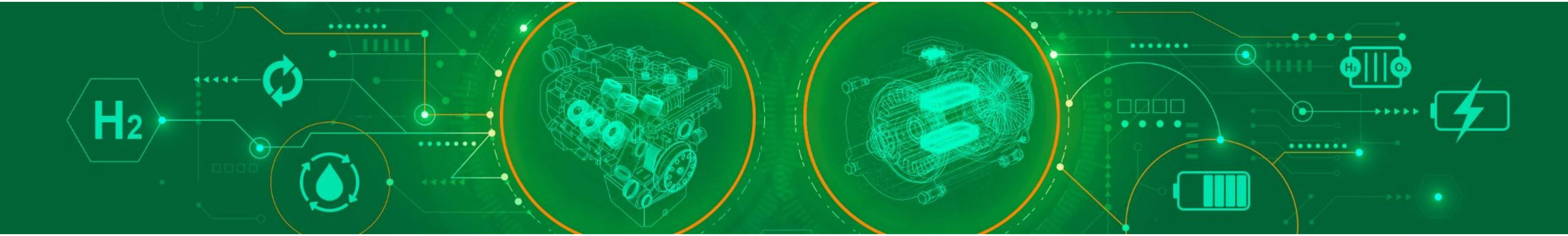
EUROMOT

TECHNICAL SEMINAR ON THE USE OF AMMONIA AS MARINE FUEL

Session 2: Developments in ammonia-fuelled vessels and onboard technologies

Engine technology



Ammonia engine technology development

EUROMOT has consultative status to IMO since 1993,
representing engine designers and manufacturers of international shipping

Members of EUROMOT association are presenting independently:

Mr. Tobias Krook (Wärtsilä)
Developments in Ammonia Engine Technologies: Wärtsilä 25 Ammonia Engine: Technology, Ammonia solution, and ongoing projects

Dorthe Jacobsen (Everllence)
Everllence B&W LGIA engine using NH3 as fuel

Mr. Anirudh Purayil (WinGD)
WinGD’s Landmark X-DF-A Engine: Powering the World’s First Oceangoing Ammonia Vessel

Wärtsilä 25 Ammonia Engine: Technology, Ammonia solution, and ongoing projects

Tobias Krook
Head of Small-Bore Platform Development
R&D and Engineering

The Wärtsilä 25 Ammonia solution: From fuel research to real-world readiness

WÄRTSILÄ

2019

Ammonia combustion in fuel lab

2021

Full scale research engine testing

2022

W25 Product development starts & single cylinder testing

2023

Conversion of W25 laboratory engine from diesel to ammonia

2025

Ammonia Type Approval & first customer Factory Acceptance Test

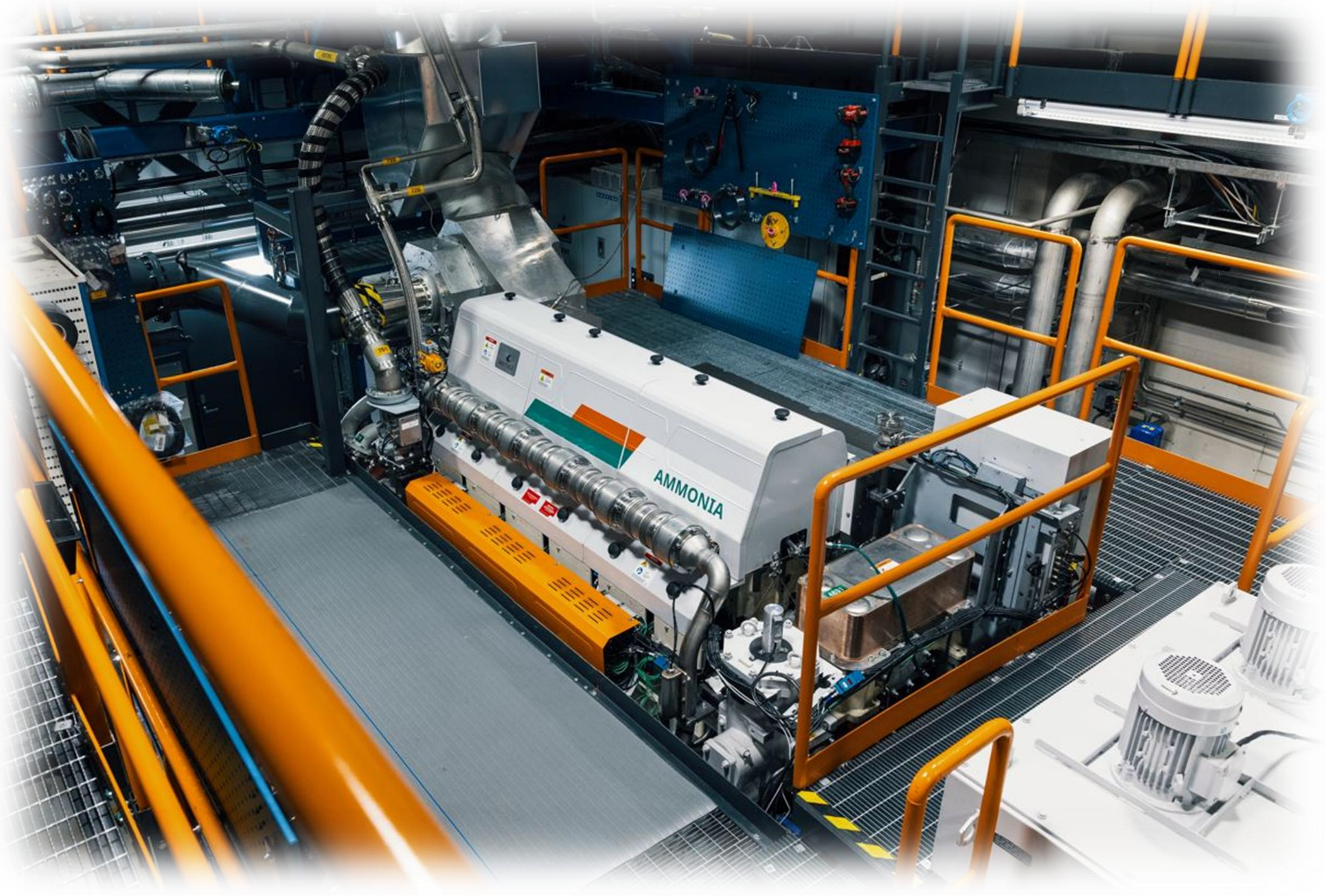
2026

Customer operation starts

Wärtsilä 25 engine power range 1.9 – 3.4 MW

	Wärtsilä 25 LFO		Wärtsilä 25DF LNG		Wärtsilä 25 Ammonia	
Nom speed (rpm)	900	1 000	900	1 000	900	1000
Power / cylinder (kW)	345	375	315	345	315	345
BMEP (MPa)	2.75	2.70	2.52	2.48	2.52	2.48
Engine power (kWm)						
6L	2 070	2 250	1 890	2 070	1 890	2 070
7L	2 415	2 625	2 205	2 415	2 205	2 415
8L	2 760	3 000	2 520	2 760	2 520	2 760
9L	3 105	3 375	2 835	3 105	2 835	3 105

WÄRTSILÄ



Key technologies on W25 enabling efficient ammonia running

COMMON RAIL FUEL INJECTION

New generation fuel injection technology with high pressures for optimum combustion. Optimized fuel injection settings for each operating point. Smokeless operation in all conditions.

1-STAGE & 2-STAGE TURBOCHARGING

High efficiency turbocharging with reduced losses for increased engine efficiency and lower emissions. Enabling more power.

VARIABLE VALVE TIMING OPTIONS

Stepless control available. Valve timing flexibility is an enabler for future fuels and low emission optimization.

GAS FUEL SYSTEM

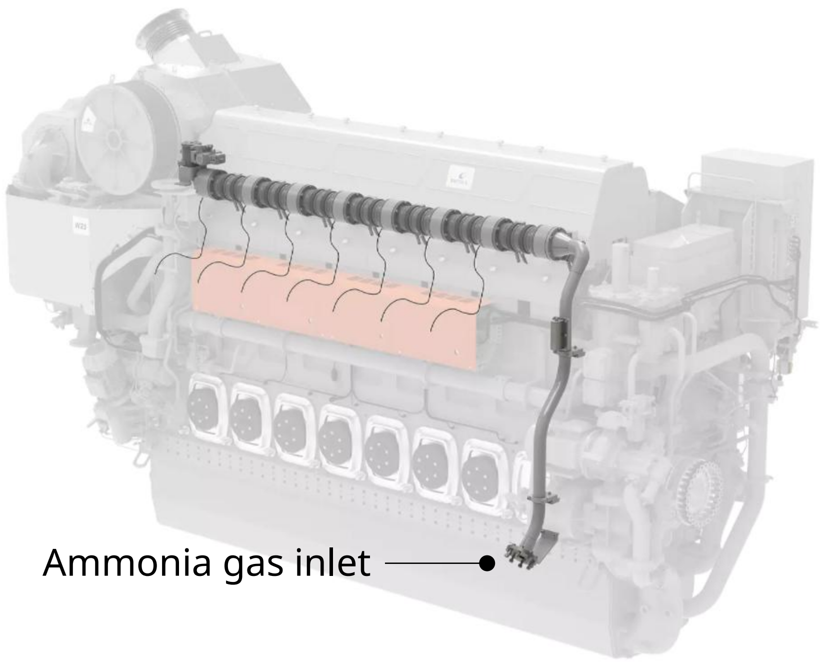
Electronically controlled. Pressure balanced system enabling lower emissions through accurate injection.

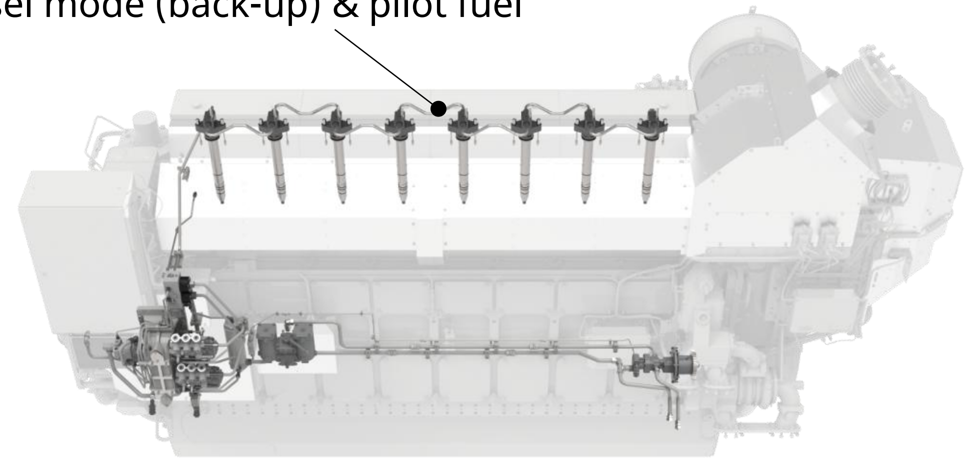
AUTOMATION SYSTEM

Combining all systems together including safety and controls.

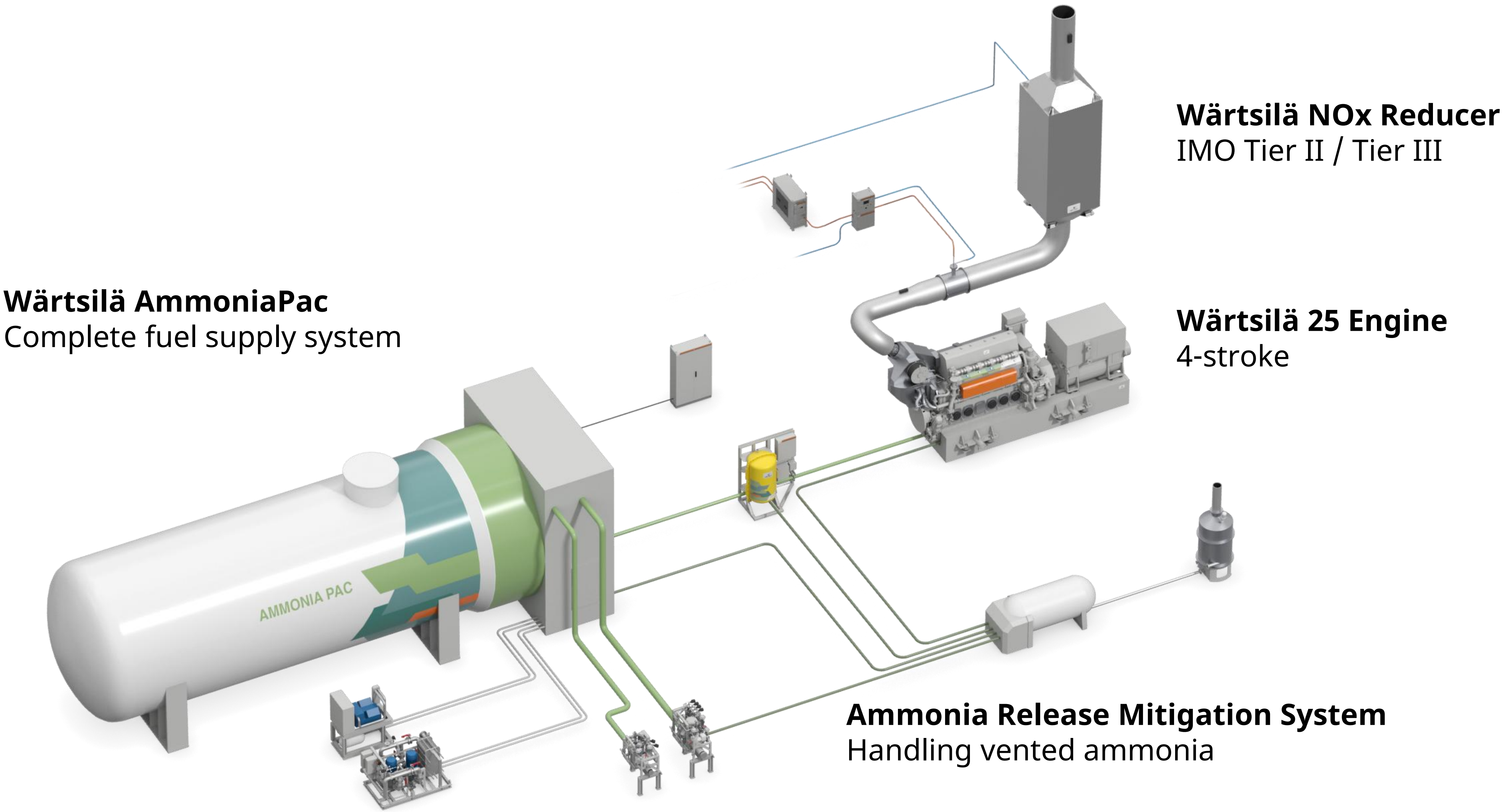
Wärtsilä 25 engine overview

- Engine is designed according to gas safe design principles
- Importance of correct sealing materials
- Gas injection through gas admission valves into the air inlet channel of each cylinder (<10bar)
- No ammonia gas is vented to the atmosphere. When emptying piping the ammonia gas is treated in the Ammonia Release Management System (ARMS)
- In case of failure situation in gas mode engine machinery protection will initiate necessary action such as trip to diesel mode





System overview – engineered as one holistic solution

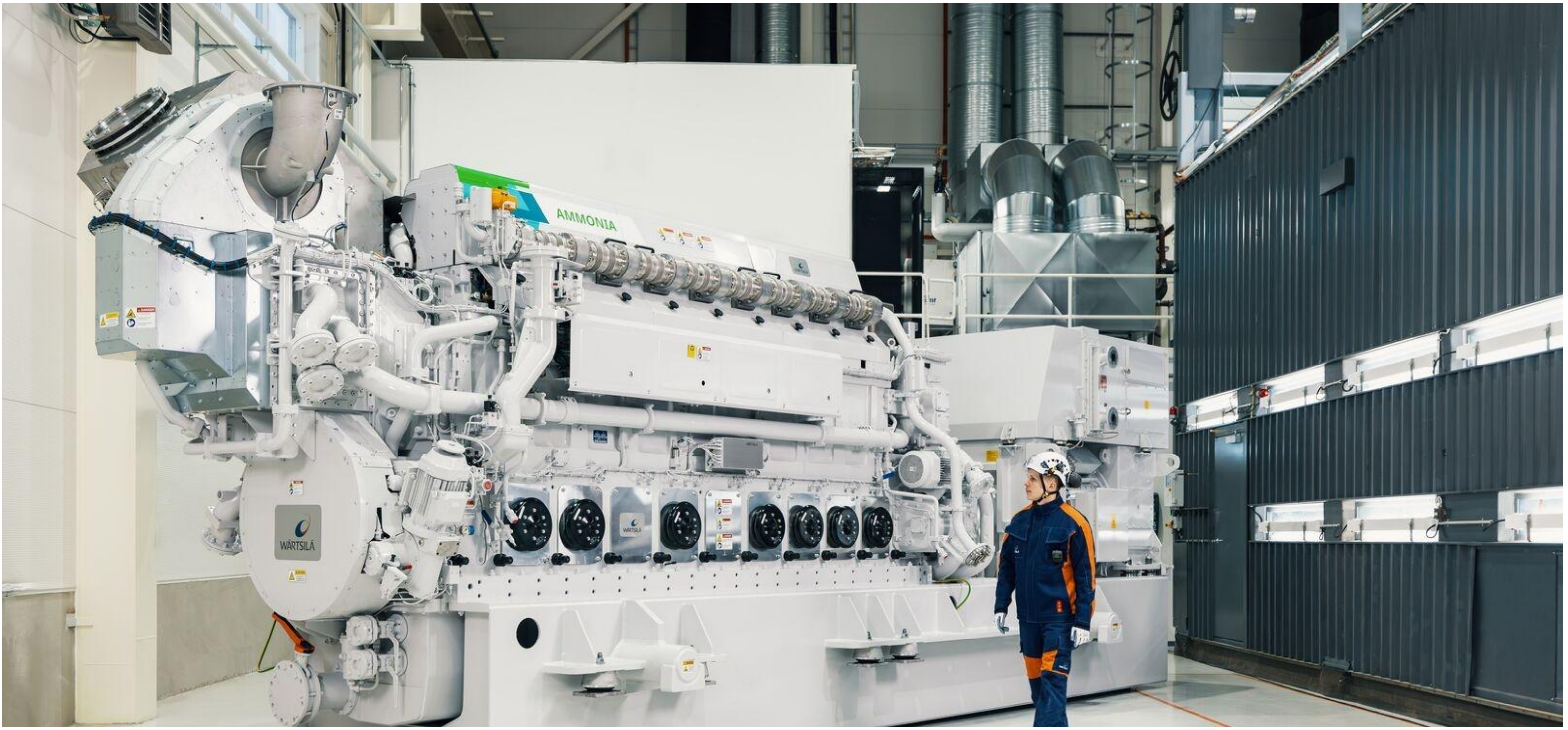


From concept to hardware

AmmoniaPac fuel tank ready for transportation

Gas valve unit (GVU)

ARMS buffer tank

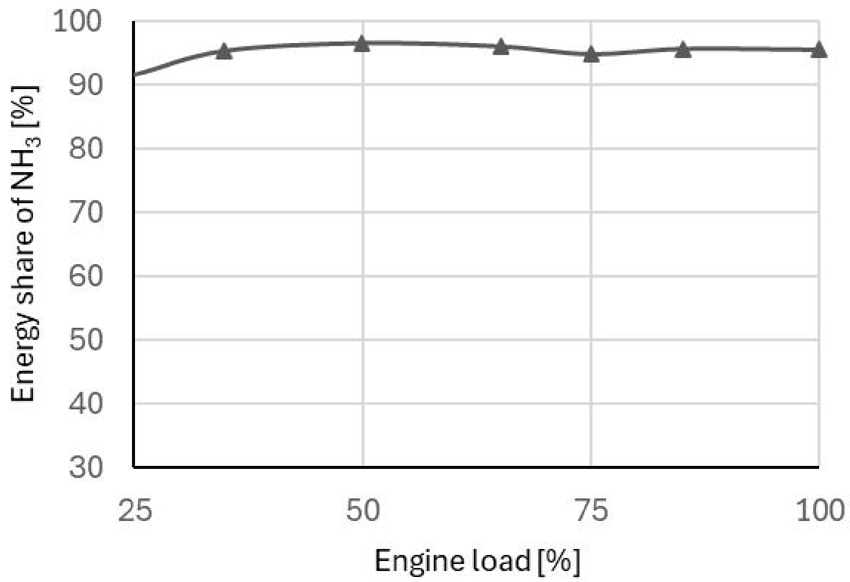


Wärtsilä 25 Ammonia engine ready for delivery after test run

The AmmoniaPac fuel tank, gas valve unit (GVU) and ammonia release mitigation system's (ARMS) buffer tank are essential parts of the Wärtsilä 25 Ammonia solution.

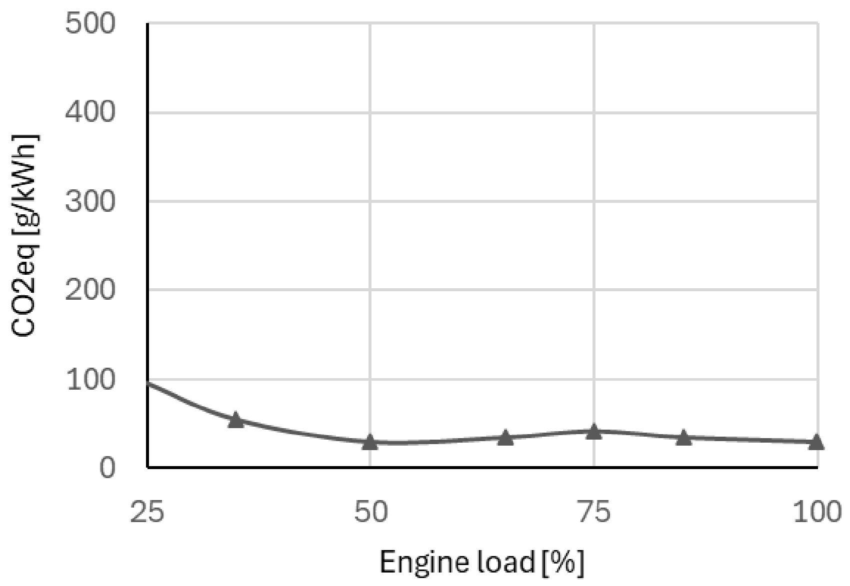
Ammonia fuel energy share – improvements step by step through extensive testing

- Ammonia is ignited by a small amount of pilot fuel.
- The energy share of ammonia is ~95% across a wide load range
- Thanks to the built-in flexibility of the Wärtsilä 25DF engine the inherent slow combustion of ammonia can be mitigated
- Fuel efficiency of the low-pressure Otto concept has been consistent with and equal to that of dual fuel LNG engines
- In the tests Ammonia has proven to be a good fuel for the low-pressure Otto concept.



GHG reduction

- CO_2 equivalent emissions are reduced by ~90% (TtW) compared to a diesel engine using LFO
- The CO_2 equivalent emissions originate from the pilot fuel used and the small amount of N_2O formed during combustion
- Emissions from engine are already low, testing shows that a N_2O catalyst can give further improvements but is not a must to reach good levels.
- The aftertreatment for NOx reduction is based on the proven Wärtsilä NOR system, Consistent Tier III compliance has been shown



Ammonia safety and reliability – based on proven LNG DF concept

- Ammonia solution is based on the proven LNG safety principles

- In case of failure situation in gas mode engine machinery protection will initiate necessary action such as trip to diesel mode

- Crankcase flushing further improved compared to traditional LNG DF

- Comprehensive personnel safety training supported by readily accessible PPE

- Gas detection & well-planned ventilation further improves safety

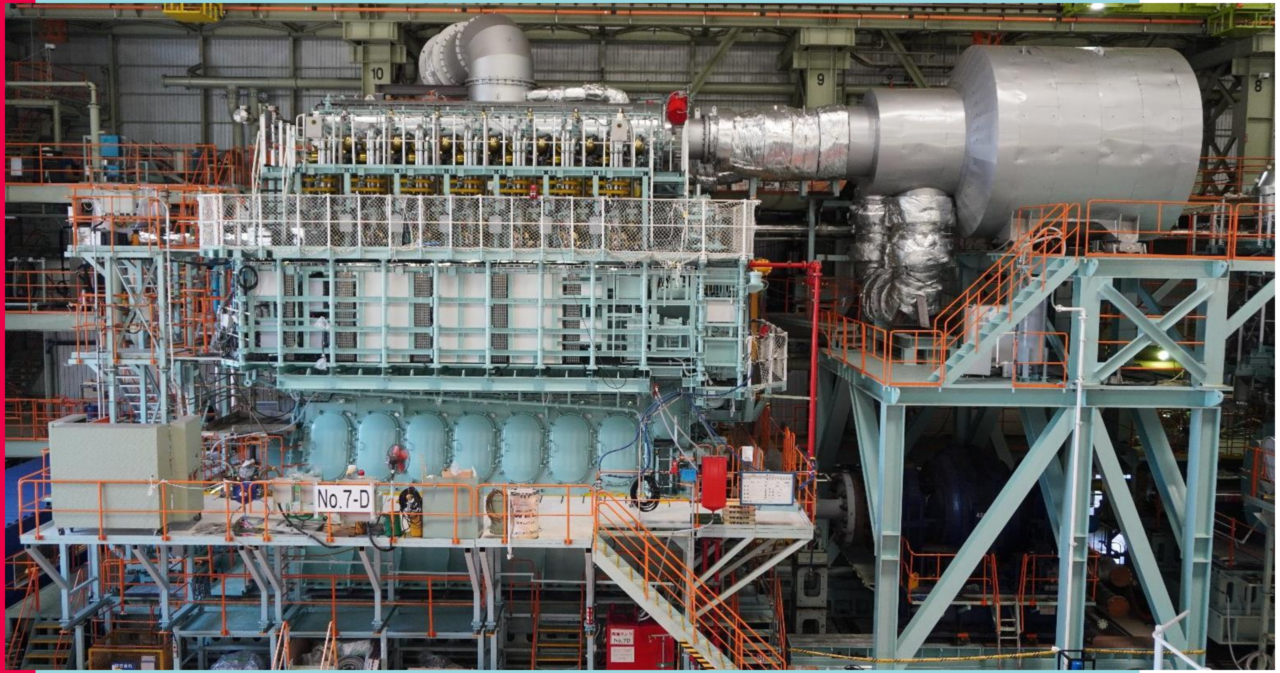
- Ammonia engine maintenance is largely similar to conventional engines, with additional safety precautions required before work begins

First ship conversion to ammonia ongoing with Wärtsilä 25 solution

- The Wärtsilä 25 Ammonia solution fit for a variety of different ships both as main engine and auxiliary engine
  - Partnership with Norwegian shipowner Eidesvik to convert the platform supply vessel (PSV) Viking Energy for ammonia operation with Wärtsilä 25 solution; Landmark deal between Wärtsilä and Eidesvik Offshore pioneers growing demand for ammonia in shipping
  - New build for Grieg Skarv with Wärtsilä 25 solution; Wärtsilä 25 Ammonia solution chosen to advance decarbonisation of new Skarv Shipping cargo vessel
  - Two new gas carriers with Wärtsilä 25 Ammonia solution for Navigator Amon Shipping; Two new gas carriers to stay ahead of environmental standards with Wärtsilä 25 Ammonia engine

Everllence B&W LGIA engine using NH_3 as fuel

IMO technical seminar on the use of Ammonia as marine fuel



Dorthe Jacobsen, Johan Hult. Everllence Two-stroke. 17-09-2026

Agenda

17 September 2026

1. **Engine technology**
2. **Emissions**
3. **Safety**
4. **Summary**

1
Engine technology

The ammonia engine builds on a decade of dual-fuel experience supported by 2100+ orders

	Methane		Methanol	Ethane	LPG	Ammonia	Diesel
	ME-GI	ME-GA	ME-LGIM	ME-GIE	ME-LGIP	ME-LGIA	ME-C & MC
No. of engines	*1202*	*280*	*246*	*94*	*302*	*7*	*30236*

2015
World's 1st **LNG** driven container vessel

2016
World's 1st **MeOH** driven vessel

2017
World's 1st **Ethane** driven vessel

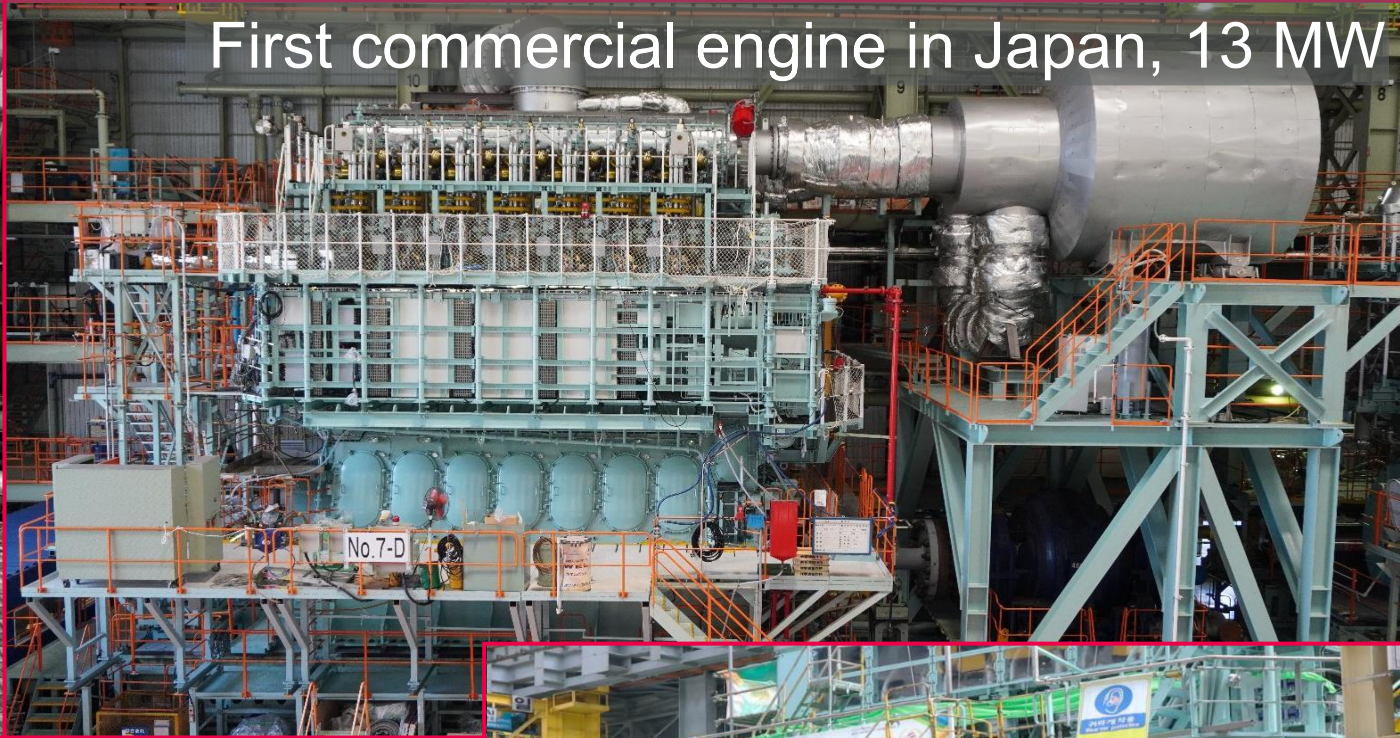
2020
World's 1st **LPG** driven vessel

2023
World's 1st **MeOH** driven container vessel

2026
NH3 driven
Vessel (not in service yet)

Test platforms

4-cylinder Ammonia test engine at Research Centre Copenhagen, 7 MW



First commercial engine in Japan, 13 MW

First commercial engine in Korea, 12 MW

- **Copenhagen 4T50 tests 2023-2026**
- **Mitsui (Japan) 7S60 tests 2025-2026**
- **HHI (Korea) 6G60 tests 2026**

Dual-fuel combustion concept

The B&W ME-LGIA design philosophy

Two separate fuel injection systems

- Fuel oil + Ammonia

Ammonia mode

- High pressure liquid NH_3 injection (~650 bar)
- Small diesel pilot flame for ignition
- 5% Specific Pilot Oil Consumption at 100% load
- Same heat rate as fuel oil mode

Fuel oil mode

- Identical performance as a conventionally fueled Diesel engine

Safety concept

- Immediate switch to diesel operation in case of failure in Ammonia operation

Dual-fuel combustion concept

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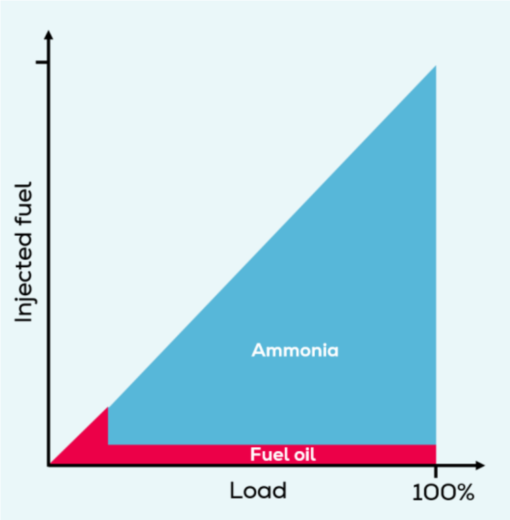
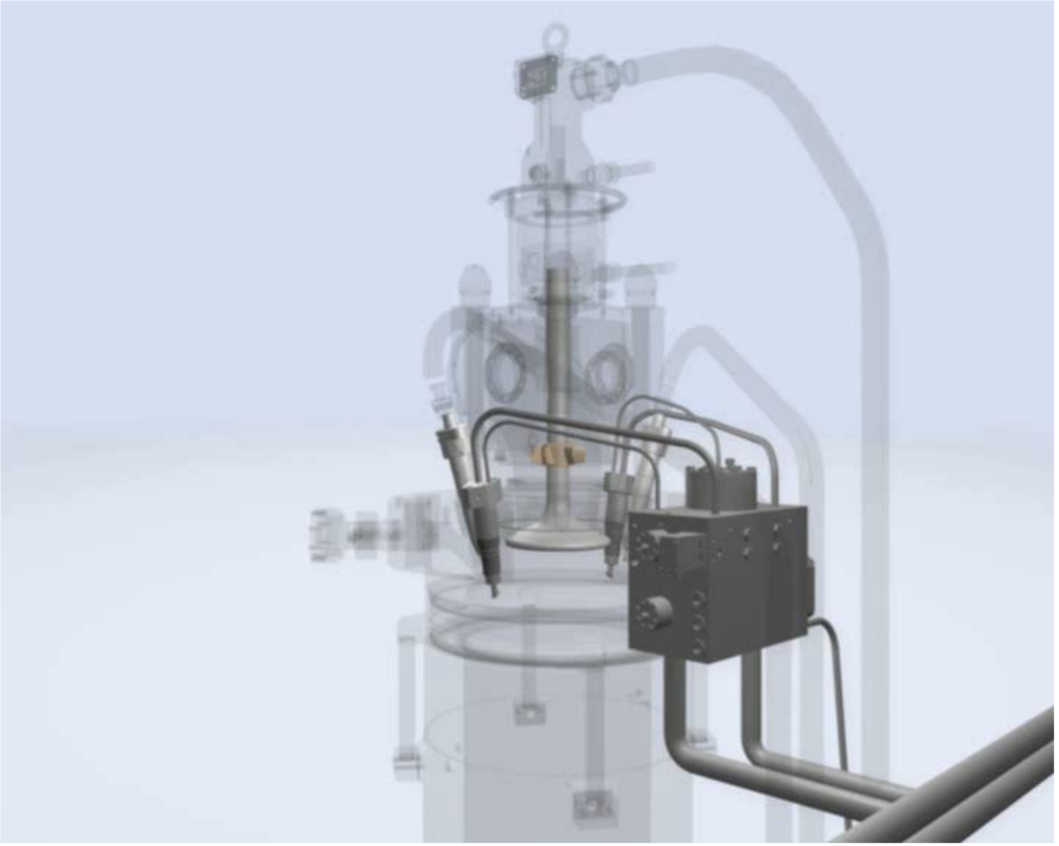




Fuel oil mode

- Identical performance as a conventionally fueled Diesel engine

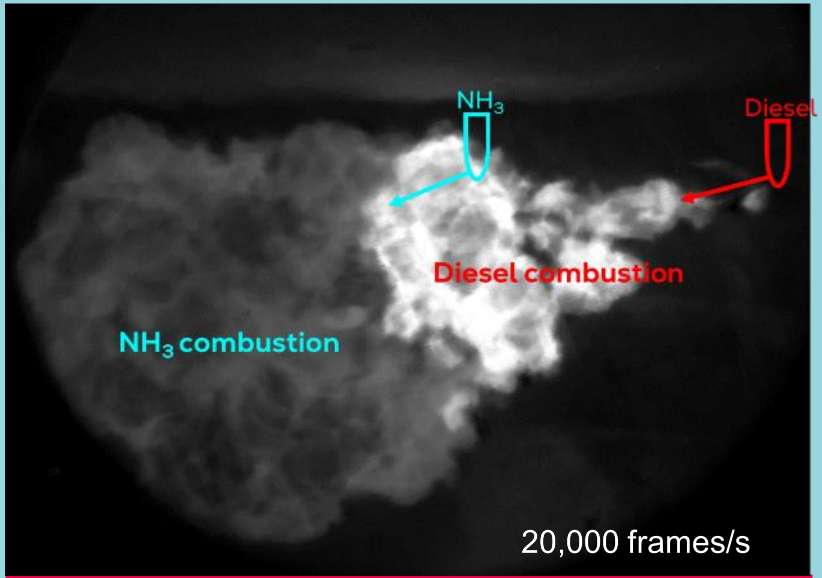
Safety concept

- Immediate switch to diesel operation in case of failure in Ammonia operation

Combustion process

Test results from full engine testing (Research Centre Copenhagen)

Ammonia



Ammonia combustion process behaves the same way as dual-fuel combustion of other fuels

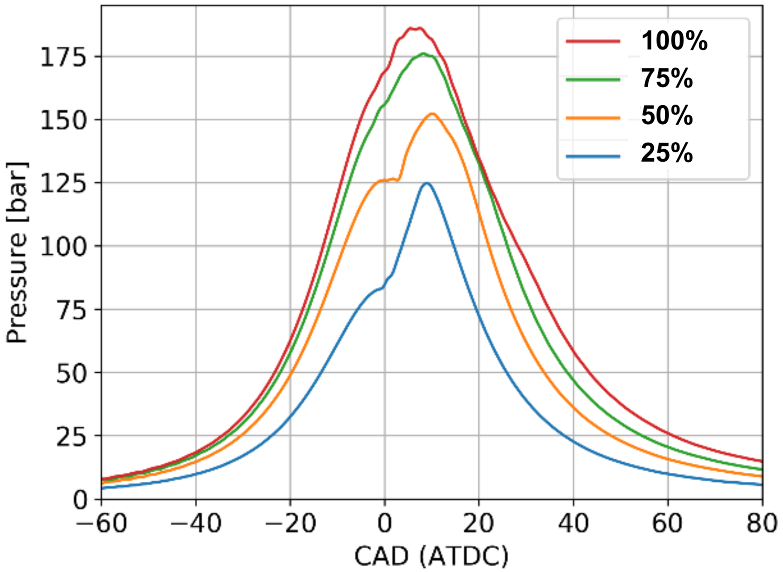
4T50ME-X

Engine combustion characteristics

Test results from full engine testing (Research Centre Copenhagen)

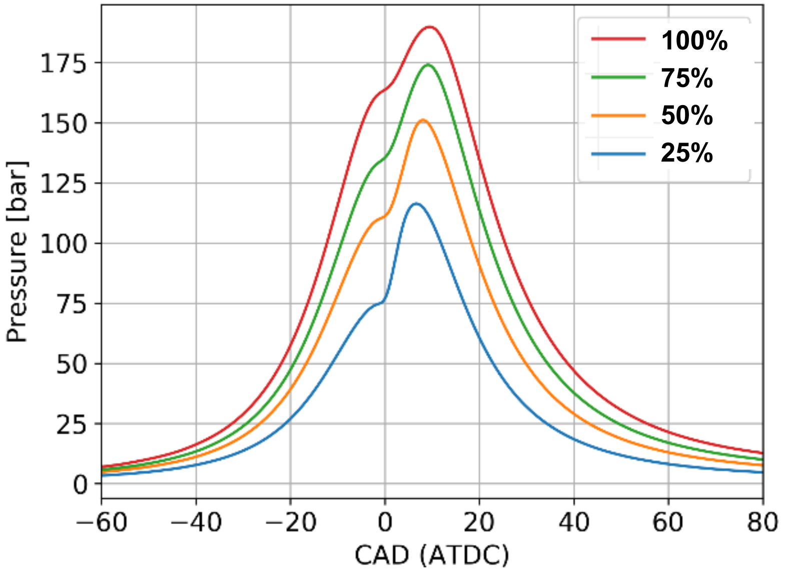
Ammonia

4T50ME-X-LGIA



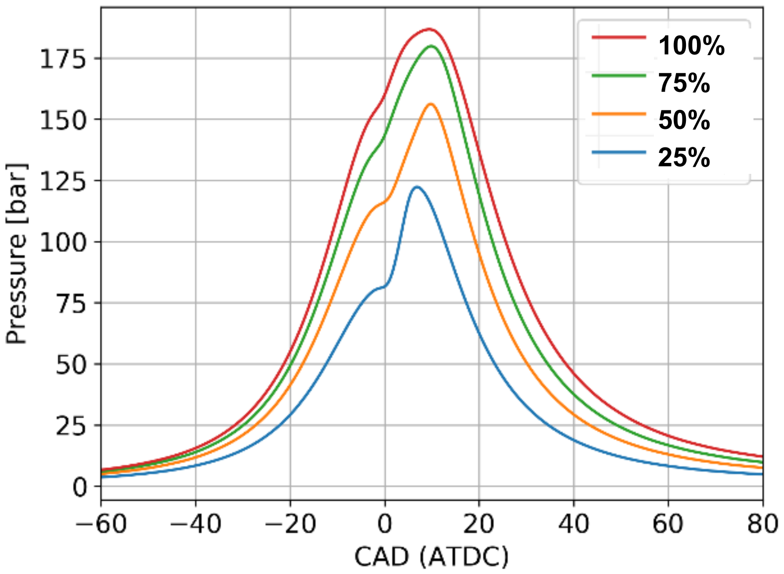
Diesel

Conventional dual-fuel engine in diesel mode (LGIM engine)



Methanol

Conventional dual-fuel engine (LGIM engine)



Ammonia engine's performance has similar compression, combustion and expansion curves to other diesel and dual-fuel engines for all tested loads

4T50ME-X

2
Emissions

Emissions from NH_3 operation

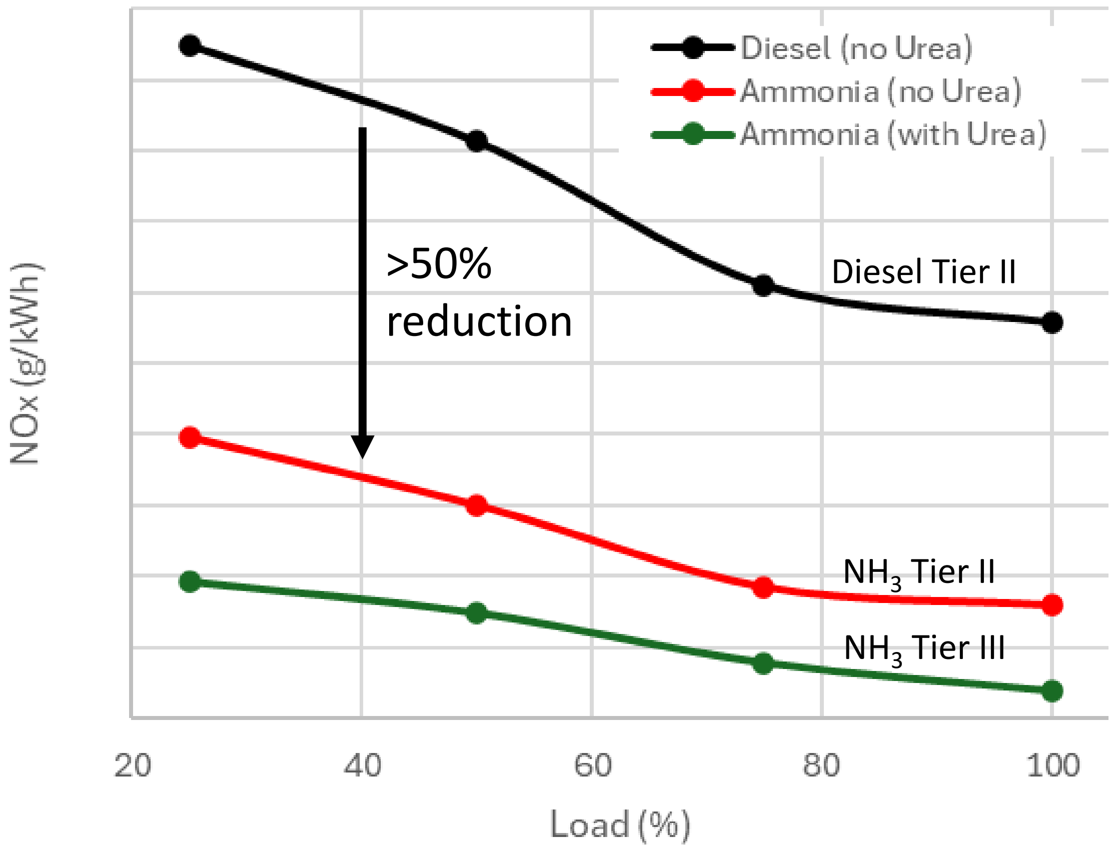
Emission	NH_3	NO_x	N_2O
Mitigation	SCR	SCR	×
Effects	*Fertiliser* *Aerosol precursor* *Efficiency loss* *Toxic*	*Smog* *Respiratory problems* *Acidification* *Fertiliser*	*Strong GHG* *Ozone depletion*

Intrinsically low: CO_2, CO, PM, SO_x, HC

High-pressure SCR

LGIA: NOx emissions

Specific NOx emissions (after SCR in stack)



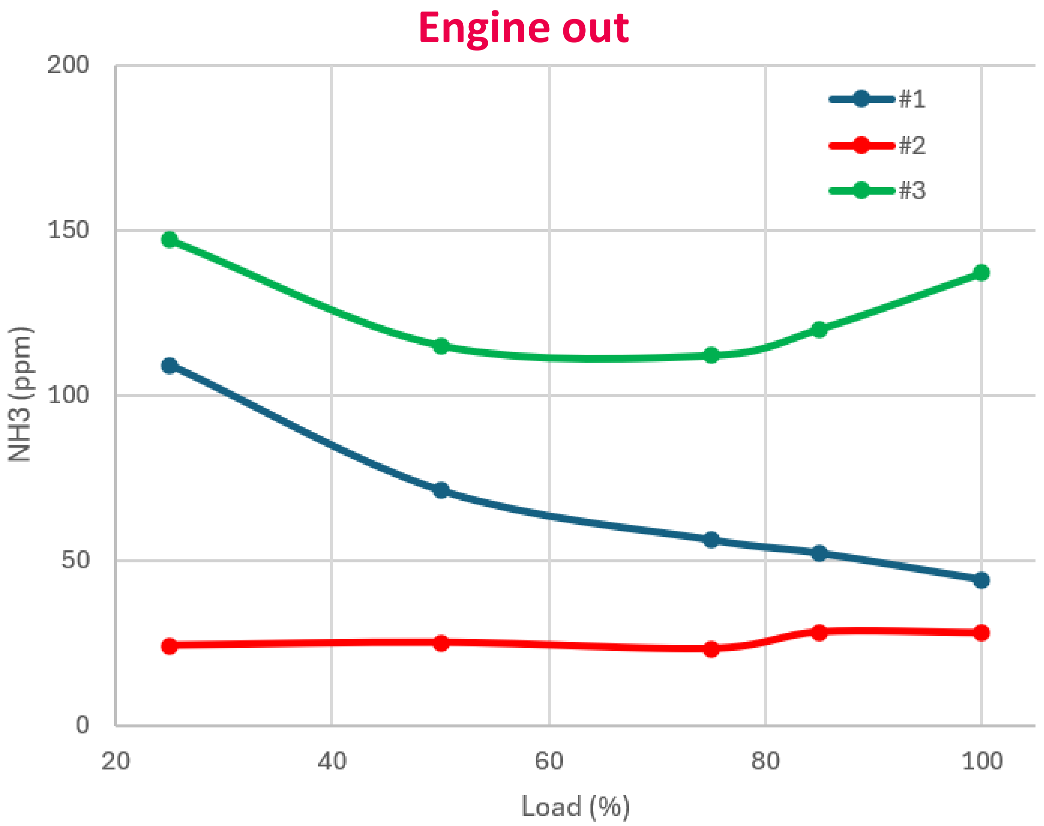
LGIA engine

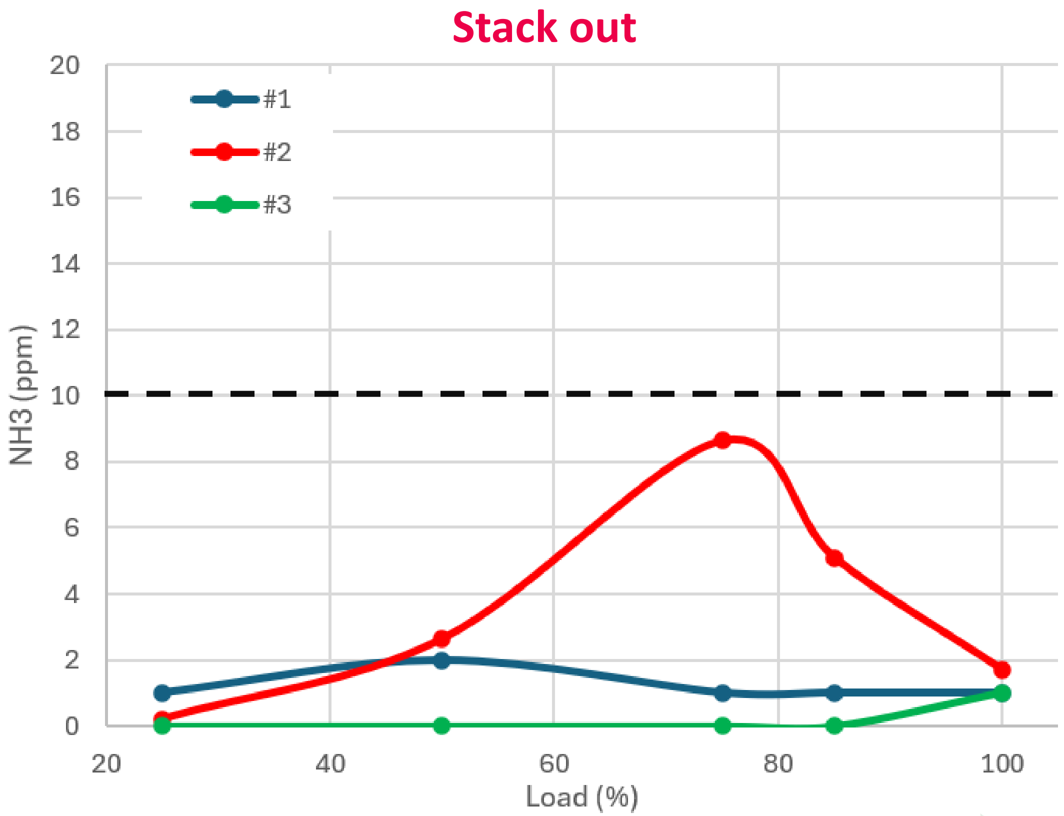
Diesel: ~10% margin to Tier II limit

NH_3 (no Urea): ~70% margin to Tier II limit

NH_3 (with Urea): ~50% margin to Tier III limit

LGIA: NH_3 slip





LGIA engine

Stack out NH_3: <10 ppm

- Injector technology ensures low NH_3 emissions out of engine
  → Further reduced in SCR

→ Compliance to any future NH_3 emission legislation expected

LGIA: N_2O emissions

LGIA engine

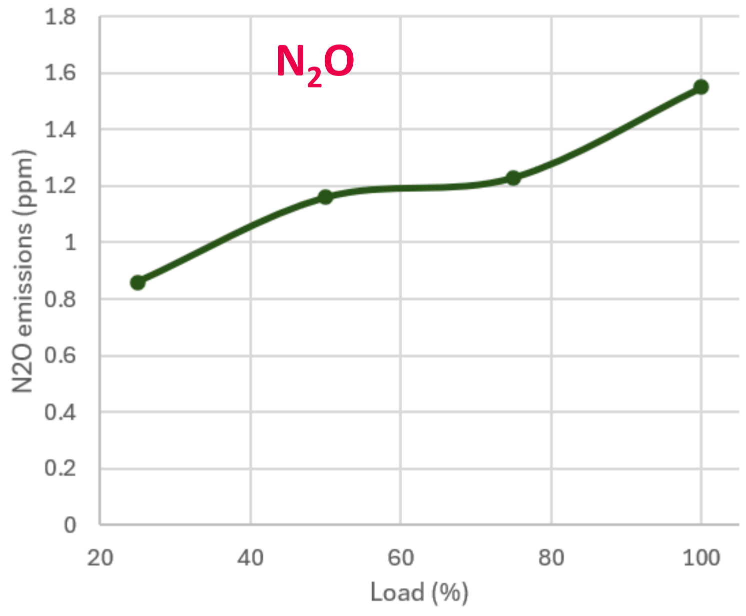
- N_2O has 265 times higher GHG impact than CO_2
- Intrinsically low N_2O emissions: 1-3 ppm

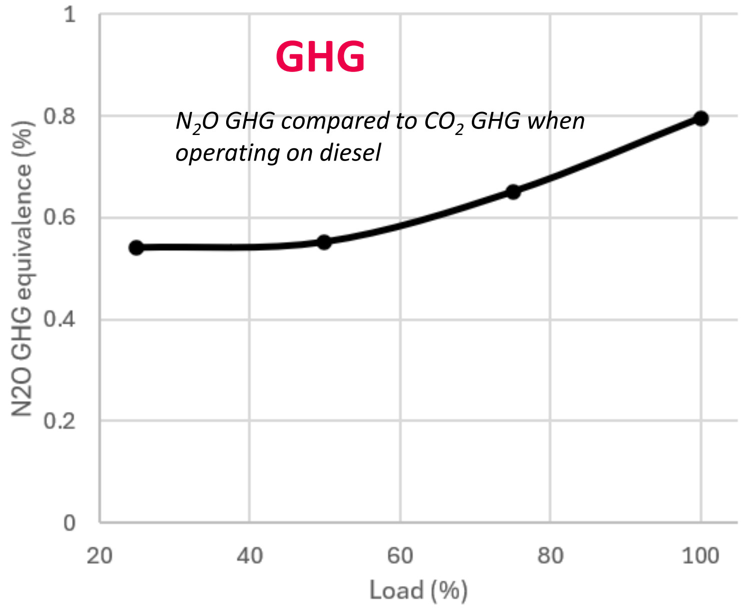
  → No mitigation needed

  → Close to measuring equipment (FTIR) detection limit
- Considerably lower than used in IMO 4th GHG study for diesel and gas, and *FuelEU* default factors for Ammonia and diesel operation
- GHG_{TTW} contribution: 1%-2%

  → >90% GHG_{TTW} saving on high loads:

$$GHG_{TOT,TTW} = N_2O + CO_{2\_pilot}$$





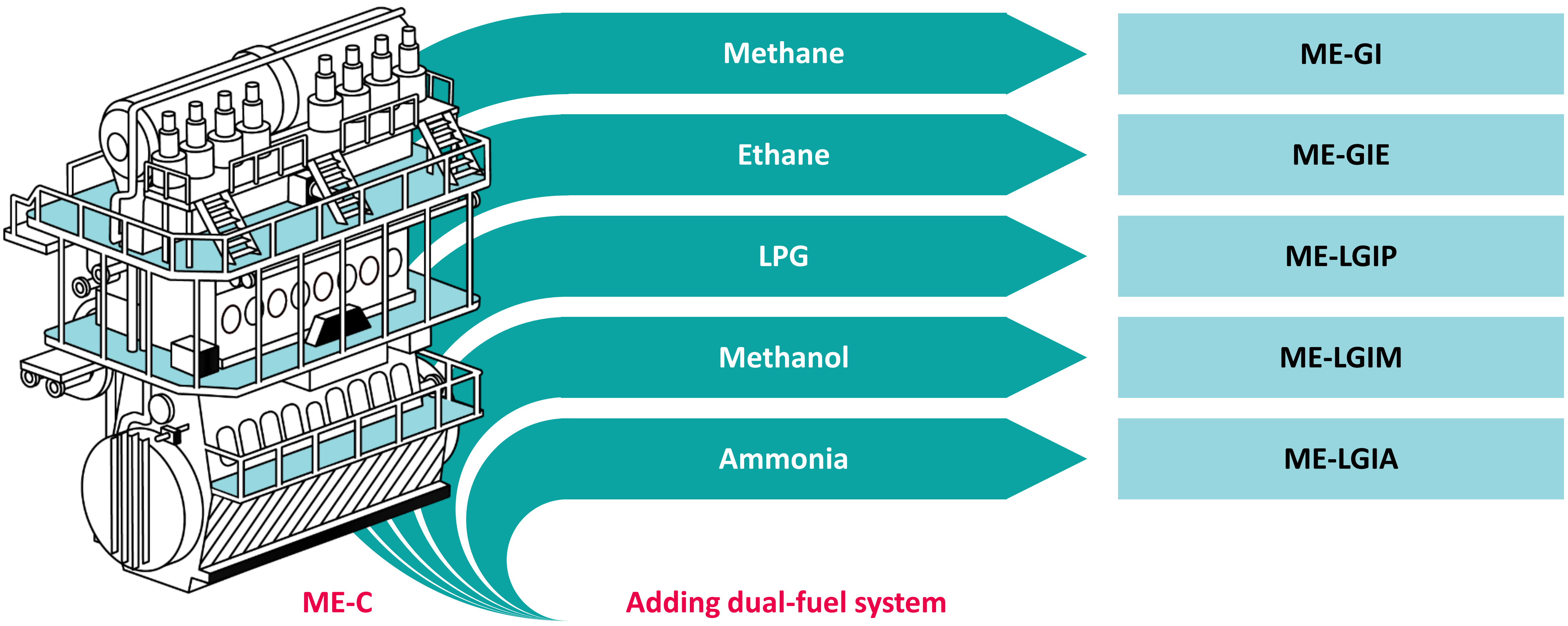
3
Safety

The modular development

Built on a trusted platform – ready for the future

Overall safety concept

- **Immediate switch to diesel operation in case of failure in Ammonia operation**



Auxiliary systems for ammonia engines

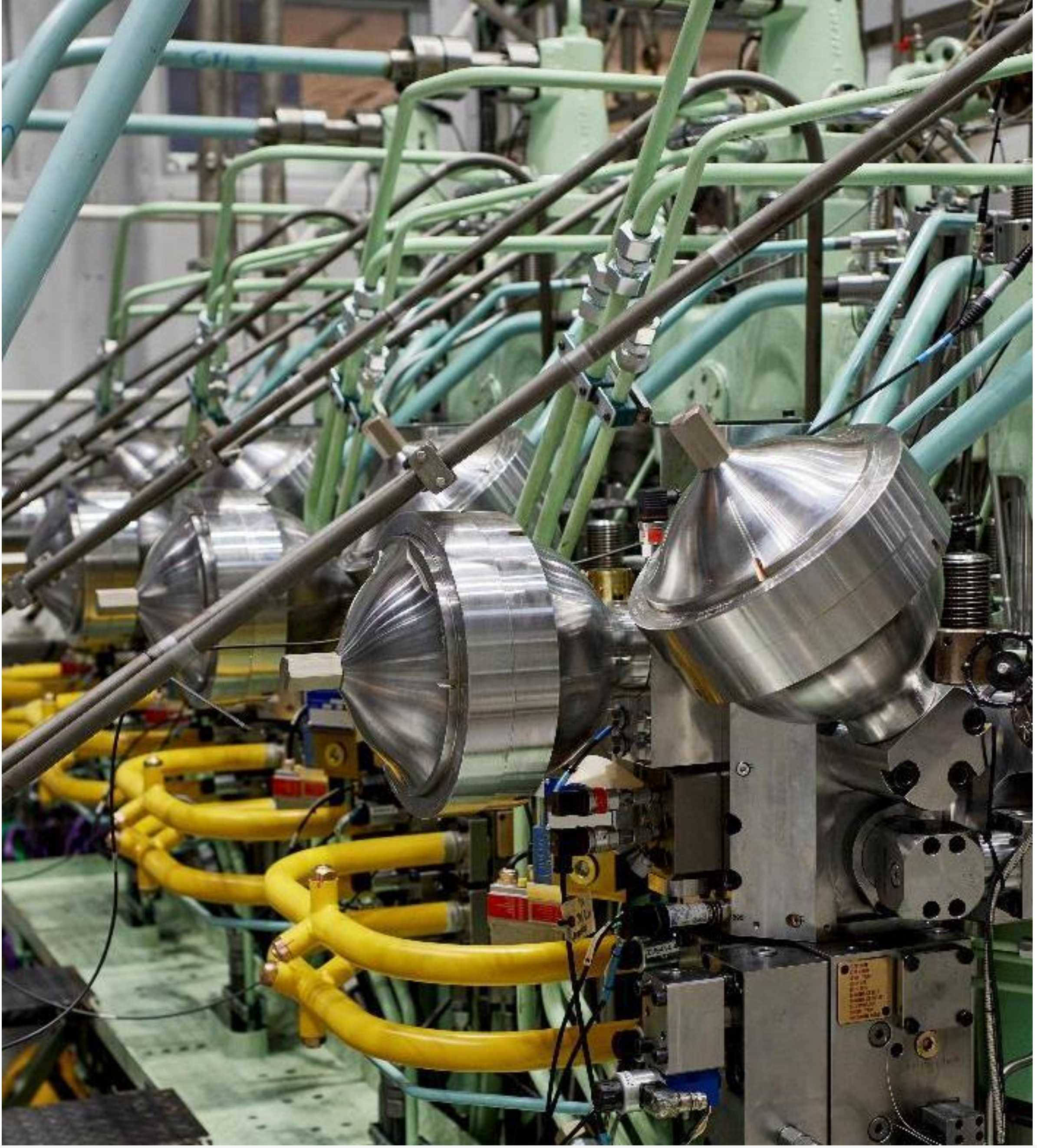
Built on the trusted ME-LGI platform – ready for the future

Tank and bunker station	Main engine knock out drum + recovery tank	Ammonia Release Mitigating System (ARMS)
Fuel valve train	Recirculation system	Double wall ventilation system + outer pipe ARMS
Fuel gas supply system	N_2 system	Seal oil ventilation system

Well-known from LGI

Added for ammonia

4
Summary



Summary

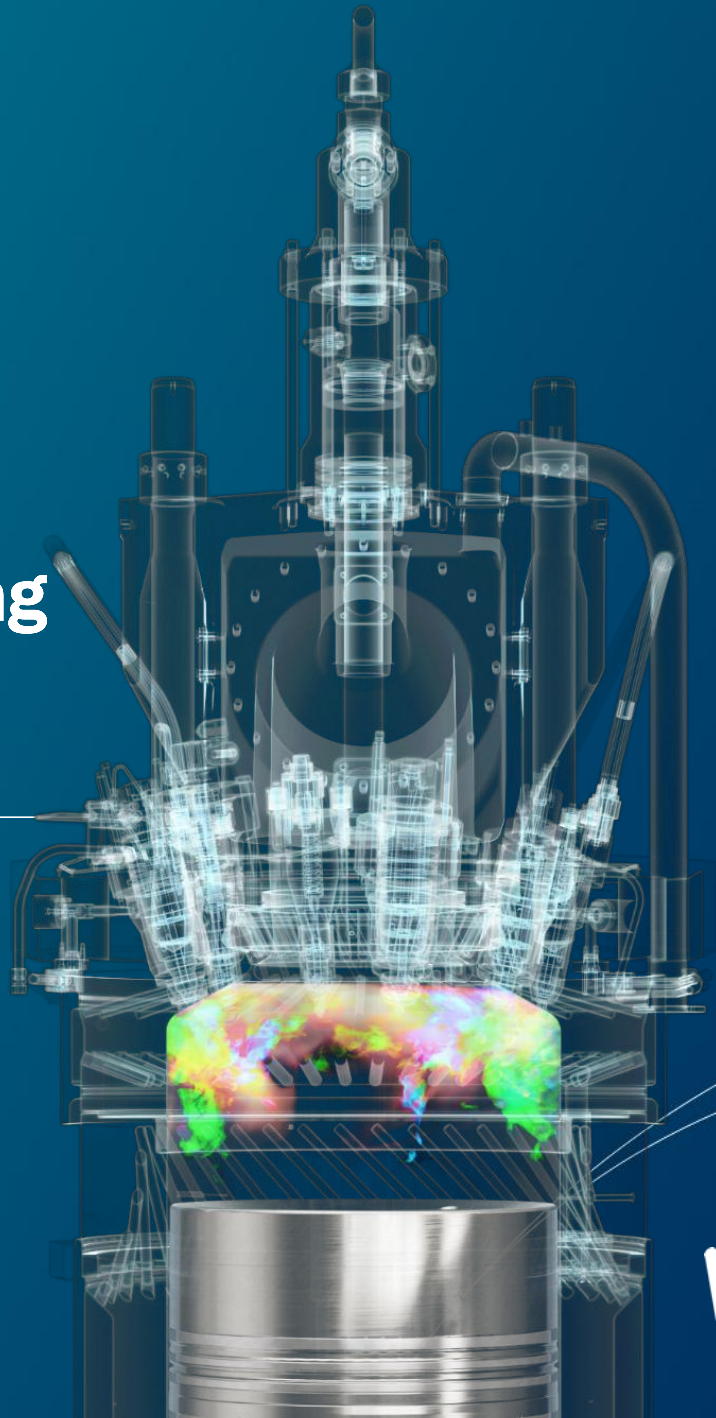
LGIA engines

- First commercial ammonia engines are now tested, certified, approved and **ready to order.**
- **Emissions are found low**.
- Everllence is ready to support ME-LGIA engines on a **wide range of engine sizes**.
- The toxicity challenge of ammonia as a marine fuel remains a **crucial focus point and requires a responsible approach**.

Thank you very much!

All data provided on the following slides is for information purposes only, explicitly non-binding and subject to changes without further notice.

WinGD's Landmark X-DF-A Engine: Powering the World's First Ocean-going Commercial Ammonia Vessel



Anirudh Purayil

Project Manager, New Engines

IMO Technical Seminar – Sept 17, 2026

WinGD's Landmark Ammonia Engine

Powering the World's First Ocean-going Commercial Ammonia Vessel

Historic Milestone in Maritime Decarbonization

→ Successful demonstration that ammonia propulsion is commercially viable for ocean-going trade

Setting the Global Benchmark

→ Real-world operational data provides crucial industry benchmarks for ammonia safety protocols, combustion and operational efficiencies, environmental impact etc.

Zero-Carbon Pathway for Deep-Sea Trade

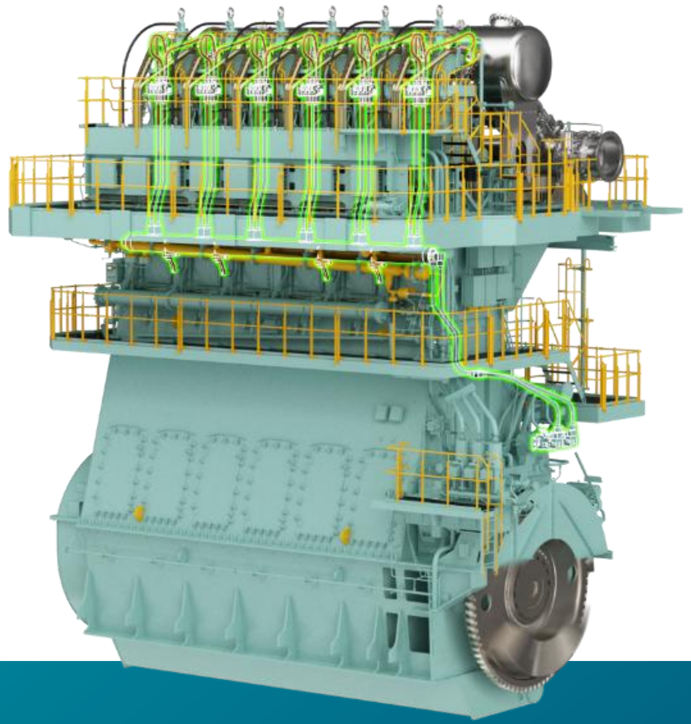
→ Transitioning ammonia from an experimental fuel into a field-tested and scalable option for this hard-to-abate sector

Commercial Traction with 40+ X-DF-A Engine Orders

→ Orders across gas carriers, bulkers, feeders and tankers showing an industry-wide movement, well beyond a single prototype

X-DF A by WinGD From Development to Commercial Application

Key Engine Characteristics



01 Same components as on diesel engine (+ ammonia injection system and safety features)

02 Diesel mode efficiency same as of a diesel engine

03 Full redundancy of diesel engine remains available

04 In ammonia mode, same power output, similar performance as a diesel engine

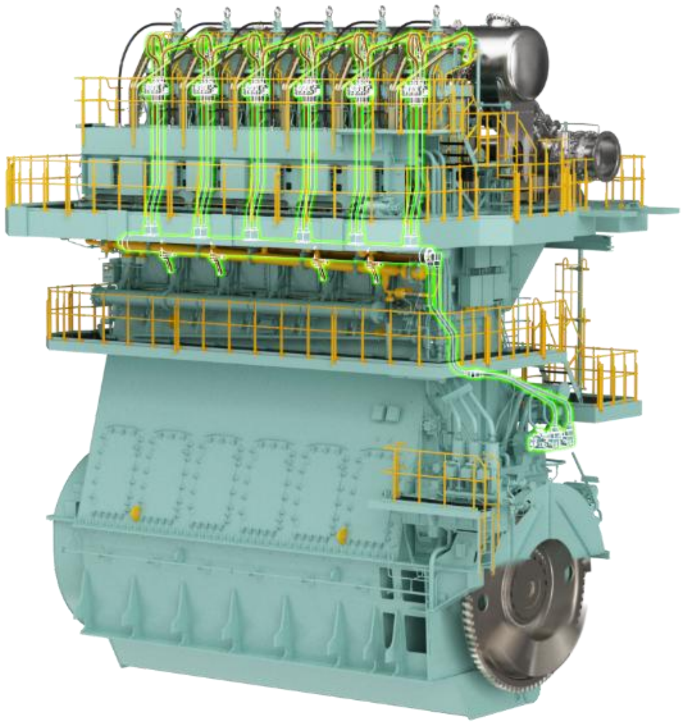
05 Same proven emission abatement concept (SCR) as on diesel engines

Retrofitability

All single-fuel X-Engines and dual-fuel X-DF engines can be converted for ammonia operation

X-DF A by WinGD — From Development to Commercial Application

Key Engine Characteristics – Safety by Design



01 **Gas Safe Machinery Space Concept**
Double wall piping
Secondary containment ventilation and automated detection

02 **Fuel Injection System**
Secondary containment and detection mechanisms
No injector sealing oil (no contamination)
No ammonia recirculation to FSS in normal operation

03 **Purging Strategy**
Safe and effective purging procedures using nitrogen and water
No icing; System pressure & temp. controlled to avoid ammonia flashing
Fully remote operation & maintenance-friendly concept

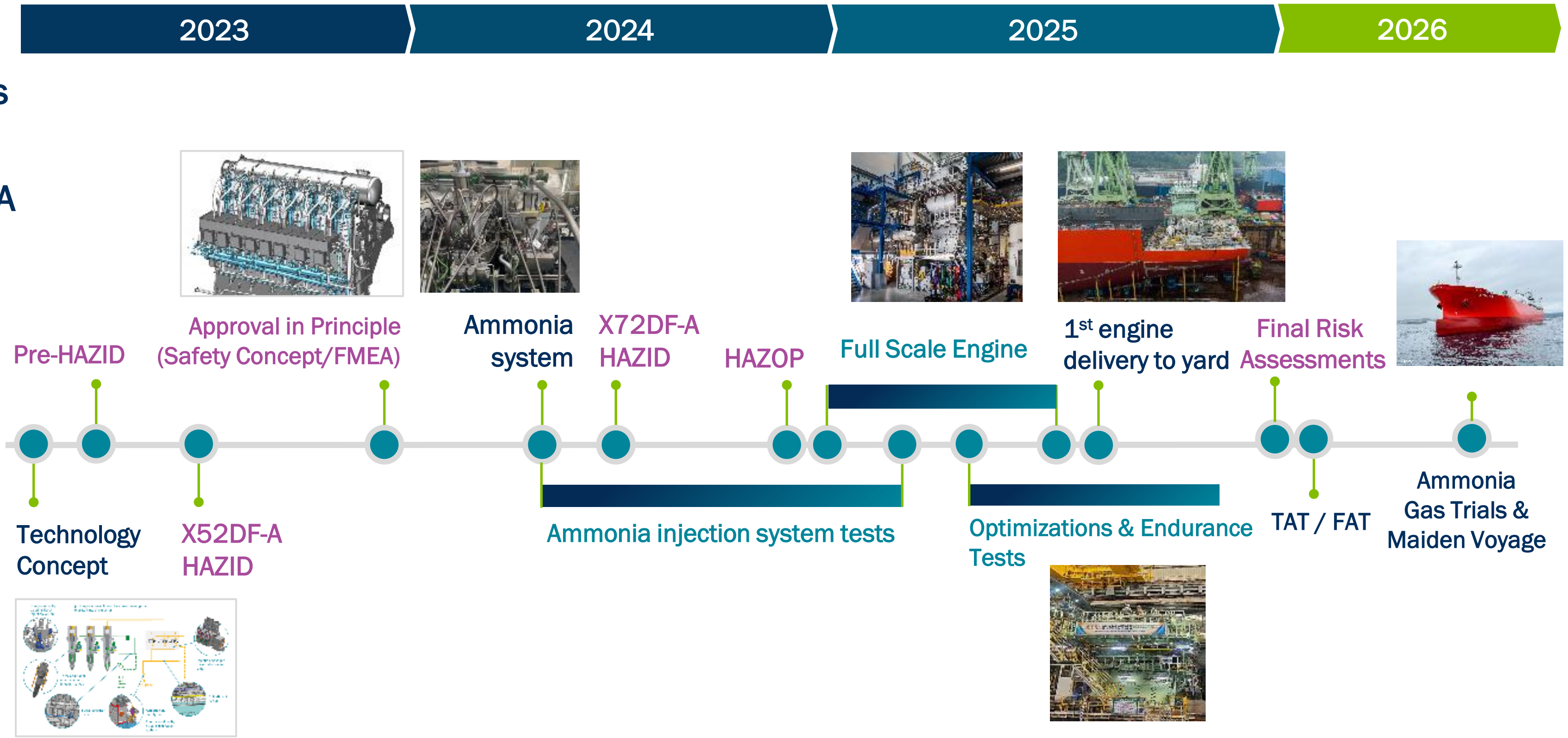
X-DF-A offers highest safety and automation standards; Safety by design and integrated safety systems

X-DF A by WinGD

From Development to Commercial Application

Extensive Risk Assessments – HAZID/HAZOP

- HAZID/HAZOP with all project stakeholders
- Extensive Internal Risk Assessments/FMEA
- First Approval in Principle (AIP)
- Complete Risk Based Certification Process with stakeholders/Class
- TAT/FAT[1] with all major Classification Societies
- Sea Trials on Ammonia

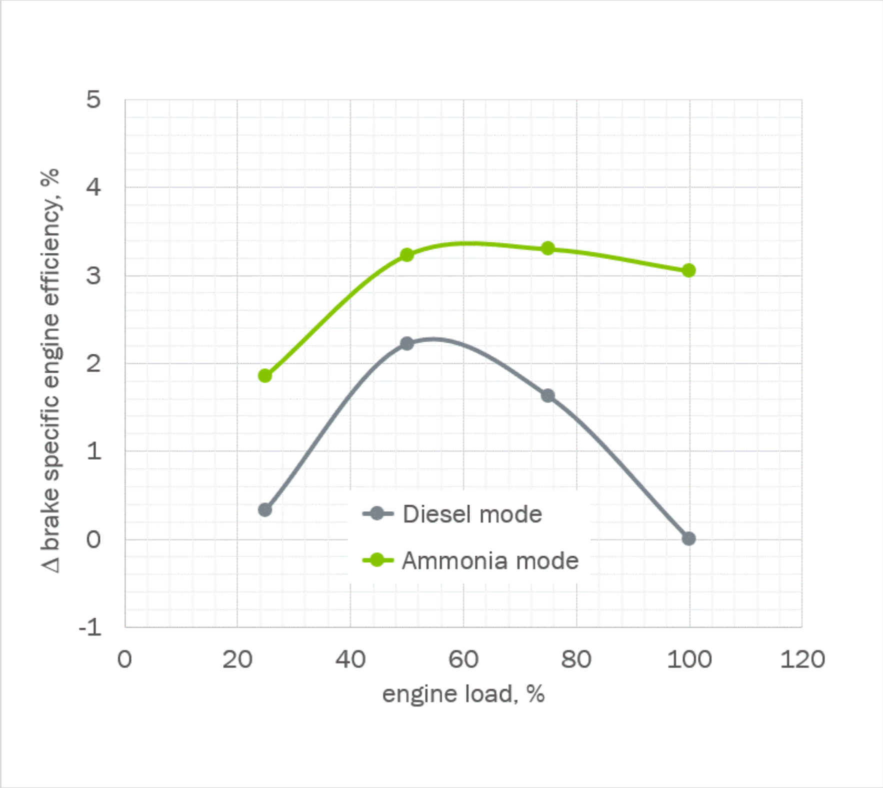


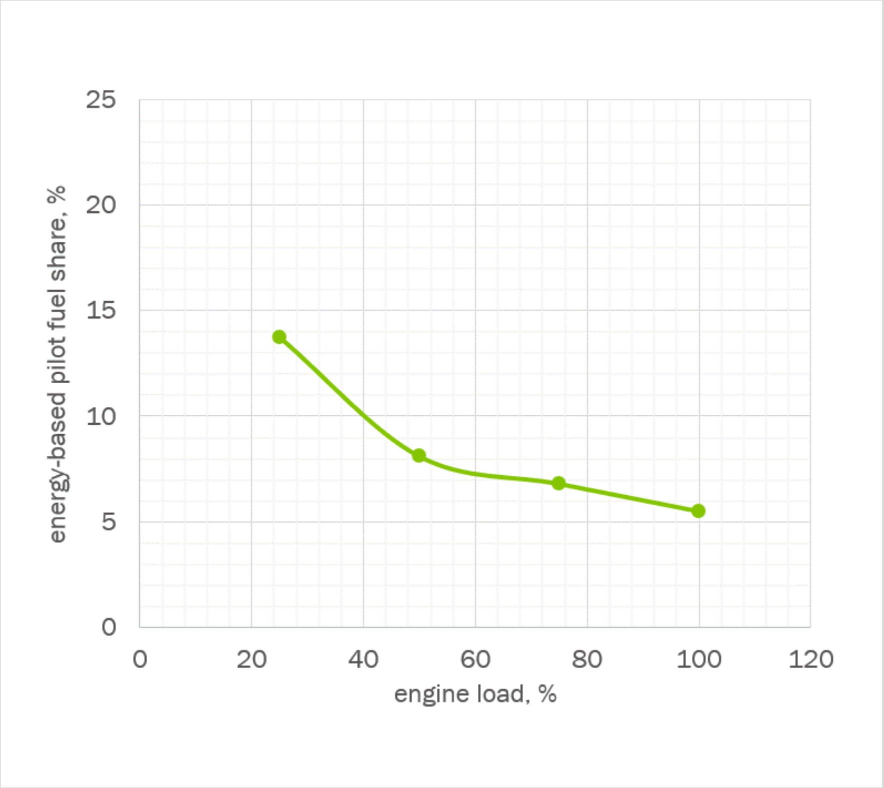
[1]TAT/FAT – Type Approval Test, Factory Acceptance Test

Joint Development Projects incl. Class to monitor, track and manage risks during the development

X-DF A by WinGD Fuel Efficiency

Measured values during the official shop test



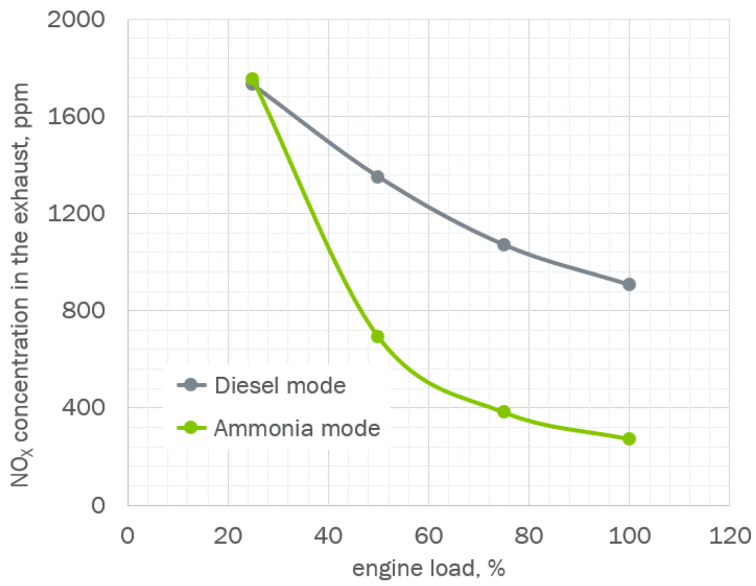


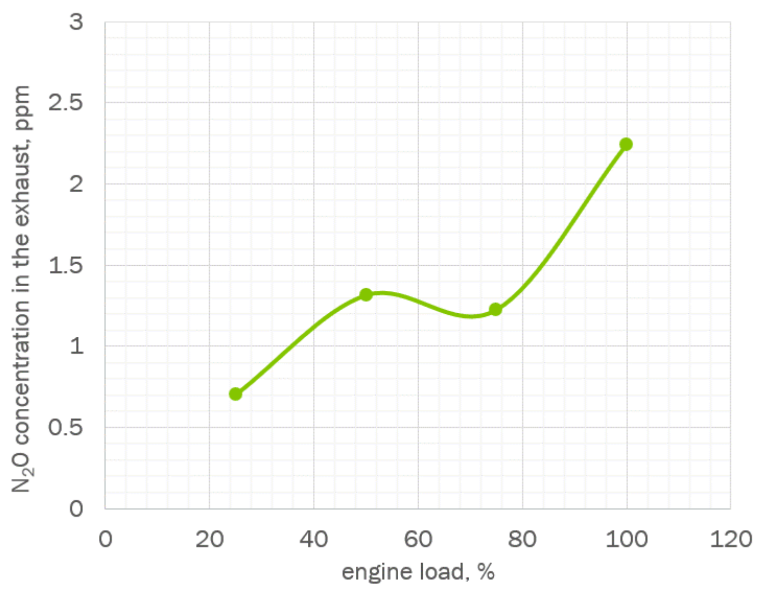
All performance targets achieved: Fuel consumption according to estimates, Pilot consumption ~5%

Fuel efficiency for ammonia mode is positive compared to diesel mode

GHG & Emissions

Measured values during the official shop test





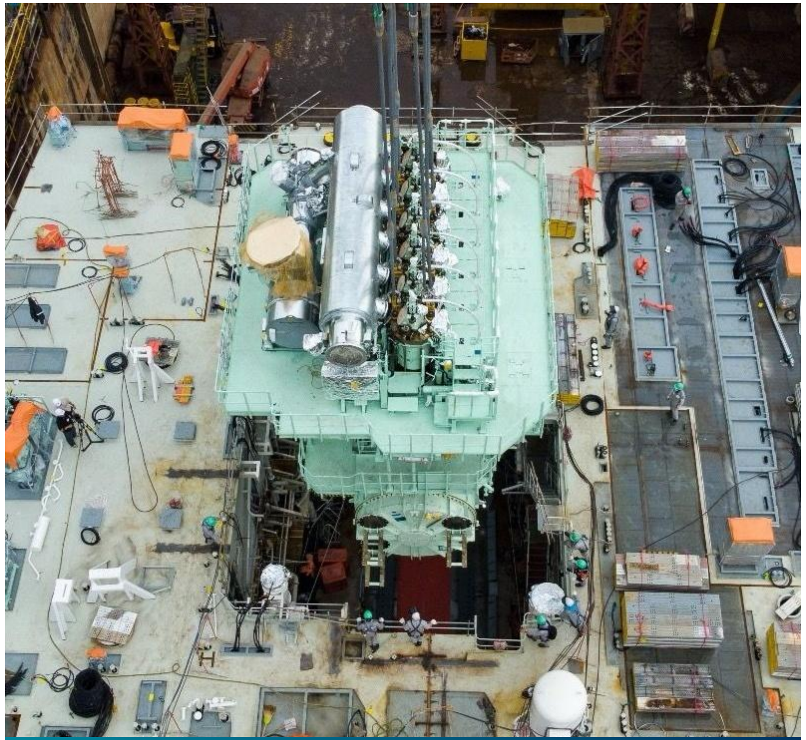
NH_3 slip: Very low engine-out emissions, ~zero NH_3 emissions downstream SCR

NOx: Tier II & Tier III compliant. Ammonia mode generates less NOx (<50%) than diesel mode

N_2O: Very low engine-out emissions, no N_2O aftertreatment needed

Commercial Application - GHG avoidance potential

Engine-cycle GHG reduction above 90%

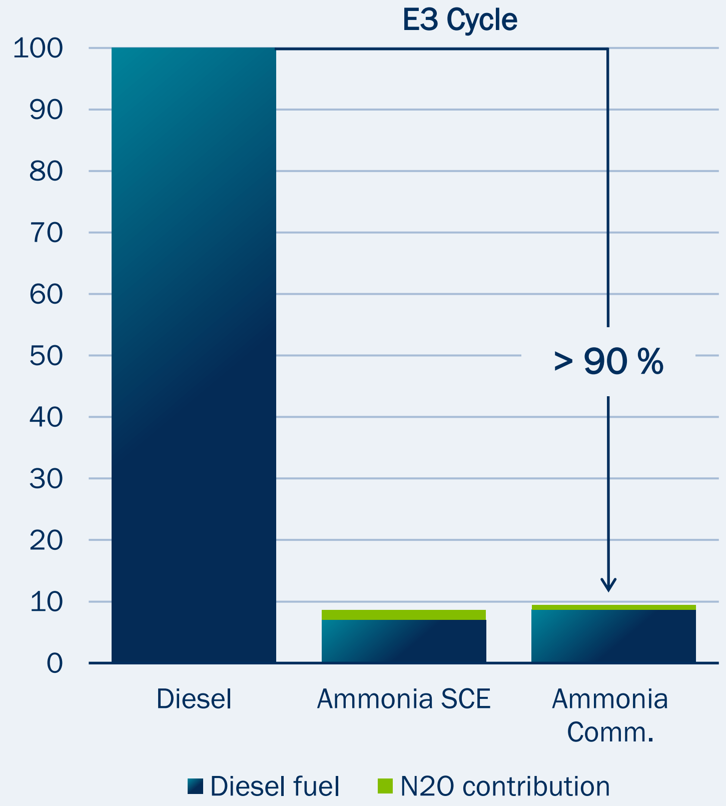


From June 2025 to today

For Tank to Wake (Engine level), GHG contributions include:

- Remaining CO_2 associated with diesel pilot combustion
- N_2O formed during combustion

Measured emissions aligned well with Full Scale Engine results



Installation of the X-DF-A engine on the world's first oceangoing ammonia-fuelled vessel. Photo courtesy Exmar.

Ammonia Regulations

Work still ongoing at IMO

- **Need for uniform guidelines for Ammonia (IGF & IGC ships)**

- **Successful first project execution and experience with IGC interim guidelines**
  - Risk assessments, risk-based approach was imperative
  - Learnings and insights could be taken forward for establishment of standardized regulatory frameworks

- **Important aspects as "Gas safe machinery space"**
  - Currently taken over directly from IGF code, where the primary focus was explosion risks (flammability)
  - While compliance to this principle was achieved, Ammonia has different challenges (toxicity over flammability)

- **Focus on standardized training and human element**
  - Managing toxic risks relies heavily on crew competence, PPE protocols, and localized monitoring in addition to physical system safeguards

X-DF A by WinGD

PRESS RELEASE

WinGD Achieves First Type Approval and Factory Acceptance Testing for Ammonia-Fuelled Two-Stroke Engine

25 February 2026 • 4 minutes to read

WINTERTHUR, SWITZERLAND

Swiss marine power company WinGD has achieved a major milestone on the path to zero-carbon shipping with the completion of both Type Approval Testing (TAT) and Factory Acceptance Testing (FAT) of their ammonia-fuelled two-stroke marine engine. Both test programmes were completed in January 2026, with testing of the X52DF-A-1.0 engine carried out at the HD Hyundai Heavy Industries' Engine & Machinery (HHI-EMD) facility in South Korea, witnessed by classification society Lloyd's Register (LR), together with representatives from all major classification societies, under the supervision of EXMAR.

The testing programmes took place on a 52-bore engine to be installed on a 46,000m³ LPG/ammonia carrier on order for EXMAR. The vessels in the series are set to become the first ammonia-fuelled gas carriers to enter commercial service, marking a significant milestone for the shipping industry's decarbonisation efforts.

"Completing Type Approval Testing and Factory Acceptance Testing with our joint development partner HHI-EMD represents a major technical milestone in the development of ammonia-fuelled two-stroke propulsion. As first movers, we are addressing a completely new fuel landscape, where safety, control and system integration are paramount. We have developed an engine that has been well proven to be safe and efficient by tackling, one by one, all the technical challenges we faced. Demonstrating our first TAT for an ammonia-fuelled two-stroke engine with strong results demonstrates that ammonia propulsion can meet the highest standards of reliability, performance and safety expected by the industry for commercial marine application."

Sotiris Topaloglou
Global Head of Testing & Validation, WinGD

Throughout a rigorous multi-year development and testing process, excellent performance has been demonstrated. Emissions data from the X-DF-A engine has impressed with NOx emissions during ammonia operation well below those generated during diesel use. Excellent results have also been recorded for emissions of N2O, with a negligible contribution to the overall greenhouse gas emissions footprint.

X-DF-A by WinGD First Successful Sea Trials

Delivery of world’s first ocean-going commercial ammonia-fuelled vessel

- **Engine Performance**
  Achieved over 100 cumulative hours in Ammonia mode. Stable engine operation up to 85% load.

- **System Integration**
  Main engine, fuel supply system, onboard systems integration performed within design and safety specifications.

- **Safety & Risk Mitigation**
  Safety functions, systems and safeguards, ammonia handling concepts successfully validated onboard.

- **Commercial Milestone**
  Successful sea trials enabled first vessel’s delivery to the customer on **10 June 2026.**

X-DF-A To the Maiden Voyage

From First Voyage to Commercial Reality

- **Route** - China (Nanjing) to India (Kakinada)
- **Extended Ammonia Operation**
  Logged >230 cumulative hours in Ammonia Mode
- **Engine Technology Validation**
  Performance in line with design expectations.
- **Safety & Integrity**
  No ammonia leakage/odor detected in the engine room; post-voyage inspections confirmed components, sealings remained in good condition.
- **Operational Optimizations**
  Controls & automation, onboard systems integration, as typically observed during new product introduction.

X-DF A by WinGD To the Maiden Voyage

Initial service experience of the first X-DF-A vessel

Data capturing first four days of the maiden voyage

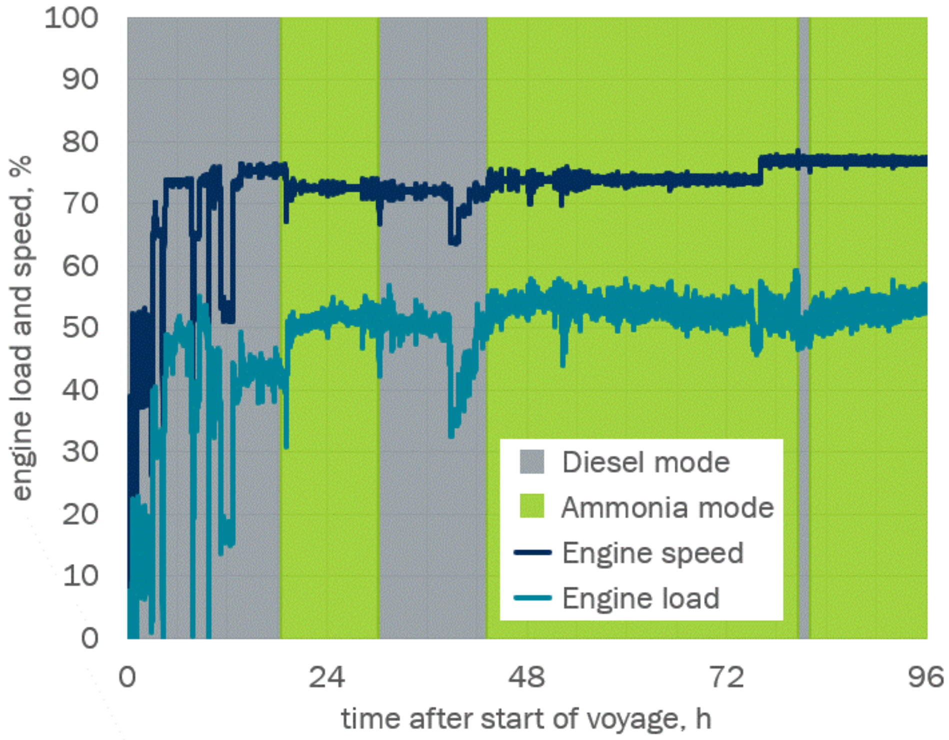
- Engine load, speed pattern as well as the operating modes
- Two trips to diesel, both related to experience building on cargo handling and its effects on the AFSS operation

~230 hours of operation on Ammonia mode

- Multiple long periods of uninterrupted Ammonia operation

System Validation

- Ship side systems integration validated
- Engine safety principles, concept and safety architecture validated
- Ammonia mode process, including transfers, trip, purging and water cooling working well and to expectations



X-DF-A From Concept to Reality

Thank you to the project partners

WinGD's X52DF-A at HD Hyundai Heavy Industries (HHI-EMD) in South Korea for a series of 46,000m³ LPG/ammonia carriers.

A strong collaboration with

- EXMAR Ship Management
- Hyundai Heavy Industries-Engine Machinery Division (HHI-EMD)
- HD Hyundai Mipo (HMD)
- Lloyd's Register, Belgian Flag State

Thank you

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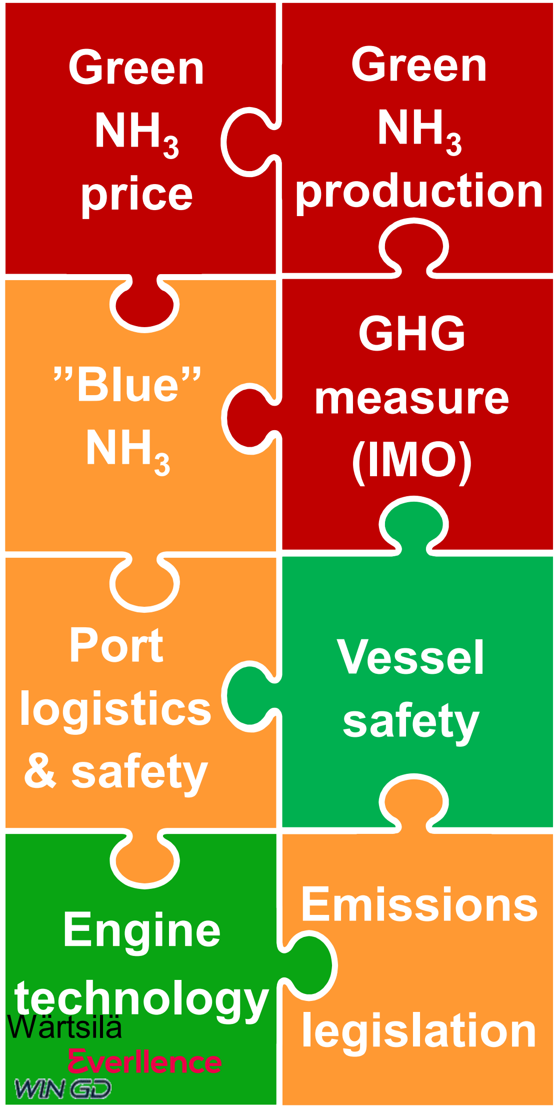
Propelling shipping towards a greener future

Challenges for making ammonia a major marine fuel by 2050



Thank you very much!

The European Association of Internal Combustion Engine and Alternative Powertrain Manufacturers