Partial Reformation of Fuels for Combustion in Heavy-Duty Engines

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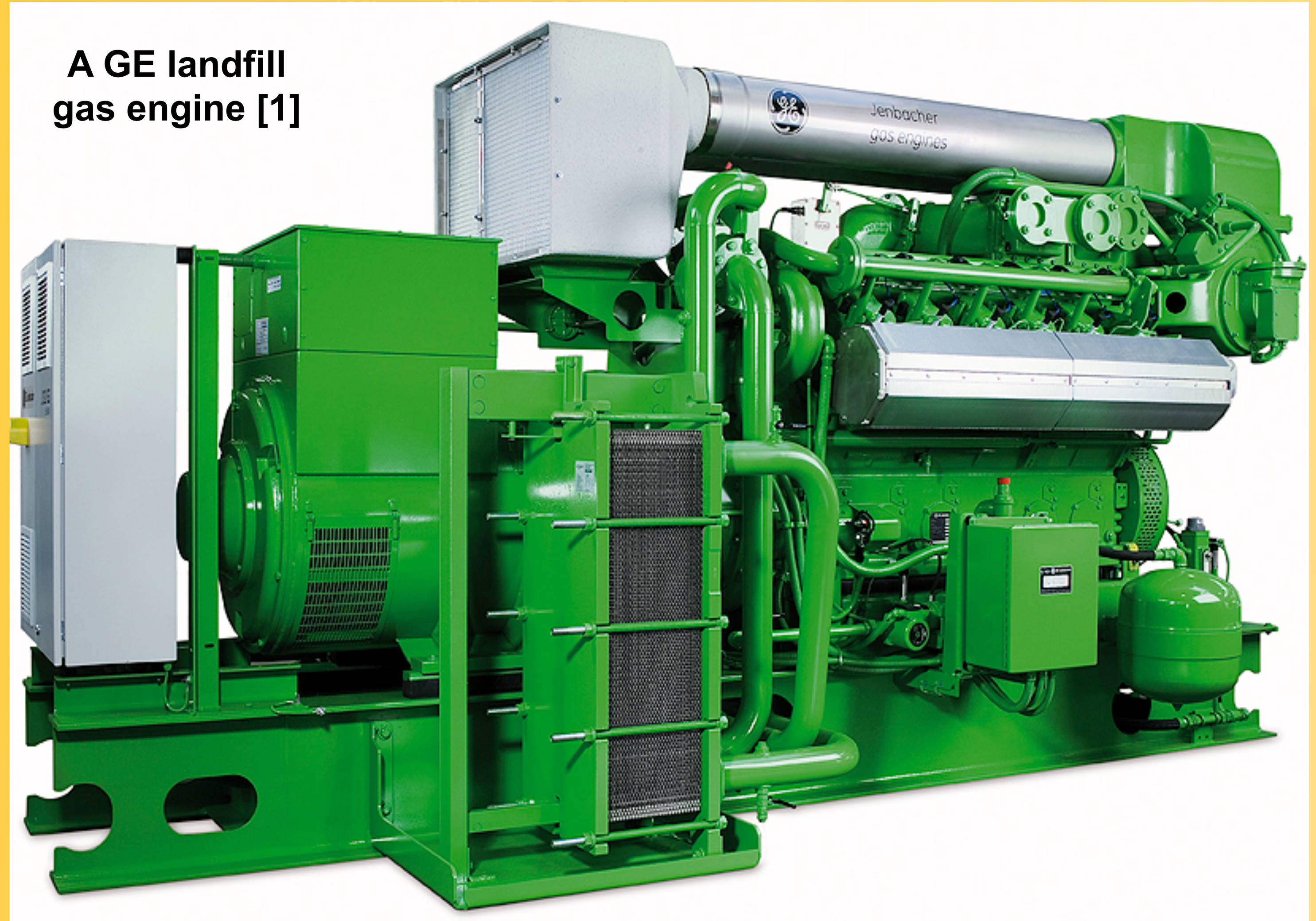
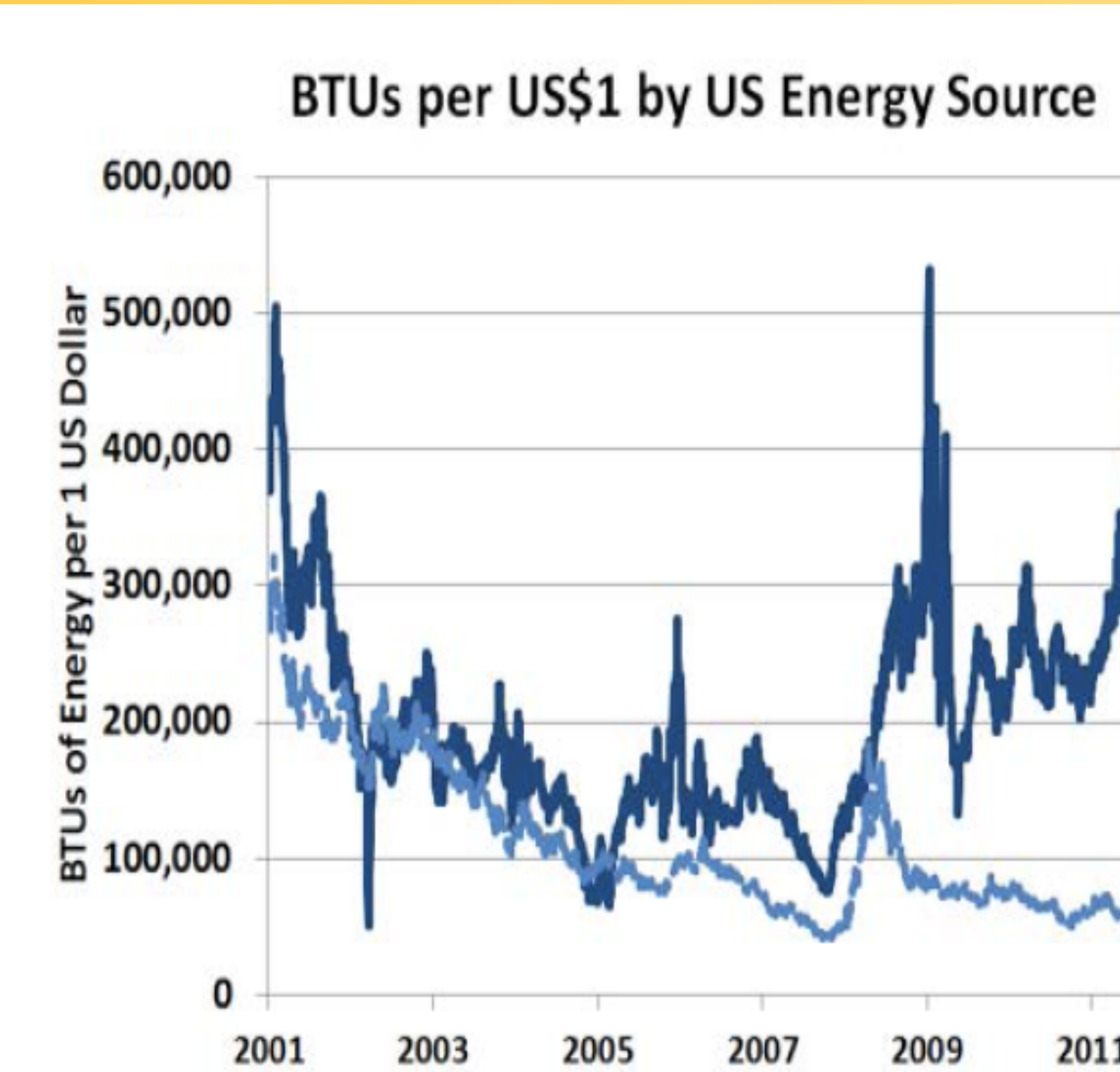
innoveering – innovative engineering solutions

Motivation

- Natural gas (NG) is an alternative fuel for power generation and transportation that is domestically available and affordable.
- NG is well-suited to spark-ignition engines (SI) because of its high octane number.
- By operating SI engines in lean conditions we can increase thermal efficiency and reduce NO_x emissions, but mixture ignitability is a challenge.
- The objective of the present work is to explore hydrogen (H_2) addition to lean natural gas-air mixtures, as a means to promote flammability and achieve lean ignition.



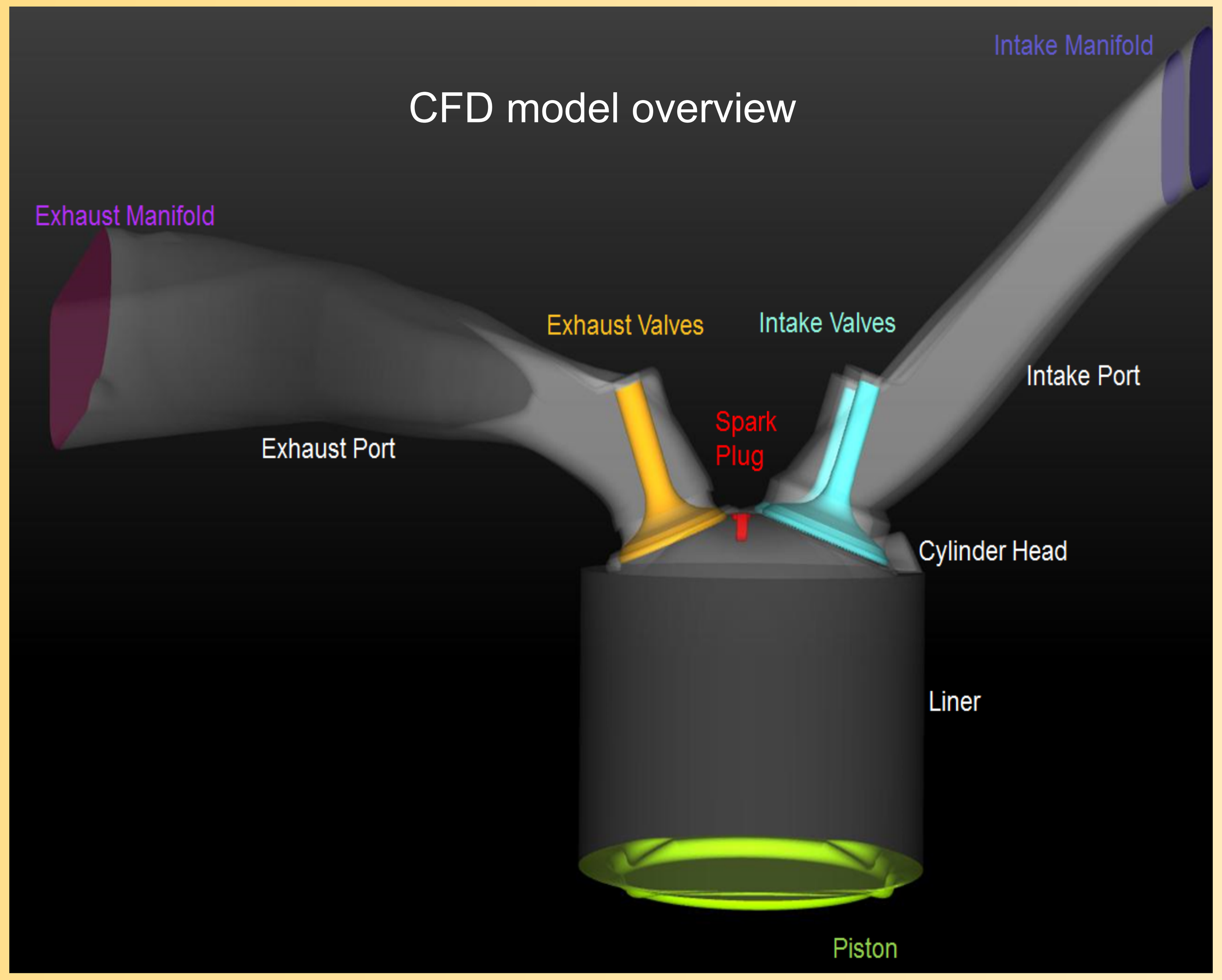
A GE landfill gas engine [1]

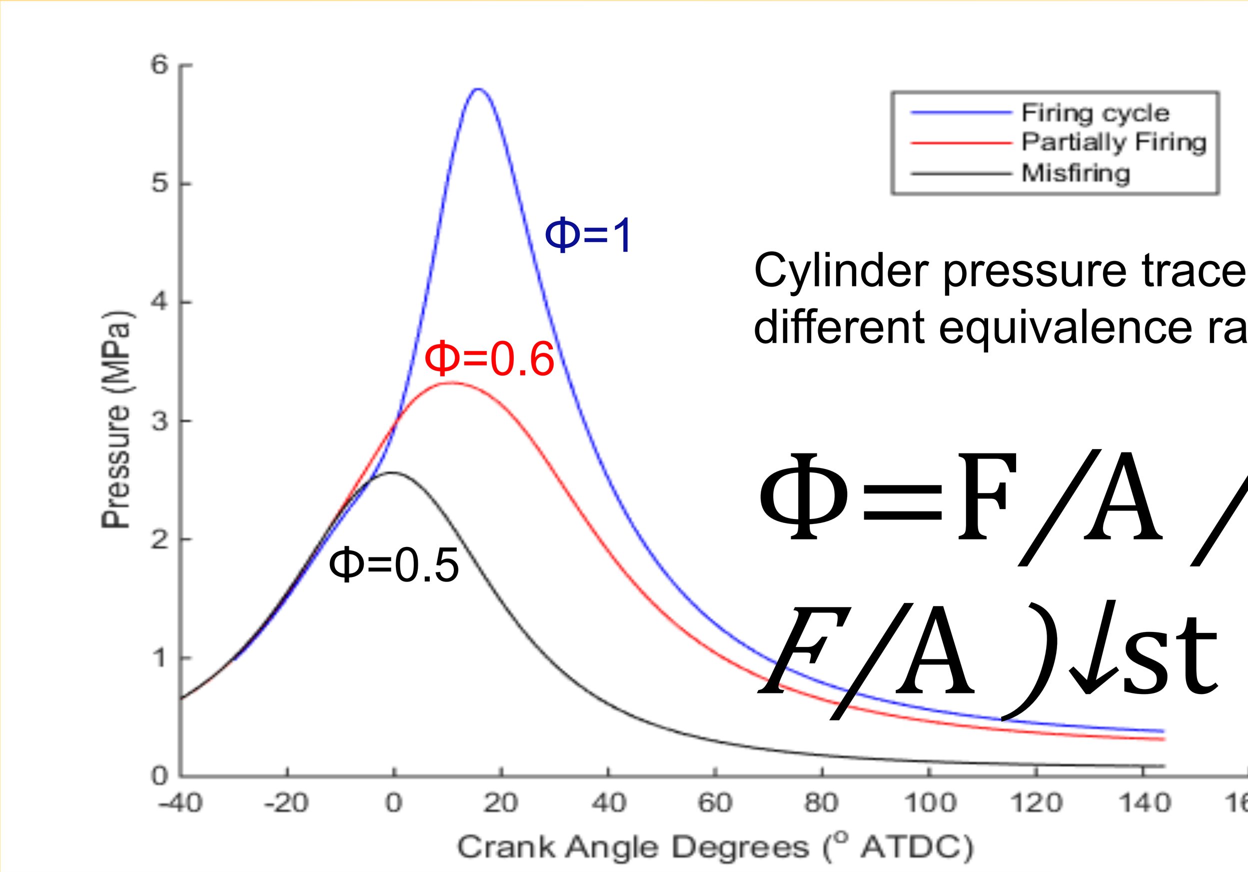


Price history NG vs Crude oil [2]

Research Methods

- Utilize a novel catalytic fuel reformer to convert part of the fuel to syngas (a mixture of H_2 and CO), that provides the H_2 needed for improving mixture flammability.
- Simulate lean NG combustion on SI engines using computational fluid dynamics (CFD) with detailed chemistry.
- Use Converge CFD as the software platform and Ensight as the visualization software. [3]
- Combine Reynolds-Averaged Navier-Stokes (RANS) flow field modeling, with combustion, heat transfer, and detailed chemical kinetics submodels. [3,4]
- Apply the METIS load balancing algorithm to increase computational efficiency and optimize parallel scalability. [5]



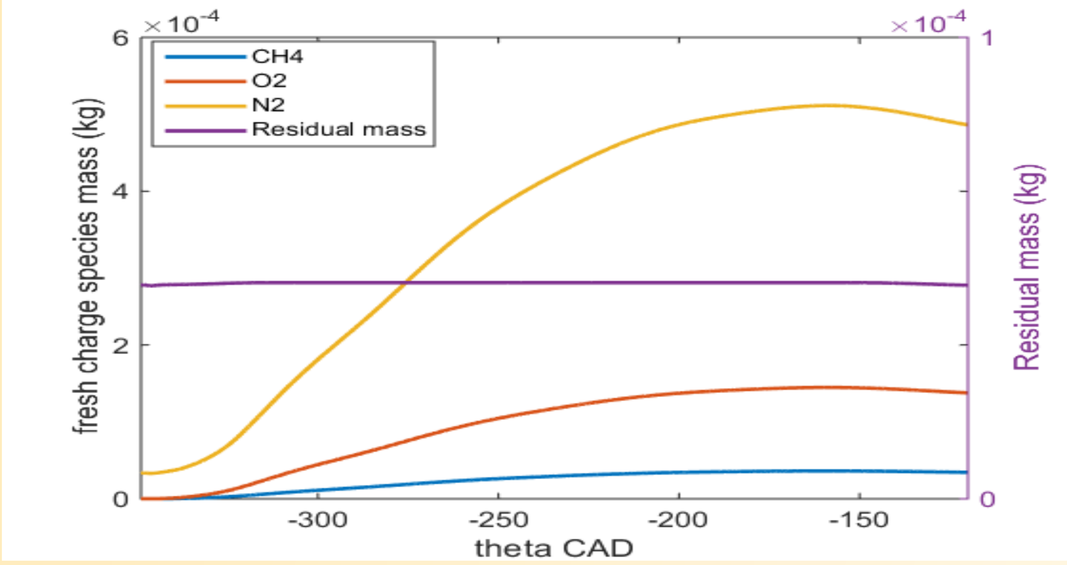


Cylinder pressure traces for different equivalence ratios

$$\Phi = F/A \,/\, (F/A)_{st}$$

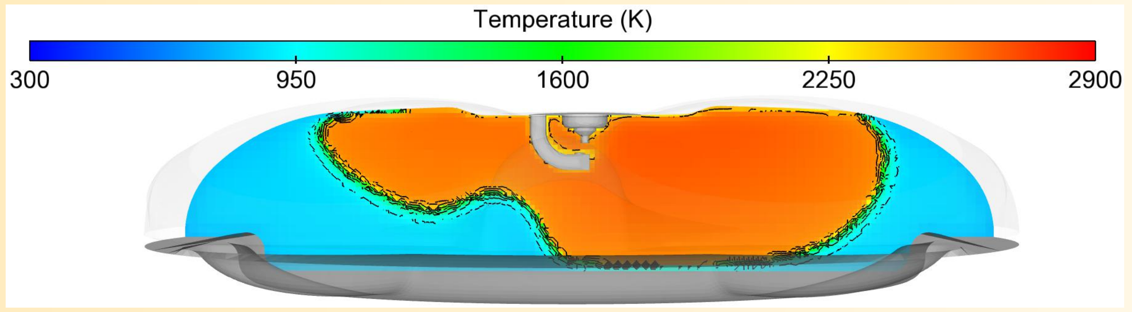
Results

- The model can simulate the full 4-X engine cycle and predict the trapped mass and residual gas fraction.
- Flame propagation is predicted with good accuracy, while capturing cylinder temperature rise from the burned gases, OH radical formation, and NOx formation using the Zeldovich mechanism.
- The lean ignition limit for premixed NG-air mixtures was identified at Φ=0.6, which agrees with experimental measurements presented in the literature. [6]

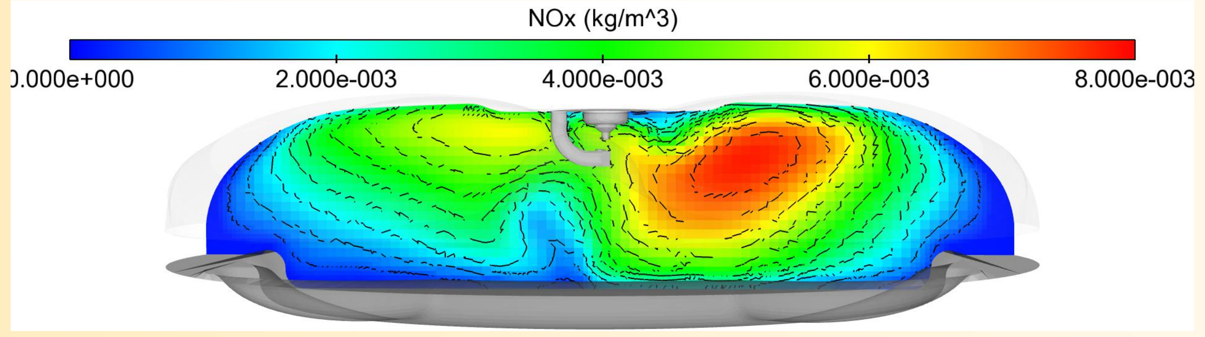


Fresh charge and residual gas mass prediction during intake

$$m_{total} = m_{air} + m_{fuel} + m_{res}$$



Temperature during flame propagation



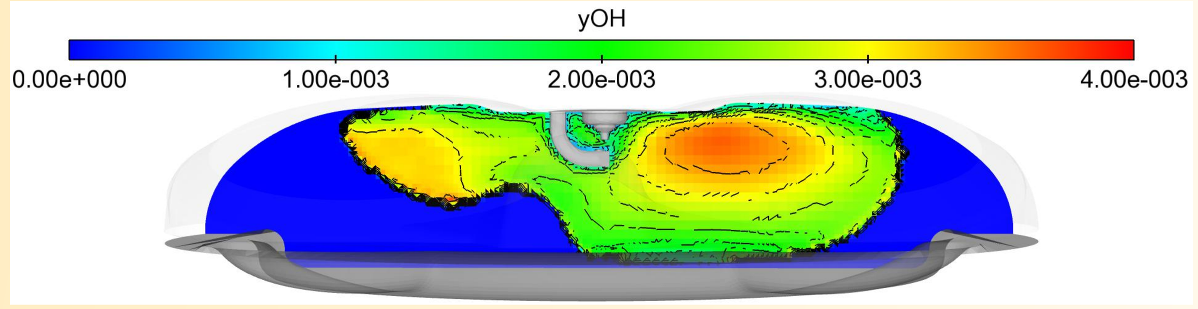
NO_x formation during flame propagation

Zeldovich Mechanism [7]:

$$O + N_2 \leftrightarrow NO + N$$

$$N + O_2 \leftrightarrow NO + O$$

$$N + OH \leftrightarrow NO + H$$



OH radical formation during flame propagation

- Future work:
  - Employ conjugate heat transfer modeling to solve for heat transfer in the cylinder walls.
  - Investigate the effect of bio-gas derived syngas addition on lean NG combustion.

References

1. EPA Landfill Gas Energy Basics Report., 2. CME Economics (2014) 3. Richards et al. Converge v2.2.0 (2014), 4. Issa et al. *Journal of Computational Physics*, Volume 62, 1986, 5. Karypis et al. METIS -- Unstructured Graph Partitioning and Sparse Matrix Ordering System, Version 2.0 (1995), 6. Singh et al. SAE 2014-01-2431, 7. Internal Combustion Engines Fundamentals, J. B. Heywood (1988)

EnSight

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