MariNH3

Clean, green ammonia
engines for maritime

Operation of a Modern SI Engine on Ammonia with E10 and H_2 Co-fuelling

28th June 2023

The partnership

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UKRI Science and Technology Facilities Council

University of Birmingham

University of Brighton

Cardiff University Prifysgol Caerdydd

Funded by

UKRI Engineering and Physical Sciences Research Council

Timeline

Engine Hardware

Test Results

Future Work

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July,22
First test in NH_3

Aug,22
Engine cylinder head swap + CAP injectors

Oct,22
Tests with CAP injectors 100% NH_3 operation

Nov,22
Engine upgrade, New piston & cams

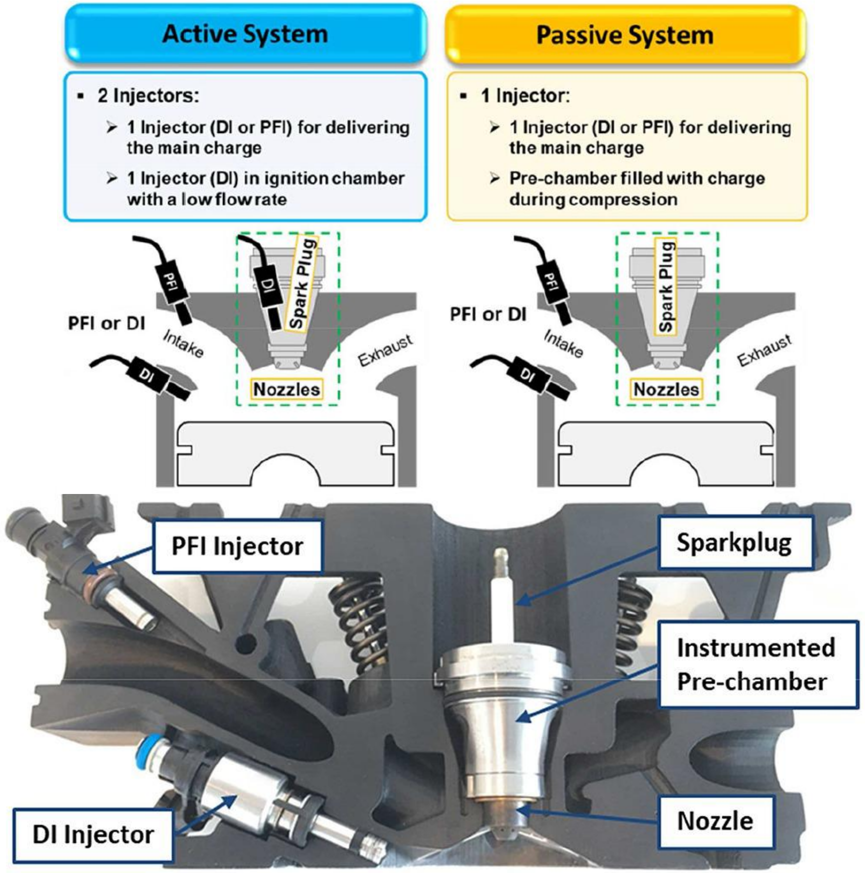
Dec,22
Mapping engine with E10+NH_3 co-fuelling

Jan & Feb,23
First Tests with NH_3+H_2

Apr,23
Mapping engine with H_2+NH_3 co-fuelling

Engine Hardware

Parameters	Value
Engine Type	Four Stroke Single Cylinder
Displaced Volume	400 cc
Stroke	83 mm
Bore	73.9 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
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



Results: Max Substitution Energy Fraction

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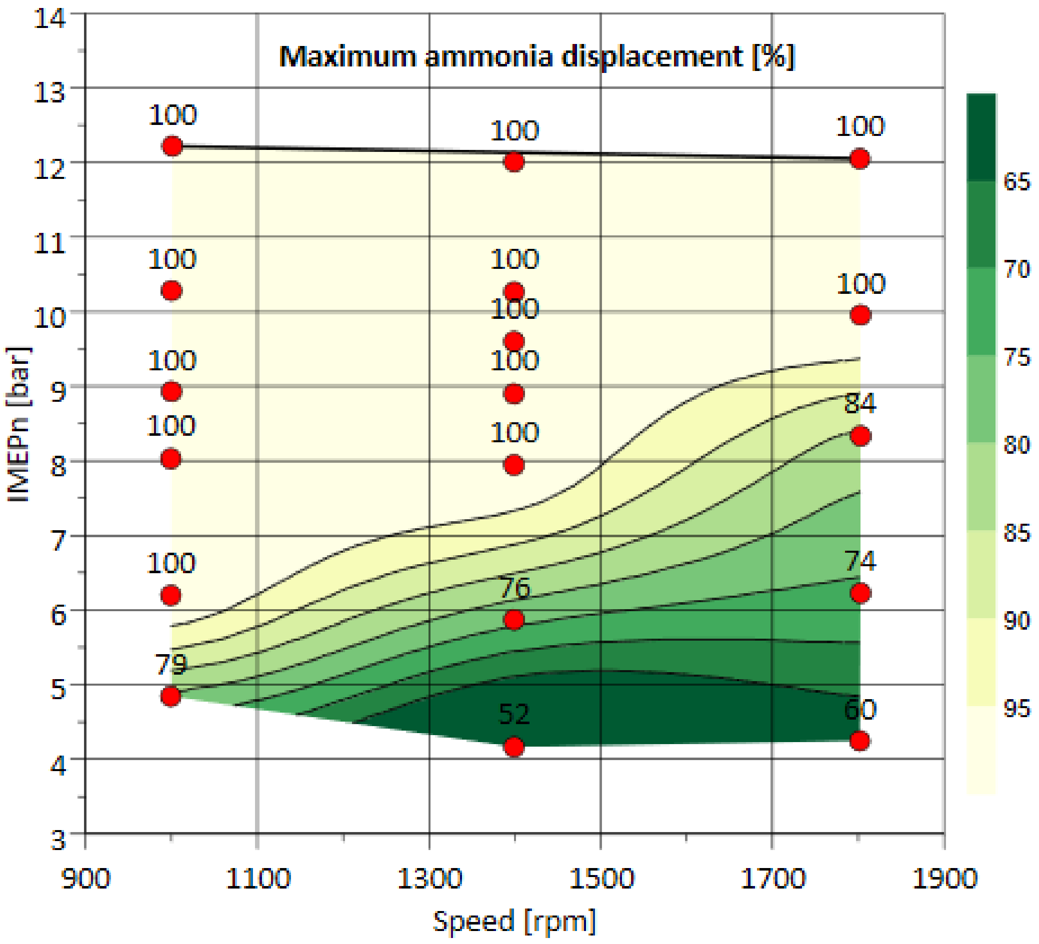
Test Conditions

Settings	Values
Operating Temperature (Coolant & Oil)	95 ^{0}C
Spark Timing	Maximum Brake Torque [MBT]
Air-fuel Equivalence ratio [λ]	1
E10 Injection Start angle	310 CAD BTDCf
Ammonia Injection End angle	400 CAD BTDCf
Inlet air temperature	45^{0}C
Ammonia rail pressure	3-5 barG
Ammonia Feed Temperature	27 ^{0}C -30 ^{0}C

In a fully warmed up state:

- Engine can operate efficiently on pure ammonia at low to moderate loads
- Threshold engine load, reduces with speed from 10bar at 1800rpm to 6bar at 1000rpm
- Stable operation below threshold load requires co-fuelling with E10
- Maximum substitution over 50% is possible for load above 4 bar IMEPn



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Results

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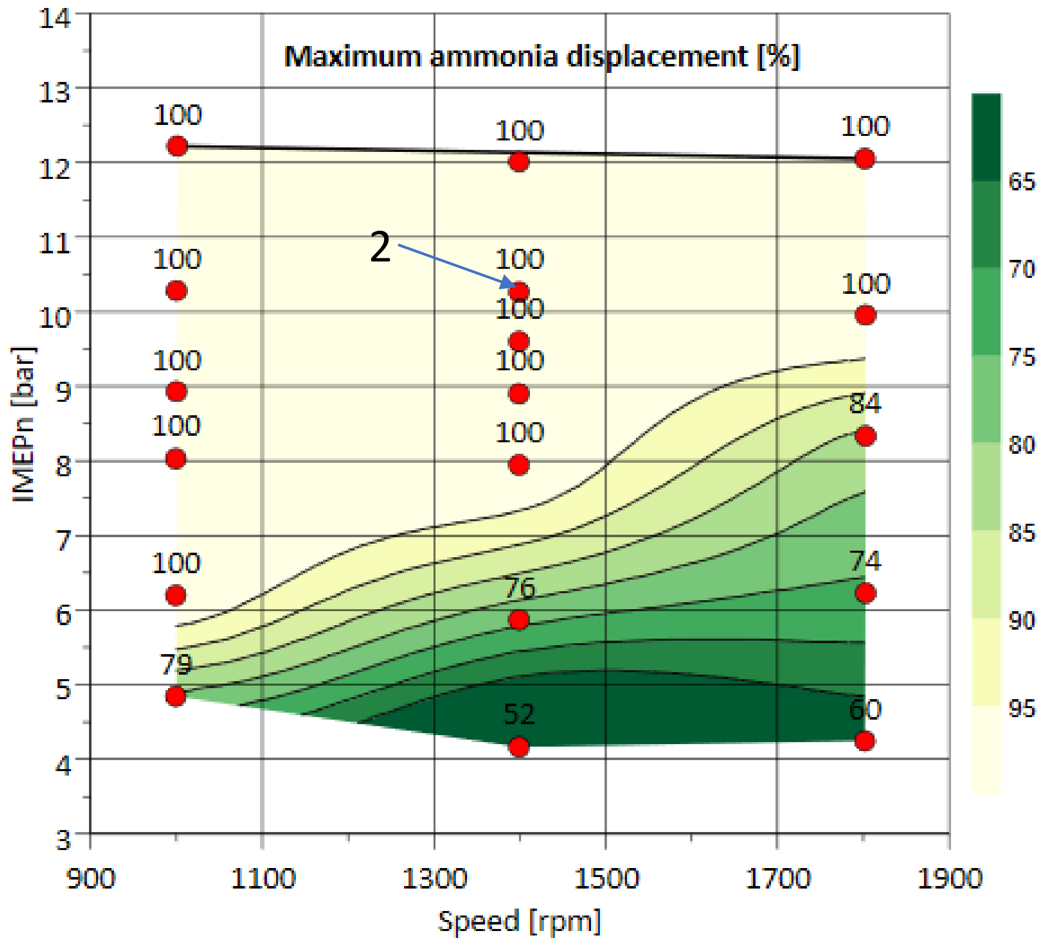
1 General Trends Of Pure NH_3 Operation in a SI Engine

2 E10-NH_3 Co-Fuelling at 100% point (10 bar IMEPn-1400 rpm)

3 H_2 Vs E10 Substitution maps



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Results: Trends Of Pure NH_3 Operation

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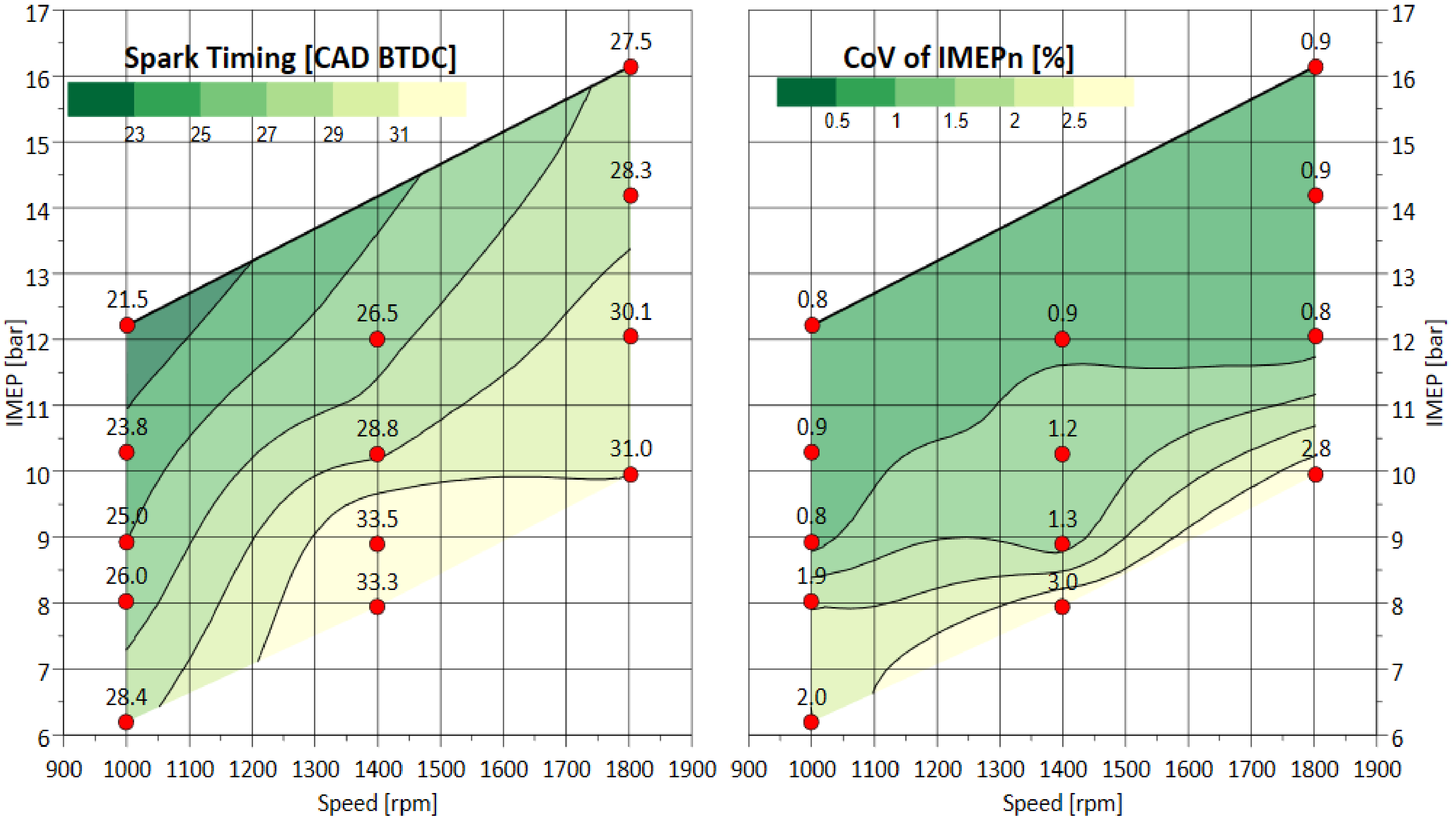
λ=1; MBT; Engine Operating Temperature = 95⁰C

Moving away from the threshold load line:

- Improves the stability and spark timing
- Stable operation can be achieved above 4bar IMEPn
- Spark timing for MBT improves with increase in Load



Lower value is better

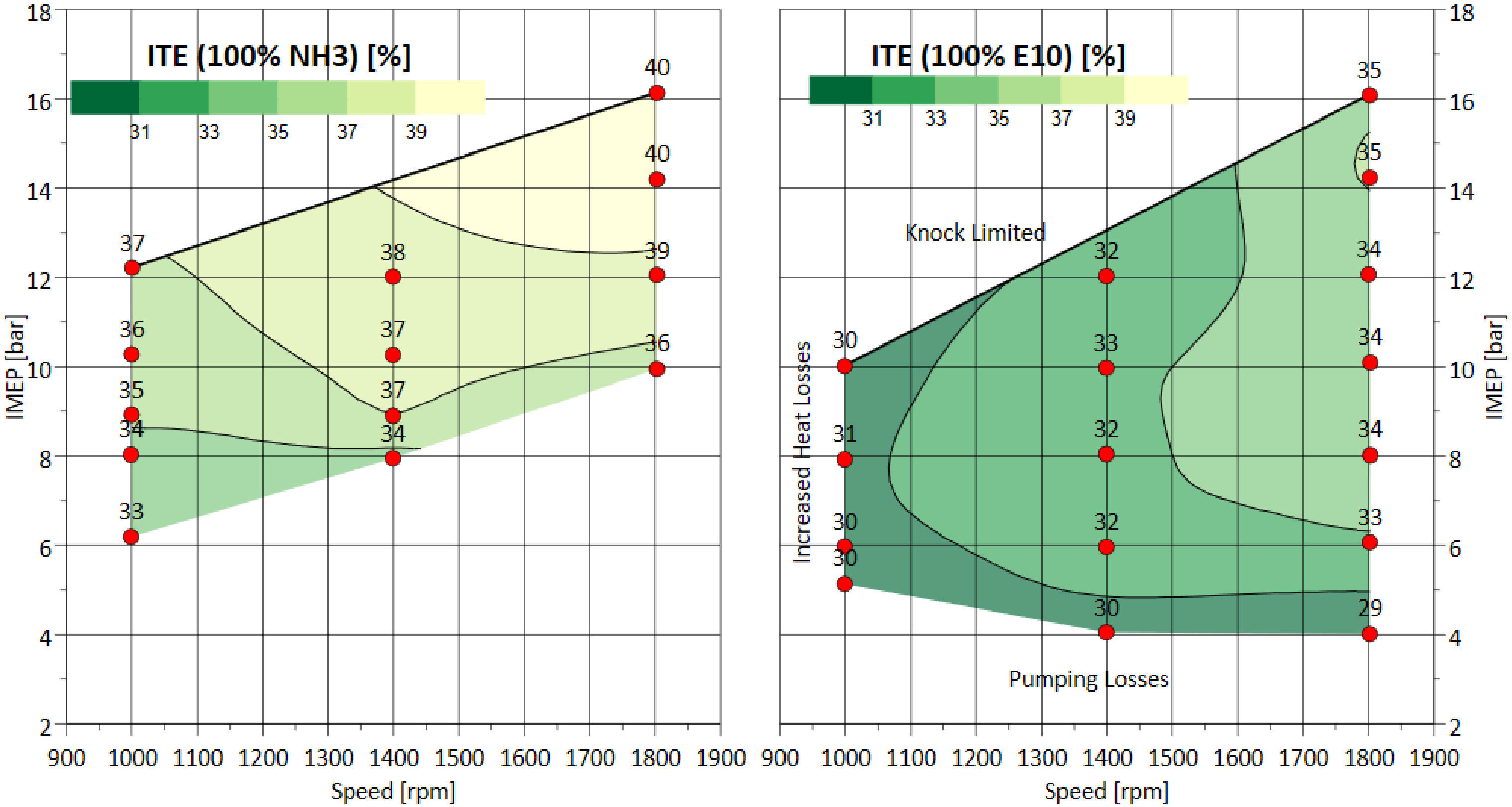
Results: Trends Of Pure NH_3 Operation

λ=1; MBT (Knock limited for E10); Engine Operating Temperature = 95 ⁰C

Indicated Thermal Efficiency

- 5% higher for ammonia at stable operating conditions (CoV <1%)
- Aided by favourable anti-knock characteristics
- Maximum ITE achieved 40% at 1800rpm/16 bar IMEPn
- Lower heat losses compared to E10

Indicated Thermal Efficiency



Higher value is better

Results: Trends Of Pure NH_3 Operation

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λ=1; MBT; Engine Operating Temperature = 95^0C

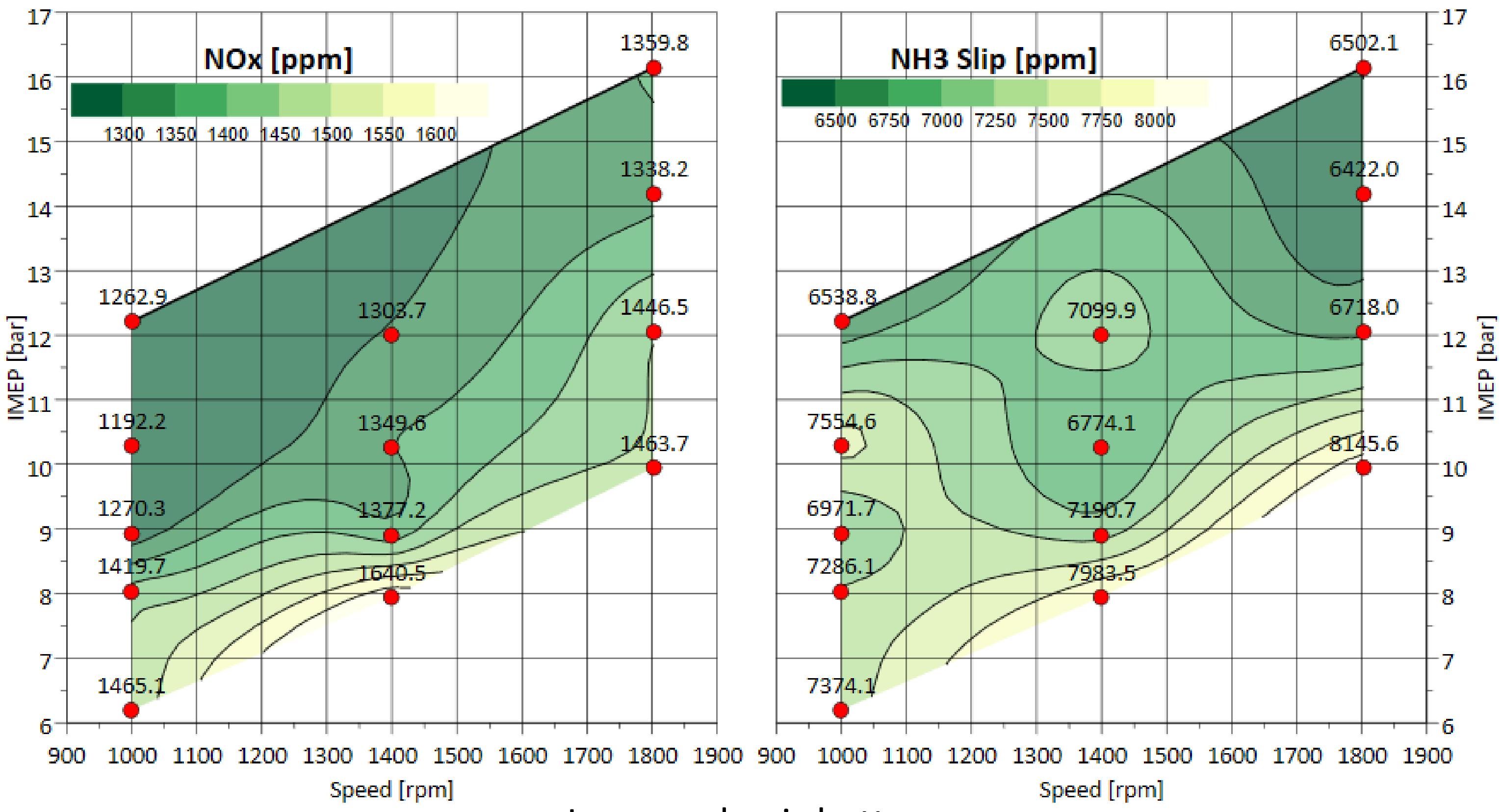
NOx

- Remains relatively same in the mapped region (within 500ppm)
- 60% reduction compared to pure E10 operation

NH_3 Slip

- Peaks near the threshold load and reduces moving away from the load point
- Remains high in stable operating region.
- Similar values are also reported various other studies

Emissions



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Results: E10- NH_3 Co-Fuelling

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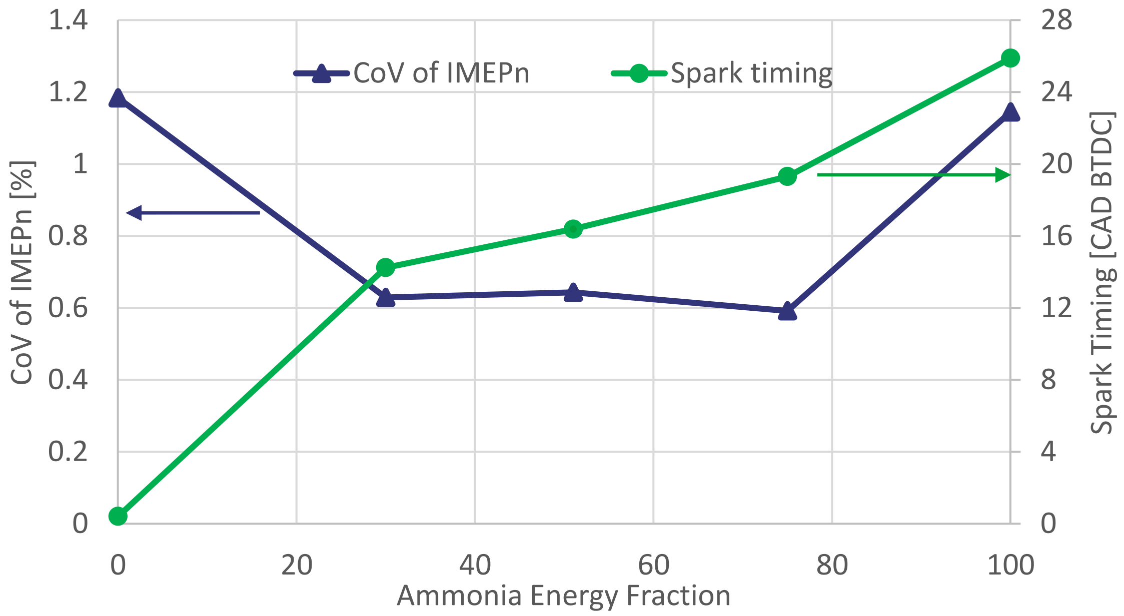
1400rpm/10bar IMEPn; λ=1; MBT; 37 CAD Valve overlap; Operating temperature 95^{0}C

Addition of E10

- Improves the stability significantly
- Reduces the spark timing by 5 CAD for 25% substitution by energy
- Further addition has reducing impact on spark timing and negligible impact on stability



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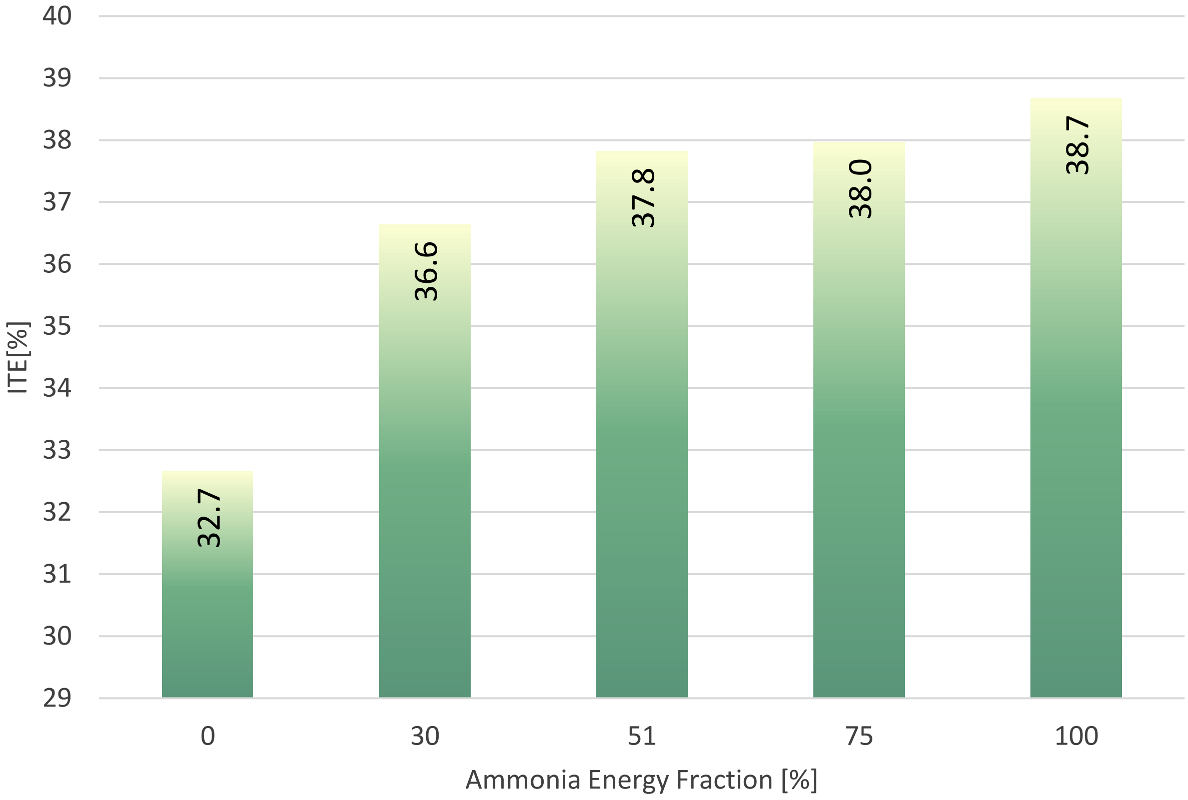
Results: E10- NH_3 Co-Fuelling

1400rpm/10bar IMEPn; λ=1; MBT; 37 CAD Valve overlap; Operating temperature 95^{0}C

Indicated Thermal Efficiency

- Improved combustion does not translate to improved efficiency
- Efficiency reduces by 1% with addition of E10
- With further decrease observed with increase in E10 substitution



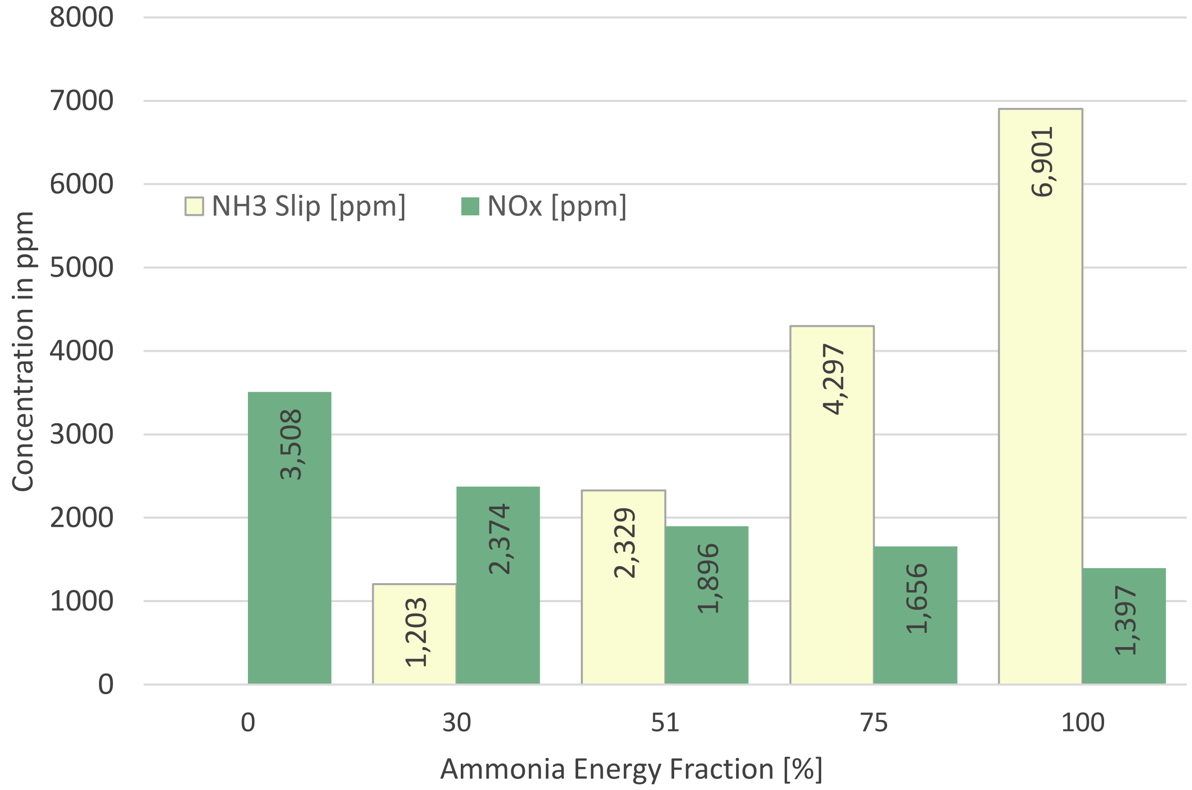
Higher value is better

Results: E10-NH_3 Co-Fuelling

1400rpm/10bar IMEPn; λ=1; MBT; 37 CAD Valve overlap; fully warmed up state

Emissions

- Ammonia slip improves considerably with E10 substitution
  - Partially due to less ammonia being injected
  - Higher in-cylinder temperatures leading to improved combustion
- NOx increases with E10 addition
- Reduction in ammonia slip is nearly 10 times compared to increase in NOx emissions



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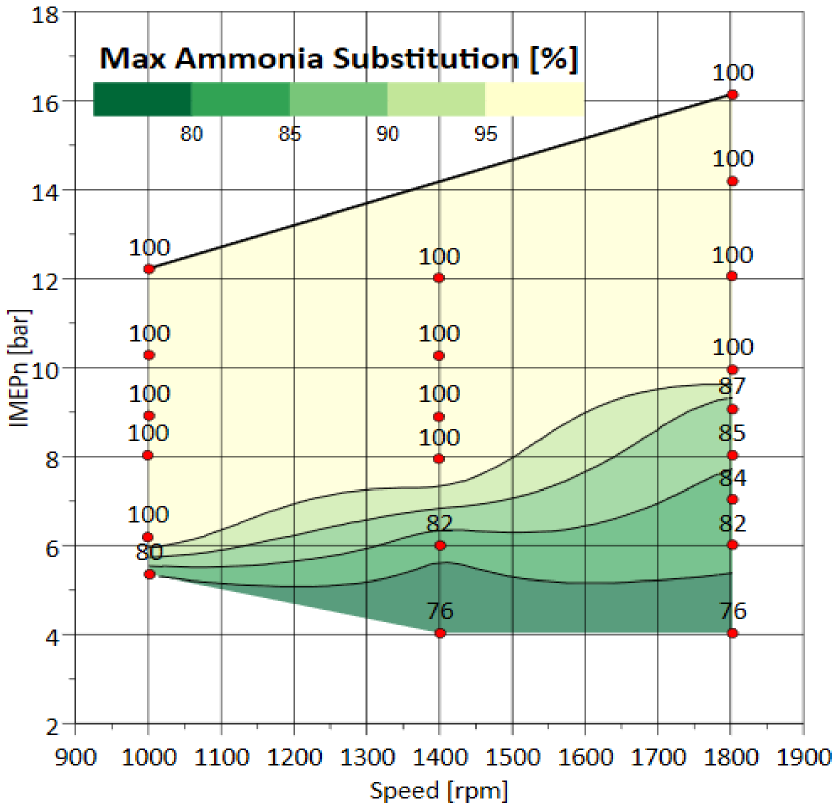
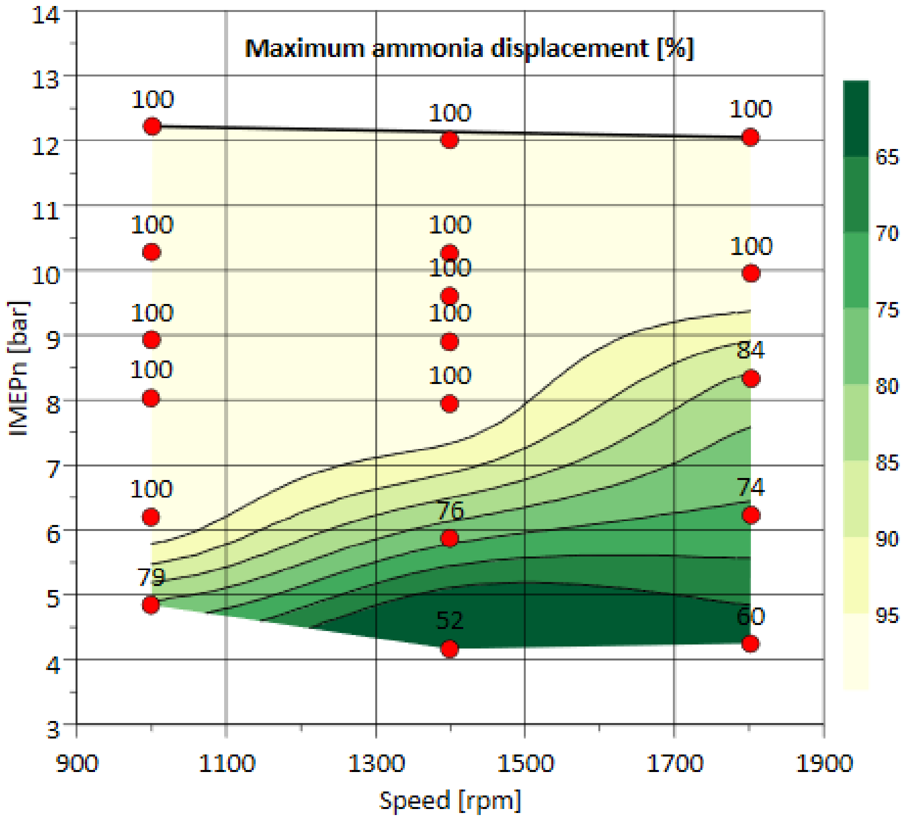
Results: H_2-NH_3 Co-fuelling

1800rpm/10bar IMEPn; λ=1; MBT; Engine Operating temperature 95⁰C

- **Performed better than expected**
  - Required flowrate lower than what can be achieved by injectors in the market
- Maximum substitution over 75% is possible for load above 4 bar IMEPn (50% improvement over E10)





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Future Work

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Planned Hardware/Test Cell Improvements

- Long stroke upgrade for the engine
- Increase in Compression Ratio from 12 to 16
- Two new emission analysers (FTIR & Species Specific) capable of measuring NO, NO_2,N_2O & H_2 Slip
- Improvements to Ammonia fuel system for winter operation

Test Plans

- Hydrogen enrichment Studies with small flow injector
- Hydrogen Assisted Jet Ignition (HAJI) of ammonia.
- Tests comparing SI, Passive JI and Active JI (Hydrogen) at higher compression ratios

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Thank you for your time

Any Questions?

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