MariNH3

Clean, green ammonia
engines for maritime

Ammonia and Hydrogen Co-Fuelling in a Modern Spark Ignition Engine

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Theme 3: Applications

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MAHLE Single Cylinder Research Engine (SCRE)

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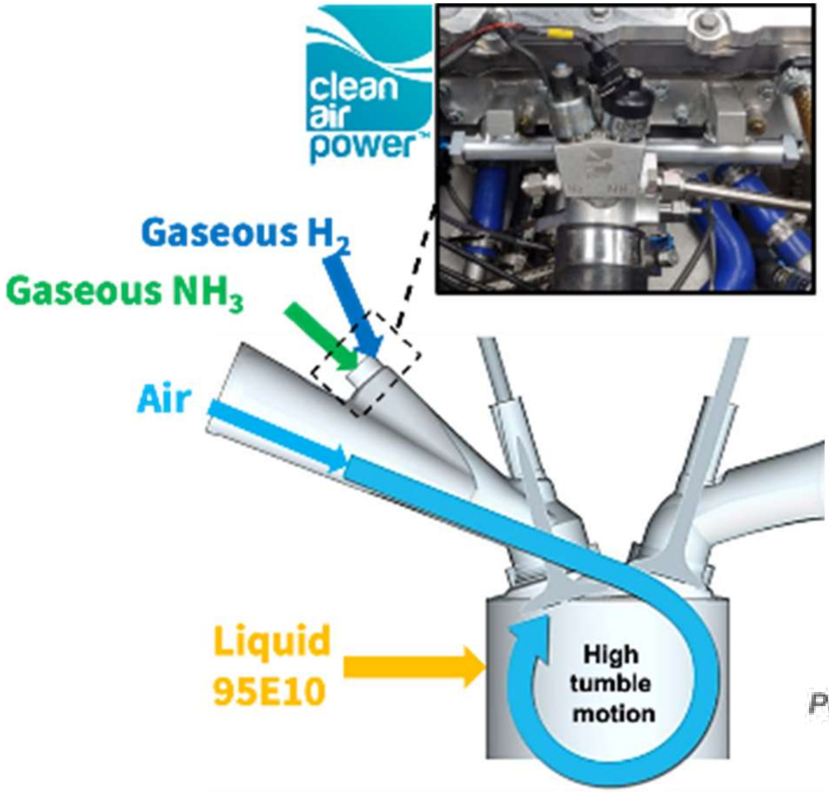
Hardware Specifications

Parameters	Value
Engine Type	Four Stroke Single Cylinder
Displaced Volume	400 cc
Stroke	73.9 mm
Bore	83 mm
Compression Ratio	11.33 upgraded to 12.39 via piston swap
Number of Valves	4
Valvetrain	Dual Independent Variable Valve Timing (40°CA Cam Phasing)
Combustion Modes	SI, Passive & Active JI
Fuel Injection Configuration	• Side DI Gasoline (E10) • PFI Ammonia & Hydrogen
Cylinder Head Geometry	Pent Roof (High Tumble Port)
Piston Geometry	Pent-Roof with cut-outs for valves
Ignition Coil	Single Fire Coil, 100mJ, 30kV
Max Power	40 kW (Gasoline)
Max Torque	96 Nm (Gasoline) [~30 bar IMEPn]
Max In-Cylinder Pressure	120 bar
Max Speed	5000 rpm
Boost System	External Compressor (Max 4barA)
Control System	MAHLE Flexible ECU
Interface Software	ETAS INCA



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Progress - Advanced Retrofit (UoN) - Baseline

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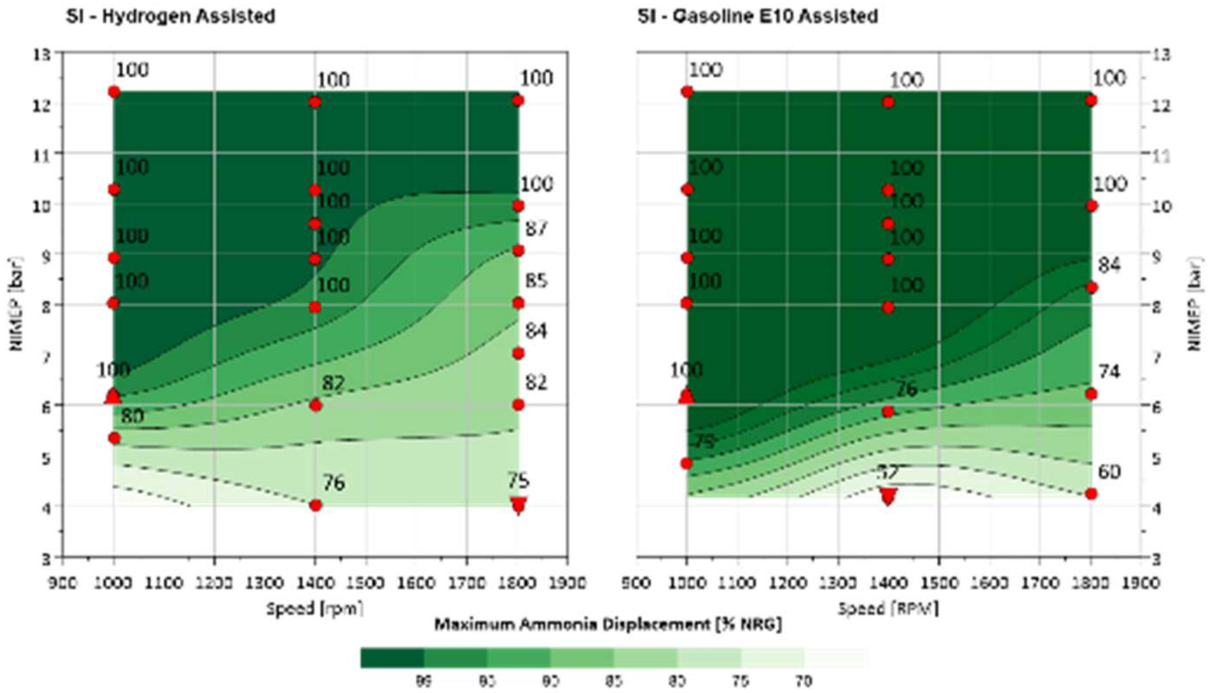
Hydrogen Co-fuelling with Ammonia

- Retrofitted ammonia on a modern Spark Ignition (SI) engine – Baseline mappings of ammonia operations with hydrogen or gasoline as the “supplementary pair” where pure ammonia operations are not viable.



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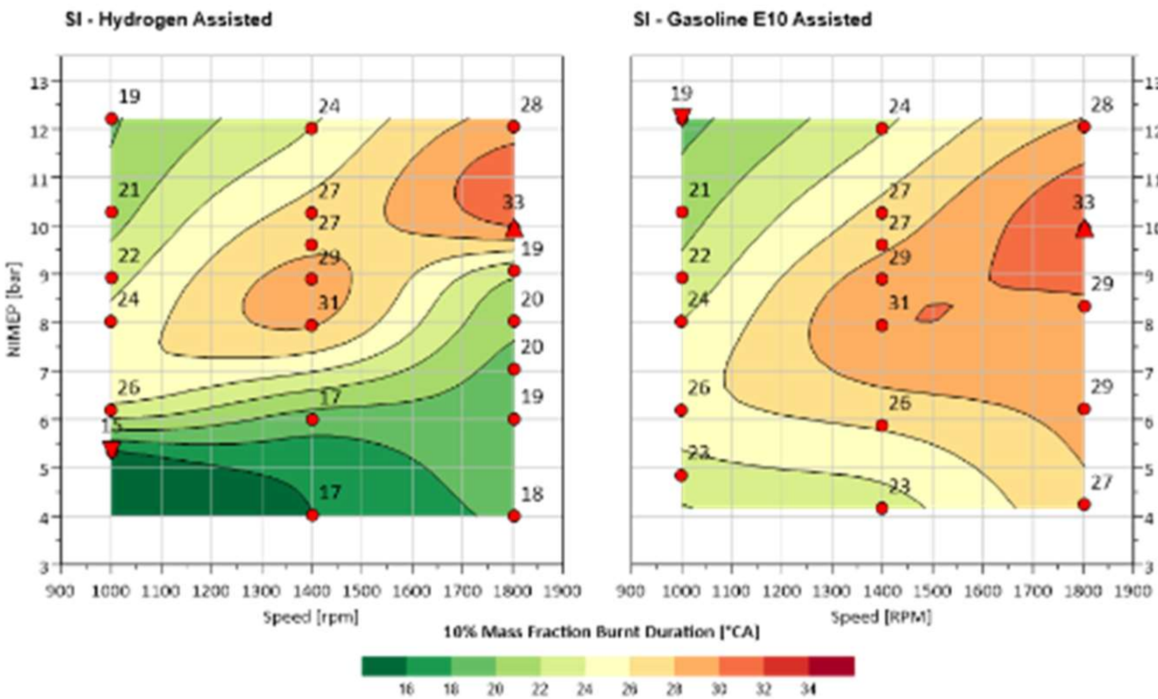
Hydrogen Co-fuelling with Ammonia

Highlights:

1. SI Engine can operate efficiently and stably on pure ammonia – However thermal threshold existed, required enrichment at low loads
2. Current maximum ammonia substitution reached over 50% with gasoline assisted, or improved to **over 75%** with hydrogen assisted
3. Ignition delay period is the key challenge for ammonia combustion
4. Up to **57%** reduction in NOx achieved with H_2 replacing gasoline for co-fuelling



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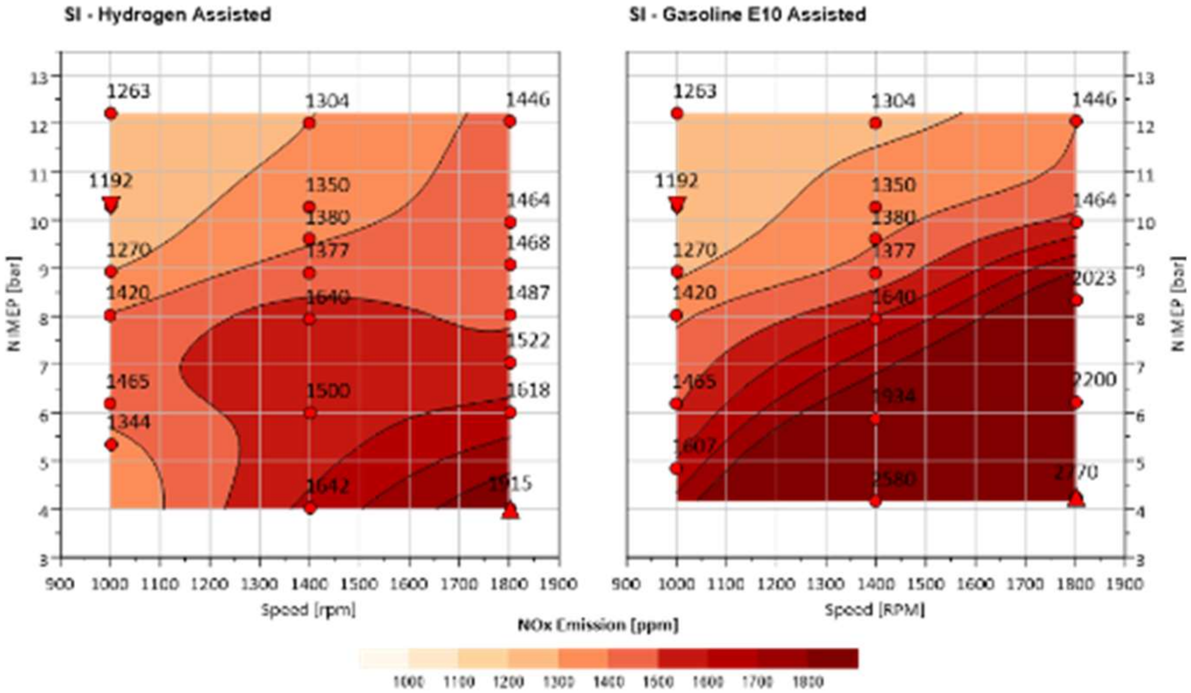

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Hydrogen-Ammonia Substitution Ratio Sweeps

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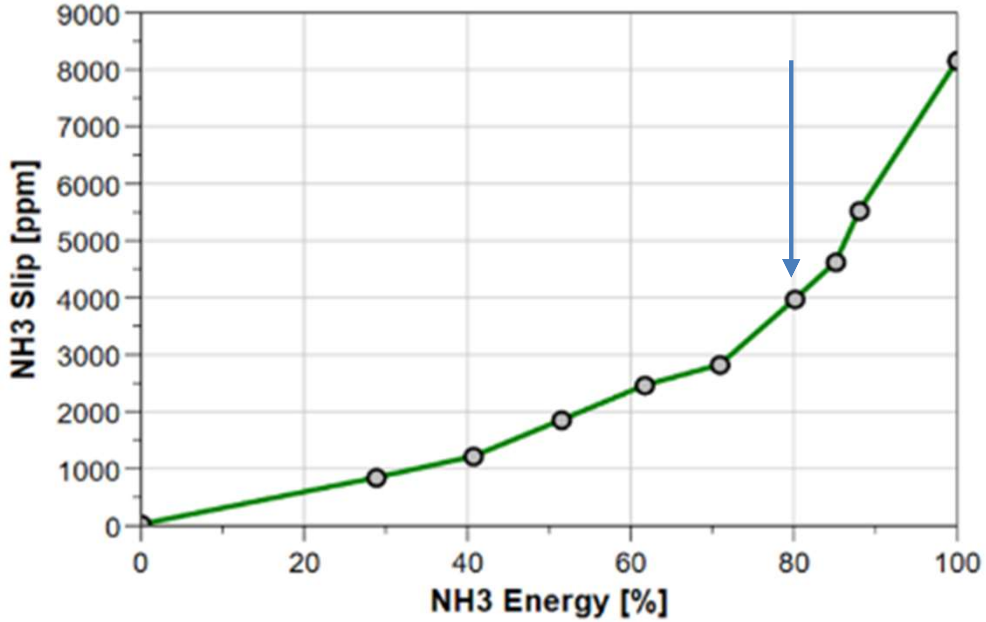
NH_3/H_2 Co-firing (1800rpm/10bar NIMEP)



A small amount of supplementary or cracked hydrogen supports stable combustion and emissions control

- **~20% H_2** leads to **~50%** reduction in NH_3 slip
- Hydrogen operation could be possible for warm-up and very low load operation (using ammonia cracker)

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Preliminary Results with MAHLE Jet Ignition

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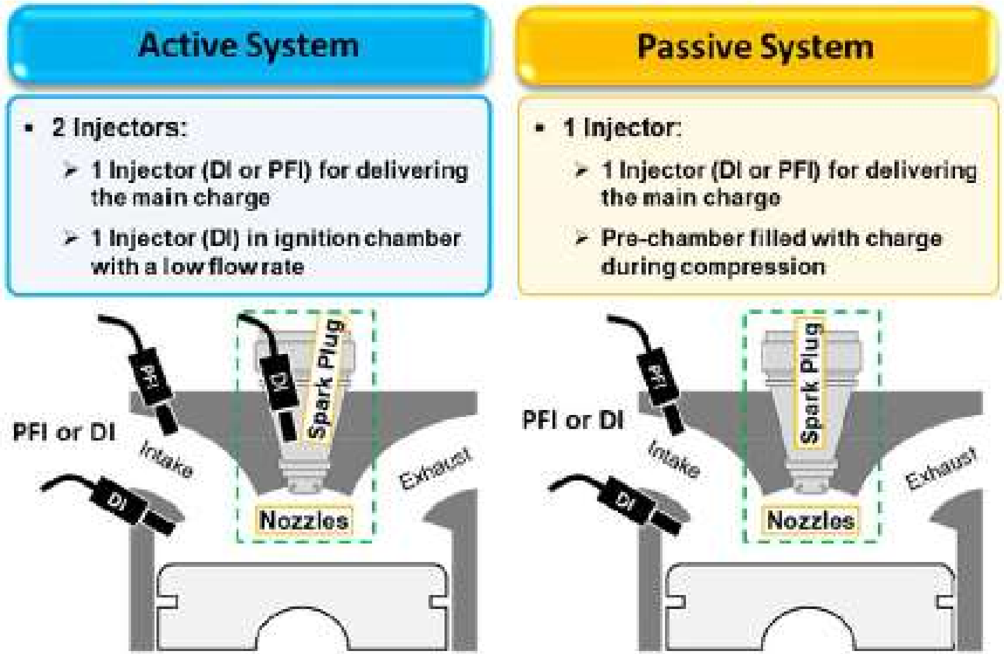
Active MJI with NH_3

- H_2 fuel is injected directly into the pre-chamber, independent to the main-chamber
- Spark-induced highly reactive radical jets from H_2 combustion forced into the main chamber primed with NH_3 mixture
- HAAJI enables distributed ignition sites in the main chamber, resulting faster flame development and propagation



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Preliminary Results with MAHLE Jet Ignition

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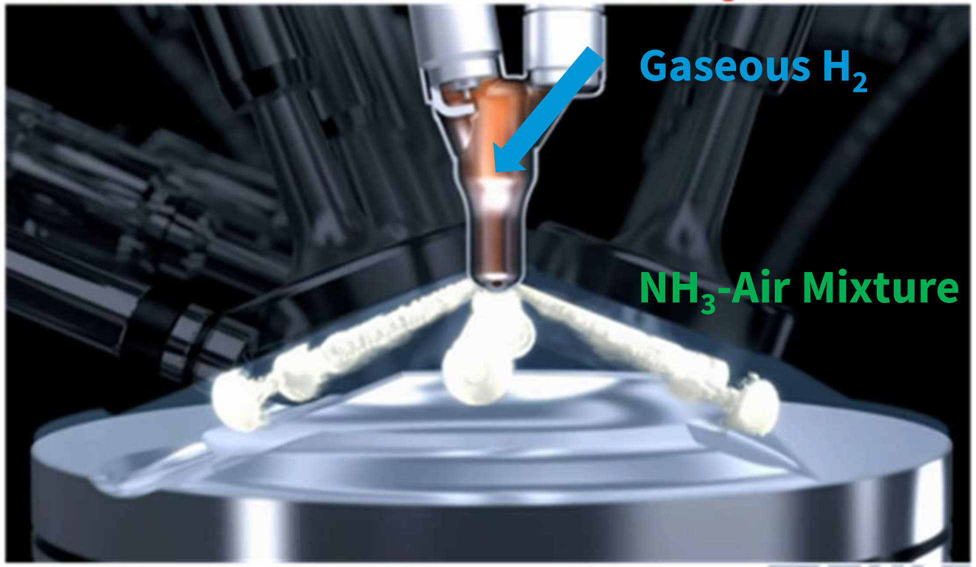
Hydrogen Assisted Ammonia Jet Ignition (HAAJI)

- At part-load conditions, HAAJI has proved to require as minimal as **1%** of H_2 (energy basis) for stable operation
- Initial combustion period shorted by **30%**
- NOx emission reductions of **21%**

Active: + Mini Direct Fuel Injector



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Progress - Advanced Retrofit (UoN) SI

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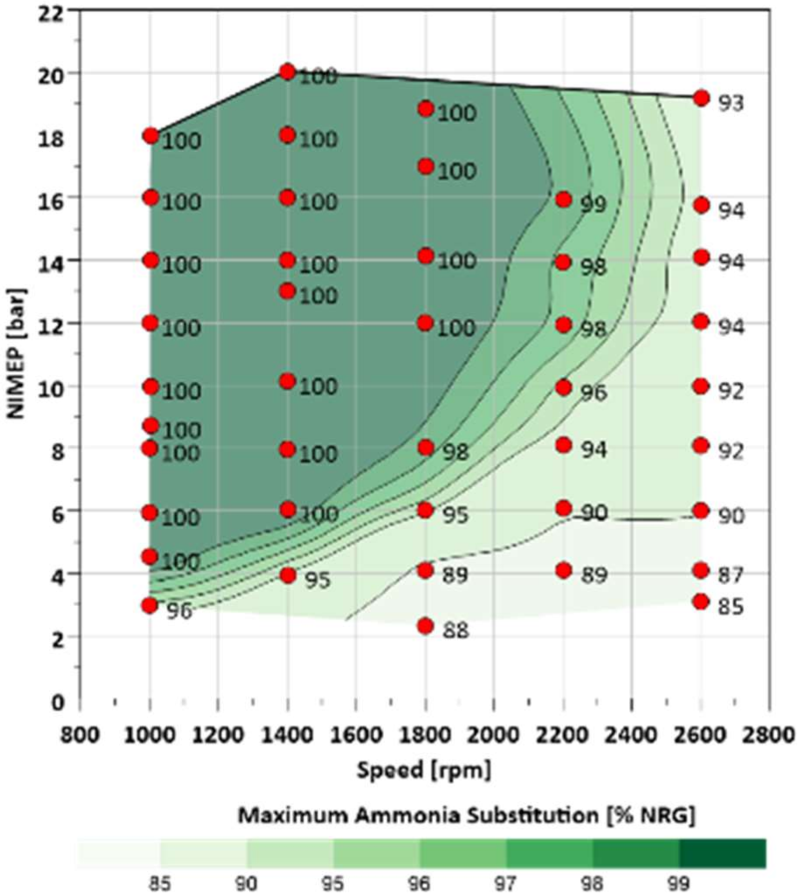
Recent focus on the Single Cylinder Spark-Ignition engine

Two key objectives:

1. **Extending Ammonia SI operating range:**
   Refining the NH_3/H_2 co-fuelling map at stoichiometric conditions (λ=1), to demonstrate the minimum amount of H_2 required for stable combustion across the map

2. **Engine-out Emissions Investigation for After-treatment:**
   Undertaking sweeps of relative air-to-fuel ratio (λ) to understand the impact of varying λ on combustion and pollutant emissions



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NH_3 & H_2 Co-fuelling (λ > 1) in SI mode with Selective Catalytic Reduction After-treatment

$$\alpha = \frac{NH_3}{NOx} \sim 1$$

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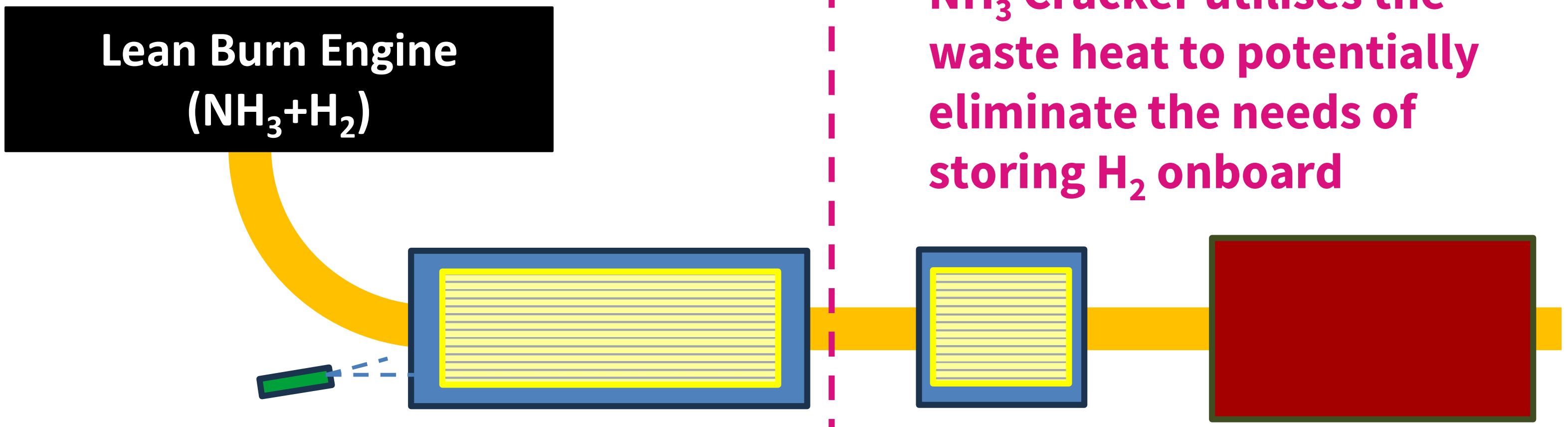
- SCRs operate lean to reduce NOx
- H_2 co-fuelling enables lean engine operation
- NH_3 slip acts as a SCR reductant (eliminating the need for any "AdBlue")

NH_3 Cracker utilises the waste heat to potentially eliminate the needs of storing H_2 onboard



"AdBlue" Injector (replaced with NH_3 injector for finite control)

SCR Catalyst (uses NH_3 to break down NOx into harmless N_2 and O_2)

NH_3 / N_2O Catalyst(s) (oxidises NH_3 and decomposes N_2O)

NH_3 Cracker (returns H_2 + N_2 to the engine)

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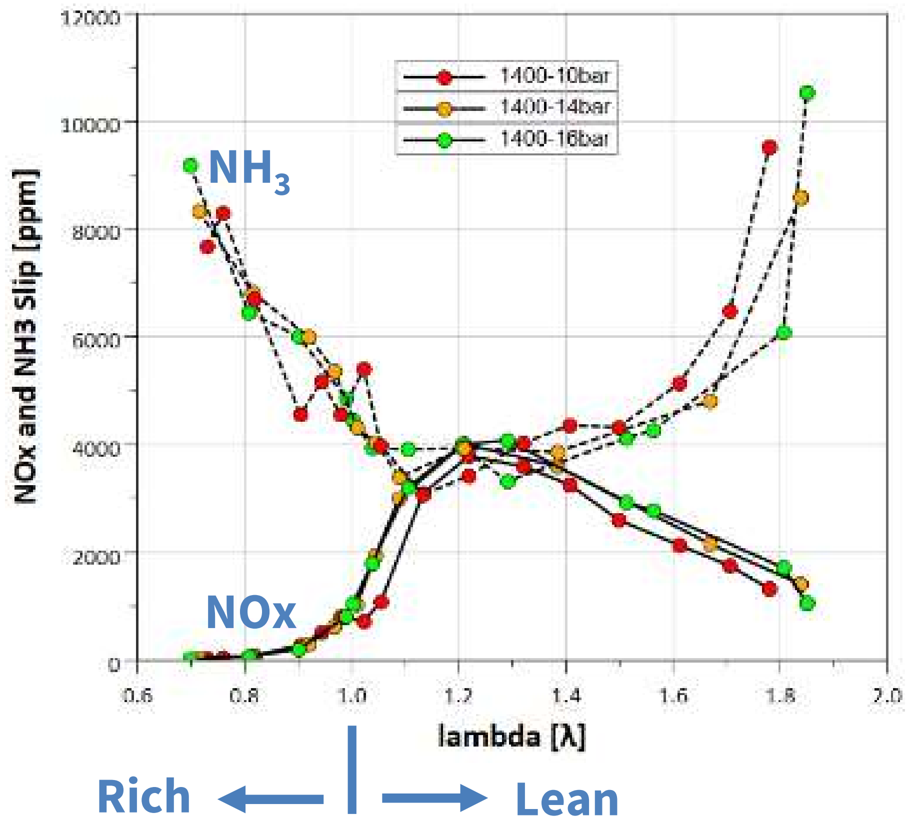
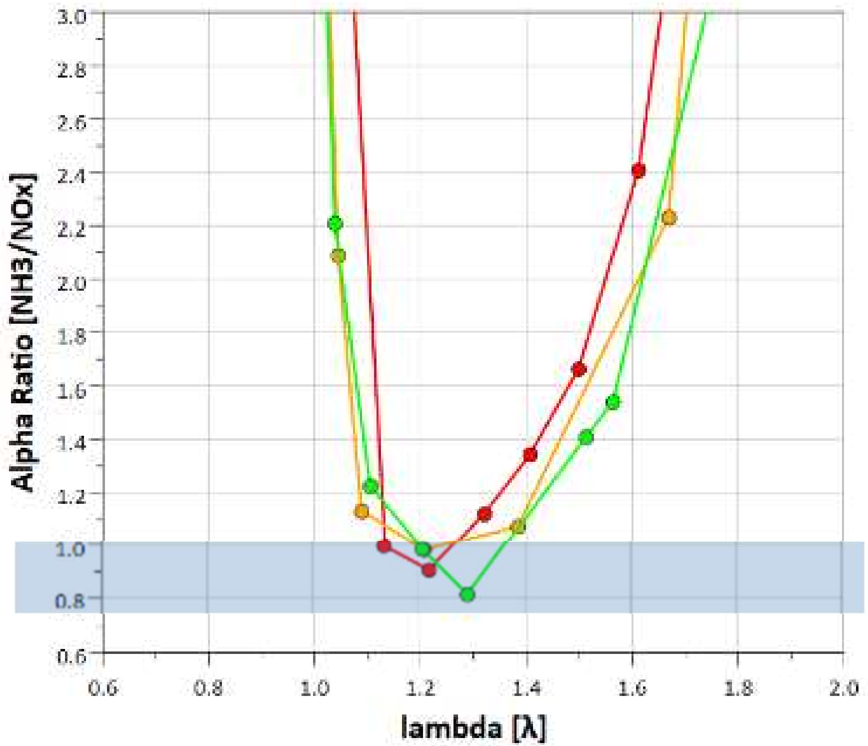
Relative AFR Sweeps at 1400rpm with ~20% H_2





- Ideal λ ratio can be achieved when lean but also needs H_2
- The minimum H_2 map with Alpha $\alpha = 1$ at lean condition, $\lambda = 1.2$, has been mapped across the full speed-load map 1000~3000rpm, 20bar NIMEP
- This is use one of several measures to be investigated to help deal with engine-out emissions

Effect of H_2 Addition to NH_3 and NOx Emission Balance

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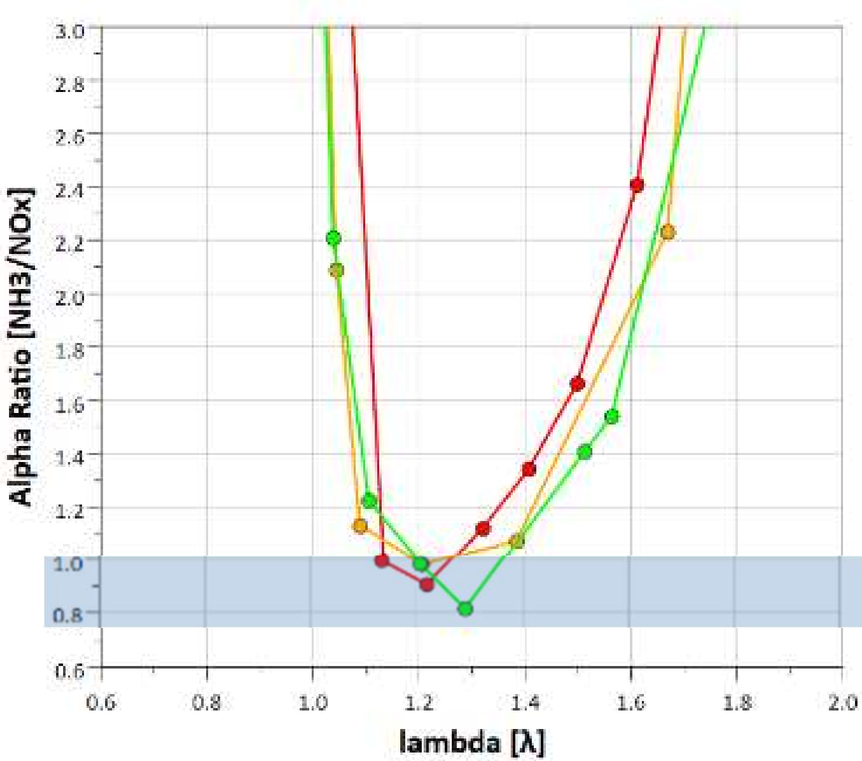
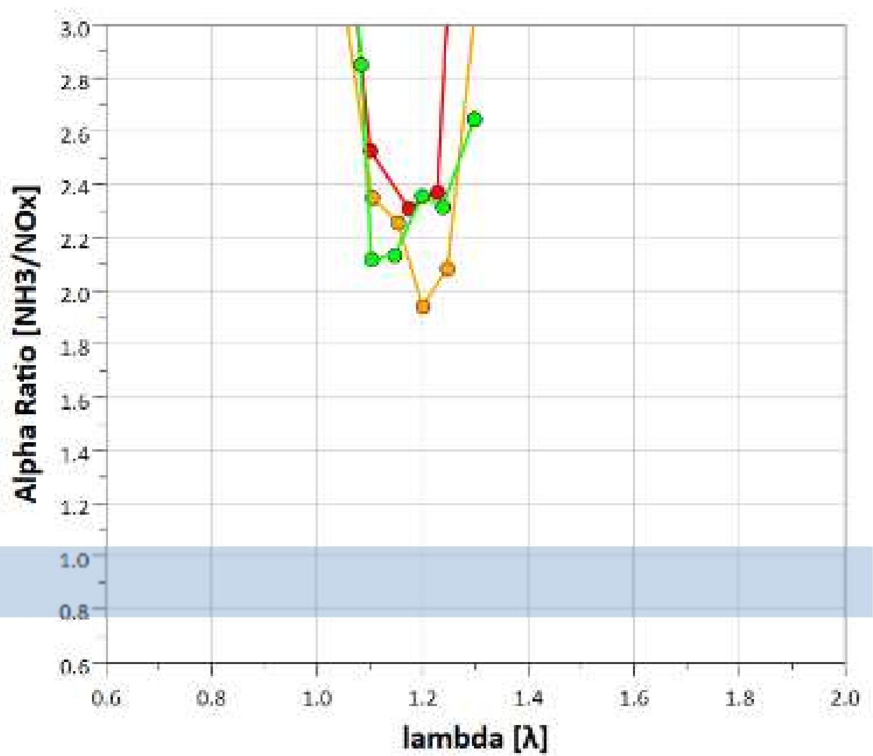
20% H_2



0% H_2



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N_2O Emissions Vs Relative AFR (20% H_2)

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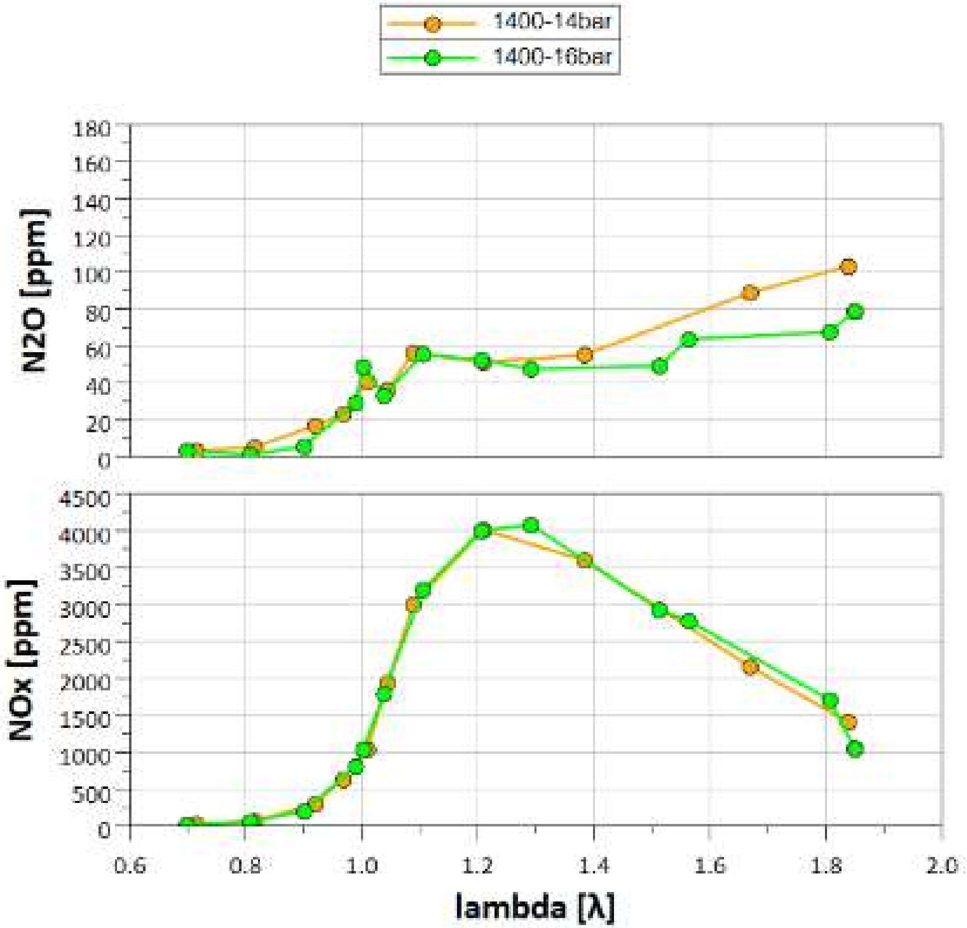

- The Global Warming Potential (GWP) of Nitrous Oxide (N_2O) is 273 times of CO_2 (100-year timescale)
- Engine out N_2O emissions remain relatively flat between λ =1 and 1.4
- Shallow increase when pushing out to ultra lean

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H, OH & O Pathways for Complete Oxidation

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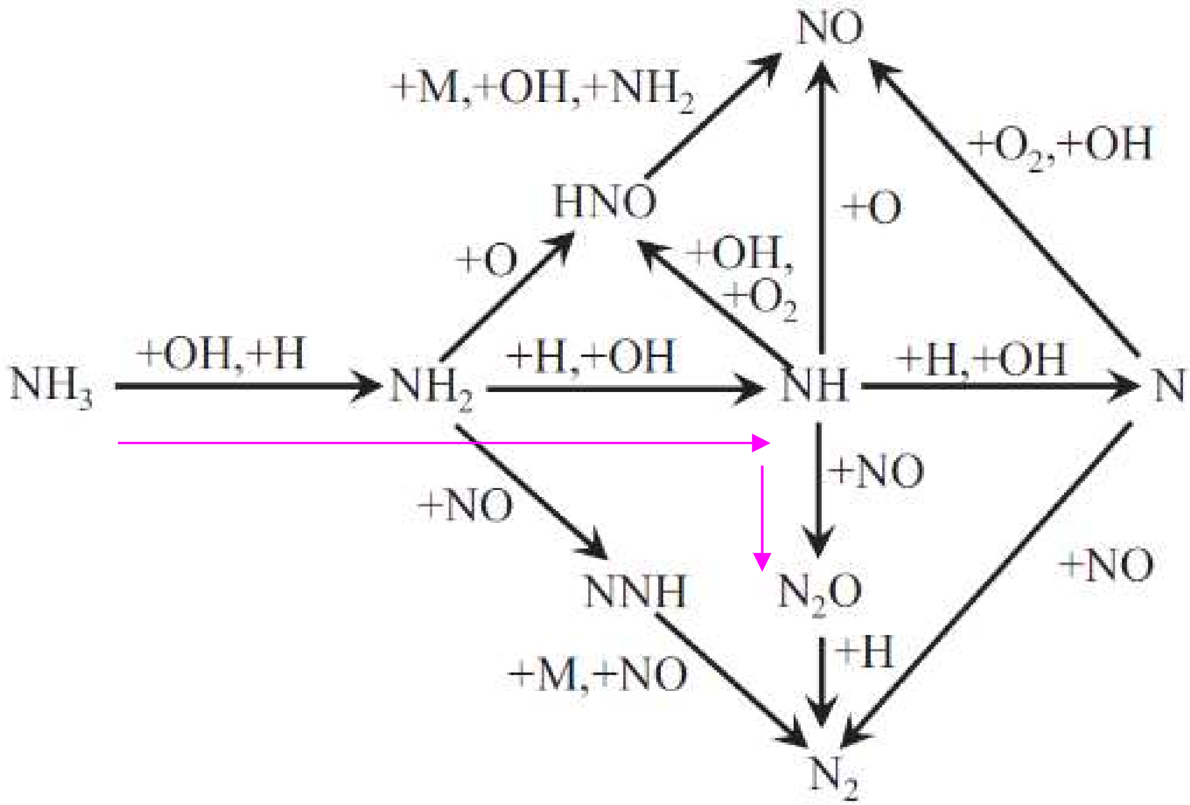
- The figure shows key NH_3 oxidation pathways (ref Miller et al.)
- Chemical modelling required, based around this engine and conditions



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Summary and Future Work

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Summary

- Ammonia ICE is a feasible solution, best suited to the marine sector
- Pure ammonia combustion is possible, with the help of advanced positive ignition technology and cracked hydrogen as a cost-effective onboard fuel storage solution
- Initial SCR investigation showed promising results for effective emission after-treatment

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Summary and Future Work

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Next Steps

Single Cylinder:

- Continue AFC Ammonia Cracker research
- Continue active Jet Ignition HAAJI mapping (full speed-load maps)
- Further NH_3 combustion optimisation at slightly lean conditions

Dual Fuel:

- New fuel rig being designed to enable liquid and/or gaseous NH_3 injection up to 500kW equivalent
- NH_3 + H_2 speed-load mapping

New MW Hybrid Propulsion Testing Facility:

- True-scale Single-Cylinder thermodynamic engine (TITANZ) for demonstration of ammonia-hydrogen fuelled high-power retrofit

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