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

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MariNH3
Clean, green ammonia engines for maritime

University of Nottingham
UK | CHINA | MALAYSIA

Introduction

Ammonia and hydrogen are explored as potentially carbon-free co-fuels for spark ignition (SI) engines to offer efficient and clean combustion, especially for the shipping industry.

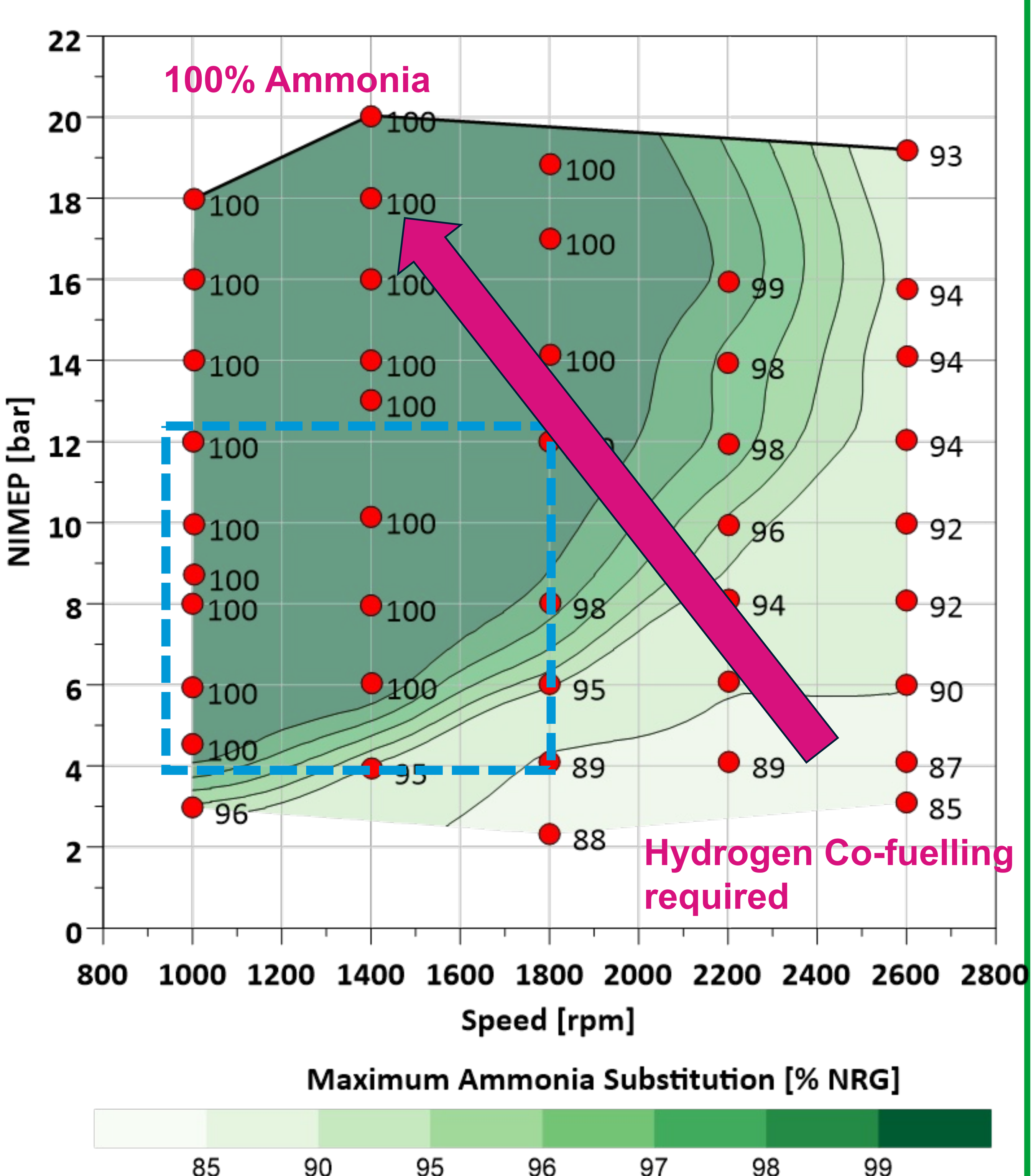
The objective is to retrofit ammonia into a modern SI engine and determine the optimal hydrogen co-fuelling conditions for stable operations whilst achieving map-wide emission profiles of NOx and NH_3 slips that can be addressed by Selective Catalytic Reduction after-treatment system.

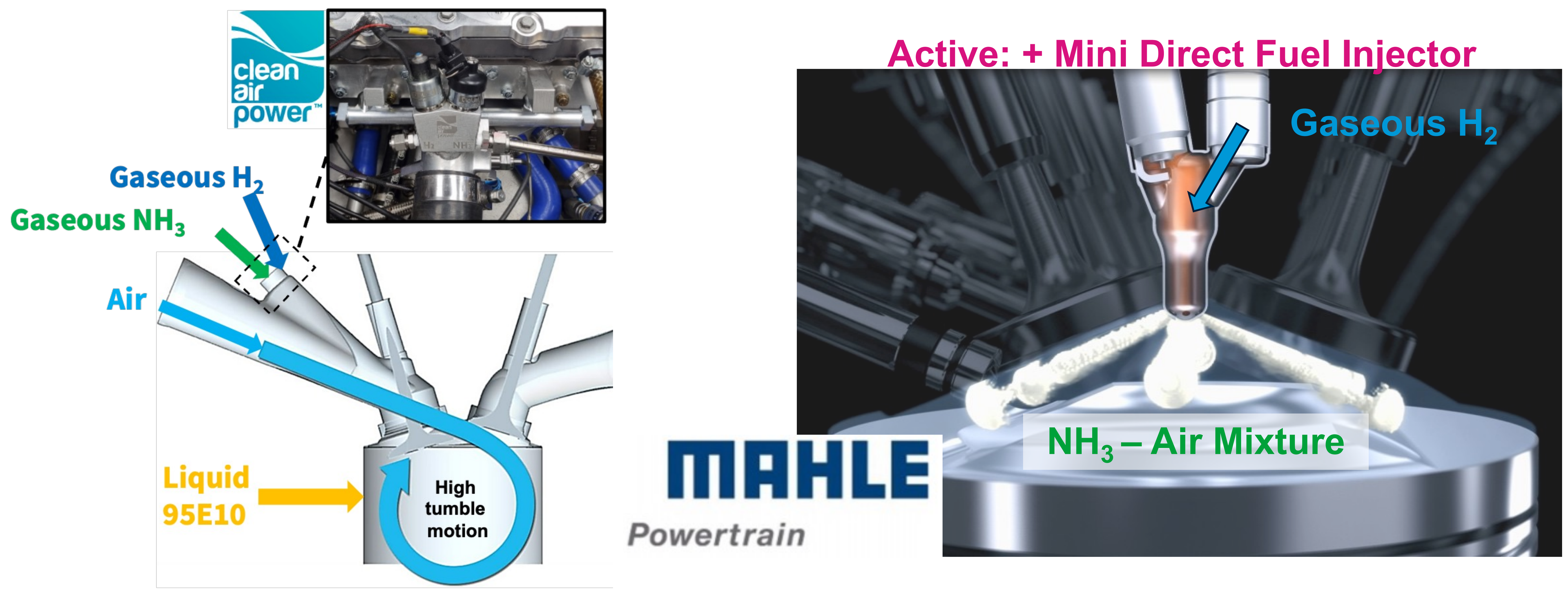
Key Results

Hydrogen Co-fuelling with Ammonia:

Nottingham has achieved their First carbon-free operation of its Spark Ignition engine with ammonia and hydrogen. Results show significant improvements in stability and emission profiles for ammonia combustion with the compensating fuel of hydrogen compared to gasoline.

- Extended stable operation map with pure ammonia but required enrichment amount at low loads - Thermal limit existed, threshold load eased with speed drops
- Reached higher maximum ammonia substitution with hydrogen assisted combustion (**~50%** less promoter fuel required at identical speed load conditions of gasoline at low loads)
- **57%** reduction in NOx achieved with H_2 replacing gasoline
- **20%** H_2 can led to **~50%** reduction in NH3 slip (1800rpm, 10bar NIMEP)

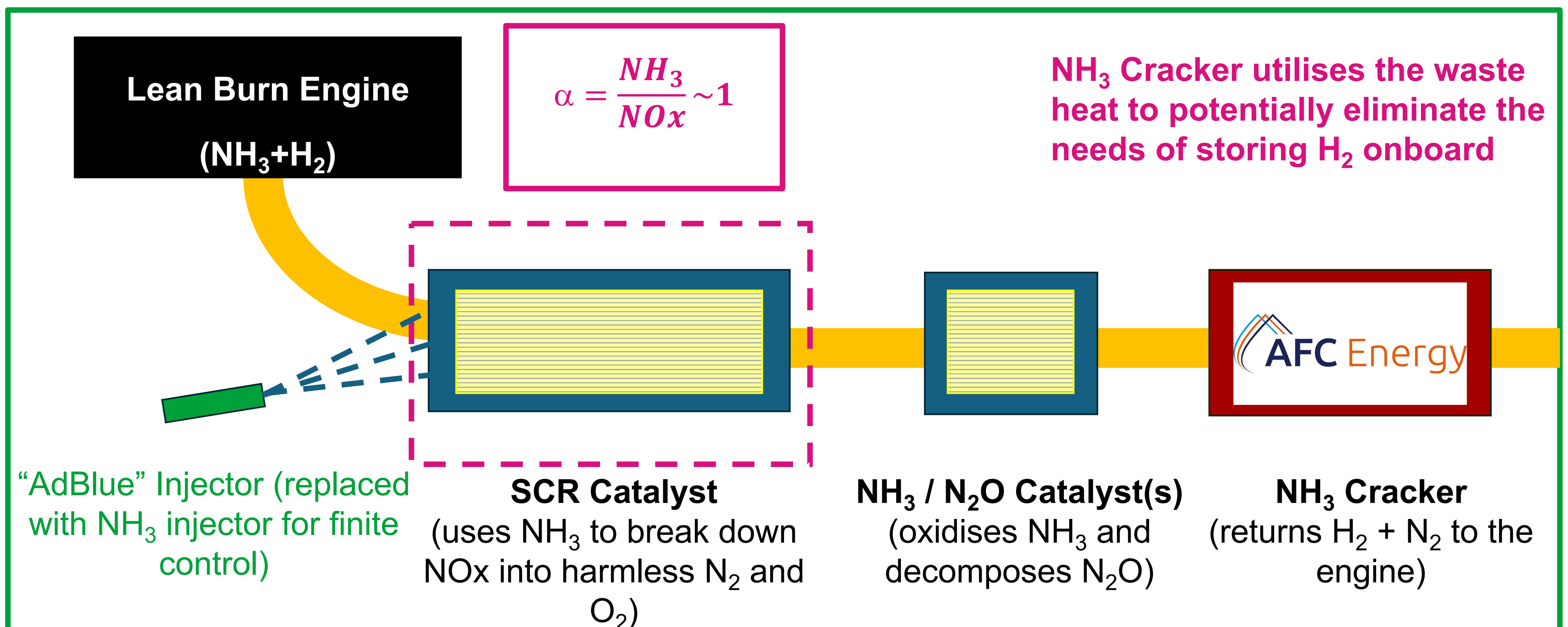




Hydrogen Assisted Ammonia Jet Ignition (HAAJI):

The MAHLE Active Jet Ignition system with fully decoupled hydrogen auxiliary fuelling in the pre-chamber was commissioned. With hydrogen, Active MJI can improve the slow flame propagation of ammonia combustion, unleashing more potential of the carbon-neutral fuel.

- H_2 fuel is injected directly into the pre-chamber, with spark-induced highly reactive radical jets (e.g. O, H, OH) igniting the NH_3 mixture at multiple ignition sites
- Required as little as **1%** H_2 for stable operation
- **~30%** reduction in the initial combustion period
- **~21%** reduction in NOx emissions with comparable efficiency



Emissions Investigation for After-treatment and Onboard NH_3 Cracker Feasibility Study

Initial results of emissions profile characterisation with parameter optimisations (substitution levels, air-to-fuel ratios, and spark timings etc.) demonstrated, at lean conditions, ammonia operations with low levels of H_2 have the potential to achieve near-zero tailpipe NOx and ammonia emissions.

- H_2 co-fuelling enables lean engine operation, with significant (~50%) reduction in unburnt ammonia emissions to balance the ratio for after-treatment (potentially <10ppm)
- SCRs operate lean to break down NOx
- NH_3 slip acts as an SCR reductant for (eliminating the need for any "AdBlue")

Electric NH_3 cracker from AFC Energy has demonstrated the capability of replacing the required amount of H_2 for lean-burn conditions as above (under an optimal Alpha ratio of ~1)

- Hydrogen could be used for warm-up and low-load operation with ammonia cracker.

Conclusion & Future Work

- 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
- Preliminary results successfully demonstrate the onboard electric Ammonia Cracker replacing supplementary hydrogen,
- Hydrogen Assisted Ammonia Jet Ignition will need to be mapped to explore the extended operating limits to hopefully control the hydrogen enrichment to its minimum quantity under lean conditions

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