Combustion of Ammonia for Reduced CO_2 in Heating and Power Generation Systems

Undergraduate Student
Kyle Redfern

Graduate Students
Praveen Kumar, Tim Rovince Victor, and Derek Wissmiller

Principal Investigator
Terrence R. Meyer

Mechanical Engineering
Iowa State University

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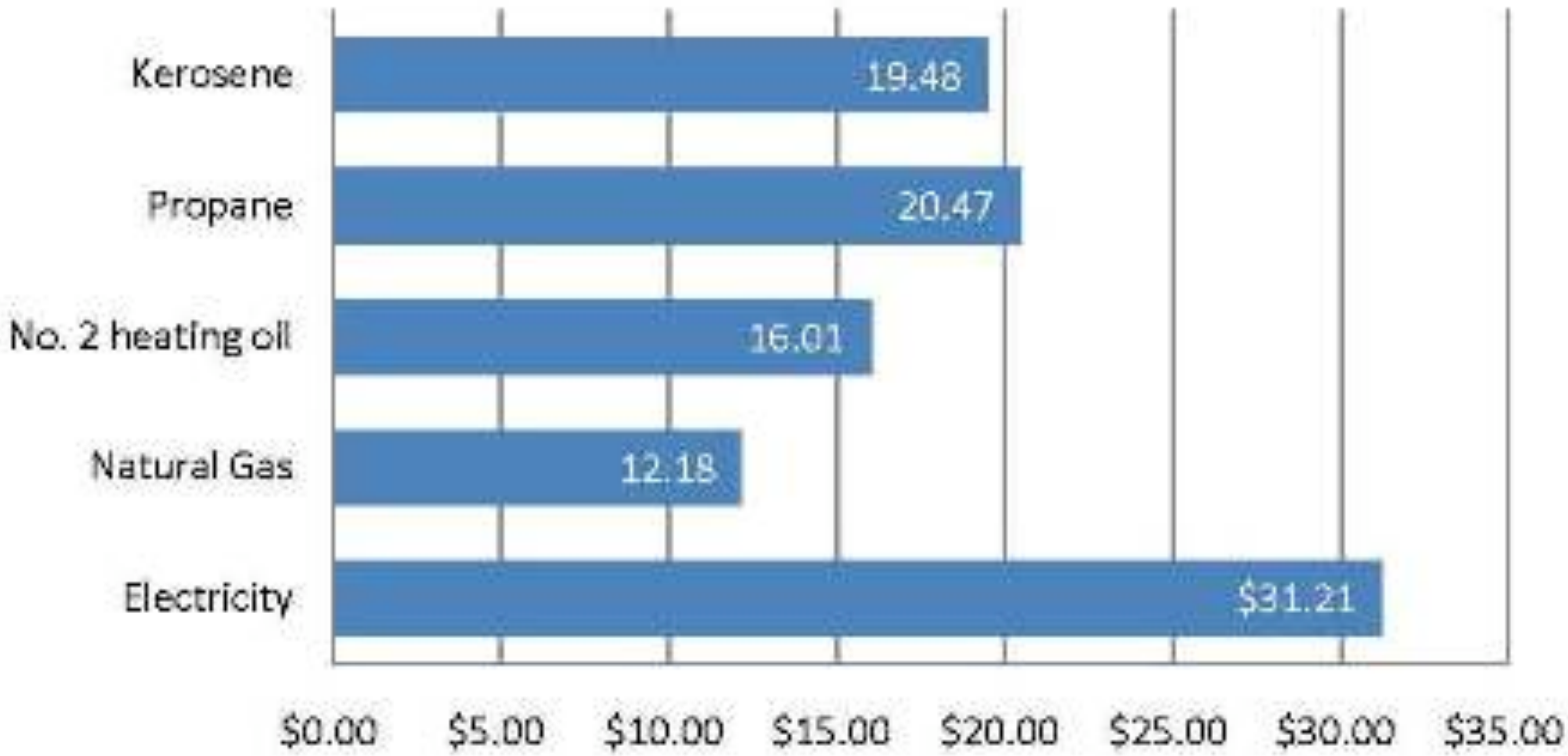
Outline

- Motivation
- Background
- Laminar Flame
- Swirl-Stabilized Flame
- Conclusions
- Future Work
- Acknowledgments

Motivation

- 60% of homes in Northeast U.S. heated by heating oil
- Residential cost/MMBtu (DOE 2007)



Background

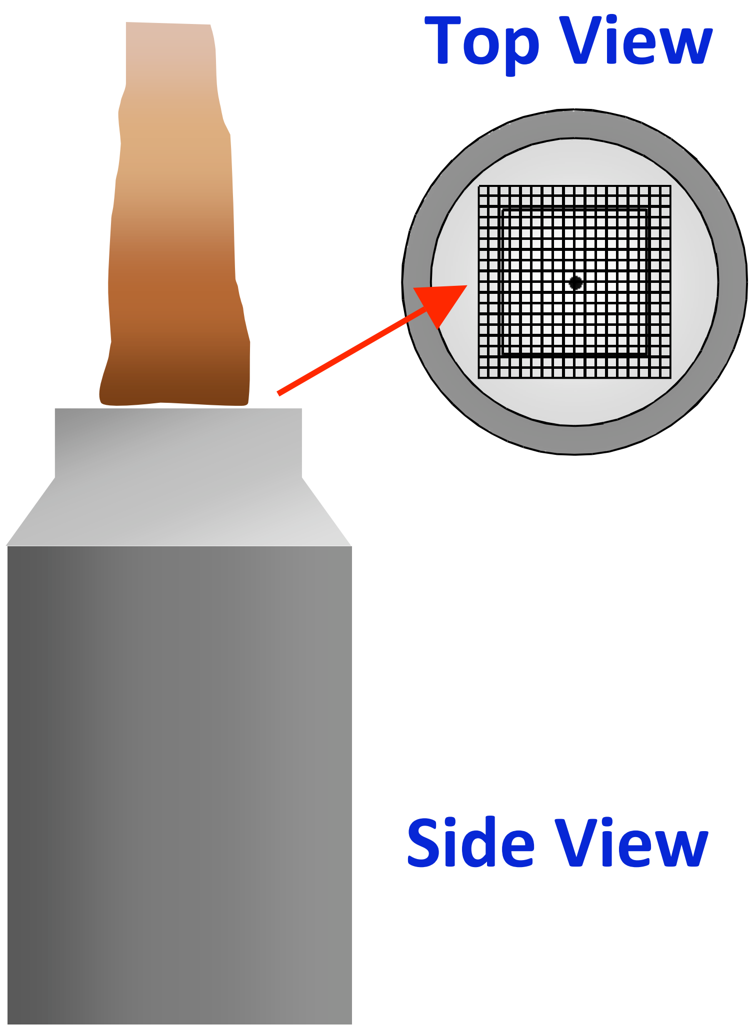
- Reiter et al., Energy & Fuels, 2008, 95% replacement in IC engines
- Ciccarelli et al., Combust. Flame, 2006 – Flammability limits of NH3-H2-N2-air mixtures widen from 400 C to 600 C
- Brandhorst et al., AIAA 2008-5610 – Ammonia combustion with Ni catalyst
- Less work has been done focusing on furnaces

Initial Tests in Laminar Flame

Laminar Diffusion Flame (Hencken Burner)

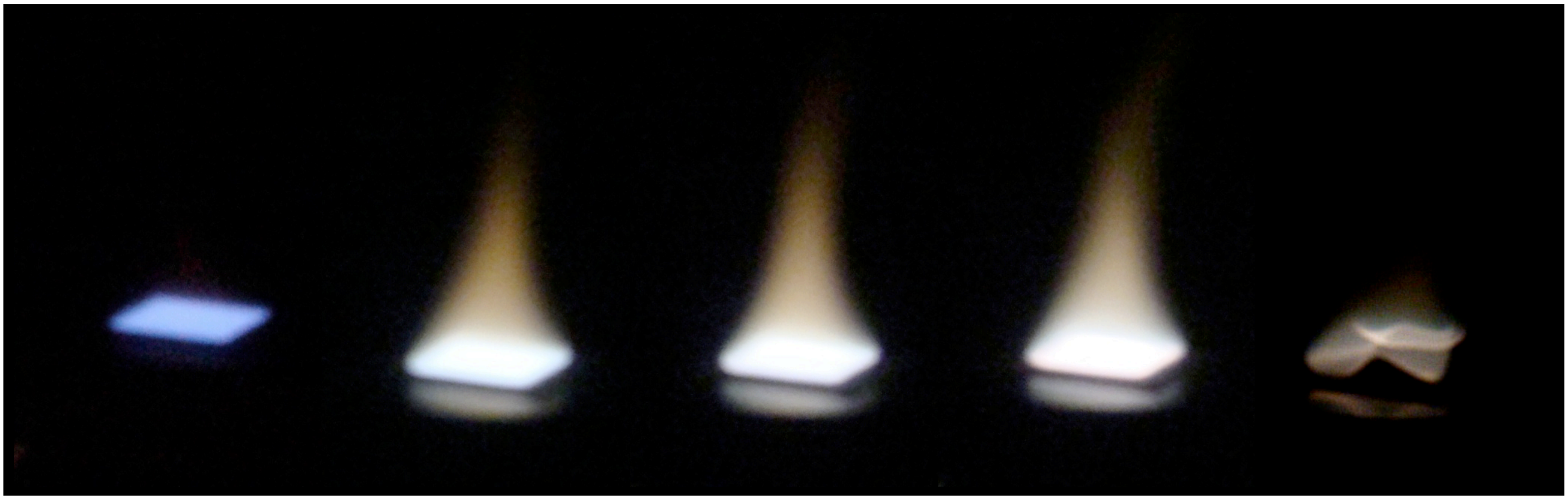
Fuels
- Ammonia
- Natural gas
- Hydrogen

Oxidizer
- Air



Results – Laminar Flame with CH_4

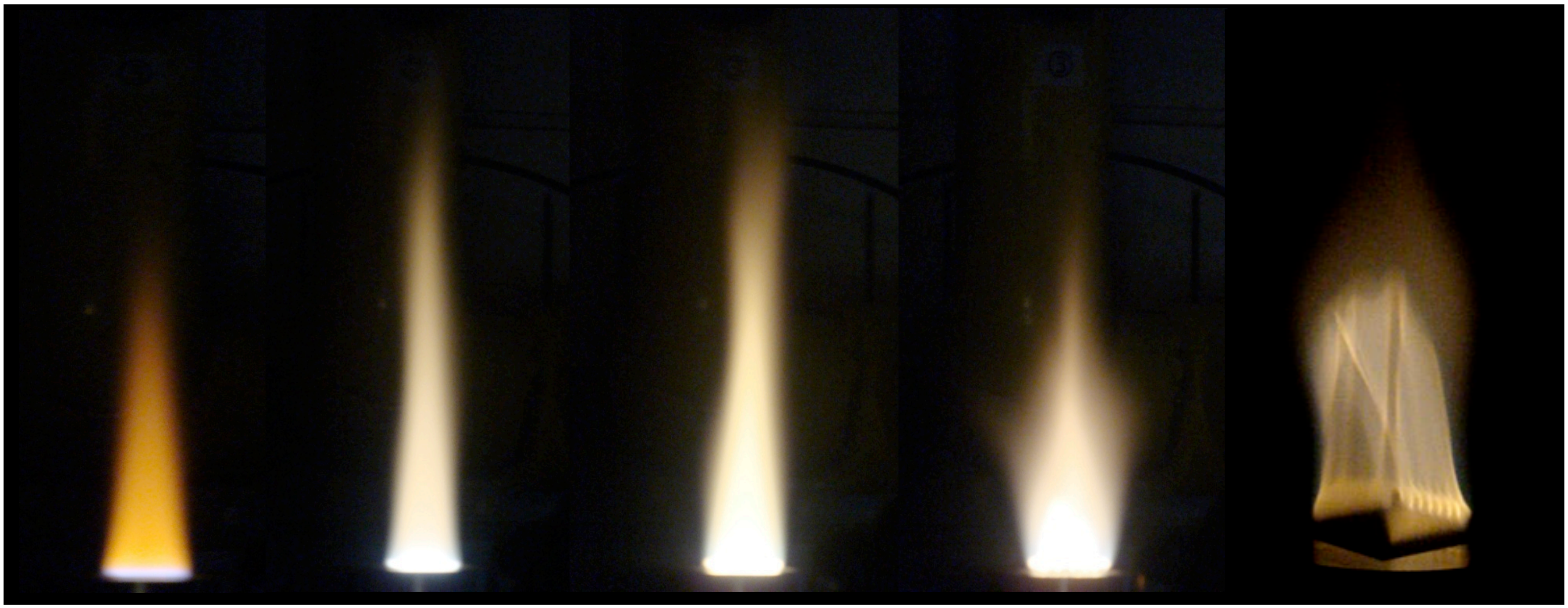
NH_3 % Energy in CH_4 @ Equiv. Ratio = 0.95



0% **11%** **23%** **35%** **47%**

Results – Laminar Flame with H2

NH_3 % Energy in CH_4 @ Equiv. Ratio = 0.95



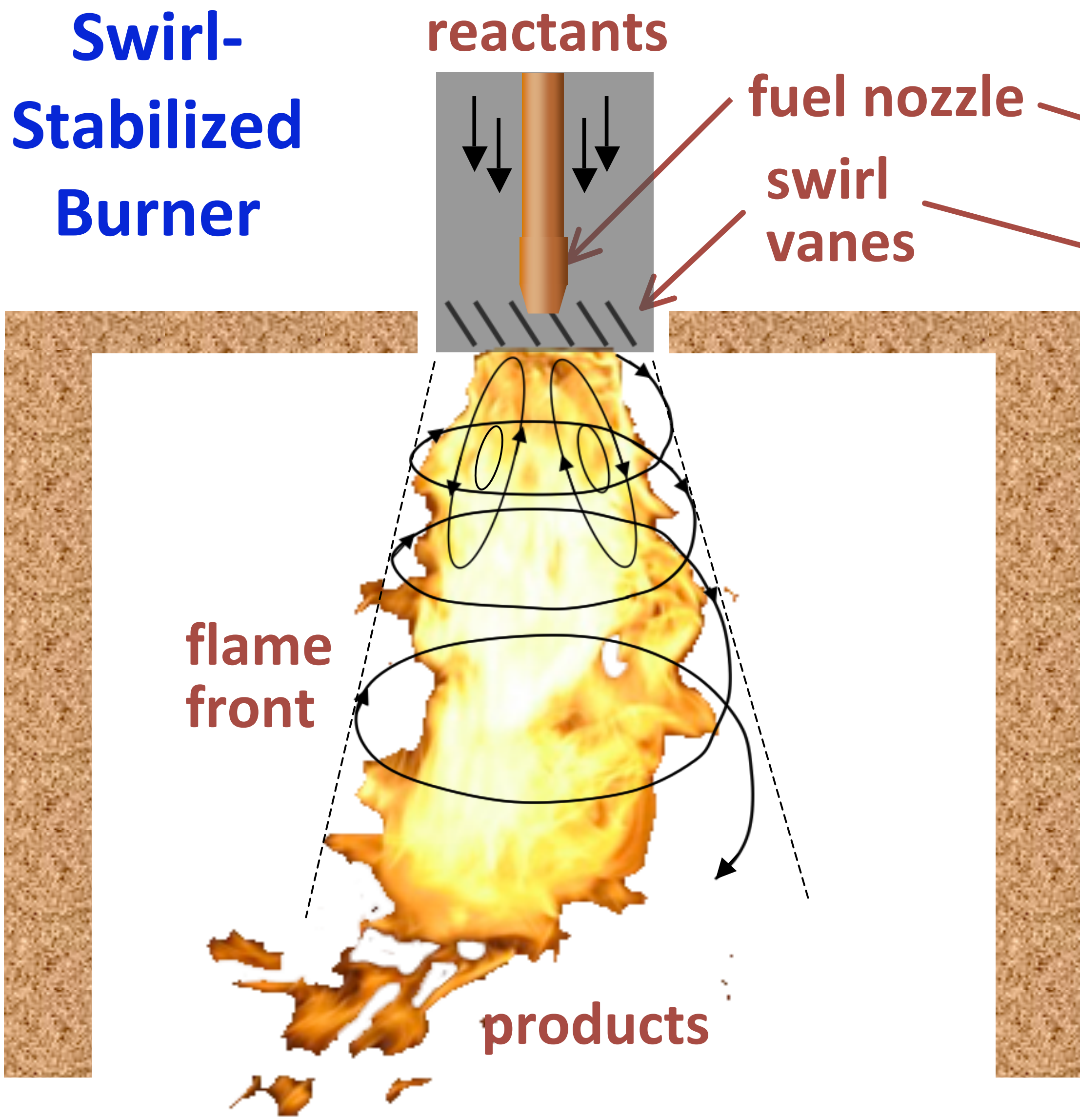
0% **21%** **52%** **74%** **> 74%**

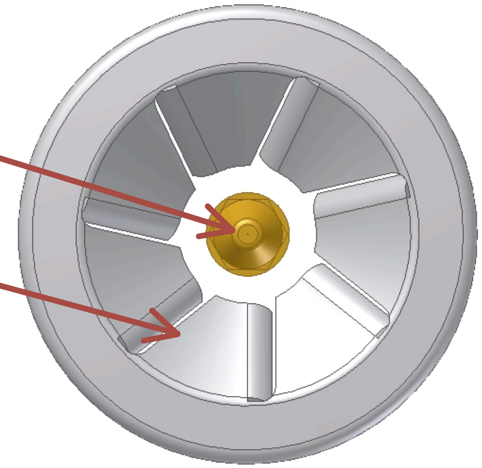
Experimental Set-Up – Swirl Flame

Modified domestic fuel oil burner (< 40 kW)

- Chamber size
- Fuel atomization
- Thermal management
- Custom air swirler
- Optical access
- Temperature and Pressure measurements
- NOx measured in exhaust

Experimental Set-Up





Fuels
- Ammonia
- Natural gas
- Hydrogen

Oxidizer
- Air

Flame Comparisons

Fuel Oil (28 kW)

60% NH_3 by Energy in H_2 (15 KW)

34% NH_3 by Energy in CH_4 (5 kW)

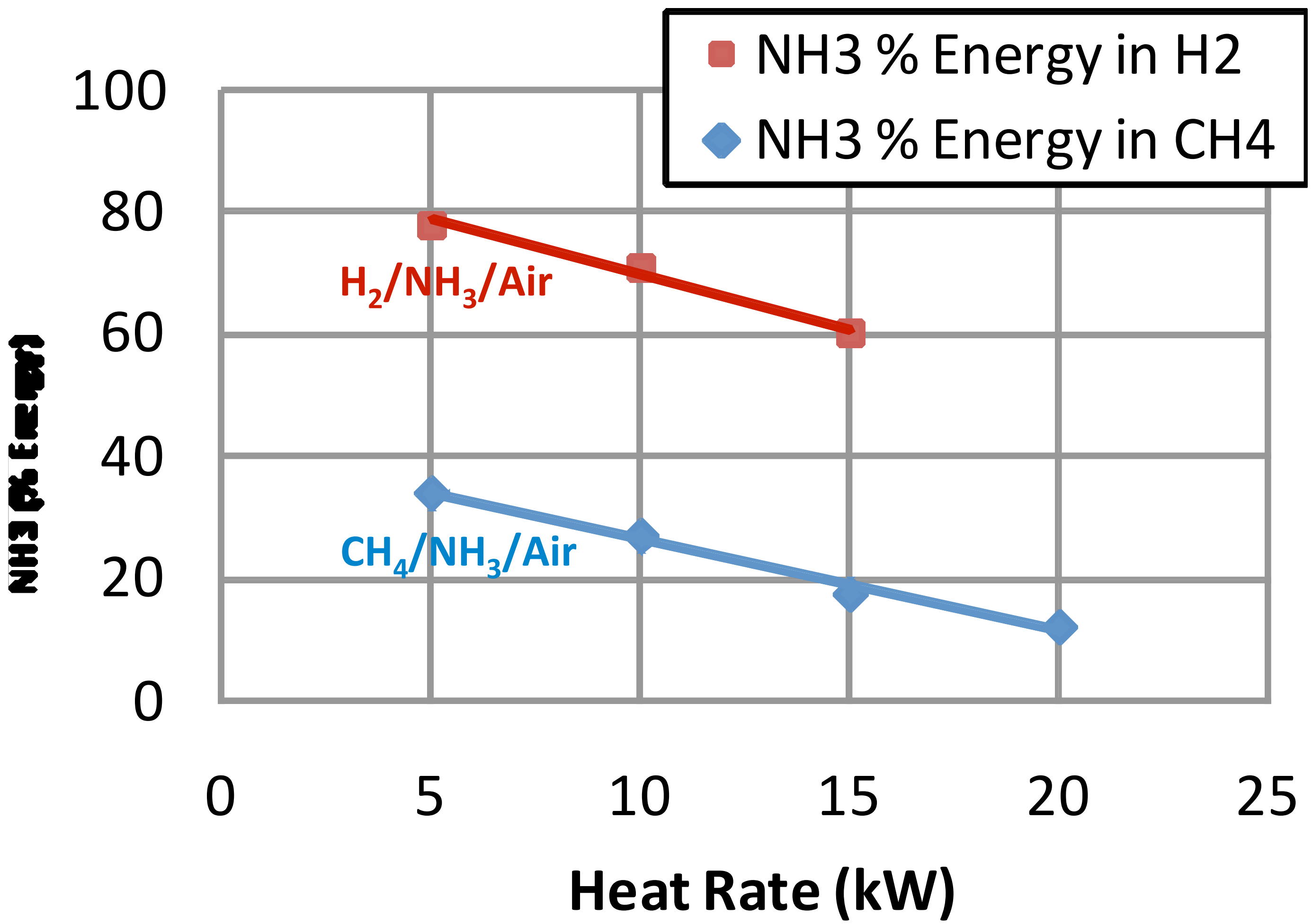
Results

Study of Natural Gas (CH_4) and Hydrogen (H_2) Replacement

- Effect of heat rate on NH3 % by energy
- Effect of air preheat on NH3 % by energy

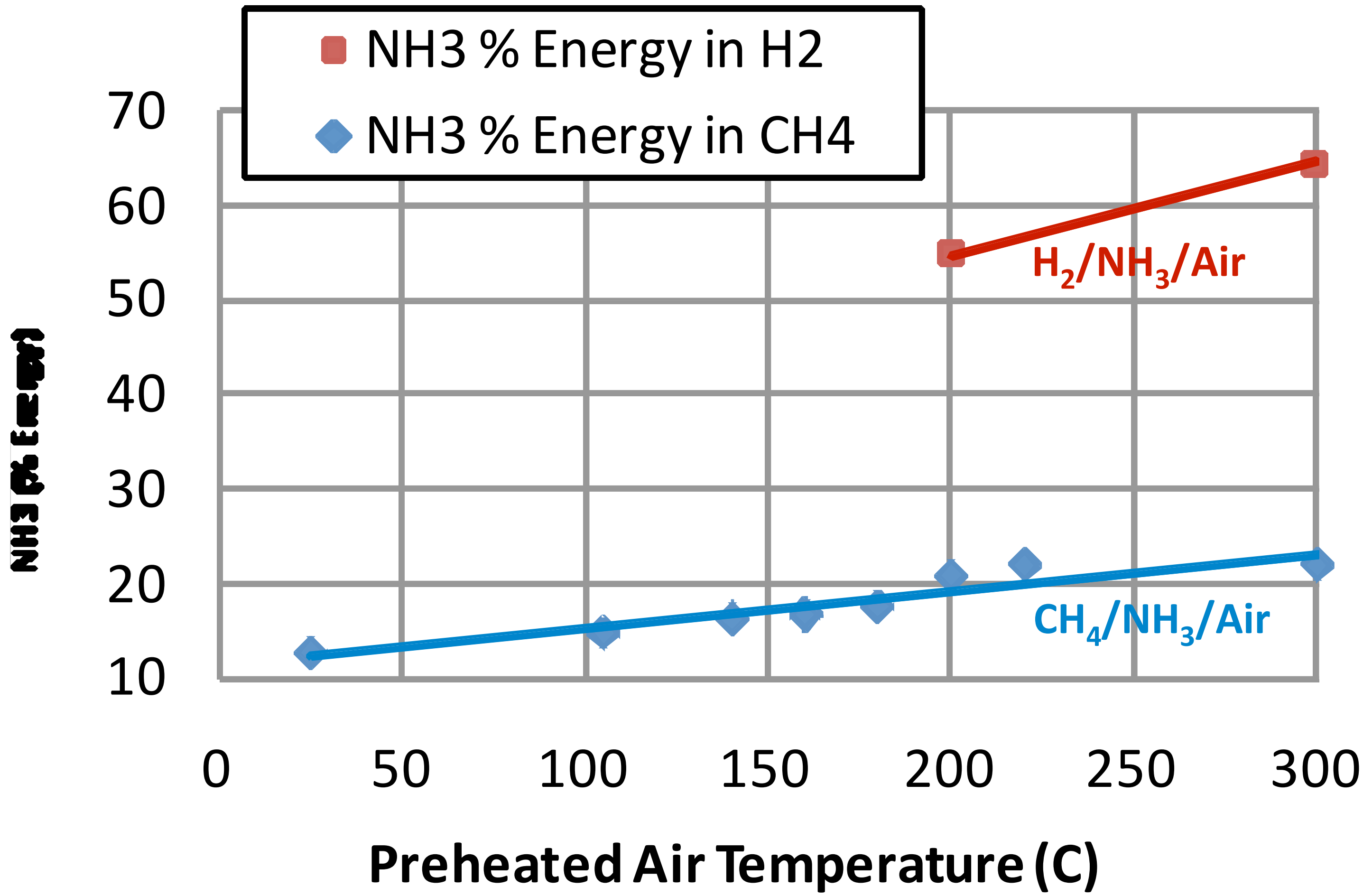
Results – Effect of Heat Rate

CH4/NH3/Air & H2/NH3/Air (Equiv. Ratio = 1.0)



Results – Effect of Air Preheat

CH4/NH3/Air & H2/NH3/Air @ 15 kW (Equiv. Ratio = 1.0)



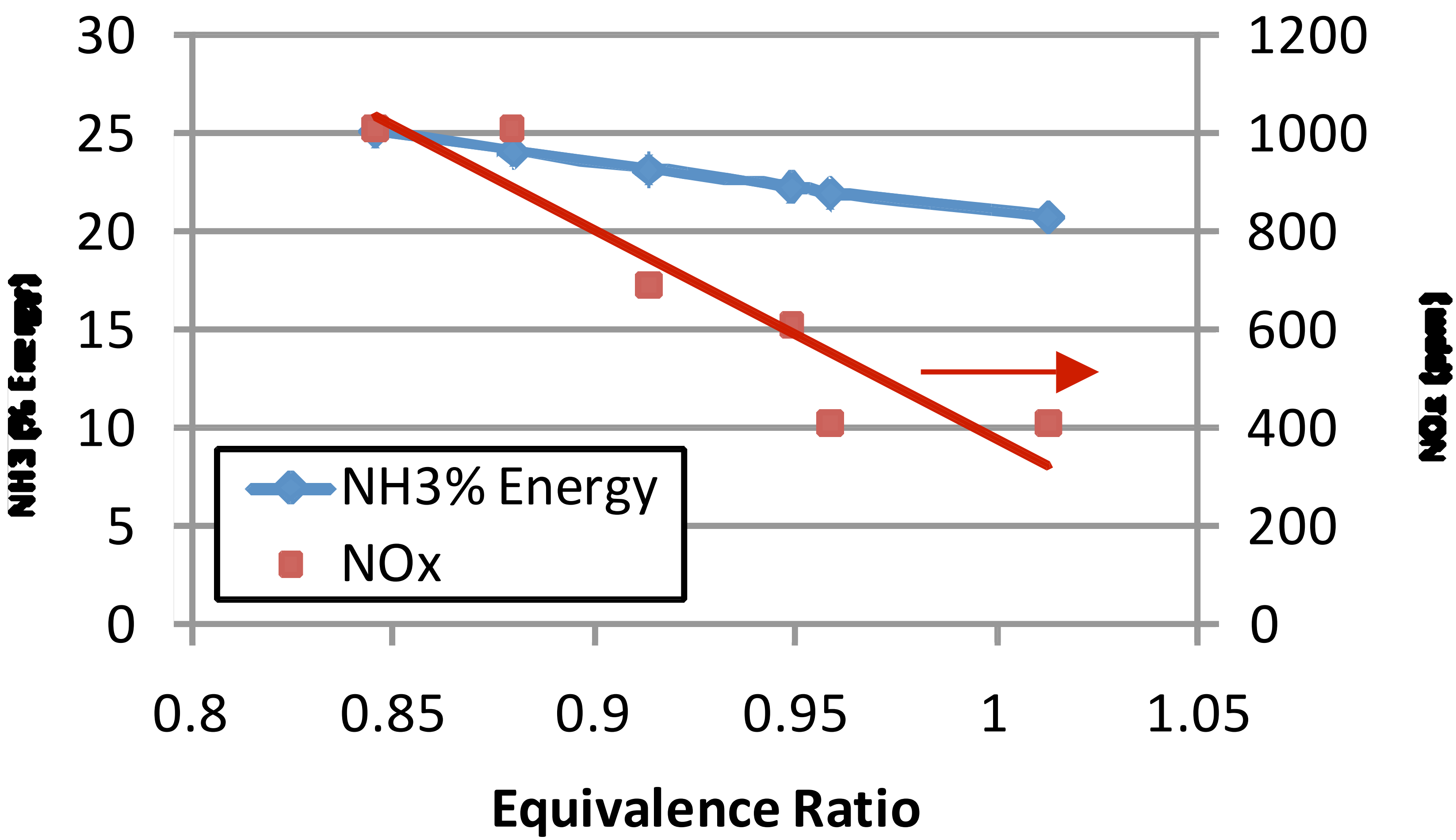
Results

Study of Natural Gas (CH_4) Replacement

- Effect of equivalence ratio on NH3 % by energy and NOx
- Effect of nozzle position on NH3 % by energy and NOx

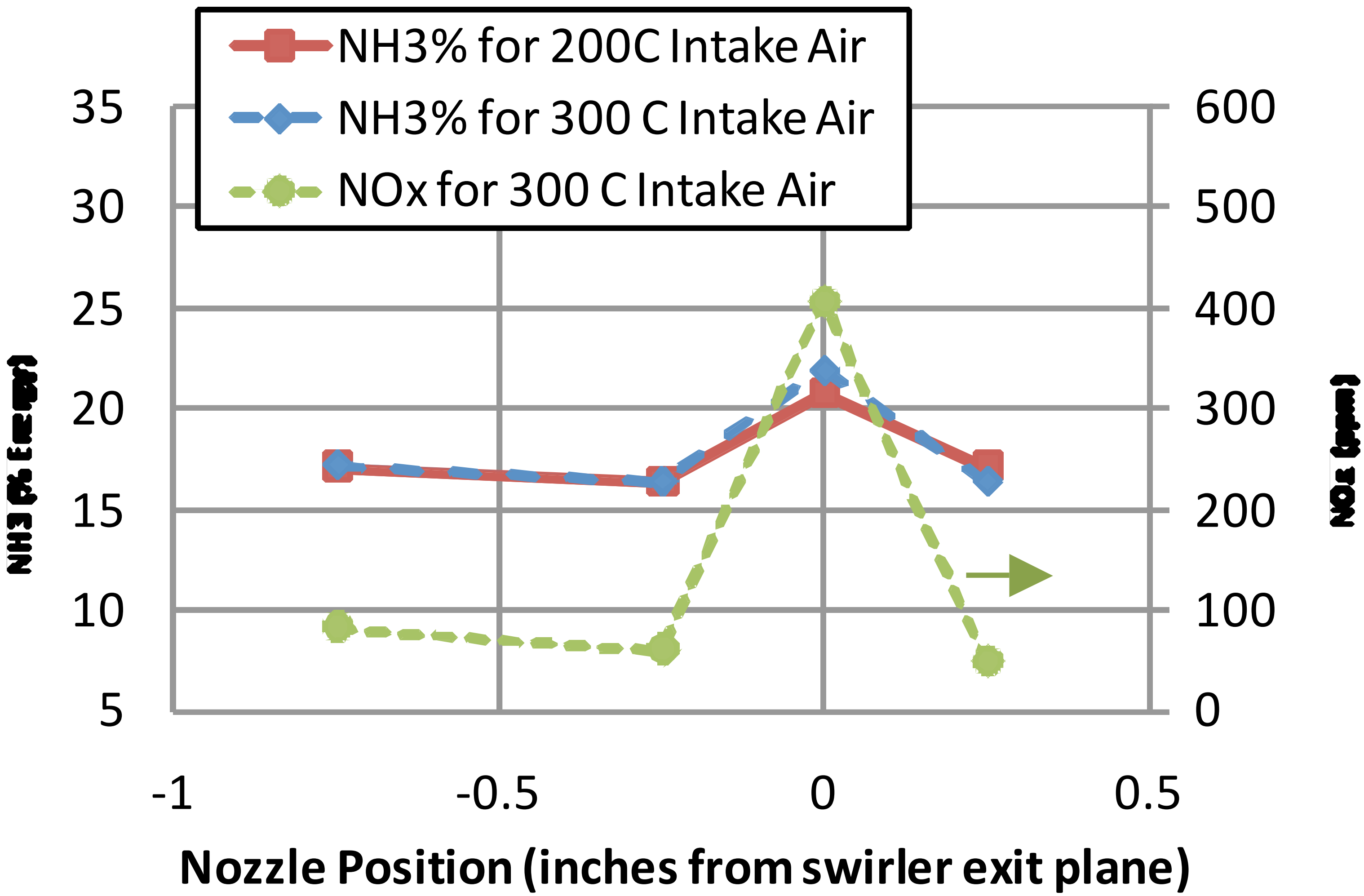
Results – Effect of Equiv. Ratio

CH4/NH3/Air @ 15 kW (300 C Intake Air)



Results – Effect of Nozzle Position

CH4/NH3/Air @ 15 kW (Equiv. Ratio = 1.0)



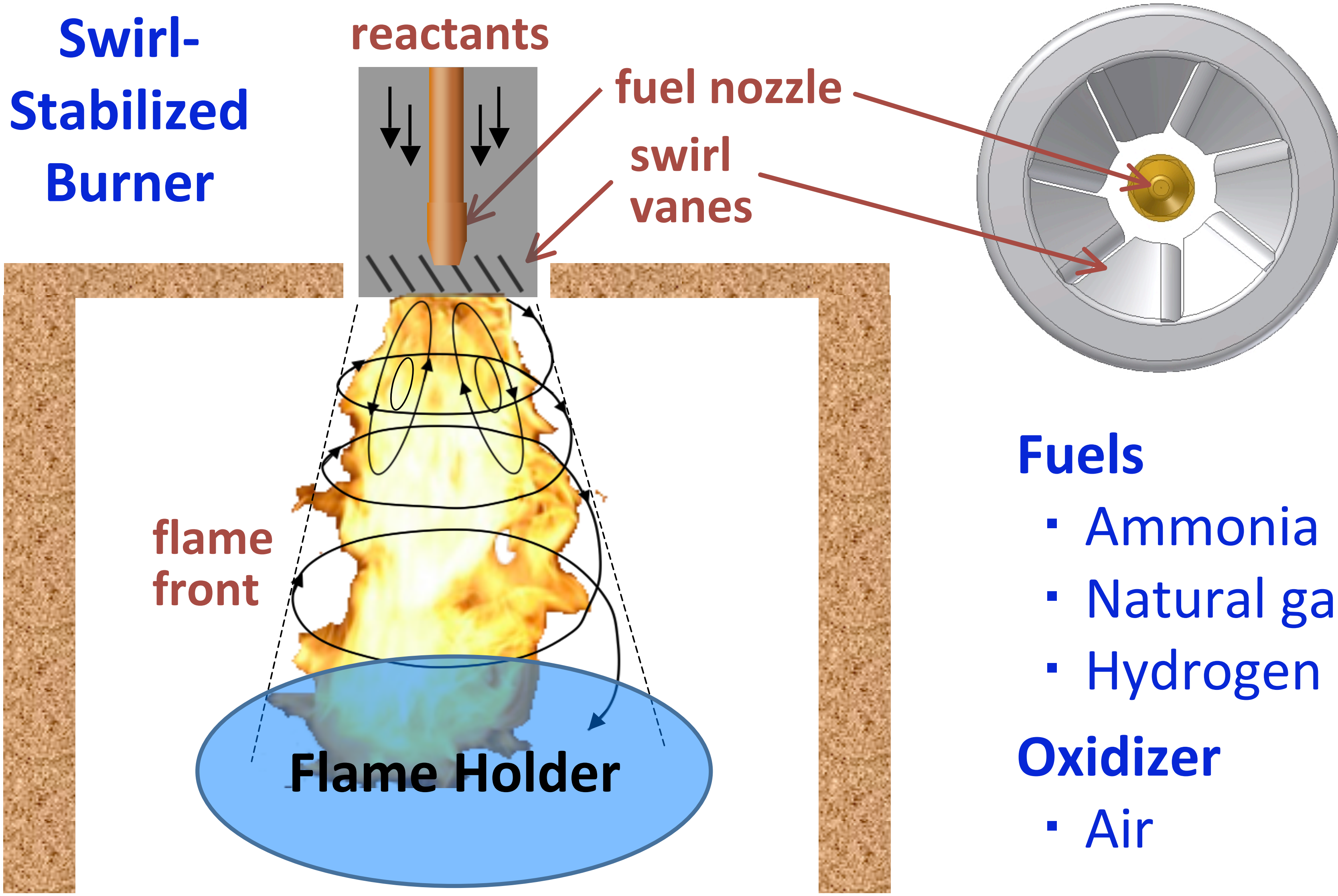
Results

Study of Natural Gas (CH_4) and Hydrogen (H_2) Replacement

- Effect of flame holder on NH3 % Energy and NOx

Experimental Set-Up

Swirl-Stabilized Burner

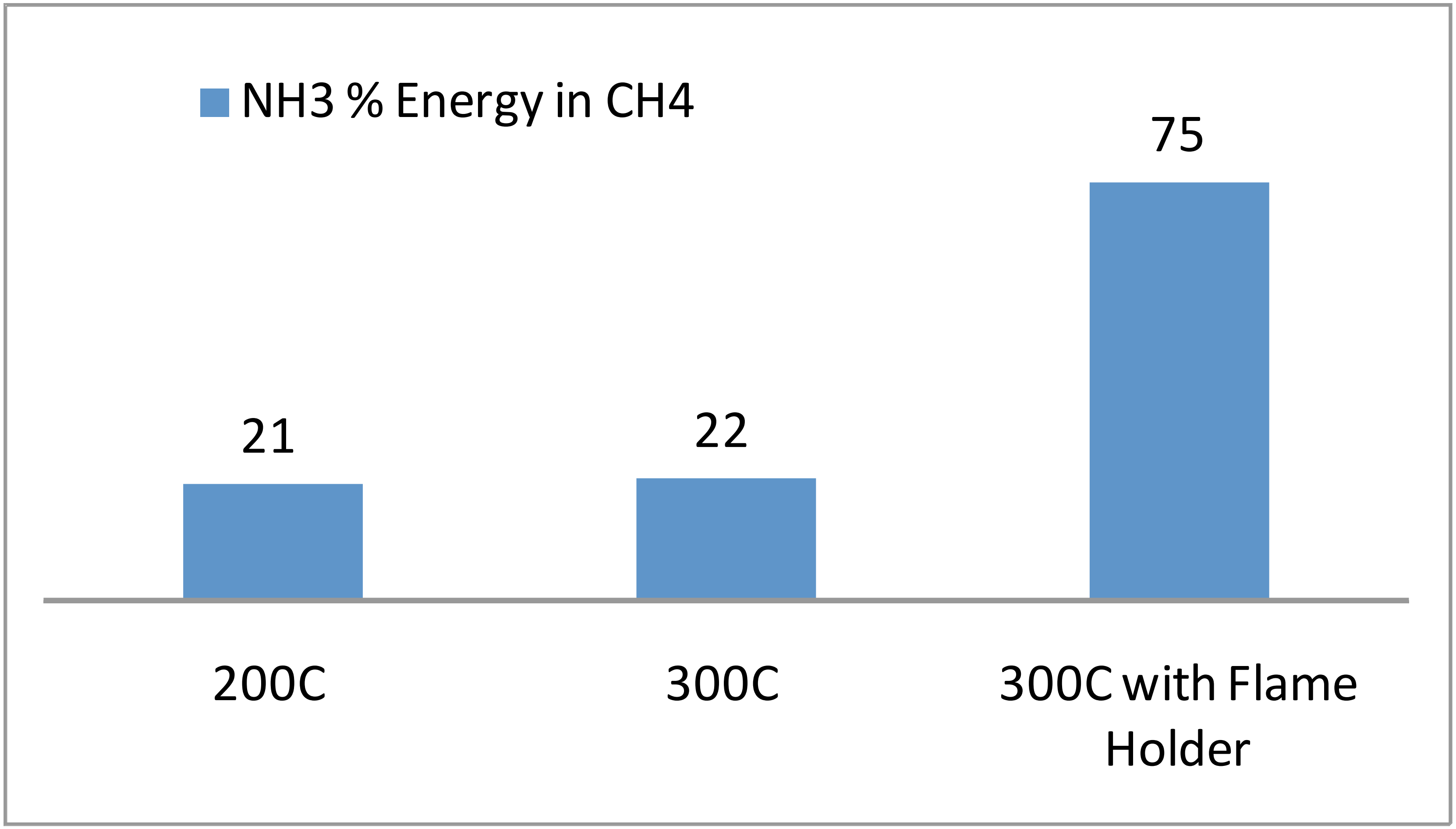


Fuels
- Ammonia
- Natural gas
- Hydrogen

Oxidizer
- Air

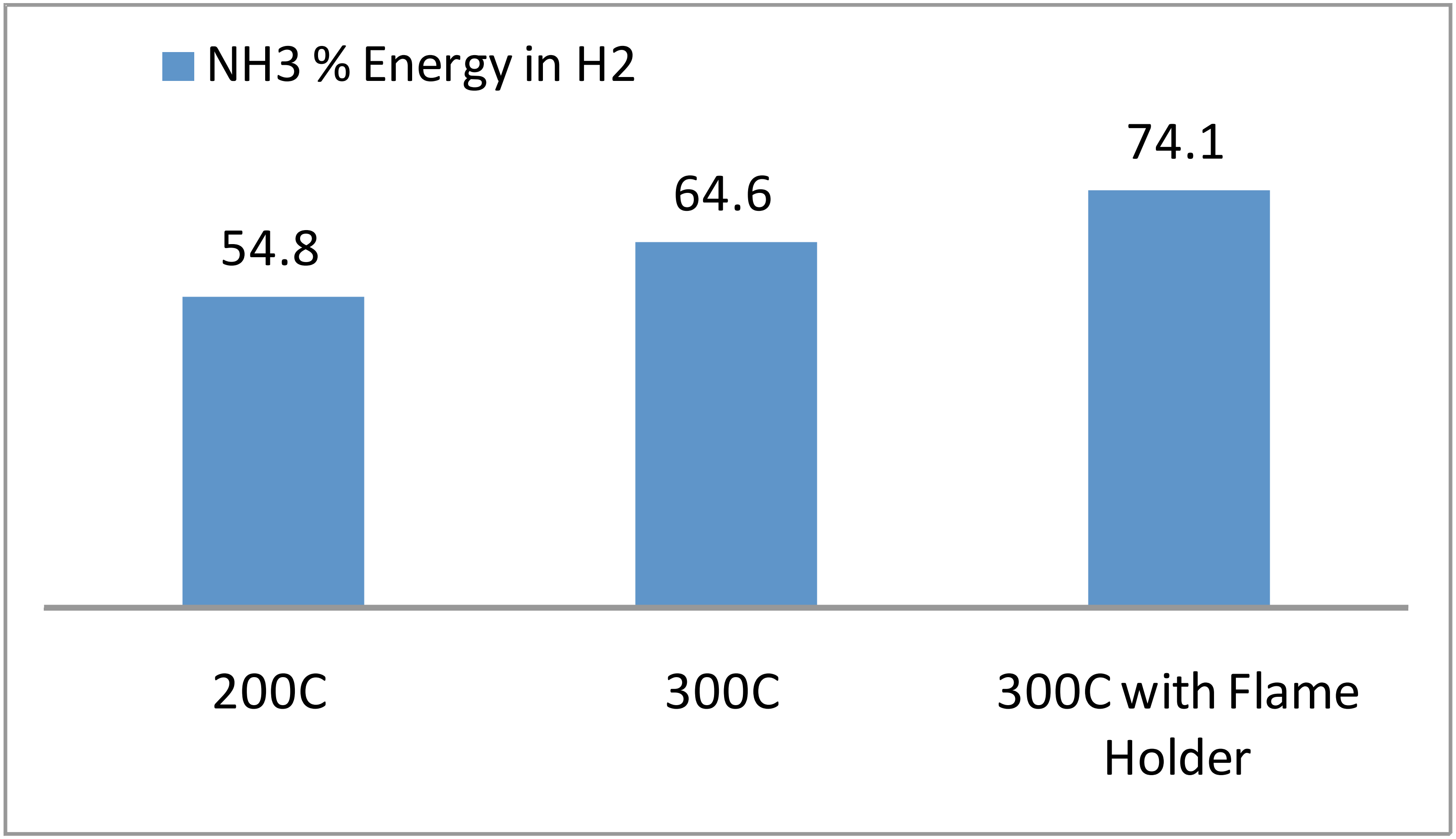
Results – Effect of Flame Holder

CH4/NH3/Air @ 12 kW (Equiv. Ratio = 1)



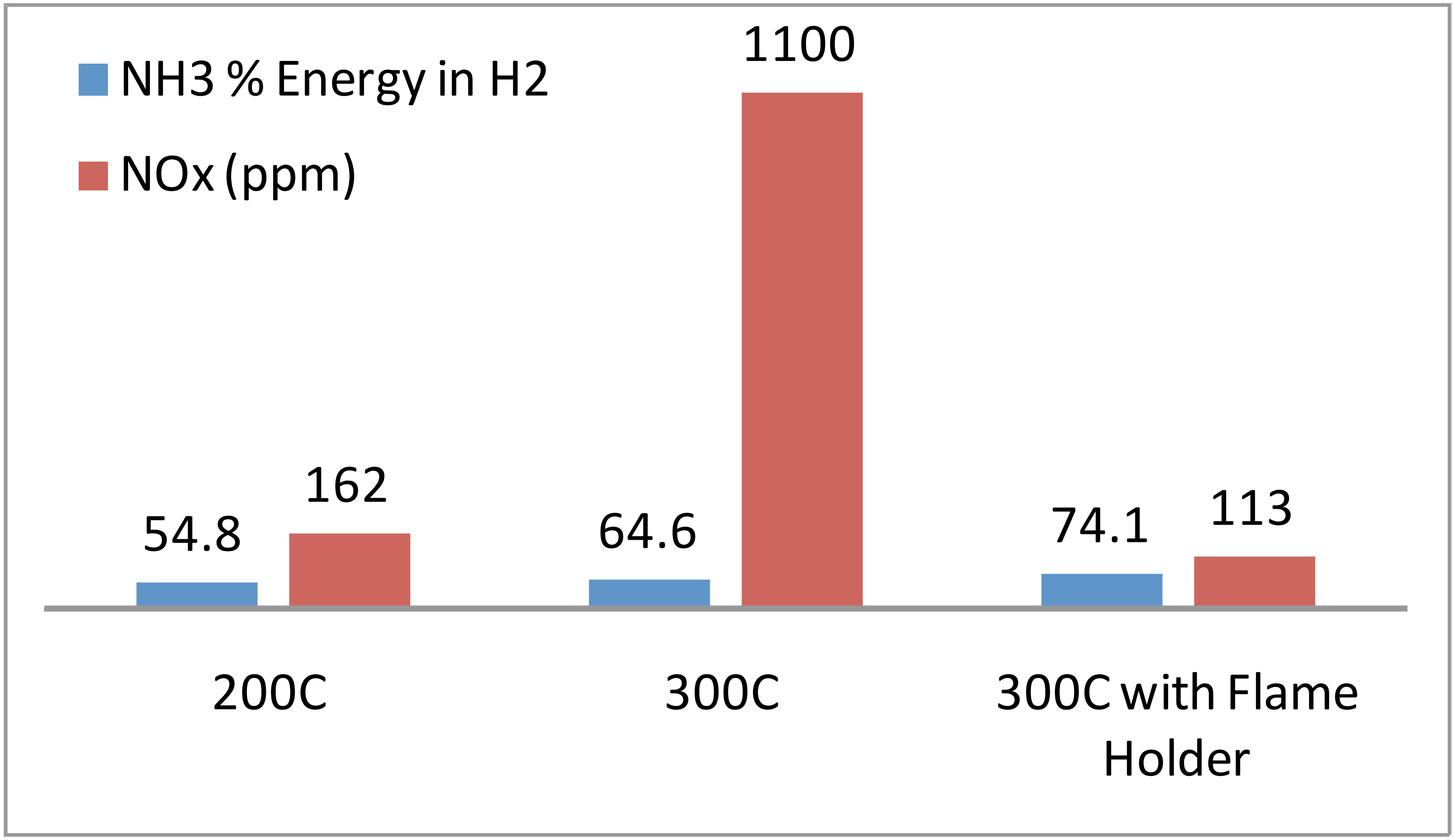
Results – Effect of Flame Holder

CH4/H2/Air @ 15 kW (Equiv. Ratio = 1)

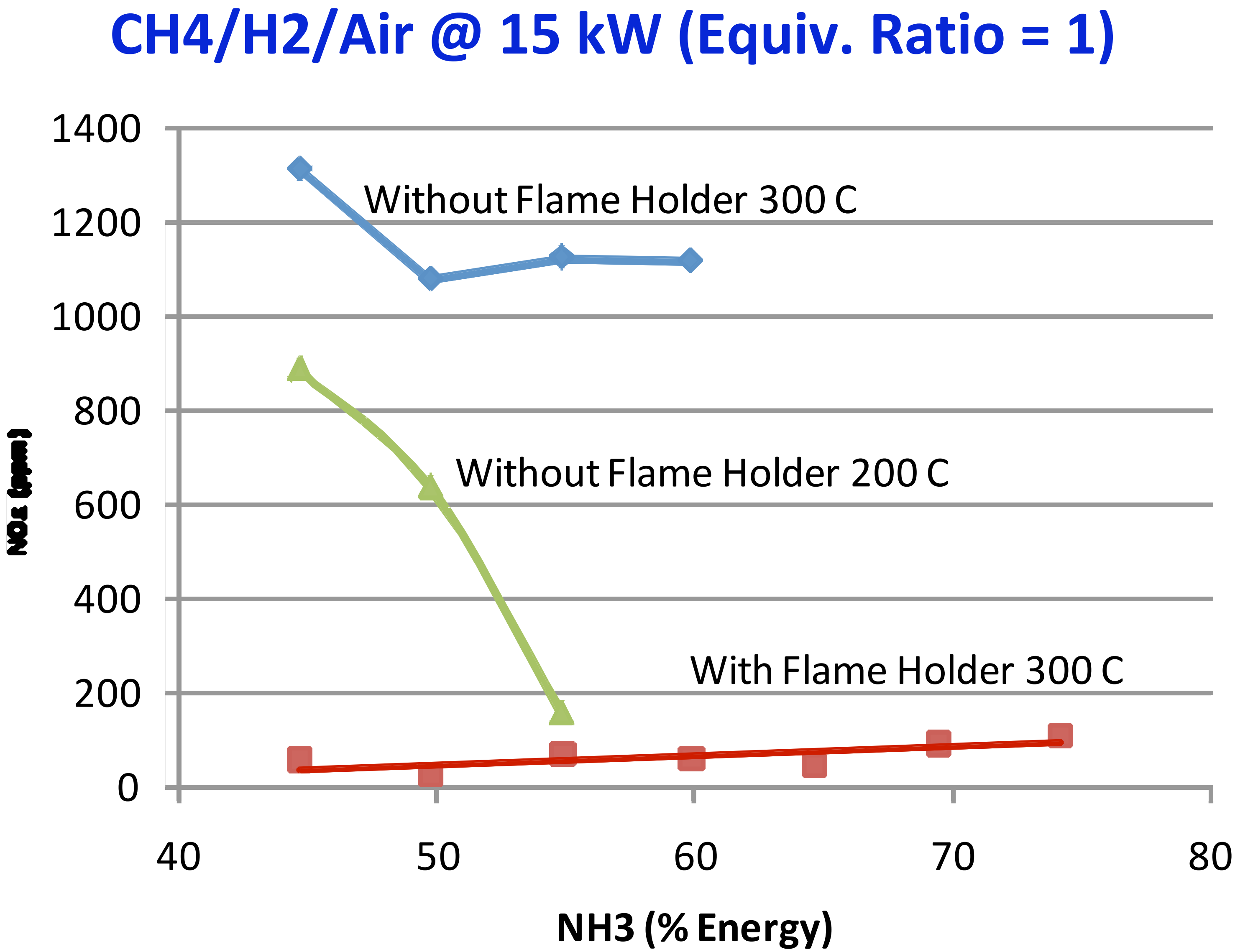


Results – Effect of Flame Holder

CH4/H2/Air @ 15 kW (Equiv. Ratio = 1)



Results – Effect of Flame Holder



Conclusions

- CH_4 replacement
  - NH_3 is tougher at higher heat rates. 20 kW feasible.
  - NH_3 replacement improves with air preheat
  - NH_3 better at fuel lean conditions, but NOx worse
  - Nozzle position critical effect on NOx
- H2 Addition
  - Air preheat has moderate effect, NOx much worse
  - More NH_3 reduces NOx with lower preheat (200 C)
- Flame holder improves NH_3 and reduces NOx

Future Work

- Refine design of chamber
- Refine design of flame holder
- Consider use of catalyst
- In-depth emissions characterization

- Combustion in furnace designed for natural gas
- Combustion in turbine combustor

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