FAQ

Methanol / Ethanol Dual-Fuel Engines

X-DF M/E

by WinGD

Methanol

Ethanol

WIN GD

FAQ Contents

Introduction

Methanol (CH_4O) and ethanol (C_2H_6O) are both technically viable fuel candidates as ship operators select their route to decarbonisation. WinGD offers a single engine platform to enable ships to use both fuels, and there is an increasing focus on building global supply of low-emissions fuel variants.

As members of the same alcohol family, the chemical similarities between methanol and ethanol mean they can be used in the same engines, with minor modifications to fuel supply and injection to optimise engine performance for one fuel or the other.

In 2025, the first methanol-fuelled WinGD engines were installed, initially known as X-DF-M engines. To date more than 80 are on order. In 2026, WinGD introduced ethanol fuel capability to the same engine type, creating the tri-fuel X-DF-M/E platform. The first ethanol-capable X-DF-M/E engines will be available for delivery from 2027.

This fuel flexibility gives ship operators wide scope when choosing decarbonisation options. They can use green methanol from renewable sources to deliver ZNZ fuel emissions benefits immediately. Or they can use progressively cleaner methanol or ethanol—or a blend of both—as emissions reduction targets tighten and as the cost of cleaner fuels is outweighed by penalties avoided and/or surpluses accrued.

This portfolio addition thus furthers WinGD's primary mission – to give ship operators the engines that they need to follow their optimal pathway towards decarbonisation, whichever fuel they choose.

A Methanol and ethanol as fuels

1 Why are methanol and ethanol in the spotlight?

Methanol and ethanol combustion produces lower emissions of sulphur oxides (SO_X), nitrogen oxides (NO_X), and particulate matter compared to conventional marine fuel oils.

Although current methanol production mainly relies on fossil energy sources, near-zero emission production methods are emerging. Combined with a low-emissions supply chain, renewable methanol can significantly reduce lifecycle emissions from shipping.

While conventional fossil methanol offers no emissions advantage over traditional marine fuel oils, conventional ethanol is produced from biomass and therefore does offer emissions reductions subject to its meeting regulatory requirements on sustainability. Conventionally produced using crop waste, more advanced production processes are emerging using different feedstocks, which result in lower lifecycle emissions.

Compared to alternatives such as LNG or ammonia, methanol and ethanol are relatively easy to store and handle. As they are liquid at ambient temperature and pressure, they do not need to be held in a cryogenic state. This results in attractive newbuilding costs for methanol fuelled vessels.

While safety is a crucial concern for any fuel, methanol and ethanol have a lower flammability range compared to conventional fuels, making them safer options in certain respects. Rigorous standards and protocols are in place to ensure the safe handling, storage, and transportation of both methanol and ethanol.

Being chemically produced rather than naturally occurring fuels, methanol and ethanol present a very narrow variation of composition and quality, meaning vessel operators will not need to consider multiple fuel grades at different locations and complex fuel treatment can be avoided.

2 What are the challenges associated with using methanol and ethanol as a fuel?

While methanol and ethanol offer several advantages as a marine fuel, there are challenges and considerations associated with its use. Some of the key challenges include:

Infrastructure development: Establishing a comprehensive infrastructure for green methanol production, storage and distribution will be required to further develop its market as an alternative fuel. The same applies for advanced ethanol variants, although existing crop-waste based ethanol already offers emissions advantages if produced sustainably, and benefits from a wide existing production and distribution infrastructure in specific markets.

Adapting existing ports and bunkering facilities to accommodate methanol and ethanol will require substantial investments.

Fuel availability: The availability of both ethanol ad methanol as marine fuels could be limited in certain regions. Ensuring a reliable and consistent supply chain is crucial for the widespread adoption of methanol- and ethanol-powered vessels.

Energy density: Methanol and ethanol have a lower energy density compared to traditional marine fuels like fuel oils. This can impact the range and storage capacity of vessels, requiring larger fuel tanks or more frequent bunker calls.

Cost competitiveness: While the cost of methanol is influenced by several factors, including production methods and regional dynamics, the anticipated high cost of near-zero or zero-emissions methanol will be an important consideration for shipowners and operators. Meanwhile conventionally produced ethanol is already competitively priced in several markets—although more advanced variants with higher emissions reduction potential are likely to cost significantly more.

Initial investments in alcohol-fuelled engines and infrastructure could also contribute to higher upfront costs.

Lifecycle calculations: The overall carbon footprint of methanol depends on the source of the carbon and energy used in its production. If produced from fossil fuels, the environmental footprint may be worse than of conventional fossil fuels. Therefore, ensuring a sustainable sourcing and production process is essential.

Ethanol is produced from a wide range of feedstocks and production processes, with an increasing focus by producers on delivering low-emission ethanol that does not impact food crops or lead to indirect land use change. However, these factors can limit the decarbonisation potential of ethanol that is not certified as sustainable.

3 How is methanol produced?

Methanol can be produced from various feedstocks through different processes. The primary methods of methanol production include:

Natural Gas Reforming or Steam Methane Reforming (SMR): The most common method for industrial methanol production involves the use of natural gas (methane) as a feedstock. In this process, methane reacts with steam at high temperatures (typically 700-1,100°C) and under pressure, producing syngas (a mixture of hydrogen and carbon monoxide). The syngas is then catalytically converted into methanol.

Coal-based Methanol: Methanol can be produced from coal through a gasification process. Coal is converted into syngas, which is then processed to obtain methanol. However, this method is less common due to environmental concerns associated with coal-based processes.

Biomass Gasification: Methanol can also be produced from biomass through a gasification process. Biomass, such as wood, agricultural residues, or municipal solid waste, is heated in the presence of oxygen and/or steam to produce a synthesis gas. The synthesis gas is then converted to methanol through similar catalytic processes used in natural gas reforming.

Carbon Capture and Utilisation (CCU): Carbon dioxide (CO_2) captured from industrial processes or directly from the atmosphere can be utilised in methanol production. Hydrogen is typically obtained from water electrolysis or other clean sources, and the combination of hydrogen and carbon dioxide results in the production of methanol.

4 How can zero or near-zero emissions methanol be produced?

Making zero-or near-zero emissions methanol involves mitigating or offsetting the carbon emissions associated with its feedstocks and production. Several approaches can be employed:

Use of Renewable Feedstocks: Utilising renewable feedstocks such as biomass or waste materials to produce methanol can significantly reduce the carbon footprint of the process. Biomass gasification or waste-to-energy technologies can generate syngas for methanol synthesis without adding carbon to the atmosphere.

Carbon Capture and Storage (CCS): Implementing carbon capture and storage technologies can capture CO_2 emissions generated during methanol production. Captured carbon dioxide can be permanently stored underground or returned for new renewable methanol production.

Direct Air Capture (DAC): Direct air capture involves capturing carbon dioxide directly from the atmosphere. Integrating DAC technologies into methanol production processes can offset emissions by removing an equivalent amount of CO_2 from the air, making the overall process carbon neutral.

Renewable Hydrogen Production: Hydrogen, a key component in methanol production, can be produced using renewable energy sources such as wind, solar or hydropower through a process known as electrolysis. Electrolysis splits water into hydrogen and oxygen without emitting carbon dioxide. Using renewable hydrogen in methanol synthesis contributes to the carbon neutrality of the overall process.

Circular Economy Approach: Implementing a circular economy approach involves recycling carbon-containing waste streams, such as industrial emissions or carbon-rich byproducts, as feedstocks for methanol production. This closed-loop system can contribute to carbon neutrality by repurposing carbon that would otherwise be emitted.

It is important to note that achieving carbon neutrality in methanol production often requires a combination of these approaches.

The selection of methods depends on factors such as feedstock availability, technological feasibility, and the specific goals of the methanol production facility. As technology advances and sustainability practices become more widespread, the goal of producing carbon-neutral methanol is becoming increasingly achievable.

5 How is ethanol produced?

Most of the fuel ethanol produced around the world is made by fermenting the sugar in the starches of grains such as corn, sorghum, and barley, and the sugar in sugar cane and sugar beets.

Sustainable producers are increasingly deploying non-edible feedstocks, including agriculture residues such as corn and rice stalks, fast-growing poplar and willow trees, grasses like switchgrass and biomass from municipal solid waste. This is known as cellulosic ethanol. At present the commercial viability of cellulosic ethanol is limited by the more expensive enzymes and processing methods needed, although the cost is likely to reduce as productions is scaled up.

6 How can zero or near-zero emissions ethanol be produced?

Different countries have different methodologies for calculating the carbon footprint of ethanol, but all demonstrate that ethanol is cleaner than fossil fuels. According to the Climate Ethanol Alliance, which has official consultative status at the International Maritime Organization, sugarcane ethanol produced at an average facility in Brazil now achieves 80% GHG savings, with grain ethanol in Europe and the US approaching 80% as well.

Cellulosic ethanol, made from waste feedstocks such as corn stalks or switchgrass, have even better environmental footprint because these feedstocks also use less fuel, fertilizers, and water to grow than grains.

Further reductions in greenhouse gas emissions can be achieved through the deployment of carbon capture and storage (CCS) technologies, which might be able to deliver GHG savings of 100% relative to baseline fossil fuel emissions.

6 **How can zero or near-zero emissions ethanol be produced?** continued...

These figures suggest that ethanol could play a role in enabling ship operators to meet IMO's target of net-zero emissions from global shipping by or around 2050.

7 Are there any regulations or standards for methanol and ethanol fuelled engines?

Using methanol or ethanol as marine fuels is covered by the 'IMO Interim guidelines for the safety of ships using methyl/ethyl alcohol as fuel' which are part of IMO's IGF Code. As the interim guidelines are still provisional, methanol- and ethanol-fuelled ships must follow the alternative design requirements under SOLAS and the related risk-based design and certification criteria provided in the interim guidelines as well as those described by the classification societies.

With the IMO interim guidelines as the basis, classification societies have also released their rules for classifying methanol- and ethanol-fuelled vessels.

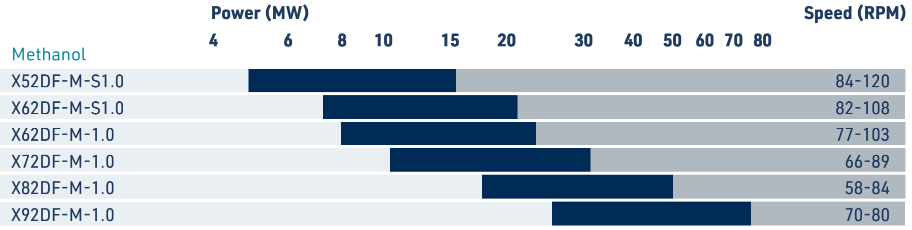
8 What are the specifications for methanol and ethanol as marine fuels?

Ethanol and methanol are both alcohols with rather similar properties and requirements. They are both low flash point fuels and the same classification rules apply to both fuels. The main difference between the two fuels is the lower calorific value, which is higher for ethanol compared to methanol, which means approximately 25% less ethanol fuel will be injected for the same engine power.

In 2024, the International Organization for Standardization published ISO 6583, the global standard for methanol in marine fuel. This is the fuel specification for which WinGD develops its engines. There is no equivalent standard for ethanol fuels yet, although the ISO has initiated a working group. Until the ISO standard is available, WinGD will specify the requirement for ethanol fuels for WinGD X-DF-M/E engines to meet available ethanol qualities in the market.

9 Which methanol and ethanol engine types do WinGD currently offer?

WinGD DUAL-FUEL ENGINES



10 When were the first WinGD methanol-fuelled engines delivered?

The first deliveries to shipyards took place in early 2025 for the 920mm bore cylinder X92DF-M-1.0 engine and in Q3 2025 for the 820mm bore cylinder X82DF-M-1.0 engine. This was followed by the first X62DF-M-1.0 deliveries in Q2 2026. The first projects for upgrading existing X52-S2.0 diesel engines to methanol dual-fuel have also been contracted and will be executed by Q1 2027.

11 When will the first WinGD ethanol-fuelled engines be delivered?

WinGD will offer its first ethanol-fuelled two-stroke marine engine in 2026, with deliveries for newbuild and retrofit applications starting in 2027.

12 When will an upgrade package be available for existing WinGD X/X-DF engines?

WinGD plans to introduce upgrade solutions enabling all diesel-fuelled X-Engines to be converted to X-DF-M/E engines. This is possible due to the common robust engine platform shared by all WinGD engines, designed to accommodate the pressures and temperatures needed for use with alternative fuels The roll-out of upgrade packages for specific engine bore sizes will follow the introduction of newbuild X-DF-M/E engine configurations in the relevant bore-size, and depending on market demand. Upgrade packages are available approximately six months after the first newbuild design has been completed, at the earliest.

13 When did WinGD begin investigating ethanol- and methanol-fuelled engines?

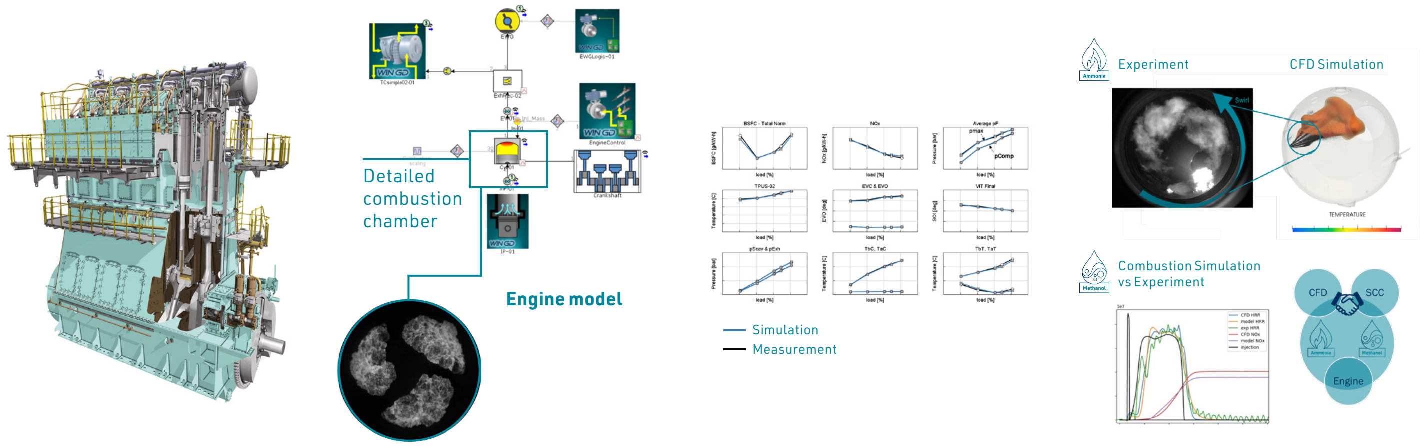
WinGD has been studying ethanol fuel, which has a similar combustion and emissions profile to methanol, since 2014, when it undertook a research project financed by the Swiss Federal Office of Energy. From 2016 it was part of the European Union funded HERCULES-2 project, which aimed to develop engines that could switch between fuels whilst operating in the most cost-effective way and complying with regulations in all regions.

As part of this project, WinGD started to investigate methanol and ethanol combustion in its own Spray Combustion Chamber (SCC), in order to understand the spray morphology and combustion performance of a multi-fuel injection concept.

In 2018 a prototype injection system was designed based on the findings from the SCC and fitted on WinGD's RTX-6 test engine to burn ethanol and diesel fuel as two representatives of a broad fuel spectrum. Both ethanol and methanol are alcoholic fuels with similar combustion behaviour.

14 How did WinGD validate the X-DF-M concept?

Data Validation Process
Spray Combustion Chamber and Simulations



Real Engine

Various engine measurment series are used for calibration and validation

Spray Combustion Chamber

Used for an accurate CFD modelling of the combustion process

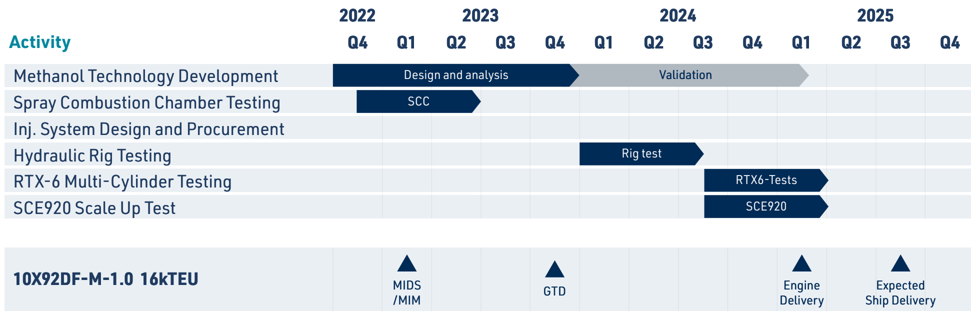
0D/1D GT-Power Model

Calibrated to engine measurement data

Methanol engines are sharing diesel base engine hardware but with specific combustion characteristics

Spray Combustion Chamber used with methanol allows for **new validated combustion models in a validated engine model**

Technology Development and Project Timelines



C Engine concept

15 What is the combustion process for X-DF-M/E engines?

The stages of the combustion process are described below.

Compression stroke: Similar to a conventional diesel engine, the piston compresses the air inside the combustion chamber during the compression stroke, raising its temperature and pressure. This high-pressure and high-temperature environment is crucial for igniting the pilot fuel and subsequently the methanol and/or ethanol fuel.

Fuel injection: Methanol and/or ethanol is injected into the engine's combustion chamber as the primary fuel. The injection system ensures proper atomisation, interaction with the diesel pilot flame and mixing of alcohol with air for efficient combustion.

Ignition and combustion: At the top of the compression stroke, just before reaching the maximum compression point, a small amount of pilot fuel is injected into the combustion chamber. The pilot fuel spray ignites due to the high temperature and pressure, initiating the combustion process.

Methanol/ethanol combustion: Once the pilot fuel ignites, the heat generated ignites the alcohol fuel injected into the combustion chamber, interacting with the pilot flame. The fuel-air mixture combusts, generating work on the piston.

Scavenging: After the piston has moved downwards during the power stroke, the combustion gases expand through the opening exhaust valve and are subsequently scavenged by new charge air from the intake ports to the exhaust valve. The cycle repeats.

16 What is the X-DF-M/E engine design concept?

WinGD's X-DF-M/E engines are developed for dual-fuel operation using either methanol or conventional fuel oil. By deploying Diesel-cycle combustion with high-pressure fuel injection, the same concept as WinGD's diesel-fuelled X-Engines, the X-DF-M/E concept ensures highest engine efficiency in both modes, allowing operators to run engines cost-effectively on conventional fuels, methanol and ethanol.

X-DF-M/E engines are based on proven diesel engine design, with a limited scope of modifications required to adapt WinGD's diesel engine technology for use with methanol and/or ethanol fuel. These include:

- Alcohol fuel injection
- Additional actuation oil rail for alcohol injection system
- Additional actuation oil supply unit
- Modified cylinder cover
- Adapted platforms and piping
- Minor modifications to bedplate and cylinder jacket

17. How is alcohol fuel supplied to the engine?

An alcohol fuel supply system is used to supply methanol from the tank to the engine.

WinGD provides interface specifications and recommendations for the layout of the system based on best engineering practice. The Fuel Supply System (FSS) components themselves are designed and delivered by third party makers.

Methanol/ethanol Storage: Methanol and ethanol are stored in dedicated tanks or containers on the vessel. These tanks are designed to handle the pressure and temperature requirements of methanol

storage and comply with safety regulations. They may include safety features such as pressure relief valves, temperature monitoring and nitrogen blanketing.

Fuel Supply System (FSS): Methanol and/or ethanol are transferred from the storage tank to the engine by the FSS as required. The fuel is delivered to the engine within a specific range of temperature, pressure (13 bar(g)) and purity. This transfer is accomplished using low-pressure pumps, heat exchanger and filters. The fuel supply system must be designed to handle the specific characteristics of methanol and ethanol, including their corrosive nature.

Fuel conditioning: Methanol and ethanol fuel may undergo conditioning processes before it reaches the engine. This can involve filtration to remove impurities or contaminants that could potentially impact engine performance or damage components. Additionally, temperature control is installed to ensure the fuel remains within the desired operating range.

18 Which companies supply the fuel system components?

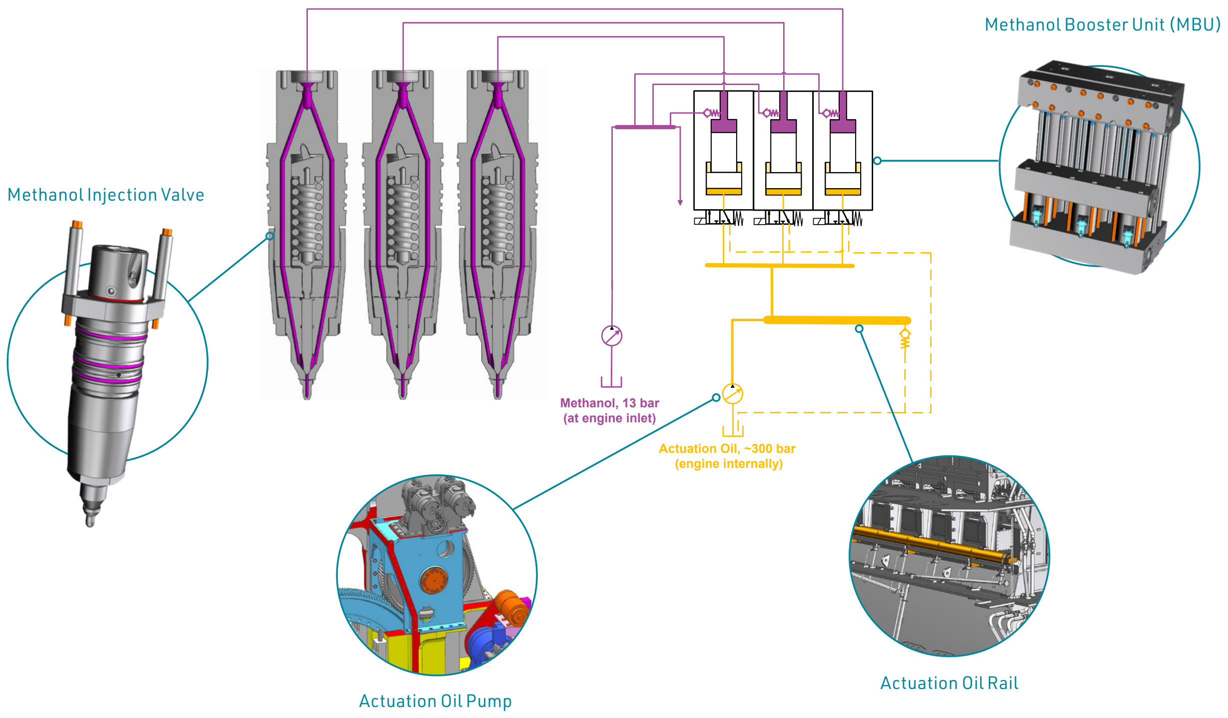
The supplier of the fuel supply system can be a preferred supplier of the shipyard or owner. However, they must meet WinGD's requirements. The supplier of the FVU additionally must be approved through WinGD's approved supplier process. The FSS and FVU can be supplied by different suppliers.

In general, the design of the alcohol fuel system must be compliant with international codes and classification society rules.

19 What are the specific requirements for methanol fuel supply at the engine inlet?

WinGD requires that methanol fuel supply for use with X-DF-M/E engines meets the standards laid out in ISO 6583:2024.

20 What does the X-DF-M methanol fuel injection concept look like?



21 What precautions are taken related to corrosiveness of methanol and ethanol?

Stainless steels, which provide sufficient corrosion resistance, are applied to components in direct contact with methanol and ethanol fuels. Many of the standard sealing materials already used in WinGD engines (such as NBR, CR, FKM) exhibit good to excellent resistance to methanol and ethanol corrosion.

22 Do engine design parameters need to be changed to optimise methanol and ethanol combustion?

Methanol and ethanol engine design parameters such as bore, stroke and mean piston speed are the same as for diesel engines in the WinGD portfolio. Tuning parameters such as injection timing, pressure, etc., are adjusted individually for methanol/ethanol operation to achieve best possible efficiency and lowest emissions.

C Engine concept

23 What modification are needed to the methanol-fuelled engine concept to enable use of ethanol fuel in the X-DF-M/E engine?

The methanol fuel injection system is used for ethanol with only minor adaptations related to additional sensors, gas leakage detection sensors, engine control software and tuning parameters.

The same fuel supply system and fuel tanks can be used for both methanol and ethanol. The differences between the two alcohols must be considered in the design of the fuel supply system, mainly the difference in Lower Heating Value (LHV), resulting in different fuel consumption and flows, and the difference in explosive limit in air for gas leakage detection.

24 Which engine parts need to be converted to upgrade an existing WinGD engine for methanol and/or ethanol?

Since X-DF-M/E engines are based on the conventional diesel engine design, all WinGD portfolio engines can be upgraded to use methanol and ethanol as fuel. Necessary modifications will be related to the installation of the additional injection system, actuation oil system and potentially an extension of the main lubricating oil supply capacity.

Cylinder covers will have to be replaced to fit the additional injectors. It is suggested to conduct case-specific studies for retrofit projects.

25 How is certification of X-DF-M/E engines handled for both methanol and ethanol fuels?

The certification of the engine must be made for the fuels which will be used. If only ethanol is used in addition to diesel, it is sufficient to do FAT and NOx certification only with these fuels. The same fuel supply system and fuel tanks can be used for both methanol and ethanol fuels.

If both ethanol and methanol are to be used, at least ethanol must be demonstrated during the FAT to confirm performance and NO_X emission compliance, at least for the parent engine.

Testing of ethanol and methanol blends during the FAT and relevant costs must be agreed separately with the customer and the classification society. The following options are available for the tuning and certification of the engine:

1. Methanol only – optimised for methanol resulting in 2% lower energy consumption compared to diesel mode. Engine performance data are available in GTD.

2. Ethanol only – optimised for ethanol with similar energy consumption to diesel mode.

3. Ethanol or methanol including any blends of the two alcohols – optimised for ethanol and certified for both alcohols and any blend ratio of the two alcohols. There is an expected methanol fuel energy consumption penalty of 1–2%, compared to the methanol optimised option 1, i.e. same energy consumption on methanol, ethanol and diesel fuels. Engine performance data are available on request.

26 How is safety ensured on the X-DF-M/E engine and across the fuel supply system?

Safety measures are implemented throughout the methanol/ ethanol supply system, including leak detection, emergency shutdown, double wall barriers, ventilation, and fire suppression to ensure the safety of the crew, vessel and environment.

Crew members must be trained on safe handling procedures, the use of personal protective equipment and emergency response protocols.

Monitoring and control systems are employed to ensure the proper functioning of the methanol/ethanol fuel supply system.

See the X-DF-M Safety Concept for a more detailed description. This will be updated to include ethanol around Q4 2026, with no major differences except those to account for ethanol's lower Lower Explosion Limit (LEL).

27 Can the existing WiCE control system also control the methanol/ethanol engine?

The latest state-of-the-art control system WiCE is installed on all new WinGD engine types including X-DF-M/E engines. WiCE covers the additional requirements for the methanol/ethanol system.

28 How are injectors sealed?

Multiple barriers are applied. A low-pressure fuel barrier is applied on the first level and sealing oil on the second level. Any small quantity of sealing oil in contact with methanol is burned during combustion and there is no recirculation of sealing oil to the service tank.

29 Is blending methanol or ethanol with water foreseen e.g. to reduce NO_X emissions?

Blending is not considered for X-DF-M/E because:

- It does not provide Tier III NO_X compliance in diesel mode
- It requires significant additional water consumption
- It increases the maximum injection quantity needed, meaning the methanol/ethanol injection system is not optimally sized for alcohol Tier II mode

30 How does pilot fuel injection work and which fuels can be used?

In alcohol mode the main fuel is liquid methanol and/or ethanol. The alcohol fuel is injected into the engine at high pressure. The normal diesel injectors provide pilot fuel to ignite the fuel. The pilot flame penetrates the methanol/ethanol plume to ignite it from the inside.

The amount of injected pilot fuel is approximately 5% of the total energy consumption of the engine at 100% Contracted Maximum Continuous Rating (CMCR) engine power. Project-specific values are available in the GTD.

The pilot fuel can be Marine Diesel Oil (MDO), Marine Gas Oil (MGO) or Heavy Fuel Oil (HFO) with a maximum sulphur content of 0.5% m/m.

In alcohol mode, the main MDO/MGO/HFO injector for diesel operation is used to inject pilot fuel.

31 Is the fuel injection duration higher for methanol and ethanol?

The injection system is adapted to the higher flow rate which comes from the smaller Lower Heating Value of methanol and ethanol. That means the injection duration is not longer than in diesel mode. The injection system design for optimal injection duration results in the best possible engine performance and emissions.

D Engine performance

32 What is the engine efficiency of the X-DF-M/E engine?

X-DF-M/E engines will achieve the same efficiency as X-Engines in diesel mode and better efficiency when running on methanol and/or ethanol.

Higher efficiency is expected in alcohol mode as combustion tests have confirmed a lower tendency to form NO_X when burning alcohol fuels compared to conventional diesel fuels. While diesel engine performance is typically limited by compliance with NO_X emission limits, the lower NO_X level on alcohol fuels allows better utilisation of the cylinder pressure design limits of the engine, delivering higher efficiencies when running on methanol/ethanol. Accordingly, energy consumption in methanol mode is approximately 2% lower than in diesel mode. The fuel consumption at each engine load point can be found in WinGD's General Technical Data (GTD).

33 Will there be major differences in the engine load acceptance and dynamic behaviour on X-DF-M/E engines compared to conventional diesel engines?

No. Similar load acceptance behaviour as on conventional diesel engines is expected since the engine employs the same Diesel-cycle combustion principle and controls.

D Engine performance

34 Which emissions are created from methanol and ethanol combustion and how are they treated with X-DF-M/E?

Methanol and ethanol combustion produces several types of emissions, although it generally emits lower levels of pollutants compared to traditional fossil fuels like diesel. The emissions include:

Carbon Dioxide (CO_2): Like other hydrocarbon fuels, methanol/ethanol combustion releases carbon dioxide, a greenhouse gas that contributes to climate change. However, when methanol is produced from renewable sources or with carbon capture technologies, the overall lifecycle emissions of CO_2 can be reduced.

Nitrogen Oxides (NO_X): NO_X emissions are formed during the combustion process when nitrogen in the air reacts with oxygen at high temperatures. Methanol and ethanol combustion typically result in lower NO_X emissions compared to diesel combustion. This brings the opportunity to increase the engine efficiency by utilising the engine design limits.

Carbon Monoxide (CO): Incomplete combustion of methanol or ethanol can lead to the formation of carbon monoxide, a poisonous gas. WinGD engine designs and efficient combustion processes aim to minimise CO emissions.

Particulate Matter (PM): Methanol and ethanol combustion can produce particulate matter, consisting of tiny particles suspended in the air. While methanol and ethanol generally produce fewer particulate emissions compared to diesel, the formation of PM can still occur, especially from pilot fuel and lubrication oil.

Formaldehyde (HCHO): Methanol and ethanol combustion can produce formaldehyde that contributes to air pollution. Although formaldehyde emissions from methanol and ethanol combustion are very low, they are still a consideration for air quality. At present there are no maritime regulations governing formaldehyde emissions.

Sulphur Dioxide (SO_2): Methanol and ethanol contains no sulphur, so combustion does not produce sulphur dioxide emissions besides the small quantity of sulphur in the pilot fuel. This is advantageous compared to traditional marine fuels like heavy fuel oil, which can have high sulphur content and emit SO2 when burned.

Overall, while methanol and ethanol combustion produce emissions like any other fuel, its use can offer environmental benefits, particularly when considering reductions in CO_2, SO_X, and particulate matter emissions compared to conventional marine fuels. As detailed above, lifecycle calculations of emissions depend on production processes and feedstocks, meaning well-to-tank emissions factors need to be considered alongside tank-to-wake emissions.

To ensure IMO NO_X Tier III compliance, a selective catalytic reduction (SCR) is installed. The SCR unit can be applied as a high-pressure SCR or a low-pressure SCR type which are fully established solutions on diesel engines.

E Engine operation

35 When does the alcohol system need to be purged?

Purging and flushing of the alcohol fuel system is performed prior to maintenance work or in the event of failure of alcohol injection system components, such as a leakage. In these cases, the fuel system must be depressurised and the remaining alcohol fuel must be removed by water and collected in the purging tank.

More details can be found in the X-DF-M concept guidance, which will be updated to include ethanol:

PDF **https://www.wingd.com/en/engines/engine-types/x-df-dual-fuel-methanol/methanol-documentation/**

36 Why is purging done with water?

Compared to conventional nitrogen purging, using water delivers several advantages, including:

- Liquid-to-liquid purging is generally more efficient than gas-to-liquid
- Purging with water allows greater flexibility in vessel layout, e.g. allowing a purge tank installation at higher level than the main engine
- Purging large vertical pipes is much easier with water than with a gas
- No additional pipe/valves are required on the main engine for the sole function of purging the engine. Water can replace methanol/ethanol following the same route.
- Gas purging can lead to some areas of piping containing methanol/ethanol being missed if a preferential path develops in the gas flow. This is less likely when using water.
- Using water for pressure tests to check for leaks or cracks is faster and more accurate than using nitrogen
- Methanol and ethanol require stainless steel, which is compatible with water

37 After purging, what happens to the water-alcohol mixture in the purge tank?

During purging of the injection system, the remaining alcohol dissolves in the purge water and is collected in the purge tank.

The water-fuel mixture in the purge tank is mixed into the main methanol/ethanol supply when the main engine runs in alcohol mode. Small quantities are introduced to the engine until the purge tank is empty or has reached the minimum level, after which the engine runs only on alcohol fuel.

E Engine operation

38 What cylinder lube oils and feed rate should be used for an engine running with methanol or ethanol?

WinGD currently foresees that operators will need to use low-BN lube oils, similar to those used in LNG dual-fuel engines and with similar feed rates. These lubricants are well-proven and widely available/

Please refer to WinGD's list of validated engine oils:
https://www.wingd.com/en/documents/w-2s/tribology/fuel-lubricants-water/validated-engine-oils-for-wingd-engines-v13.pdf/

39 Why is Selective Catalytic Reduction (SCR) favoured over Exhaust Gas Recirculation (EGR) as an NO_X Tier III emission solution?

NO_X compliance of X-DF-M/E engines is ensured via low-pressure (LP) or high-pressure (HP) SCR systems, the well-proven standard system on WinGD diesel engines. This setup guarantees compliance in both fuel modes and results in lower additional OPEX compared to an EGR system, which bears an efficiency penalty when running in Tier III mode. This efficiency drawback with an EGR system becomes increasingly costly when considering the high cost of green methanol and advanced ethanol variants.

Additionally, CAPEX for an SCR solution is typically lower than for an EGR system.

40 What is the reaction of the engine to a failure of the alcohol system or operation?

In the event of an issue while running on methanol or ethanol, the engine will automatically switch to diesel mode. The process and automation are similar to those used in dual-fuel LNG engines.

41 Can the engine start and stop with alcohol, and what is the power range available for operation on the fuels?

The engine is started in diesel mode. Fuel changeover from diesel to alcohol takes place when the engine is running between 10-80% engine power. The operation range for alcohol fuels is 10-100% of engine power.

42 Is a fuel sharing mode offered for X-DF-M/E engines?

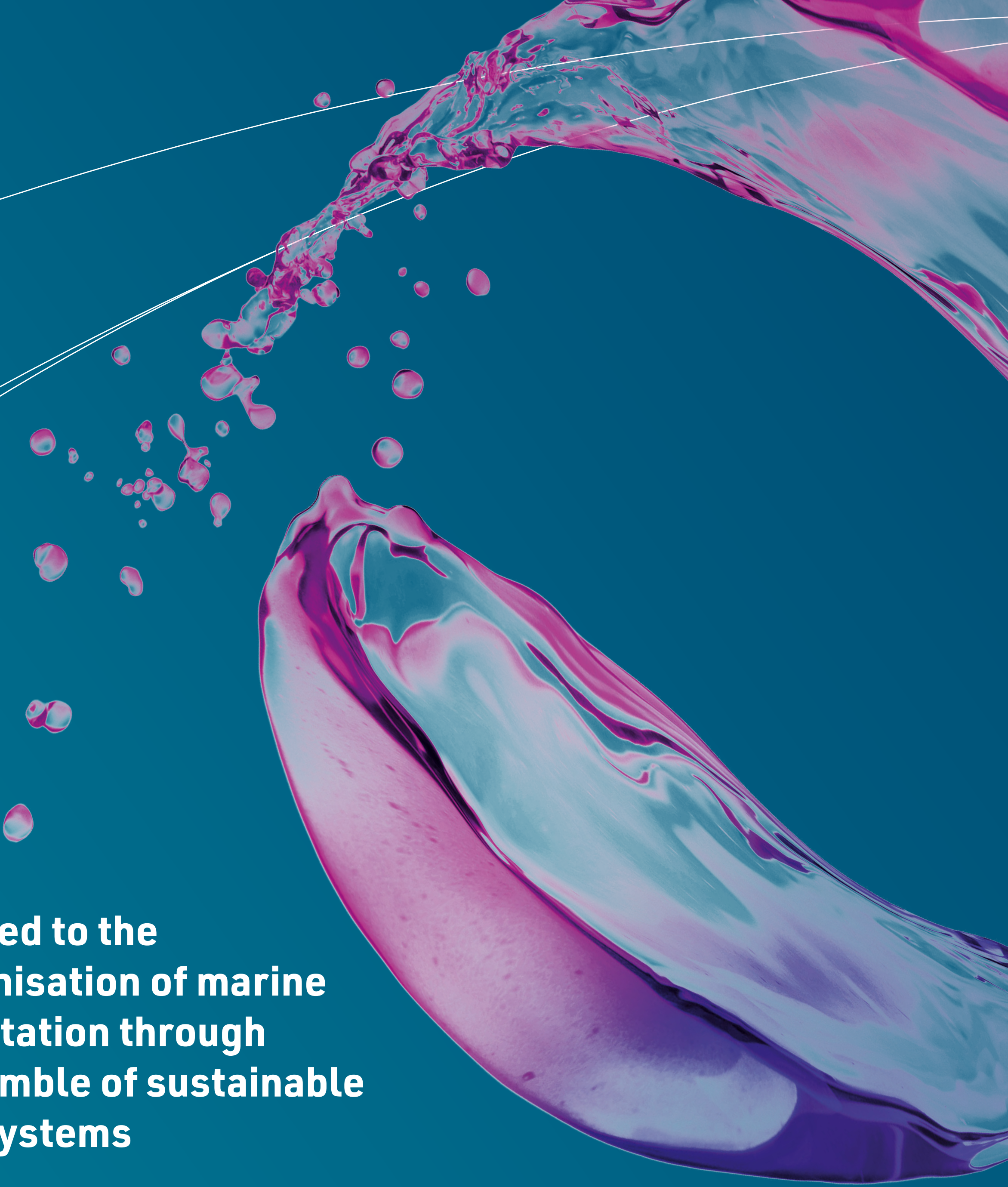
Fuel-sharing operation, combustion with a mixture of methanol/ethanol and diesel, is possible. This feature is planned to be introduced at a later stage. Ethanol and methanol can be mixed in any ratio for an ethanol-enabled X-DF-M/E engine.

43 How does WinGD support training for the operation and maintenance of alcohol-fuelled engines?

WinGD follows the same training methodology for X-DF-M/E engines as for its X-DF LNG engines, with courses covering operation and maintenance of the engine. These include information about control system logic, mechanical components and a strong focus on safety aspects related to the specific fuels as well as other relevant topics.

WinGD is already assisting operators and maritime academies in preparing training courses for the use of methanol and ethanol as a marine fuel.

Notes



Committed to the decarbonisation of marine transportation through our ensemble of sustainable energy systems

WinGD designs marine power ecosystems utilising the most advanced technology in emissions reduction, fuel efficiency, digitalisation, service and support. With our two-stroke low-speed engines at the heart of the power equation, WinGD sets the industry standard for reliability, safety, efficiency and environmental design.

Headquartered in Winterthur, Switzerland, since our inception as the Sulzer Diesel engine business in 1893, we are powering the transformation to a sustainable future.

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