SAFE AND EFFECTIVE OPERATION OF ENGINES WITH AMMONIA AND METHANOL

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R&D and Engineering

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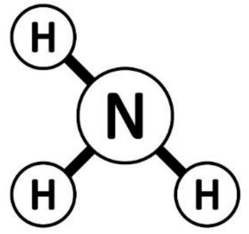
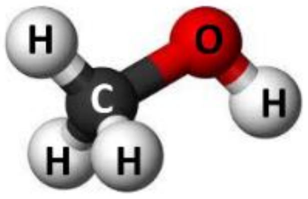
Introduction

New alternative fuels are emerging to reduce greenhouse gas emissions and eventually decarbonize the maritime industry. Green ammonia is recognized to be a viable option to create a path for maritime industry decarbonization as Ammonia is a zero-carbon fuel. Methanol as fuel was introduced the first time onboard a ship in 2015. Green Methanol can be produced by renewable sources and by re-using carbon or using renewable carbon making it carbon-neutral.



- Since ammonia is toxic ensuring safe operation using ammonia as fuel in engines is one of the main concerns to address
- Methanol is flammable in and harmful upon contact so ensuring safe handling requires certain precautions and awareness
- Several different engine concepts are being evaluated for methanol and ammonia as these fuels can be used both in gaseous and liquid form.



Stepwise approach in development ensures maximum quality and highest safety standards

Idea

Resarch

Technology development & proof of concept

Development

Industrialised solution

Deployment

  PUBLIC

WÄRTSILÄ HAS A RICH HISTORY OF INTRODUCING NEW FUELS

HFO

CNG/LNG

Ammonia for NOx reduction

High viscosity HFO

Crude oil

Orimulsion

Biodiesel

Animal-fat

Syngas from wood chips

Shale gas

Biogas

LPG

LEG

Low-viscosity diesel

OxyCAT for methane slip reduction

Methanol (STENA GERMANICA)

Hydrogen blending

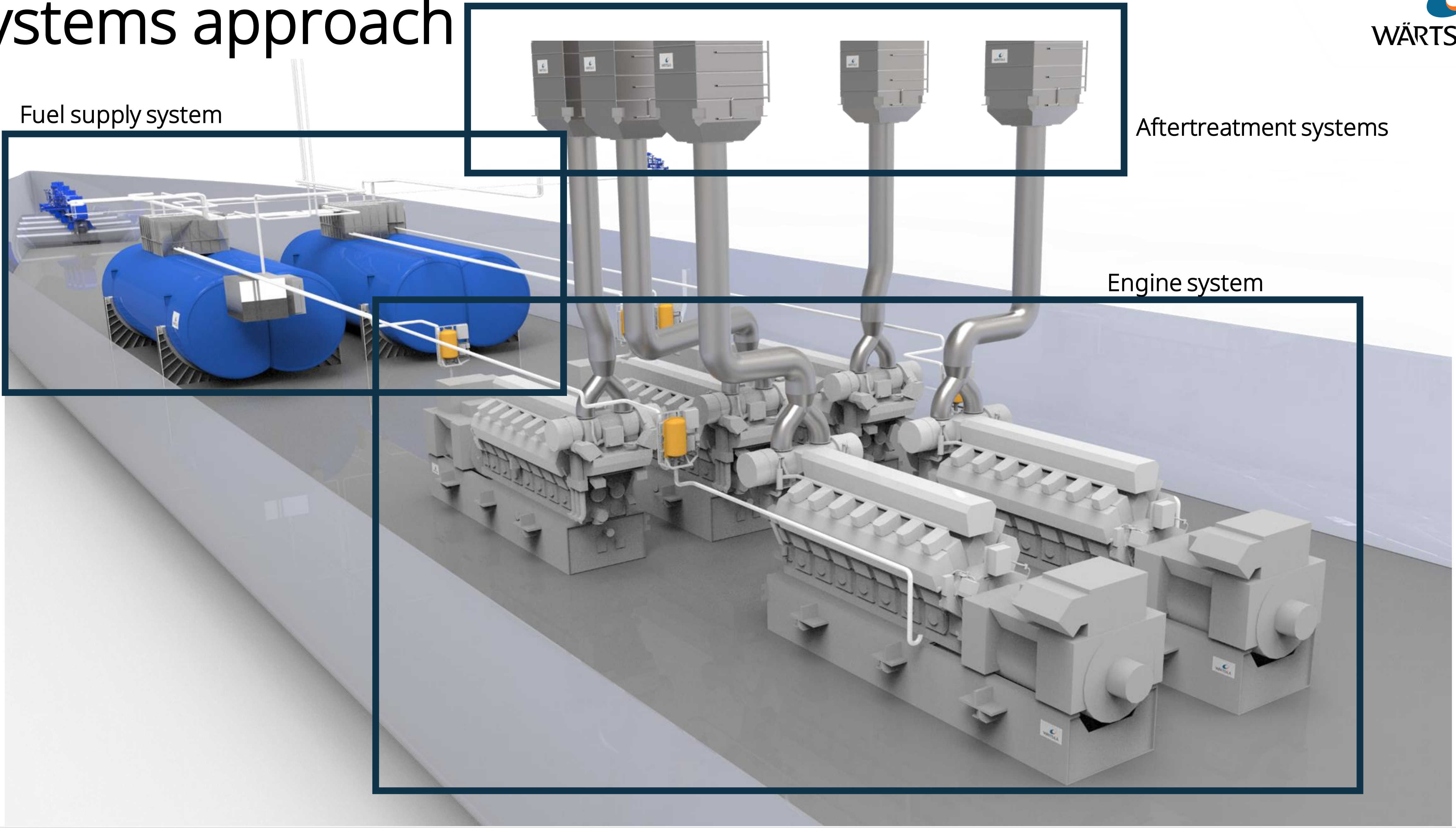
Associated gases

Ammonia

Hydrogen

1970 1980 1990 2000 2010 2020

Systems approach



  PUBLIC


Methanol

Methanol

- Consists of a methyl group (three Hydrogen atoms and one Carbon atom) linked to a hydroxyl group (one Oxygen atom bonded to one Hydrogen atom)
- Toxic, colourless liquid, characteristic odour
- Completely miscible with water and highly flammable
- It can be easily stored in liquid form
- LEL 6 %, UEL 36 % (Methane 5-15%, Hydrogen 4-75%)
- Auto ignition temperature 440 °C
- Methanol vapor is slightly heavier than air

Engine development and testing

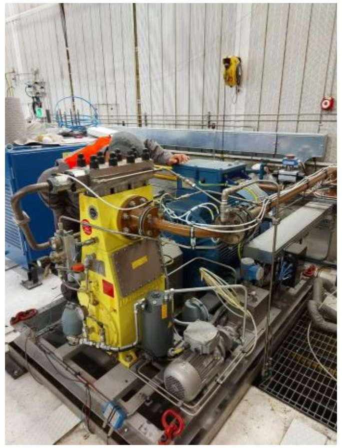
Common engine and fuel supply system development, as from a control, fuel processing, safety and energy optimisation there is need for a close interaction between engine and process system!

Field testing since 2015

[Stena Germanica the first ship in the world to run on methanol as a marine fuel]

With more than 9000 engine running hours Stena Germanica is Wärtsilä's floating laboratory – providing a lot of data as input for our Methanol Fuel Platform design

R&D laboratory full scale testing (engine and fuel supply system)



↑ W6L32M on R&D test bed

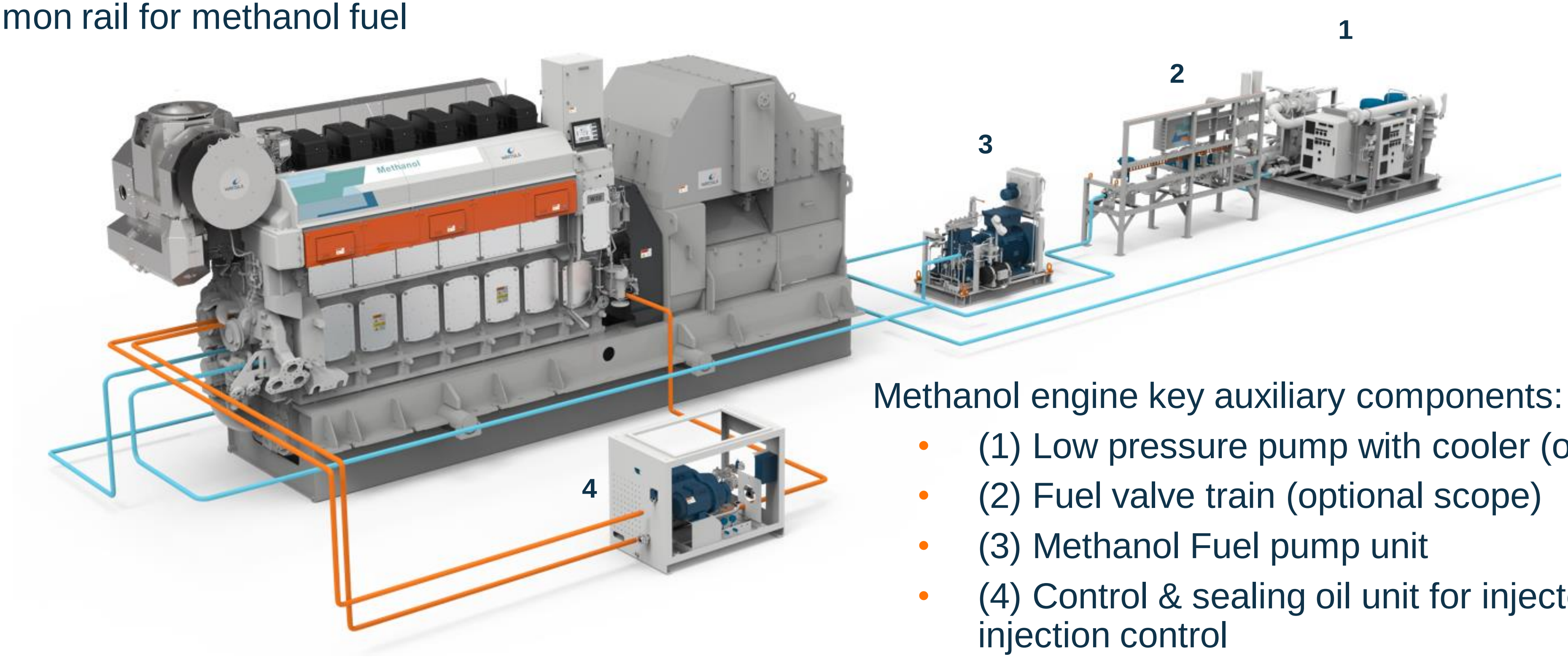
→ Left: Low Pressure Pump Skid (LPPS)
Right: Fuel Valve Train (FVT)

↗ Methanol Fuel Pump Unit (MFPU)

METHANOL ENGINE AND SYSTEM AVAILABLE TODAY

Methanol engine key components:

- Multifuel injection system (Marine Diesel Oil and Methanol)
- Cylinder heads - optimised for methanol combustion with pilot and main fuel
- Common rail for methanol fuel



Methanol engine key auxiliary components:

- (1) Low pressure pump with cooler (optional scope)
- (2) Fuel valve train (optional scope)
- (3) Methanol Fuel pump unit
- (4) Control & sealing oil unit for injector sealing and injection control
- Nitrogen generator for system purge (optional scope)

Wärtsilä 32 Methanol and Wärtsilä NOx Reducer

SCR Backpressure and reactor size optimization

- SCR design made for both Methanol mode and Diesel mode
- Solution tailoring for optimum performance and lifecycle taking installation into account
- Backpressure optimized for W32 engine aspiration, thermal load and fuel consumption
- Reactor can be oriented vertically or horizontally, with silencer integrated as option
- Reactor equipped with automatic soot blowing for prevention of backpressure increase

Common engine and SCR automation platform

- Easy installation with common interface and platform
- Ensures control of all operations
- Guarantees lifecycle support
- Engine automatic exhaust temperature control for SCR operation
- Urea dosing control based on NOx feedback control and engine operation parameters
- Assessment of catalyst condition enabled w/o need of separate NOx measurement devices

IMO Tier III EIAPP certification

Wärtsilä 32 Methanol engine is type approved and has received its EIAPP certificate

IMO EIAPP Tier III certification includes both the Wärtsilä 32 Methanol engine and Wärtsilä NOx reducer system

- Separate engine and SCR manufacturers pose certification-, technical-, reliability- and delivery related risks and uncertainty

IMO Tier III compliancy through the lifecycle is hereby secured

- ✓ Availability of NOx critical components like catalyst elements
- ✓ Lifecycle services
- ✓ System updates
- ✓ Troubleshooting engine and SCR together
- ✓ Reporting compliancy to authorities


AMMONIA
NH_3
WÄRTSILÄ

Ammonia

- Consist of three hydrogen atoms and one nitrogen atom. It is carbon-free fuel.
- Toxic, colourless, strong pungent odour
- In STP conditions ammonia is a gas and it is lighter than air
- It can be easily stored in liquid form
- LEL 15 %, UEL 28 % (Methane 5-15%, Hydrogen 4-75%)
- Auto ignition temperature 651 °C
- Boiling point (at 1 atm.) -33,4 °C

Ammonia PPE

Ammonia specific personal protective equipment (PPE) used during laboratory ammonia engine tests:

I. Powered Air-Purifying Respirator (PAPR) with ammonia cartridge with full face coverage.

II. Gas tight protective suit, boots, and gloves suitable material for protection against ammonia.

III. Hand-held ammonia detector.

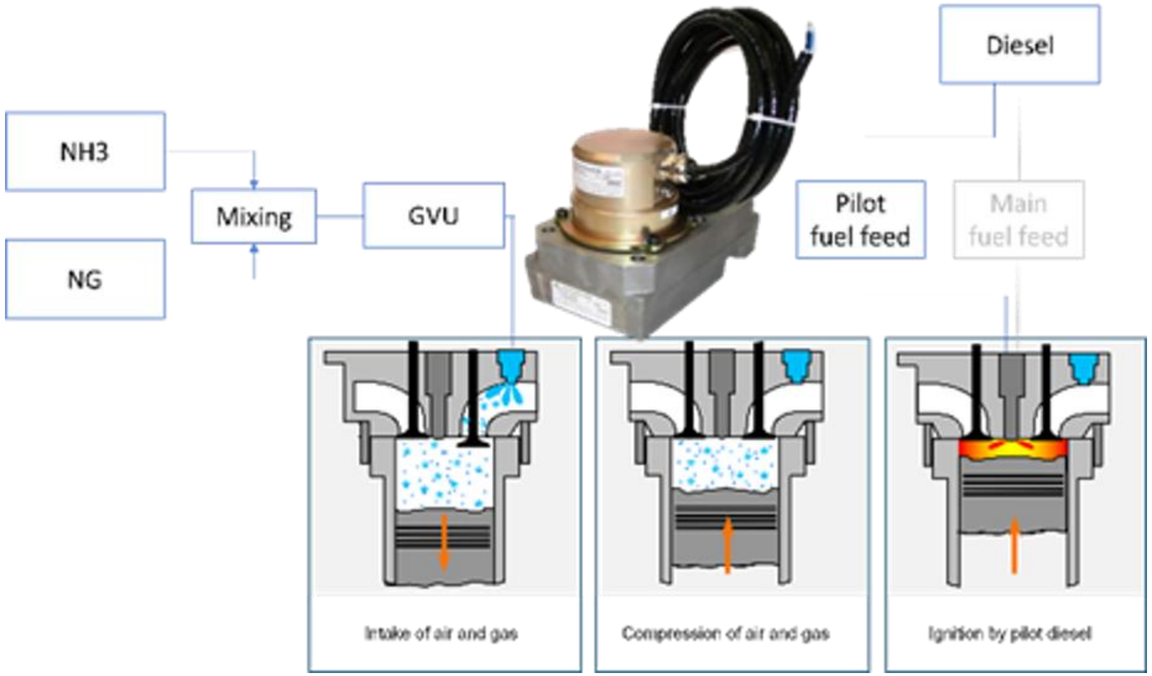
Ammonia engine concepts

Low pressure dual fuel and pure gas

- The engine operates in gas mode according to the otto combustion principle and in liquid fuel mode according to the diesel combustion principle.
- In this type of engine, ammonia can be used in two different ways:

I. As blended with natural gas (or LNG) in gaseous form before the engine gas inlet. This operation will then be like a DF engine operating in gas mode.

II. As separate admission of ammonia via the gas system and operated together with the liquid fuel (fuel sharing)

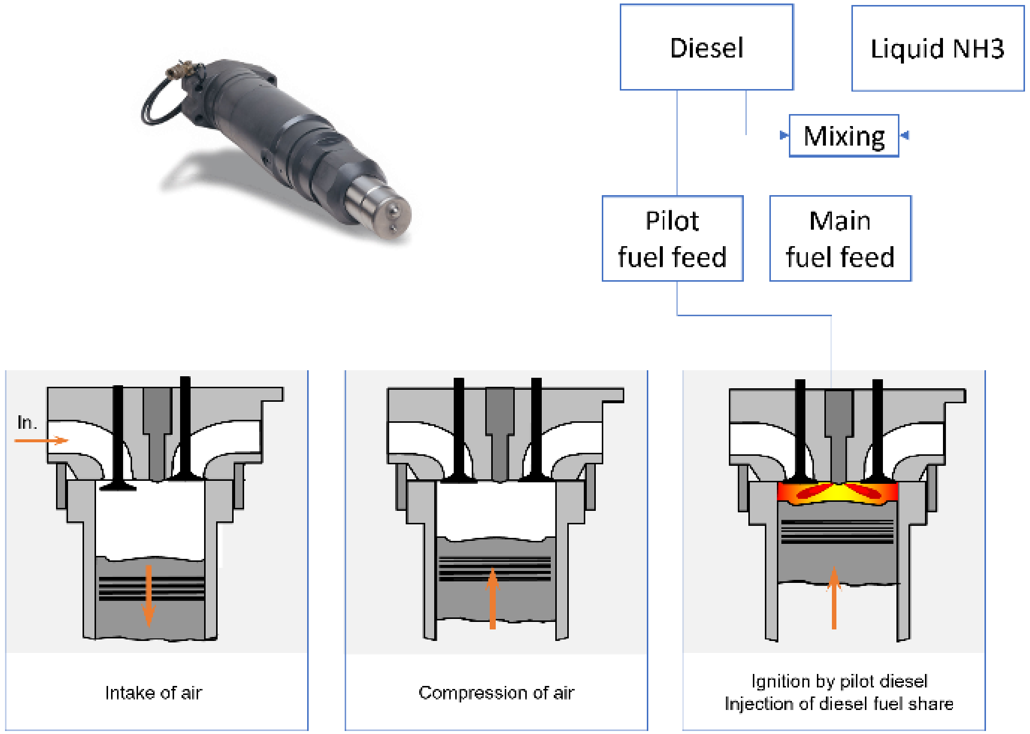


High pressure dual fuel

- The 4- stroke, medium speed, high pressure diesel engine is a multiple fuel engine that can operate on several liquid fuels.
- Can be operated in fuel sharing mode.
- In this type of engine ammonia can be used in two different ways:

I. As separate injection of ammonia via the secondary fuel system and operated together with a pilot liquid fuel. This is similar to the methanol usage in Stena Germanica

II. As blending of ammonia via the secondary fuel system before the engine inlet and operated together with the liquid fuel (fuel sharing)



Ammonia engine testing laboratory

Ammonia engine testing laboratory

- Testing started in June 2021
- Focus on safety systems. Several measurement and control devices were added to deal with potential ammonia leaks.
- Extensive hazard and operability study (HAZOP) was done to ensure safe operation in case of a failure. Dispersion modelling to simulate leakage

Ammonia container area

- Anhydrous ammonia is stored in a container as pressurized liquid ammonia.
- The container is located next to engine laboratory in tank area, where other fuels are also located.
- Water mist cannons were added to the tank area.
- pumped as a liquid fuel to the engine
- vaporized and transferred as gaseous ammonia to the engine.

Ammonia mitigation systems in laboratory tests

- Water washing system was installed for the ammonia engine tests.

  Water spray nozzles that create water curtain.

  Ammonia contaminated test cell air can be cleaned with this system before realising it to the outside of the laboratory area.
- A flare was used to burn the ammonia purged from fuel pipes. The flare operates on a separate diesel flame, that must be kept on at all times while running the engine on ammonia fuel.
- An ammonia scrubber system was installed as a backup system for the flare to ensure safety while testing the ammonia engine. The wastewater from the ammonia scrubber is collected into separate tank.

Ammonia engine test cell

- Access restricted to authorized personnel only
- A permission must be obtained from the operator running the engine
- Ammonia suitable PPE must be used
- After running on ammonia, the engine and fuel system should be flushed efficiently.
- Despite thorough flushing, small amounts of ammonia may remain in the system and cause oudor.

DEMO 2000 – NH3 Demonstration project at Stord

2020 - 2023

WÄRTSILÄ

PARTNERS

SUSTAINABLE ENERGY | NORWEGIAN CATAPULT CENTRE

Forskningsrådet

REPSOL

Knutsen OAS Shipping

equinor

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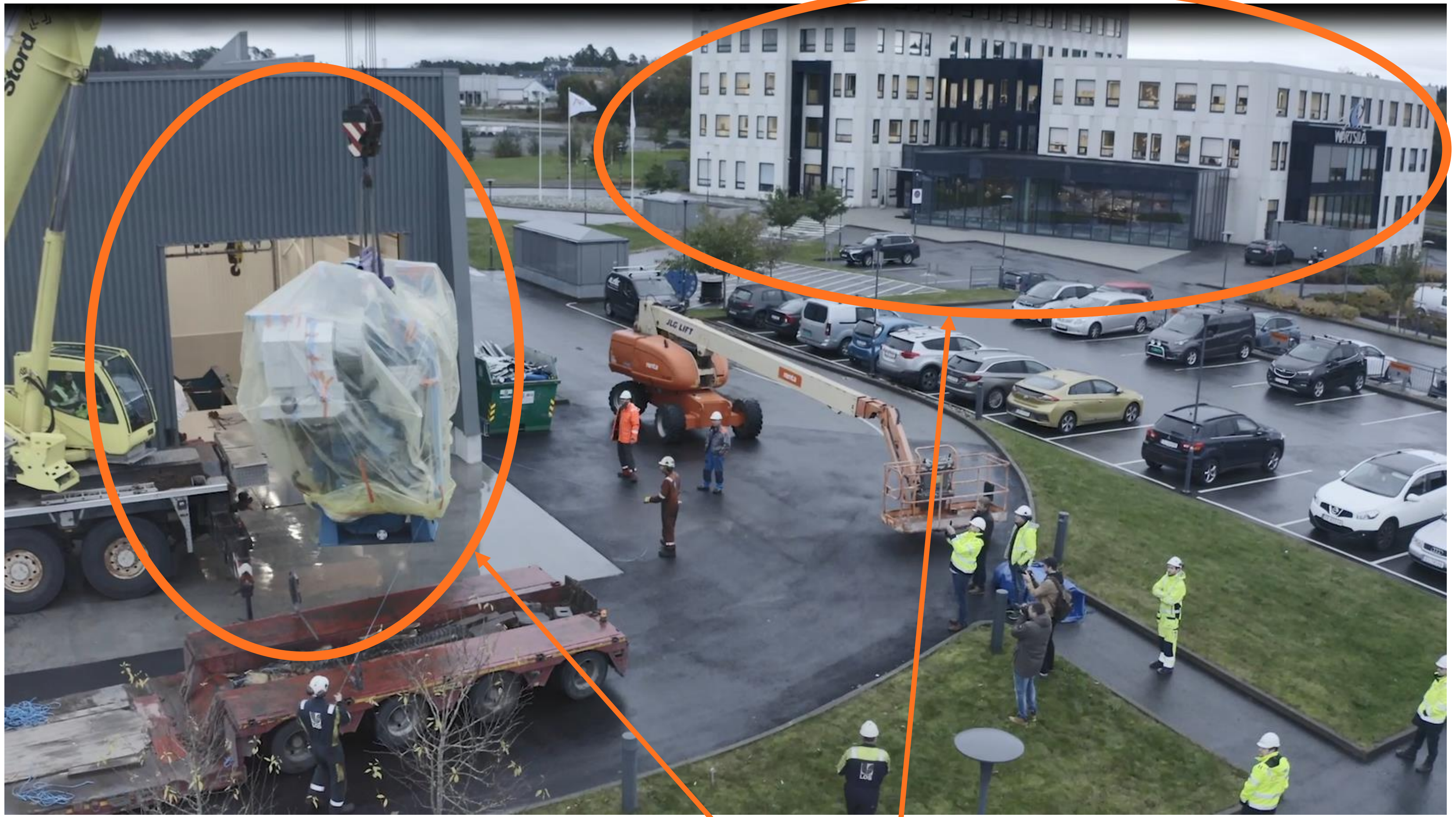
The ship view of the Demo 2000 ammonia engine testing

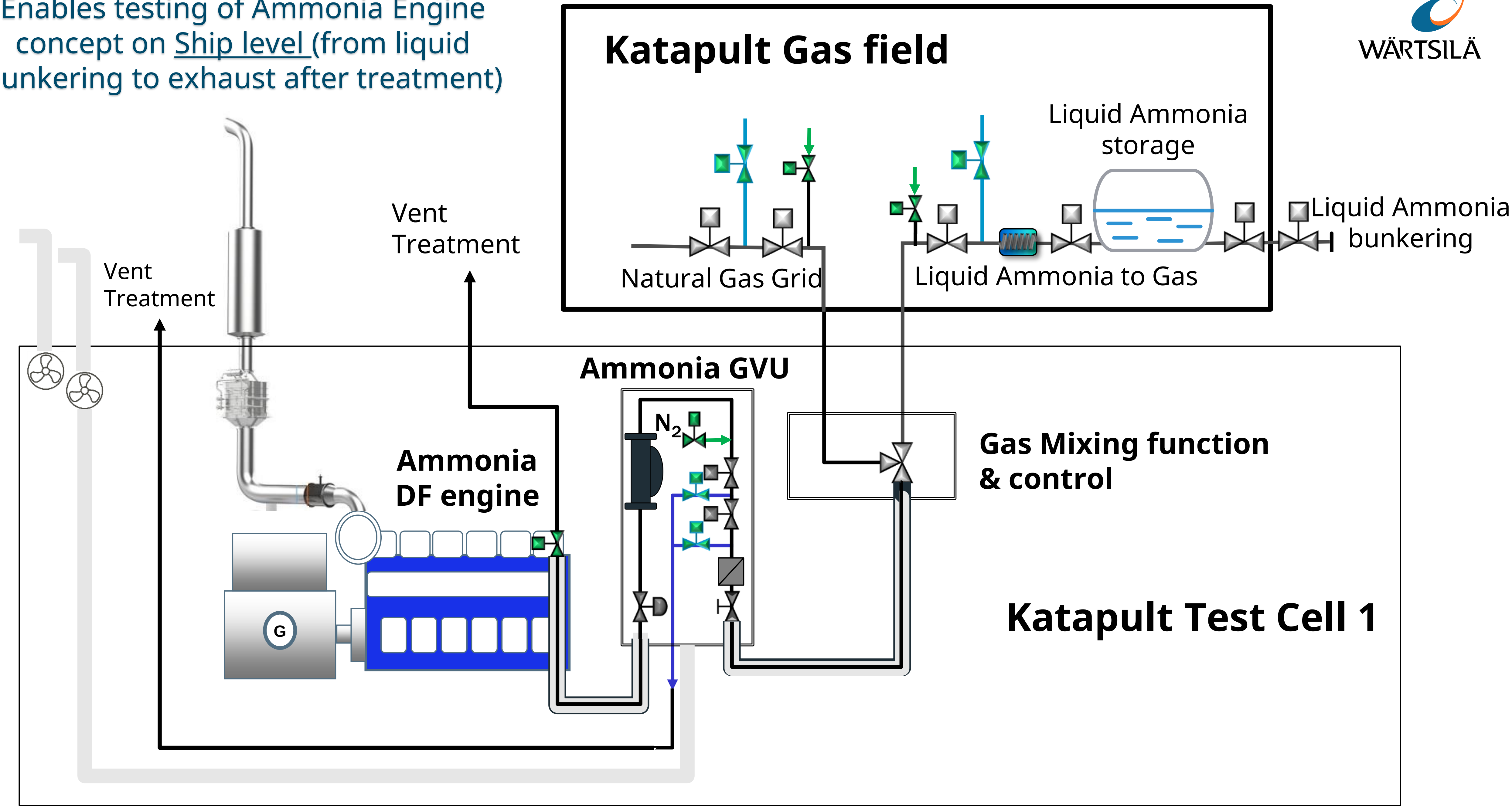
Katapult Test Centre Stord

Heiane, Stord



Test Centre is next to Wärtsilä E&A Office with a strong customer base nearby in the region and nationally

Enables testing of Ammonia Engine concept on Ship level (from liquid bunkering to exhaust after treatment)



Test results

Ammonia detectors and leakages

- Minor leakages have occurred during two years of testing.
- Quickly located and noticed by the ammonia detectors.
- Due to wrong material O-rings and faulty valves.

- In the beginning 100 ppm of ammonia readings were detected.
- After some investigations it was determined that the ammonia sensors were giving faulty readings.

Lubricating oil

- After running the engine low pressure otto combustion mode with gaseous ammonia it was noticed that the lube oil had a ammonia oudor.
- Samples were taken of the lube oil. Tests confirmed that the lube oil contained a small amount of ammonia.
- No changes were observed in the properties of the lubrication oil.

Engine operation

- The engine operation has been smooth most of the times.

- Engine tests were done both with
  I. low pressure ammonia in gaseous form
  II. high-pressure ammonia in liquid form

- The challenge with the fuel handling control
  - pressure and temperature of ammonia
  - ammonia/diesel mix or ammonia/gas mix ratio

- The challenge is to keep the fuel on the correct phase at all times.
  - For a gas-fuelled engine to void condensation
  - Utilizing ammonia as liquid fuel to void evaporation

AMMONIA DF-ENGINE TESTING UPDATE OCTOBER 2023

ACHIEVEMENTS FROM TEST PROGRAM:

52 tons Ammonia consumed in Stord tests

During 130 running hours

Testing 10 to 95%+ Ammonia energy share

90% GHG reduction potential compared to MDO

Emission control

Emission control

- A Review to understand the performance of SCR, ammonia slip and N_2O catalysts under various conditions.
- Different exhaust matrices and catalysts have been simulated (mainly NO, NO_2, NH_3, N_2O, HC, H_2O, O_2) in various flow and temperature conditions.
- Results: Differences in the performance of the catalysts with ammonia oxidation and N2O formation.
- In general, a high exhaust temperature is beneficial to achieve high ammonia removal without excessive N_2O formation.
- Good emission performance achieved by control of ammonia to NO_x ratio (ANR).

  ANR > 1.0 ➞ excess ammonia, can increase N_2O formation over the catalysts.
- The tests performed both in laboratory and full scale have shown that it is possible to take a great step in greenhouse gas footprint but also highlighted the criticality of extensive testing and an integrated approach.

Conclusions

Conclusions

- The ammonia engine tests have showed that with ammonia fuel handling system, safety equipment and updating of the engine, ammonia can be utilized as fuel with minor changes to the engine design.
- The toxicity of ammonia and methanol will require additional design elements for the fuel systems, as well as for spaces with fuel system components, so that an acceptable level of safety can be obtained.
- Emission performance testing has shown that ammonia and methanol as fuel can provide excellent emission performance both in terms of GHG components and traditional pollutants.
- Fuel production industry must provide sufficient level of green ammonia and green methanol production in order enable the adaptation of these as marine fuels.

Marine Power Product Development – Methanol

Current Status → Current Plan → Ambition

Technology Development
Developing combustion technologies, fuel systems, automation systems and safety features to operate on future fuels

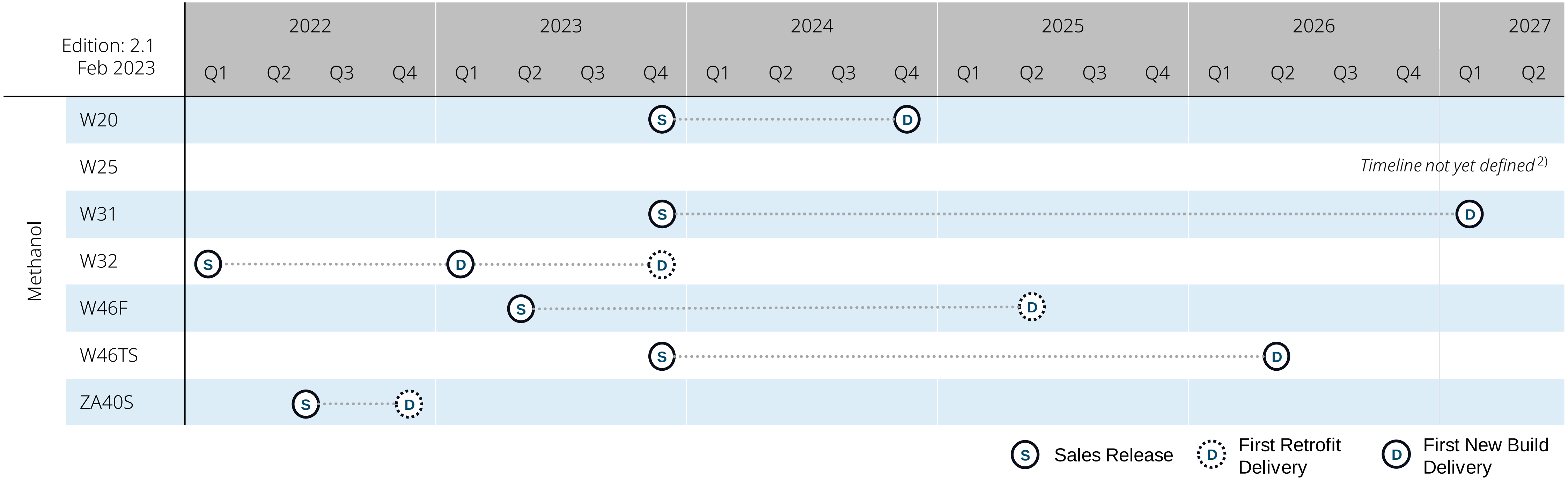
Product Development
Applying technologies to specific product types

Industrialised Solution
Decarbonise the marine industry with portfolio of engines running on future fuel applications

Product Development
W32 Methanol engine now available to market and scheduled for delivery in 2023

Roadmap of Development[1)]
Indicated product timelines remain subject to change

At Which Time
Methanol is available with supporting infrastructure to meet customer demand and these fuels are economically viable



1) *Disclaimer: Subject to sufficient technology progression and quality, while ensuring maximum safety in these developments, the following indications in development have been made. It should be noted that both engine model and timeline remain subject to change based on market demand and other influencing factors.*
2) *The W25 Methanol timeline is not yet defined. Tentative plans indicate a sales release may occur not earlier than 2027*

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Product Development
Current indications predict first Ammonia engine available for delivery as early as 2024

Roadmap of Development[1)]
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At Which Time
Ammonia is available with supporting infrastructure to meet customer demand and these fuels are economically viable

	Edition: 2.1 Feb 2023	2022				2023				2024				2025				2026				2027	
		Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2
Ammonia[2]	W25								S				D										
	W31														S								D
	W32 / W34 [3)]									Timeline not yet defined [3)]													

S = Sales Release; D (dotted circle) = First Retrofit Delivery; D = First New Build Delivery

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2) *40-60% blend based on fuel volume*
3) *Retrofit package is under planning. Sales release and first delivery dates are dependent on results from on-going technology tests. Tentative plans indicate a sales release not earlier than 2024.*

Expertise centre Vaasa Finland following Ammonia engine testing in Norway

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