FAQS
Ammonia Dual-Fuel Engines

X-DF A by WinGD

Ammonia

WIN GD

FAQS **Contents**

1 Why are ammonia marine engines in the spotlight?

Ammonia is gaining attention as a marine fuel because of its potential to decarbonise ship operations.

Ammonia contains no carbon, only nitrogen and hydrogen (NH_3). This means there are no CO_2 emissions on a tank-to-wake basis (but see Q.22 on ammonia's GHG and air pollutant emissions profile). Although current ammonia production mainly relies on fossil energy sources, near-zero-emission production methods are emerging, including electrolysis, methane pyrolysis and fossil-based routes with Carbon Capture and Storage (CCS). Several companies are working on cost efficient ammonia production, ready to support the transition to ammonia fuel.

As a widely used industrial chemical, ammonia benefits from an existing global supply infrastructure – a network that will grow as ammonia's role as a hydrogen-carrier is recognised and as global trade in energy shifts to open routes between regions with high renewable energy potential and consumers around the world.

Ammonia has a high energy density compared to other alternative fuels such as hydrogen, meaning it can provide power for long-range marine applications. Ammonia is also liquid at near ambient conditions, meaning less parasitic power demand for refrigeration than cryogenic alternative fuels such as LNG.

2 Are there any challenges associated with using ammonia as a fuel?

For ammonia to be adopted widely as a marine fuel, several key issues needed to be resolved:

- Ammonia is toxic and corrosive, requiring careful handling and storage to ensure the safety of crew and the marine environment.
- Developing the necessary infrastructure to deliver ammonia from existing supply networks to vessels for bunkering will require significant investment and coordination.
- The technical maturity and capacity to produce low-carbon (green and blue) ammonia remains low, although scaling up rapidly as demand emerges – e.g. Japan is aiming to supplement coal used at power plants with 20% ammonia by 2030, leading to a forecast national demand of 40 million tonnes a year by 2040. Agriculture, the primary user of ammonia currently, will also drive demand for green fertiliser.
- Adapting existing ships or designing new vessels to accommodate ammonia-fuelled marine engines involves modifications and additional engineering work.
- The anticipated cost of green or blue ammonia is expected to be multiples of conventional marine fuel, although this is expected to reduce in the long-term as production matures and as carbon pricing makes alternatives relatively more expensive.

A Ammonia as a fuel

3 How is ammonia produced?

Ammonia can be produced through a process called ammonia synthesis, which involves the combination of nitrogen (N_2) and hydrogen (H_2) gases. The primary method for ammonia production is the Haber-Bosch process. Key steps in the production of ammonia are:

Nitrogen production: Nitrogen gas is extracted from the air through a process called air separation. Air is compressed, cooled, and passed through a molecular sieve or a cryogenic process to separate the nitrogen from other gases present in the air, such as oxygen and argon.

Hydrogen production: Hydrogen can be obtained from various sources, including natural gas, coal, biomass or water. Hydrogen gas is generated using different methods, depending on the chosen feedstock. Common methods include steam methane reforming (SMR), partial oxidation and or electrolysis. SMR involves reacting natural gas with steam to produce hydrogen and carbon dioxide, while electrolysis uses an electric current to split water into hydrogen and oxygen.

Ammonia synthesis: Nitrogen and hydrogen gases are combined in a reactor under high pressure and temperature. A catalyst, typically based on iron or ruthenium, is used to facilitate the reaction. The nitrogen and hydrogen molecules react to form ammonia through a process known as Haber-Bosch synthesis.

Product purification: The resulting gas mixture undergoes purification to remove any contaminants such as unreacted nitrogen,

3 How is ammonia produced? continued...

hydrogen or other byproducts. This purification process can involve multiple stages, including condensation, cooling and separation.

Storage and distribution: The purified ammonia is stored and transported. It is typically stored in specialised tanks or containers, designed to handle ammonia safely. Ammonia can be transported as a liquid, either under pressure or in the form of an aqueous solution.

4 How can ammonia be made carbon neutral?

To ensure that ammonia is carbon-neutral or carbon free on a lifecycle basis, green or blue ammonia needs to be produced. Green ammonia is produced using renewable energy as opposed to fossil sources; blue ammonia uses fossil fuels but with carbon capture, dramatically reducing the environmental impact associated with traditional production.

Key features and considerations include:

Renewable energy sources: Green ammonia production involves using renewable energy sources, such as solar, wind or hydroelectric power to generate the required electricity for the ammonia synthesis process. By utilising clean energy, the carbon footprint associated with the production process is significantly reduced.

Electrolysis: One common method of green ammonia production is through electrolysis. Renewable electricity is used to split water (H_2O) into hydrogen (H_2) and oxygen (O_2) through a process called water electrolysis. The hydrogen gas is then combined with nitrogen gas to produce ammonia (NH_3) using the Haber-Bosch process.

Carbon Capture & Utilisation (CCU): Another approach to green ammonia production is to capture carbon generated as a byproduct of the fossil ammonia production process. CCU helps to reduce CO_2 emissions and provides a potential means for carbon recycling.

Market developments: The concepts of green and blue ammonia are gaining traction as part of global efforts to transition to a low-carbon economy. There are ongoing research and development initiatives, pilot projects and investments around scaling up green and blue ammonia production.

Several countries and organisations are exploring the use of green and blue ammonia for energy applications – for example Japan aims to co-fire all coal powerplants with at least 20% green ammonia by 2030 – and to decarbonise various industries.

5 Are there any regulations or standards for ammonia fuel and engines?

Using ammonia as a marine fuel is due to be covered in a future extension to the International Maritime Organisation's IGF Code. Until then, ammonia-fuelled ships must use the alternative design requirements under SOLAS and the related risk-based design and certification criteria used by several class societies. Several class societies have already released their initial sets of rules for classifying ammonia-fuelled vessels.

The IGC Code contains requirements for the carriage of ammonia on gas carriers that can be used for understanding handling and storage on ammonia-fuelled vessels. However, the use of ammonia as a fuel on gas carriers is currently challenged by the IGC Code, which prohibits the use of toxic cargoes as fuel. The difficulties posed by this clause have been accepted and an amendment to allow gas carriers to use ammonia is under development.

To date there are no rules or standards for ammonia as a marine fuel. There are several ISO standards that relate to ammonia quality for use in land-based industrial applications, which can serve as guidelines until a specific marine bunker standard is developed.

B Engine availability

6 Are ammonia marine engines currently in use?

Both four-stroke and two-stroke engine designers are developing the first commercial ammonia-fuelled marine engine concepts, with the first deployments on vessels expected in 2025.

7 When will the first WinGD ammonia-fuelled engines be delivered?

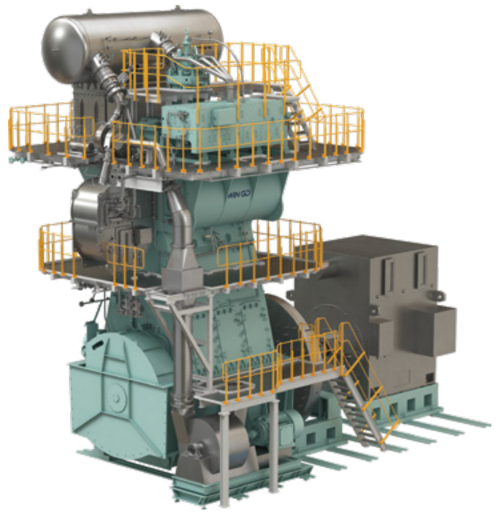
The first WinGD-designed X-DF-A ammonia-fuelled engines, in 52- and 72-bore sizes, will be delivered by Q2 2025.

WinGD is developing the X52DF A engine, with an order for two engines for LPG/ammonia carriers being built for Exmar LPG. It is also developing the X72DF A as part of a collaboration with CMB, the Belgian ship owner, for a series of ammonia-fuelled 210,000 dwt bulk carriers.

8 How will WinGD roll out ammonia capability across its engine range?

The portfolio will be extended in the following years to cover applications for different vessel types. The planned roll-out, subject to change based on market demand, is presented below:

Engine Type	Earliest delivery date
6X52DF-A-1.0	Q2/2025
6X72DF-A-1.0	Q3/2025
X62DF-A-1.0	Q3/2026
X82DF-A-1.0	Q3/2026
X62DF-A-S1.0	Q1/2027
X52DF-A-S1.0	Q3/2027



9 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 and LNG-fuelled X-DF engines to be converted to X-DF-A engines. This is possible due to the common robust engine platform, so that all engines are 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-A engines in the relevant bore-size.

Conventionally, upgrade packages are available at the earliest six months to a year after the first newbuild design is completed.

10 When did WinGD begin investigating ammonia-fuelled engines?

WinGD began combustion tests on a third-party spray combustion chamber (SCC) in 2021. It became clear that the ignition and combustion conditions relevant to two-stroke engines were not adequately covered by smaller SCCs and so a dedicated WinGD SCC was built at our Global Technology Centre in Shanghai and set up at the Engine Research and Innovation Centre in Winterthur.

Combustion tests on WinGD's spray combustion chamber started in December 2022 to obtain detailed data about how ammonia combusts in two-stroke relevant conditions. The tests in WinGD's specifically-designed spray combustion chamber have been the base of all subsequent development and delivered very good results.

Data from the specific combustion tests was used to refine simulations of ammonia combustion in the test engine, helping WinGD to calibrate its own simulation models and derive clear design specifications. It has also shown that it is possible to stay below 5% pilot fuel rate, which has been the target from the beginning.

Essential fuel injection modelling work has contributed to the refinement of engine management models for operating on different alternative fuels. All the simulations that we have built for these new fuels, which have been developed from our combustion modelling, will also be represented in the engine control system and in the Digital Expert system, to monitor these engines continuously.

11 When will WinGD begin engine tests using ammonia as fuel?

Before the modelled emissions profile can be fully validated, the first single cylinder combustion tests will need to begin on WinGD's X-DF-A ammonia dual-fuel engine. The dedicated Single Cylinder Engine (SCE) tests are expected to begin in H1 2024 and will be followed by multi-cylinder engine tests.

The SCE test bench is currently being commissioned, operating on diesel, and will subsequently be converted to operate on ammonia.

12 What are X-DF-A type engines?

WinGD's X-DF-A engines are developed for dual-fuel operation using either ammonia or diesel as fuel. By deploying Diesel-cycle combustion with high-pressure fuel injection – a similar concept to WinGD's diesel-fuelled X Engines – the X-DF-A concept ensures high engine efficiency in both modes, ensuring that operators can run engines cost-effectively on conventional fuels until ammonia is available.

The fuel used can be changed in operation without interruption to power when the engine is running at 25% or more of contracted maximum continuous rating (CMCR).

Only minor modifications are required to adapt WinGD's diesel engine technology for use with ammonia fuel. These include:

- Ammonia fuel injection
- Additional actuation oil rail for ammonia injection system
- Additional actuation oil supply unit
- Modified cylinder cover
- Adapted platforms and piping
- Slight modifications to bedplate, gears and cylinder jacket

13 What is the combustion process for X-DF-A engines?

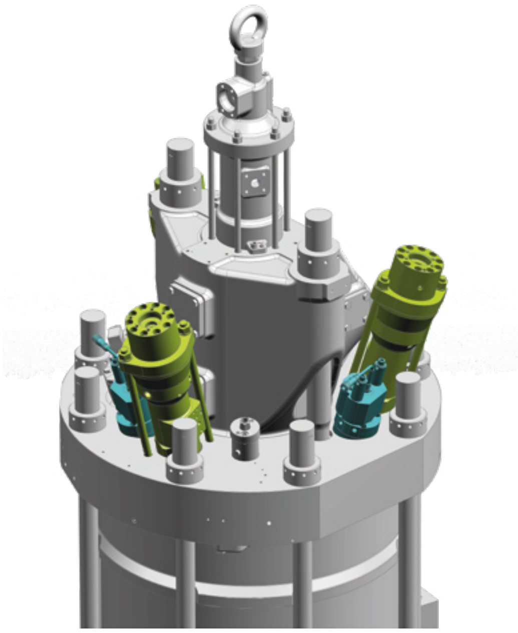
Ammonia combustion in a Diesel-cycle engine refers to the process of using liquid ammonia as a fuel in a diesel engine configuration. The stages of the combustion process are described below.

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 and subsequently the ammonia fuel.

Fuel injection: In an ammonia-based diesel engine, ammonia is injected into the engine's combustion chamber as the primary fuel. The injection system ensures proper atomisation, interaction with the pilot flame and mixing of ammonia with air for efficient combustion.

C Engine concept

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.



Ammonia combustion: Once the pilot fuel ignites, the heat generated ignites the ammonia fuel injected into the combustion chamber, interacting with the pilot fuel spray. The ammonia-air mixture combusts, releasing energy and 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.

14 How is ammonia fuel supplied to the engine?

An ammonia fuel supply system is used to supply ammonia from the tank to the engine. An overview of fuel supply equipment is provided below. See the MIM for the relevant X-DF-A for a detailed description.

Ammonia Storage: Ammonia is stored in dedicated tanks or containers on the vessel. These tanks are designed to handle the pressure and temperature requirements of ammonia storage and comply with safety regulations. They may include safety features such as pressure relief valves and temperature monitoring.

Fuel Supply System (FSS): Ammonia is transferred from the storage tank to the engine by the FSS as required. The ammonia fuel is delivered to the engine within a specific range of temperature, pressure (85 bar) and purity. This transfer is accomplished using low-pressure and high-pressure pumps, heat exchanger and filters. The fuel supply system should be designed to handle the specific characteristics of ammonia, including its corrosive nature.

Fuel conditioning: The ammonia 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 may be employed to ensure the ammonia remains within the desired operating range.

14 How is ammonia fuel supplied to the engine? continued...

Fuel Valve Unit (FVU): The conditioned ammonia fuel is further transported to the FVU, which comprises a series of fuel control valves before the consumers and represents the interface between the engine and the fuel supply system. The purposes of this unit are to isolate the engine from the ammonia supply system, to control the return of ammonia flow to the catch and purge tanks as well as to connect the nitrogen supply system.

As a safety precaution, to ensure the tightness of valves and the proper functioning of components, the FVU performs an ammonia leakage test before the engine starts operating on ammonia fuel. The FVU concept is under WinGD's responsibility and specifications are delivered to certified suppliers.

An ammonia vapour venting system and ammonia fluid drainage system, including recovery components such as catch tank, purge tank and recovery technology must also be installed.

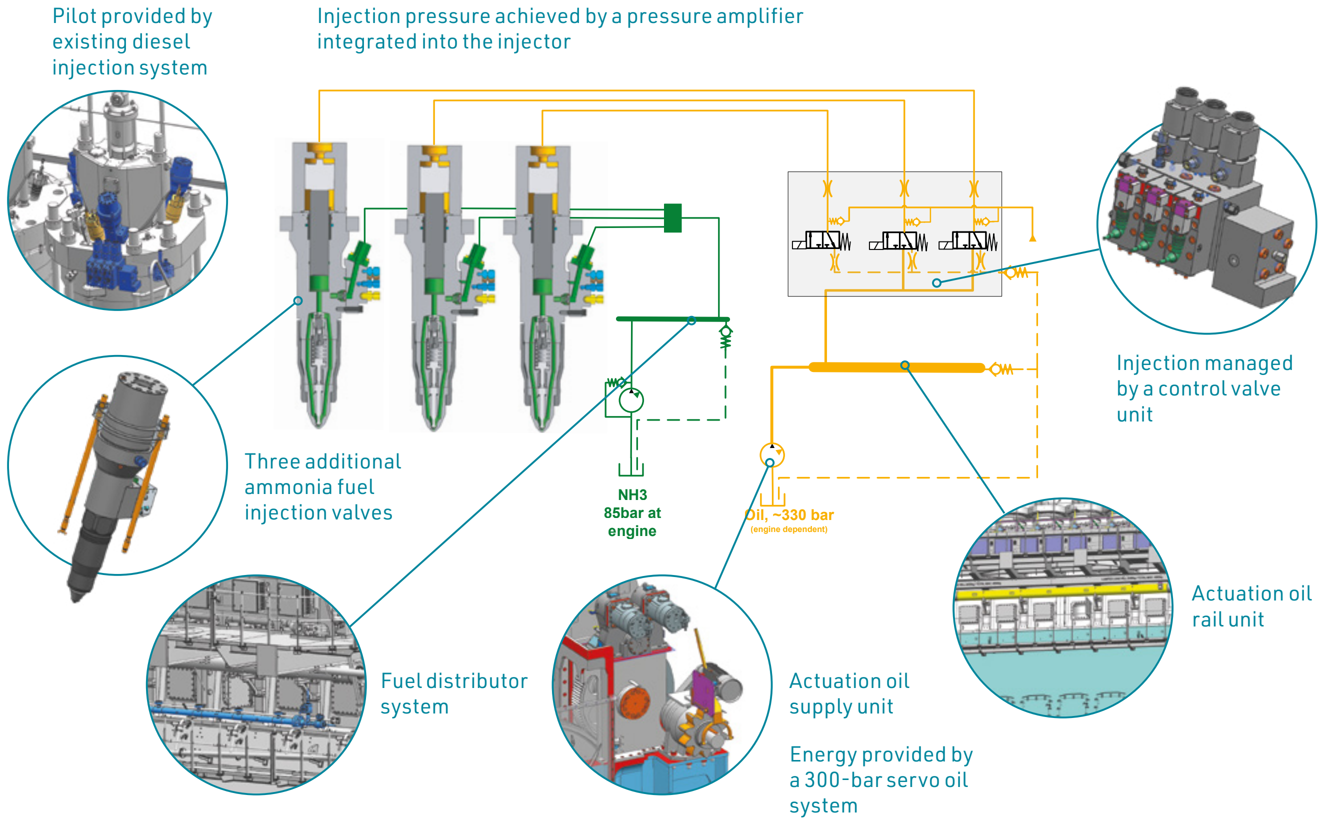
15 What are the specific requirements for ammonia fuel supply to the engine?

Property	Value
Lower Heating Value (LHV)	**≥ 18.6 MJ/Nm 3**
Purity	**≥ 99.5 (% w/w)**
Water	**0.2-0.5 (% w/w)**
Oil	**≤ 0.4 (% w/w)**
Oxygen	**2.5 ppm**
Ammonia temperature range	**35 - 45 °C***
Ammonia feed pressure	**85 bar(g)**
Permissible ammonia pressure fluctuation	**± 2 bar (across all frequencies)**

* Note that no condensate is allowed in the annular space of the main engine ammonia piping.

C Engine concept

16 What does the X-DF-A ammonia fuel injection concept look like?



17 Do engine design parameters need to be changed to optimise ammonia combustion?

Ammonia engine design parameters such as bore, stroke and mean piston speed are the same as for diesel engines in the WinGD portfolio. For upgrades from LNG engines, tuning parameters such as compression ratio may be needed to optimise ammonia combustion.

18 Which engine parts need to be converted to upgrade an existing WinGD engine for ammonia?

Depends on the engine being converted. See question 32 (page 20) for more details.

C Engine concept

19 How is safety ensured on the X-DF-A engine and across the fuel supply system?

Safety measures are implemented throughout the ammonia supply system, including leak detection systems, emergency shutdown systems, double wall barriers, ventilation, and fire suppression systems 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 ammonia fuel supply system. Sensors are used to monitor parameters such as pressure, temperature, flow rate, and fuel quality. The X-DF-A safety concept is available and published on the WinGD website:

PDF https://www.wingd.com/en/documents/w-2s/engine-installation/concept-guidances/dg9729-concept-guidance-for-x-df-a/

D Engine performance

20 What is the engine efficiency of the X-DF-A engine?

WinGD is aiming to deliver the best possible efficiency and, at this late stage in development, projects that X-DF-A will achieve the same efficiency to that of X-Engines in diesel mode and similar efficiency when running on ammonia.

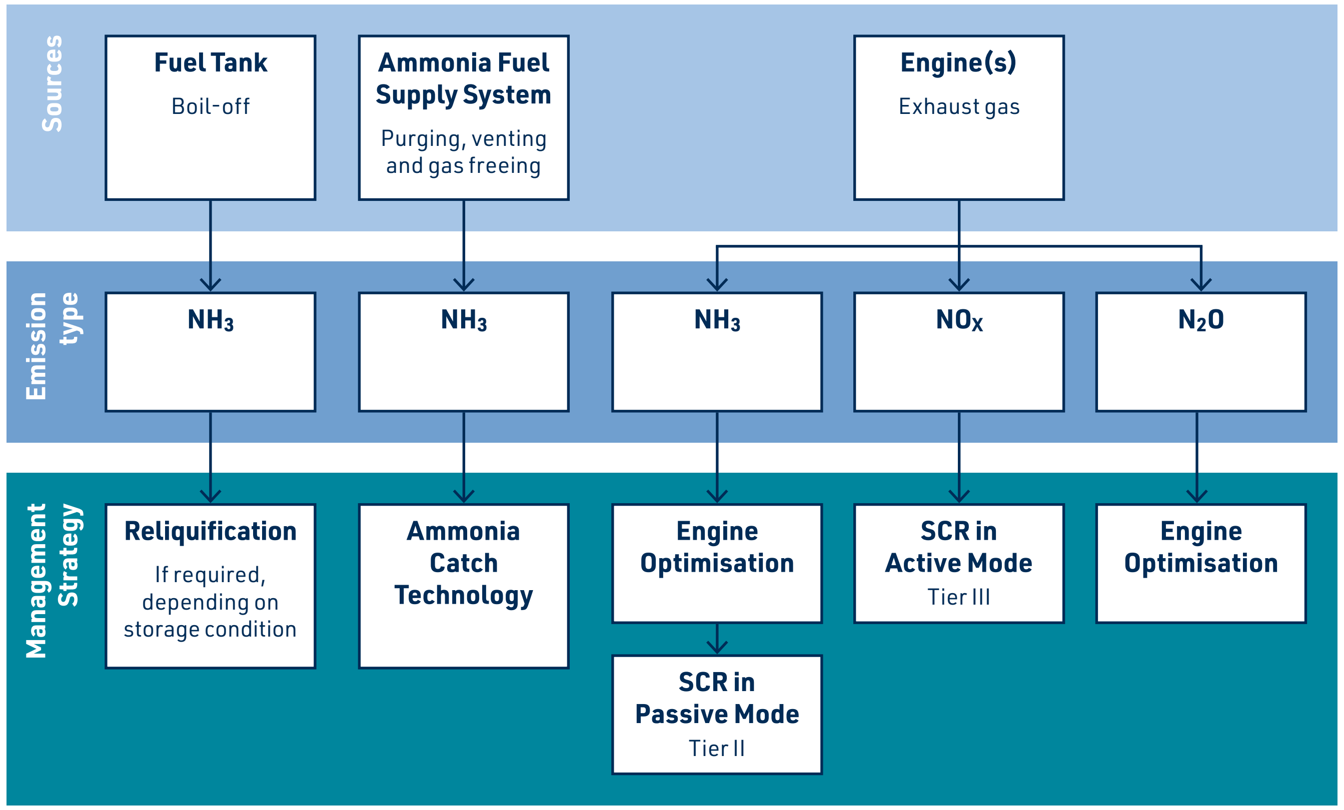
21 Will there be major differences in the engine load acceptance and dynamic behaviour on X-DF-A engines compared to conventional diesel engines?

No.

D Engine performance

22 Which emissions are created from ammonia combustion and how are they treated with X-DF-A?

While ammonia itself is a carbon-free fuel, the combustion process in ammonia engines produces certain exhaust gas emissions.



Nitrogen oxides (NO_X): During combustion, ammonia can contribute to the formation of nitrogen oxides (NO_X), including nitrogen dioxide (NO_2) and nitric oxide (NO).

NO_X emissions can have environmental and health impacts, contributing to air pollution and the formation of smog. On X-DF-A engines, NO_X levels can be kept within IMO Tier II levels without aftertreatment and, with existing abatement technology, Tier III emission levels can be reached.

N_2O is another potential emission from ammonia combustion, with significant greenhouse warming potential. In the absence of IMO limits, WinGD has developed the X-DF-A engine, maximising engine efficiency, minimising N_2O, whilst remain compliant with the emission regulations in place. Combustion and injection system design have been designed to drastically reduce CO_2-equivalent emissions without additional aftertreatment.

D Engine performance

22 **Which emissions are created from ammonia combustion and how are they treated with X-DF-A?** continued...

Particulate matter (PM): Ammonia engines can produce particulate matter emissions, primarily in the form of ammonium salts. These particles can be formed through the reaction of ammonia with other exhaust components.

Ammonia slip: In some cases, unburned ammonia can be present in the exhaust gases. Ammonia slip occurs when the combustion process does not completely convert all ammonia into nitrogen and water vapour. This can occur due to suboptimal combustion conditions or incomplete mixing of ammonia with air. Minimising ammonia slip is important to improve overall engine efficiency and reduce emissions.

IMO does not yet regulate ammonia slip but WinGD can provide solutions for very low concentrations, following class recommendations. Where selective catalytic reduction (SCR) is installed and Tier III NO_X performance is not needed, the SCR unit can be employed to reduce the ammonia emission under limit target without urea dosing.

E Engine operation

23 Is it possible to mix ammonia and traditional liquid fuel? There is the risk of ammonia bi-sulphate formation if mixed with diesel?

Although mixing of ammonia with fuel oil before the engine cannot be considered viable, a 'fuel-sharing' mode is being considered. This involves injecting both ammonia and MGO into the combustion chamber, at the minimum level needed for piloting the ammonia combustion. Creation of ammonia bi-sulphate is not expected to be an issue if ammonia and MGO are not mixed before combustion.

24 In case of an ammonia trip, how will the ammonia pressurised in the engine piping be released?

Refer to the X-DF-A concept guidance.

25 What lube oil shall be used for an engine running with ammonia or Methanol? Is the feed rate similar to the traditional engine?

WinGD is currently working closely with oil and additive suppliers to answer these questions. The feed rate is expected to be similar to today's engines.

26 What will be the backup mode when the engine is running on ammonia?

In the event of an issue with running on ammonia the engine will automatically switch to diesel mode.

27 What will the pilot fuel be? And in what amount?

Pilot fuel can be used as with current WinGD dual-fuel engines. Pilot fuel is expected to be about 5% at 100% load.

28 Will the engine start and stop with ammonia?

No. Fuel changeover from diesel to ammonia will take place when the engine is running at 25-80% engine CMCR power. Developments are ongoing to reduce minimum CMCR power for running with ammonia.

29 How does WinGD support training for the operation and maintenance of ammonia-fuelled engines?

WinGD follows the same training methodology for X-DF-A engines as for its X-DF LNG engines, with courses including information about control system logic, mechanical components and a strong focus on safety aspects related to fuel.

WinGD is already assisting operators and maritime academies in preparing training syllabuses for the use of ammonia as a marine fuel, for example under a joint venture with AET and Akademi Laut Malaysia.

E Engine operation

30 How do operators prevent exposure of crew to the toxicity of ammonia and what countermeasures are required?

A risk assessment is also mandatory for ammonia engines (e.g., HAZID). There are several design precautions and countermeasures recommended in class rules and based on IGC Code provisions.

These include.

- The engine room must be a gas safe area
- Double-wall piping concept
- Annular space ventilation arrangement
- Ammonia leakage detectors (engine side):
  - Annular space ventilation air outlet
  - Piston underside area for toxicity
  - Exhaust gas system
- Ammonia leakage detectors against toxicity in the engine room must be located at least at ceiling and bottom. Additional ammonia detectors may be required depending on the results of ammonia dispersion studies as performed by the shipyard.
- Ammonia piping protection against damage

Operational precautions include maintaining safe and fast escape routes and procedures, and restricting access to non-gas-safe areas (e.g. fuel storage rooms). Despite the fact that the engine room is a gas-safe area, Emergency Escape Breathing Devices (EEBD) must be available in the main engine machinery space, and crew entering the main engine machinery space must be equipped with portable ammonia detectors.

Independent emergency exits should be planned, with clear floor markings to guide to the closest exit, considering potential limited visibility caused by an ammonia cloud.

F Capital and operating costs

31 What is the cost of upgrading to an ammonia engine?

Upgrade prices are not clear yet, as this depends on the features already installed on the existing engine. As an example, the cost items on an upgrade from X-DF to X-DF-A will be:

- Ammonia injection and pilot fuel system
- WICE control system

32 What do you know about costs for the NO_X aftertreatment system?

NO_X emissions are expected to be comparable to today's diesel installations. With current information we estimate that the CAPEX range will be similar to today's iSCR systems.

OPEX could be slightly lower than today, as the expected reduction agent consumption can be optimised in a different way (e.g., leveraging NH_3 in the exhaust stream).

33 Ammonia fuel price

Understanding the price of the various types of ammonia (blue, green, etc) is challenging whilst production is being scaled up, but current forecasts are that it will be more expensive than HFO – although carbon prices will reduce this gap considerably – but cheaper than equivalent methanol as there is no need for carbon capture or biogenic carbon.

Committed to the decarbonisation of marine transportation through sustainable energy systems.

WinGD designs marine power ecosystems utilising the most advanced technology in emissions reduction, fuel efficiency, digitalisation, service and support. With their 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 its inception as the Sulzer Diesel Engine business in 1893, it is powering the transformation to a sustainable future.

WinGD is a CSSC Group company.

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