MariNH3

Clean, green ammonia
engines for maritime

Crack, Burn, Compare: Evaluating Electric and Thermal Recuperated Ammonia Crackers in SI Engines

Sponsored by: CIMAC INTERNATIONAL COUNCIL Power | Drives | Propulsion

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Recap

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RECAP: Work up to last year

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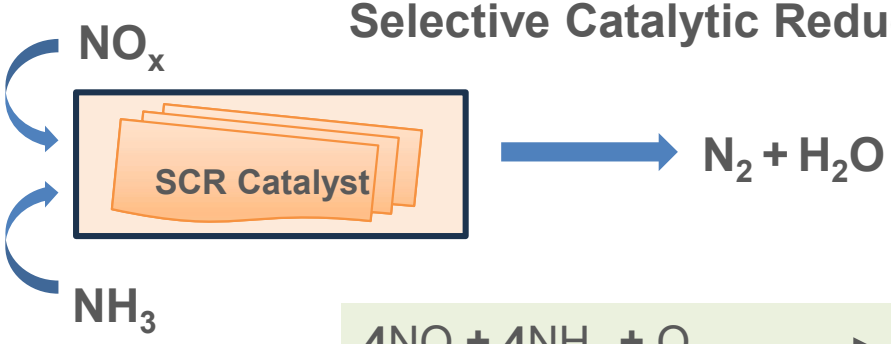
- Bottled Gas testing revealed that slightly lean AFR (**λ=1.2)** with 20% H_2 is required for Alpha =1 Operation

(Ideal zone for SCR operation)

Selective Catalytic Reduction (SCR)



λ :- Air to Fuel Ratio (AFR)

Alpha = NH_3/NO_x

$$4NO + 4NH_3 + O_2 \longrightarrow 4N_2 + 6H_2O$$
$$NO + NO_2 + 2NH_3 \longrightarrow N_2 + 3H_2O$$
$$NO_2 + 8NH_3 \longrightarrow 7N_2 + 12H_2O$$

Basu, P. (2013)

- Bottled gas testing demonstrated that nitrogen returning from the cracker can be more easily tolerated than anticipated.

$$NH_3 \xrightarrow{\text{cracker}} H_2 + N_2$$

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Objectives

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1. How different does a Spark Ignition (SI) engine operate with cracked gas?

   :- Comparison of Bottled vs Cracked Gas Tests

2. How much of the total energy required for cracking can be taken out of the exhaust gas?

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Spark Ignition NH_3+ H_2 Co-firing:
What we completed

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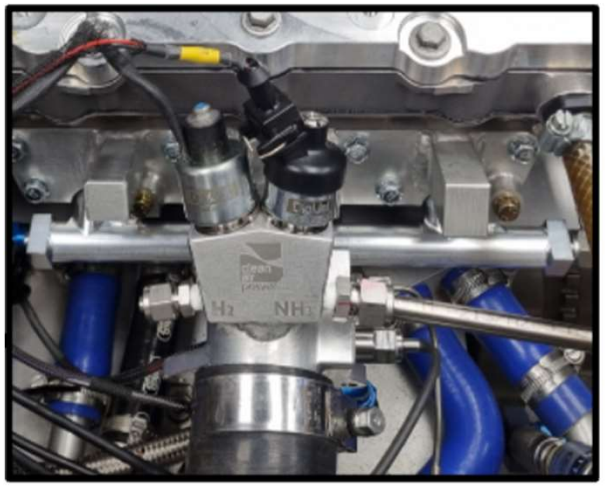
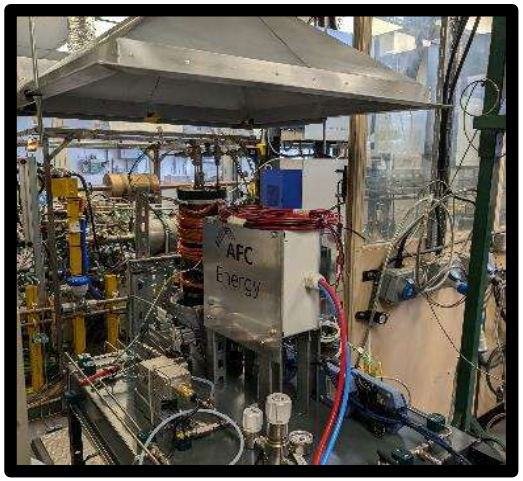
1

- NH_3 + H_2 co-firing
- Bottled H_2



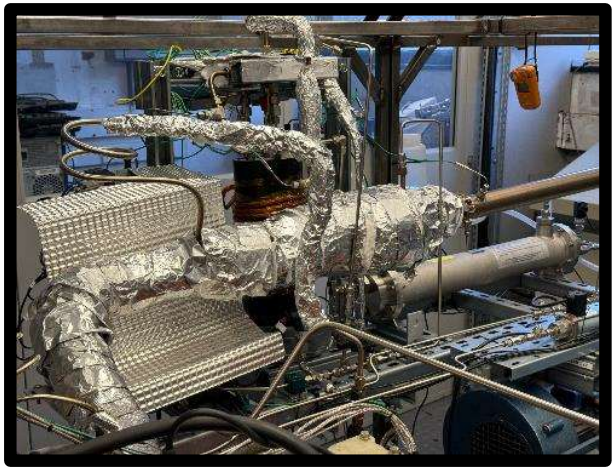
2

- Electrically heated cracker



3

- Integrated cracker with exhaust heat recovery



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Integrated Cracker Testing (SI Single Cylinder)

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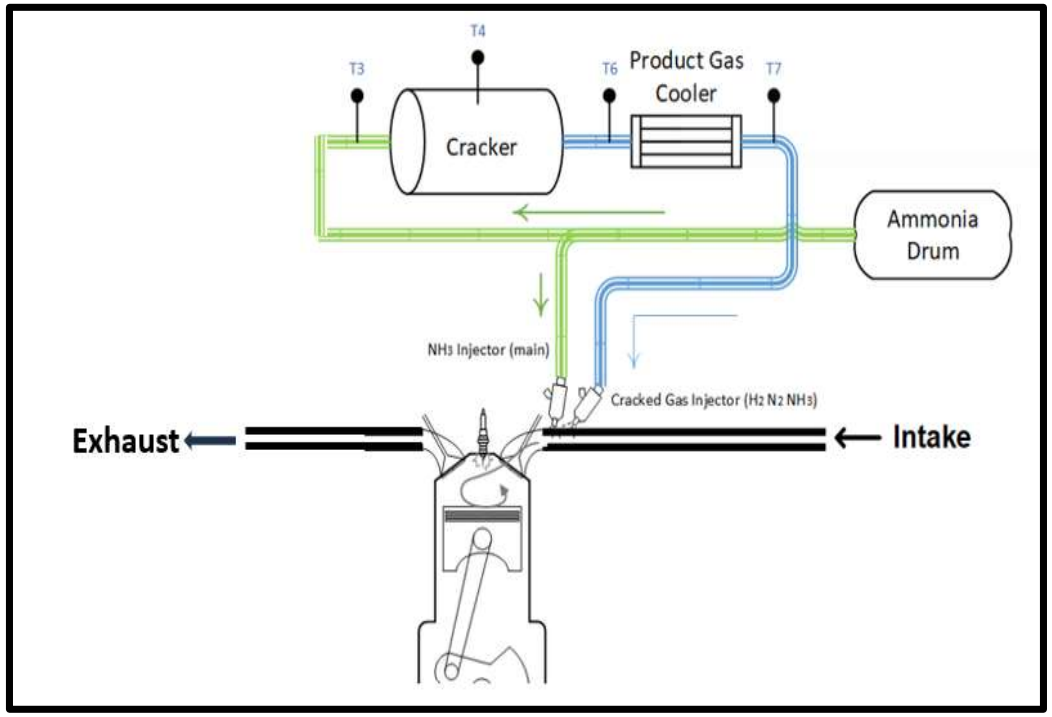
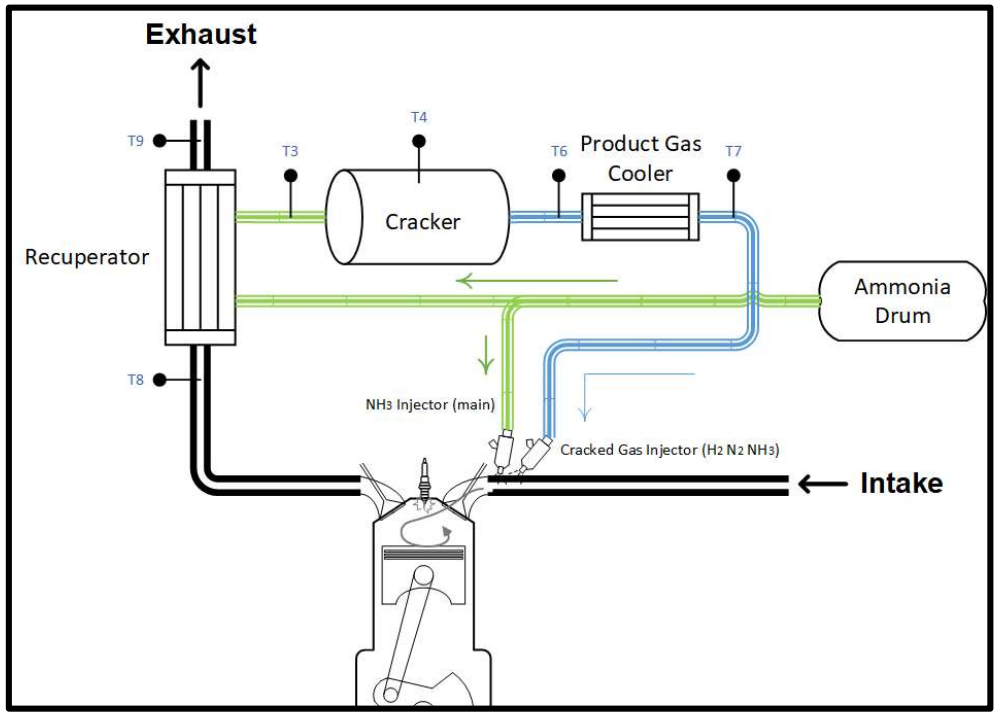
E-Cracker



Thermal Recuperated Cracker



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Engine Characteristics

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Indicated Thermal Efficiency (ITE)

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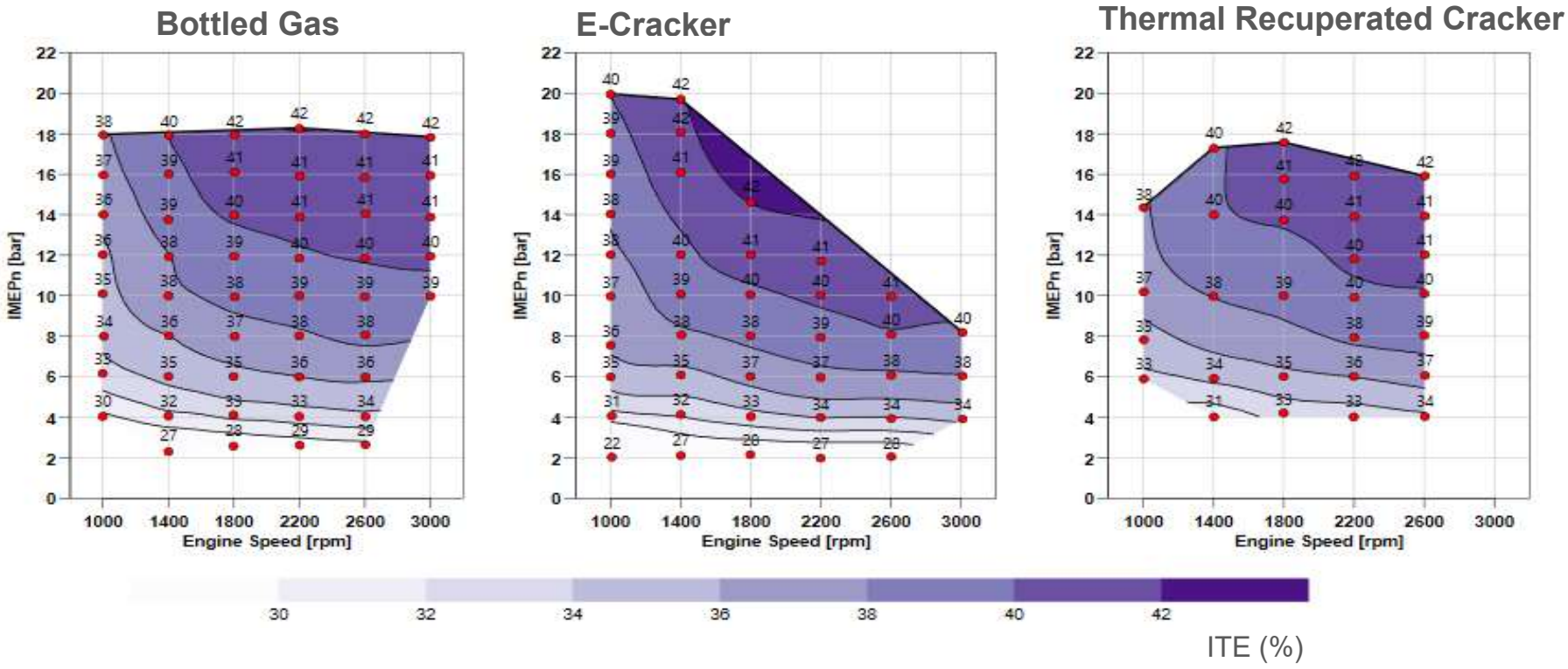
:- Cracking has negligible impact on Indicated Thermal Efficiency



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Unburned Ammonia (NH_3) Emissions

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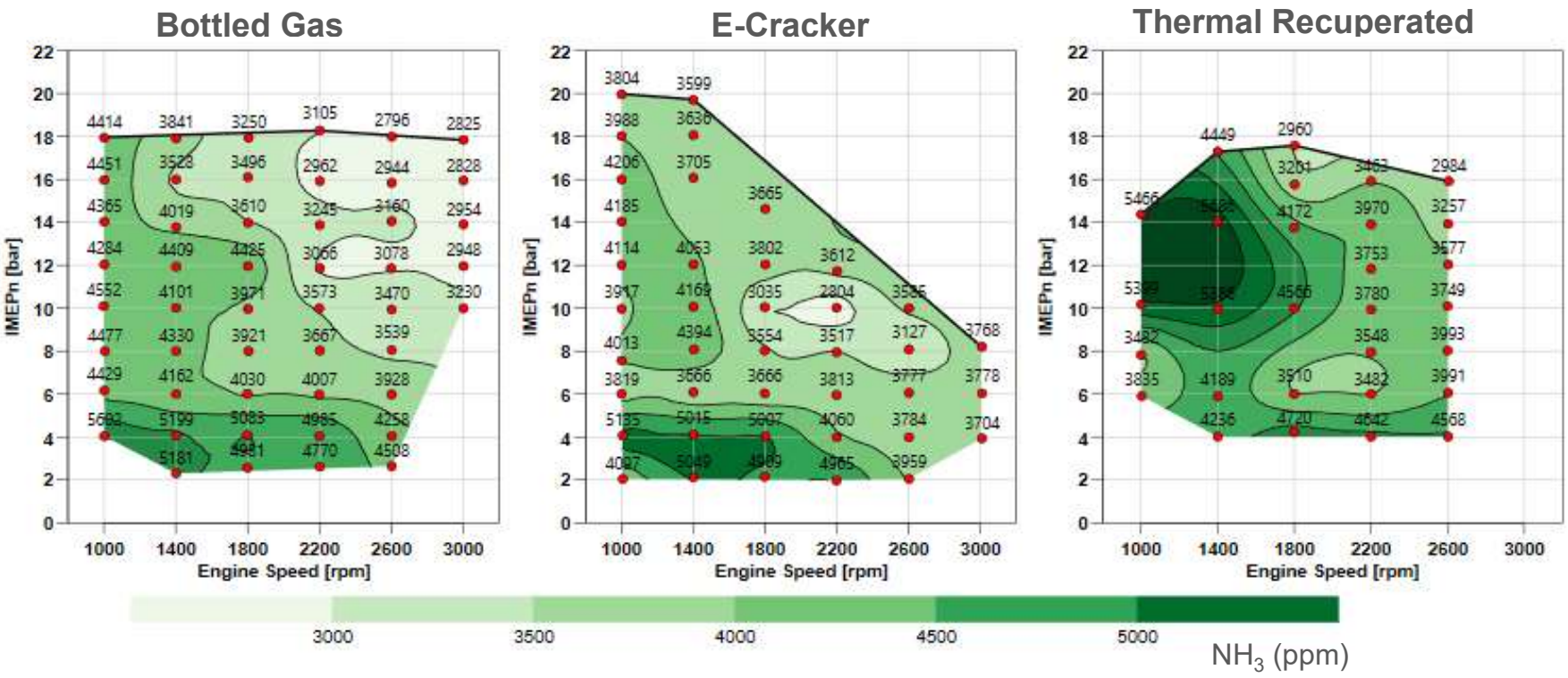
Unburned NH_3 emissions were found to be similar across certain test points among the three cases.



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NO_x Emissions

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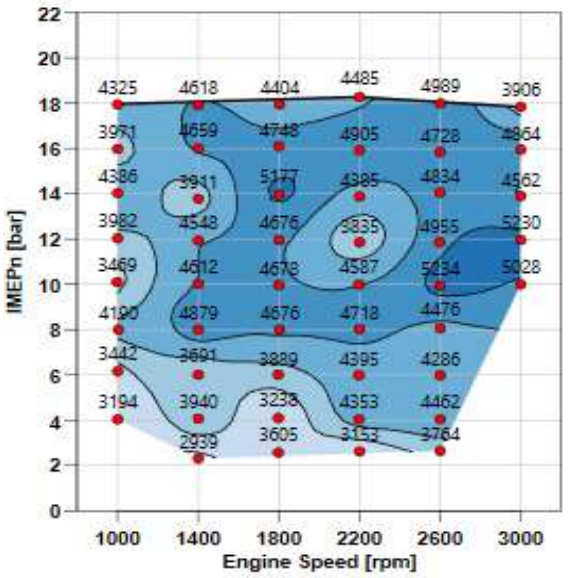
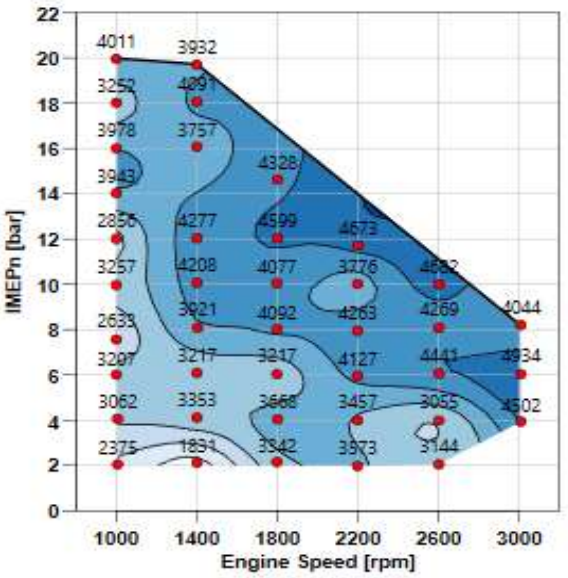
NO_x emissions exhibited similar trends across specific test points among the three cases.

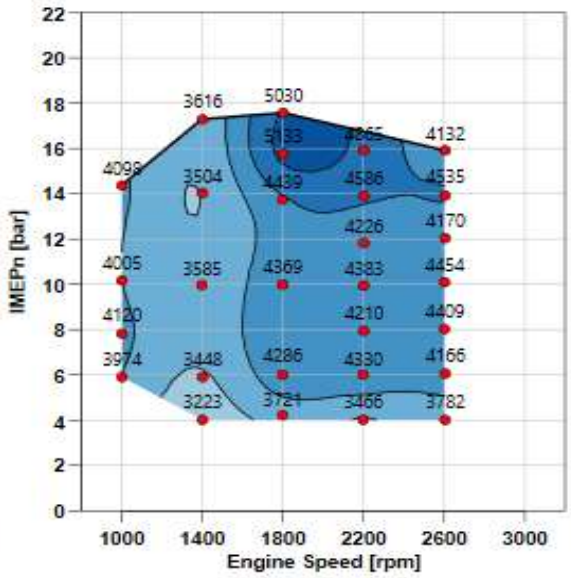
Bottled Gas



E-Cracker



Thermal Recuperated Cracker



NO_x (ppm)

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Alpha Ratio (NH_3 /NO_X)

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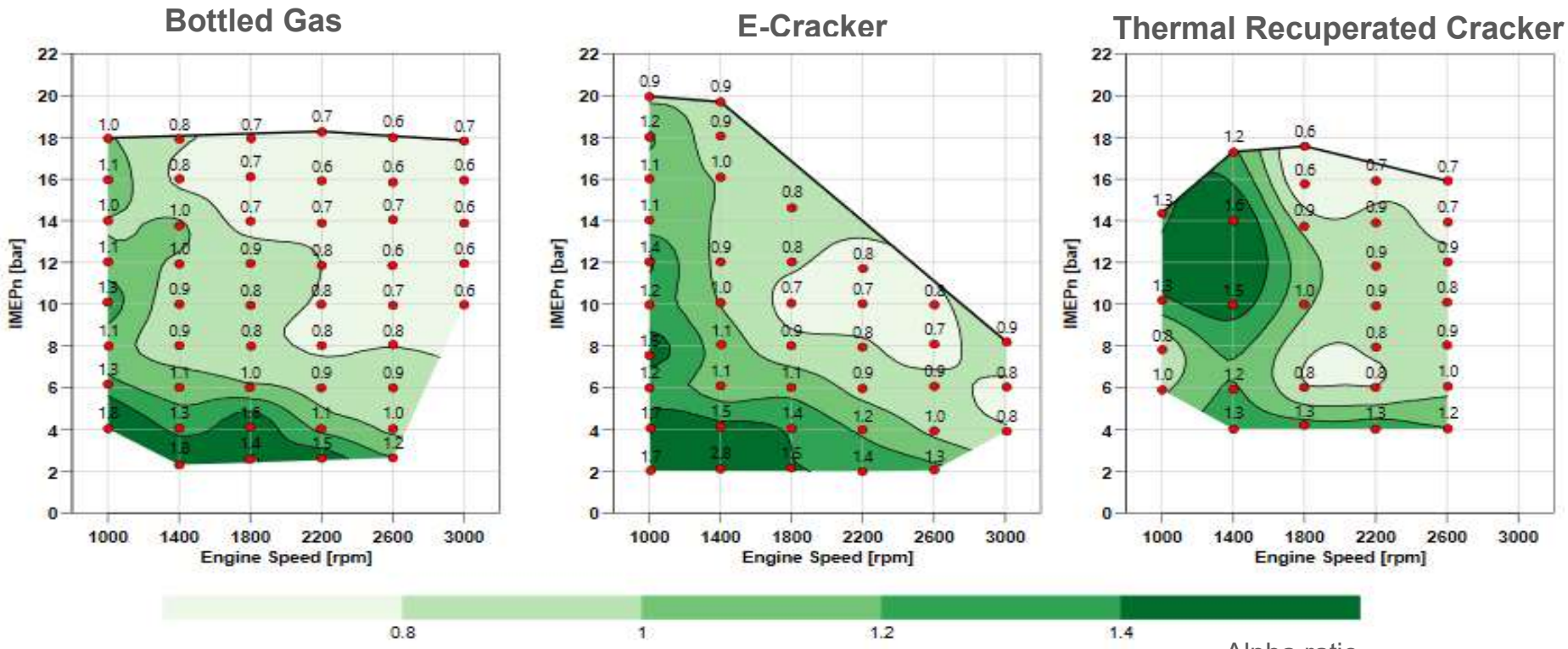

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Comparison of Electric and Thermal Recuperated Ammonia Cracker

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Cracker Inlet Temperature (NH_3)

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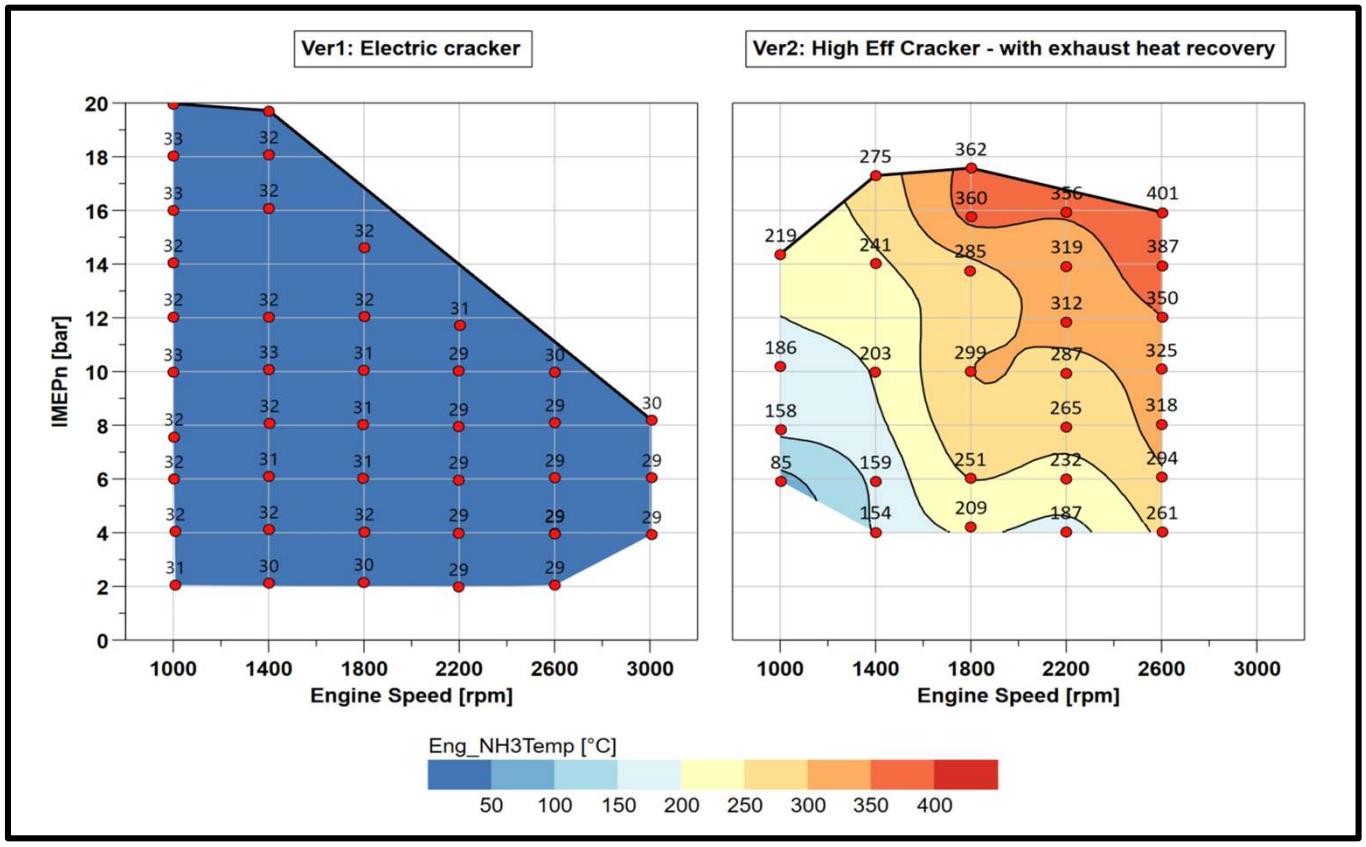

Thermal Recuperated Cracker

- Recuperator warmed the incoming ammonia **up to 400℃** from room temp

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Comparison of Mass Flow Rate
(Electric vs Thermal Recuperated Cracker)

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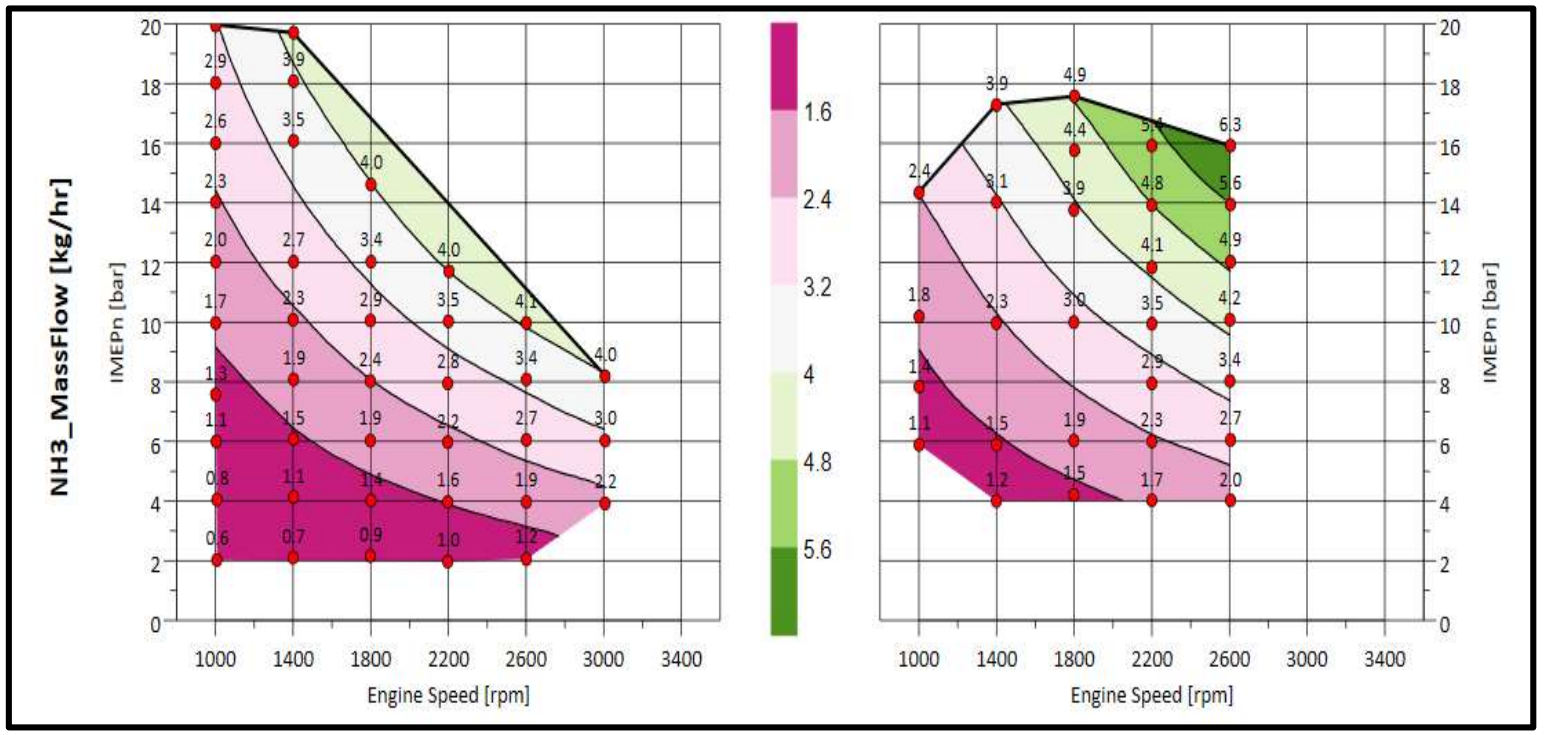
E-Cracker **Thermal Recuperated Cracker**



Thermal cracker handles more fuel, ideal for high-load, high-power operation.

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Power Gain of Thermal Recuperated Cracker

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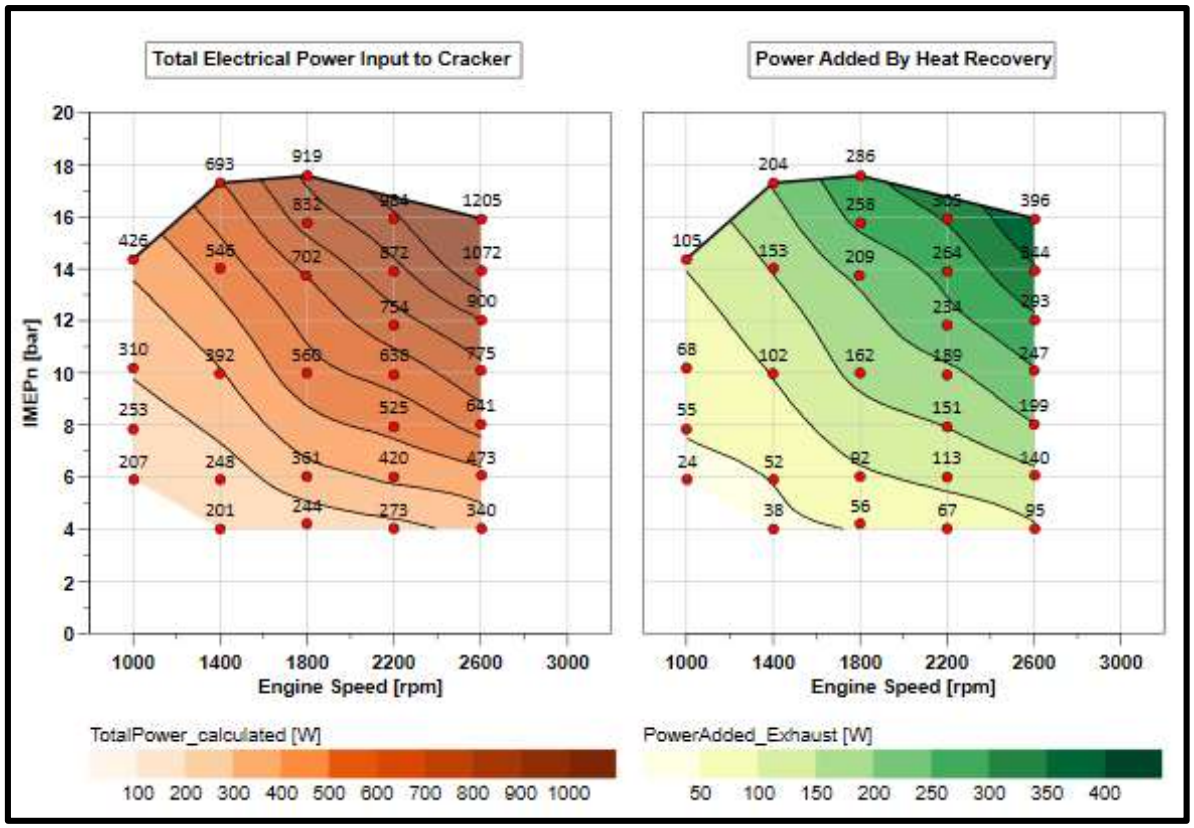

Power Saving

Calculated total power demand based on energy required to decompose the NH_3 mass flow with the gas path temperature measurements.

Temperature measurement post-recuperator indicated a max **400W** gain from waste heat

$$PowerAdded_{cracker} = \dot{m}_{crk} * Avg\ C_p * (T_4 - T_3) + \dot{m} * Enthalpy_{decomposition}$$

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Power Saving by Thermal Recuperated Cracker

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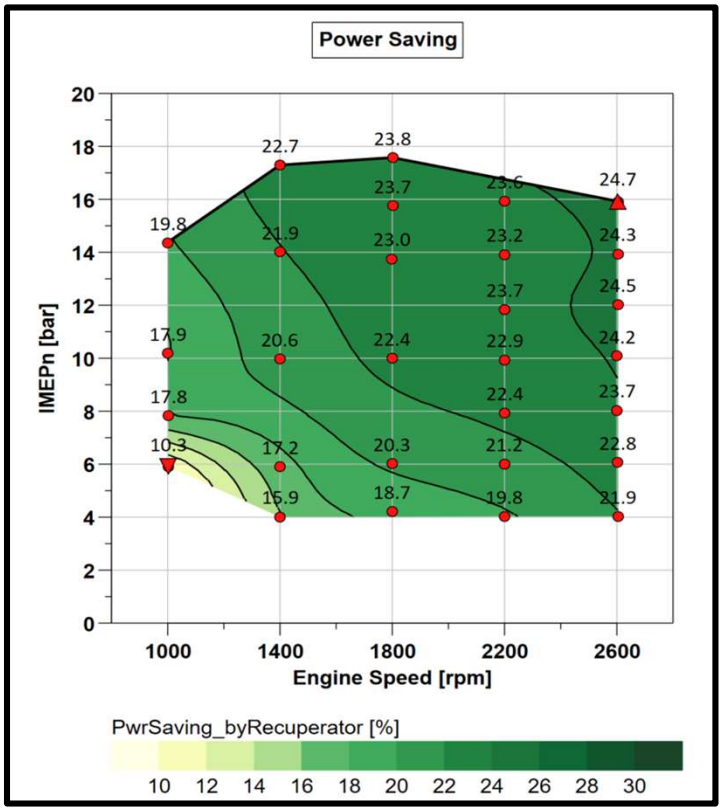

Power Saving

Saving in electrical power demand increased with engine output.

– favourable for combined heat power units running at 70~80% rated load at steady state

~25% saving at peak power tested

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100% Cracked Gas

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Emission Analysis

Cracked Gas Substitution Sweep (1400rpm/4bar IMEP)

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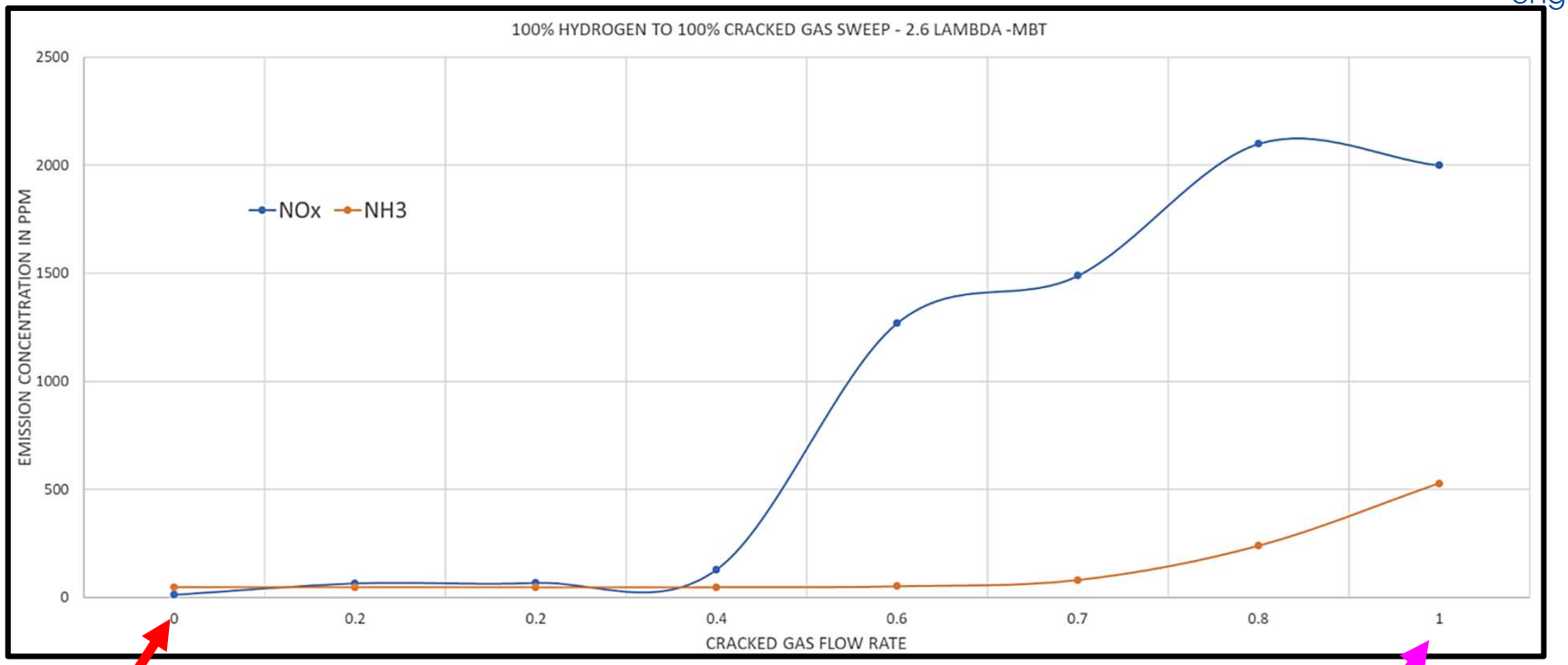

100% H_2

100% cracked gas

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Emission Analysis

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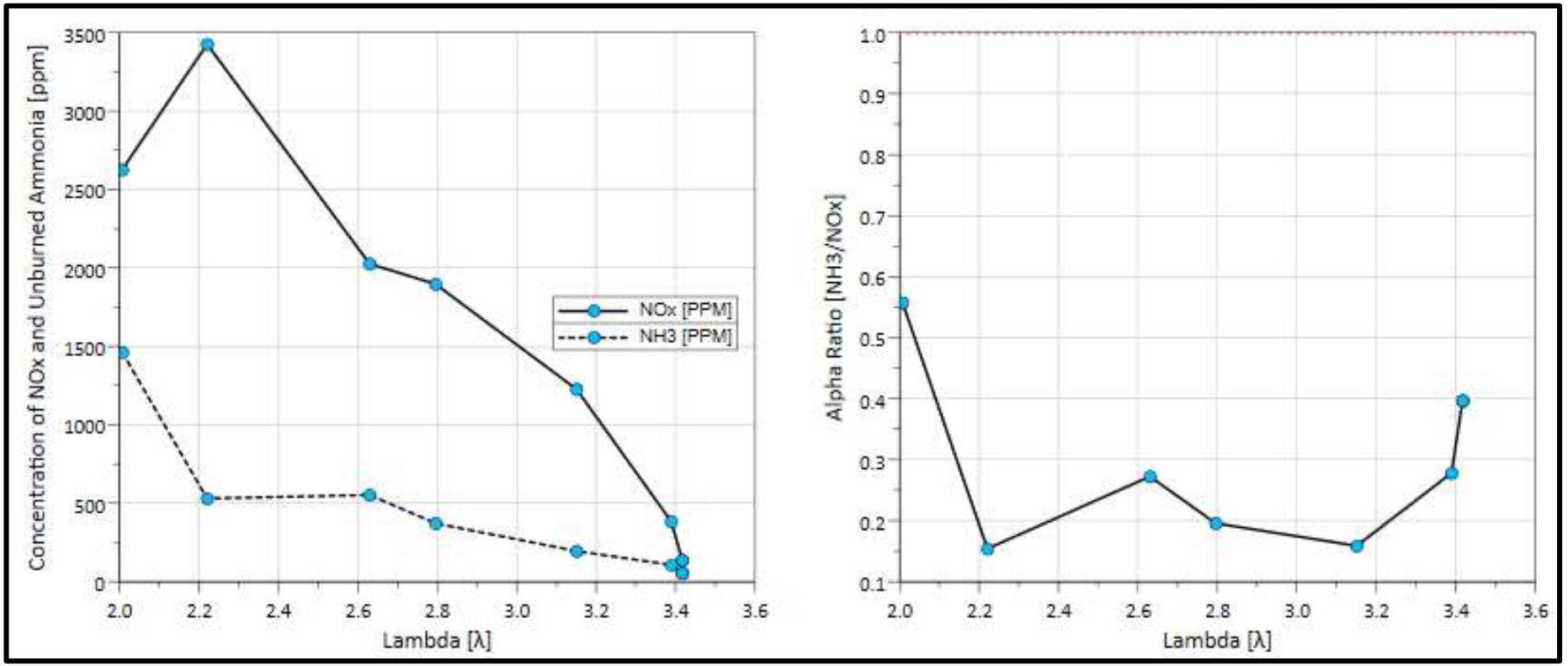
100% Cracked Gas (1400rpm, 4 bar IMEP)



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Conclusions

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Objectives

1. How different does a Spark Ignition (SI) engine operate with cracked gas compared to bottled gas?

2. How much of the total energy required for cracking can be taken out of the exhaust gas?

Nitrogen in the cracked gas had **minimal impact** on engine operation

Around **25% reduction in energy consumption** was observed for an **unoptimised** cracker setup

These tests don't consider trade-off with the temperature required for the after-treatment.

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Future Work

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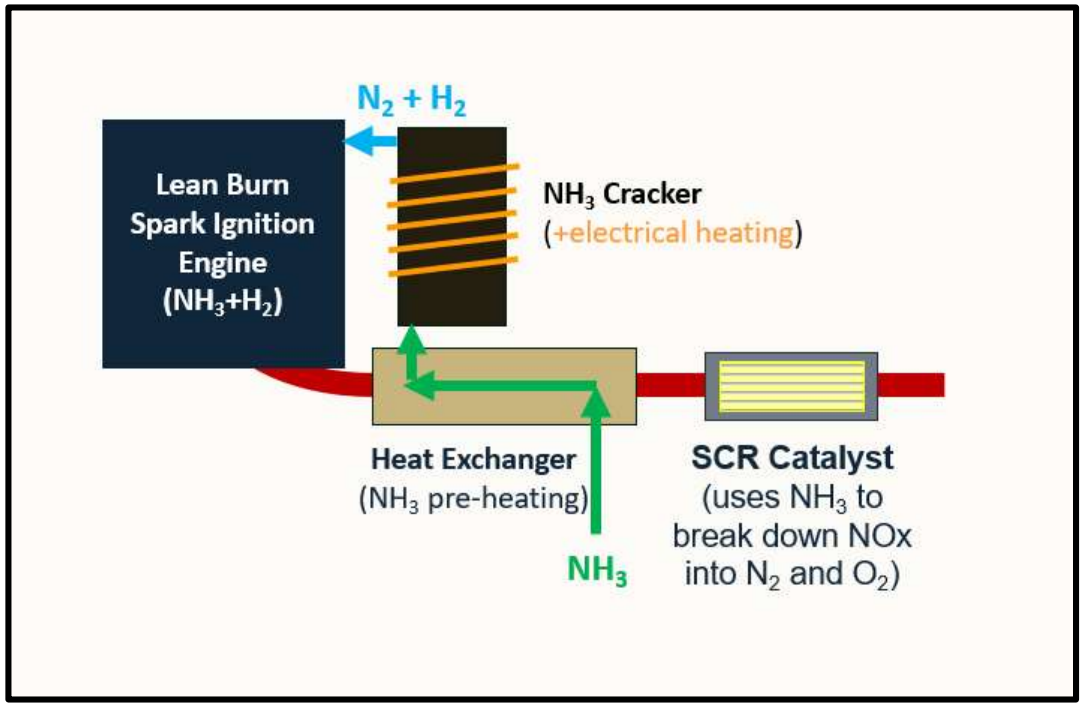

1. Lean burn SI with rightsized cracker with SCR (versus full cracking)
2. Mapping Volvo Engine on cracker

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Thank you for listening!

Any questions??

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