FAQ

Ammonia Dual-Fuel Engines

X-DF A by WinGD

Ammonia

WIN GD

Introduction

WinGD's X-DF-A engine platform is the first commercially available two-stroke marine engine capable of using ammonia fuel, which can be produced entirely from renewable electricity and therefore represents a potential pathway to zero- or near-zero emissions ship operation in line with current and anticipated maritime regulation.

The first X-DF-A engines are already in operation, with a substantial early orderbook confirming extensive market interest in ammonia as marine fuel.

This document provides brief, non-technical answers to some of the most commonly asked questions around X-DF-A engines and ammonia fuel.

For more extensive, technical details to support project planning, WinGD has published a range of manuals on design, operation and the X-DF-A safety concept.

To view the full range of documentation available for X-DF-A engines, please visit https://wingd.com/products-solutions/engines

FAQ 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.25 on ammonia's GHG and air pollutant emissions profile). Although current ammonia production mainly relies mostly on fossil energy sources, near-zero-emission production methods are emerging, including electrolysis (green ammonia) and fossil-based routes with carbon capture and storage (blue ammonia). 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 with reasonable storage volumes. Ammonia is also liquid at near ambient conditions, and is therefore easier to handle than cryogenic alternative fuels such as LNG.

2 What are the main 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. While handling ammonia as a cargo is widely established, using it as a fuel is not common practice yet.
- 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 conventional fuels relatively more expensive.

3 What types of ammonia are available?

There are several different types of ammonia, available to greater or lesser extents and at varying cost.

Grey ammonia is the most common form of ammonia produced today. It is made with fossil feedstock such as natural gas and its production emits significant amounts of CO_2.

Blue ammonia is produced from fossil feedstock but with separation of CO_2 for utilisation or sequestration, resulting in lower well-to-tank emissions. Green ammonia, conversely, is produced entirely from renewable hydrogen and therefore its production only results in CO_2 emissions arising from the transportation and processing of feedstocks and products.

As operating a marine engine on grey ammonia results in higher CO_2 emissions than using conventional fuel oils, only blue or green ammonia can be considered to realise the decarbonisation potential of ammonia fuel.

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.

4 How can ammonia be made carbon neutral? continued...

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 and storage (CCS): Another approach to green ammonia production is to capture carbon generated as a byproduct of the fossil ammonia production process. CCS 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?

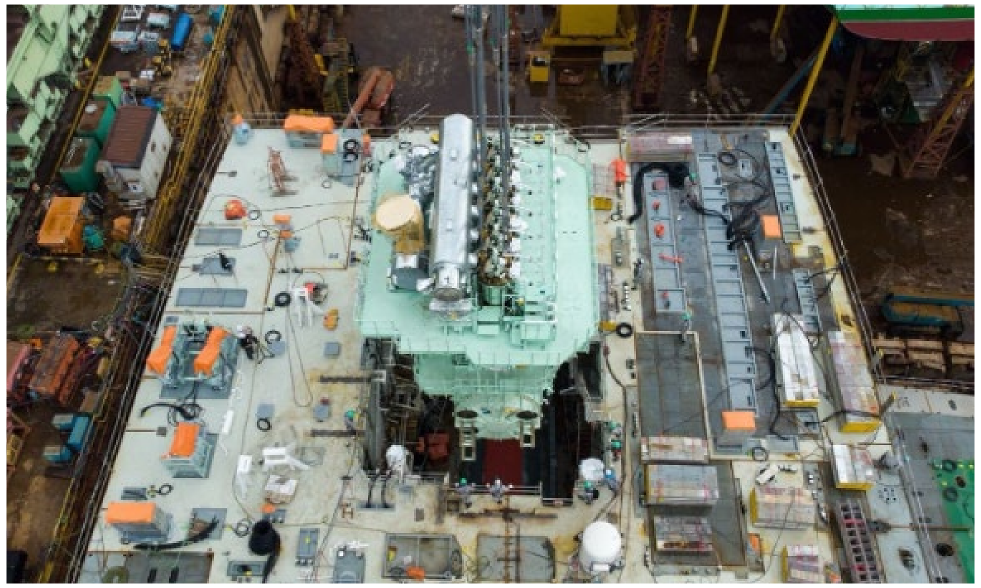
Yes. Under the International Maritime Organization's IGF code, vessels fuelled with ammonia are regulated under interim guidelines. Specific interim guidelines for ammonia carriers allowing the use of ammonia cargo as fuel were finalised under IGC Code in September 2025 and are set to enter into force in July 2026. This also allows for early and voluntary application, providing a formal pathway for operators to adopt ammonia fuel sooner.

All major classification societies have already issued supporting rules for ammonia-fuelled vessels, aligned with these IMO frameworks. While a dedicated ISO standard for marine ammonia bunkering is under development, existing industrial ammonia standards serve as the temporary technical reference for fuel specifications and handling.

B Engine availability

6 What is the current status of X-DF-A production engines?

The first ammonia two-stroke engine was delivered to the shipyard in June 2025. The sea trial is scheduled for Q2/2026, after which the world's first ammonia two-stroke engine will enter operation.



As of February 2026, 34 X-DF-A engines have already been contracted. These engines will serve a diverse range of ship types using ammonia as fuel, including mid-sized ammonia/LPG carriers, bulkers, feeders, and Aframax tankers. Additional applications are currently under discussion.

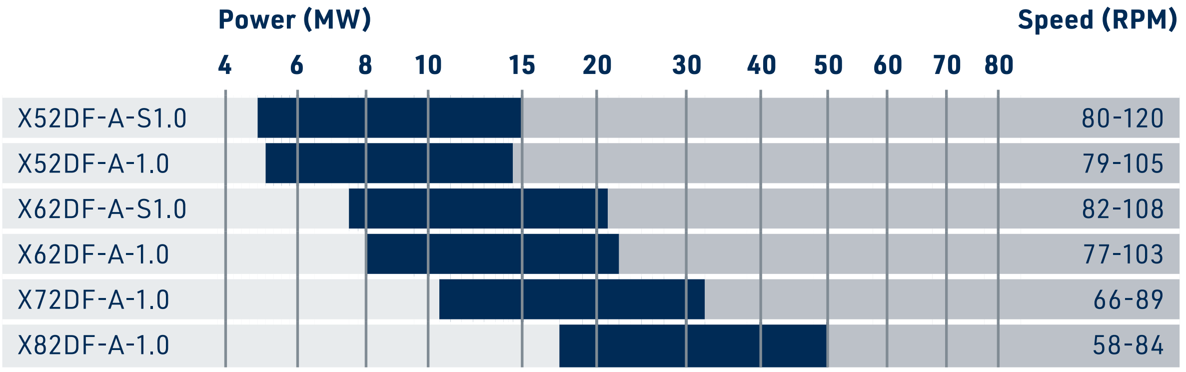
B Engine availability

6 What is the current status of X-DF-A production engines? continued...

In January 2026, the 52-bore X-DF-A successfully passed its type approval test, meaning future engines of this size are assured to fulfil IMO and class requirements if built in accordance with the qualified design. Type approval tests for the 72 bore X-DF-A will also take place in the first half of 2026.

7 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 engines which are ready to be ordered, are presented below:



8 Are upgrade packages available for existing WinGD X/X-DF engines?

WinGD offers 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 base 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 follows the introduction of newbuild X-DF-A engines in the relevant bore-size. Conventionally, upgrade packages are available at the earliest six months after the first newbuild design is completed.

B Engine availability

9 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 2-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.

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.

C Engine concept

10 What are X-DF-A type engines?

WinGD's X-DF-A engines are developed for dual-fuel operation using ammonia and 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 and ammonia.

13 What are X-DF-A type engines? continued...

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

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

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

X-DF-A engines use the Diesel cycle combustion process, whereby liquid ammonia is injected at high pressure and ignited with a small amount of pilot fuel.

12 How is ammonia fuel supplied to the engine?

Ammonia is supplied to the engine at 85 +/-2 bar(g). See the MIM for the relevant X-DF-A for a detailed description:

https://wingd.com/media/tzcefywl/mim_wingd_x52df-a-10.pdf

Ammonia bunkering station and storage system: allows the transfer of ammonia on board vessel.

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 final design may vary depending on the FSS supplier.

Delivery of ammonia fuel to the engine 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 Valve Unit (FVU): The purpose of the Fuel Valve Unit is to isolate the engine from the ammonia supply system, to control the ammonia flow to the catch and purge tanks as well as to connect the nitrogen supply system and the Ammonia Injector Cooling Water System (AICWS). The FVU concept is under WinGD's responsibility and specifications are delivered to certified suppliers.

Ammonia Processing System: The purpose of the Ammonia Vapour Processing System (AVPS) is to collect and treat ammonia vapour released from the ammonia fuel system.

During normal ammonia operation, and even during purging, the amount of vapour directed to the AVPS is minimal, as primarily nitrogen from the purging process – with only a small residual concentration of ammonia – needs to be handled.

Inert gas supply system: The purpose of the inert gas supply system is to provide inert gas (e.g. N2) to the engine during the purging procedures and pressure testing.

13 Why does the X-DF-A deploy a cooling water system, unlike other proposed ammonia-fuelled engine concepts?

The Ammonia Injector Cooling Water System is used for two main purposes:

- Cooling of ammonia injectors during diesel mode
- Remove the remaining ammonia during the purging procedure

WinGD uses water after purging with inert gas to remove traces of ammonia that may remain trapped in cross sections of the injection system. Water, being a liquid, follows the same paths as liquid ammonia and is able to absorb the residual ammonia it encounters. After completing the maintenance purging procedure, the crew can service the system with confidence.

When water is available, it can also be circulated continuously after purging ammonia from the system. This has a beneficial effect on injector lifetime during diesel mode operation.

13 Why does the X-DF-A deploy a cooling water system, unlike other proposed ammonia-fuelled engine concepts? continued...

The system includes:

- Ammonia injector buffer tank
- Heat exchanger (cooling and heating)
- Injector cooling water pump
- Interface valves
- Piping system

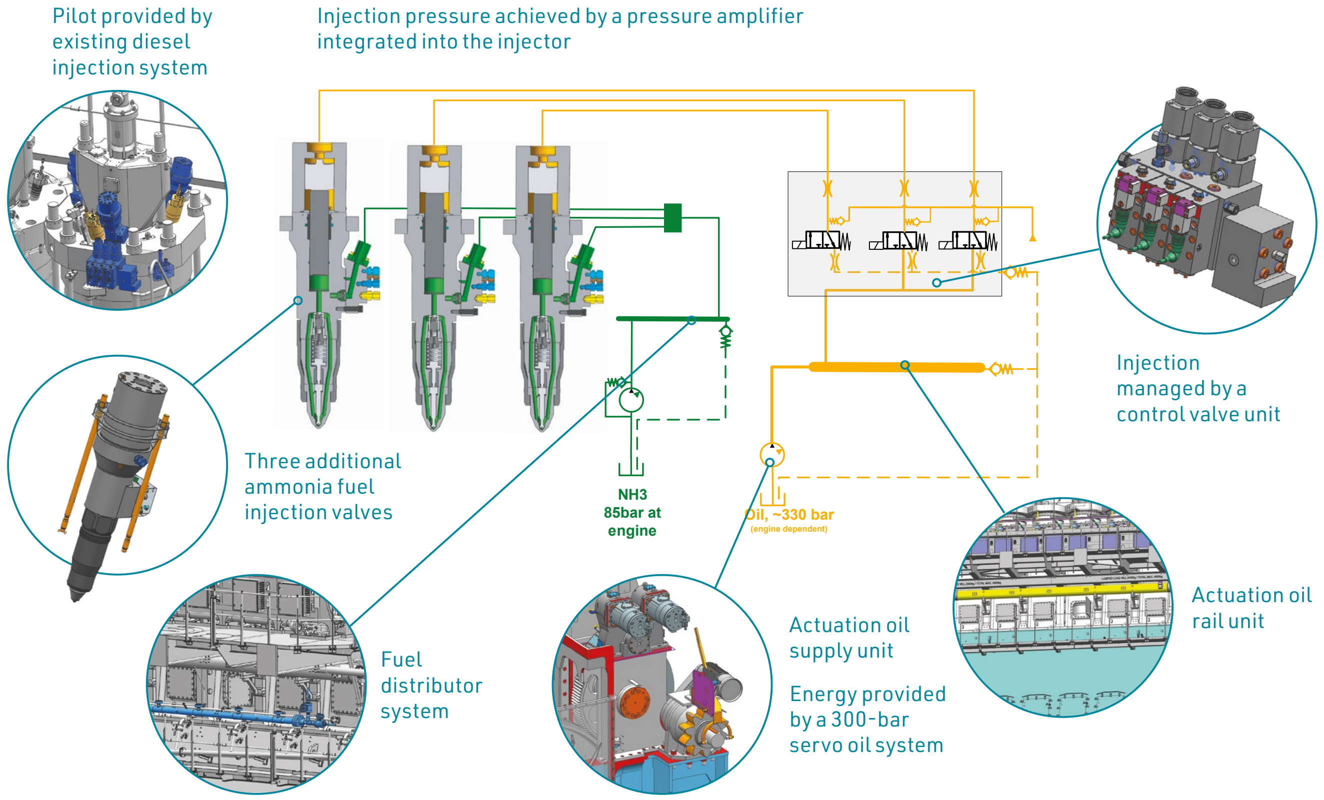
AICWS parameters	
Water buffer tank operational pressure	**22 bar(g)**
Pump head and water buffer tank design pressure	**30 bar(g)**
Water buffer tank volume	**min. 5 times system volume**
Ammonia/water mixture in the buffer tank	**max. 10%**

14 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	**≤ 0.5 (% w/w)**
Oil	**≤ 0.4 (% w/w)**
Oxygen	**Not specified**[1]
Ammonia temperature range	**25 - 45 °C**[2]
Ammonia feed pressure	**85 bar(g)**
Permissible ammonia pressure fluctuation	**± 2 bar (across all frequencies)**

[1] Limits for the tank system can apply.
[2] 35 - 45 °C if no dry air is supplied for annular space.

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



16 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.

17 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.

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

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 WinGD website:

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

18 How is ammonia vapour production minimised during purging?

During purging, by maintaining the pressure and the temperature from the engine (25-45°C) at 22 bar, we ensure that the ammonia remains liquid to the catch tank. Some traces of ammonia vapour in the nitrogen (due to partial pressure) can be generated but evacuated from catch tank by the vent to AVPS (description in 12). This eliminates the need for knock out drums and represents a key advantage of WinGD's technology concept.

19 How does X-DF-A prevent release of ammonia from the injection system?

Recirculation of ammonia in the injectors is controlled and managed by an Ammonia Containment and Management System (ACMS).

This allows the annular space of the double wall piping to be decoupled from the normal ammonia concentration in the injector ventilation system.

The injectors are connected to the ACMS, which is an on engine system that neutralises ammonia.

20 How are injectors sealed?

The injector is sealed without using sealing oil against ammonia, to improve injection system reliability. Instead, ammonia at high pressure at the injector tip is contained through component tolerances and a low pressure ammonia ring. Additional mechanical seals further block ammonia.

On the upper side of the injector, the oil circuit follows a similar principle: high-pressure oil acts on top of the plunger, component tolerances reduce the pressure, and sealing is then applied to limit the mass flow to the drain. To prevent any mixing between oil and ammonia, several barriers are implemented, consisting of seals and air gaps.

The injector is also ventilated to collect any internal ammonia recirculation and route it to the Ammonia Management and Containment System (ACMS), where the ammonia is neutralised.

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

In Ammonia mode the main fuel is liquid Ammonia. The Ammonia fuel is injected into the engine at high pressure. The normal diesel injectors provide pilot fuel to ignite the Ammonia fuel. The pilot flame penetrates the Ammonia 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 maximum sulphur content of 0.5% m/m.

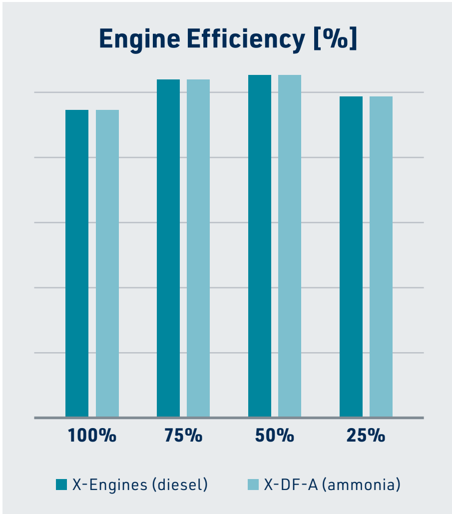
22 Is the fuel injection duration higher for ammonia fuel?

The injection system is adapted to the higher flow rate which comes from the lower LHV of ammonia. 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.

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

Initial tests on both the test and commercial engines confirm simulation and spray combustion chamber result, with engine efficiency matching that of a conventional diesel engine. This validates the expected efficiency provided in GTD data.

Based on initial performance and developments on commercial engines, it is anticipated that efficiency in ammonia mode will be improved to higher than that achieved in diesel mode.

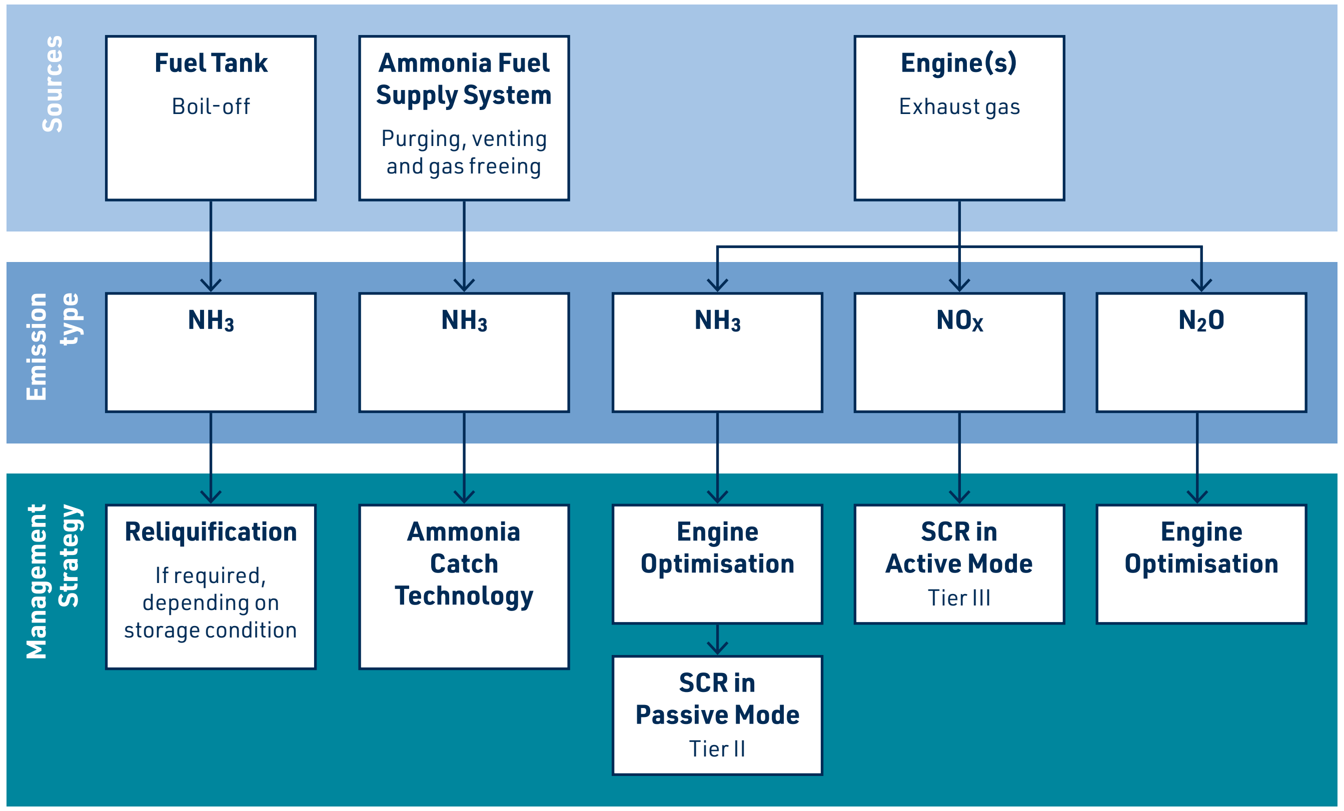


24 Will there be major differences in the engine load acceptance and dynamic behaviour on X-DF-A engines compared to conventional diesel engines?

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

25 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 remaining 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.

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.

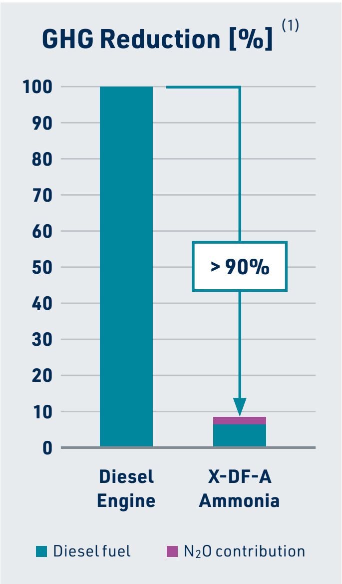
25 Which emissions are created from ammonia combustion and how are they treated with X-DF-A? continued...

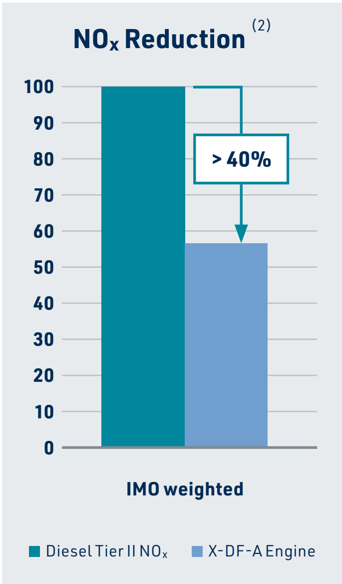
Ammonia slip: In some cases, unburned ammonia can be present in the exhaust gases. Ammonia slip occurs when the combustion process does not completely convert all ammonia into nitrogen and water vapour. This can occur due to suboptimal combustion conditions or incomplete mixing of ammonia with air. Minimising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

26 What emissions measurements has WinGD taken for the X-DF-A engine?

Emissions measured on WinGD's test engine – and subsequently confirmed on commercial engines – show very good results. Compared to a conventional Diesel engine, greenhouse gas emissions were reduced by >90%, with low N_2O (1-2.5 parts per million) and diesel pilot achieved. Very low NH3 emissions and NO_x were also recorded.





[1] Calculated over E3 cycle, IMO weights applied.
[2] Results are referred to Tier II values (measurements before SCR)

27 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.

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

Please refer to the X-DF-A Operation Concept, available on our website www.wingd.com. The document is part of the engine documentation and can be found under **Installation Instructions, Concept Guidance, and Safety Regulations**.

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

Please use the link below to view the document of validated engine oils for WinGD engines with approved lubricants.

PDF https://wingd.com/media/watb1kkz/validated-engine-oils-for-wingd-engines_v17.pdf

As for diesel, LNG or methanol engines, the feed rate is determined by the lubrication pump and can be set from 0.6 to 1.2 g/kWh.

30 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.

31 What pilot fuel does the engine use and how much?

The pilot fuel can be Marine Diesel Oil (MDO) and MGO with maximum 0.50% m/m sulphur (0.10% m/m sulphur for Tier III operation). 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.

32 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 the minimum CMCR power for running with ammonia.

33 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.

Furthermore WinGD is already assisting operators and maritime academies in preparing training syllabuses for the use of ammonia as a marine fuel.

34 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 and monitoring (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

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

Upgrade prices will need to be calculated in detail according to the bore size, cylinder numbers and future-fuel readiness of the engine, i.e. will depend on the features already installed on the existing engine.

For further information on retrofit scope and cost, contact retrofit.solutions@wingd.com.

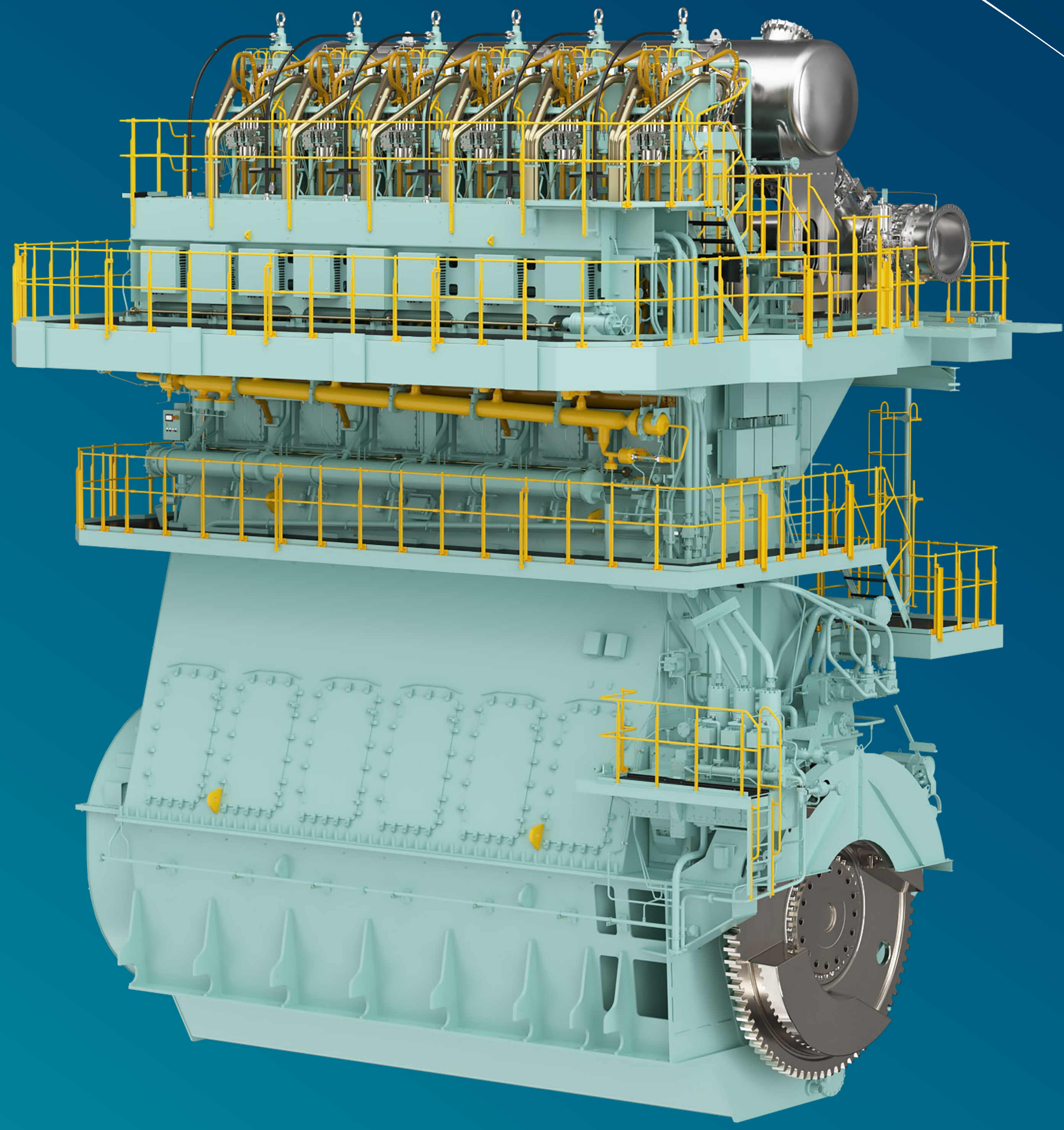
36 What are the costs of the NO_X aftertreatment system?

SCR size is determined by diesel mode, which has higher NO_x than ammonia mode. Therefore there is no impact on cost compared to a diesel engine.

WinGD also offers an Integrated Selective Catalytic Reduction (iSCR) system for 52- and 62-bore ammonia engines, which allows for further optimisation of installation and performance.

37 How much does green ammonia cost

Although fuel costs are decreasing as renewable ammonia production scales up, this may not be enough for it to become competitive with VLSFO, meaning that carbon pricing will be needed to reduce the gap.



Notes

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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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