Everllence B&W
two-stroke
marine engines

Update on the development of ammonia-based propulsion systems based on Everllence two-stroke technology

Everllence B&W two-stroke engine operating on ammonia

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Ammonia as a marine fuel is put into perspective as this paper presents our current knowledge about ammonia as a potential long-term fuel for two-stroke marine engines. We address the challenges encountered by the maritime market, which are best described as a paradigm shift to ensure compliance with global decarbonisation goals.

To develop an engine for a new fuel such as ammonia calls for partnerships, cooperation and an understanding of the market interests. Everllence works diligently towards designing the Everllence B&W engine for operation on ammonia and offering retrofit conversions of existing two-stroke engines to ammonia.

Decarbonisation constitutes one of the largest transitions encountered, and the short deadline to succeed requires a united and committed approach from the entire supply chain from well to wake.

1. Introduction

One of the future fuel candidates receiving a growing global interest and likely to play a significant role in the decarbonisation is ammonia (NH_3). Our aim with this paper is to share our current knowledge about ammonia as a potential long-term fuel for two-stroke marine engines and to give an update on the development of ammonia-based propulsion systems based on the Everllence two-stroke technology.

Thanks to the carbon- and sulphur-free molecular composition of NH_3, combusting it in an engine creates near-zero CO_2 and SO_X emissions. From a well-to-wake perspective, ammonia becomes a carbon-neutral fuel when produced from renewable energy sources like electricity produced from hydropower, wind or solar energy. Furthermore, emissions of air pollutants related to carbon (black carbon or soot, unburned hydrocarbons (HC), methane slip, and carbon monoxide (CO)) are eliminated.

One of the characteristics defining the two-stroke engine portfolio of Everllence in Fig. 1 is the fuel diversity.

Another distinctive feature is the ability to operate on almost any fuel or fuel quality with no or limited decrease in efficiency and with the reliable performance and operating characteristics as the conventional two-stroke engine even in adverse weather conditions.

The fundamental reasons for the large tolerance to poorly ignitable and burning fuels are the low speed of the engine, allowing time for the combustion to finish, and the large dimensions, leading to large volume-to-surface ratios, which is beneficial for a complete combustion and low wall heat losses.

The beneficial carbon-free nature of ammonia implies that ammonia combustion physics will not fully resemble the combustion characteristics of previously known two-stroke fuels. To provide our customers with an optimised and reliable engine of the well-known standard of Everllence, it is vital to research the entire propulsion solution and two-stroke engine processes, that is, ignition, combustion and emissions as well as fuel handling.

Therefore, research of ammonia as a fuel for two-stroke engines involves extensive testing with a complete engine monitoring setup to achieve fundamental information about, for example, the ignition properties of ammonia in a two-stroke engine, pilot fuel requirements and emissions. These research results govern the final design of the ammonia-burning engine and auxiliary systems.

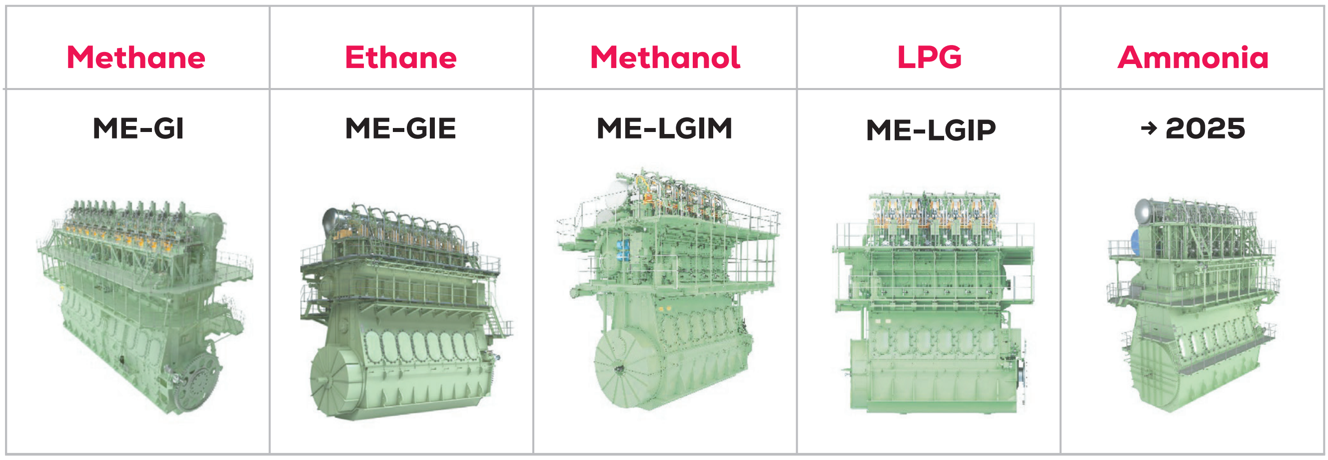


Fig. 1: Everllence B&W dual-fuel two-stroke engine portfolio

2. United effort towards a future decarbonising fuel

At Everllence, we are committed to optimise the environmental impact of our engines. To develop an engine for new fuels such as ammonia calls for partnerships and an understanding of the market interests. An analysis of the actual potential is also essential before starting the development of the ammonia engine. In this case, the fuel can enter the market as an intermediate fuel until green ammonia is available and the logistics are in place.

Minimising the impact of shipping on the climate and the environment is a crucial contribution to reaching the global climate targets. One of the goals would be carbon-neutral transportation. Currently, worldwide maritime transport emits around 3% of the global greenhouse gas (GHG) emissions. Like other industries, the marine industry must decarbonise, and the International Maritime Organization (IMO) has set a target of net-zero CO_2 emissions from shipping by 2050.

An uncertain and most essential parameter in the decision of the future fuel is the prices of the future fuels. On the one hand, if green ammonia was available today, it would be several times more expensive than very-low-sulphur fuel oil (VLSFO) and liquefied natural gas (LNG). On the other hand, we acknowledge that the marine market widely understands that if CO_2 and GHG footprints are to be reduced for the foreseeable future, some kind of international regulation of the CO_2 and GHG emissions will come into force. New European Union (EU) and IMO regulations, focused on emissions among others, are set to take effect.

We have entered into commitments with other players to investigate the opportunity for ammonia as the coming future fuel and hydrogen carrier. Everllence integrates existing technology in the ammonia-based propulsion system while designing the ammonia fuel injection, combustion components, exhaust gas after-treatment technology, and engine components. In addition, Everllence provides the engine test bed and conducts the engine trial run.

3. Reflections on ammonia as a future two-stroke marine fuel

The physical/chemical properties of ammonia govern many of the design aspects of an ammonia-fuelled propulsion system and auxiliary systems, including storage. Vessel owners have to consider ammonia storage and availability, vessel trade pattern, and related emission regulations combined with an increased focus on the environmental impact of the vessels.

3.1 Physical properties

Generally, ammonia is produced via the Haber-Bosch synthesis process from hydrogen and nitrogen. While the nitrogen comes from air separation, several production routes can be used to produce hydrogen, most prominently from steam reforming of hydrocarbons or from electrolysis of water, as outlined in more detail below.

For comparison, Table 1 shows the physical properties of ammonia, other alternative fuels, and marine gas oil (MGO.)

Parameters for fuel supply and injection pressures for NH_3 are 80 bar and 600–700 bar, respectively. These parameters have been confirmed through engine testing.

A comparison of the properties related to storage in Table 1 shows that hydrogen (H_2) liquefies when cooled to temperatures below -253°C, and LNG at -162°C. By contrast, ammonia liquefies already at -33°C.

Liquid ammonia can be stored at a pressure above 8.6 bar at ambient temperature (20°C). To keep it in the liquid phase if the ambient temperature increases, it is common to design non-refrigerated ammonia tanks for approximately 18 bar.

3.2 Transition towards green ammonia production

Although it is in the nature of things that combustion of ammonia emits no CO_2, as it contains no carbon atoms, large-scale industrial productions of ammonia are based mainly on a fossil fuel feedstock for grey and blue ammonia production. This conventional ammonia production produces CO_2 as a by-product. Blue ammonia production involves capture of the generated CO_2, which is liquefied and stored using the carbon capture and storage (CCS) principles.

Energy storage type/ chemical structure	Energy content, LHV	Energy density	Fuel tank size relative to MGO	Supply pressure	Emission reduction compared to HFO Tier II [%]			
	[MJ/kg]	[MJ/L]		[bar]	SO_x	NO_x	CO_2	PM
Ammonia (NH_3) (liquid, -33°C)	18.6	12.7 (-33°C) 10.6 (45°C)	2.8 (-33°C)*1 3.4 (45°C)*1	80	100	~50	~90	~90
Methanol (CH_3OH) (65°C)	19.9	14.9	2.4	10	90–97	30–50	11	90
LPG (liquid, -42°C)	46.0	26.7	1.3*2	50	90–100	10–15	13–18	90
LNG (liquid, -162°C)	50.0	21.2	1.7*2	300	90–99	20–30	24	90
LEG (liquid, -89°C)	47.5	25.8	1.4*2	380	90–97	30–50	15	90
MGO	42.7	35.7	1.0	7–8				
Hydrogen (H_2) (liquid, -253°C)	120	8.5	4.2					

1) The relative fuel tank size for ammonia has been provided for both cooled (-33°C) and pressurised tanks (45°C)
2) Assuming fully refrigerated media

Table 1: Alternative fuel comparison

However, ammonia has the potential to become the sustainable future fuel choice, when it is produced using hydrogen obtained by using renewal energy sources, see Fig. 2.

Ammonia (or anhydrous ammonia) is a globally traded commodity. The annual global ammonia production is approximately 180 million tonnes, of which approximately 80% becomes feedstock for fertiliser production [1]. Therefore, transport and storage of ammonia from production facilities to end users have been going on for years.

3.2.1 Electrolysis of water
To produce sustainable green ammonia using hydrogen obtained by electrolysis of water ($2\ H_2O \rightarrow 2\ H_2 + O_2$), the electricity must be produced using only renewable energy sources.

3.2.2 Nitrogen separation from air
Separation of nitrogen from air for ammonia production takes place via various technologies depending on the required purity and amount of ammonia. In large-scale productions of nitrogen, air is liquefied and separated into its constituents. However, the Haber-Bosch process is still the industrially applied method for ammonia synthesis.

3.3 Challenges and advantages of ammonia fuel

There are challenges but also advantages associated with storage, transport, and combustion of ammonia governed by the physical and chemical properties [1]:

- NH_3 is carbon- and sulphur-free and gives a clean combustion with near-zero generation of CO_2 or SO_X
- The volumetric energy density of NH_3 is higher than for H_2
- NH_3 can be cracked to N_2 and H_2
- NH_3 is non-explosive unlike H_2
- The widespread use of ammonia in industrial processes and as an agricultural fertiliser means that it is already a commercially attractive product
- It is less expensive and less complex to transport and store than hydrogen and other fuels in need of cryogenic temperatures
- The low risk of ignition in an ambient atmosphere makes the storage of large quantities of ammonia safer than hydrogen in terms of fire safety.

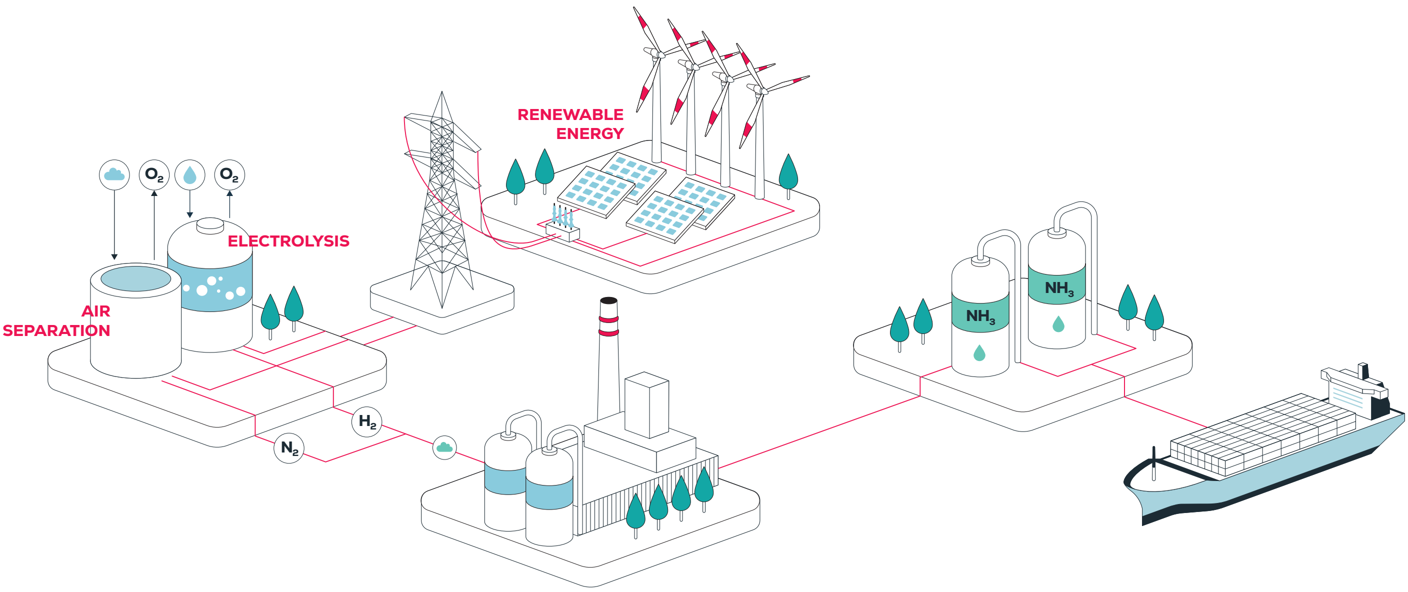


Fig. 2: Illustration of green ammonia production

The lower heating value (LHV) of approximately 18.6 MJ/kg for ammonia is comparable to methanol. Ammonia's energy density per unit volume (12.7 MJ/L) is significantly lower than that of MGO (35 MJ/L), as is the case with other alternative fuels. To carry the same energy content of ammonia relative to MGO, it will require an approximately 2.8 times larger volume if the ammonia tank is cooled.

Everllence has developed a guiding specification for the use of ammonia as fuel in its B&W ammonia engines.

3.4 Thermophysical properties of ammonia

Some of the physical properties of ammonia differ significantly from those of other fuels typically used for marine propulsion (see Table 1). These differences will dictate both the combustion system and the performance layout of an ammonia two-stroke engine.

Even though ammonia has a lower LHV than most other standard fuels, the low stoichiometric air-fuel ratio compensates for this, resulting in a comparable in-cylinder energy content. In this context, ammonia is similar to methanol. Ammonia as a fuel has a low flame speed compared to the other common fuels. This leads to a slower combustion process, which can reduce the efficiency for smaller engines, but not for low-speed two-stroke engines.

Ammonia has a high autoignition temperature and a high heat of vaporisation, which acts to cool the in-cylinder charge.

3.4.1 Handling characteristics of ammonia

The physical properties for storage and fuel distribution are similar to those of liquefied petroleum gas (LPG).

From a handling perspective, the most important aspect of ammonia is its high acute toxicity, which will have consequences for the design of storage, supply, engine, and after-treatment systems.

Despite the high toxicity, methods to safely handle ammonia have also been developed in other industrial applications – such as refrigeration. Ammonia has been stored and transported in tanks under modest pressure similar to LPG, and bulk transport of ammonia on board large chemical tankers is done using established technology. It is a common global commodity, which means that the handling and shipping infrastructure is readily available.

Because of the low reactivity, the hazards of accidental combustion or explosions are much lower than for other fuel gases and liquids. Despite the high toxicity to humans, a slip of ammonia to the environment, even in large amounts, leaves no significant long-term effects. Due to the high volatility in the gas phase, large solubility in water, and rather high chemical reactivity in water, it is readily diluted and disintegrated in the environment.

3.5 Trends in marine fuels

The introduction of regulation initiatives will be one of the cornerstones of the transition. To incentivise the industry to invest in equipment for future fuels, regulation initiatives governed by GHG pricing have to be introduced.

The general public opinion is that the global warming challenge needs to be addressed and that the maritime industry must contribute to the GHG emission reduction. Today, the maritime industry accounts for approximately 3% of the global human-caused GHG emission. The existing fleet consumes close to 300 million tonnes of fuel oil annually. However, it also plays a fundamental role in the global economy, transporting more than 80% of the world's total trade volume [2].

3.5.1 Prediction of the future fuel

It is difficult, if not impossible, to predict which fuels will carry off the title as future fuels and we expect to see a mixture of fuels in the future. Since the future costs of different fuels are hard to predict, the shipowners want to be prepared. They are aware that the transition requires new fuels instead of the fuels we know today. The shipowners face a complex puzzle in the light of carbon-free or carbon-neutral fuel prices several times higher than the fuel oil prices today, and the fact that fuel often makes up the largest operational costs for vessels.

When looking at the market, we have picked up a distinct preference for ammonia compared to hydrogen. The explosion risk is one argument, but the discussion more often concerns the actual handling of hydrogen, and the cost of handling it ashore and on board. Another important aspect is the high energy consumption required to liquefy hydrogen at -253°C, a more efficient approach is to use the hydrogen gas in the production of ammonia, which liquefies at -33°C.

Handling hydrogen is complicated and expensive compared to the ammonia solution. Engineering a practical solution for handling hydrogen that can be adapted to a typical two-stroke engine room is not without its hurdles.

While green ammonia is widely regarded as the ultimate decarbonisation solution, blue ammonia offers a cost-effective and scalable intermediate pathway. Produced via conventional methods with CCS, blue ammonia can meet EU and IMO emission targets for several years to come [3]. Its lower production cost compared to green ammonia makes it a viable near-term solution, enabling early adoption of ammonia-fuelled propulsion while infrastructure and renewable energy capacity are given time to scale up.

3.5.2 Regulatory initiatives

For future net-zero GHG fuels to become attractive, the fuel prices, when considering all costs/incentives, must be comparable with traditional fuel prices. An effective way to achieve this is through regulation. The UN's IMO and the EU have introduced regulation to promote the uptake of zero and near-zero GHG fuels. Both IMO and EU regulate emissions of CH_4 and N_2O in addition to CO_2, on a well-to-wake basis.

In 2023, the IMO adopted the 2023 GHG Strategy, which aims to reach net-zero GHG emissions from international shipping in 2050, with intermediate reduction goals in 2030 and 2040. The IMO 2023 GHG Strategy also sets goals for the uptake of zero or near-zero GHG emission technologies, fuels and/or energy sources, which should represent at least 5%, striving for 10%, of the energy used by international shipping by 2030. To implement the IMO 2023 GHG Strategy, the IMO approved the "net-zero framework" (NZF) in April 2025. The NZF includes a global GHG fuel standard, mandating ships to reduce their annual greenhouse gas fuel intensity (GFI) over time, based on a well-to-wake approach. Further, it includes a pricing mechanism for GHG emissions where ships emitting above GFI thresholds will need to acquire so-called remedial units to balance their deficit emissions.

However, the IMO did not adopt the NZF in October 2025 as originally planned due to resistance from several member States. Instead, it was decided to postpone the adoption by one year. It is currently unclear if the NZF will be adopted in its current form next year. Unfortunately, this creates uncertainty on the timeline on entry into force of the NZF.

In 2023, the EU adopted the FuelEU Maritime regulation and decided to include maritime transport in the European emissions trading system (EU ETS). FuelEU Maritime sets limits on the GHG intensity of the fuel and energy used on board ships calling EU ports from 2025. EU ETS requires ships to buy an allowance for each tonne of GHG emitted from 2025. In this regulatory context, blue ammonia emerges as a practical solution to bridge the gap between current fossil fuels and future green alternatives. Blue ammonia applications are built complementary to existing infrastructure and its ability to significantly reduce GHG emissions, make it a strong candidate for compliance with upcoming regulations. By enabling early decarbonisation at a lower cost, blue ammonia (short to medium term) supports the transition towards green ammonia (long term).

IMO NZF, FuelEU Maritime, and EU ETS apply to both new and existing ships as it is the GHG intensity of the fuel/energy used, which is regulated.

3.5.3 Regulatory framework from a safety perspective

In recent years, the safe use of ammonia as a marine fuel has received growing attention, since regulatory efforts to support the uptake of zero- and near-zero GHG fuels have been intensified.

The IMO is actively developing guidelines to enable this transition, primarily through the International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels (IGF) and the International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk (IGC), whose structures serve as the fundamental blueprint. This approach ensures consistency from a regulatory point of view and provides a robust framework for further development.

The IGF Code, which governs low-flashpoint fuels for ship propulsion, currently includes the first interim guideline for ammonia [4]. This was developed at an early stage, when limited safety references and operational data were available. Accordingly, the interim guideline was established as the first regulatory framework for ammonia-fuelled vessels, developed at a time when no established standards existed for this emerging fuel. Its creation required significant effort and collaboration, laying the groundwork for the safe handling of ammonia – even in the face of limited operational experience within the maritime applications. With the growing technological maturity, it is a natural progression to revisit and refine the interim guideline. The first revision and review of MSC.1/Circ.1687 is scheduled to take place during the 13th session of the IMO Sub-Committee on Carriage of Cargoes and Containers (CCC), to be held at the IMO Headquarters in London in September 2027.

On the other hand, the IGC Code, which regulates the use of ammonia cargo as fuel, was recently discussed at CCC 11, following a more technology-open approach. This resulted in a more adaptable guideline, which is expected by 2026. The upcoming revision is a result of real testing, technology development, and industry feedback, providing significant inputs to strengthen the guideline to better address the safety for ships operating with a toxic fuel such as ammonia.

Together, both guidelines play a crucial role in supporting the industry and especially flag states, by guiding the progression of approval processes for ammonia-based systems. These regulatory instruments are essential pillars in the IMO's GHG strategy, helping to unlock innovation and accelerate the safe adoption of alternative fuels in the maritime sector.

As a leader in marine innovation, Everllence is in a strong position to support IMO in the regulatory development process. Our insights coming from extensive testing and operational experience may help cover the gap between regulation and innovation. By providing practical safety considerations, Everllence can further support the safe rollout of ammonia technologies across the maritime value chain.

3.5.4 Future proof with ammonia

Expectations for fuel oil engines to remain in the maritime industry for many years to come are lower due to the recent IMO and EU regulation of GHG emissions from shipping. Therefore, many of the vessels delivered today are ready for later dual-fuel adaption, as the engine builders are ready, or working on being ready, to retrofit their engine design accordingly.

The capability of the ammonia dual-fuel engine to operate on various types of ammonia (e.g., blue and green) as well as on diesel provides flexibility to comply with existing and upcoming GHG emission regulation for the lifetime of the engine.

4. In the process of developing the first two-stroke, dual-fuelled engine for ammonia

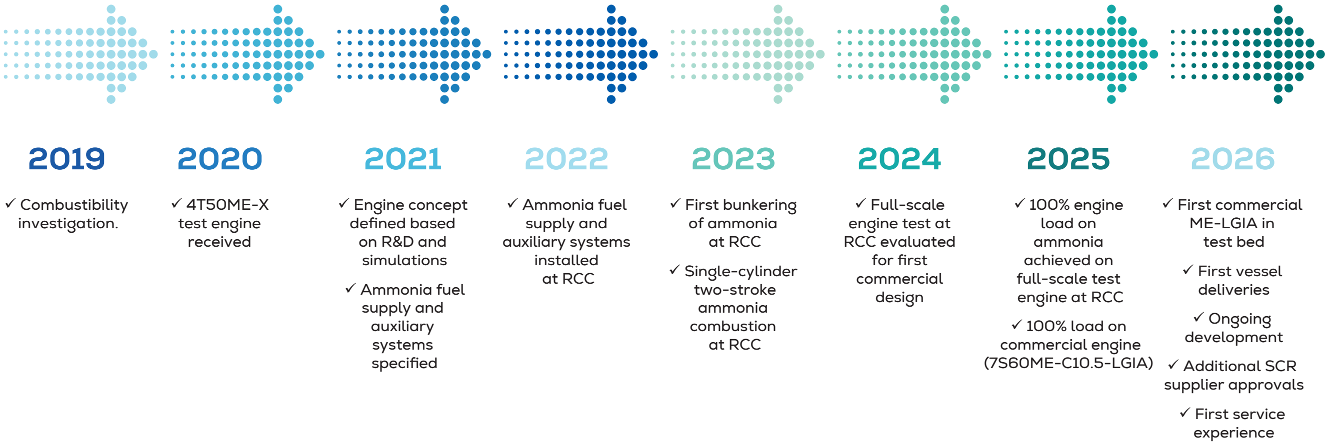


Fig. 3: Two-stroke ammonia engine development schedule

One of the characteristics describing the two-stroke engine portfolio of Everllence is the fuel diversity. Since the beginning, the development of the Everllence B&W two-stroke engine has been adapted to combust diverse fuel types.

In 2019, the journey towards a two-stroke engine operating on ammonia began, as Fig. 3 illustrates.

We started a pre-study of the fuel supply and injection concept and conducted several hazard identification, and hazard and operability studies (HAZID/HAZOP) together with classification societies, shipowners, yards, and system suppliers.

In July 2023, we were able to confirm the R&D potential of ammonia as a fuel, when the first combustion confirmations tests were obtained at the test facility Research Centre Copenhagen (RCC) of Everllence [5]. In 2025, the ammonia development project reached a major milestone when the first commercial ammonia engine was tested on the test bed.

4.1 Basic engine

When designing an engine governed by altered combustion physics due to the chemical composition of a new fuel, it requires thorough research of the influence on all conceivable engine design parameters to provide an efficient and safe engine and fuel supply system to the customers.

Everllence has carried out research at the RCC and in different partnerships to assess the combustion and heat release characteristics of ammonia. The findings of the research, described in more detail in Chapter 5, have guided the development of the specific fuel injection properties and clarified the nature of two-stroke emissions, when operating on ammonia.

Ammonia is a toxic substance, and proper safety measures must be in place to safeguard the ship's crew and the surrounding environment. In addition to catering for these requirements, Everllence brings technology to the market that is engineered to adapt to the skills and work routines of the crew and the resources onboard. This is achieved without fundamentally changing the ship operation. An advantage of the ammonia-fuelled low-speed two-stroke engine is that it will not fundamentally change merchant shipbuilding or operation, and thus a simple and well-engineered solution is in place to cater for the requirements of this novel fuel.

The findings from our tests have also governed the fuel supply system (FSS) configuration. Part of the testing included installation aspects and the FSS design has eventually been adapted to the outcome of these tests. We can confirm that the configuration for ammonia will inherit main features from the well-known LPG supply system for liquid injection.

As for the engine, development of an FSS calls for a safe and reliable design based on the outcome of HAZID and HAZOP investigations. Currently, we have performed eight HAZID investigations observed by representatives from the classification societies, shipowners, yards, and suppliers of components for the FSS.

In principle, the main differences between the fuel characteristics governing the ME-LGIP and the ammonia engine designs are related to heating values, the foul odour, and the corrosive nature of ammonia:

Lower heating values (LHV) of the fuels:

- 46.0 MJ/kg for propane (LPG)
- 18.6 MJ/kg for ammonia
- ammonia is corrosive to copper, copper alloys, alloys with a nickel concentration larger than 6%, and plastics.

The ideal solution is to reuse part of the dual-fuel LGIP injection system on the ammonia engine as well as part of the LPG fuel supply system from tank to engine [6].

4.2 Fuel supply and auxiliary systems consideration

Fig. 4 and the following sections highlight the main principles of the fuel supply and auxiliary systems for the ammonia engine and dual-fuel operation.

4.2.1 Principles of dual-fuel operation

During dual-fuel operation, the ammonia fuel supply to the engine comes from the storage tanks via the fuel supply system. To maintain the required fuel conditions at the engine, the recirculation system continuously recirculates a fraction of ammonia fuel to the FSS.

When the engine is not in dual-fuel mode, the double block-and-bleed arrangements of the fuel valve train (FVT) depressurise and completely isolate ammonia fuel systems inside the engine room from ammonia fuel supply and return systems. Before every start, the systems are pressurised with nitrogen to verify the tightness of the system.

When dual-fuel operation stops, the nitrogen pressure pushes back the ammonia fuel from the engine to the recirculation system. When the purging sequence is complete, the FVT will once again ensure the isolation of engine room systems from supply and return systems.

Throughout the entire operation, the double-walled ventilation system from existing Everllence dual-fuel engines monitors and detects any potential ammonia fuel leakage and directs it away from the engine room to a separate ammonia trapping system.

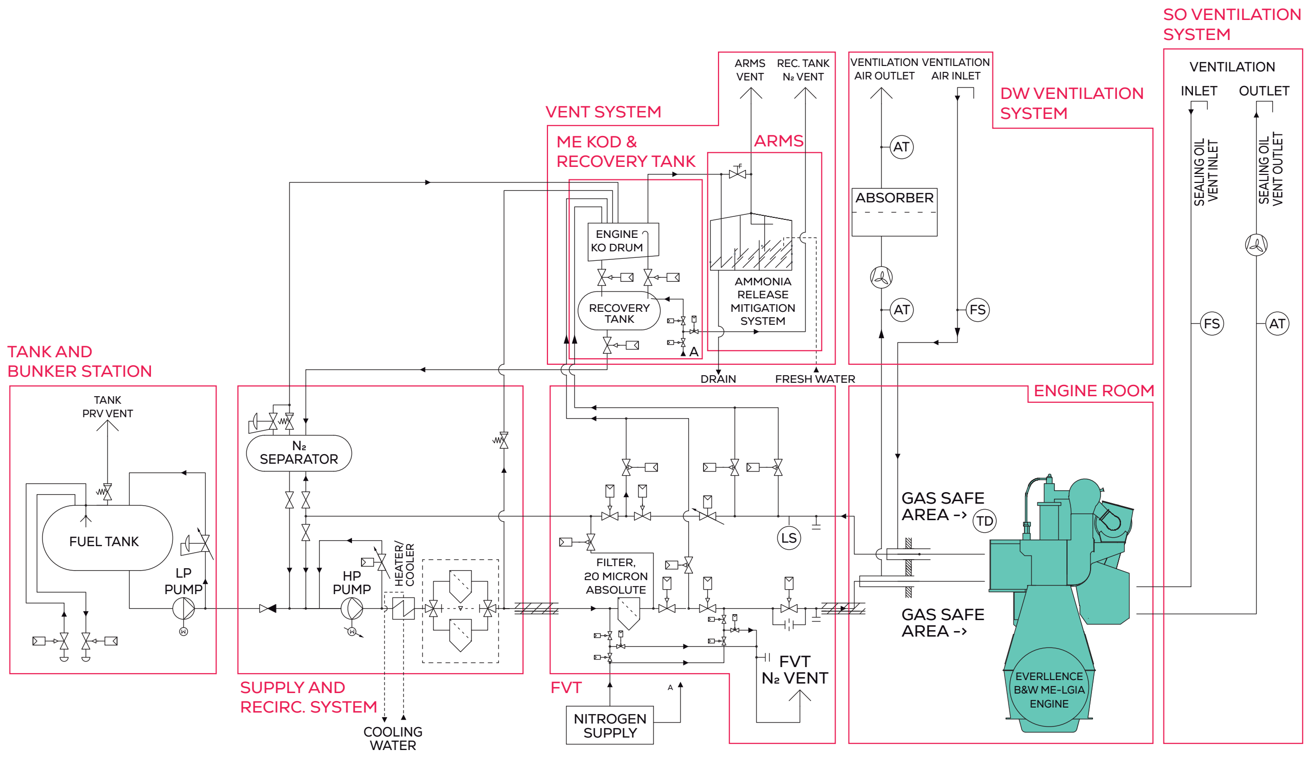


Fig. 4: Principles of the ammonia supply and auxiliary systems, showing the main components

4.2.2 Recirculation system
The recirculated ammonia fuel will heat up in the engine during operation. To avoid two-phase conditions, a certain amount of ammonia fuel is recirculated to a dedicated recirculation line. The same recirculation line recovers the ammonia fuel from the engine whenever dual-fuel operation is stopped.

The recirculated fuel may contain traces of sealing oil from the injection valves. The recirculation line eliminates the risk of contaminating fuel storage tanks with oil. The recirculation line also separates and bleeds off nitrogen from the recovered ammonia fuel during the purging sequence.

4.2.3 Fuel supply system
The FSS contains the equipment necessary to ensure that ammonia fuel is delivered to the engine at the required temperature, pressure and quality. Usually, the FSS has a high-pressure pump, a heater, filters, valves, and control systems to maintain the ammonia fuel pressure and temperature at varying engine consumptions.

4.2.4 Fuel valve train
The FVT is the interface between the engine and auxiliary systems. The purpose of the FVT is to ensure a safe isolation of the engine during shutdown and maintenance, and to provide a nitrogen-purging functionality. The engine software control system actively monitors and controls the valves in the FVT. This functionality ensures a safe environment on the engine after shutdown.

4.2.5 Nitrogen system
Nitrogen must be available for purging the engine after dual-fuel operation, for gas freeing prior to maintenance and for tightness testing after maintenance. The capacity of the nitrogen system must be large enough to deliver a certain flow at a pressure higher than the service tank pressure. The flow required depends on the engine size.

4.2.6 Double-walled ventilation system
To maintain a safe engine room, it is vital to detect any leakages from the ammonia fuel system and direct these to a safe location. This has led to the double-walled design of ammonia fuel systems and piping inside the engine room. A constant flow of ventilation air is kept in the outer pipe in accordance with IMO requirements. The system is also part of other Everllence B&W dual-fuel engine designs.

For ammonia systems, an absorber unit is required and integrated into the double-walled ventilation system to treat any potential leakage into the annular space. This ensures compliance with applicable emission limits and safety regulations.

4.2.7 Vent system
Ammonia systems must be designed with a vent system to mitigate release of ammonia to the surroundings, ensuring concentrations remain within allowable safety thresholds. The vent system includes a knockout drum (KOD) where the ammonia pressure is released, see Fig. 4.

Flash evaporation results in ammonia in liquid and vapour phases in the drum. The liquid phase is pushed back to the nitrogen separator, and ammonia in the vapour phase is captured in an ammonia catch system (ACS) consisting of several columns filled with water. The amount of ammonia emission is controlled by the total water volume in the columns. During operation of the ACS, part of the water is drained off and replaced by freshwater.

Everllence has successfully validated a robust ammonia release mitigation system designed to ensure compliance with safety thresholds and minimise environmental impact. While this solution demonstrates proven effectiveness, we remain committed to innovation and continuous improvement. Our approach is open to collaboration and further development, recognising that building safe ammonia-fuelled vessels is a shared responsibility across the industry.

4.2.8 Safety and control systems
The engine control system used for an ammonia engine is based on the system used for previous dual-fuel engines such as ME-GI (methane) and ME-LGIP (LPG). However, most similarities are found with the ME-LGIM (methanol) system.

The control and safety strategies used for methanol and ammonia are largely unchanged since the demands are quite similar. Both media are toxic to humans and pose a significant fire hazard if they enter the engine room.

The double-walled piping is continuously monitored to detect fuel leakages during engine operation. A positive detection leads to a controlled stop of ammonia operation on the engine while the piping containing ammonia is purged clean using nitrogen, and any further leakage is prevented. Note that a leakage takes place from the inner to the outer pipe and not to the engine room. This additional barrier keeps the ship and crew safe at all times.

4.3 Emission reduction technologies

Our research shows that the ammonia combustion typically generates around ≥50% less NO_X compared to diesel operation, as discussed in more detail in Section 5.5.

Obviously, ammonia will only be an environmentally viable fuel if emissions known from a conventional engine are not merely replaced with other types of harmful emissions. Naturally it is an important part of Everllence development efforts to ensure that only very low levels of harmful emissions escape from the ammonia engine, and that the new fuel will not create a problem for the shipping industry to consider.

4.3.1 Selective catalytic reduction technology

To reduce emissions of nitrogen oxides (NO and NO_2, commonly referred to as NO_X) and to fulfil the regionally different emission regulations, engines from Everllence have been equipped with high-pressure selective catalytic reduction (HPSCR) technology. The SCR system using ammonia was introduced in four bulk carriers in the 1990s and has since then achieved many references. So this SCR system constitutes a mature technology.

After testing, Everllence is in a position to inform that the ammonia mode is not the limiting factor for the SCR system design. The size of the SCR reactor should not be based solely on exhaust data from the ammonia running mode, instead the sizing factor is the oil mode running of the engine.

The SCR technology is an after-treatment process, where NO_X formed during the combustion is removed from the exhaust gas, using a reducing agent in the presence of a catalyst (catalytic reduction).

Normally, the ammonia (reducing agent) required is added by injecting a urea solution ($CH_4N_2O + H_2O$) into the exhaust gas. However, ammonia can be injected as the catalytic agent instead of urea. One of the benefits is that an ammonia-fuelled vessel already carries ammonia, so a simplification of the system can be expected. The consumption of ammonia for the SCR system is expected to be marginal compared to the ammonia fuel consumption.

As Fig. 5 shows, the ammonia slip neutralises some of the NO_X emissions in the SCR system.

In the catalytic reaction, NH_3 and NO_X are converted to diatomic nitrogen (N_2) and water (H_2O):

$$4NO + 4\,NH_3 + O_2 \rightarrow 4N_2 + 6\,H_2O$$

$$6NO_2 + 8\,NH_3 \rightarrow 7N_2 + 12\,H_2O$$

By ensuring complete combustion conditions via engine tuning, the emission of unburned NH_3 (ammonia slip) will be minimised and the majority of any residual molecules can be oxidised in the after-treatment system, ensuring the lowest possible slip into the atmosphere.

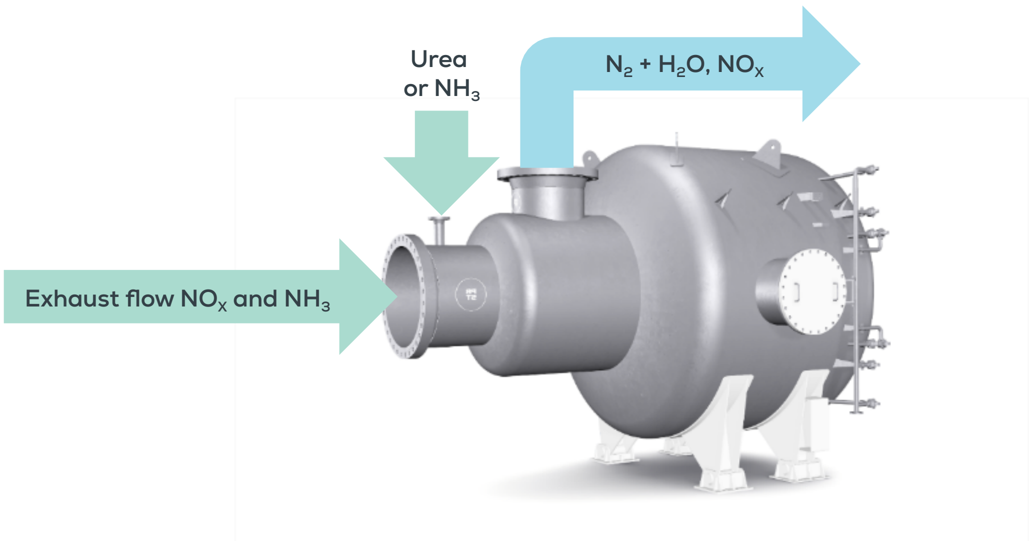


Fig. 5: SCR reactor and the neutralisation process

5. Result of multi-cylinder ammonia engine tests

The 4T50ME-X-LGIA research engine at the RCC (Fig. 6) has been operated on ammonia across all four cylinders at load levels in the range of 25–100% to establish the engine performance characteristics for ammonia combustion as described in this chapter.

R&D ammonia tests have also been performed on the 7S60ME-LGIA engine at Mitsui in Fig. 7. Data from full engine testing of this engine will be included here as well.

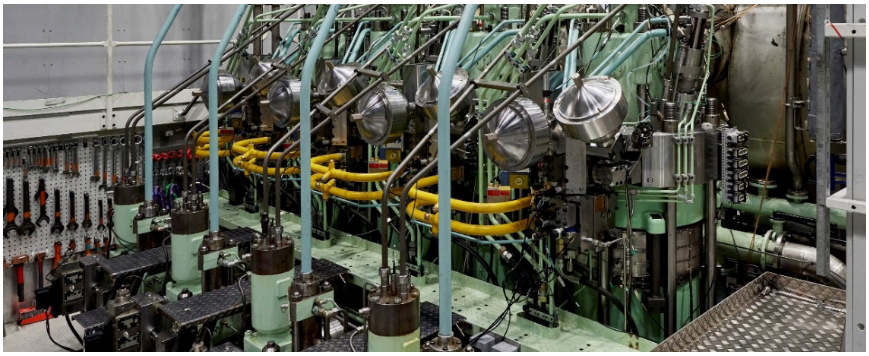


Fig. 6: 4T50ME-X-LGIA research engine rebuilt for four-cylinder ammonia operation at the Research Centre Copenhagen

Fig. 7: 7S60ME-LGIA engine at Mitsui

5.1 Combustion characteristics

Fig. 8 compares combustion characteristics for the 4T50ME-X-LGIA engine running on ammonia with those of a conventional, commercial dual-fuel ME-LGIM engine operated on diesel as well as methanol. Both engines have been tuned to the same maximum pressure (Pmax) level.

The conclusion from Fig. 8 is that the 4T50ME-X-LGIA engine performance has similar compression, combustion, and expansion curves as the ME-LGIM engine running on diesel and methanol for all tested loads. This is a positive result and an indication of an efficient ammonia fuel combustion, comparable to that of diesel and methanol.

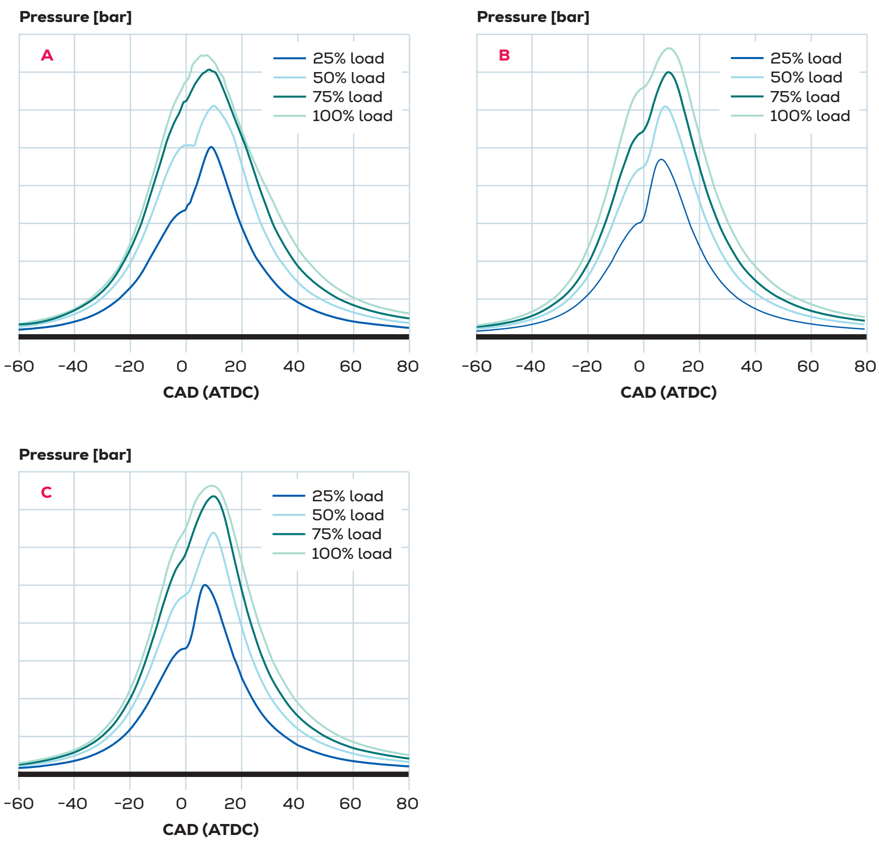


Fig. 8: Cylinder pressure measurements at four different loads for operation of a) 4T50ME-X-LGIA on ammonia, b) ME-LGIM engine on diesel, and c) ME-LGIM engine on methanol

5.2 Cylinder-to-cylinder combustion stability

To investigate the combustion stability from cylinder to cylinder, the 4T50ME-X-LGIA engine is operated on ammonia at high load (75%), while measuring the cylinder pressure on all four cylinders (Fig. 9).

Fig. 9 shows a balanced ammonia engine performance, with no cylinder-to-cylinder variation in the pressure curves. Even under magnification, all four curves remain identical.

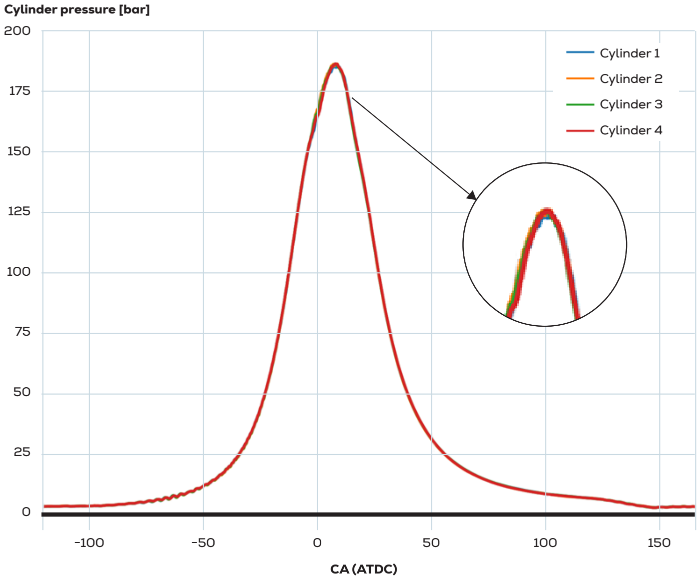


Fig. 9: Cylinder pressure measurements for the four cylinders of the 4T50ME-X-LGIA research engine operated on ammonia at 75% load

5.3 Cycle-to-cycle combustion stability

The next step in evaluating engine performance was to examine whether ammonia combustion remains stable from cycle to cycle, as this reflects the combustion stability over time. To investigate cycle-to-cycle stability, the 4T50ME-X-LGIA engine was operated on both ammonia and diesel at 75% load, while monitoring cylinder pressure in a single cylinder over time (Fig. 10).

Fig. 10 reveals that the pressure deviations observed during ammonia combustion fall within a range similar to that of diesel, which is noteworthy given the fundamentally different properties of the two fuels. Besides, a closer look at the highlighted area in Fig. 10 reveals that cycle-to-cycle deviations during ammonia operation are minimal and comparable to the variation levels typically observed in diesel combustion. For the data in Fig. 10, the standard deviation for ammonia pressure curves is 0.6% and for diesel operation, the standard deviation is 0.8%.

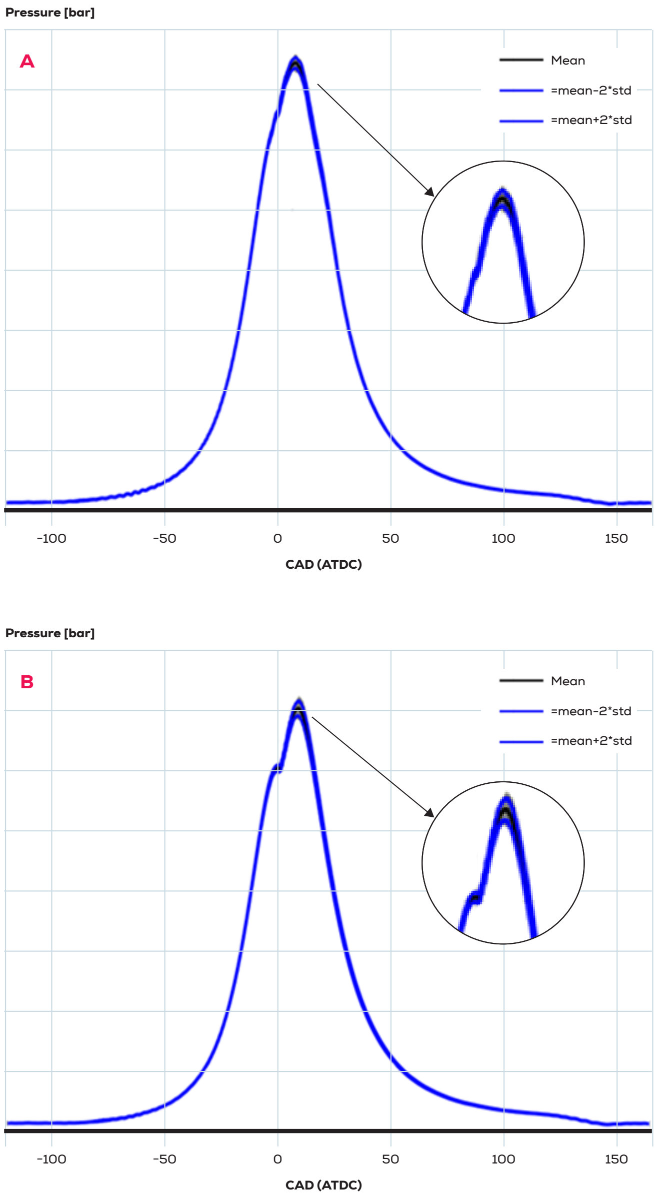


Fig. 10: Cylinder pressure measurements (one cylinder) for the 4T50ME-X-LGIA engine operated at 75% load on a) ammonia and b) diesel

The ammonia engine design and control software result in a combustion stability similar to other dual-fuel engines and a stable nature of injection and combustion as known for diesel operation.

5.4 Propeller and generator curve operation, and PTO application

The testing of the 4T50ME-X-LGIA engine has included performance assessments under conditions defined by the nominal propeller curve in Fig. 11, as well as evaluations at both light (generator) and heavy running points for each load.

The RCC has a water brake capable of simulating the conditions on the propeller curve, which gives real life sailing conditions. Our research confirms the combustion stability in all test points and the validity of the results and values presented previously.

The research also included simulations and tests to evaluate the impact of operating with a power take-off (PTO) on engine performance. The results confirmed that a shaft generator or PTO can be effectively integrated in ammonia-fuelled operation under conditions comparable to those of other dual-fuel engines.

Tests were also performed at a higher full load rating, still with preserved combustion stability.

5.5 Nitrogen oxide (NO_x) emissions

As part of the performance research, Fig. 12 shows NO_x emissions from the ammonia-fuelled 7S60ME-LGIA engine for both ammonia and diesel operation.

It is evident from Fig. 12 that ammonia operation leads to a 50% reduction, at least, of engine-out NO_x emissions compared to diesel operation.

This is a remarkable result, achieved on a production engine using an R&D tuning configuration.

The SCR unit that will accompany an ME-LGIA engine will always be active in both Tier II and III, reducing NO_x emissions to compliance levels.

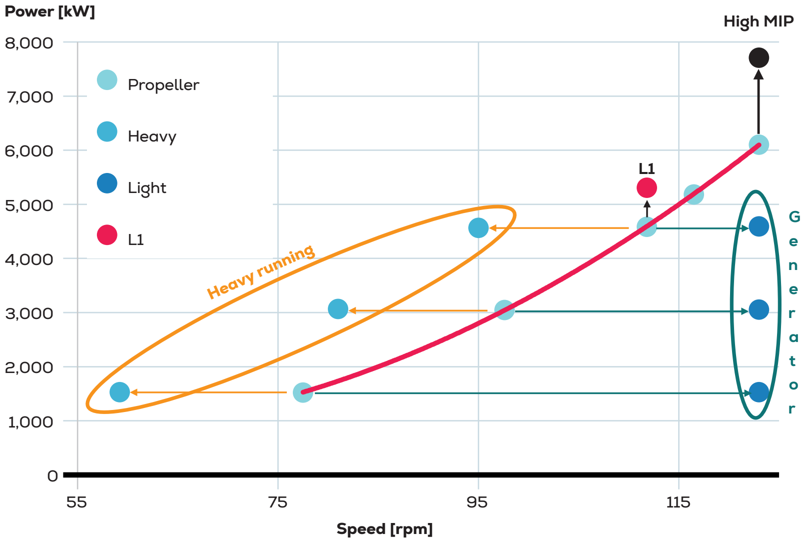


Fig. 11: Nominal propeller curve, light and heavy engine running points for each load. Tests at higher ratings are included as well.

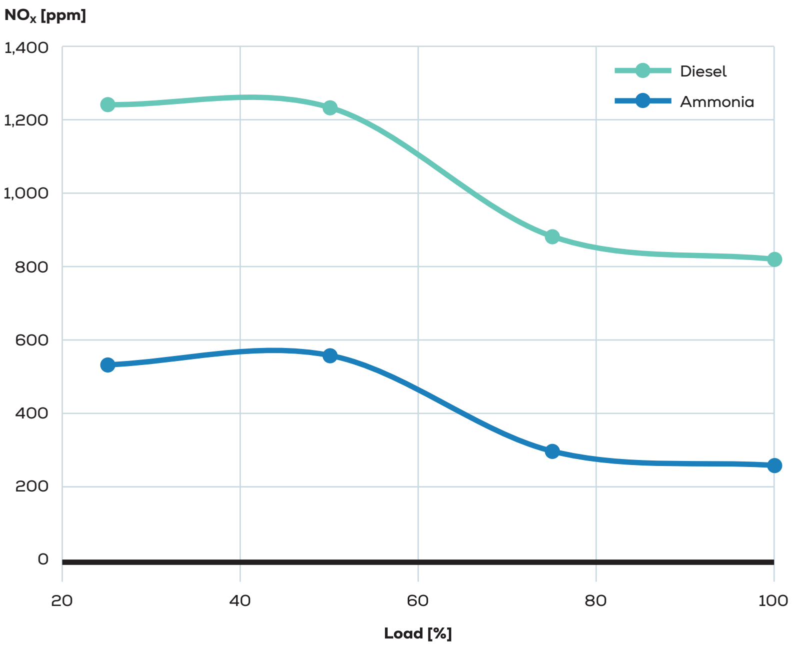
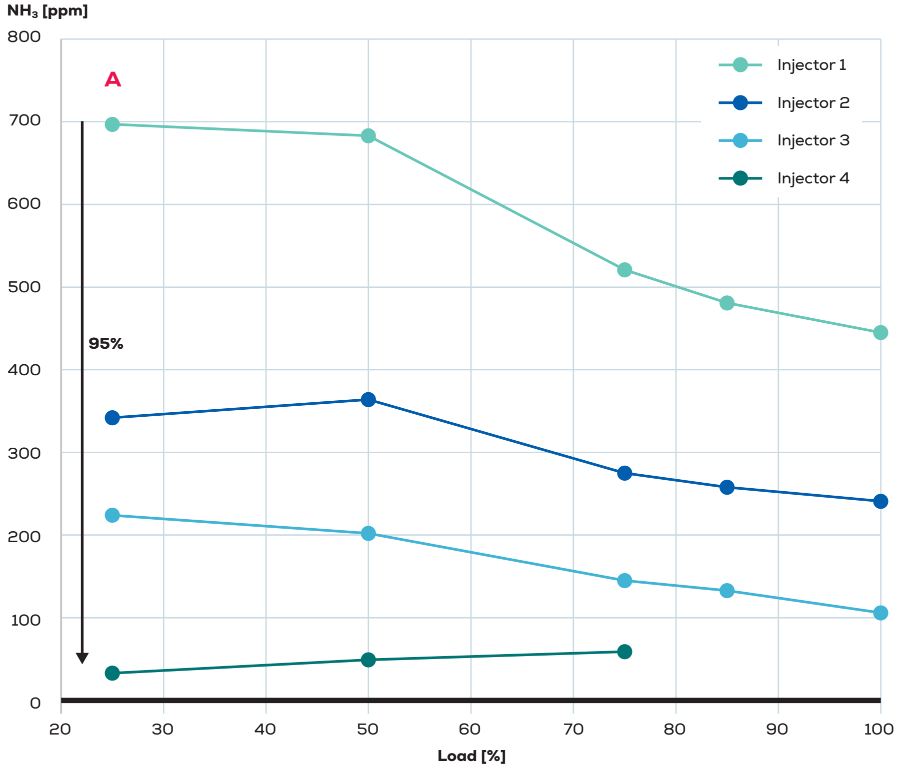


Fig. 12: Measurements (after turbocharger) of NO_x emissions for ammonia and diesel operation of the 7S60ME-LGIA engine as a function of load

5.6 Ammonia (NH_3) slip

The next step in the process of evaluating emissions from ammonia combustion is the measurement of ammonia slip from the research engine. The measured ammonia slip in Fig. 13a was obtained for four different designs of the fuel booster injection valve for ammonia (FBIVA). The tests were performed on a single-cylinder of the 4T50ME-X-LGIA engine. Fig. 13a shows that injector design and injection technology directly influences the amount of ammonia slip, by as much as 95% at low load.

The SCR unit accompanying an ME-LGIA engine will reduce the already low NH_3 emissions before the SCR to even lower values out of the engine. Fig. 13b shows an example of NH_3 emissions measured after the SCR and the turbocharger for R&D test on the 7S60ME-LGIA engine. Emissions are only a few ppm in this example, clearly illustrating that Everllence will have the technology needed to meet any future legislation for allowable ammonia slip (currently not regulated) for the LGIA engine.



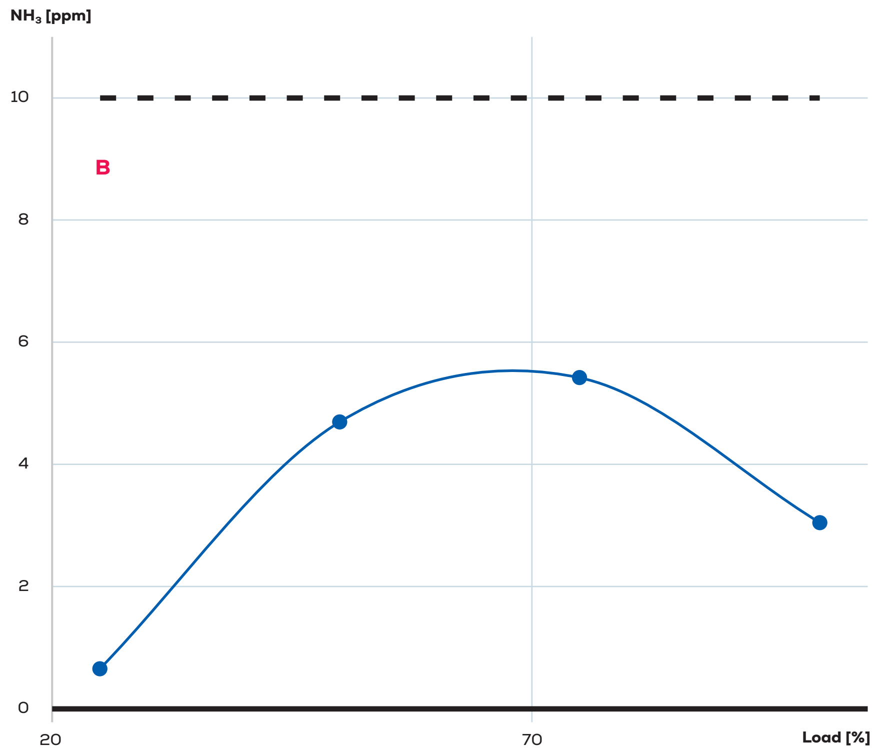


Fig. 13: a) Ammonia slip measurements from single-cylinder tests on the T50ME-X-LGIA research engine (without SCR) with four different FBIVA designs, b) Ammonia slip measured on the 7S60ME-LGIA engine after the turbocharger (full engine operation with SCR active)

5.7 Nitrous oxide (N_2O) emissions

Nitrous oxide emissions are expected to be low for the dual-fuel diesel-cycle ammonia combustion, since the high stratification in the cylinder minimises regions with a temperature and chemical composition promoting N_2O formation. After numerous tests, measurements, and observations, it is confirmed that nitrous oxide levels are very low for both 4T50ME-X-LGIA and 7S60ME-LGIA engines operated on ammonia, typically well below 5 ppm, see Fig. 14a.

For the ME-LGIA engine, N_2O will be removed by engine tuning alone and emission levels will be extremely low.

N_2O is a very potent greenhouse gas with a global warming potential (GWP) of 265, and N_2O will be accounted for in regulations. In this respect, and considering the greenhouse gas potential of nitrous oxide, the test results are impressive and the expectation is that the N_2O emission impact of the ME-LGIA engine will be less than 2% of the GHG equivalence of a fuel oil engine, as indicated by the right-hand axis in Fig. 14a.

Considering total equivalent emissions from an ammonia engine, more than 90% saving of GHG emissions (considering both pilot oil and N_2O emissions) is possible with the ME-LGIA engine at 100% load. Fig. 14b indicates total GHG emission equivalence compared to conventional diesel operation at 100% load for the 7S60ME-LGIA. Total GHG emissions correspond to only 6.5% of the diesel case in this example, with the largest contribution coming from the diesel pilot CO_2 emissions.

5.8 Fuel efficiency

According to our research, there is a close similarity between the thermal efficiencies of ammonia and diesel. The initial takeaway from Fig. 15 is that measurements confirm that ammonia-fuelled operation achieves a thermal efficiency comparable to that of diesel.

The commercial ME-LGIA engine will be engine tuned and, therefore, the efficiency will not be exactly as shown in Fig. 15. Also, ME-LGIA engines will have optimised engine running modes depending on the fuel, maximising the efficiency potential.

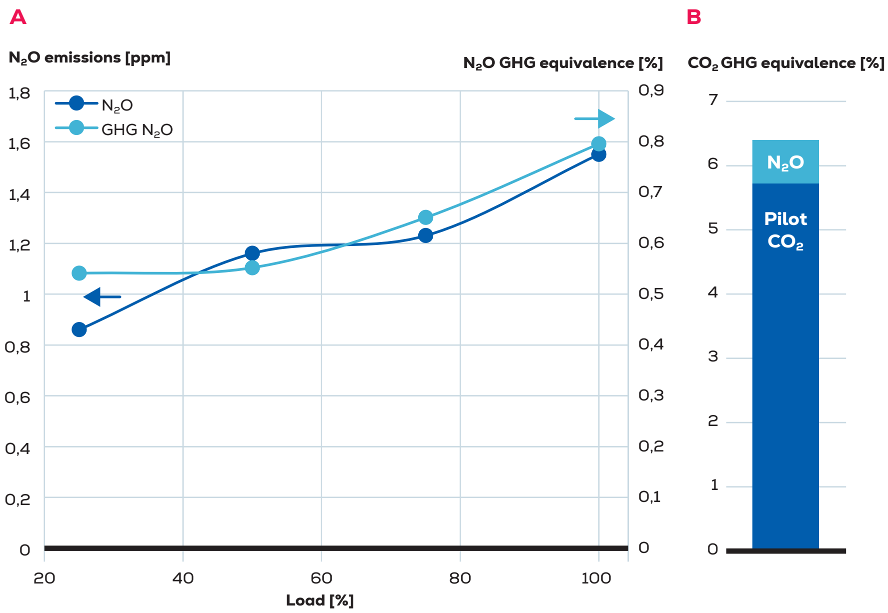


Fig. 14: a) Nitrous oxide levels for the 7S60ME-LGIA engine operated on ammonia (less than 5 ppm), b) Total GHG emission equivalence compared to diesel operation (at 100% load)

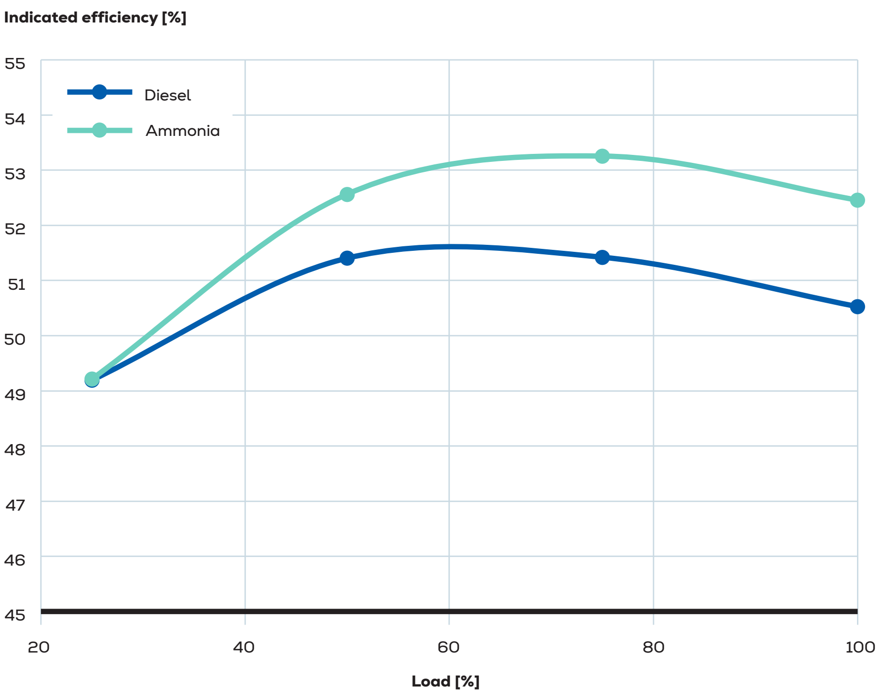


Fig. 15: Relative thermal efficiency of the 7S60ME-LGIA engine running on ammonia compared with diesel running during R&D tests

6. Summary and outlook

Decarbonisation is a central and highly integrated part of developing sustainable technologies and solutions at Everllence.

Ammonia is used as an energy carrier of sustainable hydrogen and it is intrinsically carbon free. Everllence has developed the dual-fuel two-stroke engine operating on ammonia. The technology developed aims for up to 90% decarbonisation of the ship powertrain in a tank-to-wake sense, while maintaining high power, energy density and efficiency, and low emissions.

However, as decarbonisation remains a global endeavour and one of the largest transitions within the maritime world, it will require a united maritime industry to question and evaluate the entire supply chain.

As an important step towards a carbon-neutral economy, a combined global and cross-disciplinary effort will take us one step closer to the research required to highlight decarbonisation pathways. Research, which can guide and accelerate the development of carefully selected decarbonising fuels.

Furthermore, the global teamwork has supported the establishment of vital regulatory, financial, and commercial means to enable the transformation.

The future will see cleaner fuels, and the two-stroke engine technology will likely remain the prime propulsion motor for deep-sea shipping. Our engine portfolio shows that the Everllence B&W two-stroke engines combust various fuel types. Everllence B&W ME-C engines are based on future-proof technology that already can be retrofitted to run on methane, LPG, ethane, and methanol as the fuel. The development of the engine type for ammonia supplements our extensive dual-fuel portfolio with an engine that will meet future market demands for CO_2-neutral propulsion, including retrofits.

The future installation of an ammonia-combusting engine can be adapted to the customer, for example, as a dual-fuel, modular retrofit solution for existing electronically controlled engines, as an ammonia-ready engine, or from newbuilding.

Everllence works diligently towards offering retrofit conversions of existing two-stroke engines to ammonia, preferably accommodating the vessels' five-year docking schedules after Q1 2026.

The advanced research and development of Everllence supports the transition of the industry by delivering the technology that helps our customers bring emissions to regulatory compliance, and even all the way to net zero.

7. Bibliography

[1] Ammonfuel – an industrial view of ammonia as a marine fuel, Alfa Laval, Hafnis, Haldor Topsøe, Vestas, Siemens Gamesa, 2020

[2] Efficiency of Ships, IMO, 2004

[3] Will CO_2 transport and storage limit blue fuel availability for the maritime industry?, Mærsk Mc-Kinney Møller Center for Zero Carbon Shipping, 2023

[4] MSC.1/Circ.1687, IMO, 2025

[5] Press release – Groundbreaking first ammonia engine test completed, Everllence, 2023

[6] Everllence B&W ME-LGIP dual-fuel engines, 5510-0210-00, Everllence, 2018

8. Acronyms and abbreviations

ACS	Ammonia catch system
ARMS	Ammonia release mitigation system
CCS	Carbon capture and storage
DW	Double walled
EEDI	Energy efficiency design index
EEOI	Energy-efficiency operational indicator
EGR	Exhaust gas recirculation
EU ETS	European emissions trading system
FBIVA	Fuel booster injection valve for ammonia
FSS	Fuel supply system
FVT	Fuel valve train
GFI	Greenhouse gas fuel intensity
GHG	Greenhouse gas
GI	Gas injection
GWP	Global warming potential
HAZID	Hazard identification study
HAZOP	Hazard and operability study
HC	Hydrocarbon
HP	High pressure
HPSCR	High-pressure selective catalytic reduction
IGC	International Code for the Construction and Equipment of Ships Carrying Liquefied Gases in Bulk.
IGF	International Code of Safety for Ships Using Gases or Other Low-Flashpoint Fuels.
IMO	International Maritime Organization
KOD	Knockout drum
LGI	Liquid gas injection
LGIA	Liquid gas injection ammonia
LGIM	Liquid gas injection methanol
LGIP	Liquid gas injection LPG
LHV	Lower heating value
LNG	Liquefied natural gas
LP	Low pressure
LPG	Liquefied petroleum gas
MGO	Marine gas oil
NZF	Net-zero framework
PRV	Pressure relief valve
PTO	Power take-off
RCC	Research Centre Copenhagen
SCR	Selective catalytic reduction
SO	Sealing oil
VLSFO	Very-low-sulphur fuel oil

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