Ammonia and methanol –
Green fuels for sustainable propulsion systems?

November 14th, 2024 • Malin

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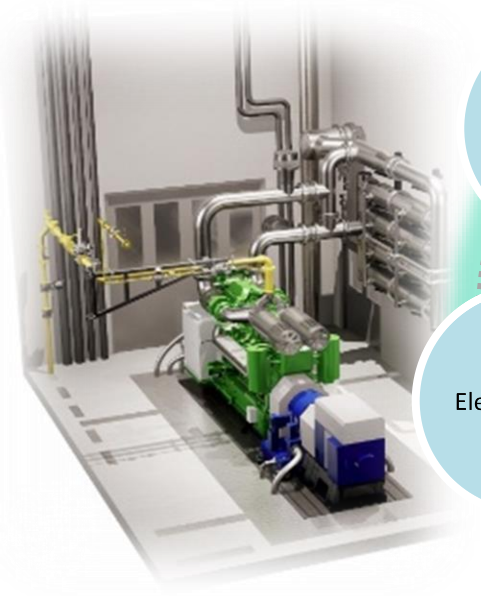
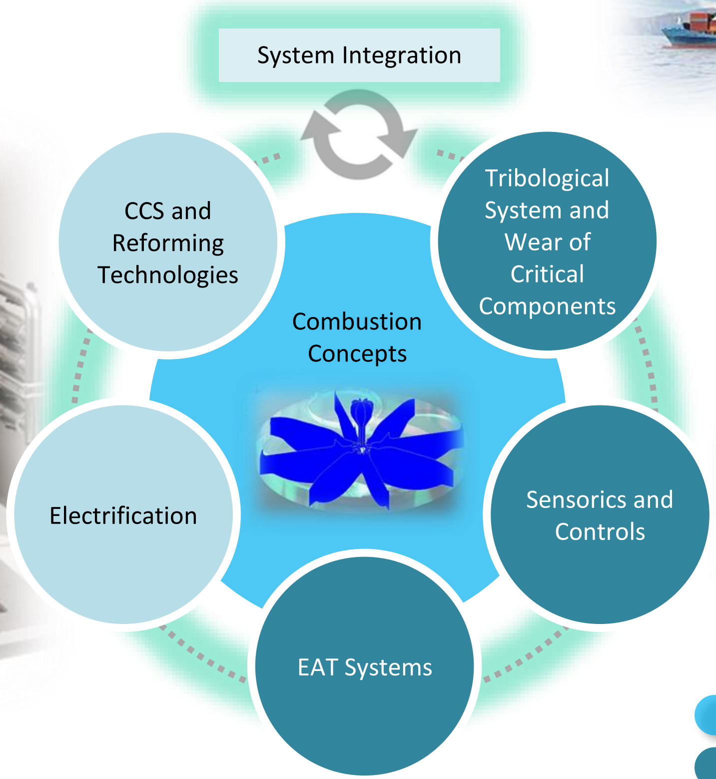
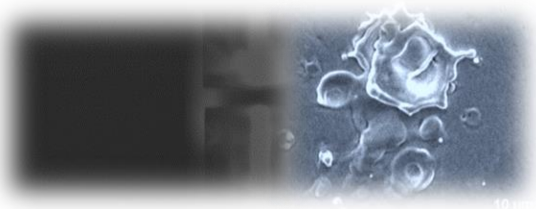
Large engines and the LEC GmbH

Research focus



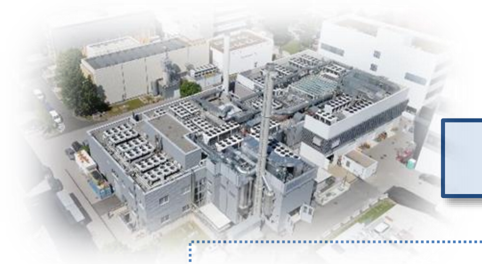




- Key competence – comprehensive consideration at all levels
- Comprehensive consideration at certain levels
- Primarily at system level

Large engines and the LEC GmbH

Infrastructure



LEC Laboratory at the Graz University of Technology Campus

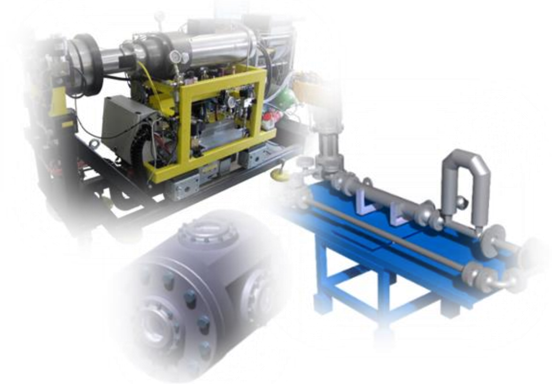
(Suitable for a wide range of fuels such as H_2, CO, MeOH, ammonia, etc. and all types of conventional fuels)

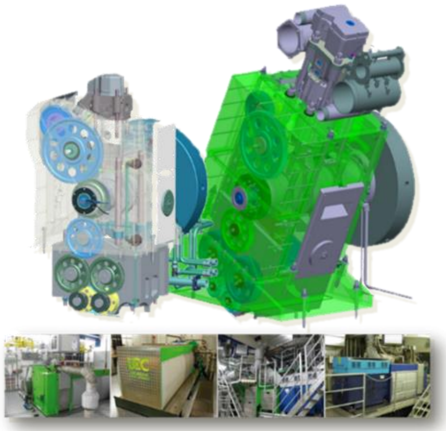
Test Rig Investigations → SCE Experiments → MCE Experiments → System Validation

IIC Laboratory
(Injection, Ignition and Combustion)

4 SCE Test Beds
(up to 900 kW)

MCE and System Test Bed
(up to 3,500 kW)





Large engines and the LEC GmbH

Application field

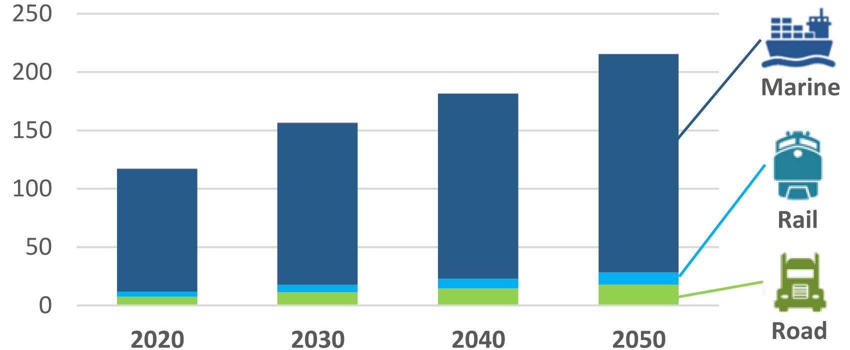
Transportation

Power generation

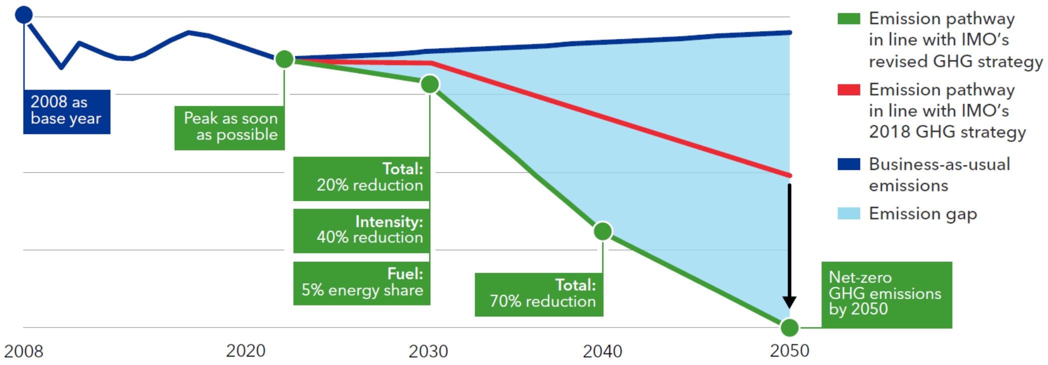
Large engines and the LEC GmbH

Transport demand vs GHG targets

Worldwide transport is expected to **increase rapidly** in the next decades, mainly in the **marine sector.**



Source: ITF Transport Outlook 2023 (Current Ambition Scenario)



***Source**: https://www.dnv.com/maritime/publications/maritime-forecast-2023/* **© DNV 2023**

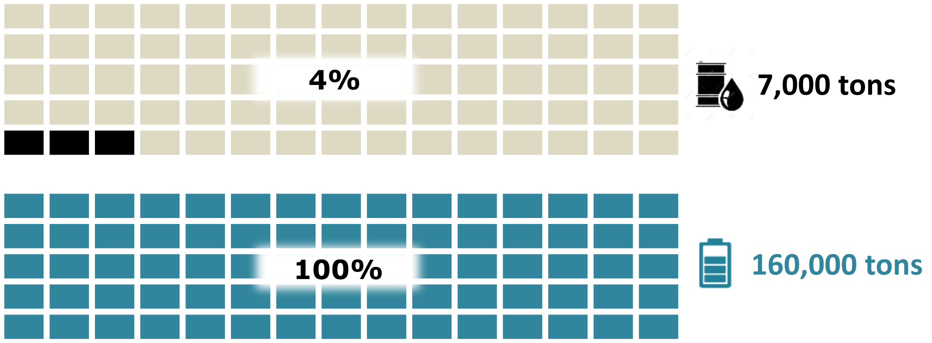
To reach the **net-zero GHG emissions target by 2050**, actions need to be taken as soon as possible.

Pathways towards decarbonization

Energy density vs storage capacity

14.770+ TEU
156.900 tons DWT
81 MW Propulsion
325 tons HFO per day

Trip Asia to Europe (appr. 3 weeks)
Estimated storage demand



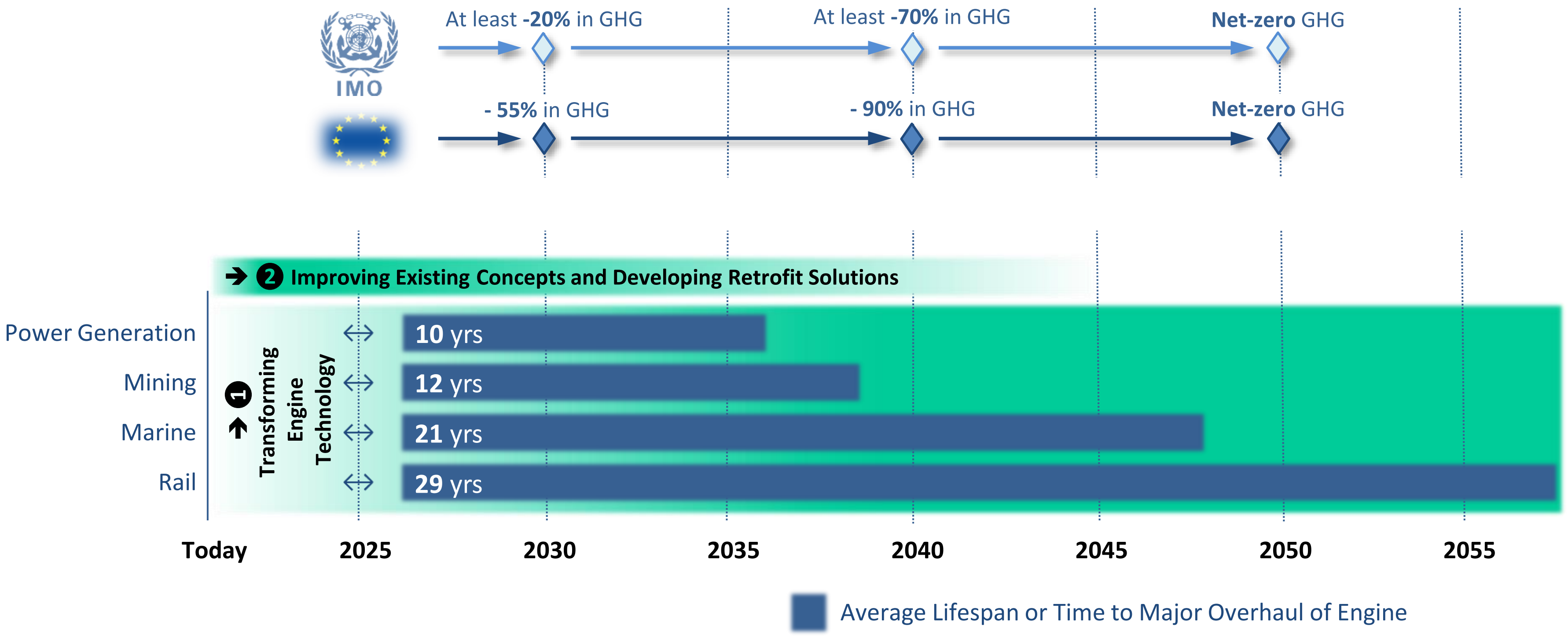
1 Fossil Fuels
+ CC Post-combustion
Direct Use
➔ Not sustainable, only for transition

2 Biofuels
Direct Use
➔ Limited

3 Green Electricity
Batteries
➔ Low storage density
E-fuels (PtX)
➔ **Main path**
Direct Use
➔ Not everywhere, not always

Pathways towards decarbonization

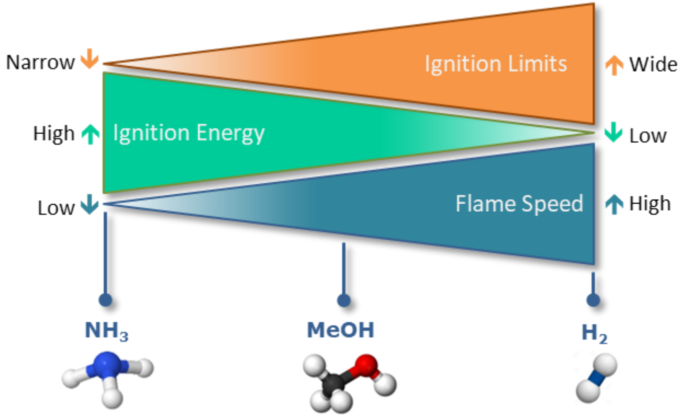
Engine Lifespan vs. Climate Targets



Pathways towards decarbonization

Green E-fuels | fuel properties and combustion characteristics

Fuel	Lower heating value (gravimetric) [MJ/kg]	Lower heating value (volumetric) [MJ/l]	Laminar flame speed (stoichiometric) [m/s]	Min. ignition energy [mJ]	Autoignition temperature [K]
Drop-in e-fuel (diesel-like)	43	36	0.87	0.23	483
e-methane	50	36	0.38	0.29	868
e-methanol	**19**	**15**	0.36	**0.14**	**712**
e-ammonia (liquid, -33°C)	**20**	**14**	**0.07**	**8.00**	**930**
e-hydrogen (liquid, -253°C)	**120**	**9**	**3.50**	**0.02**	858

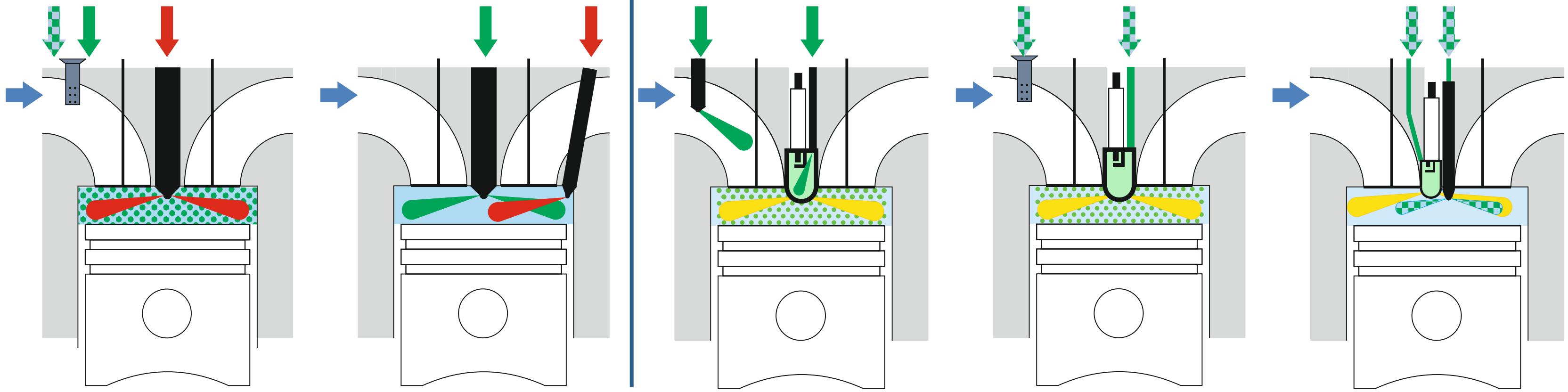


Combustion process of ammonia and methanol

Fuel admission and ignition process

CI combustion concepts

SI combustion concepts



Air Diesel Alternative fuel (gaseous) Alternative fuel (liquid)

Combustion process of ammonia and methanol

Fuel admission and ignition process

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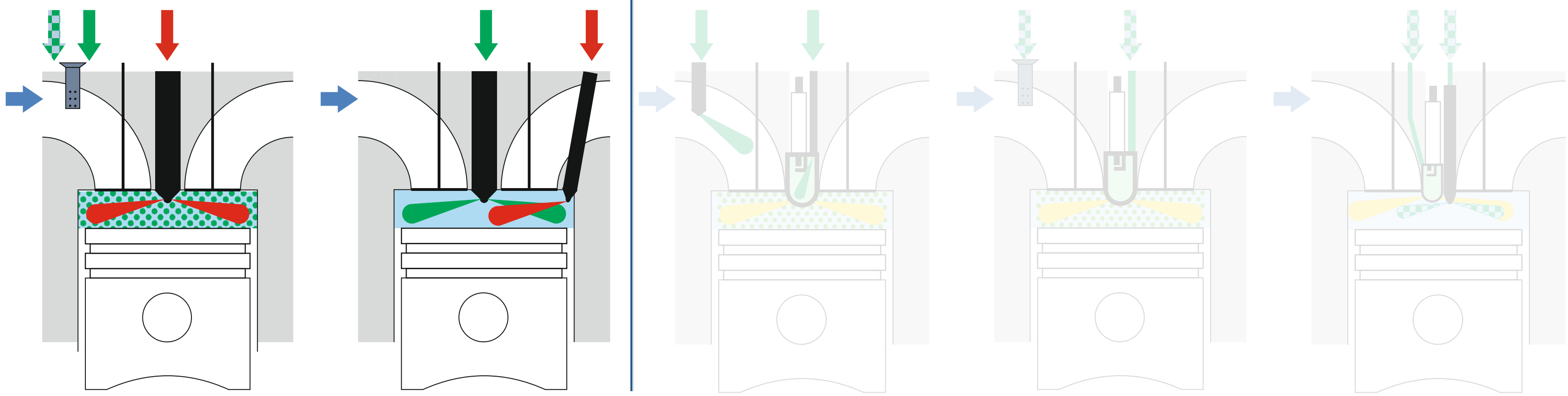


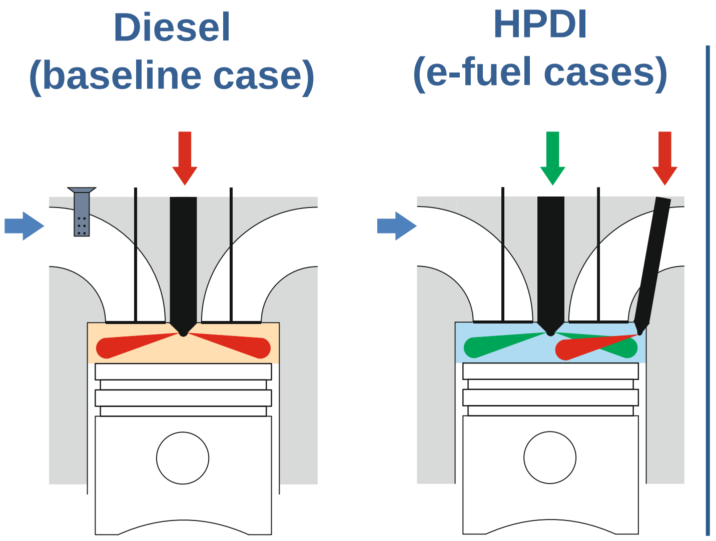
Diesel ignition concepts well suited for marine propulsion

- Fuel flexibility
- Diesel back-up mode

Air Diesel Alternative fuel (gaseous) Alternative fuel (liquid)

Combustion process of ammonia and methanol

Objectives of this investigation



Objectives

- Investigation of the methanol and ammonia combustion process using a high-pressure direct injection (HPDI) concept
- Assessment of the combustion performance of methanol and ammonia in comparison to diesel fuel

Approach

- The investigation is carried out on a single-cylinder research engine (SCE)
- Each fuel is investigated on a similar engine hardware
- In the e-fuel cases, a diesel energy fraction variation is used to investigate the combustion process

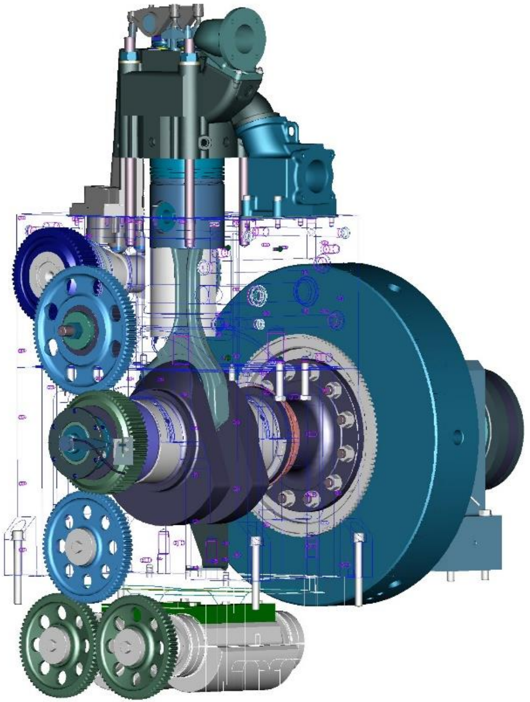
Air Diesel Alternative fuel (liquid)

Combustion process of ammonia and methanol

Experimental setup & boundary conditions

Engine specifications	
Engine speed [1/min]	750
Displacement per cyl. [dm^3]	≈15.7
Compression ratio [-]	17:1
Valve timing	Early IVC

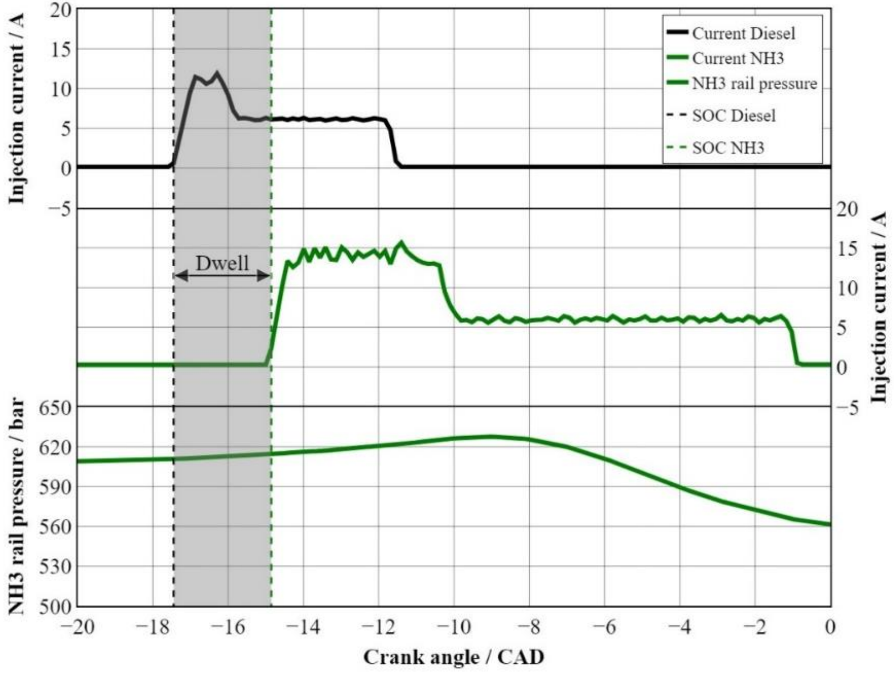
Boundary conditions	Diesel-Case	Methanol-Case	Ammonia-Case
IMEP [bar]	12	20.3*	12
MFB50% [°CA]	≈10	≈10	≈10
Energetic diesel fraction [%]	100	var.	var.
Diesel rail pressure [bar]	1600	1200	1200
Alternative fuel rail pressure [bar]	-	650	600

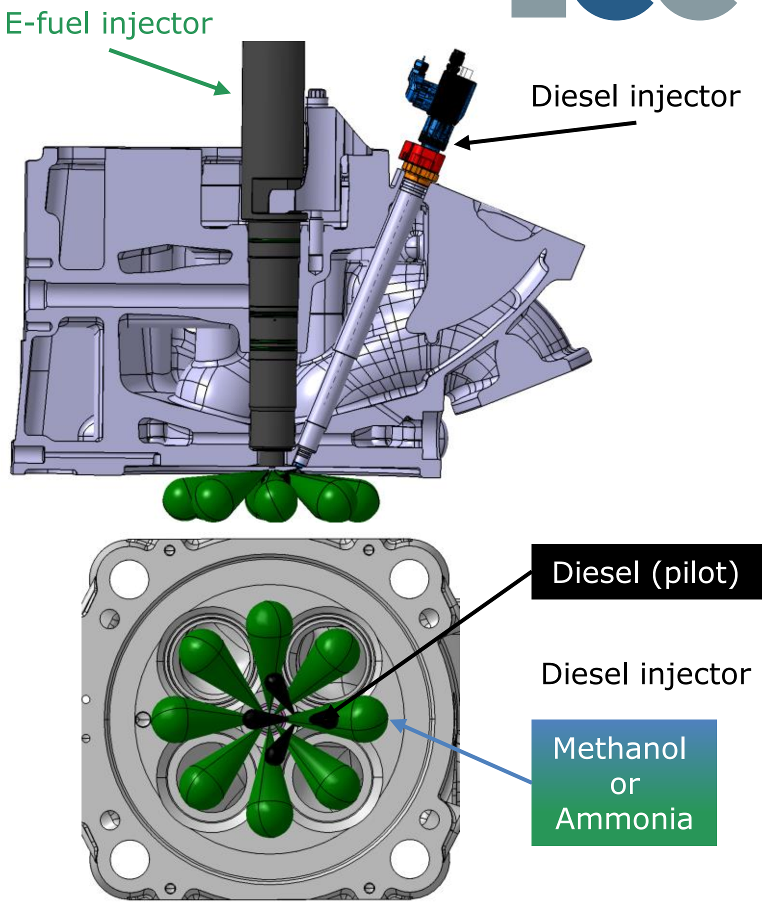


*for the methanol case the engine was operated at a higher load

Combustion process of ammonia and methanol

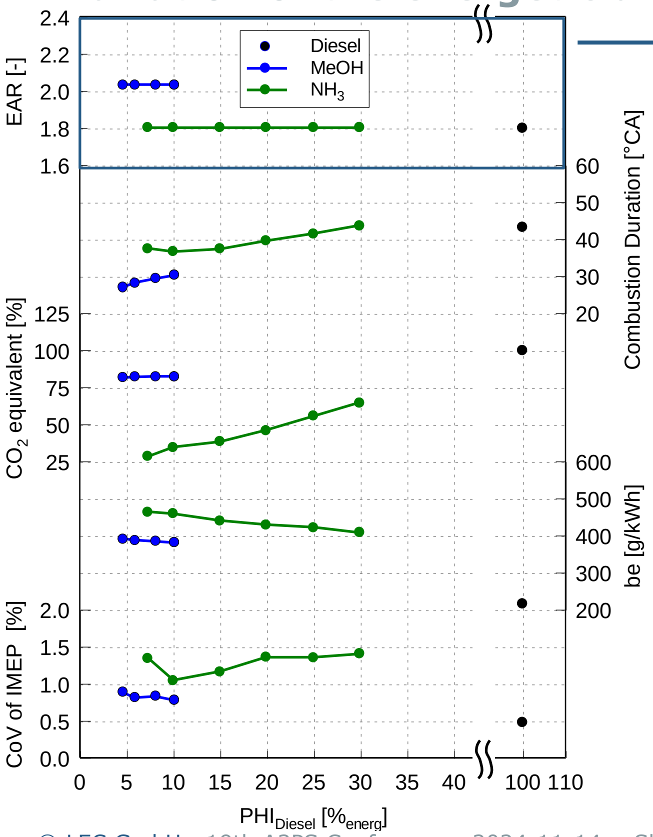
Injection strategy





Combustion process of ammonia and methanol

Variation of the energetic diesel fraction

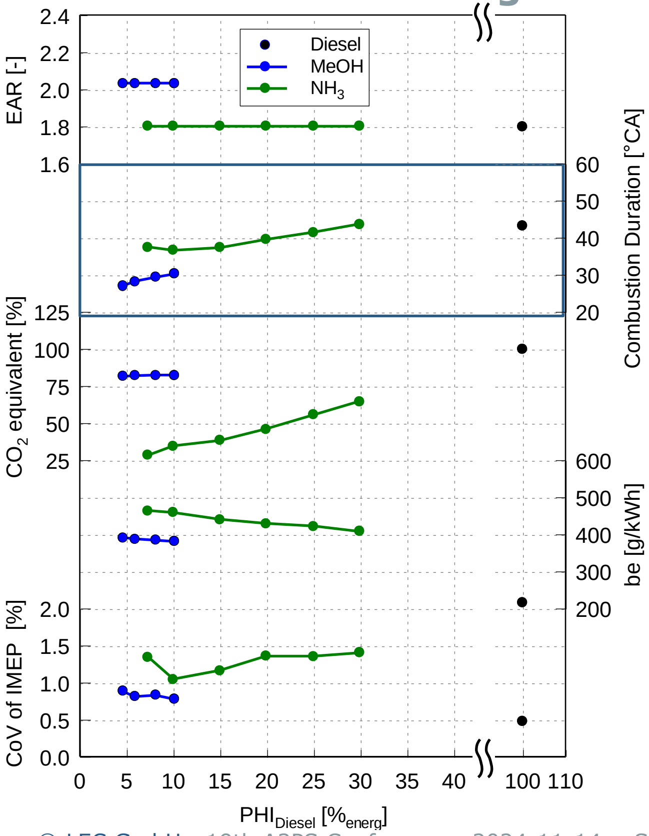


Excess air ratio (EAR)

- Similar EAR like the diesel concept
- Similar boost pressure levels
- Similar requirements on turbocharger system

Combustion process of ammonia and methanol

Variation of the energetic diesel fraction

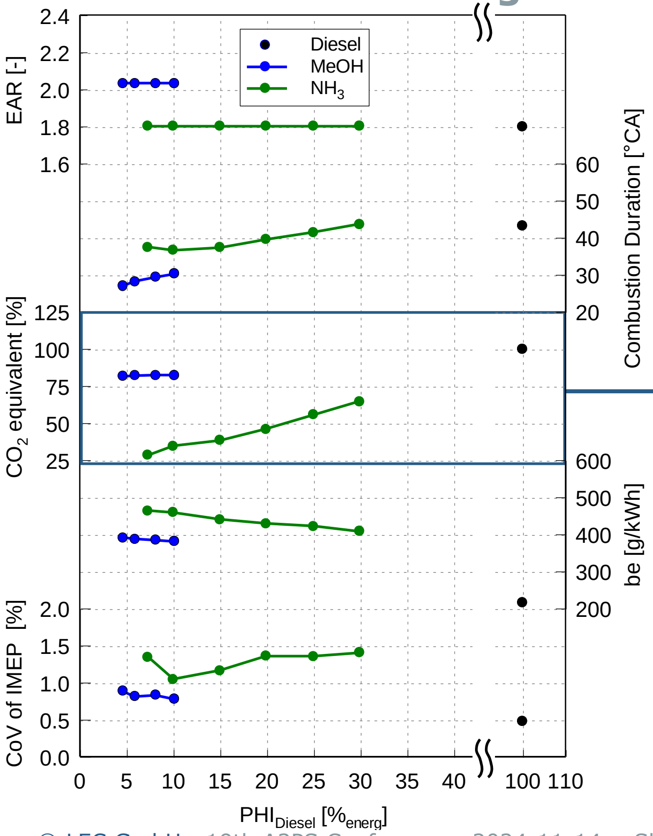


Combustion duration

- Methanol and ammonia allows a reduced combustion duration
  - → Compact heat release rate
  - → Benefit in combustion efficiency

Combustion process of ammonia and methanol

Variation of the energetic diesel fraction

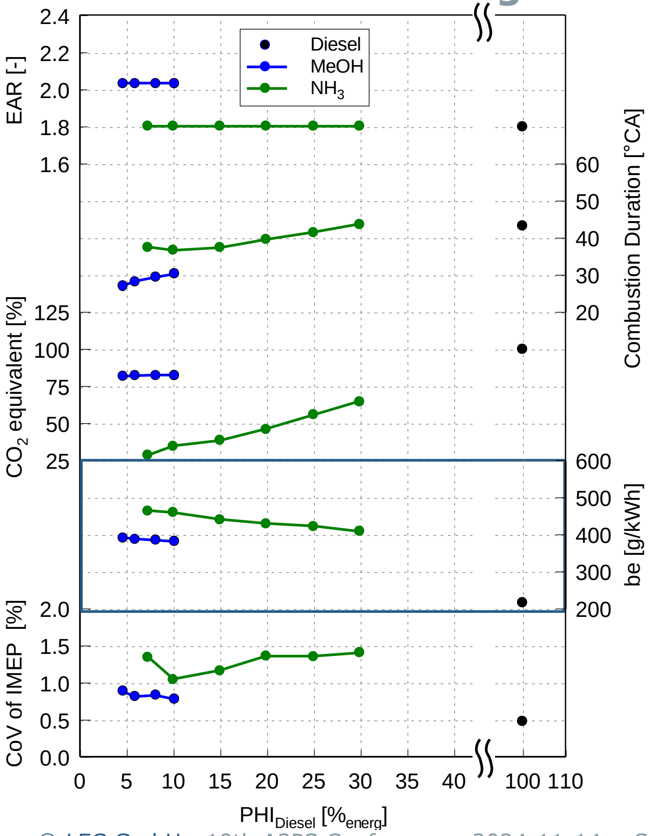


Potential to reduce CO_2 emissions

- Carbon-neutral fuels → methanol (MeOH)
- Carbon-free fuel → ammonia (NH_3)
- Reduction of GHG
- Attention to combustion products which have a high GWP potential e.g. N_2O

Combustion process of ammonia and methanol

Variation of the energetic diesel fraction



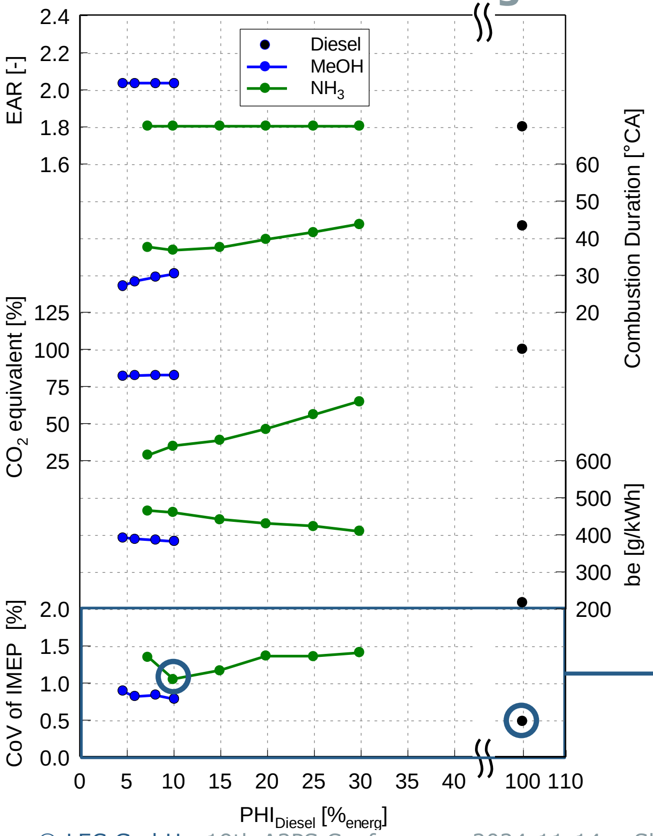
e.g. for MeOH $g_{fuel} = g_{MeOH} + g_{Diesel}$

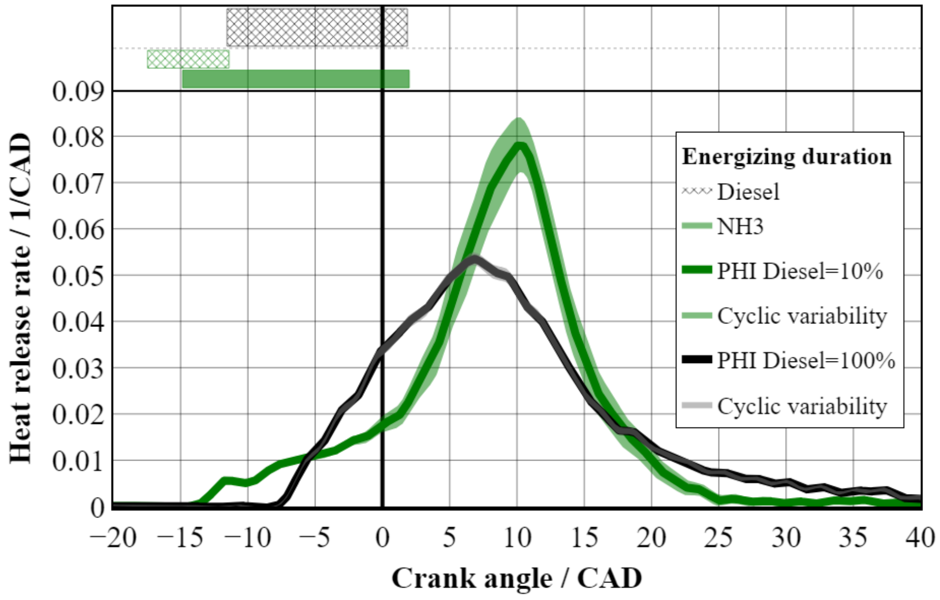
Specific fuel consumption [g/kWh]

- Reduced lower heating value for MeOH and NH_3 compared to diesel
- Higher fuel mass rate
- Challenging for nozzle design and injection equipment

Combustion process of ammonia and methanol

Variation of the energetic diesel fraction



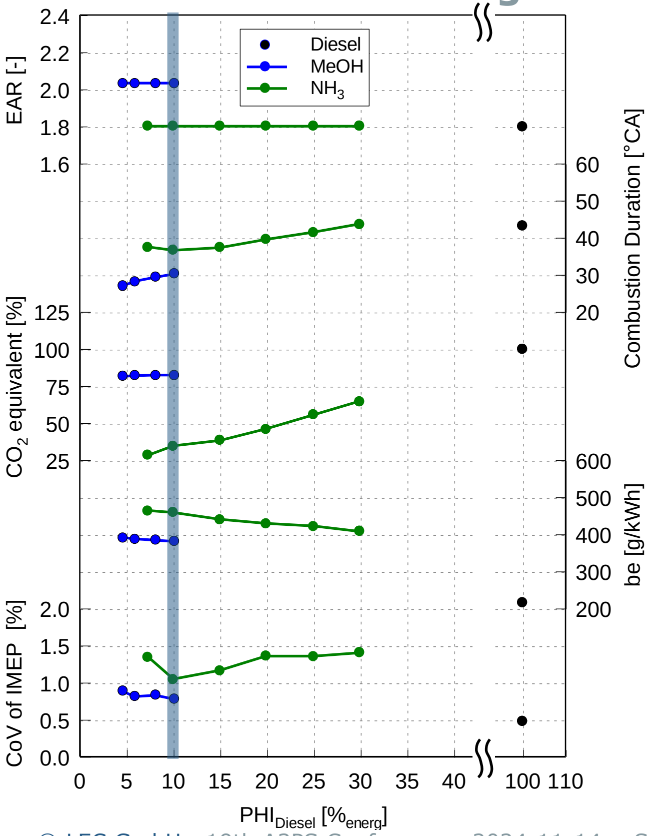


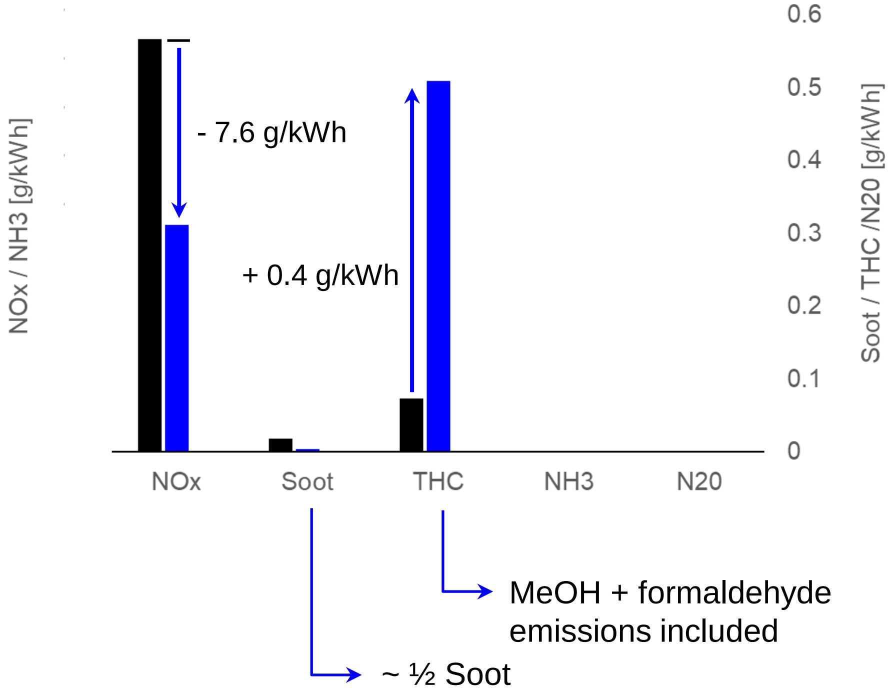
Combustion stability

- Higher cycle-to-cycle variation for MeOH and NH_3 compared to diesel
- Still of an acceptable level

Combustion process of ammonia and methanol

Variation of the energetic diesel fraction





Combustion process of ammonia and methanol

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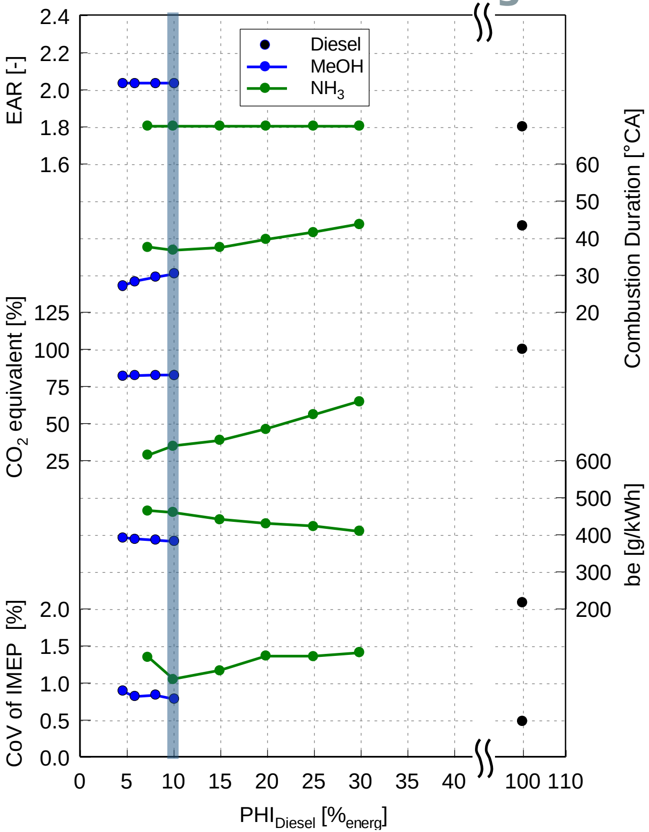

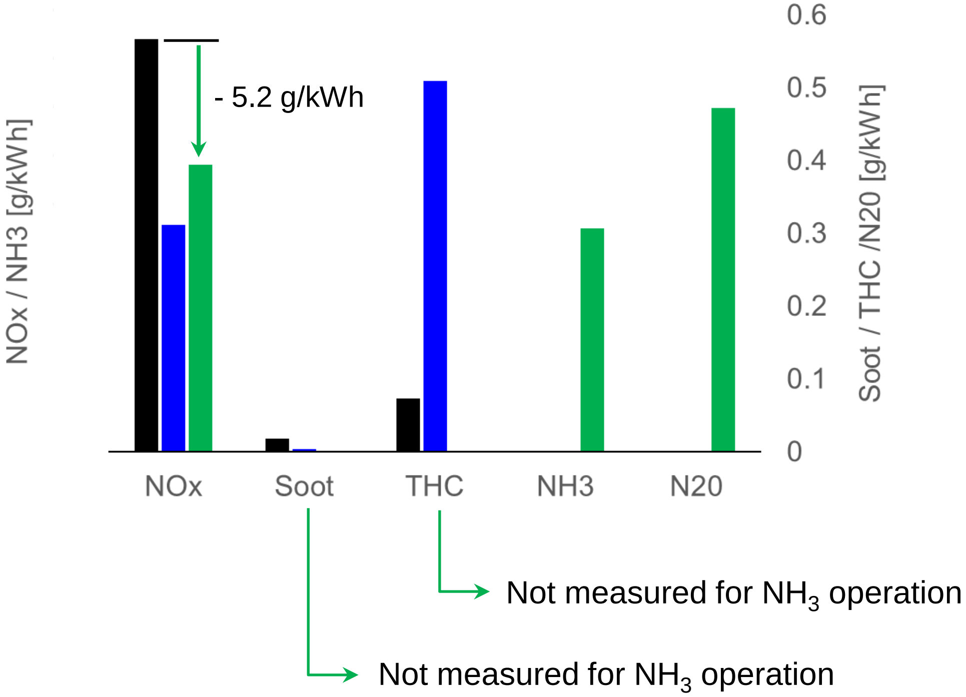

Summary and Outlook

- In the **marine market** in particular, **methanol and ammonia** will play an **important role** in the decarbonization of propulsion systems
- **Methanol** is an **attractive choice** for **retrofit solutions** due to its fuel properties and therefore easier handling on board
- The **toxicity** of **ammonia** and the associated **additional safety requirements** make this e-fuel **more suitable** for **new ship designs**
- The combustion process for **both e-fuels** showed a **high potential** to be able to **increase efficiency** and **reduce NOx emissions** compared to the conventional diesel fuel
- The **HPDI** concept **enables** operation with **excess air ratios similar** to **diesel engines**, allowing for **simpler turbocharger** concepts
- The combustion process for **both e-fuels** introduce **new exhaust gas species** such as NH_3, N_2O and formaldehyde that **require attention**
- Future work will focus on the **development of efficient** exhaust gas **aftertreatment** technologies following **further optimization** of the **combustion processes**

Thank you for your attention!

Evolutionary Green Energy and Transport Systems for a Sustainable Tomorrow

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