressure, communication system infrastructure (e.g., mooring, piping, communications systems, etc.). If accepted by the shore facility, a methanol drain connection interface may also be arranged in the bunker station.

## 3.4.3 Evaluation of hazardous zone and radiant heat

If the bunker station is located near other openings, such as cargo holds, an evaluation should be made of the hazardous zone surrounding the bunker station. This is necessary because the IMO guidelines require that air outlets from non-hazardous spaces should be located outside hazardous areas.[12]

The hazardous zone of the bunker station may impact cargo/vent locations/air intake locations.

Furthermore, it may be necessary to evaluate the influence of radiant heat on loaded cargo during a fire in the bunker station.

### 3.4.4 Bunker station configuration

Since large bunker quantities are required, multiple liquid lines to allow a high flow rate are necessary to minimize the impact from bunkering on vessel operation.

To enable easy handling by the crew, the connection pipe size should not exceed 8”.

One bunker station should be arranged on each side of the vessel with the configuration given in Table 5 for small and large bunker stations.

Methanol fuel is not cryogenic, and saddles are therefore not needed.

### 3.4.5 Compatibility and safe design

In addition, the requirements described next should be in place to ensure a safe design and the compatibility of the bunker station and the bunkering operation.

For each bunker station:

- Dry-disconnect type connections equipped with an additional safety dry breakaway coupling/self-sealing quick release
- Fixed alcohol-resistant foam system and portable dry powder extinguisher
- Ventilation fans complying with the regulation[12]
- Eye washer and shower stations (also for fuel preparation spaces)
- Drip tray below the bunkering connectors together with a means of safely collecting and storing the spills (Figure 13)

Furthermore, consider also that:

- A crane system is required to support hose handling.
- The receiving vessel will be equipped with an emergency shutdown link that complies with linked ship/shore emergency shutdown systems for oil and chemical transfers.
- A holding tank is needed to safely capture and store the liquid collected in the drip tray, and the liquid should be processed onboard or arranged for discharge at port.
    - Bunker vessel compatibility study and Simultaneous Operation (SIMOP) to be carried out to reduce the impact on operation. This is especially important for container ships.
- The bunker stations will create a hazard zone, which will impact cargo/vent locations/air intake locations. On container ships, this especially impacts the reefer containers, which are normally positioned on deck at the lashing bridge levels.

Table 5: Configurations of small and large methanol bunker stations.

| | Configuration | Manifold size | Main pipe size | Flow rate | Small tank (8,000 m³) | Large tank (13,000 m³) |
|---|---|---|---|---|---|---|
| Small bunker station | L-V | 8”– 6” | 1 x 8” | about 800 m³/h | about 10 hours | about 17 hours |
| Large bunker station | L-L-V | 8”–8”–8” | 1 x 12” | about 1,600 m³/h | about 5 hours | about 9 hours |

## 3.5 Tank connection space

The TCS is the enclosed space surrounding the methanol storage tank connections (e.g., tank valve and deep-well pump penetration) as defined by the IMO.[12] If the tank connection is placed in an open area, the TCS is not necessary. However, if the tank connection is in an enclosed space, the TCS is mandatory. The TCS is categorized as a hazardous area.[12] Ship designers/owners should consider fitting the TCS with mechanical ventilation, although this is not described by the IMO.[12]

## 3.6 Inerting/purging

The oxygen content in a methanol tank must not exceed 8% by volume,[12] which requires an inert gas system for inerting the tank. Normally, a nitrogen generator is used to supply nitrogen gas used for inerting.

Traditionally, the inert gas system is also used for line purging. The inert gas system needs to meet the capacity and pressure required by the LFSS and the main engine.

Both tank inerting and line purging functions should be considered when determining the specifications of a vessel's inert gas system.

## 3.7 Fuel tank vent outlet

If there is overpressure in the methanol tank, a tank safety valve releases the pressurized vapor to the atmosphere via a fuel tank vent outlet. An area from the vent outlet becomes a hazardous zone, defined as a vertical cylinder with a radius of 10 m and unlimited height above the vent outlet, and a hemisphere with a 10-meter radius below the vent outlet. Safety area openings should not be arranged within this area, and electrical equipment should be of the explosion-proof type.

During cargo loading and unloading, the loader/unloader may need to pass this hazardous zone. Therefore, if the hazardous zone is in the cargo area, particular consideration may be necessary.

The arrangement of the fuel tank vent outlet should therefore consider not only the safety area openings, but also cargo handling operations. Different vent outlet arrangements can be considered that enable more flexibility and a safe distance from the accommodation and crew spaces. For this, a feasibility study will be necessary to assess the potential impact.

## 3.8 Drainage and bilge cofferdam – methanol drain tank

The vessel needs at least one dedicated holding tank for collecting drainage from the methanol tank and equipment containing methanol. In addition, the means to transfer the methanol drainage from the holding tank to onshore, reception facilities must be selected. These include transfer methods such as hose/pipe connections, drums, and containers.

## 3.9 Dual-fuel engine and fuel injection

Dual-fuel engines are designed for operation on alternative fuels (for example, low-flashpoint liquid fuels) and conventional fuels. The dual-fuel engine can run in two different modes depending on the fuel and the operating conditions. As an example, the ME-LGIM engine developed by MAN Energy Solutions can run in either conventional-fuel-only mode or dual-fuel mode. The operator can switch between these modes and between operation on very low-sulfur fuel oil (VLSFO), marine gas oil (MGO), or liquid methanol fuel. The changeover between fuels takes place seamlessly, maintaining both power and efficiency.

The functionalities of a dual-fuel engine concept include safety features and monitoring practices. MAN Energy Solutions has shared the following safety functionalities of the ME-LGIM engine (Figure 14):

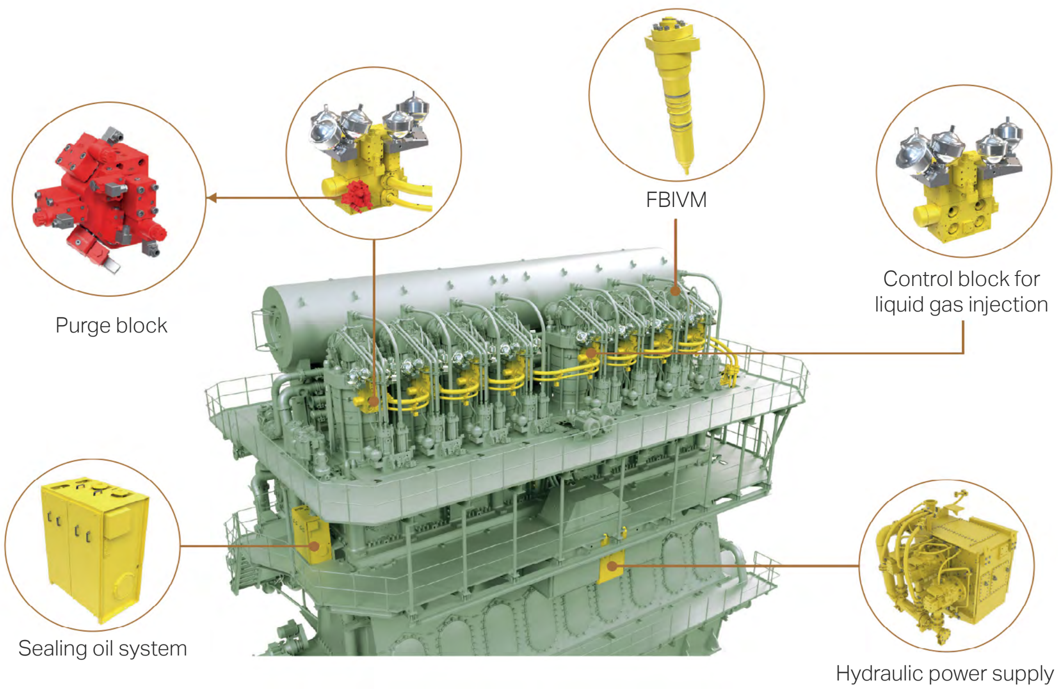
- Fuel booster injection valves for injection of methanol (FBIVM) into the combustion chamber
- Hydraulic control systems for the FBIVMs
- Sealing oil supply unit mounted on the engine to ensure that no methanol leakage occurs in the moving parts of the methanol injection system
- Double-walled piping distributes methanol to the cylinders

- Drain and purge system for quick and reliable removal of methanol from the engine
- Additional safety system that monitors the methanol injection and combustion, and reverts to conventional fuel operation if there is an alarm
- FVT provides a block-and-bleed function between the fuel supply system (FSS) and the engine

The design of the methanol fuel supply pipes is based on a double-barrier concept, where a second layer encapsulates all methanol piping inside the engine room. This outer piping is ventilated to the outside atmosphere to eliminate the risk of methanol leakage into the engine room and to allow detection of leakage from the inner pipe with hydrocarbon sensors.

The retrofit conversion will enable the engine to run on both conventional fuel and methanol. When running in dual-fuel mode, a small pilot injection of conventional fuel will initiate the combustion of the methanol. VLSFO, MGO, sustainable biofuel, or synthetic fuels can be used as pilot oil. After the retrofit, the expected pilot oil fraction in dual-fuel mode is 5%.

Figure 14: LGIM engine and the main LGIM system components (source: MAN Energy Solutions, 2024).




FBIVM = fuel booster injection valves for injection of methanol

## 3.10 Other design aspects

The following subsections address segment-specific considerations, such as bending moments and visibility. Additionally, they cover equipment aspects applicable to various vessel types, including anchorage and mooring equipment, as well as firefighting and fire protection systems.

### 3.10.1 Longitudinal strength

Adding additional structure and tanks will change the shear force, bending moment capacity and light weight distribution, which must be recalculated and evaluated to determine whether these are within the allowable longitudinal strength limits for both intact and flooded cases.

In general, reinforcing the longitudinal strength during the conversion phase is unrealistic due to the extensive construction work. This limitation might affect the capacity of the methanol storage tank or the loading flexibility of the vessel.

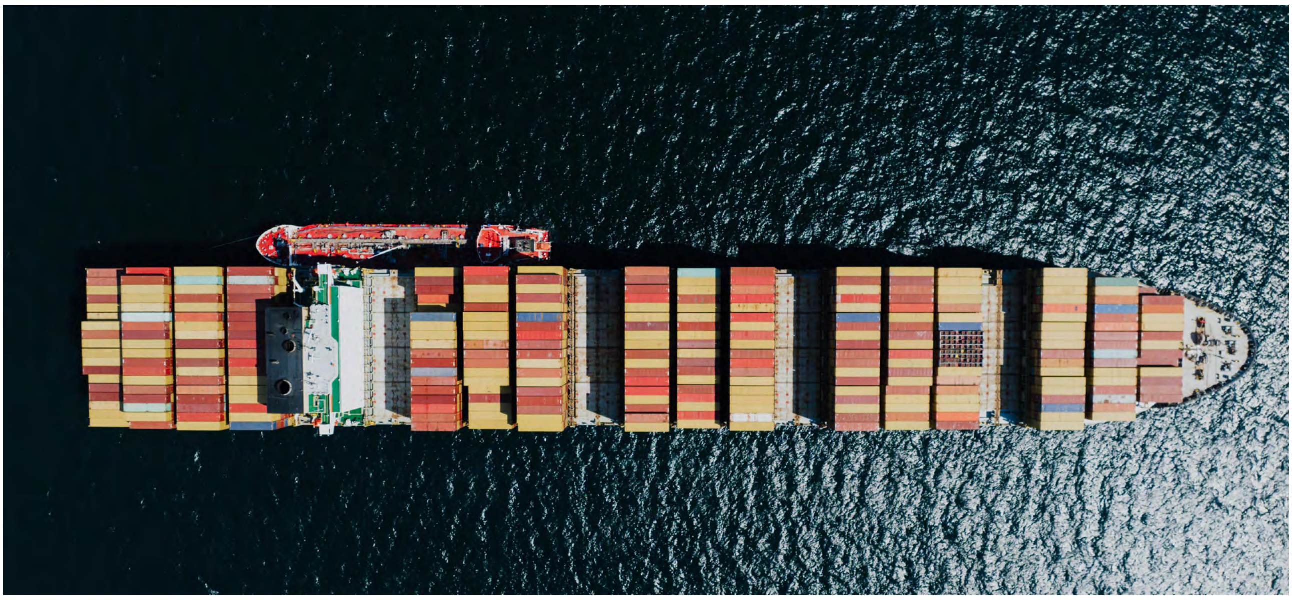
For a bulk carrier, the allowable methanol tank capacity depends on the longitudinal strength for loading low-stowage-factor cargo, like iron ore. A larger tank capacity can be achieved if the methanol fuel tank is arranged near the midship section.

### 3.10.2 Anchorage and mooring equipment

The size of the anchor, length of anchor chain, etc., is determined by the equipment number, which is calculated by using full load displacement, projected area of the structure, effective height of the structure, etc. There are several boundary numbers, and, if the calculated equipment number exceeds the boundary number, the required specification, such as the size of the anchor, must be changed.

Because of the additional structure (for example, the methanol storage tank and FPR) needed as part of the conversion, the equipment number of the vessel may increase and a larger anchor, anchor chain, mooring rope, and related machinery (for example, windlass and mooring winch) may be needed. This upgrade may require a major conversion and it is therefore important to consider the increased equipment number. In general, it is better to ensure that the size of additional structures does not exceed the boundary equipment number.

Other rules related to mooring equipment, such as the International Association of Classification Societies (IACS) UR A2 and the Oil Companies International Marine Forum's (OCIMF) Mooring Equipment Guidelines, should also be checked.



## 3.10.3 Fixed firefighting and fire protection system

In areas where methanol leakage can occur, the risk of a potential fire needs to be addressed by installing a fixed fire extinguishing system using an alcohol-resistant-type foam. Normally, the classification society should approve this system.

Furthermore, vessels with the methanol storage tank arranged on an exposed part need a water spray system installation.

In addition, the FPR and the methanol drain tank space need fixed fire extinguishing systems (i.e., a $CO_2$ system). The number of $CO_2$ bottles necessary is determined by the engine room volume or the cargo hold volume, and therefore additional $CO_2$ bottles are not deemed necessary for the FPR and methanol drain tank space.

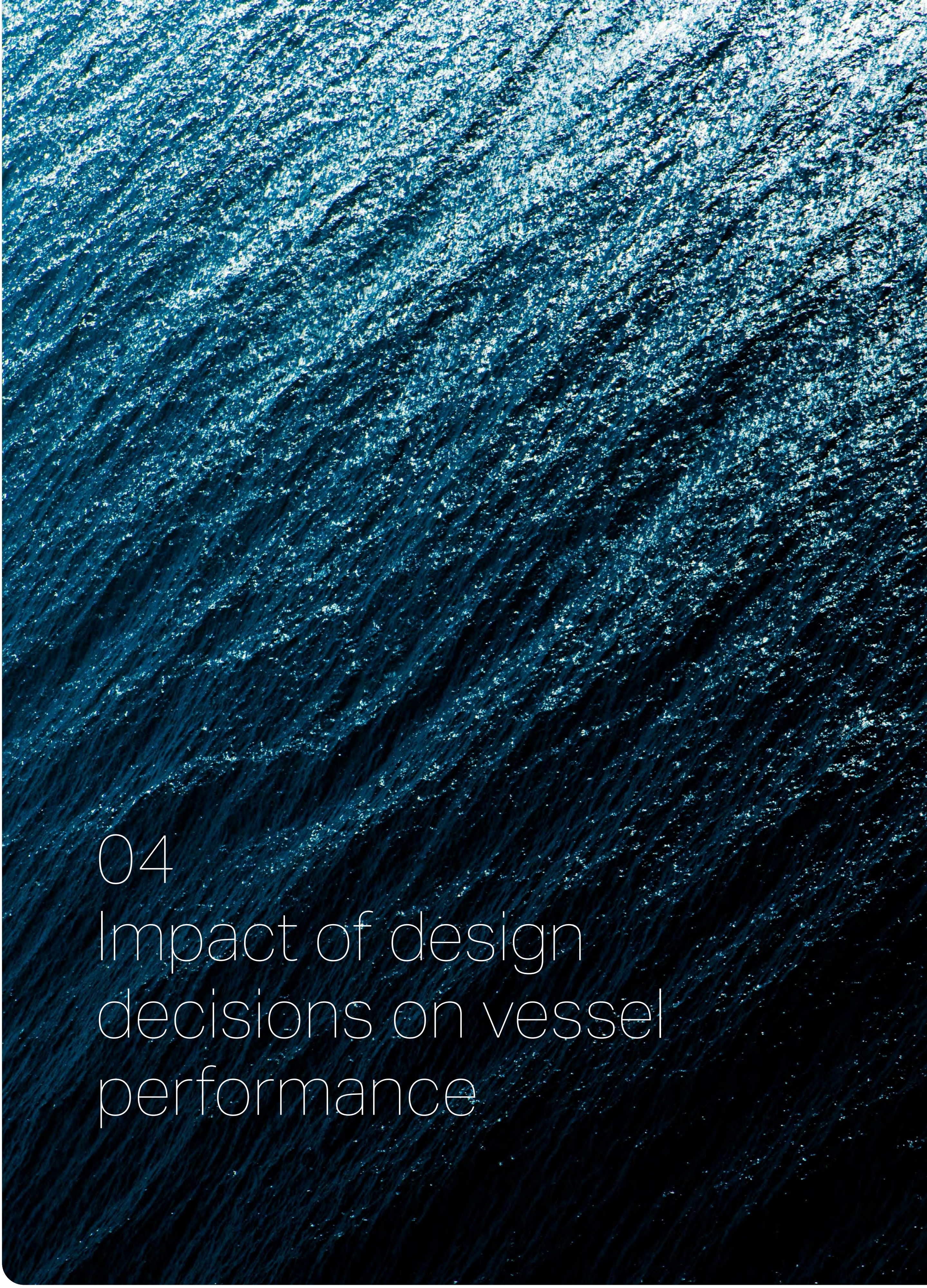
The additional water spray system and fixed foam system use seawater, and it should be evaluated whether an upgrade of the seawater pump is required. The electric power consumption for additional firefighting and protection systems should also be checked.

An additional fixed firefighting system and a fire protection system need to be provided as described in Table 6.[12]

Table 6: Comparison of firefighting and protection systems.

| Protected area | Water spray system | Fixed fire extinguishing system using alcohol-resistant foam | Fixed fire extinguishing system in accordance with SOLAS (i.e., $CO_2$ system) |
|---|---|---|---|
| Methanol fuel tank | Applied (For exposed surface) | Applied (For areas where leakage can occur) | Not necessary |
| Methanol drip tray | Not necessary | Applied | Not necessary |
| Engine room | Not necessary | Applied | Applied |
| Fuel preparation room | Not necessary | Applied | Applied |
| Methanol drain tank space | Not necessary | Applied | Applied |
| Bunker station | Not necessary | Applied | Not necessary |

SOLAS = International Convention for the Safety of Life at Sea



# 04 Impact of design decisions on vessel performance

When designing methanol tanks for ships, several factors come into play. These include endurance, bunkering frequency, cargo loadability, and the vessel's operational profile. The most important areas for consideration are mentioned below.

## Tank size and fuel availability

The tank size depends on the ship's operational profile and the availability of methanol as a fuel source. Tank size is of major importance, as it affects the ship's loadability and, thereby, the compromise between endurance and cargo loadability (see next subheading).

Two main factors must be considered when determining the tank size:

- endurance
- number of times needed to bunker annually

## Endurance versus cargo loadability

The endurance determines the maximum sea voyage distance between bunkering for a specific fuel. There are three values that must be considered during the design phase:

- endurance on conventional fuel
- endurance on methanol with minimum pilot fuel
- maximum endurance with all fuel tanks full (slightly less than the sum of the first two due to the pilot fuel consumption)

The maximum endurance is not always meaningful, because ships will not bunker fuel that is unnecessary for the leg of the voyage. The fuel consumption rate determines the endurance, and the endurance can be increased by reducing the ship speed, thereby allowing for a smaller tank size. Depending on the vessel type, size, and operational route, a minimum endurance is typically a transpacific crossing of 5,500 NM.

## Bunkering

The ship designer must consider the number of times the vessel will need to bunker with methanol. Varying fuel prices, trading routes, and availability require a certain level of bunkering flexibility.

## Long-term planning and outlook

When designing for a methanol retrofit, it is important to consider the current age of the vessel and the remaining expected life. This must be followed by a prediction of the average energy consumption of the vessel and of the quantity of methanol required to meet potential GHG emissions reduction targets on a vessel or company level. The number of times the vessel will need to bunker per year depends on the annual quantity of methanol consumed and the size of the tank. A smaller tank size naturally means more frequent bunkering. Assuming that methanol will become more widely available in the future, the number of times the vessel must bunker per year will expectedly increase without impacting the operation of the vessel.

A vessel's required endurance when operating on methanol will also influence the selection of fuel tank size. Table 7 shows an example calculation considering the impact of methanol tank size on endurance for a medium-sized container vessel. Here, the endurance signifies the maximum distance between two ports which have e-methanol available if the vessel needs to minimize GHG emissions.

Table 7: Impact of tank size (8,000 $m^3$ and 13,000 $m^3$) on the endurance for a medium-sized container vessel.

| Speed (kn) | Medium methanol tank: 8,000 $m^3$ | Large methanol tank: 13,000 $m^3$ |
|---|---|---|
| 12 | 32,100 NM | 52,200 NM |
| 14 | 24,600 NM | 40,000 NM |
| 16 | 19,400 NM | 31,500 NM |
| 18 | 15,500 NM | 25,200 NM |
| 20 | 12,500 NM | 20,300 NM |

NM = nautical miles

# 05 Improvement considerations – design optimization

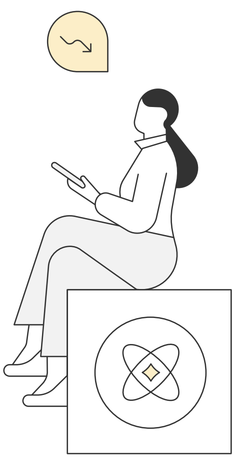
The lower calorific value of methanol is approximately half that of fuel oil, whilst the density of methanol is only 80% that of fuel oil (Figure 1). This difference requires methanol tanks to be over 2.5 times larger than fuel oil tanks to match the energy content.

To satisfy the endurance and minimum annual bunker frequency requirements for the vessel's assigned trading route, significantly larger tanks will be required. For retrofit projects, the vessel is very unlikely to be designed to accommodate this, and the addition of large methanol tanks will require changes to the vessel's arrangement and, hence, impact on its performance.

The methanol tank will affect the vessel's existing arrangements and the loadability in the following ways:

- Reduces cargo space, if the tank is positioned in a cargo hold
- Increases the change in bending moment from departure to arrival condition and, thereby, reduces the flexibility in cargo distribution
- Impacts stability (vertical center of gravity and free surface effect)
- Impacts visibility, either directly if the tank is positioned on-deck or indirectly if the tank causes a large trim
- Impacts loading and discharge operations

To counteract these effects, alternative design solutions are sought by designers to identify the most suitable tank location providing the best loadability whilst achieving the required tank size. These alternative solutions include lengthening the vessel, using ballast tanks as either cofferdams or methanol tanks, and fitting insulation systems or other novel systems for reducing the cofferdam size. Each solution is explored in more detail in the upcoming subsections.



## 5.1 Lengthening

One way to accommodate larger methanol tanks without impacting the cargo space is to increase the length of the vessel. Vessel lengthening requires a relatively extensive rebuilding, which involves cutting the vessel along the parallel midbody and inserting a new section. This section can either give space for methanol tanks and equipment, or be used as an additional cargo hold, compensating for the cargo space lost by including a tank.

### 5.1.1 Prefabricated lengthening

Compared to other alternative design solutions, one benefit of lengthening the vessel is the possibility of prefabricating and preparing the new section to reduce the time spent in dry dock and thereby reducing a major part of the conversion cost. Furthermore, a rebuilding strategy that incorporates all necessary methanol equipment in the new section will enable prefabrication of most of the conversion, which significantly simplifies the rebuild work and the final hazard zones on the vessel.

### 5.1.2 Limited space and change of equipment number

Since the new section needs to be inserted at the parallel midbody of the vessel, the longitudinal location where the insert can be fitted will be limited. This could result in significantly long piping and the key components to the fuel system being spread out. Another important factor relates to the potential change in equipment number, which could require modifications to the mooring system and anchoring equipment.

### 5.1.3 Major conversion

It is important to evaluate whether lengthening the vessel will fall under the category of 'major conversion' which is defined by the classification society and triggers a requirement for compliance with the latest IMO regulations. We recommend discussing the impact of a major conversion on the vessel design with the classification society at the initial design stage.

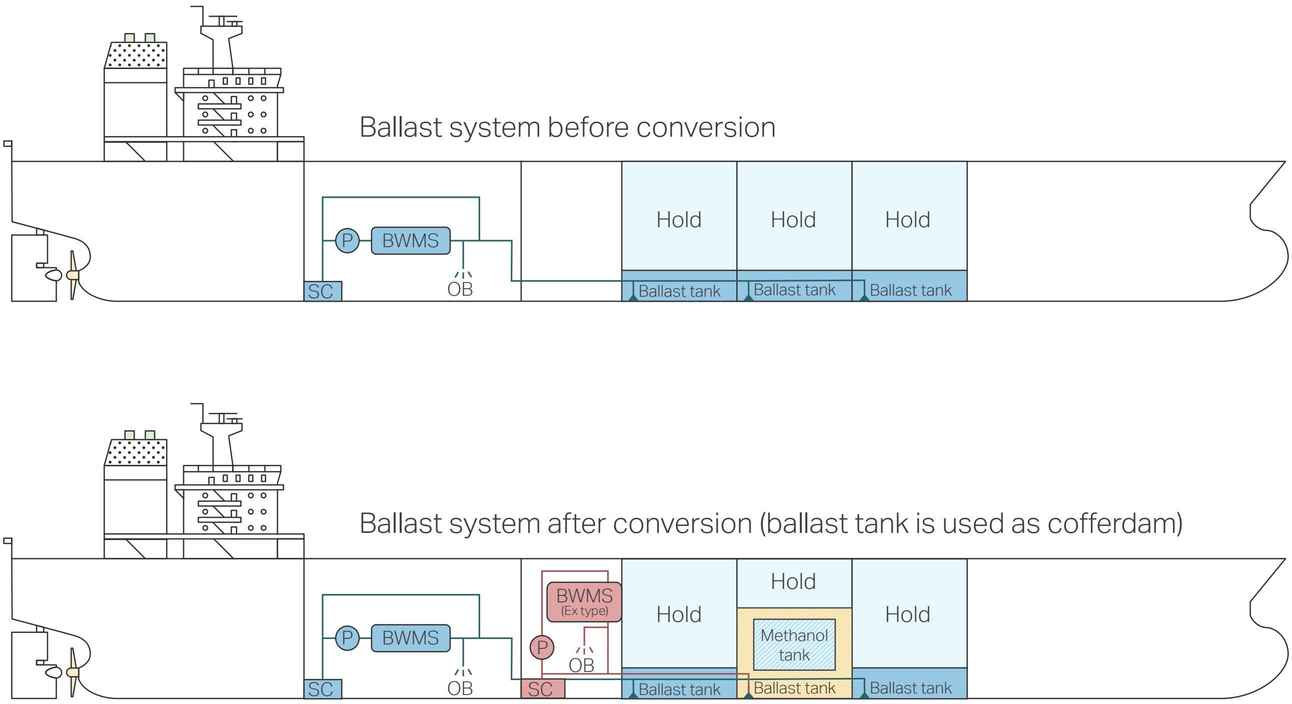
## 5.1.4 Operational constraints

Finally, lengthening a vessel might severely restrict the ports or canals that the vessel can access. Therefore, it is important to take the expected operational profile into consideration before lengthening a vessel.

## 5.2 Ballast tanks as cofferdam

One solution for optimizing the conversion design is to place the methanol tank in a cargo hold and integrate the existing ballast water tank as a cofferdam space surrounding the methanol tank. Figure 15 shows this solution implemented on a vessel.

Figure 15: Ballast system before and after a conversion where the ballast tank is used as a cofferdam.




SC = sea chest, OB = overboard, BWMS = ballast water management system, P = ballast pump, Ex. type = explosion-proof type

### 5.2.1 Ballast water treatment system

If there is a methanol leak from the fuel tank, it must be possible to flood the cofferdam space. Ballast tanks already meet this requirement. However, the ballast water or water used to flood the cofferdam will contain methanol and should be handled safely. The solution shown in Figure 15 places the ballast water treatment system outside the engine room.

If the ballast water pumps are placed in the engine room as normal, a separate pump system for the tanks used as a cofferdam will be required.

If the ballast water treatment system is fitted on the inlet to the ballast tank via a non-return valve, the ballast water treatment system could be exempt from being explosion-proof. However, ballast water treatment systems fitted on the outlet must be of explosion-proof type.

### 5.2.2 Other design aspects

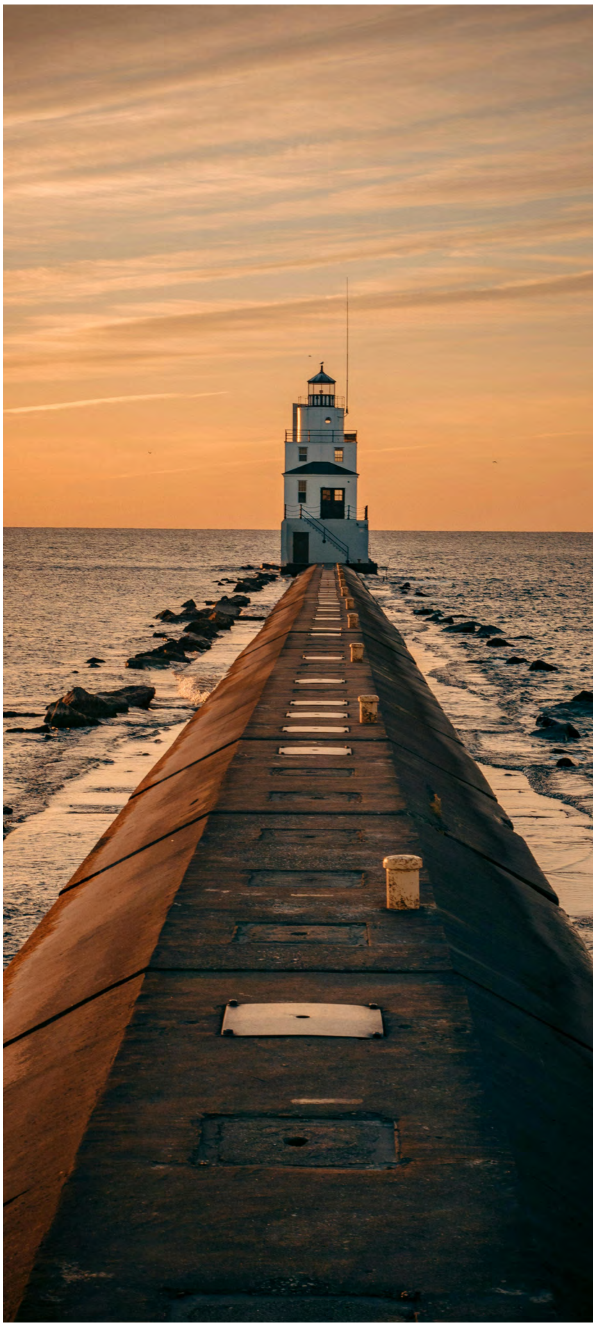
There are some additional design aspects to consider if using a ballast tank as a cofferdam:

- A ballast tank used as a cofferdam will be defined as a hazardous zone.
- Methanol detection will be difficult considering different environments for full/empty and partial-fill heights of the cofferdam space.
- Dirt and sediment buildup will impact and damage methanol sensors.

### 5.2.3 Flag state and class approval

If the ballast tank is going to be used as a cofferdam after the conversion, the described design will be regarded as an alternative design and would need approval from the flag state and the classification society. We recommend involving the class in design development to ensure that all technical and safety aspects are covered.

Table 8 summarizes the safety considerations needed and related technical changes to consider during the design phase.



In summary, using the ballast tank as a cofferdam can result in an efficient design providing dual use of the cofferdam space. If implemented, designers should carefully consider how to manage potential flammable and toxic gases in the ballast tank system in the event of a methanol leak.

Table 8: Examples of the IMO safety requirements, interpreted from the IGF Code,[11] MSC.1/Circ.1621,[12] and MSC.1/Circ.1455,[14] to be complied with when using a ballast tank as a cofferdam.

| Safety requirements for application of ballast tank as cofferdam | Technical considerations |
|---|---|
| Ballast tanks next to methanol (low-flashpoint liquid, LFL) tanks will be defined as a hazardous zone. | Electrical equipment in the ballast tank should be of the explosion-proof type.<br>Normally, the electrical equipment in ballast tanks is a level gauge or a level switch. |
| Air pipes for ballast tanks next to LFL tanks must be led to the open deck, and areas on the open deck within 1.5 m of the air vent heads for these ballast tanks will be defined as hazardous zone 1.<br>In addition, areas on an open deck surrounding zone 1 will be defined as hazardous zone 2. | Normally, an air pipe for a ballast tank is led to an open deck. The area of the hazardous zone from the air pipe head is not clearly described, but it can be considered that zone 2 is within 1.5 m from zone 1 (in total 3 m from air vent heads).<br>The location of the air pipe head should be determined considering other openings of a safety zone, such as a deck store. Such openings should be outside of the gas hazardous zone.<br>On deck, electrical equipment within 3 m from air vent heads should be relocated to a place outside of the 3 m, or changed to an explosion-proof type. |
| Spaces where the ballast pumps are located, and ballast treatment spaces, will be defined as hazardous zone 2. | The area containing the ballast pump and ballast water management system should be separated from the engine room.<br>It should not be possible to access the area directly from a safety area. The access should be from open deck, or via an airlock space.<br>Deep-well pumps on open deck for ballast water might be another solution. |
| Means are provided, on the open deck, to allow measurement of flammable gas concentrations within the ballast tanks with a suitable portable instrument. | Normally, portable gas detectors are used for measurement of flammable gas concentrations. Such detectors should be available onboard. |
| Sounding pipes must be led to open air. | Normally, sounding pipes for ballast tanks are led to an open deck. |
| Entry space must be provided for ballast tanks without access to the open deck. | If the access to the ballast tank is not from an open deck, an entry space with a mechanical ventilator should be arranged. |
| Gas detection must be arranged in all ballast tanks next to LFL tanks. | An additional fixed gas detector system should be provided for ballast tanks. The system is normally applied for tanker vessels. |

## 5.3 Ballast tank as methanol tank

Another solution for optimizing the conversion design is to use an existing ballast tank(s) for methanol storage. When converting a ballast tank to a methanol tank, several aspects need to be considered: the difficulty of blasting and coating with inorganic zinc silicate, the rerouting of the ballast tank piping, additional ventilation routing and associated hazard zones, and a reduced ballast water capacity.

### 5.3.1 Cofferdam

Depending on adjacent spaces, a cofferdam space will be required when carrying methanol in a former ballast tank. However, if conducting a Hazard Identification Study (HAZID) review of the design, an exemption could be granted to avoid this requirement. Furthermore, ballast tanks placed next to the side shell would not need a cofferdam below the water line.

### 5.3.2 Coating

It is difficult and time-consuming to remove the existing ballast tank paint to prepare for the tank coating, increasing the cost and the time out of service for the retrofit. Furthermore, it is difficult to ensure an even coating of zinc silicate on complex stiffener structures in the ballast tanks.

### 5.3.3 Ballast tank piping and ventilation system rerouting

If the piping for the remaining ballast water tanks is run through the converted ballast water tank, separate pipe routes would be required to be made for the remaining ballast water tanks. It will also be necessary to remove the existing fill height measuring system for the ballast tank used for methanol and to reroute the ventilation system.

### 5.3.4 Reduction of ballast water capacity

If the ballast water capacity is reduced, the ballasting flexibility will also be reduced, with a negative impact on bending moment, loadability, trim optimization, and maneuverability.

When gas-freeing or stripping the tanks, a quantity of unpumpable residual methanol could remain in the tank, which should be considered for the trim/heel of the vessel. Therefore, a stripping/gas-freeing strategy should be selected early on and the appropriate equipment added, e.g., the ability to dilute with freshwater and then process this wastewater repeatedly until the methanol concentration is low.

## 5.4 Novel insulation systems reduce the cofferdam size

Normally, if a methanol tank is arranged in an enclosed space, IMO guidelines (MSC.1/Circ.1621)[13] require at least a 600-mm deep cofferdam around the methanol tank. However, novel insulation systems that have the same effect as a conventional cofferdam, but take up less space, are being introduced (see Figure 16).

These insulation systems can potentially be a good solution for maximizing the methanol tank capacity or reducing the retrofit work needed for the conversion. Because of their novelty, it is important to consider whether the basic requirements of the cofferdam space are met:

- Does the system permit leak detection?
- Does the system limit heat transfer?
- Can the system contain any leaks and safely neutralize the risk to the environment?

The application of a novel insulation system will require an assessment of the design considerations associated with heat transfer, inspections, and countermeasures for methanol leakage. To obtain flag state approval, the classification society and/

or the shipyard must establish a procedure to prove the equivalency to a conventional system to relevant authorities.

For a conventional cofferdam system, A-60 insulation should be provided for the steel wall between the cofferdam and the machinery spaces of category A/other rooms with high fire risks. If the conventional cofferdam system has a heat ingress prevention function equivalent to A-60, additional insulation is not necessary.

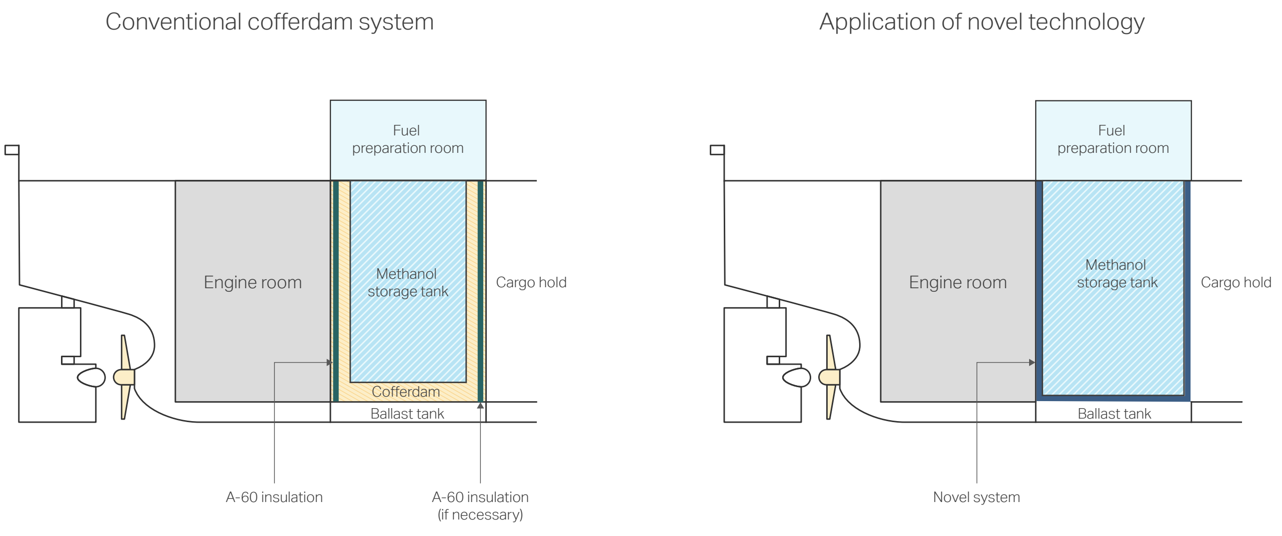
There will be some challenges during the design phase which are related to the integration of the novel system on board:

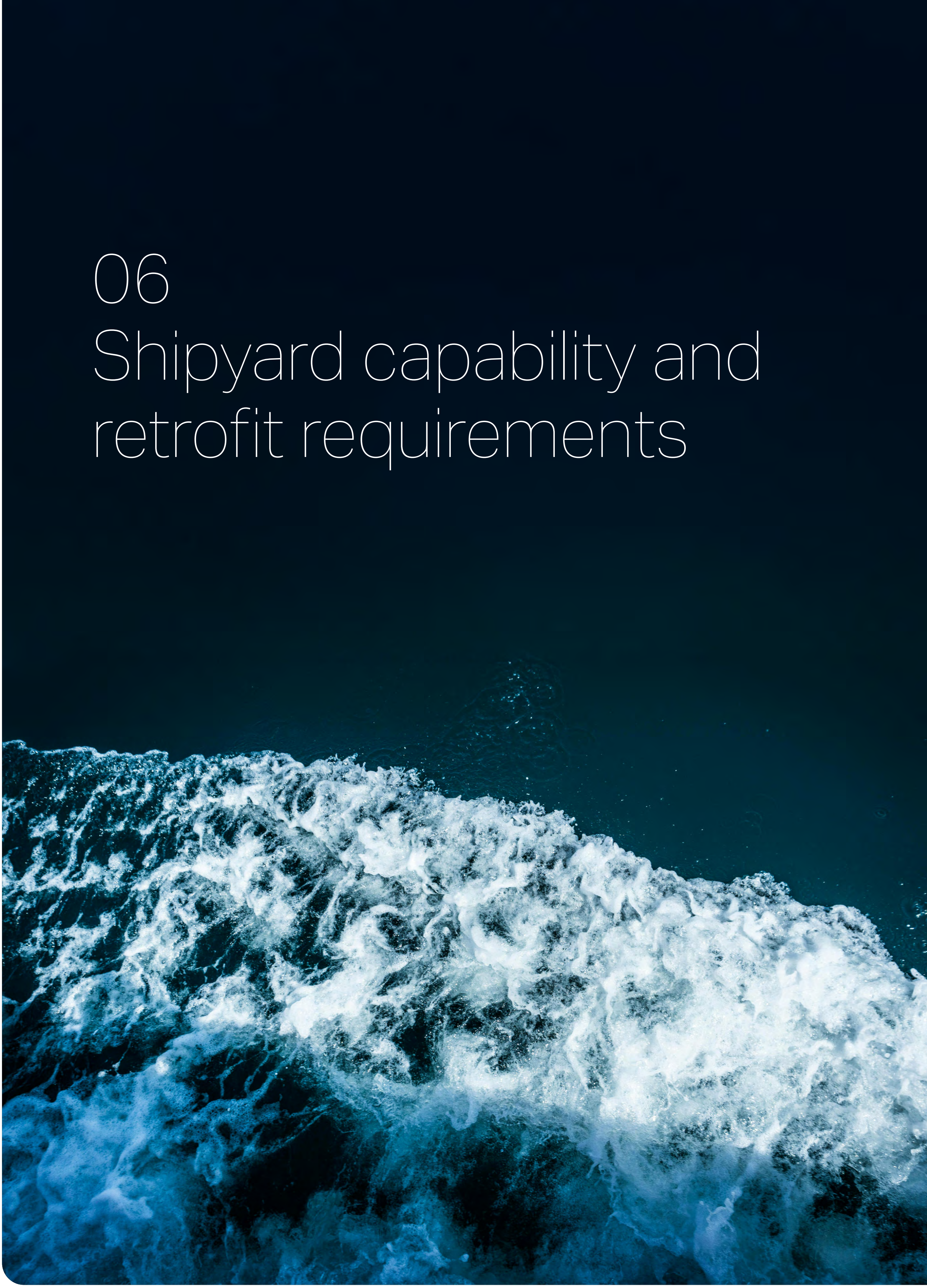
- Novel insulation systems are regarded as a deviation from MSC.1/Circ.1621 and require flag approval for an alternative design in accordance with the International Convention for the Safety of Life at Sea (SOLAS) II-1/55.
- The procedure for obtaining flag state approval in the specific project must be agreed between the system supplier/shipyard, the classification society, and the flag state.
- From a risk perspective, the function of the novel technology must be proven to be equivalent to a conventional system. This might require a definition of the purpose and function of the conventional system beforehand. A HAZID or Hazard and Operability Study (HAZOP) will be needed to address risks emerging from such an application.

For the first project applying the novel system, the following procedure can be considered:

- Determine the framework for proving the equivalence to the conventional system to manufacturer, shipyard, and classification society
- Obtain the flag approval for the framework
- Conduct the activity to prove the equivalence or risk assessment according to the approved framework
- Finalize the documents for submission to the flag
- Obtain flag approval of the finalized documents

Figure 16: Application of novel insulation system for a cofferdam around a methanol tank.





# 06
# Shipyard capability and retrofit requirements

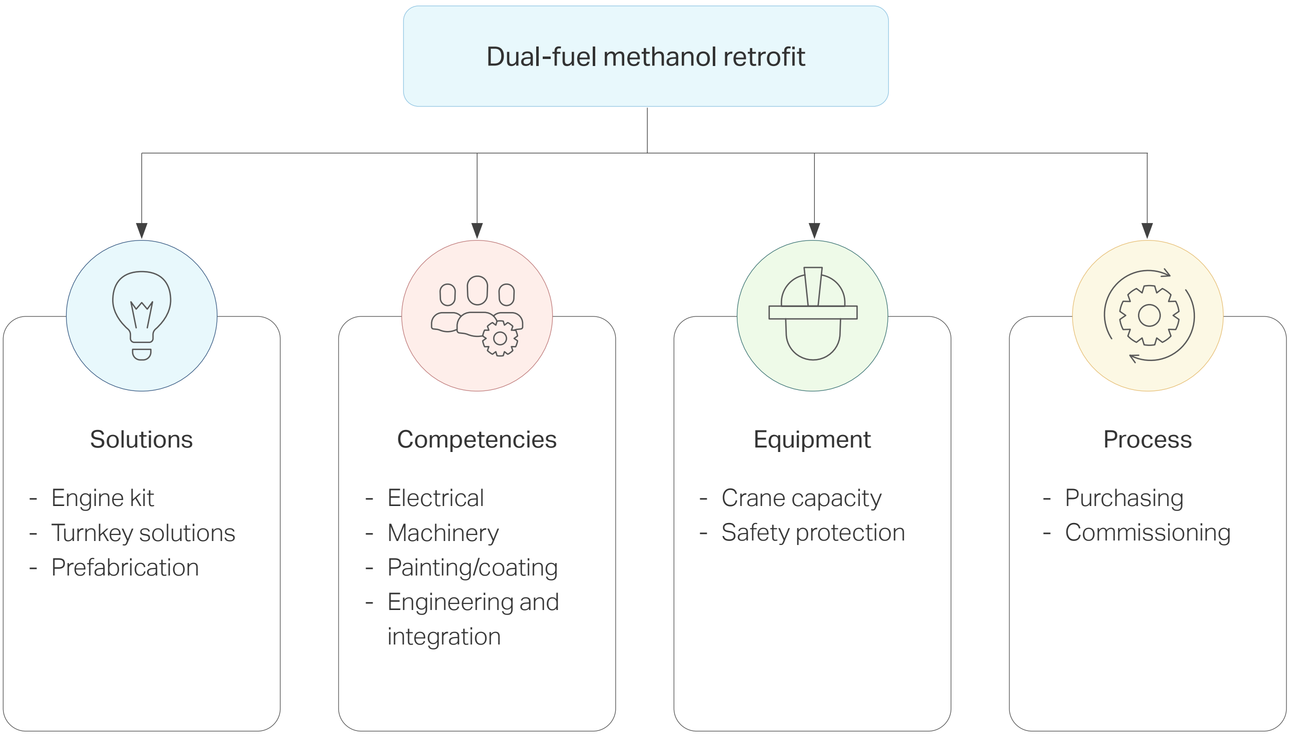
For a successful conversion to dual-fuel methanol operation, the shipyard must be able to integrate the new dual-fuel equipment on board.

Traditionally, retrofits are laborious and require an adequate supply of equipment and materials, as well as proper vendor management. Various challenges exist across the supply chain and at different levels of the retrofit, but, with appropriate planning and the necessary preparation and procedures in place, these can be overcome.

Figure 17 gives an overview of different practical elements required during the conversion process. These include engine expertise, engineering competencies, shipyard capabilities and equipment, and processes.

In the following subsections, we present and discuss the various elements needed to complete conversion of a vessel to methanol operation.

Figure 17: Requirements and capabilities needed for dual-fuel methanol retrofit.



## 6.1 Turnkey solutions

The process of converting a vessel to dual-fuel methanol operation is complicated. The shipyard must manage various vendors and parts, so good management and procurement skills are essential to keep costs low while ensuring a high quality. Proper management affects both costs and construction time, and also impacts the quality of the conversion.

## 6.2 Engineering capability

A conversion to methanol fuel operation means a significant change in the ship's weight. As a result, the vessel must adjust its loading conditions. To meet regulatory requirements, several calculation sheets, such as those related to longitudinal strength, stability, and equipment, need revision and approval from the classification society. If these calculations and revisions are undertaken by the shipyard, it is essential to have strong engineering capabilities available.

## 6.3 Crane lifting capacity

The shipyard must ensure that sufficient crane capacity is available, especially if the methanol tank is large. Results of a previous shipyard study shared with this project team showed that the weight of an on-deck empty tank with 1,000 $m^3$ capacity was more than 200 tonnes, and the compartment for FPR was more than 50 tonnes. If the tank weight is greater than the shipyard crane capacity, measures such as dividing the tanks might be necessary. However, this approach may extend the construction period.

The crane lifting height may also impact the construction period, depending on the conversion arrangement. Costs will also be impacted if a floating crane is needed for the conversion work.

## 6.4 Electrical and wiring capacity

In general, electrical and wiring work is carried out in the later stages of the retrofit work. Nevertheless, it is important to plan both the design and the installation to ensure that the conversion schedule can be followed and delays can be avoided.

Examples of design aspect planning:

- Investigate whether it is possible to add more electrical lines in the existing electrical piping. If not, plan the layout and routing of the additional electric cables.
- Investigate the equipment in the new gas hazardous zone. If an existing electric box is inside the gas hazardous zone, consider moving it away from the hazardous area or making the existing electric box gas-tight.

Examples of construction aspect planning:

- Estimate the cabling work needed for gas-tight penetration points and the use of insulated cables in gas hazardous areas – this may affect the daily cabling length capability.
- Plan for parallel work between cabling tasks and other construction activities, including estimating any extra time needed.

## 6.5 Coating capability

Strict cleaning and surface preparation is required for steel methanol tanks and existing tanks being converted to methanol tanks. The specific coating procedure depends on the paint used, and it is important that the shipyard has the necessary knowledge and experience.

## 6.6 Purchasing capability

Special equipment and systems are needed for the methanol conversion of the vessel. This includes an LFSS, an $N_2$ generator, and an alcohol-resistant fire extinguishing system. Accordingly, the ability to find and purchase such reliable equipment from manufacturers is key. Moreover, the shipyard must purchase methanol fuel in order to conduct the sea trial in methanol dual-fuel mode. The scope of the order may depend on the negotiations between the shipyard and the shipowner.

## 6.7 Engine integration

Before starting the engineering, work and preparing the methanol engine conversion kit, the engine manufacturer's team must complete an inspection and a 3D scan of the engine. This involves taking measurements and documenting the vessel that will undergo the conversion.

The shipyard chosen for the conversion project should have experience in overhauling methanol engines. It might also be necessary for the engine manufacturer to train the shipyard workers. In addition, engineers from the manufacturer will provide guidance and consultation to the shipyard workers during the engine conversion.

Once the engine conversion is complete, we recommend following these steps for commissioning:

1. **Quay trial:** Testing the engine while the vessel is docked.
   - Sea trial (fuel oil): Testing the engine at sea using fuel oil.
2. **Second fuel trial (dual-fuel methanol operation):** Testing the engine with methanol as a dual-fuel option.

## 6.8 Safety standards and protection

Methanol is flammable and toxic and may potentially cause an accident. The shipyard should have appropriate safety standards in place and sufficient experience with methanol handling.

## 6.9 Commissioning capability

Commissioning is a paramount element in ensuring that the methanol system will operate as planned. The sea trial therefore plays a key role in the main engine commissioning. The sea trial differs from normal dry docking work, and the shipyard should have the capability to perform sea trials to commission the converted propulsion system.

In some cases, a tank pressure test procedure should be included in the retrofit schedule. If seawater is used for pressure testing of large tanks, the salt contamination level of the tank should be monitored. If freshwater is used for the pressure test, the availability should be considered.

Furthermore, the handling of the water might be quite time-consuming if the tanks are large, and the fuel transfer pumps are relatively small. Hence, the vessel's pumping capacity should also be considered.

## 6.10 Prefabrication

Methanol retrofits require installation of several components and equipment, and it is therefore essential to evaluate how downtime can be reduced. Prefabrication is one effective solution, as it allows the construction work to start onshore before the vessel enters the dock.

To make prefabrication feasible, a number of studies are necessary:

- Maximum weight of the prefabricated component and crane lifting capacity
- Location of prefabrication work and transportation
- Installation procedure for the prefabricated component
- Scope of prefabrication

## 6.11 Summary of key shipyard capability requirements

### Turnkey solutions

Conversion work is complex and requires strong management to maintain the original design plan with high quality. Clear communication and control over the project timeline are essential.

### Engineering capability

The shipyard must have the capability to revise engineering and calculation documents to meet regulatory requirements, with classification society approval for the changes being a critical step.

### Crane lift capacity

Floating cranes may be needed if the shipyard's crane capacity or height is insufficient for the conversion. This impacts both cost and construction time, and planning around these constraints is essential.

### Electrical and wiring capacity

Electrical and wiring work occurs at the later stages of a retrofit. Delays here can push back the delivery date, so proper pre-planning and scheduling are key to staying on track.

### Coating capability

The shipyard must have the necessary procedures and equipment for proper methanol tank painting, especially in double-bottom spaces, where the work is intricate.

### Purchasing capability

The shipyard needs to be able to source methanol fuel and ensure reliable methanol-compatible equipment.

### Engine integration

The shipyard should have experience with methanol engines, although its workers may need additional training from the engine manufacturers.

### Safety standards and protection

The shipyard must develop specific safety standards for handling methanol during commissioning and sea trials to protect workers and the vessel.

### Commissioning capability

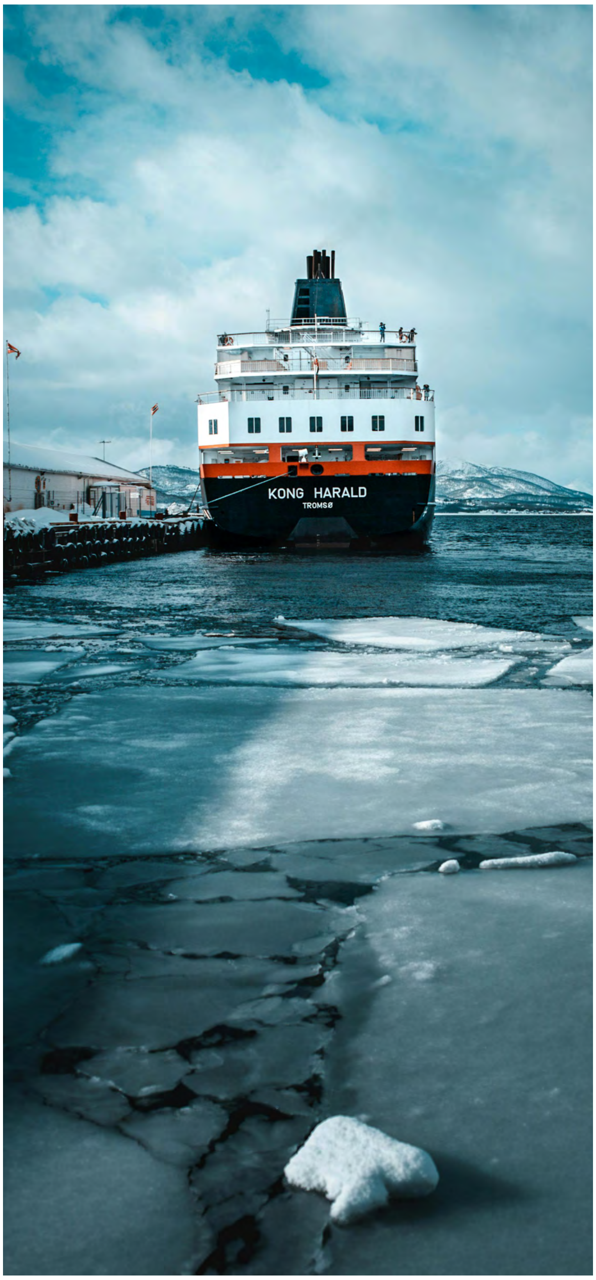
The shipyard should have the ability to conduct tank testing, commissioning, and sea trials to validate the retrofit.

### Prefabrication

Prefabrication can significantly reduce downtime, but careful planning and integration of prefabricated systems aboard the vessel are necessary to avoid complications.

# 07
# Summary and recommendations

Retrofitting ships for operation on methanol can allow the vessel to reduce GHG emissions and ensure compliance with future regulations. Methanol offers a technically feasible, cost-effective, and manageable transition fuel with fewer technical barriers towards installation and safety challenges compared to other alternative shipping fuels, such as methane or ammonia. While retrofitting to methanol is technically feasible for most vessel types, there are a number of considerations and constraints that need to be accounted for.




The design and space constraints related to retrofitting ships for methanol fuel need to comply with IMO IGF Code and MSC 1621 regulations. However, the IBC Code requirements for tank arrangements could be used to justify deviations, supporting alternative design approaches.

The methanol tank type and material should reflect the vessel's specific operational needs and budget constraints. Independent tanks offer simple retrofits, while integral tanks maximize fuel endurance with minimal structural changes, and portable tanks allow for flexible and rapid bunkering. Stainless steel provides longevity with higher upfront costs, while zinc-silicate-coated steel offers a budget-friendly alternative with more intensive preparation requirements.

The choice of methanol tank location must balance installation ease, stability, capacity, and cost. Open deck tanks offer simplicity and quick retrofitting, while cargo hold tanks improve stability but reduce cargo space, and double-bottom/side/topside tanks maximize capacity while maintaining cargo volume but involve complex preparation.

The bunker station design should permit methanol bunkering safely and efficiently with a vapor return fitted so venting is not required and should support safe gas freeing for dry docking.

Designing the tank size and position is critical and requires a balance between endurance, bunkering frequency, and cargo capacity. A comprehensive review is required to select the tank size that considers the vessel's expected operational profile and endurance.

Options to optimize cargo and tank capacity exist, such as lengthening the vessel, using ballast tanks as cofferdam or fuel tanks, and potentially the removal of the cofferdam space altogether. However, these solutions require rigorous design and planning.

Methanol fuel conversions are complex, requiring strong management, proficient engineering, and careful pre-planning to keep the agreed budget, quality, and schedule. Shipyards must be capable of handling specialized equipment procurement, electrical work, and strict coating procedures. Safety standards for methanol handling and collaboration with engine manufacturers are crucial for successful integration and commissioning, while prefabrication can significantly reduce downtime if thoroughly planned.

# 08
# The project team

This document was prepared by the Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping (MMMCZCS) with assistance from our partners. Team members marked with an asterisk (*) were seconded to the MMMCZCS from their home organizations. Special thanks to Seaspan for their kind contributions and information sharing.

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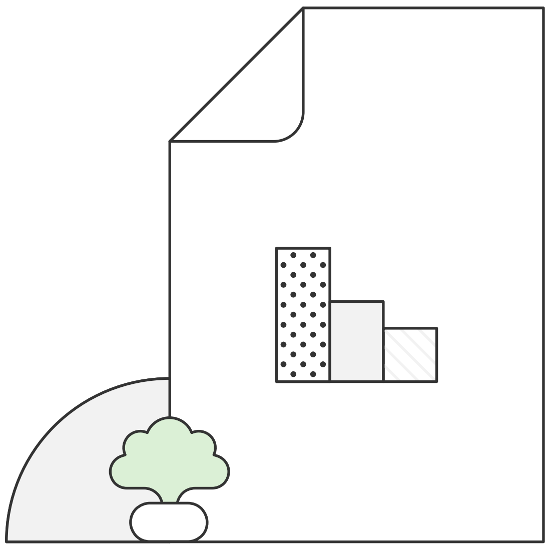

# Abbreviations

| | |
|---|---|
| ABS | American Bureau of Shipping |
| AE | Auxiliary engine(s) |
| BV | Bureau Veritas |
| CapEx | Capital expenditure |
| DNV | Det Norske Veritas |
| FBIVM | Fuel booster injection valves for injection of methanol |
| FPR | Fuel preparation room |
| FVT | Fuel valve train |
| GHG | Greenhouse gas |
| HAZID | Hazard Identification Study |
| HAZOP | Hazard and Operability Study |
| HFO | Heavy fuel oil |
| IACS | International Association of Classification Societies |
| IBC Code | International Code for the Construction and Equipment of Ships carrying Dangerous Chemicals in Bulk |
| IGC Code | International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk |
| IGF Code | International Code of Safety for Ships Using Gases or Other Low-flashpoint Fuels |
| IMO | International Maritime Organization |
| KR | Korean Register |
| LCA | Life-cycle assessment |
| LFL | Low-flashpoint liquid |

| | |
|---|---|
| LFSS | Low-flashpoint fuel supply system |
| LNG | Liquefied natural gas |
| LR | Lloyd's Register |
| LR2 | Long-range 2 [tanker] |
| MGO | Marine gas oil |
| MMMCZCS | Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping |
| MSC | Maritime Safety Committee |
| $N_2$ | Nitrogen |
| NM | Nautical mile |
| OCIMF | Oil Companies International Marine Forum |
| SIMOP | Simultaneous Operations |
| SOLAS | International Convention for the Safety of Life at Sea |
| TCS | Tank connection space |
| TEU | Twenty-foot equivalent unit |
| TTW | Tank-to-wake |
| VLCC | Very large crude carrier |
| VLSFO | Very low-sulfur fuel oil |
| WTW | Well-to-wake |

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# Appendix A- Comparison of MSC.1/Circ. 1621 and IBC Code

Table 9: Comparison of requirements for methanol fuel and methanol cargo tanks in MSC.1/Circ. 1621 and the IBC Code.

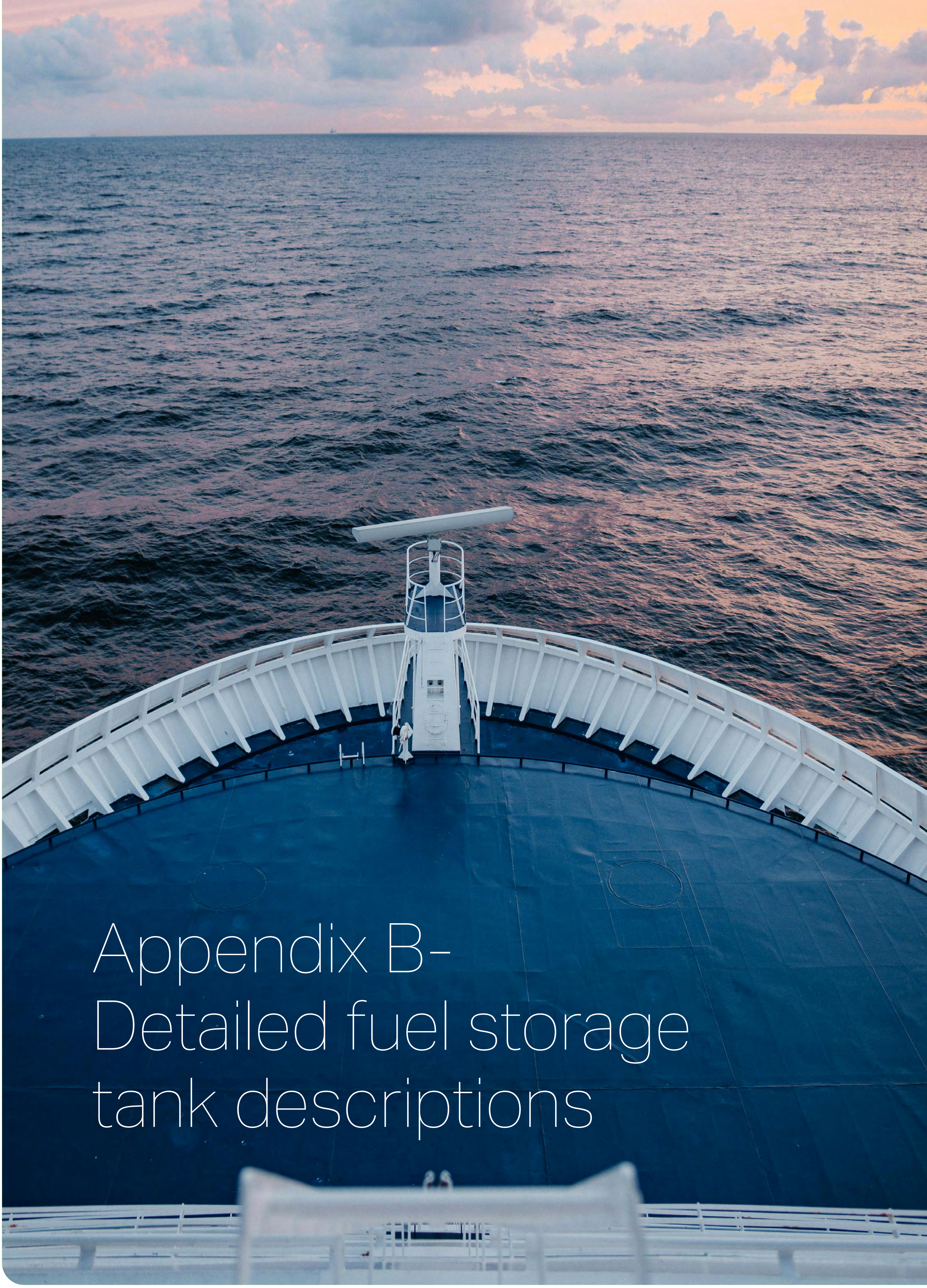
| Item | MSC.1/Circ.1621 | IBC Code |
|---|---|---|
| Material and coating | - No significant difference between MSC.1/Circ.1621 and IBC Code.<br>- In many cases, carbon-manganese steel is used for methanol fuel tanks, which are coated with inorganic zinc. | |
| Location and arrangement | - The fuel containment system should be abaft of the collision bulkhead and forward of the aft peak bulkhead. (5.3.3)<br>- Integral fuel tanks should be surrounded by protective cofferdam. (5.3.2)<br>- Fuel tanks on open decks should be surrounded by coamings and spills should be collected in a dedicated holding tank. (5.3.5) | - Cargo tanks are to be segregated from accommodation, service and machinery spaces and from drinking water and stores for consumption by means of cofferdam, void space, cargo pump room, pump room, empty tank, oil fuel or other similar space. (3.1)<br>- Continuous coaming of suitable height is to be fitted to keep any spills on deck and away from the accommodation and service areas. (3.7.7) |
| Venting system | - Height of fuel tank vent: 3 m (6.4.7)<br>- Exhaust opening: 10 m from the air intake or opening to accommodation and service spaces and ignition source. (6.4.7) | - Height of fuel tank vent: 6 m (8.3.4)<br>- Exhaust opening: 15 m from the air intake or opening to accommodation and service spaces. (15.12.1.3, requirement for toxic products) |
| Gas free vent | - Height of fuel tank vent: 3 m above the deck (6.4.10)<br>- Underwater discharge is permitted. | - Height of fuel tank vent: 2 m above the cargo tank deck level. (8.6.1) |
| Level indicators | - 2 closed devices unless any necessary maintenance can be carried out while the fuel tank is in service. (15.4.1) | - 1 closed device. (13.1.1) |
| Level alarms | - Independent high-level alarm and high-high-level alarm. (15.4.2)<br>- A high-high-level sensor actuates a shut-off valve. (15.4.2) | - Independent high-level alarm and overflow (high-high-level) alarm. (15.19)<br>- An overflow (high-high-level) sensor activates the shutdown of onshore pumps or valves or both and of the ship's valves. (15.19) |

Table 10: Comparison of requirements for loading equipment for methanol bunkering and cargo loading in MSC.1/Circ. 1621 and the IBC Code.

| Item | MSC.1/Circ.1621 | IBC Code |
|---|---|---|
| Bunkering station | (8.3/8.4)<br><br>- Open deck with sufficient natural ventilation.<br>- Safe management of fuel spills.<br>- Connection part: dry breakaway coupling/quick connect-disconnect coupler.<br>- Emergency showers and eye wash stations.<br>- Openings to accommodation, service and machinery spaces and control stations should not face the bunkering station. | (14.3.4)<br><br>- Emergency showers and eye wash stations. |
| Bunkering system | (8.5)<br><br>- Means for draining from the bunkering line.<br>- Inerting and gas-freeing arrangement (when not engaged in bunkering, the bunkering line is free of gas).<br>- A manual and remote valve fitted as close to the connection point.<br>- A ship-shore link.<br>- Not to be led directly through accommodation, control stations or service spaces.<br>- In non- hazardous enclosed spaces, bunkering line should be double-walled/in ducts. | (5.6)<br><br>- A manual valve.<br>- Emergency stop button for cargo pump without emergency shutdown link to shore.<br><br>(15.12.2)<br><br>- Vapor return line shall be provided (requirement for toxic products). |

Table 11: Comparison of requirements for inspection.

| Item | Methanol-fueled ships (IGF Code ships) | Methanol carriers (IBC Code ships) |
|---|---|---|
| Survey item | Survey items for IGF code ships are applied.<br><br>- Administration specific requirements | Survey items for IBC code ships are applied.<br><br>- Administration specific requirements |



# Appendix B- Detailed fuel storage tank descriptions

# Tank options

## Independent tanks

- Independent tanks can be prefabricated before the vessel enters the dry dock.
- Prefabricated independent tanks can reduce the installation work and off-hire time.
- An independent tank requires more steel, adds more weight, reduces the deadweight capacity, and positioning the tank on the deck impacts stability, potentially reducing the load ability, as well as increasing the gross tonnage of the vessel.
- The bulkhead of accommodation facing the independent tank must be fitted with A60 insulation in accordance with the IMO guidelines.[12]

### Summary

Easy installation work and reduction of off-hire time but requires more steel weight, which in turn reduces deadweight capacity.

## Integral tanks

- For vessels with limited free space, an integral tank is an option to get enough tank capacity for the required endurance, considering the vessel operation route, at the expense of other fuel tanks and/or cargo carrying capacity.
- This tank configuration uses the existing hull structure as the tank boundaries, or to support the tank boundaries, and reduces the additional quantity of steel required compared to an independent tank.
- Integral fuel tanks need to be surrounded by protective cofferdams, except on those surfaces bound by shell plating below the lowest possible waterline, other fuel tanks containing methyl/ethyl alcohol, or fuel preparation space.
- A cofferdam surrounding the integral tank is required in accordance with the IMO guidelines.[12]

### Summary

Integral tanks offer the possibility to get enough fuel endurance and reduce the additional quantity of steel work. On the other hand, they reduce the existing tank capacity, such as fuel oil or ballast water, or cargo hold capacity.

## Portable tanks

- A portable tank can be categorized as an independent tank. In general, the concept is that the tank size is small, the vessel has multiple tanks, and they are removable.
- The advantage is reducing bunkering time by exchanging the empty tank on board and the prefilled tank onshore.
- Each small tank has boundary walls, and the weight becomes relatively high. This solution is therefore not suitable for a large capacity.
- Specific connect/disconnect equipment is necessary for securing the tank and each line.

### Summary

Portable tanks are easy to convert and reduce bunkering time at the cost of losing deadweight. They are not suitable for large capacity.

# Tank locations

## Open deck

The open deck has the most potential space for an additional methanol tank if there is enough free space. This solution has no impact on cargo carrying volume and offers easy installation.

It is necessary to check obstacles to the visibility and cargo handling. If a high tank is arranged on the cargo deck, the cargo loader may be required to lift up and have more loading time, which can have a negative impact depending on the port facilities' capability.

A heavy fuel tank arranged on open deck causes worse stability. It is necessary to check if the post-conversion stability is acceptable.

Independent tanks on open deck need not be surrounded by a cofferdam. However, if a cofferdam is provided, the hazardous area can be limited, and the following items can be omitted:

- Water spray system for exposed tank surface
- A-60 insulation for wall of accommodation, machinery space, etc. facing the tank. It would be hard work to remove the existing modular panel and add A-60 insulation on the steel wall.
- Drip tray below the tank.

Tank connection space is not necessary.

Disadvantages

- Stability
- Hazardous zone around the tank

Advantages

- No need for a cofferdam structure or tank connection space
- Prefabricated tank
- No effect on cargo volume
- Easy installation

## Cargo hold (independent/integrated)

A large-capacity methanol tank can be arranged in the cargo hold.

Compared with an open-deck arrangement, the center of gravity of the tank is lower, leading to better stability.

Due to a decreased cargo volume, an economic feasibility study is necessary prior to conversion.

Normally, the cargo hold is an enclosed space. To arrange a methanol tank in the cargo hold, the steel plate or the independent tank should be brought into the cargo hold via a hatch opening. This requirement may limit the methanol tank volume. If the vessel has a small hatch opening, or no opening, such as tankers, the outer hull or upper deck steel plate might need to be cut, and this may impact retrofit work.

Disadvantages

- Reduce cargo volume
- Hard retrofit work might be required

Advantages

- Stability
- Large tank volume

## Double-bottom/side/topside tank (integrated)

A large-capacity methanol tank can be arranged as an integrated tank.

If the tank location is under the water line, a cofferdam is not necessary towards the outer hull, and the tank can be larger.

Fuel oil or ballast water will be reduced, so endurance, trim, draft, etc. should be checked.

The coating procedure should be considered. In general, strict cleaning and surface preparation are required for methanol tanks. An existing double-bottom/side/topside tank may have a narrow area with many ribs, which may cause a big impact to retrofit work.

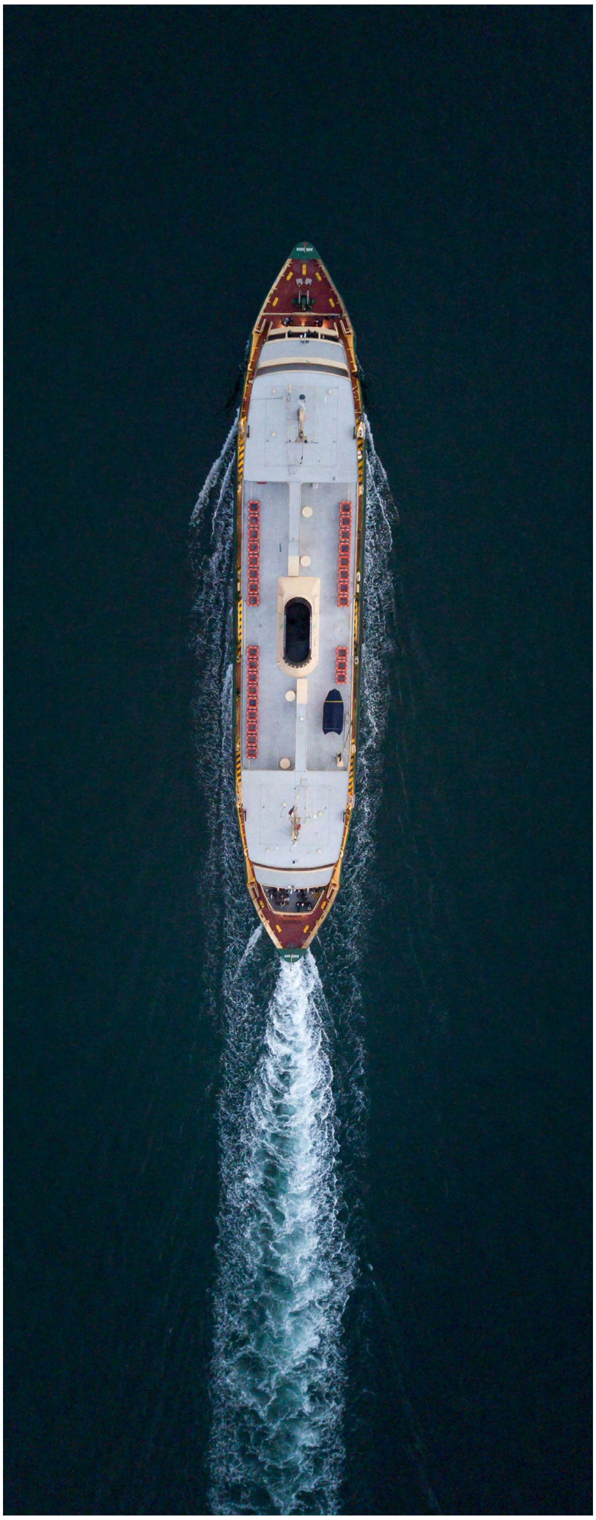
Existing tank walls can be utilized for methanol tanks. This may have less impact on deadweight compared with other arrangements.

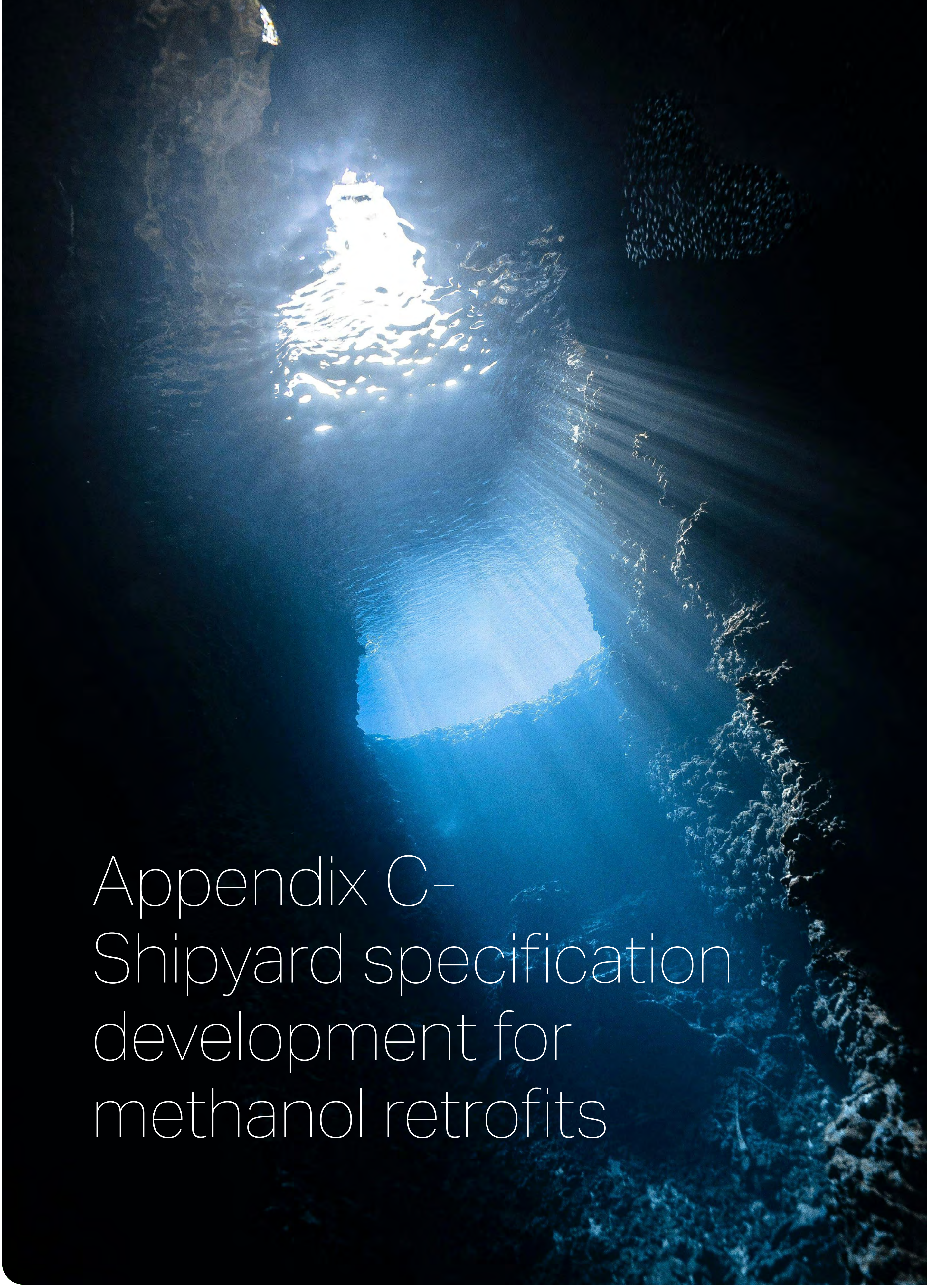
Disadvantages

- Hard retrofit work, especially for coating
- Reduction of fuel oil or ballast water
- Difficult to strip the low-level fuel

Advantages

- No need for a cofferdam structure between outer hull and methanol tank if outer hull is underwater
- Large tank volume
- No effect on cargo volume
- Smaller decrease in deadweight relative to other arrangements





# Appendix C- Shipyard specification development for methanol retrofits

The shipyard specification should include the main chapters:

## General

### Materials and workmanship

- Specify class-certified shipbuilding standard equipment to be used.
- Specify applicable steel standards as needed.

### Classification

- Specify the class to be used for the conversion and the required notation.
- Define whether the conversion is considered a major conversion or not. A major conversion would make new rule requirements applicable. It is recommended to discuss with the class whether the planned retrofit constitutes a major conversion.
- Specify that the integrator is responsible for obtaining class certification and provision of necessary documents, drawings, inspections, and certification.

### Flag

- Define the flag the vessel will be registered with and who will maintain this through this conversion.

### Principal particulars

- Specify the principal particulars of the conversion. These can include tank size, vessel main particulars, main equipment specification, cargo capacity, methanol fuel consumption, power generation, and navigation equipment.

### Documentation

- Specify who will be responsible for the documentation. Define the list of the owner's required documents for owner's review and comments. Specify the document management control system to be used. Define the IP owner of the documentation. Requirements for hard copies on board the vessel to be requested.
- Specify all documents to be provided before delivery of the vessel from the shipyard.

### Supervision, testing and trials

- Specify all newly added equipment to be adequately tested. Hull part items to be tested according to class requirements.
- Adequate notice to be provided. Request pipe cleanliness by endoscope before tightness test.
- Sea trials are expensive considering the fuel and time required. Detailed discussion and agreement with the yard and original equipment manufacturer (OEM) on what is required for the sea trial and how long the sea trial will take. It is advantageous to include the class in the requirements to ensure that all relevant certifications can be achieved.
- Lightweight to be re-estimated considering the additional equipment. Specify revision and preparation of revised trim and stability booklet if the lightweight changes are significant enough to trigger recalculation. Request revised inclining test as required by class. Specify that adequate notice is to be provided.

## Hull structural part

### Tank modification

- Specify the methanol tank position, required tank size and tank configuration.
- Specify changes to the heavy fuel oil (HFO) tank arrangement and required tank size, if applicable.
- Specify changes to cargo hold and cargo operation equipment, if applicable.
- Specify required cargo capacity and operational aspects (required operational aspects).

## Outfitting, hull piping and accommodation part

Bunker hose davit for bunker station
- Specify the davit requirements to allow the connection of the bunker hoses (safe working load (SWL) requirements).

Maintenance access and platform for vent mast
- Require structure to permit access to vent mast for maintenance. Request vibration analysis.

Fire protection partition and insulation
- Require compliance with SOLAS requirements.

Weight and center of gravity change
- Lightship to be reassessed. The change is expected to trigger an inclining test and revised loading manual. Refer to class for weight change which would trigger this.

## Machinery part

General equipment
- Items to be converted to be listed.

Main engine
- Description of the main engine spec and the converted main engine specification. OEM to support with population. Items will include exchanged main engine parts, new parts, yard scope items for machinery and sea trial, lubricating oil equipment, sealing oil system, panel equipment, gas detection systems, and information on the fuel tests to be clarified.

Methanol tank layout
- Describe the main requirements of the methanol tanks and the changes to the existing tanks as applicable.

System description
- Describe information on the methanol filling and transfer system, methanol service system, drain system, nitrogen system, vapor system, cooling water system, and ventilation system.

## Electrical part

Methanol fuel control and monitoring system
- Describe the alarms and transmitters needed to control and monitor the methanol fuel system.

Methanol fuel safety system
- Describe the alarms required for the safety system.

Methanol gas detection and alarm system
- Describe sensors, detectors, and alarms for the methanol gas detection and alarm system.

Fire detection for methanol retrofit
- Describe the specifications of smoke and fire detectors and positions.

$CO_2$ release alarm system
- Specify the $CO_2$ firefighting equipment required.

Fixed firefighting system
- Describe the type of firefighting system required.

Monitoring and alarm system
- Describe alarm points required to be added to the existing system.

Cargo-related items
- Describe the cargo impact and requirements imposed due to hazard zones, e.g., reefer slots.

## Methanol fuel containment system

Methanol fuel storage tank
- Table of the methanol tanks showing size, shape, and position.

Methanol fuel service tank
- Table of the methanol fuel service tank showing size, shape, and position.

Methanol tank structure
- Description of tank type, cofferdam requirements, access requirements, flooding, and inspection.
  - Description of the analysis to be completed (strength and fatigue), description of the testing plan, non-destructive testing and continuous monitoring plan.

### Methanol tank painting

- Describe inorganic zinc silicate paint for the tank. Details to be discussed with paint supplier.

### Methanol fuel tank vent system

- Describe the requirements, hazard zones, overpressure and vacuum valve types, and pressure limits for the methanol fuel storage and service tanks, the main methanol drain tank, and cofferdams/voids surrounding the methanol fuel tank. Pressure drop to be calculated by the yard.

## Methanol bunkering and transferring system

### Methanol bunkering system

- Specify a bunker station to be positioned on both port and starboard side. Description of the number of liquid lines and vapor return lines.

### Methanol bunker station

- Describe the bunker station location, the drip tray requirements, the number of manifolds, railing requirements, quick connect-disconnect coupler requirements, compressed air, freshwater, firefighting equipment, and the nitrogen systems.

### Methanol transferring system

- Describe the pump requirements, flow rates, size, and type.

### Tank crossover

- Specify whether the tank should include a tank crossover system to permit transfer of fuel between the different methanol tanks. Size and flow rates to be specified.

## Methanol fuel supply system and equipment

### Methanol supply system

- Describe items related to fuel conditioning, fuel safety management, and fuel provisioning.

### Methanol fuel supply equipment

- Describe the transfer pump, supply pump, service pump, fuel heat exchanger, circulating pump, and flow meters for the methanol and glycol systems.

## Nitrogen and inert gas system

### Nitrogen system

- Specify the nitrogen system requirements (generators, air compressors, air dryers, capacity, type, and purity requirements).

### Methanol tank blanketing top-up and piping inert/purge system

- Describe the inerting philosophy of the system.
- Describe the inerting gas for the methanol tanks and service tanks. Define the flooding requirements for flooding the cofferdams and void spaces surrounding the methanol tanks.

## Piping

Describe the piping requirements, including double-walled pipe requirements for safe spaces, valve type, material requirements of the piping components, and piping material and thicknesses of the piping.

## Safety system

### Description of the safety systems including:

Gas detection system and portable measuring instrument

- Emergency shutdown system.
- Ship-shore/ship-ship emergency shutdown link or bunker vessel.

## Monitoring system of methanol tanks

- Level gauging system
- Pressure measuring system.
- Temperature measuring system.
- Automation, alarm, and communication system.

## Fire extinguishing system and fire insulation

- Fixed fire extinguishing system
- Fire insulation
- Fire detection system
- Personal safety and protective equipment

## Hazardous bilge and drain system

- Hazardous drain system
- Hazardous space bilge system
- Bilge discharge system
- Local collection system
- Hazardous cofferdam discharge system
- Bunker station spill trays

## Mechanical ventilation system

- Ventilation for nitrogen generator room
- Ventilation for fuel preparation room
- Ventilation for tank connection space
- Ventilation for bunker station
- Ventilation for air locks
- Ventilation of double wall piping and duct

## Tank ventilation, vapor and tank pressure control system

- Manual pressure relief system
- Bunker vapor return
- Emergency pressure relief
- Cofferdams and voids surrounding methanol tanks

## Electrical and control system

- Safety and pressure control system
- Engine control console
- Bridge control console
- Methanol changeover system
- Overall function of integrated control and monitoring system

## Tests

- Main engine
- Onboard tests
- Sea trial tests

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