MariNH$_3$

Clean, green ammonia engines for maritime

Emissions from NH_3 Combustion Engines

28/06/2023

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How do emissions from NH_3 differ to conventional fossil-based fuels

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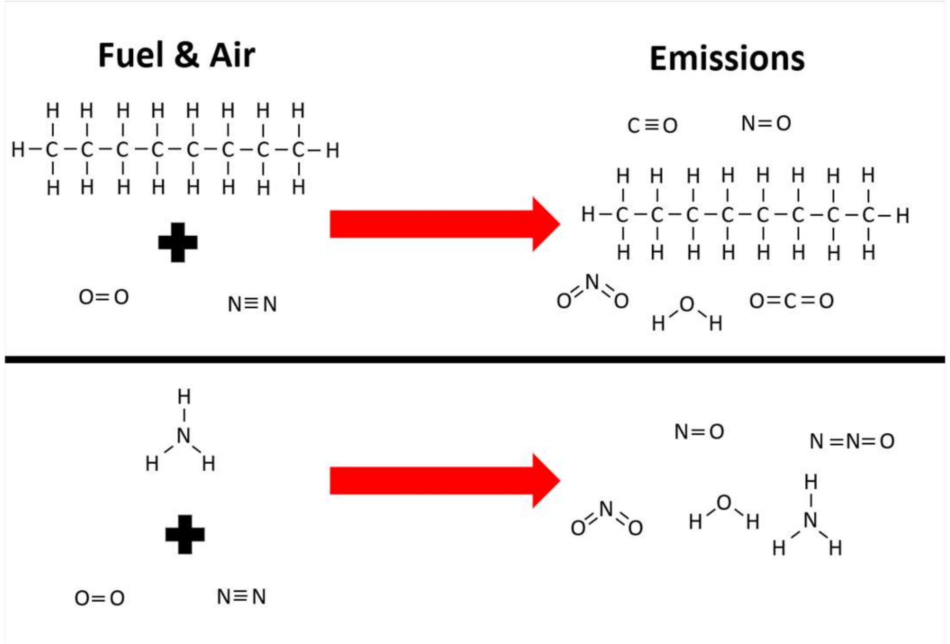
- NH_3 is a carbon-free fuel meaning there are no CO or CO_2 emissions produced.
- As NH_3 is not a HC there will be no HC emissions (other than any emitted from the lubrication oil).
- Unburnt NH_3 that did not partake in the combustion process (slip ammonia).
- NO_X emissions are still prevalent from NH_3 combustion and present a challenge.



Emissions produced from combustion of gasoline (iso-octane) and ammonia.

Formation of NO_X through NH_3 combustion

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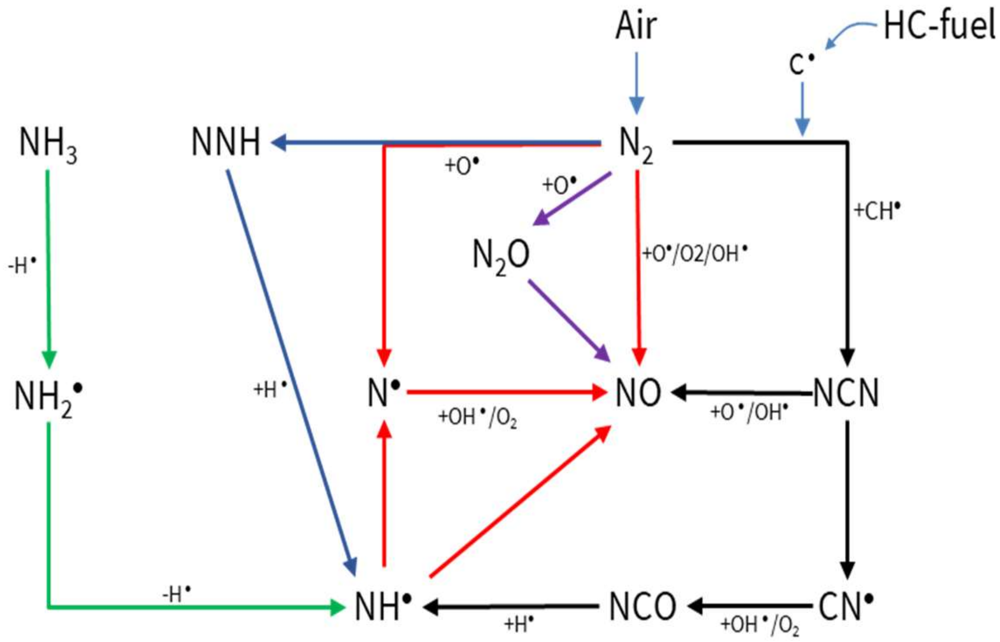
- NO_X production is done through 5 main pathways:
  - Thermal (T-sensitive)
  - Fuel (N in fuel sensitive)
  - Prompt (fuel rich, T < 1800 K)
  - N_2O intermediate (fuel lean, T< 1800 K, ↑ P)
  - NNH mechanism (H sensitive)
- Due to the nitrogen present within NH_3 the fuel NO_X pathway becomes important.
- The lower adiabatic flame temperature of NH_3 compared to gasoline reduces the contribution from thermal NO_X.



Simplified scheme of formation pathways of the NO species by different mechanisms

Emissions Abatement for NH_3 Combustion

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Aftertreatment for NH_3 exhaust

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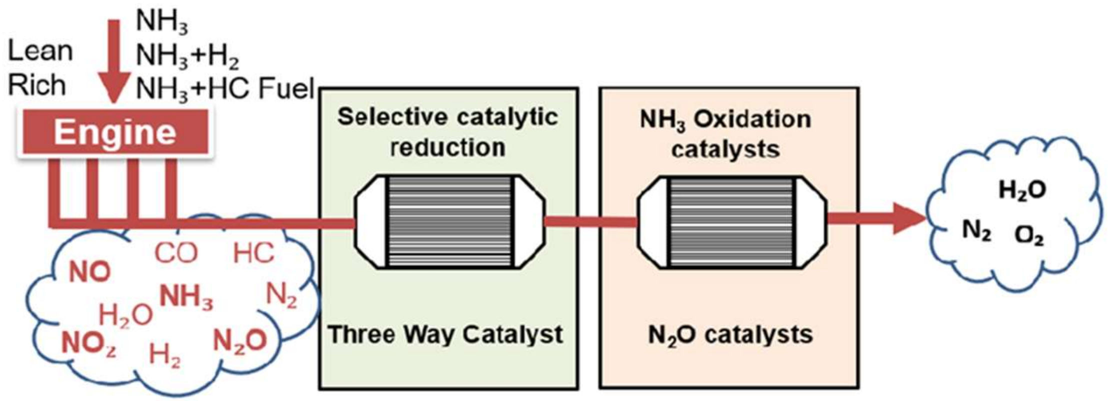
- The different composition of NH_3 exhaust gas produces different challenges to aftertreatment systems than conventional gasoline exhaust gas.
- There are several options for catalytic aftertreatment systems applicable to NH_3 exhaust gas control:
  - Selective catalytic reduction (SCR)
  - Ammonia slip catalyst (ASC)
  - N_2O catalyst



Aftertreatment solutions for ammonia combustion engines.

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Selective catalytic reduction (SCR)

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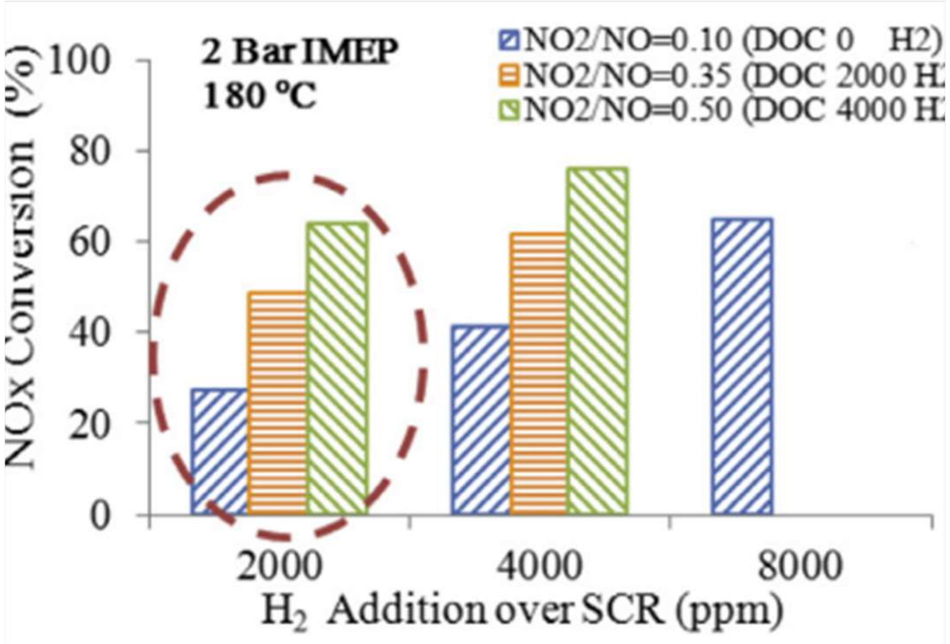
- Removes NO and NO_2 through reduction reactions with a suitable reductant.
- Reductants include:
  - Ammonia
  - Hydrogen
  - Hydrocarbons (alcohols, alkanes, etc.)
- If there is not a sufficient number of reductants available in the exhaust gas they must be added through injection.
- If there are too many reductants, they will slip through the SCR.



Effect of H_2 addition on SCR NO_X conversion efficiency . (Chemical Engineering Journal 270 582–589.)

Ammonia slip catalyst (ASC)

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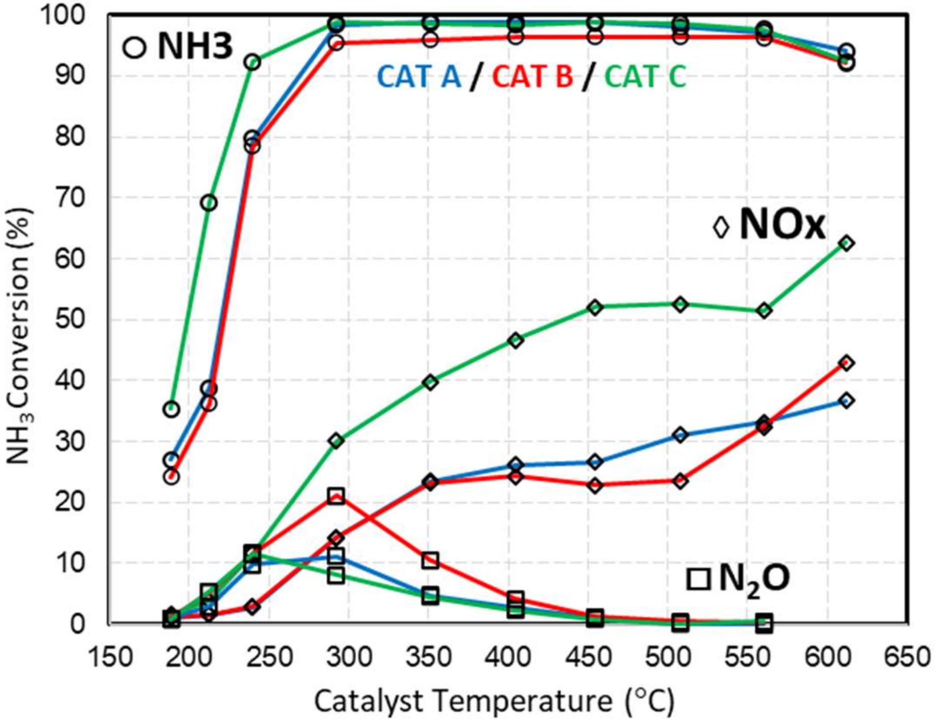
- Excess NH_3 from combustion or SCR dosage is an issue.
- NH_3 slip catalysts have been studied when paired with SCR catalysts to address over dosage.
- There is secondary production of N_2O and NO_X as NH_3 is oxidized.
  - $2NH_3 + 1.5O_2 \rightarrow N_2 + 3H_2O$
  - $2NH_3 + 2O_2 \rightarrow N_2O + 3H_2O$
  - $2NH_3 + 2.5O_2 \rightarrow 2NO + 3H_2O$



NH_3 conversion & products. (SAE Transactions, Vol. 116, Section 4: JOURNAL OF FUELS AND LUBRICANTS 182-186)

N_2O catalyst

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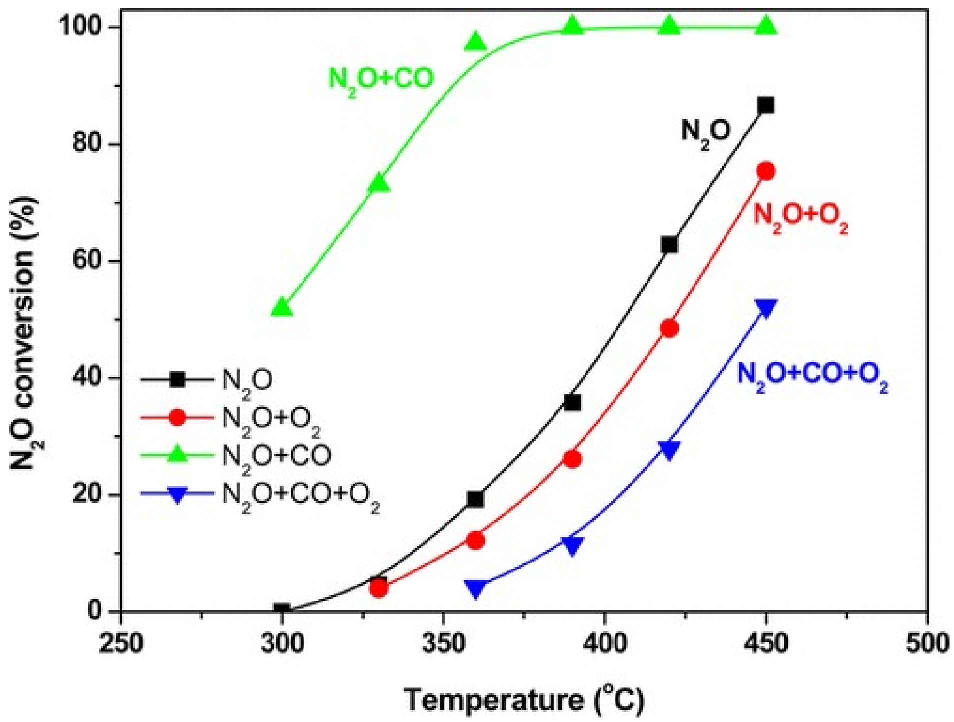
- N_2O decomposition catalysts break down N_2O into N_2 and O_2.

- $N_2O + O^* \rightarrow N_2 + O_2$
- Nobel metal based: High cost with sensitivity to H_2O/O_2 sensitivity.



N_2O conversion – (Applied Catalysis B: Environmental 75, 167–174)

Summary & Future Directions

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Summary and future directions

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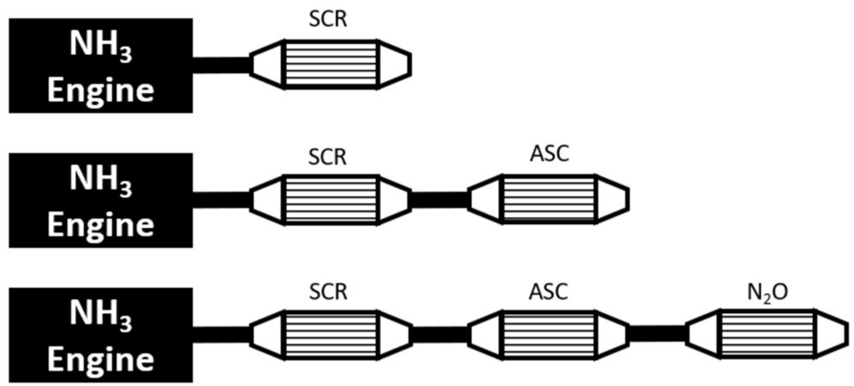
- Aftertreatment for NH_3 combustion requires different catalytic solutions compared to conventional fossil-fueled combustion.
- Main challenges are NH_3 slip and emissions of NO_X and N_2O.
- Catalytic aftertreatment systems can provide a solution to this challenge but further research is required.
- There will be a trade off between emissions, cost and practicality.



Different proposed aftertreatment architecture for NH_3 engines.

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