Methanol in shipping

MAN Energy Solutions
Future in the making

Marine Four-Stroke

Global shipping has entered a transition phase. A phase where well-known certainties are being questioned and future pathways, technical alternatives, and bunker fuel options appear to be diverse and opaque at the same time. All of this is happening against the backdrop of global warming and ever more stringent emission rules and regulations.

In this technical paper, MAN Energy Solutions provides some insights, guidance, and technical answers relating to one of the fuel options that is increasingly being discussed and considered as an alternative shipping fuel – methanol (MeOH).

It is worth remembering why there is a need to replace current conventional, i.e. fossil, fuels in shipping. According to the third IMO GHG study, shipping is responsible for at least 2.5% of global greenhouse gases (GHG), amounting to 940 million tons of CO2 per year. GHG emissions in turn lead to global warming. At the same time, the UN Framework Convention on Climate Change predicts that the planet is on a pathway to 2.7 degrees of heating by the end of this century, which will result in rising sea levels and flooded areas, more deserts, and in general more uninhabitable space. So the question is whether it is reasonable to continue using current fossil fuels to fuel shipping. Obviously not. This is why MAN Energy Solutions with its decarbonization strategy is working hard towards net zero with its propulsion technology portfolio. More sustainable fuels from biogenic or synthetic sources – such as blue and green variants of methanol – will be able to support this sustainable transition in shipping.

1. Characteristics of methanol

Methanol, also known as CH_3OH and MeOH, occurs naturally in fruits, vegetables, fermented food, and beverages, the atmosphere, and even in space. It is one of the four critical basic chemicals (alongside ethylene, propylene, and ammonia) and is used to produce all other chemical products such as formaldehyde, acetic acid, and plastics. MeOH is used for gasoline blending (it has been used as an oxygenated anti-knock fuel additive and octane booster), and for the production of biodiesel and DME (dimethyl ether).

Methanol is a colorless water-soluble liquid with a mild alcoholic odor, with the highest hydrogen-to-carbon ratio of any liquid fuel at regular ambient conditions. Hence it can be a key energy carrier and used as an alternative shipping fuel. It is a low-viscosity fuel (like ammonia), i.e. (a) MeOH has a low calorific value (e.g. 40% of diesel), meaning that more fuel is needed for the same power output and (b) MeOH has poor ignitability, meaning that diesel pilot fuel is required for stable engine operation.

It can be used both in a diesel and Otto combustion cycle and its efficiency is similar to that of current dual fuel (DF) engines. Since methanol can be stored at room temperature and ambient pressure with an indefinite shelf life due to its stability, it comes very close to a drop-in fuel that is compatible with existing infrastructure. However, there are downsides, e.g. its toxicity and the resultant increasingly complex safety systems, as well as its corrosive behavior. The most relevant benefits and challenges are listed in the overview below:

Boiling (freezing) point	65 °C (-97.6 °C)
Octane number	110
Calorific value (LHV)	19.9 MJ/kg (compared to 50 MJ/kg for CH_4 and 120 MJ/kg for H_2)
Ignition temperature	470 °C (auto)
Density	791 kg per cubic meter (at 20 °C)

Benefits:
- Liquid state in ambient conditions, i.e. close to a drop-in fuel to be used in existing infrastructure
- Lower local emissions (and lower GHG on well-to-wake basis when green MeOH is used)
- Easy to handle, stable with indefinite shelf life
- Mature production processes (industrial scale)
- Advanced bunkering infrastructure (cf. alternatives)
- Regulatory acceptance under IGF Code (IMO interim guidelines as of Nov 2020) and class/bunkering guidelines
- Water-soluble, readily biodegradable
- Molecular structure (nearly soot-free combustion)
- High octane number (RON 109, high efficiency)
- High flame velocity (less knocking behavior)
- Low flame temperature (less NO_x during combustion)

Challenges:
- Carbon footprint, requires synthetic/green PtX production pathway -> lack of green supply and CO_2, high fuel costs
- Competition for renewable feedstock and with other sectors as outlets
- Toxic, can be lethal if ingested
- Highly flammable (burns with a non-luminescent flame)
- Safety system more complex than conventional fuels
- Lower energy content/volumetric caloric value (2.25 times the mass needed)
- Low viscosity (injection system design, leakage, lubrication)
- Corrosive behavior (leakage, sealing, etc)
- Less ignitable (ignition delay, explosive mixture formation, etc)
- Can absorb moisture from the atmosphere

When discussing the emission profile of shipping fuels, these are usually subdivided into well-to-wake (WtW) and tank-to-wake (TtW) emissions. There are accepted calculation standards in place for life-cycle assessments (LCA), e.g. the European Union has a standardized method for the evaluation of GHG in biofuels, and default GHG factors for the different shipping fuels are defined in the current FuelEU Maritime legislative proposal.

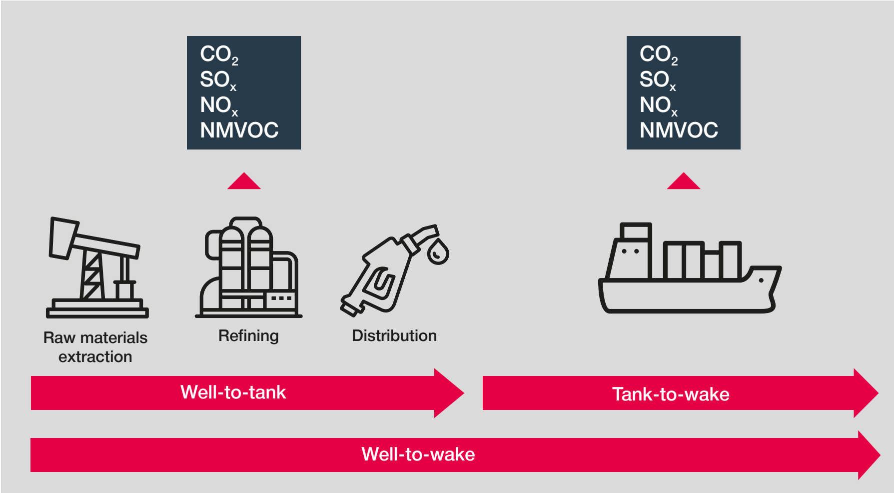
WtW covers the whole chain (upstream and downstream) and allows for net-zero emission profiles with biogenic or synthetic sources. TtW only looks at tailpipe emissions and allows for zero with non-zero emission profiles.

For local emissions, with methanol we can assume a TtW reduction of 99% (SO_x), 60% (NO_x, assuming port fuel injection technology), and 95% (PM) respectively, when compared to fuel oil.

For GHG emissions, namely CO_2, on a TtW basis we see a reduction of only 5%. When we consider WtW, this depends on the feedstock and production pathway – methanol from fossil sources will have a significantly worse footprint, but biogenic and synthetic methanol (i.e. renewable energy plus green hydrogen plus CO_2 from biogas or direct air capture) could achieve GHG savings on a WtW basis of up to 90%.

This makes it clear that, in order to reduce global GHG emissions, shipping needs to aim for synthetic ("green") methanol – with blue methanol or hybrids such as low-carbon methanol as an intermediate step. This, as a side note, will also help operators with their operational costs and their license to operate, as fossil fuels are increasingly being regulated and taxed/penalized. Current methanol production pathways, which are 65% from natural gas ("gray") and 35% from coal ("brown"), will not get us there.

Life-cycle emissions – subdivisions



2. Methanol as a fuel (supply and demand, types, bunkering, and costs)

Methanol production in 2020 stands roughly at 100 million tons per year (mtpa), the actual capacity being 50% higher according to the Methanol Institute. Only 0.2% (200,000 tons) is being produced from somewhat sustainable sources, i.e. the ramp-up of green, blue, and hybrid methanol production pathways is still in its infancy – like the production pathways of its main competitors methane, ammonia, and hydrogen.

Capacity is expected to grow to potentially 500 mtpa by 2050 – depending on many other competing factors and with all the uncertainty that is involved. This increase in capacity is prevalent in regions with low-cost natural gas as a means to monetize stranded natural gas through methanol exports. IRENA estimated annual production of 250 mtpa of synthetic methanol and 135 mtpa of biomethanol by 2050. This translates to about 280 methanol plants with a capacity of 2,500 tons per day that will need to be constructed to produce 250 mtpa (of synthetic methanol). As a reference, a global-scale methanol plant typically has a capacity ranging from 1.5 to 2 mtpa, with estimated costs of approximately USD 1.5 to 2 billion, depending on the construction location.

The above might be the reason why we have not seen many FIDs on the production of synthetic methanol. One example though is in Denmark, where a sustainable fuel project aims to achieve an electrolyzer capacity of 10 MW by 2023, 250 MW by 2027, and 1.3 GW by 2030 respectively.

Most of the demand is absorbed by the chemical industry, with the largest outlets being formaldehyde at 25% and MTO (methanol-to-olefins) at 33%. Another outlet is the automotive industry, where methanol is used as an octane booster. Obviously, those industry segments are also pursuing a defossilization strategy – so there is an unanswered question about the competition for supply and the willingness to pay a premium for more sustainable fuels.

All these types of methanol can be blended, as the chemical is identical. Hence, in the future, guarantees of origin will become important for fuels in order to prove the source and carbon footprint of your fuel.

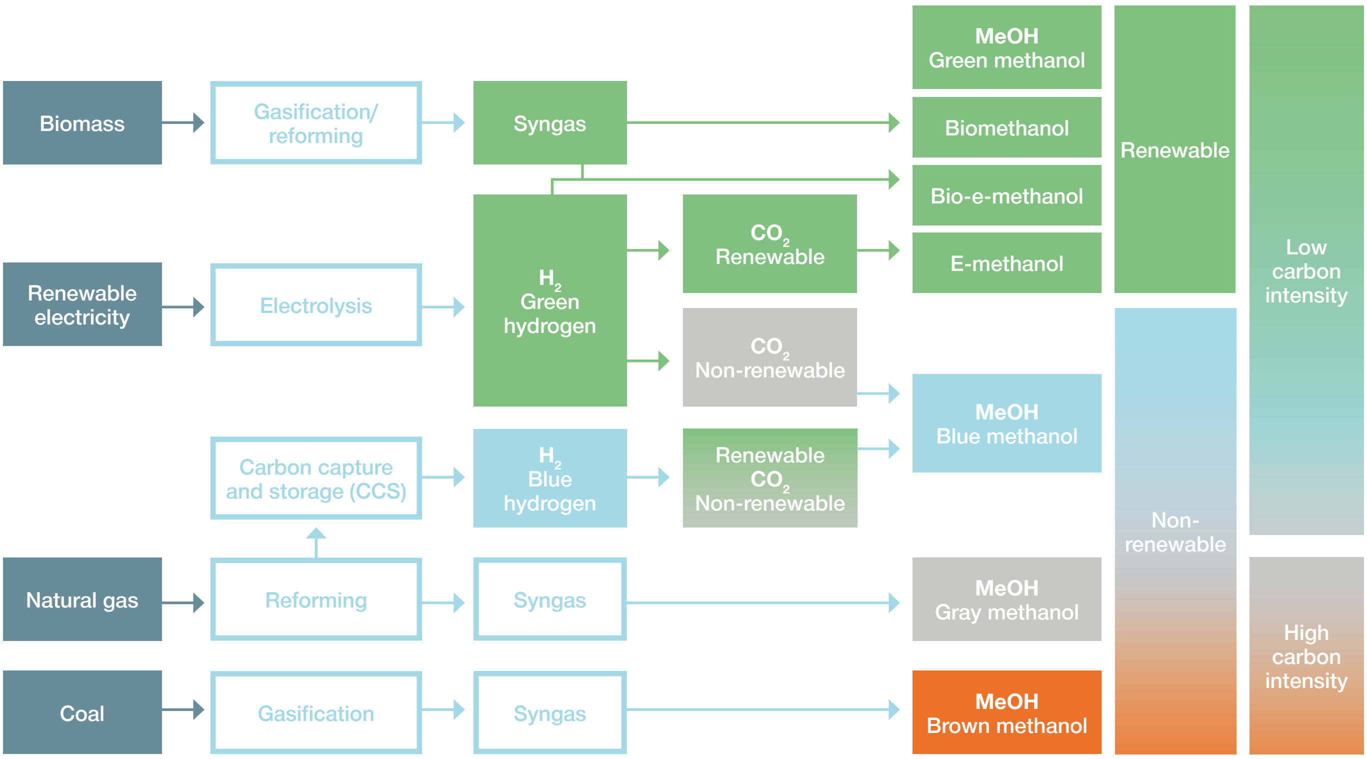
Without going into detail about the production pathways, it is worth noting that green, synthetic methanol is obtained by using CO_2 captured from renewable sources, i.e. bioenergy with carbon capture and storage (BECCS) or direct air capture (DAC) plus green hydrogen, i.e. hydrogen produced with renewable electricity. "Recycling" CO_2 from the exhaust of a plant for a second use will not be considered green methanol.

There are hybrid solutions using low-carbon methanol (LCM) processes by injecting CO_2 captured from an industrial facility into the methanol synthesis loop.

Fuel availability and bunkering capabilities play a decisive role when considering the use of alternative marine fuels. As a new shipping fuel – today only 20+ vessels use methanol as a fuel, mainly tankers burning their own cargo – the bunker supply chain naturally still needs to be developed. There are no dedicated bunkering vessels yet, but in 2021 the methanol producer Methanex conducted the first ship-to-ship bunkering operation in Rotterdam to demonstrate feasibility and safety procedures.

There are currently methanol depots in slightly over 100 global ports, which is, however, not at the same level as bunker locations. For this, some further upgrades and investments, such as a jetty or a local bunker barge, are still required. However, when compared to ammonia and liquefied hydrogen as

Methanol production pathways ©IRENA 2021



alternatives, this is more advanced. This "competitive edge" also holds true for the necessary guidelines, and the IMO's Maritime Safety Committee already adopted interim guidelines for methanol in 2020.

Commenting on future commodity prices is like looking into a crystal ball and predictions tend to prove wrong almost immediately – hence, we will only make a few general remarks about methanol costs here.

Methanol is being traded globally as a commodity; as such, there is an existing index/marker in place, with regional differences – data is publicly available from the usual sources and directly from energy companies. A rebate, plus any supply chain markups, will usually apply to that marker – depending on the operator's location, volume uptake, and negotiation skills. It is fair to assume that the supply chain markup will be higher than for conventional fuel/gas oil – but lower than for LNG, ammonia, and liquefied hydrogen.

Current public studies and assumptions, e.g. from IRENA, place production costs for methanol at 100–250 USD/ton (fossil), 320–770 USD/ton (bio) and 1,200–2,400 USD/ton (synthetic, estimated to decrease to 250–630 USD/ton by 2050).

Any future taxes, potential CO_2e penalties or potential reimbursements for differences via contracts will have to be considered in the equation accordingly.

3. (Methanol) shipping regulation

The global regulatory landscape is almost as diverse as the available fuel options. Not all of these are aligned or even compatible – and they are only in the process of evolving at the moment. This means that not only do operators need to prepare for a multi-fuel environment, they also need to get ready for a multi-regulatory environment, where the responsible party that pays for pollution might differ.

The IMO, as the global governing body, has seen some recent moves toward stricter regulation and policies, which will have an impact on costs and therefore choice and supply/demand balance of shipping fuels. Shipping is increasingly expected to play its part in meeting the Paris Climate Accord targets as the recent COP26 discussions have shown, e.g. in the Clydebank Declaration where more than 20 nations vowed to develop zero-emission shipping routes.

The industry itself has suggested setting up R&D funds to green the maritime operations with a USD 2 surcharge on any ton of fuel sold, a decision that has been postponed by MEPC77.

Regionally, the European Union has pushed ahead with its Fit for 55 regulatory proposal, which includes plans for an emission trading system for shipping, as well as the FuelEU Maritime legislation that aims to promote fuel demand in shipping and define fuel pathways based on the GHG intensity per fuel being used. Similar regulatory activities, albeit less ambitious ones, can be observed in China and the United States.

At the same time, ship owners have to manage the sustainability expectations of two other stakeholder groups: Cargo owners and their consumers, as well as investors and financial institutions.

The establishment of the Sea Cargo Charter and recent pledges by a new cargo owner-led network that is committed to switching all of its ocean freight to vessels powered by zero-carbon fuels by 2040 should make it clear that imminent action needs to be taken, for example via the use of net-zero versions of methanol.

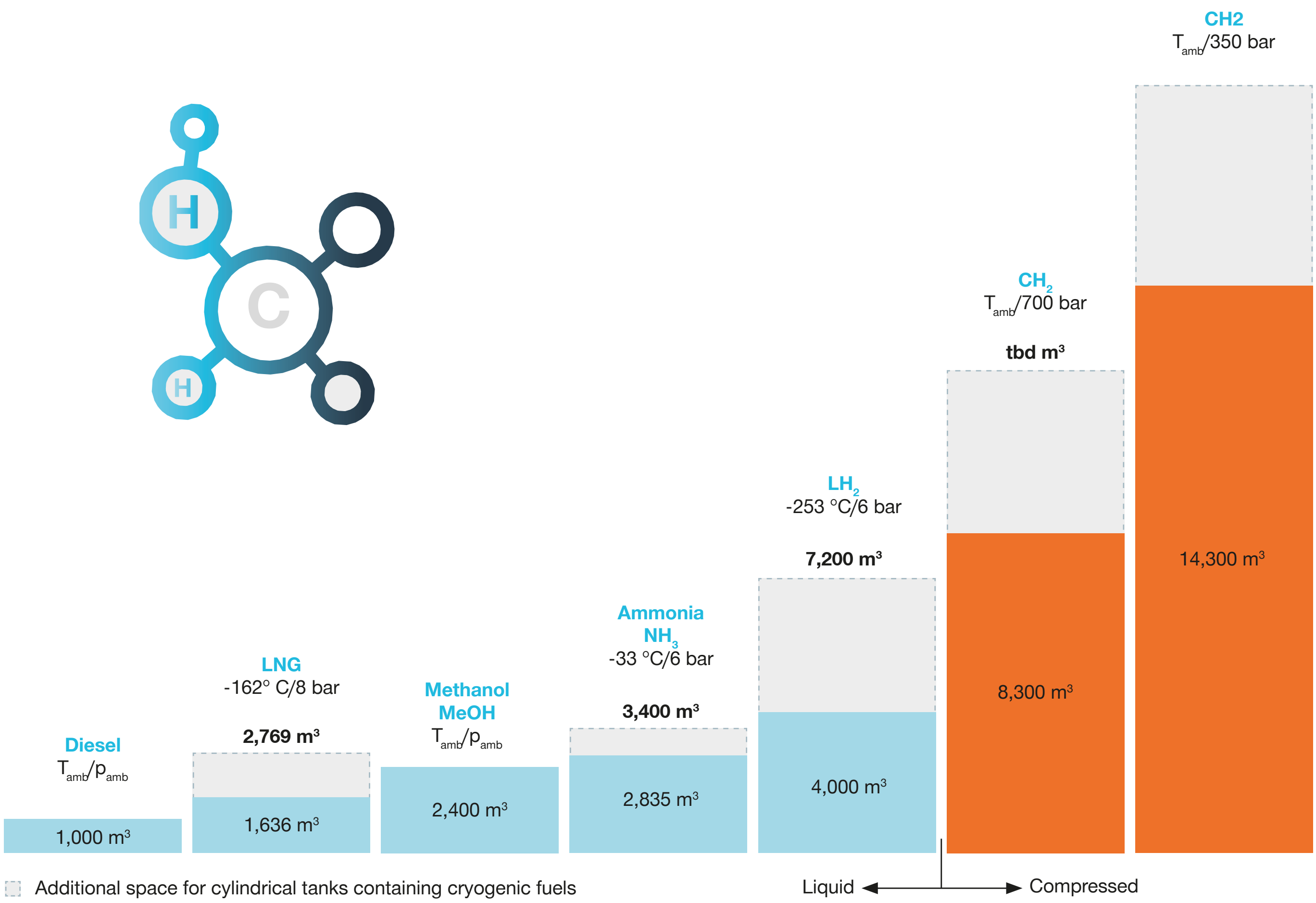
Finally, yet importantly, private capital lenders, e.g. banks that are part of the Poseidon Principles signatory group and EU governments that are bound by the EU taxonomy regime, are increasingly looking for green financing assets. The financial criteria for conventional assets are likely to become less preferential and access to capital might become restricted.

4. Storage (incl. tank size comparison for future fuels and impact on cargo space loss)

From a storage perspective, methanol is easy to handle compared to other future fuels discussed on the market. This is because there is no requirement for a cryogenic tank system or a pressure requirement to store methanol in a liquid phase. This allows methanol to be stored in almost any tank shape. As mentioned at the very beginning, the volumetric energy density of methanol is lower than diesel fuel by a factor of around 2.5. Therefore, to get the same amount of volumetric energy as with diesel, the amount of methanol stored on a vessel has to be increased by 2.5 times or, if an existing tank is reused, the operation range will be halved. From a safety point of view, the tank itself, as well as the pipes from the tank to the engine, have to be double-walled to ensure no leakages of methanol. Boil-off gas (BOG) management, as is standard practice for LNG installations, is not required for methanol.

Methanol in general is covered by the IGF Code and its annex for methyl alcohol (Interim guidelines for the safety of ships using methyl/ethyl alcohol as fuel). These rules specify provisions for the arrangement, installation, control, and monitoring of machinery, equipment, and systems using methanol as

Comparison of storage volume for the same energy amount



fuel to minimize the risk to the ship, its crew, and the environment. The hazardous area classification and safety distances are similar to LNG according to these rules.

5. MAN methanol solutions

5.1 MAN Energy Solutions two-stroke marine

MAN Energy Solutions developed the two-stroke ME-LGIM dual fuel engine for operation using methanol, as well as conventional fuel. The engine is based on the company's proven ME series, with its approximately 5,000 engines in service, and works according to the diesel principle. When operated using methanol, the ME-LGIM significantly reduces emissions of CO_2, NO_X and SO_X.

Additionally, any operational switch between methanol and other fuels is seamless. Tests on the engine, when running on methanol, have recorded the same or a slightly better efficiency compared to conventional, HFO-burning engines. (Figure 1)

MAN developed the ME-LGI engine in response to interest from the shipping world in operating engines using alternatives to heavy fuel oil. Methanol carriers have already operated at sea for many years using this engine, and, as such, the ME-LGIM has a proven track record in offering great reliability in combination with high fuel efficiency.

5.2 MAN Energy Solutions four-stroke marine

The various types of future fuels, e.g. methanol, ammonia, and hydrogen, and their market requirements in terms of fuel availability, prices, and regulations require different technologies for the injection and combustion of large four-stroke engines.

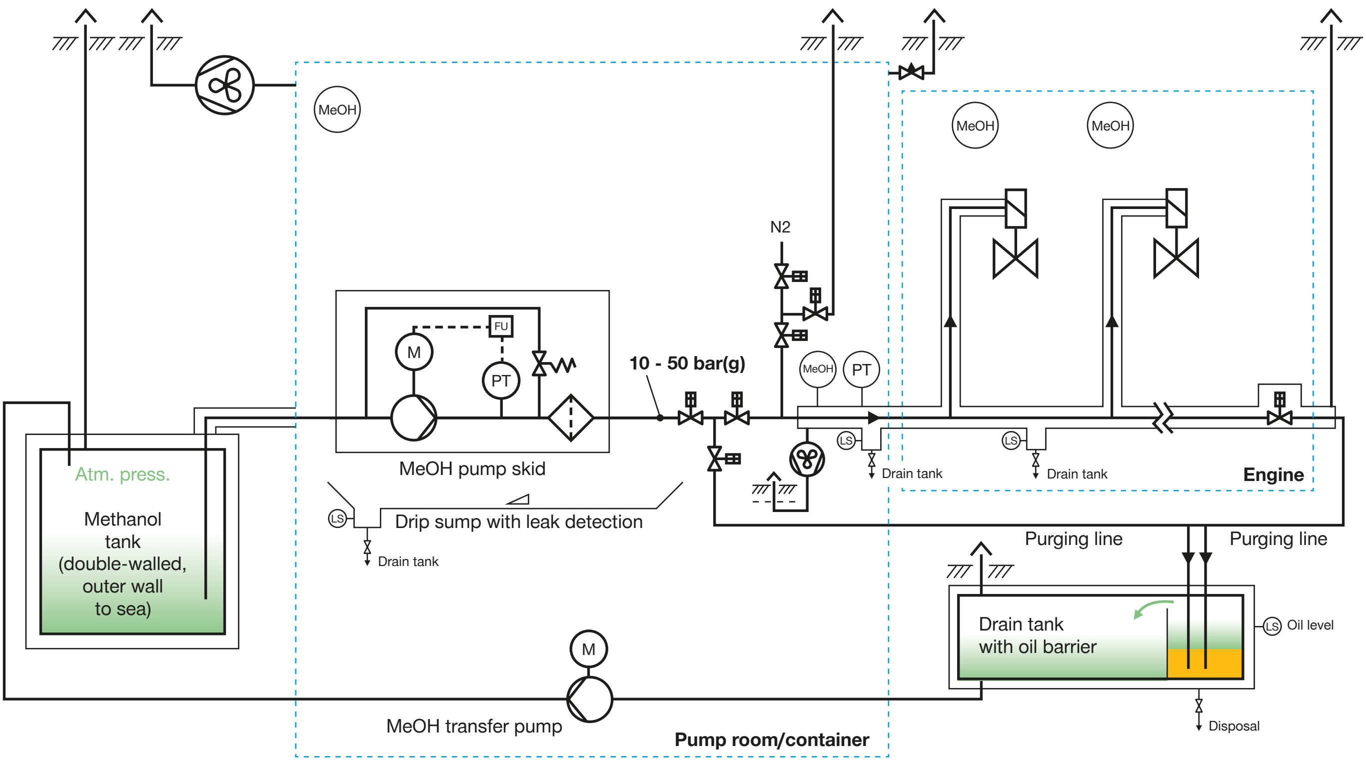
For this reason, MAN Energy Solution is developing its methanol four-stroke engines with a step-by-step, modular approach to decarbonize its fleet. According to this approach, the engines can already be operated with blend-in solutions (e.g. 25% of H_2 admixture in gas operation with LNG) and biofuels (e.g. biodiesel and bio-LNG).

In the near future, engine operation using methanol as the main fuel will be possible with port fuel injection (PFI) technology. This PFI technology enables a solid operating range with a high methanol share in the relevant engine operation modes. By using green methanol in combination with biodiesel, it will be possible to achieve fully carbon-neutral engine operation with this simple and robust injection technology.

With the MAN PFI readiness concept, our four-stroke engine is ready to order now for methanol operation in 2024, both for newly built diesel and dual fuel engines.

Furthermore, MAN Energy Solutions is already working on a high-pressure direct injection (HP-DI) technology as a long-term solution. With this technology, the full power output in

MAN methanol solution



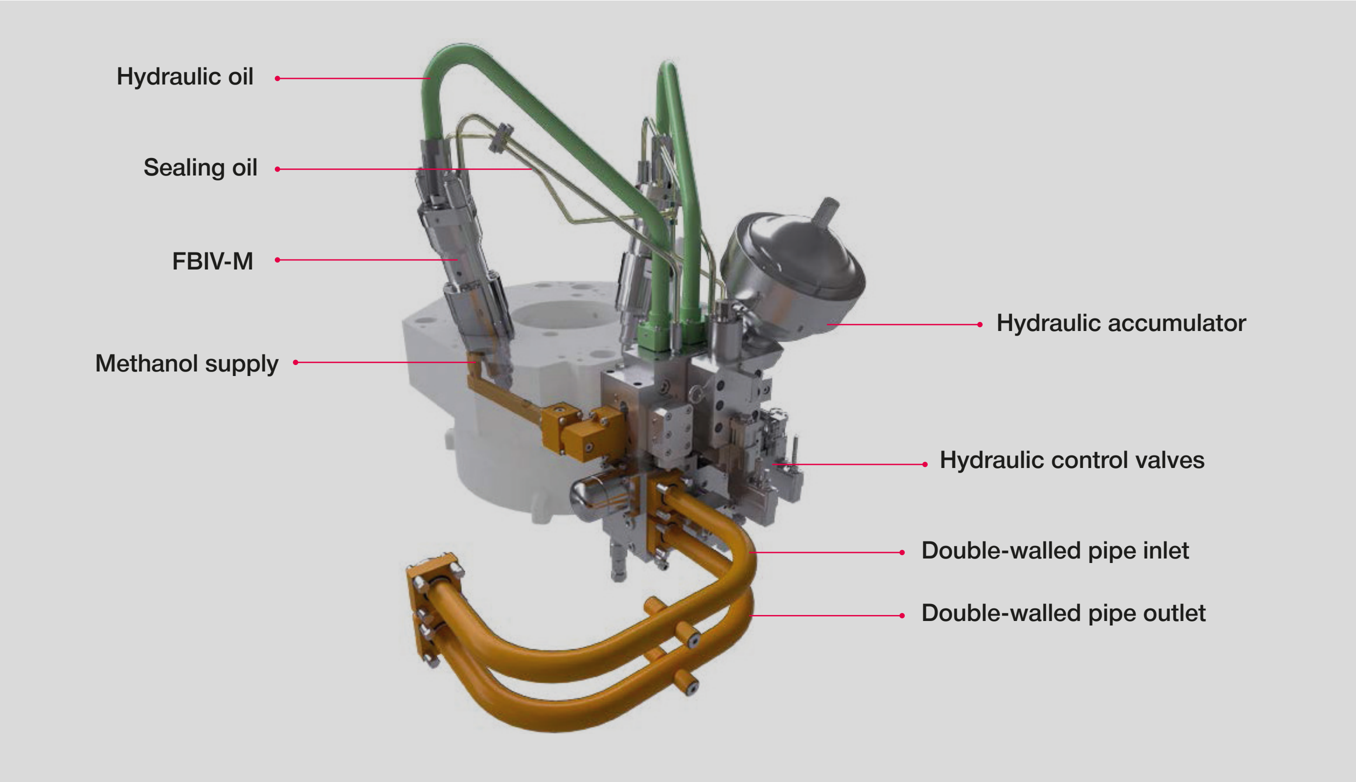


Figure 1

methanol can be achieved with the highest efficiency in the entire engine operation mode.

5.3 MAN PrimeServ Retrofit and Upgrade

MAN PrimeServ, the service and aftersales division of MAN Energy Solutions, provides several retrofit and upgrade solutions for existing engines in the market. As a result, upgrade solutions are also offered for methanol operation on MAN four-stroke engines such as the 48/60, 51/60 or 32/40 models, to give just a few examples. This is possible due to the modular design of MAN four-stroke engines, which enables existing engines to be easily retrofitted and new-build engines delivered as "ready for methanol operation" to be operated using methanol by the start of 2024.

As a special service, MAN PrimeServ Retrofit and Upgrade offers a CO_2(e) reduction calculation to figure out which solution is the best to meet the customers' requirements and to comply with current and upcoming regulations. Therefore the options start with a life-cycle upgrade (LCU) for existing engines such as the 48/60 model – a solution which upgrades them to the latest design of 51/60 engines. This upgrade not only results in lower SFOC, reduced maintenance costs, and avoids unplanned services; the LCU gives either the option to choose the future fuel at a later stage with an engine ready for whatever comes up in the future, or a solid basis for a direct upgrade to LNG or methanol dual fuel operation (Figure 2).

With the port fuel injection system (PFI), MAN PrimeServ Retrofit and Upgrade offers an easy retrofit solution to run existing engines on methanol. During the conversion, an additional injector will be installed into the inlet manifold by either machining the existing cylinder head or – in the case of a previous LCU – into the existing interface.

In addition, the following assemblies will be installed in the event of conversion to methanol operation. (Figure 3)

- Combustion chamber components
- Safety devices
- Automation components
- Methanol fuel system

MAN Energy Solutions as a provider of solutions also offers advanced exhaust gas after-treatment systems to reduce the emissions of current and future fuels. Therefore, the low-maintenance and tested MAN SCR system will be extended by additional layer, to meet the requirements of current and future regulations depending on the fuel being used. In any case, the MAN SCR system keeps your vessel compliant with the current IMO Tier III regulation and beyond. Methanol as the fuel will reduce the NO_x emissions by up to 60% compared to HFO operation. The remaining NO_x emissions are related to the consumed air and the high temperatures during the combustion process.

Possible pathways for e.g. 48/60 engine types

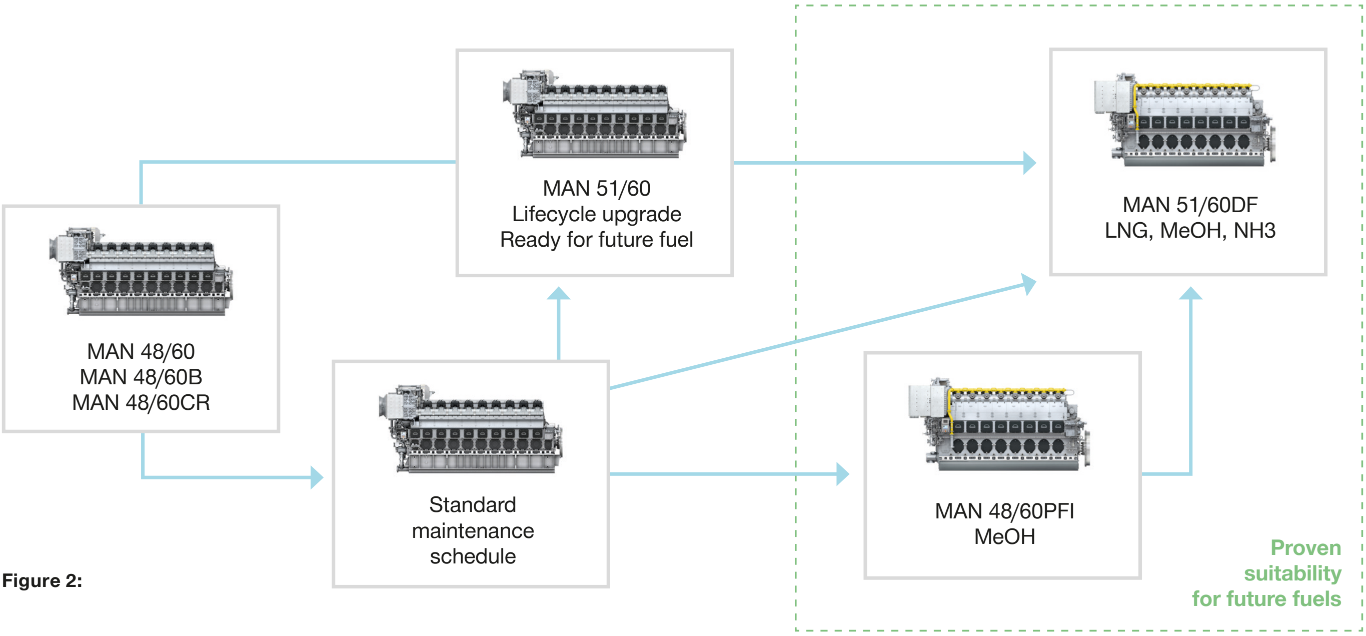


Figure 2:

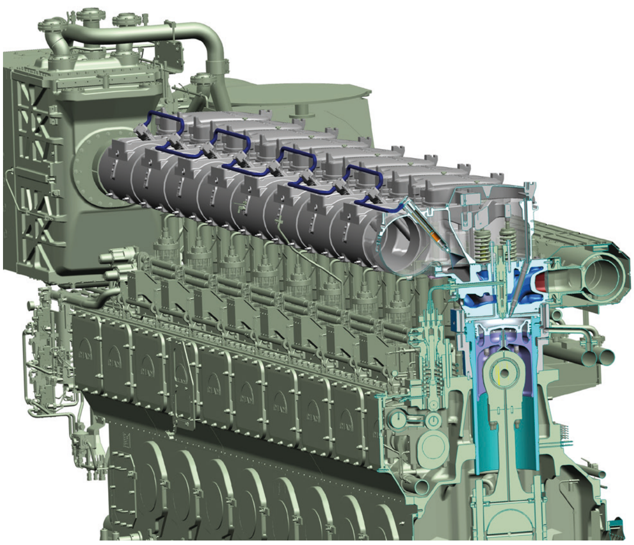


Figure 3: Possible upgrade for methanol operation

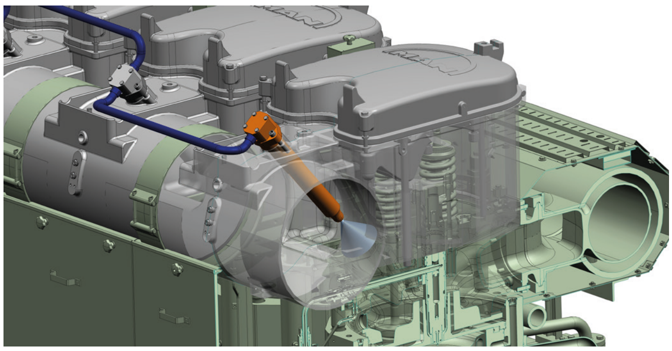


Figure 4: Combustion chamber

Summary

Methanol's popularity is growing as a clean-burning, low-carbon fuel, and methanol-fueled engines are already in use today. However, the fuel is still conventionally produced. To advance the maritime energy transition, the gradual development of climate-neutral methanol production from renewable green hydrogen and captured carbon must progress.

The major appeal of methanol as an alternative fuel is that it can be stored as a liquid at ambient temperatures and pressures, and that it has a favorable energy density. Thus, while its production as a green fuel is a complex process, its handling costs are low, reducing the complexity of storage and bunkering infrastructure at ports. As a cargo, methanol is already present in many sea ports around the world and safe procedures already exist for its handling as both a cargo and a fuel.

It is our mission at MAN Energy Solutions to provide the necessary tools and state-of-the-art technology to support this maritime energy transition, as laid out in this paper on methanol and respective combustion and retrofit solutions for shipping.

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Printed in Germany GGKM-AUG-1221