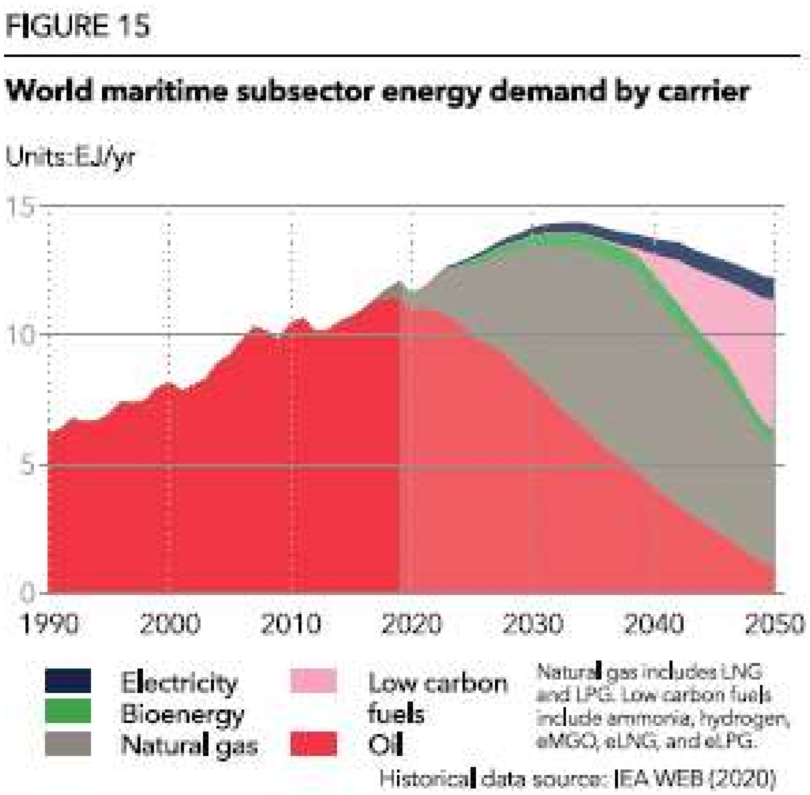
SUSTAINABLE FUELS ROADMAP

GRAZ, 22 SEPTEMBER 2021

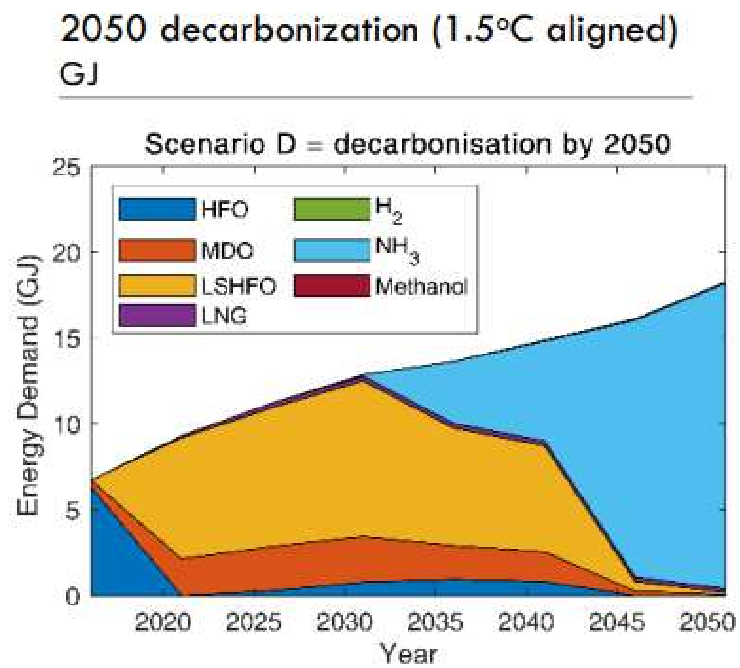
KAJ PORTIN

GENERAL MANAGER SUSTAINABLE FUELS & DECARBONIZATION
ENGINES R&D MARINE POWER SYSTEMS
WÄRTSILÄ FINLAND

Marine fuel scenarios and road maps



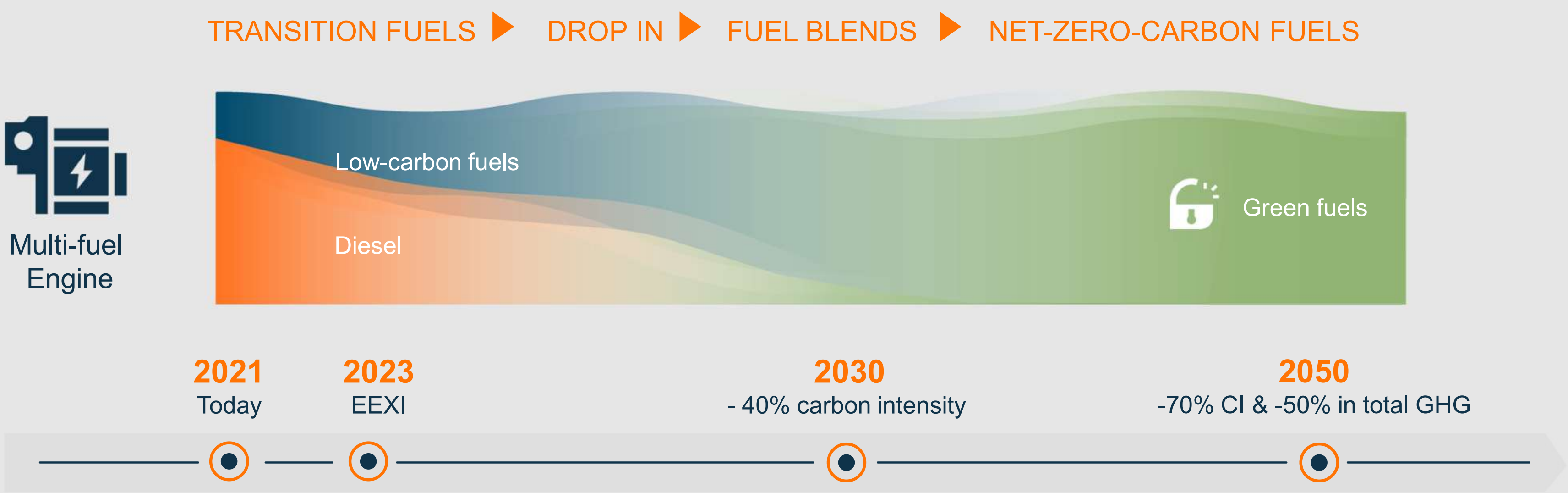
DNV: ENERGY TRANSITION OUTLOOK 2021



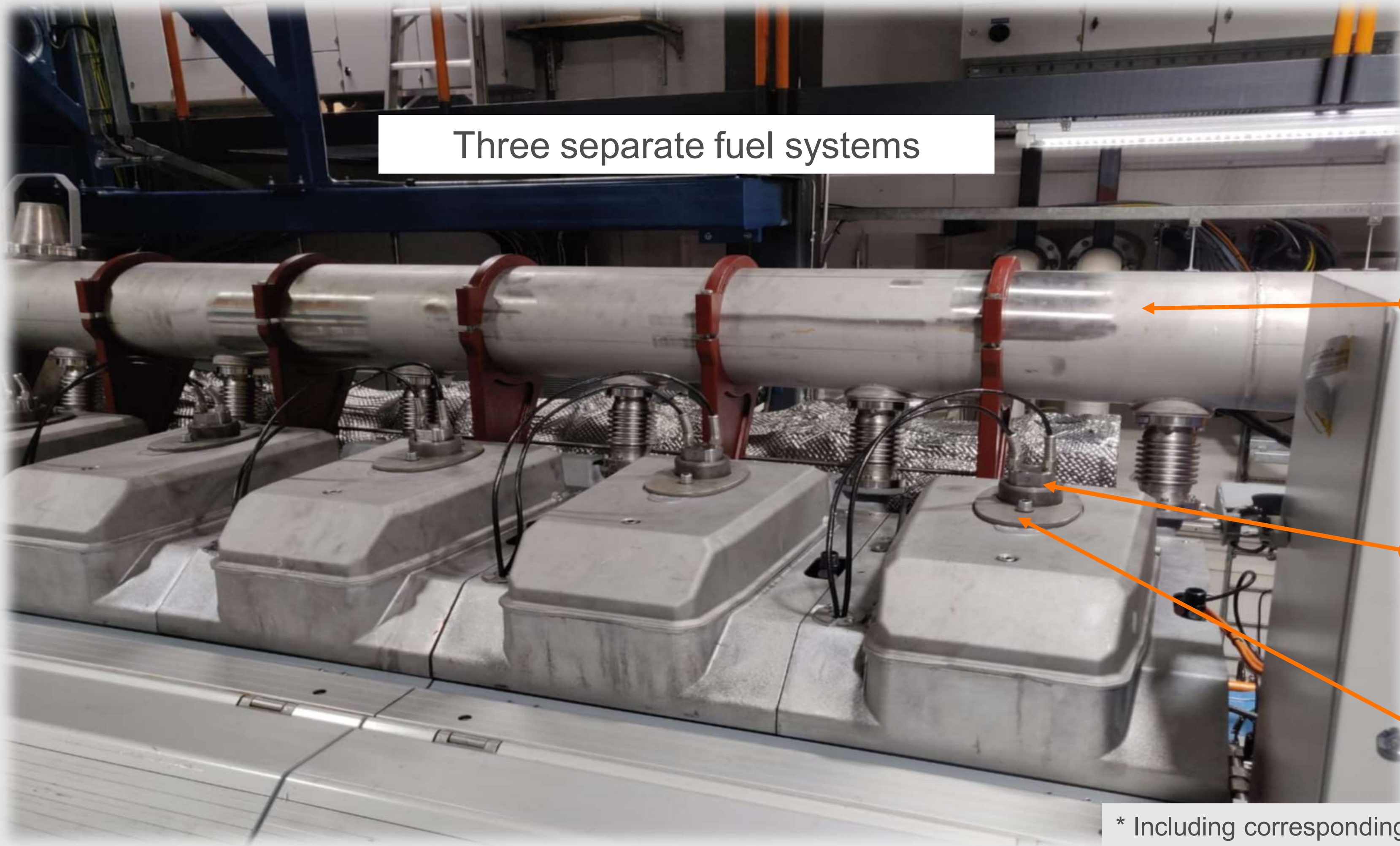
UMAS: Aggregate investment for the decarbonisation of the shipping industry 2020

certainty in transition

Infrastructure and availability of green fuels need time to mature – **current Wärtsilä multi-fuel technology** offer a viable upgrade path



The multifuel engine



Gaseous fuels*
- LNG
- LPG
- Ammonia
- Hydrogen

Liquid fuels*
- HFO
- MDO
- LPG
- Ammonia
- Methanol
- Ethanol

Pilot fuel*
- MDO

* Including corresponding bio and synthetic fuel

FUEL ROADMAP – FOCUS ON RENEWABLE FUELS

WÄRTSILÄ

2020 2030 2050	Pros	Cons
Fossil LNG **Bio LNG** **Synthetic LNG**	• Cleanest fossil fuel, -5 to -20% GHG depending on engine type (well-to-wake/power) LNG infrastructure, rules and regulations exist, fuel is available	• Methane emissions
Fossil liquid **Bio liquid** **Synthetic liquid**	• Bio/syn GHG -70 to -100% depending on source (well to wake/power) • Clear transition pathway as same infra can be used for all	
*) green Hydrogen	• No CO_2 emissions • Can be blended with LNG	• NO_x emissions • Challenges in handling, spec if liquid (minus 253°C)
*) green Ammonia	• No CO_2 emissions • Can be blended with liquids or gases	• NO_x, N_2O emissions • Toxic, not available, no rules & regulations
*) green Alcohols (methanol, ethanol...)	• Carbon neutral • Can be blended with liquids	• NO_x emissions • Toxic

*) *timing depends on the market demand*

Development of Engine Technology is ongoing

Time schedule for engine performance

Verified: 2003

CH_4

Bio- or Synthetic methane

Contains about 99% methane and can readily be used in liquid form with equipment made for LNG.

Verified: 2015

MeOH

Methanol

A methanol conversion package is available for the ZA40 engine and we have the technology to burn methanol.

The next step is to industrialise this technology on the relevant portfolio engines according to market needs.

Indicative: 2020, Verified*: 2022

NH_3

Ammonia

We have already technologies that are capable of using Ammonia.

The needed combustion concepts to maximise engine performance and related safety technologies are currently being investigated

Indicative: 2020, Verified*: 2025

H_2

Hydrogen

Our gas engines are already able to blend LNG with up to 25% hydrogen, and combustion concepts are specified for 100% hydrogen.

Our future efforts will be directed towards maximising engine performance.

** timing depends on the market demand*

PRESS RELEASE HYDROGEN

WÄRTSILÄ

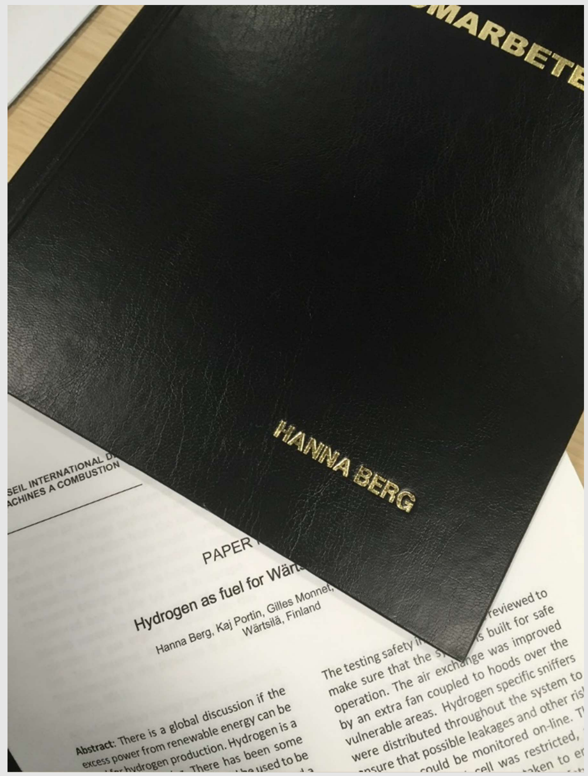
Wärtsilä gas engines to burn 100% hydrogen

Wärtsilä Corporation, Press release, 5 May 2020 at 11:00 AM E. Europe Standard Time

The technology group Wärtsilä is developing the combustion process in its gas engines to enable them to burn 100% hydrogen fuel…tested its engines with blends of up to 60% hydrogen and 40% natural gas.. is part of the company’s strategy to future-proof… the global trend towards decarbonisation of the energy and marine markets. “The world is on a path towards 100% decarbonization, and Wärtsilä continues to support this trend with our research and development of future fuels, such as hydrogen. The market for hydrogen-fuelled power plants will emerge along with regulations restricting the burning of fossil fuels. We are well positioned to serve the power industry in its transition to 100% renewable electricity generation. Wärtsilä’s engines, capable of running on a variety of sustainable fuels, are offering a highly dynamic balancing power for these future generating systems,” commented Marco Wiren, President, Wärtsilä Energy Business

Hydrogen mixed in natural gas

- Target to study the effect of hydrogen mixed in NG in lean-burn DF and SG engines
- Specific caution on safety
  - Hydrogen sniffers for gas pipes
  - Protective hood above the engine
  - Improved gas ventilation
- Up to 30% of hydrogen in NG could be used as fuel in Wärtsilä gas engine after optimized controls



Regulations / standards

- Natural gas still classified as methane as long as hydrogen content is under 25 vol-%

IEC/EN 60079-20-1

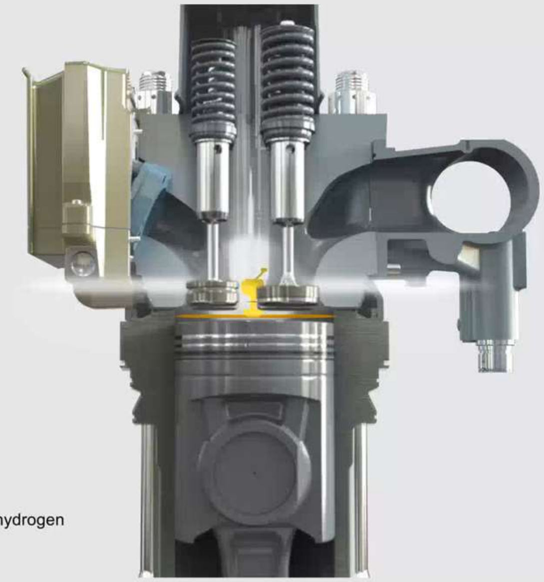
5.2.4 Methane, Group IIA

Industrial methane, such as natural gas, is classified as Group IIA, provided it does not contain more than 25 % (V/V) of hydrogen. A mixture of methane with other compounds from Group IIA, in any proportion is classified as Group IIA.

- When hydrogen content is over 25 vol-% the classification goes from class IIA to **IIC**
  - Lower allowed voltages in components
  - Part of the equipment (e.g. pumps) in the fuel supply line needs to be changed to hydrogen specific components (details are under investigation)

Pure hydrogen?

Otto engine



0 Spark ignited hydrogen prechamber, combustion

Diesel engine

0 High pressure (~700 bar) gas hydrogen injection

0 Compression ignition of hydrogen, diffusion combustion

Pure hydrogen concepts

Hydrogen Otto Master's Thesis
T&V Tech Training 17.1.2020

Alexander Ehrs

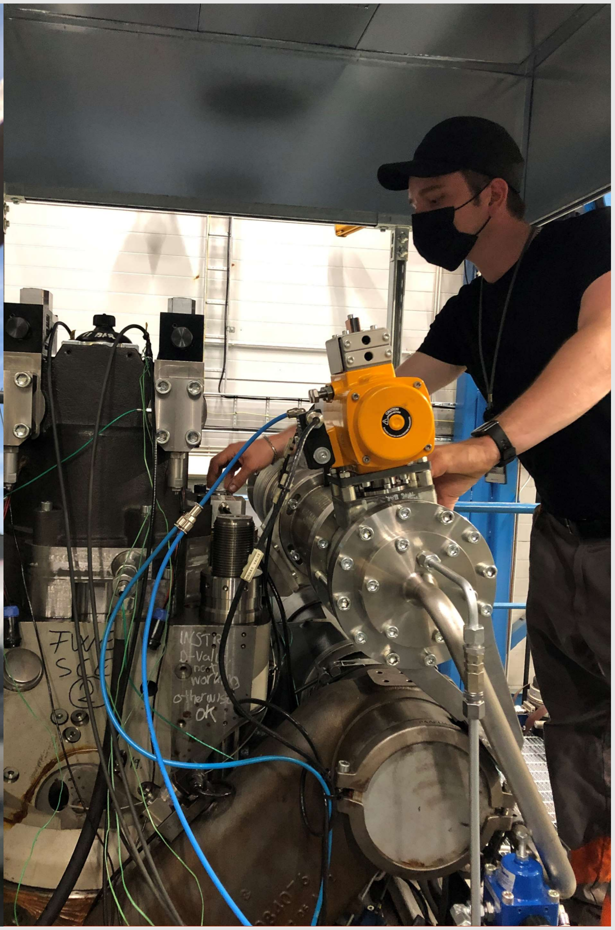
Advisor: Kaj Portin
Supervisor: Prof. Martti Larmi (Aalto University)

H2 – Diesel Thesis

17.1.2020 Westberg

Advisor: Kaj Portin
Supervisor: Prof. Martti Larmi (Aalto University)

Pure hydrogen engine tests 1 July 2021



PRESS RELEASE AMMONIA

WÄRTSILÄ

World's first full scale ammonia engine test - an important step towards carbon free shipping

Wärtsilä Corporation, Trade press release, 30 June 2020 at 10:01 AM E. Europe Standard Time

The technology group Wärtsilä, in close customer cooperation with Knutsen OAS Shipping AS and Repsol, as well as with the Sustainable Energy Catapult Centre, will commence the world's first long term, full-scale, testing of ammonia as a fuel in a marine four-stroke combustion engine. The testing is made possible by a 20 MNOK grant from the Norwegian Research Council through the DEMO 2000 programme.

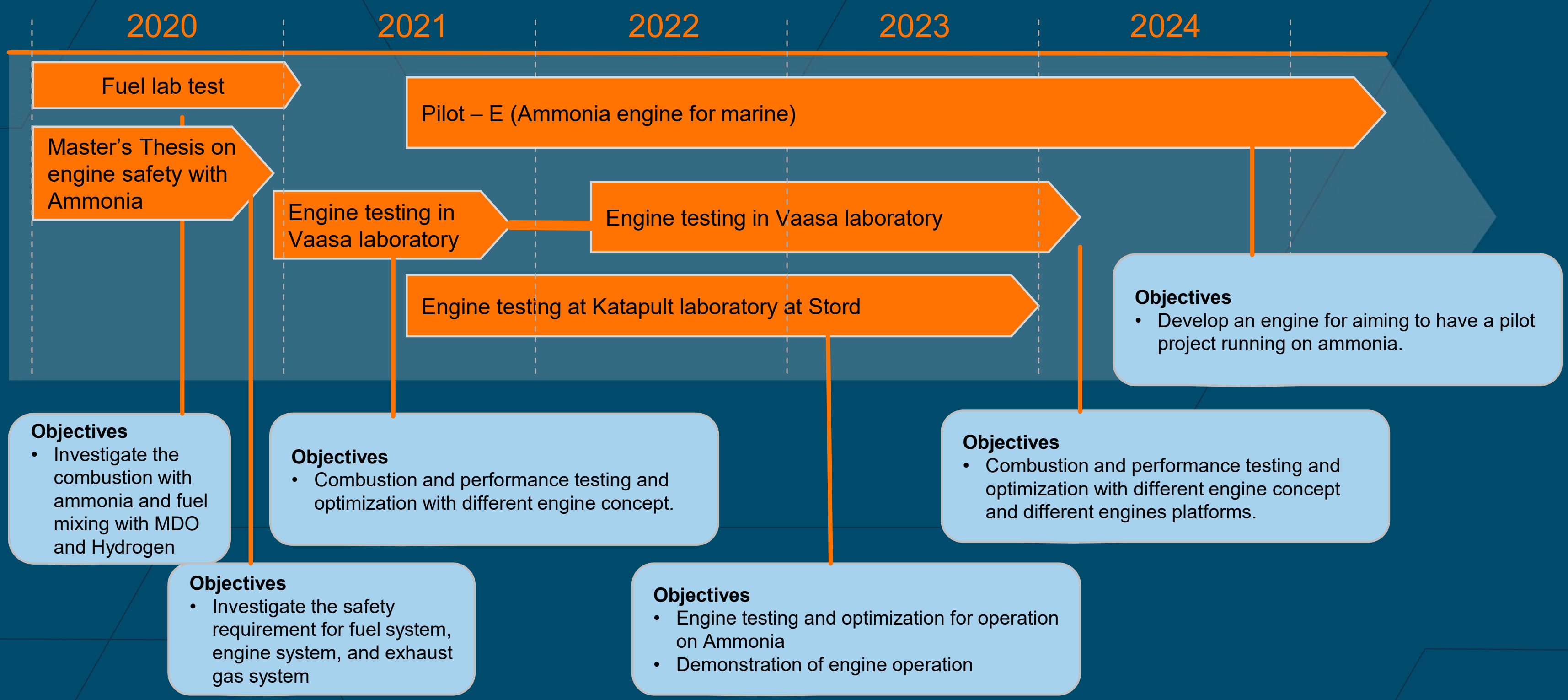
ARTICLE

Wärtsilä, Repsol, and Knutsen to test ammonia four-stroke engine

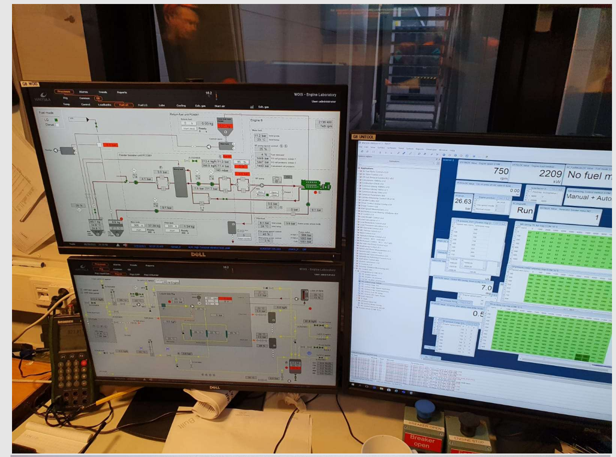
By Trevor Brown on July 01, 2020

This week, engine manufacturer Wärtsilä announced "the world's first long term, full-scale, testing of ammonia as a fuel in a marine four-stroke combustion engine." The project will begin in the first quarter of 2021, at the Sustainable Energy Catapult Centre's testing facilities at Stord, Norway. It is supported by a NOK 20 million (USD 2 million) grant from the Norwegian Research Council.

TECHNOLOGY ROADMAP - AMMONIA AS A FUEL



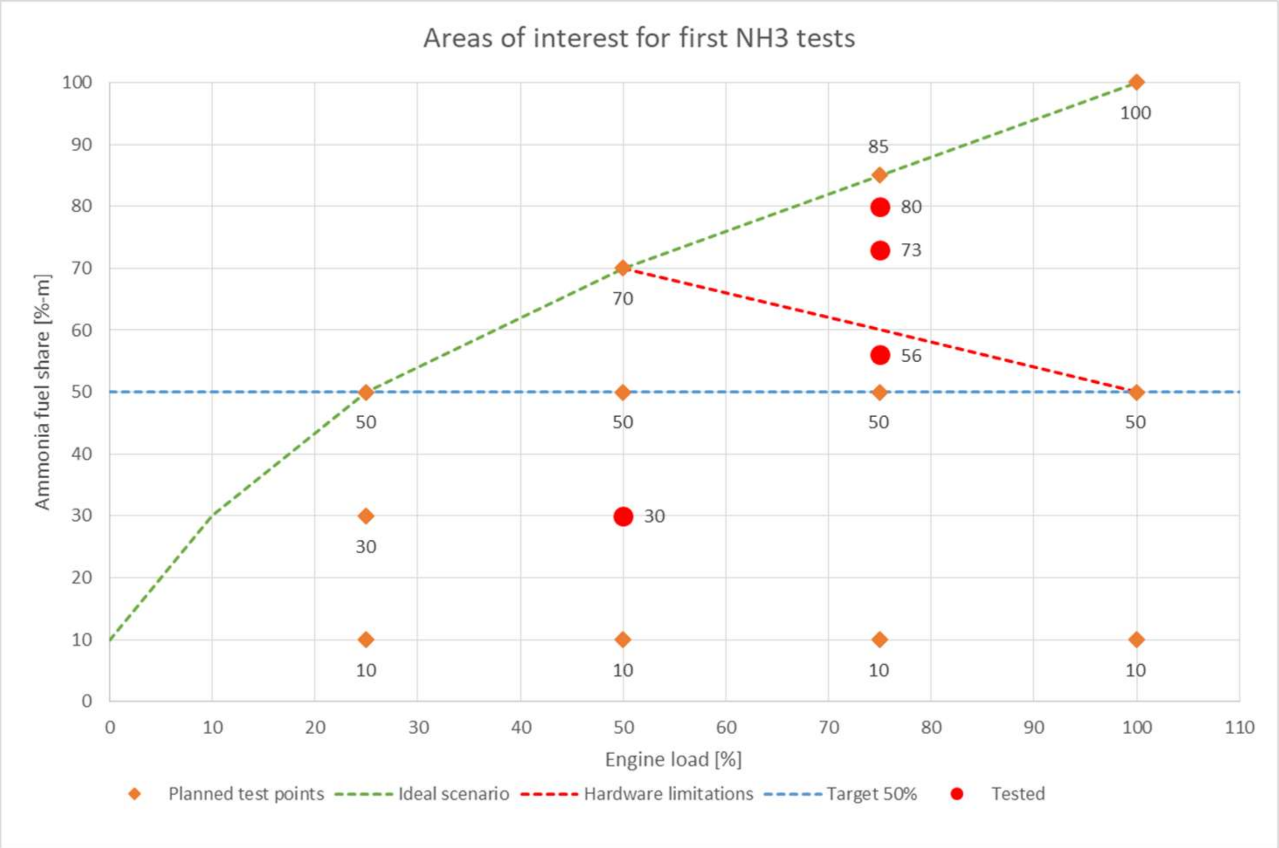
Ammonia engine tests 30 June 2021



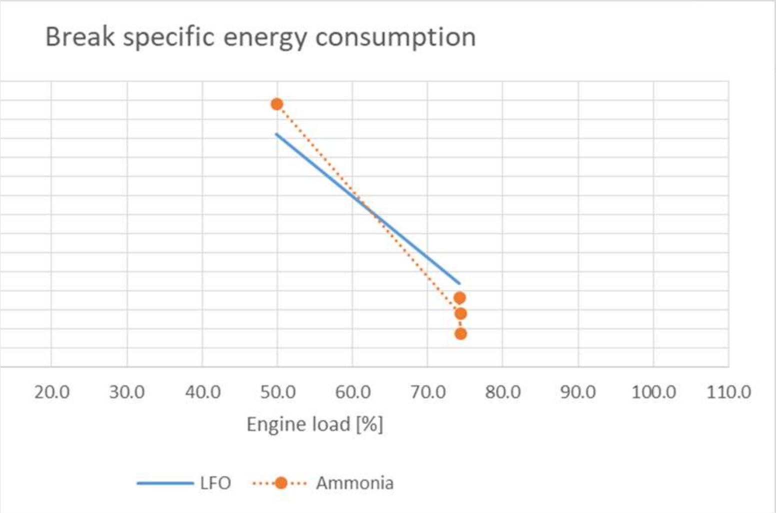
AMMONIA TEST RESULTS

- The graph shows the recorded test points within the original rough test plan, ammonia shares shown in %-m

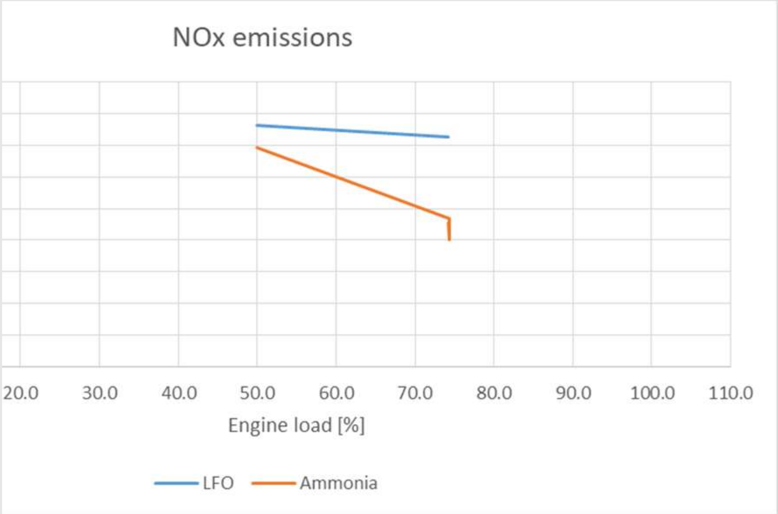
- Based on these tests the understanding is that above 50% engine load very high ratios of ammonia can be mixed in, at lower loads further engine tuning and higher compression ratio can increase the potential ammonia share



- Engine BSEC can increase or decrease slightly depending on the engine load and ammonia share, but engine thermal efficiency is not significantly reduced with ammonia blending

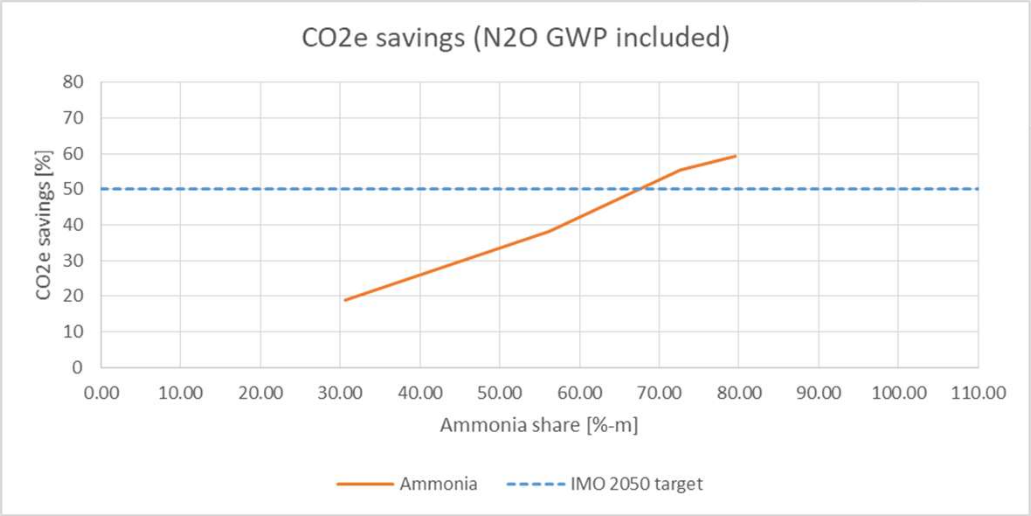


- Increasing the ammonia share reduced NOx emissions against expectations, nearly 50% reduction with the highest ammonia share



AMMONIA TEST RESULTS

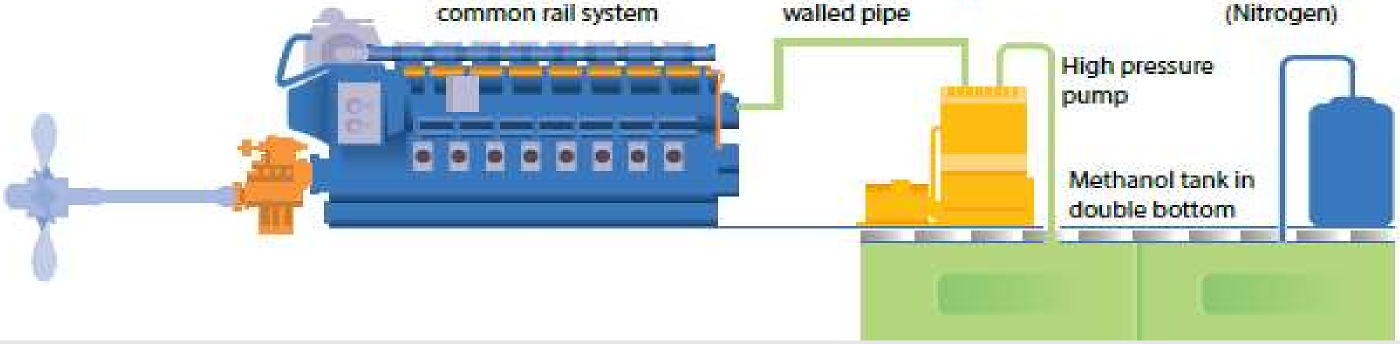
- **CO2e savings of nearly 60%** were reached in comparison to pure LFO operation, **exceeding IMO's 2050 target**
  - In the calculation CO2 emissions from LFO fuel share (incl. pilot fuel) and CO2e of N2O emissions (GWP 298) are included



Engine Speed	rpm	750.0	750.0	750.0	750.0
Engine Power	%	75.0	75.0	75.0	50.0
Cylinder Power	kW/Cyl	372	372	372	250
Ammonia fuel share (mass)	%	79.6	72.7	56.2	30.6
Ammonia fuel share (energy)	%	60.8	51.7	34.6	15.1
CO2e savings (incl. N2O GWP)	%	59.3	55.5	38.3	18.9

Methanol adaptation of Stena Germanica

Stena Germanica – Conversion Scope



Summary

- Low carbon fuels need to be developed to achieve the future targets regarding greenhouse gas emissions improvements.
- Natural gas operation results in low emissions already today, and provides gaseous fuel infrastructure for future fuels
- GHG reduction enablers
  - Fuel flexible engine technologies
  - Renewables - both on liquid and gaseous fuels
  - Hybrid solutions
- GHG is an important topic, but local emissions should not be forgotten

WÄRTSILÄ