AACHEN, 03.05.2022

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CHAIR OF THERMODYNAMICS OF MOBILE ENERGY CONVERSION SYSTEMS &
CENTER FOR MOBILE PROPULSION

SHORT STUDY

Amonia as ship fuel

AMMONIA FOR COMBUSTION ENGINES

GreenShipping Niedersachsen

FINAL PRESENTATION

tme | cmp | RWTH AACHEN UNIVERSITY

AGENDA

PROPERTIES OF AMMONIA

AMMONIA COMBUSTION

CONSIDERED ENGINE AND AFTERTREATMENT CONFIGURATION FOR THE LIFE CYCLE ANALYSIS

SUMMARY

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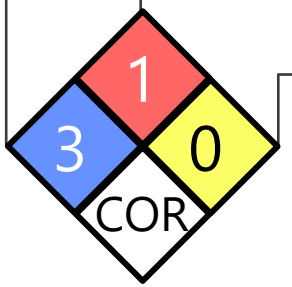
Main hazard from ammonia to humans is its toxicity, which must be considered carefully in ammonia applications

AMMONIA HAZARDS

HEALTH HAZARD

- Ammonia is classified as "**extremely dangerous**" for human health (class 3 out of 4)
- Typical injuries from ammonia include **inhalation** of ammonia **gas or vapors** and **direct skin or eye contact**
- **Smell of ammonia is detectable** for humans at concentrations above 5 ppm, so exposure without knowledge is rare
- **Safety limits** of ammonia:
  - 8 hours (EU): 20 ppm
  - Short term (EU) : 50 ppm
  - Sever health effects: 300 ppm
  - Lethal: >1,700 ppm



FIRE HAZARD

Due to a very **high flash point** of 132°C the fire **hazard** is rated as **relatively low**

INSTABILITY HAZARD

Ammonia is **physically and chemically stable**.

CORROSIVITY

Ammonia is **corrosive to copper, copper-alloys, alloys with a nickel** concentration above 6% as well as **plastic** which makes handling more difficult

Health hazard | Fire hazard | Instability

Note: NFPA 704 diamond is rated on a scale from 0 to 4 for each hazard type
Source: New Jersey Department of Health, GESTIS, FEV Consulting

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Ammonia's lack of carbon and comparably high energy density make it a promising alternative for de-fossilization and decarbonization

METHANOL AND AMMONIA – A COMPARISON TO MGO AND ALTERNATIVE FUELS

Properties

	Diesel / MGO (liq.)	Methanol (liq., 65°C)	Ammonia (liq., -33°C)	LNG (Methane) (liq., -162°C)	Hydrogen (liq., -253°C)	LPG (Propane) (liq., -42.4°C)
Lower Heating Value in MJ/kg	42.7	19.7	18.6	50	120	46.4
Mixture Heating Value (DI) in MJ/m³	3.8	3.92	3.92	3.76	4.54	3.82
Fuel tank size relative to MGO*	1.0	2.3	2.8	1.7	4.2	1.3
Adiabatic Flame Temperature In °C	2030	1880	1800	1950	2110	2000
Ignition Temperature °C	≥ 225	440	630	595	560	470
Lower / Upper Flammability Limit Vol.-%	0.6 / 6.5	6 / 50	14 / 32.5	4.4 / 17	4 / 77	1.7 / 10.8

*Only considering fuel volume
Source: NIST, Kobayashi2019, GESTIS, TME, FEV

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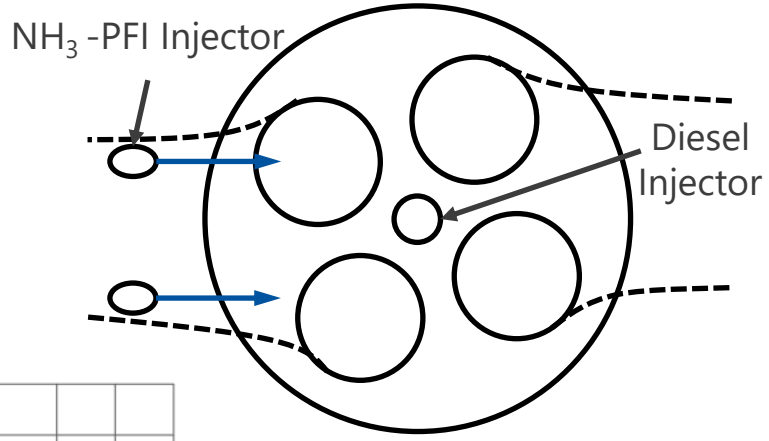
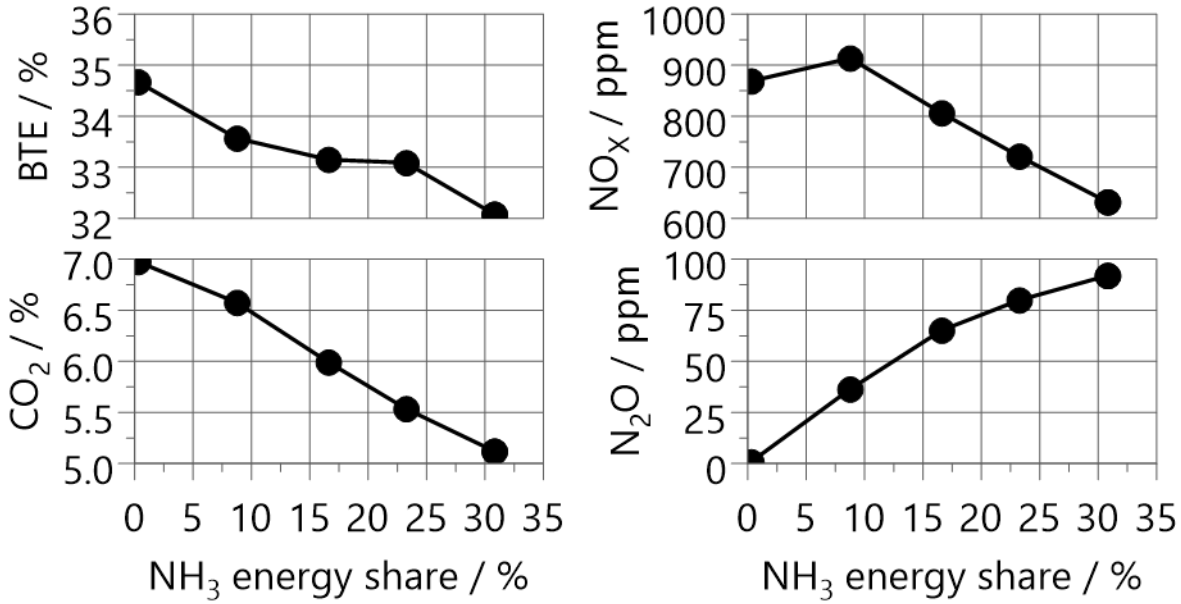
Ammonia fumigation in the port of a diesel engine – passive ammonia combustion in the diesel flame for low ammonia shares

AMMONIA FUMIGATION IS AN APPROACH SIMILAR TO E.G. CO-FIRING COAL AND AMMONIA

Combustion system

Ammonia
Four-Stroke
Cyl. displacement: 1.1l Class
Compression ratio: 18.5
RS = 1500 1/min
BMEP ~6 bar





Source: Niki2018 - EMISSION AND COMBUSTION CHARACTERISTICS OF DIESEL ENGINE

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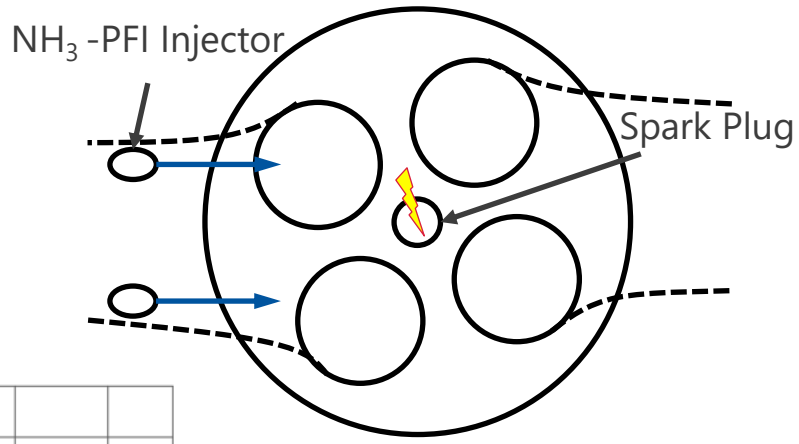
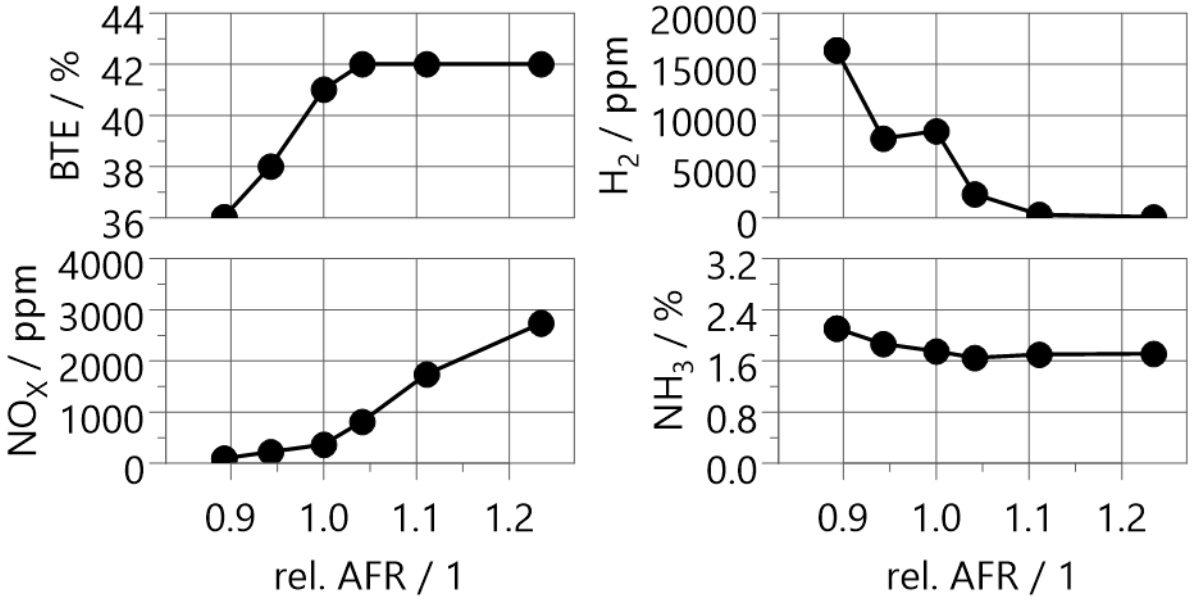
Combustion of pure ammonia in a spark ignition engine is possible at higher loads, if the operation is close to stoichiometric – NO_X emissions are critical

CONVERSION OF NATURAL GAS DUAL FUEL ENGINES TO PURE AMMONIA IS DIFFICULT

Combustion system

Ammonia
Four-Stroke
Cyl. displacement: 0.8 l Class
Compression ratio: 18
RS = 1500 1/min
BMEP ~9 bar





Source: Duynslaegher2011 - Ammonia Combustion in Spark Ignition Engine Conditions

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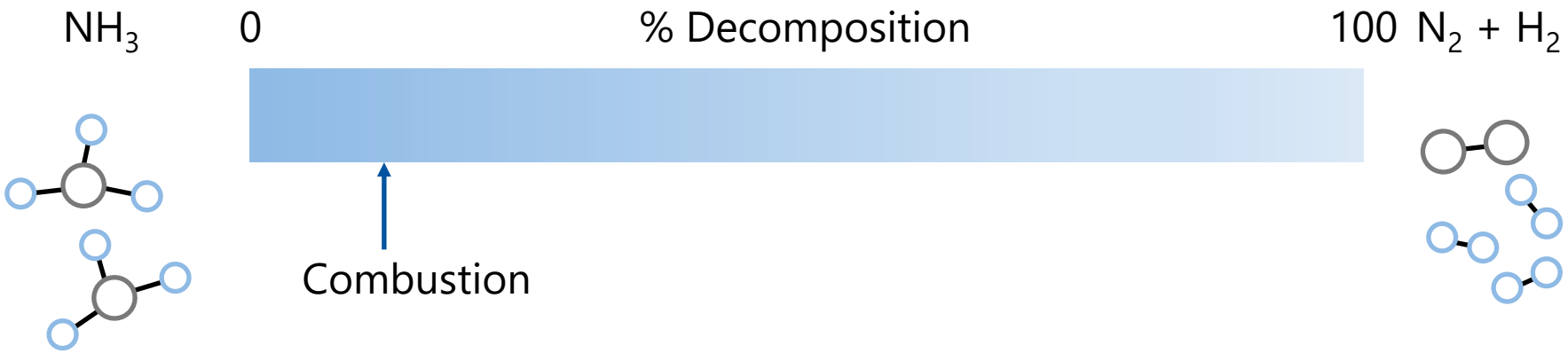
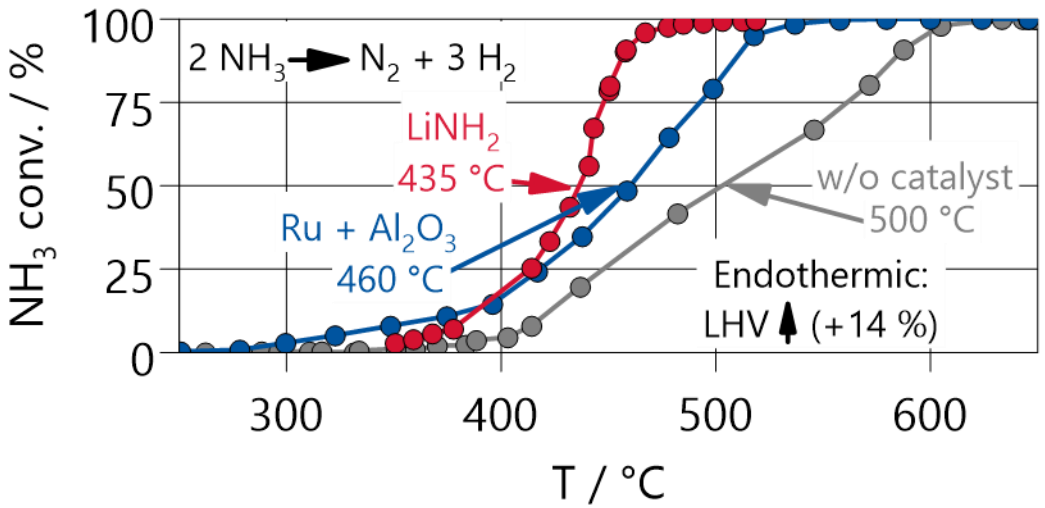
Cracking ammonia: Hydrogen(-assist) widens the applicability of ammonia without the need for storing a second fuel

AMMONIA FUEL CELLS AND GAS TURBINES CAN BE ALTERNATIVES TO COMBUSTION ENGINES IN SOME APPLICATIONS





Source: TME, https://doi.org/10.1039/C5SC00205B, Cracking Ammonia: panel wrap-up from the Ammonia Energy Conference - Ammonia Energy Association

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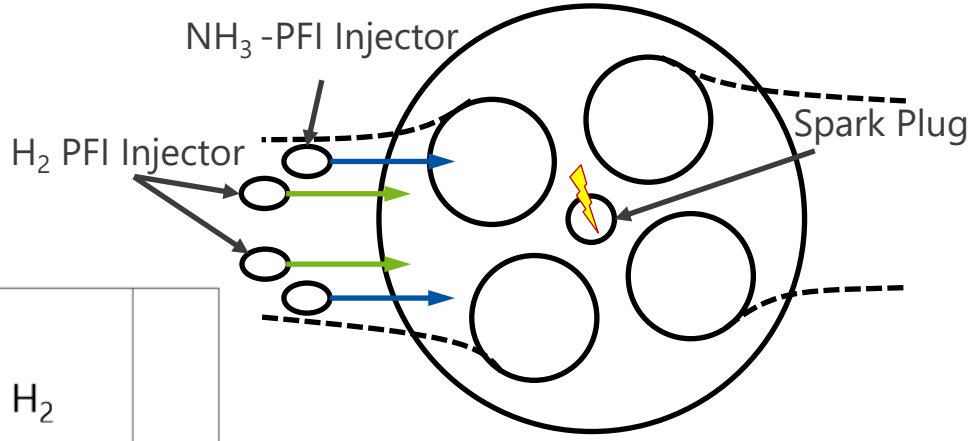
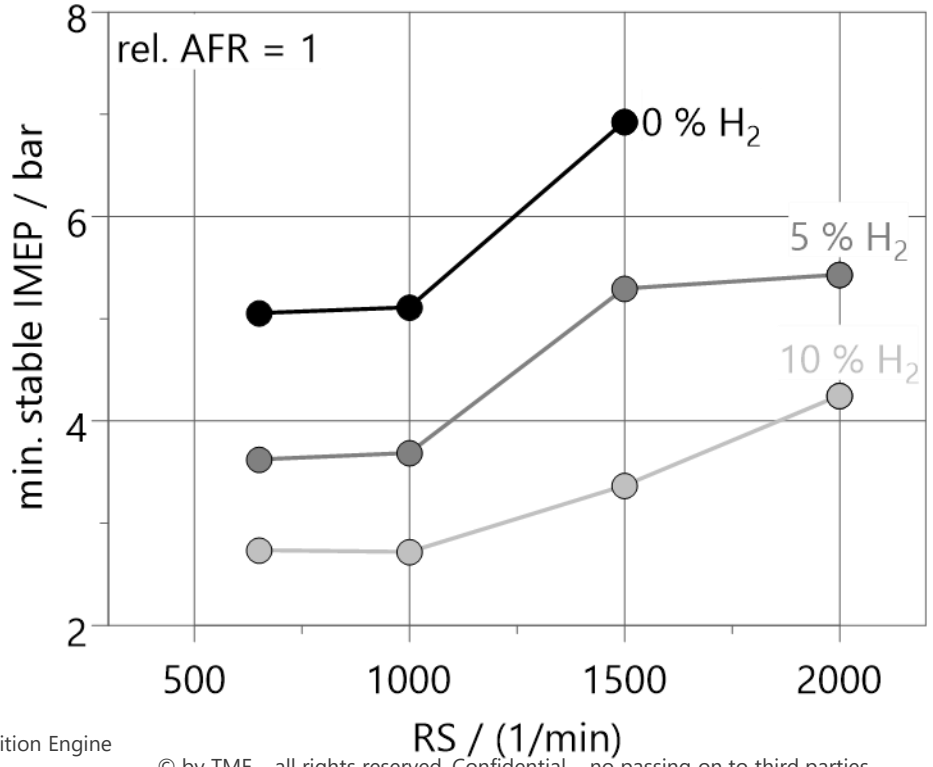
Hydrogen assist enables stable operation at low loads or for lean air-fuel mixtures – challenges with N_2O and NO_X emissions remain

CONVERSION OF NATURAL GAS DUAL FUEL ENGINES TO OPERATE ON A MIXTURE OF NH_3 AND H_2 IS POSSIBLE

Combustion system

Ammonia
Four-Stroke
Cyl. displacement: 0.4 l Class
Compression ratio: 10.5
Stability limit: COV IMEP < 5 %





Source: Rouselle2021 - Operating Limits for Ammonia Fuel Spark-Ignition Engine

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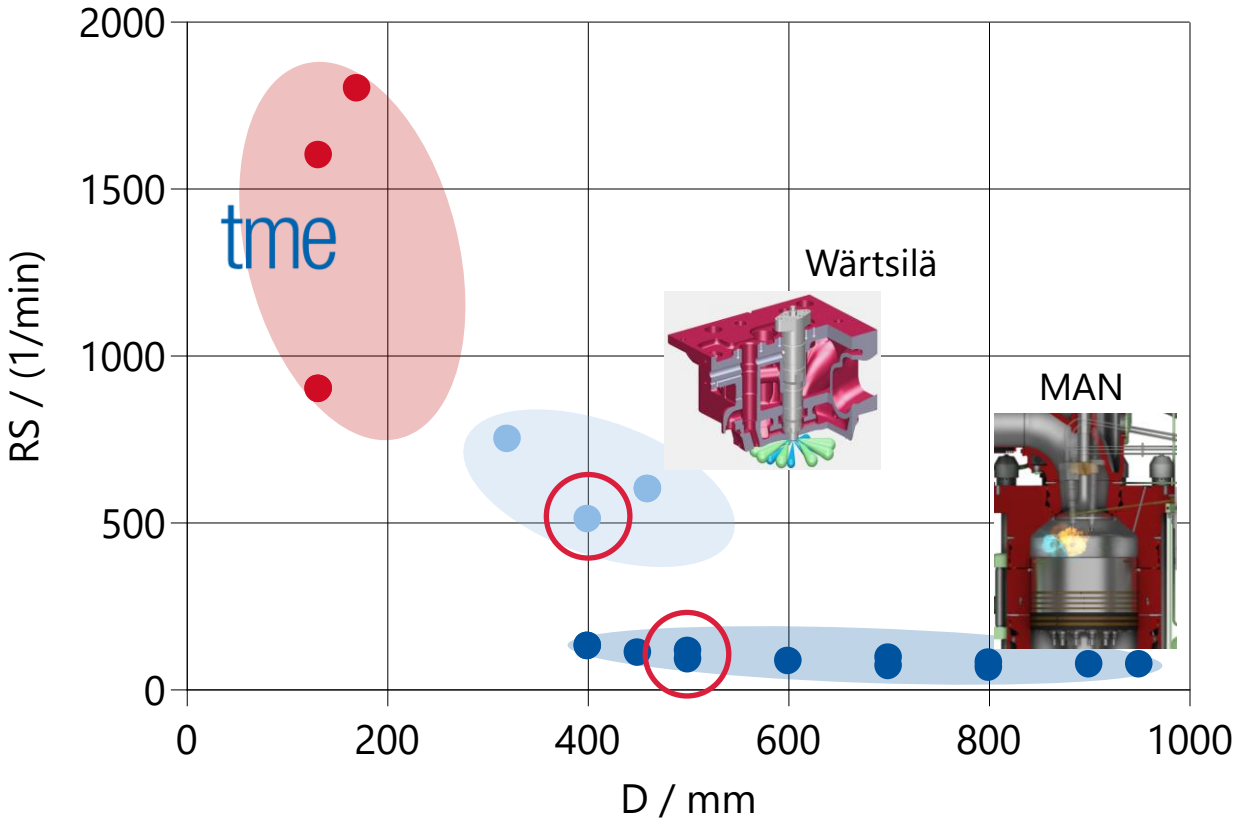
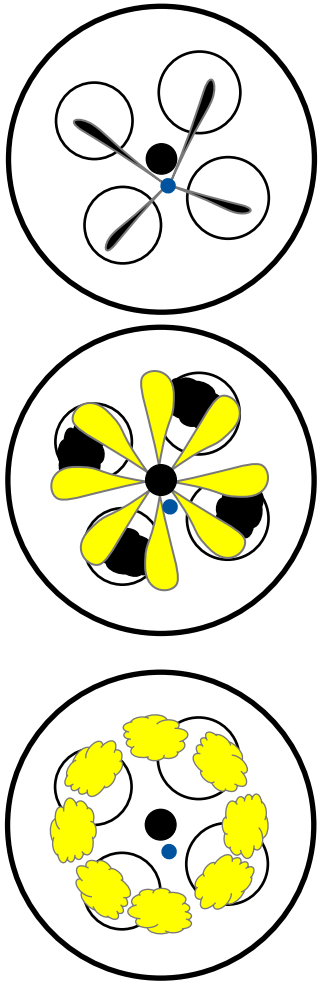
Diffusive combustion with pilot diesel introduces carbon to the combustion, but high temperature combustion might help to dodge N_2O emissions

SIMILAR CONCEPTS ARE USED E.G. FOR METHANOL AND HAVE BEEN ANNOUNCED BY MAN ES FOR NH_3

Combustion system





Pilot Injection

Pilot Combustion & Main Injection

Main Combustion

Source: MAN Energy Solutions, Wärtsilä, TME, FEV

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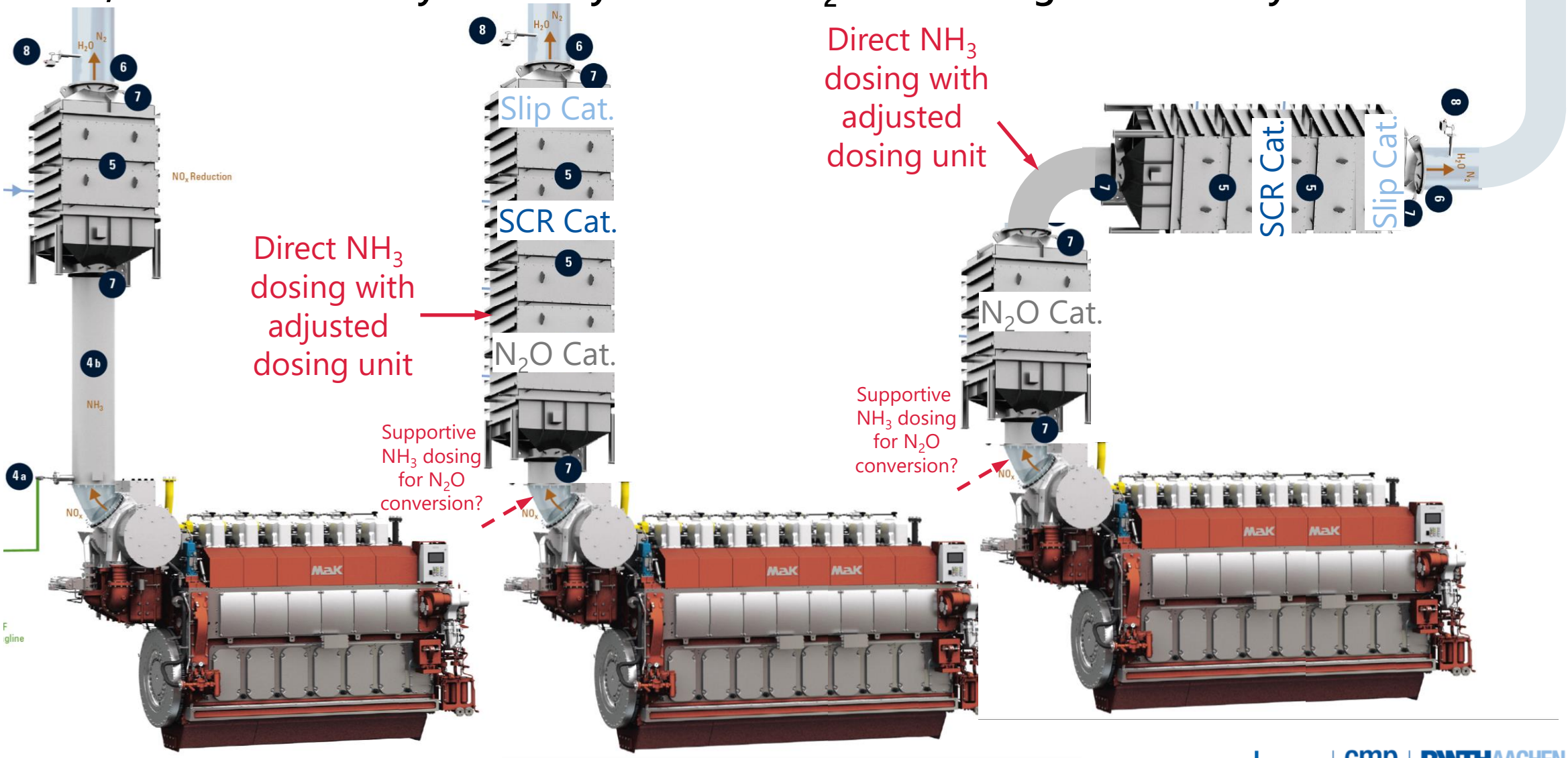
Lower specific power of first engines could be compensated with higher cylinder count; aftertreatment system may include a N_2O and a larger SCR catalyst



Source: http://s7d2.scene7.com/is/content/Caterpillar/CM20160901-09572-49272; TME

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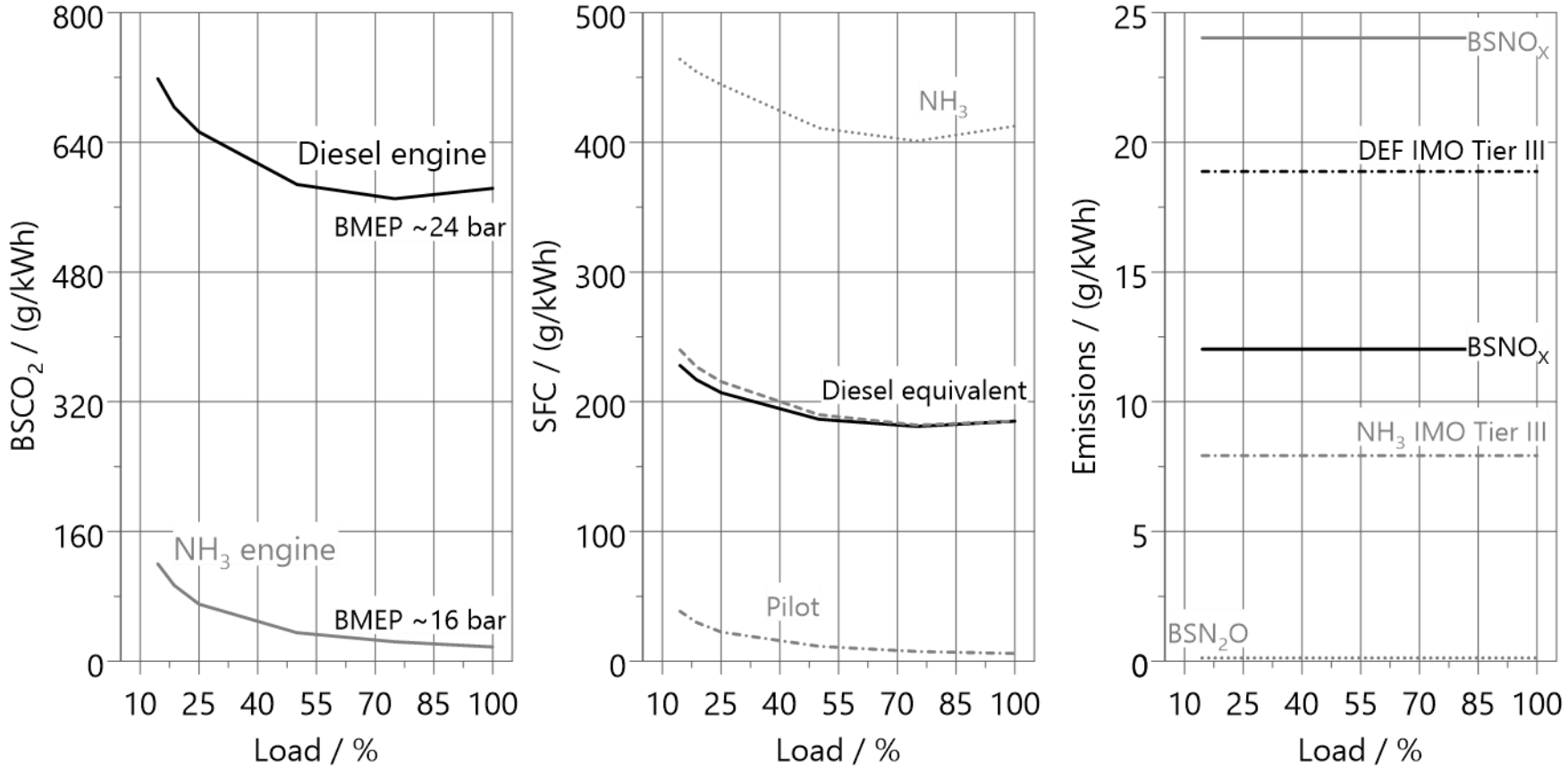
Based on experience at TME and published investigations from Wärtsilä with methanol, a conservative performance and emission estimation is created

PERFORMANCE AND EMISSIONS AS INPUT FOR THE FOLLOWING LIFECYCLE ANALYSIS



Realistic long term estimate of SFC and NO_X emissions:

- Pilot share at full load 3 % by energy
- Diesel efficiency met at full load
- NO_X emissions +100 %
- BSN_2O = 0.1 g/kWh

Source: TME

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SUMMARY

As a carbon free energy carrier, Ammonia is a promising fuel candidate.

Challenges regarding safety and Nitric oxide emissions must be addressed for serial application.

- Ammonia is toxic to humans and must be handled in a professional way
- Flammability risks with ammonia are comparably low
- High ignition temperature and narrow flammability limits are unfavorable both for premixed otto cycle and diffusive diesel cycle combustion
- Possible solutions are:
  - Premixed combustion: Hydrogen admixture
  - Diffusive combustion: Pilot diesel assist
- Both NO_X and N_2O emissions are elevated with Ammonia
  - N_2O formation in intermediate temperature regime can be reduced with a diffusive high temperature combustion concept
- Regardless of the selected combustion concept, both the engine and the aftertreatment system will likely require more space

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