Linking research and industry
– ammonia and hydrogen-based solutions to marine engines

Jari Hyvönen

Nordic Maritime Transport and Energy Research Programme Conference
Malmö, 3-4 May 2023

3 May 2023

Wärtsilä 2022

Shaping the decarbonisation of marine and energy

The decarbonisation transformation is accelerating

The world is changing.

We will see an unprecedented rate of change in maritime in the coming decades. Driven by regulatory frameworks and the demand for greener transport, the move towards decarbonisation will only accelerate.

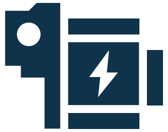
The energy sector is undergoing a massive transformation: decarbonisation and renewables are fundamentally going to change the way energy is generated.

Wärtsilä is in key position in shaping the decarbonisation of marine and energy.

certainty in transition

Infrastructure and availability of green fuels need time to mature –
multi-fuel engine and combustion technologies offer a viable upgrade path

TRANSITION FUELS ▶ DROP IN ▶ FUEL BLENDS ▶ NET-ZERO-CARBON FUELS



Multi-fuel Engine

EEDI
In force

2021
EEXI and CII clarifications

2023
EEXI

2030
- 40% carbon intensity (CII)

2050
-70% carbon intensity & -50% in total GHG

IMO
MEPC76

Fit for 55 in 2030
- 55% GHG in EU ref 1990

Bunkering activities

Data set from MarineTraffic:

- All bunkering activities in ports between 20-9-2022 and 20-3-2023
  - 1302 ports
  - 234660 bunkering activities

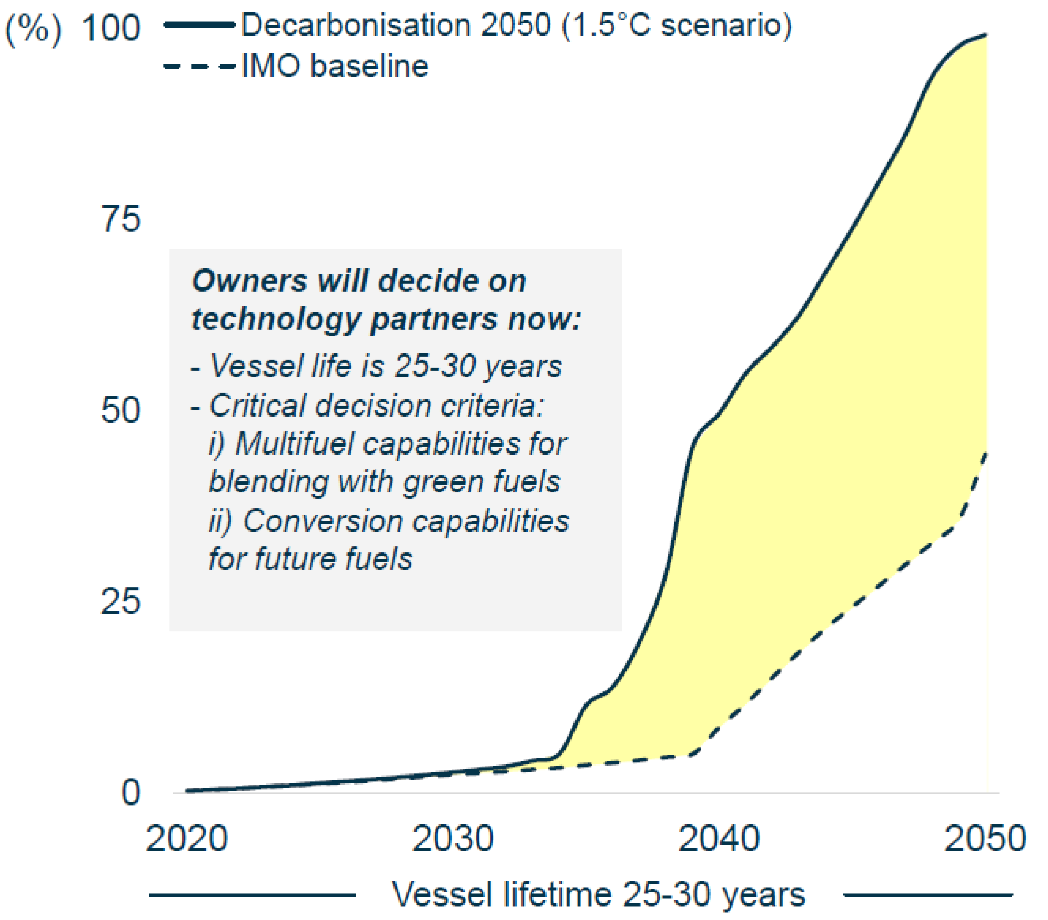
Green fuel transition:

- **Renewable energy availability**
- **Production**
- **Distribution**
- **Storage**
- **Regulations**
- **Users and Consumers**

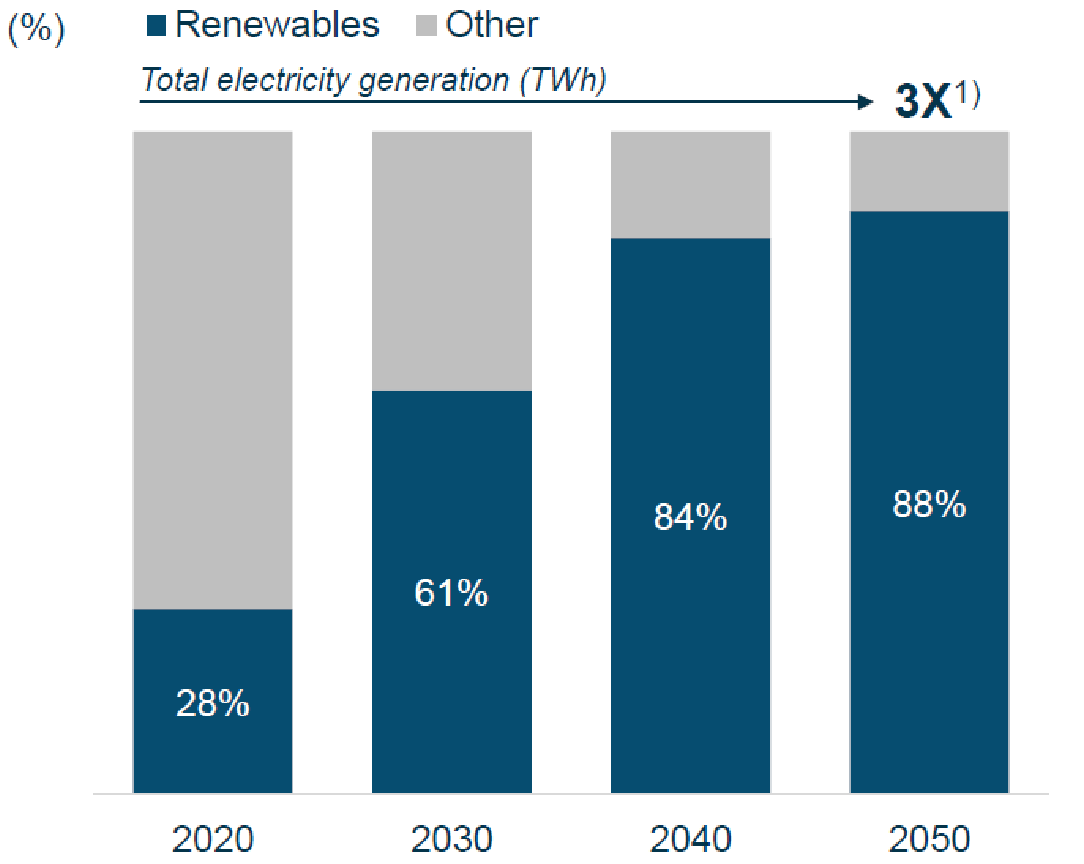
Source: 1) The Global Industry Alliance to Support Low Carbon Shipping (Low Carbon GIA workstream) IMO-Norway GreenVoyage2050 Project
2) Wärtsilä

Decarbonisation of Marine and Energy is accelerating – large regional variances in speed of change

Share of carbon neutral and zero carbon fuels in maritime



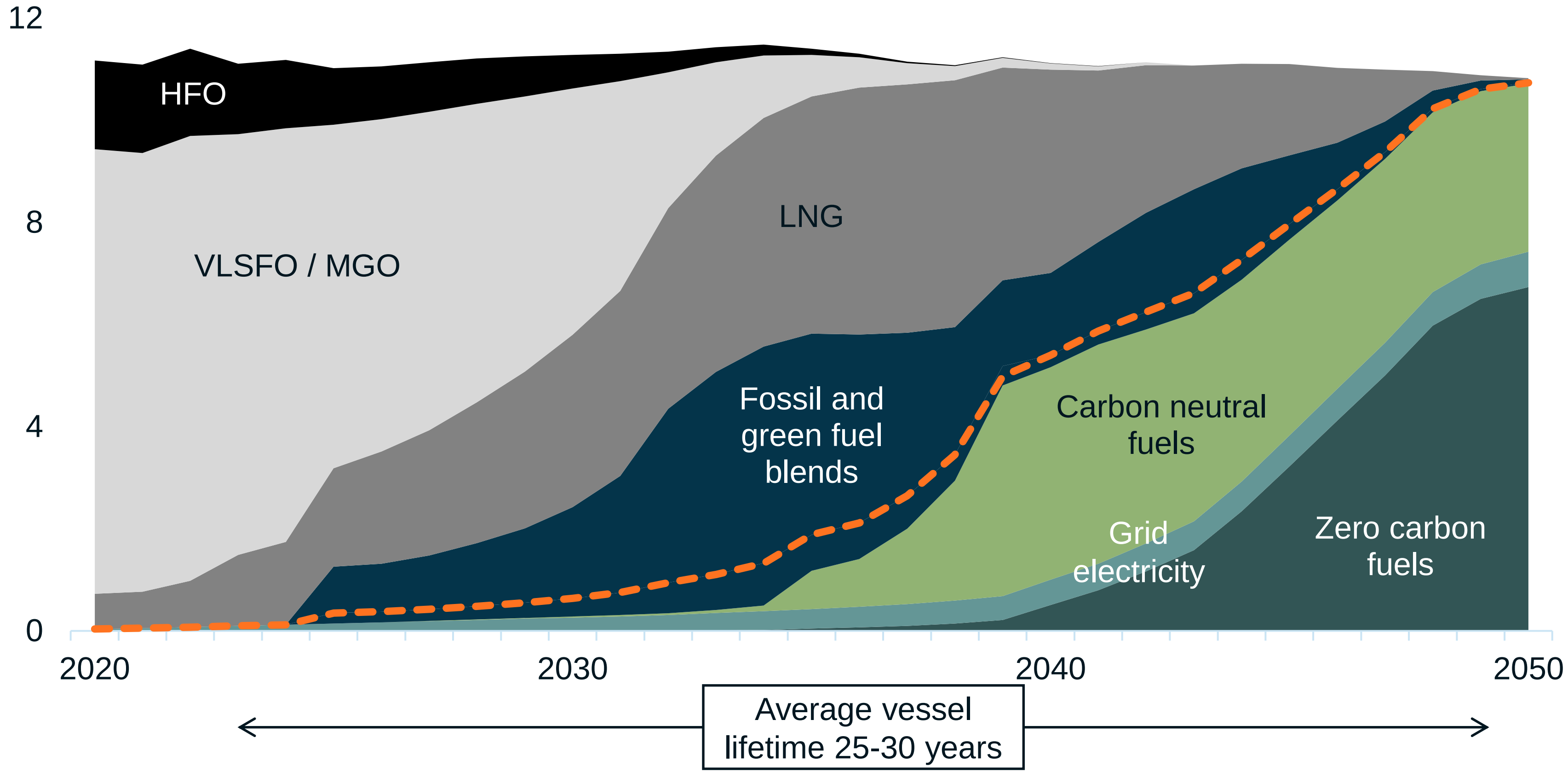
Share of renewables in global electricity generation



Source: DNV Maritime Forecast 2050 model, Wärtsilä Internal estimates 1) Total electricity generation (TWh) from 2020 to 2050, IEA World Energy Outlook 2021 (Net Zero Emissions Scenario)

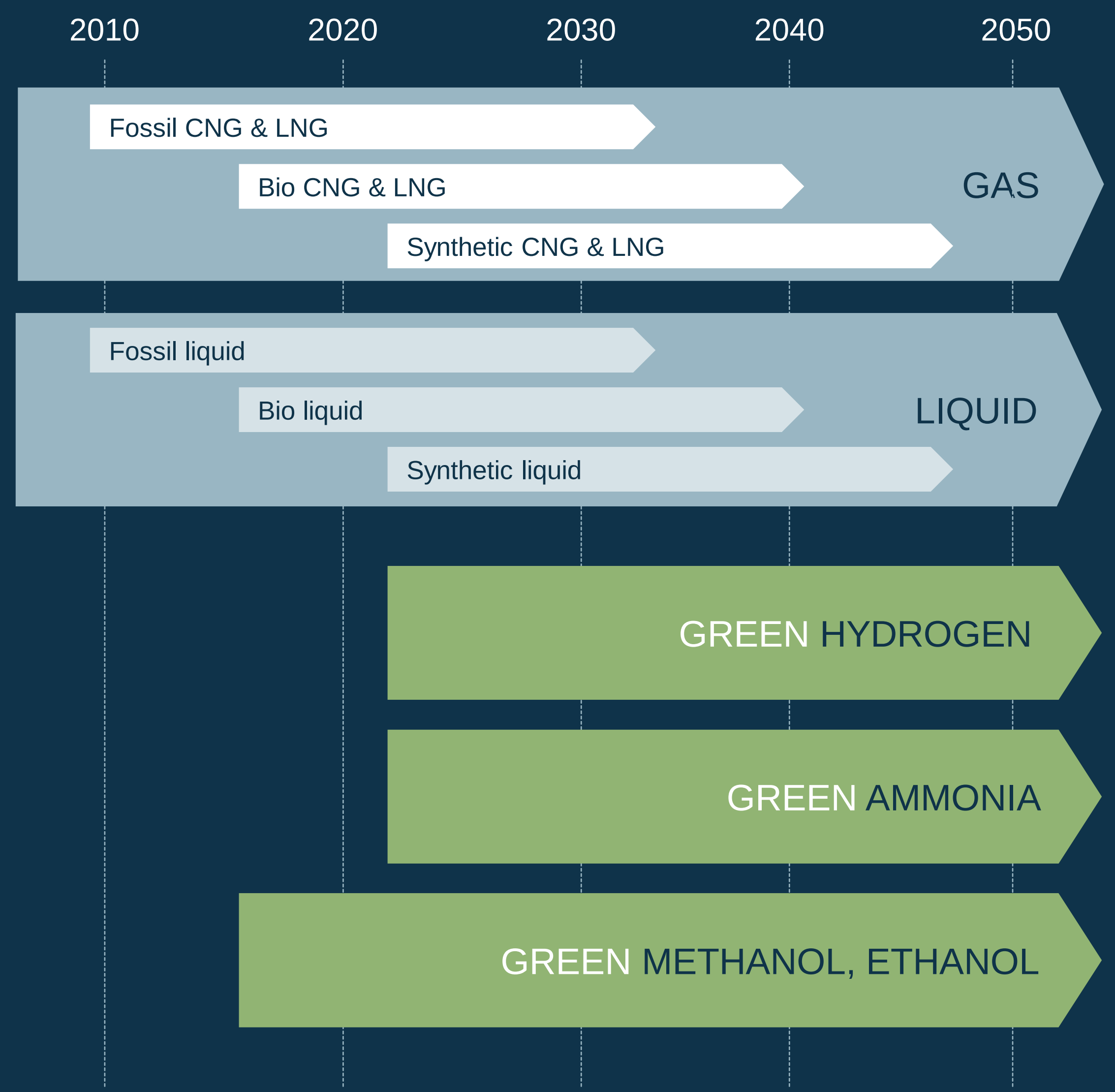
Shipping have to invest in fuel flexibility to avoid risk of stranded assets

Distribution of fuel types for Decarbonisation 2050 (1.5ºC scenario), EJ



Source: DNV Maritime Forecast 2050 model, Wärtsilä internal estimates

- By 2050, 60-100% fleet will use a **different fuel compared to today**
- Shipping is moving to a **multi-fuel model**; LNG is considered as the bridge fuel
- **Drop-in fuels will play a key role in the short term**, as they can be used in varying blending fractions with no or minimal modifications to engines and fuel systems;
- The path to decarbonised shipping may appear like a long winding road and yet it is **less than one vessel lifetime away**



TECHNOLOGY ENABLING A FUEL TRANSITION IS AVAILABLE ALREADY TODAY

Gaseous and liquid fuels

- Possible already today, infra, rules and regulations exist and supply infrastructure adaptation has started

Hydrogen

- Wärtsilä gas engines blend up to 25%-vol hydrogen in natural gas, combustion concepts aim for 100% hydrogen
- Pure Hydrogen operation achieved, focus on improving performance

Ammonia

- Combustion concepts maximising engine performance, developing safety technologies
- 70% Ammonia blend achieved

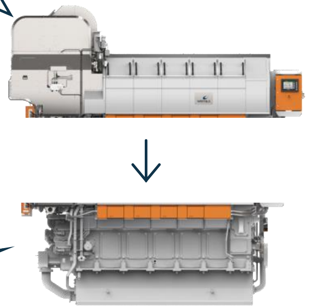
Methanol

- March 2015, ZA40 retrofitted for Methanol operation

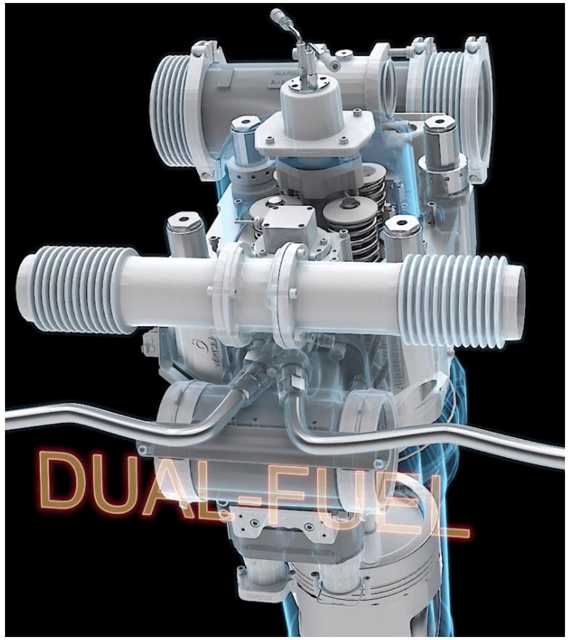
THE INTERNAL COMBUSTION ENGINE: A TRUE OMNIVORE

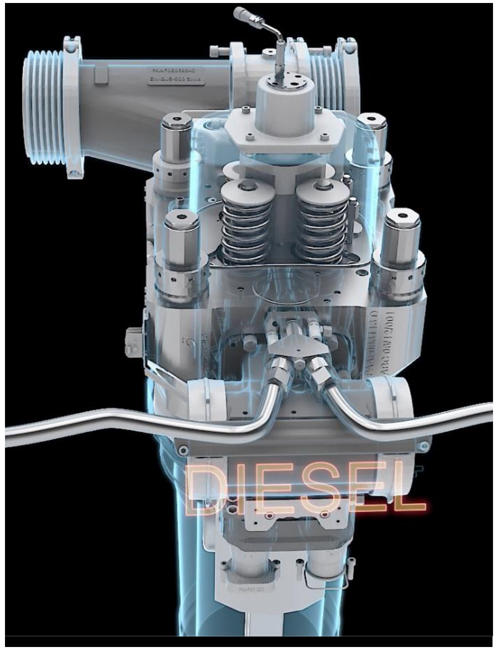
Change fuel injection system and power pack

No change



HFO, MGO, HVO, LNG, LPG, HYDROGEN, METHANOL, AMMONIA, ...

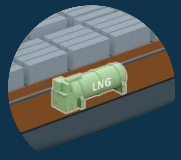
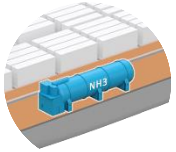
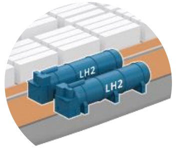
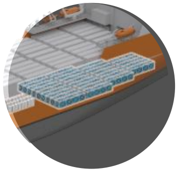




WITH 95% PARTS COMMONALITY, THE ENGINE IS NOT THE LIMITING FACTOR

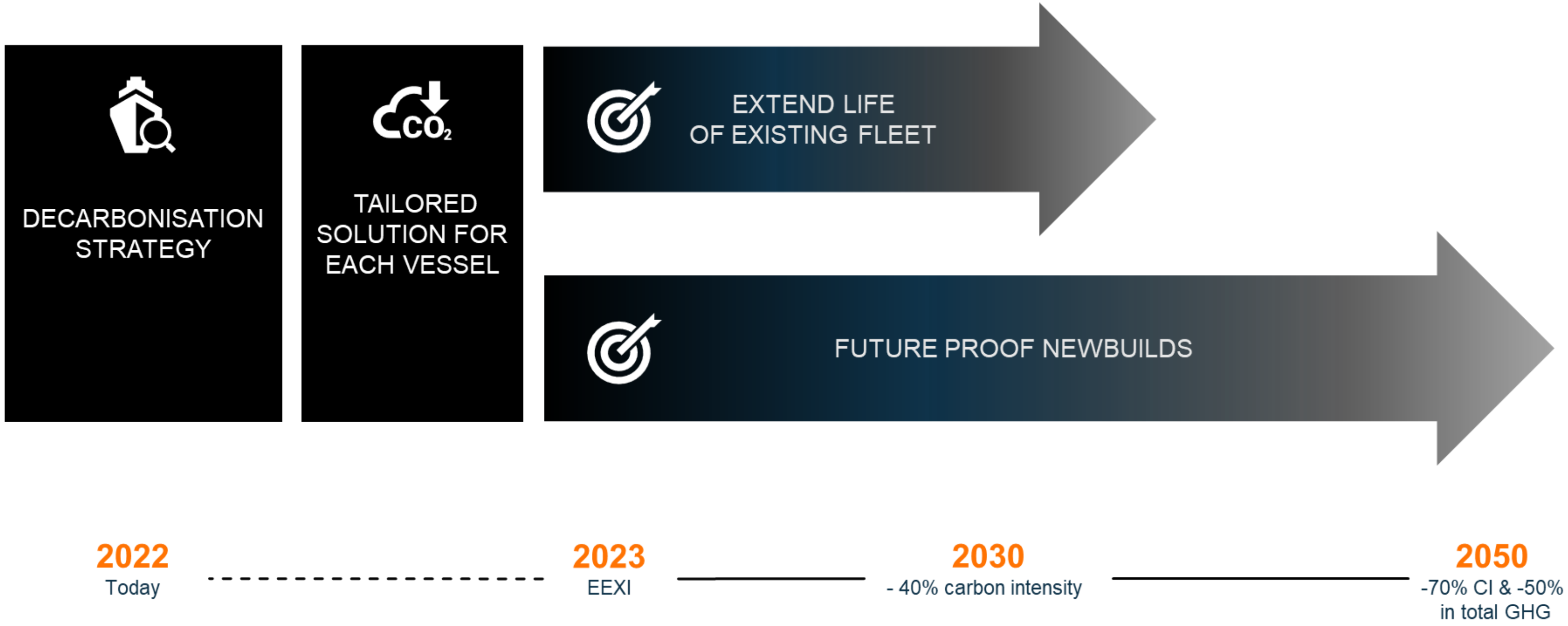
Fuel availability, storage, safety and regulations determine the environmentally and economically sustainable solutions

Fuel price and Gross tank factor varies between different fuels

Fuel type	 **Heavy Fuel Oil** @ 20°C	 **Liquified Natural Gas** @ -162°C	 **Methanol** @ 20°C	 **Ammonia** @ -33°C	 **Liquid Hydrogen** @ -253°C	 **Compressed Hydrogen** @350bar	 **Marine Battery Rack**
Key considerations	▪ Standard tank arrangement	▪ Cryogenic system	▪ Mildly toxic ▪ Flexible tank arrangement	▪ Toxic ▪ Corrosive	▪ Highly reactive ▪ Cryo system	▪ High pressure ▪ Multiple tanks arrangement	▪ Marine adaptation reduces density
Fuel price factor (per GJ)	1X	0.7X [2]	2.2X-5.4X [3]	2.2X-4.5X [3]	2.7X-4.5X [3]	1.6X-2.6X [3]	1.3X-2.3X
	Production cost estimate 2025 [1]						
Gross tank size factor	1X [4]	2.4X	1.7X	3.9X	7.3X	19.5X	~40X (future potential ~20X)

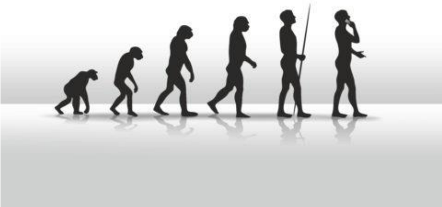
1) Sources: Maersk Mc-Kinney Møller Center for Zero Carbon Shipping – Industry transition strategy 2021, Wärtsilä-DNV collaboration; 2) fuel price for e-methane is expected to be in a range similar to e-methanol; 3) fuel price range spans across blue, bio and green-electro equivalent; 4) gross tank estimations based on Wärtsilä experience

Financially viable, tailor-made pathway to achieve decarbonisation



- Tailor-made path by picking the **right solution for each vessel** and specifying the correct mix of technologies.
- A **decarbonisation strategy**, required for the fleet to 2030, 2050 and beyond.
- **Extending the life of existing vessels** to meet the next waves of legislation head-on.
- **For newbuilds, ensuring fuel flexibility and storage** to enable upgrading to green fuels.

Ammonia @Wärtsilä: from basics, via learning, to concepts.



2021

First engine tests with ammonia blends

2022

Industry collaboration for solution validation

2023

Technical concept ready

2024

First ammonia engine deliveries

Hydrogen @Wärtsilä: From blends to 100% hydrogen

WÄRTSILÄ

2021

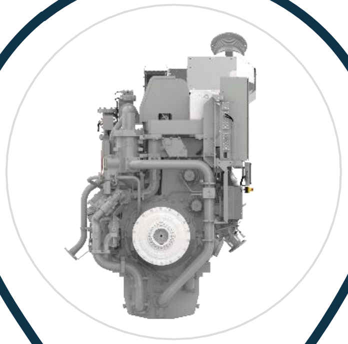
Focused research started on 100% H2

2022

Blending validation at power plants (first tests 2015)

2023

Combustion system development for 100%H2



2025

Technical concept ready for pilot

H2 BLENDING – FROM THE LAB TO OUR CUSTOMERS

WÄRTSILÄ

CONDUCTED TESTING – OCTOBER 2022

WEC Energy Group (US, 3 x Wärtsilä 50SG)

AGREED TESTING – Q2-2023

Capwatt (Portugal, 1 x Wärtsilä 34SG)

UNDER DISCUSSION

US, Wärtsilä 50DF

UK, Wärtsilä 34SG

India, Wärtsilä Vasa 34SG

Japan, Wärtsilä Vasa 34SG

GAS COMPRESSION magazine

Wärtsilä To Test Hydrogen-Blended Fuel In Michigan Power Plant

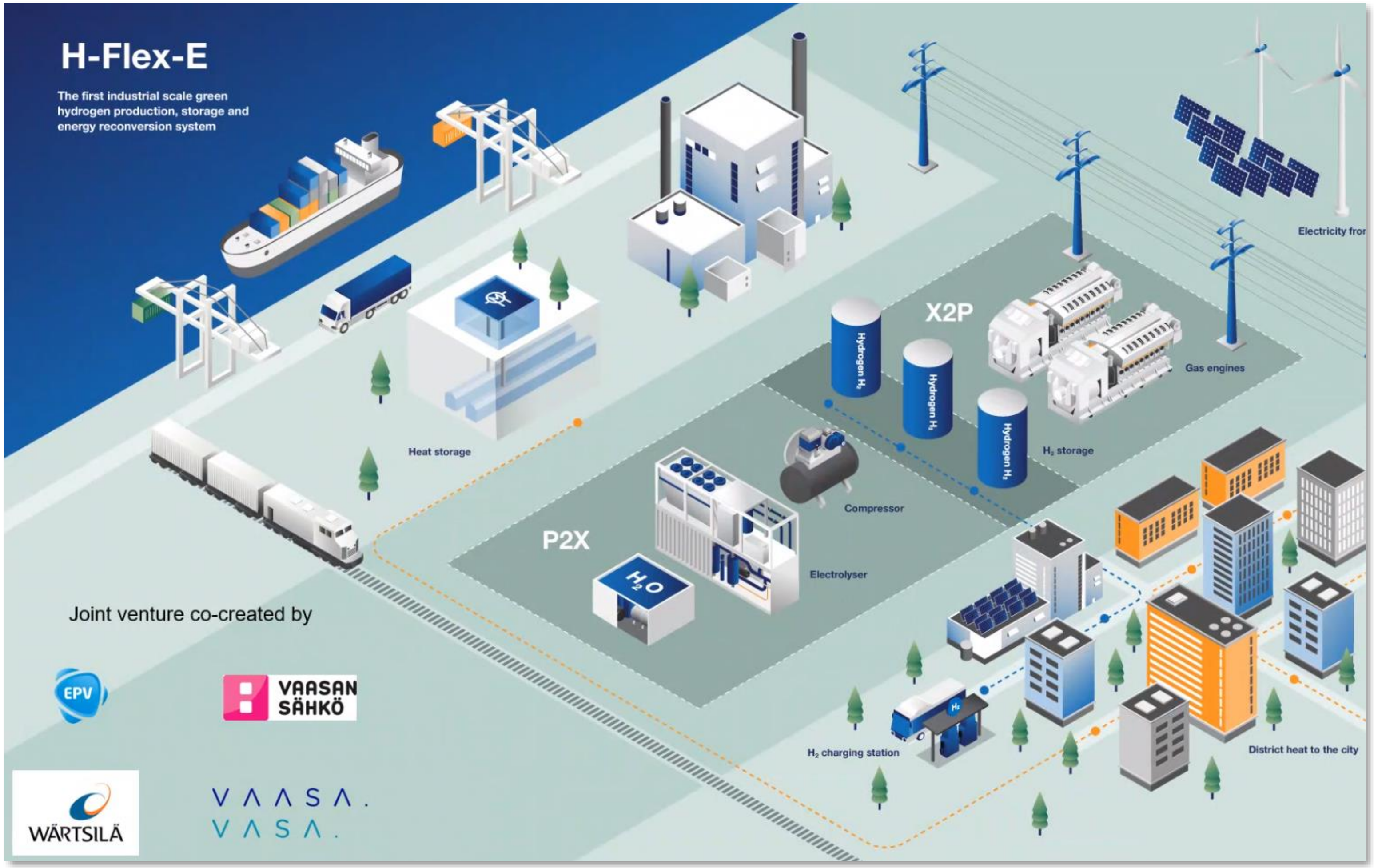
KEY TAKEAWAYS (WEC, US):

- *Successful testing with up to 25% blends*
- *CO2 and GHG emission reductions*
- *No mechanical changes to engine, stable engine behaviour*

PURE HYDROGEN PILOT COLLABORATION

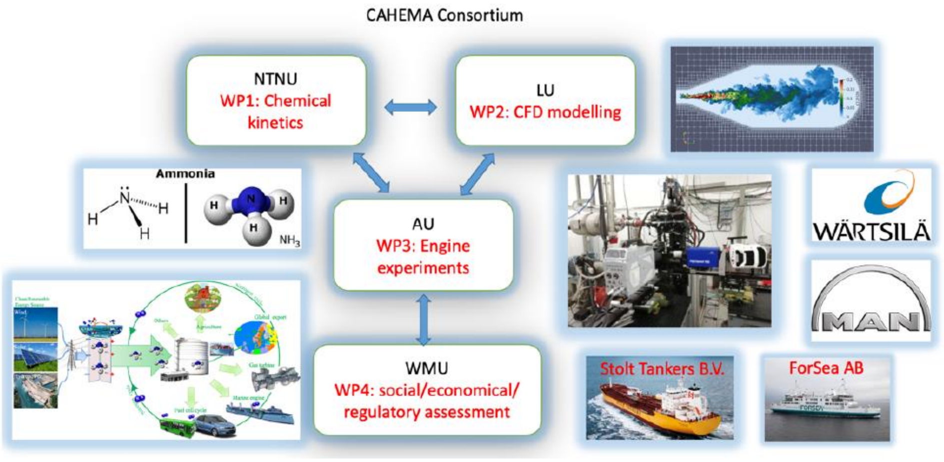
H-Flex-E project in Finland

- J/V with local utility for a renewable fuel-powered engine power plant, including P2X2P value chain.
- Stepwise transition from natural gas/biogas to pure H2 demonstration by end of 2026.
- Permitting ongoing, FID 2023.



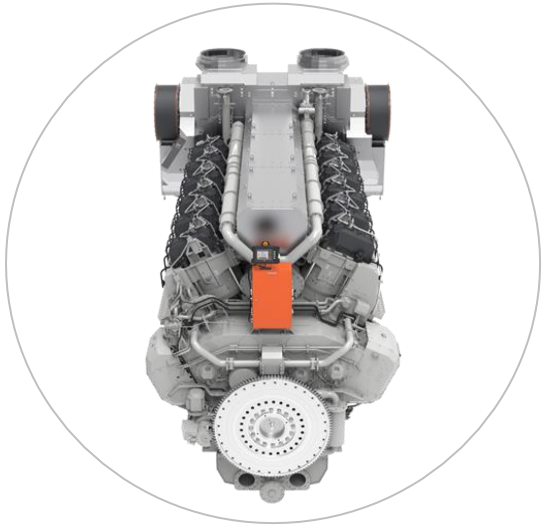
So what is the role of research at universities and research institutes?

Since ammonia and hydrogen engines are soon available in the market?



Research at universities and research institutes

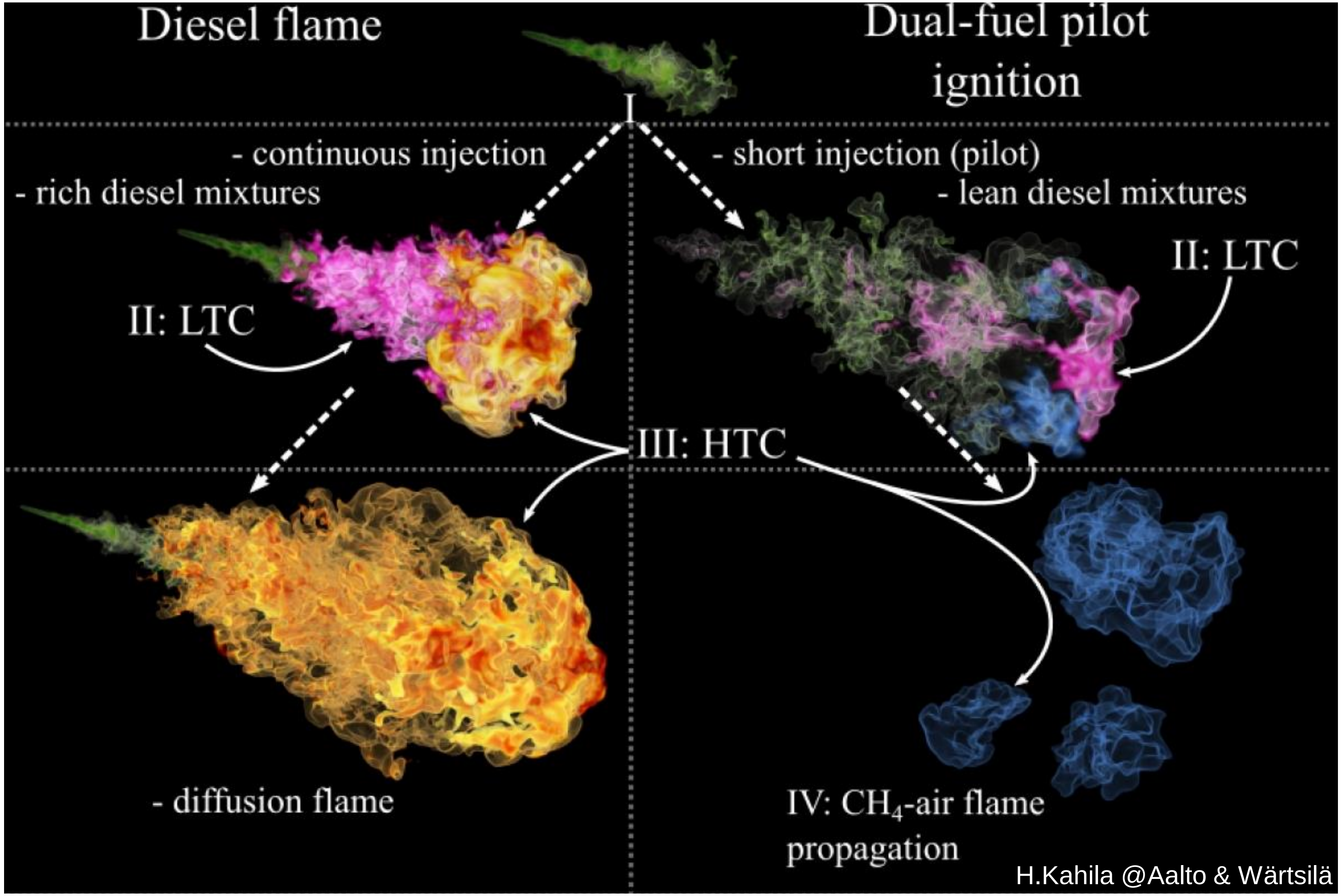
Technology development & proof of concept



Industrialised solution

”IT’S ALL ABOUT COMBUSTION”

- How to prepare it ?
- How to initiate it ?
- How to control it ?
- How to contain it ?



WÄRTSILÄ

NH3 fuel supply options

- Liquid – NH3 high pressure injected
- Gaseous – NH3 low pressure port fuel injected

Support fuel options

- Liquid NH3 / Liquid – diesel / HVO direct injected
- Liquid NH3 / Liquid – emulsion with ignition improver

- Liquid NH3 / Gaseous – ignition improver gas LNG / CH4
- Liquid NH3 / Gaseous – ignition improver gas H2

- Gaseous NH3 / Gaseous – ignition improver gas LNG / CH4
- Gaseous NH3 / Gaseous – ignition improver gas H2

Ignition options

- Pilot diesel / HVO direct injected compression ignition
- Compression ignition
  - Conventional diesel mixing controlled (rich)
  - Reactivity controlled (lean) – RCCI

Combustion options

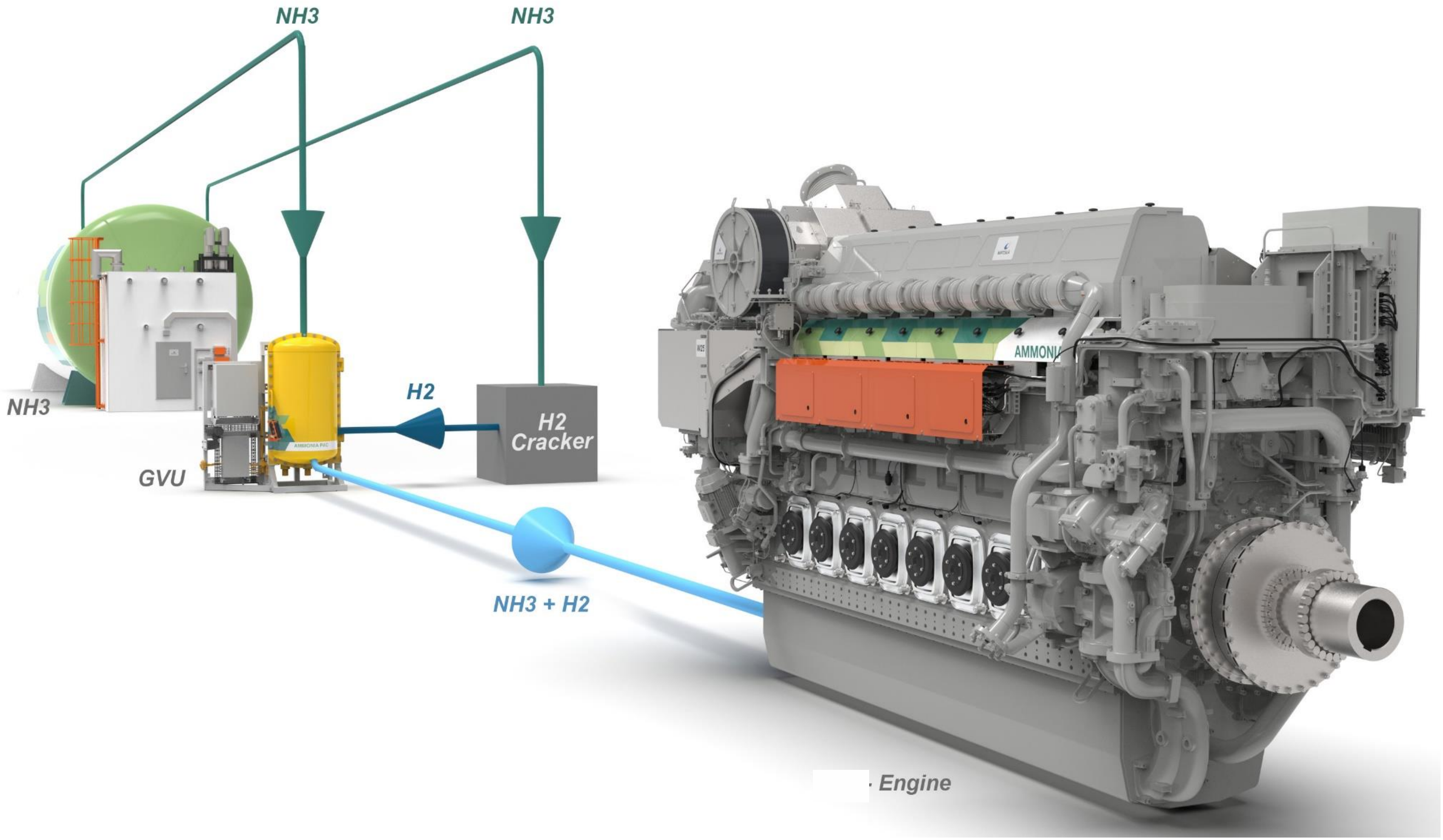
- Mixing controlled diffusion combustion
- Pre-mixed flame propagation
- Reactivity controlled distributed combustion

Other considerations

- Total GHG / CO2e (CO2, N2O, CH4) – LCA
- Aftertreatment (NH3 slip, NOx, N2O formation)
- Main fuel to support fuel ratio
- Combustion and thermodynamic efficiency
- Combustion control
- System efficiency, including parasitic losses for fuel handling
- New build and/or retrofit
- Overall system complexity
- Cost (CAPEX – OPEX)
- etc

OR remove the NH3 combustion challenge – convert all NH3 to H2

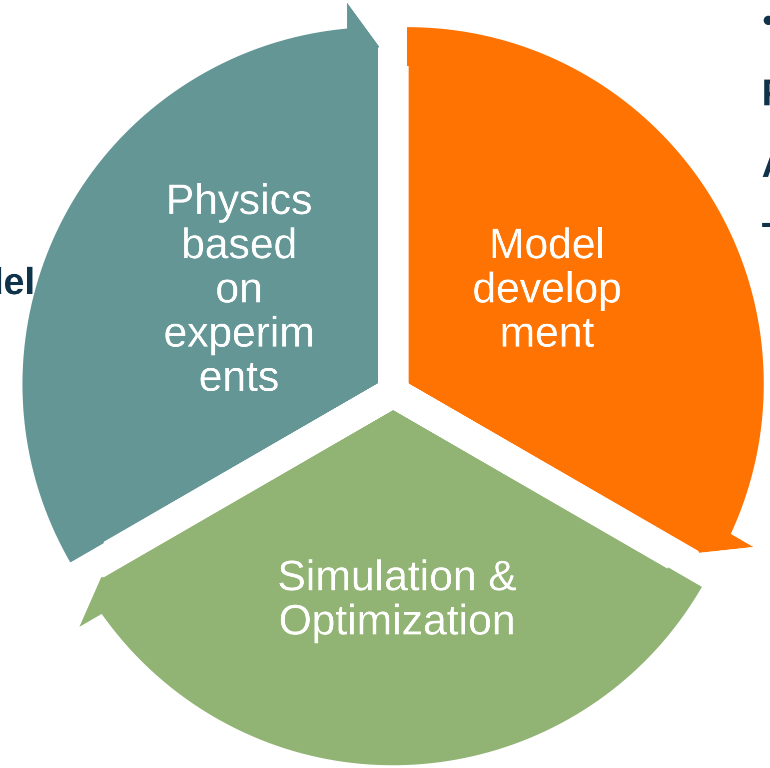
Pure Ammonia engine concept with hydrogen cracking



Research focused on fundamental understanding and modelling the physics

Experimental rigs, e.g.:
- Research engines, metal and optical
- Spray & combustion chambers
- Rapid compression machines
- Shock tubes, etc.

Testing focused on:
1. Generating data for modelling and model validation
2. Final optimization and validation of simulations
3. Direct analysis of results needed



Model development, including validation:
- Physical models (0,1,3D)
- Data based empirical models

Predictivity requirement affects modelling strategy

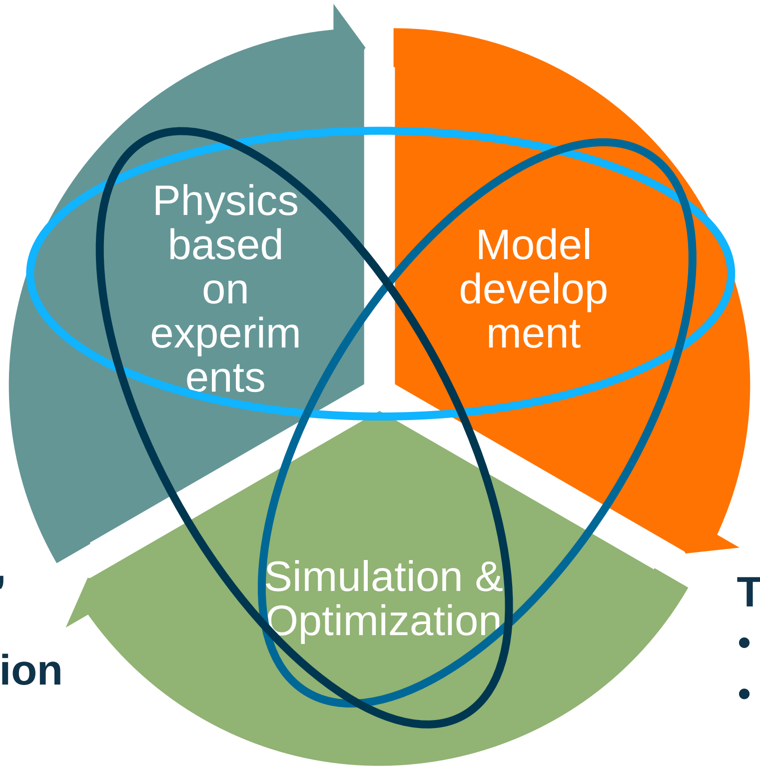
Accuracy based on simulation purpose

Test data enrichment by models for direct analysis

Simulation of use cases – optimization methodologies
- Exploring options
- Developing concepts
- Optimizing solutions
- Selecting most promising cases for experimental validation

Linking research and industry => through experiments, modelling and simulations

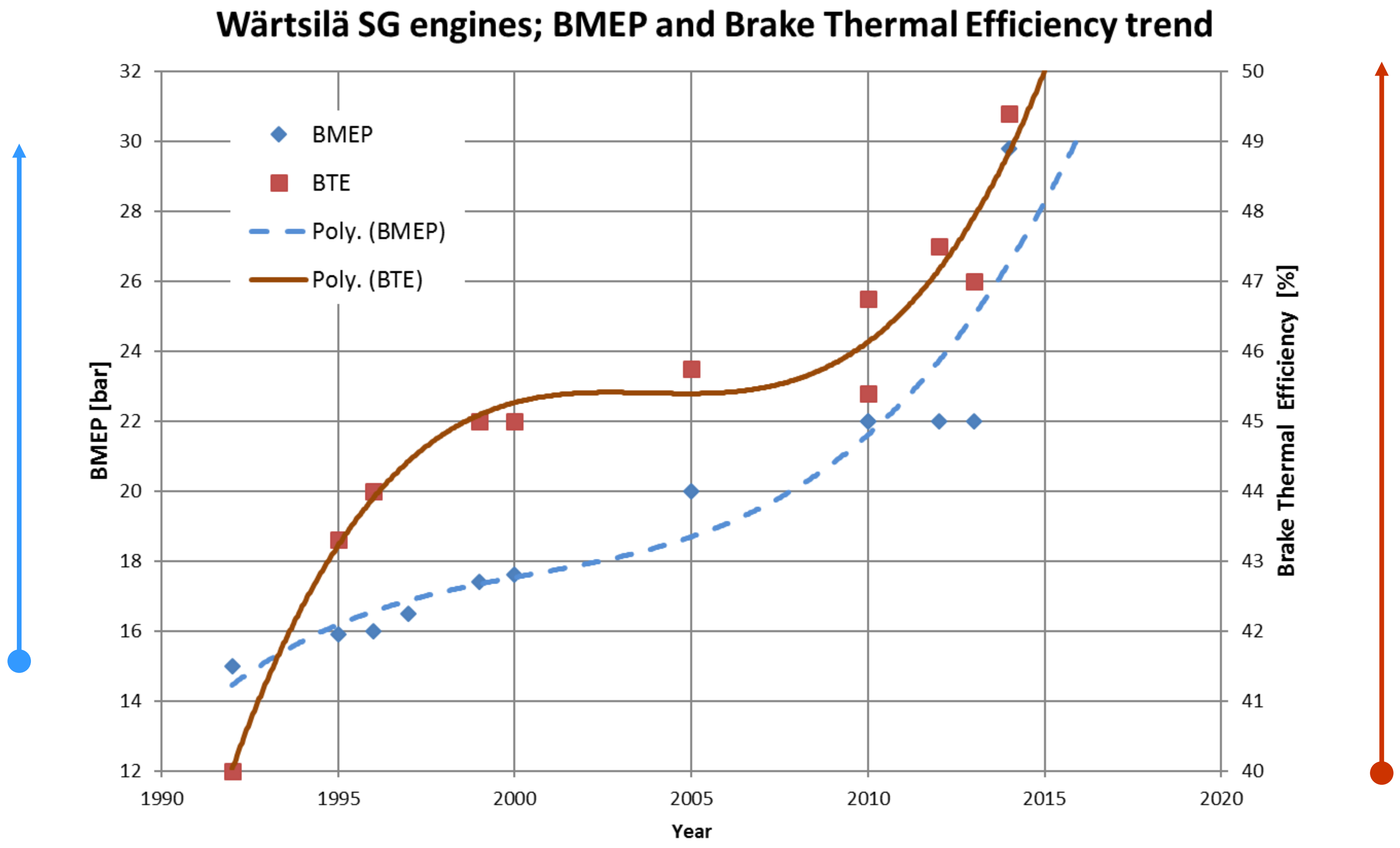
Experiments and Model development
- **Universities and Research institutes**
- **Experiments also at the industry**



Industry:
- **Optimization,**
- **Validation**
- **Industrialization**

Tools development
- **Universities and Research institutes**
- **Use cases and requirements from industry**

BMEP doubled



Brake Thermal Efficiency +25%

Thank you for your attention !

Any questions before we are beyond the horizon?