Fuel-Induced System Responses The Role Unconventional Fuels May Play in Altering Exhaust Conditions from Conventional and Low Temperature Modes of Combustion

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MECHANICAL ENGINEERING

Objective

The objective of this presentation is to highlight potentially changing exhaust conditions (temperature, flow rate, and species) resulting from different fuels (petroleum diesel and biodiesel) and different modes of combustion (conventional and low temperature modes of combustion).

Basic Outline

- How does fuel change exhaust conditions?
  - Engine system responses
  - Fundamental responses

- How does mode of combustion change exhaust conditions?

- Opportunities to predict NO concentrations via pressure-based feedback control?

Background (System Responses)

A system response is that manifested by a difference in fuel property on the engine or one of its systems; system responses depend on the design of the system.

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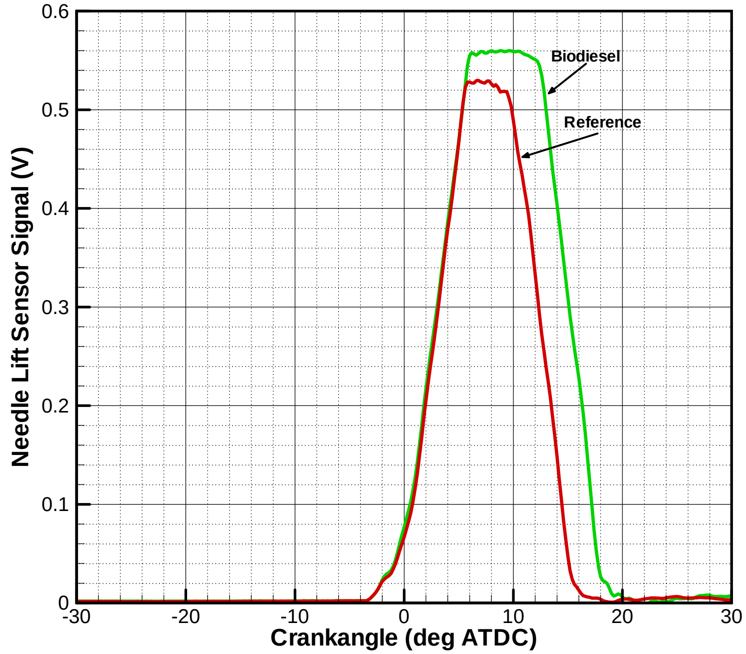
Indirect System Response

Difference in fluid property manifests a change in engine behavior, leading to indirect changes to combustion and exhaust conditions.

- Higher bulk modulus leads to advance in injection timing
- Lower exhaust temperatures lead to differences in boosting capabilities

A lower heating value, in spite of a slightly higher density, requires a longer injection pulsewidth to deliver roughly the same amount of energy, to deliver the same brake torque.



Controlled System Response

The necessarily higher / longer injection profile (to match engine torque) manifests a change in a controlled parameter.

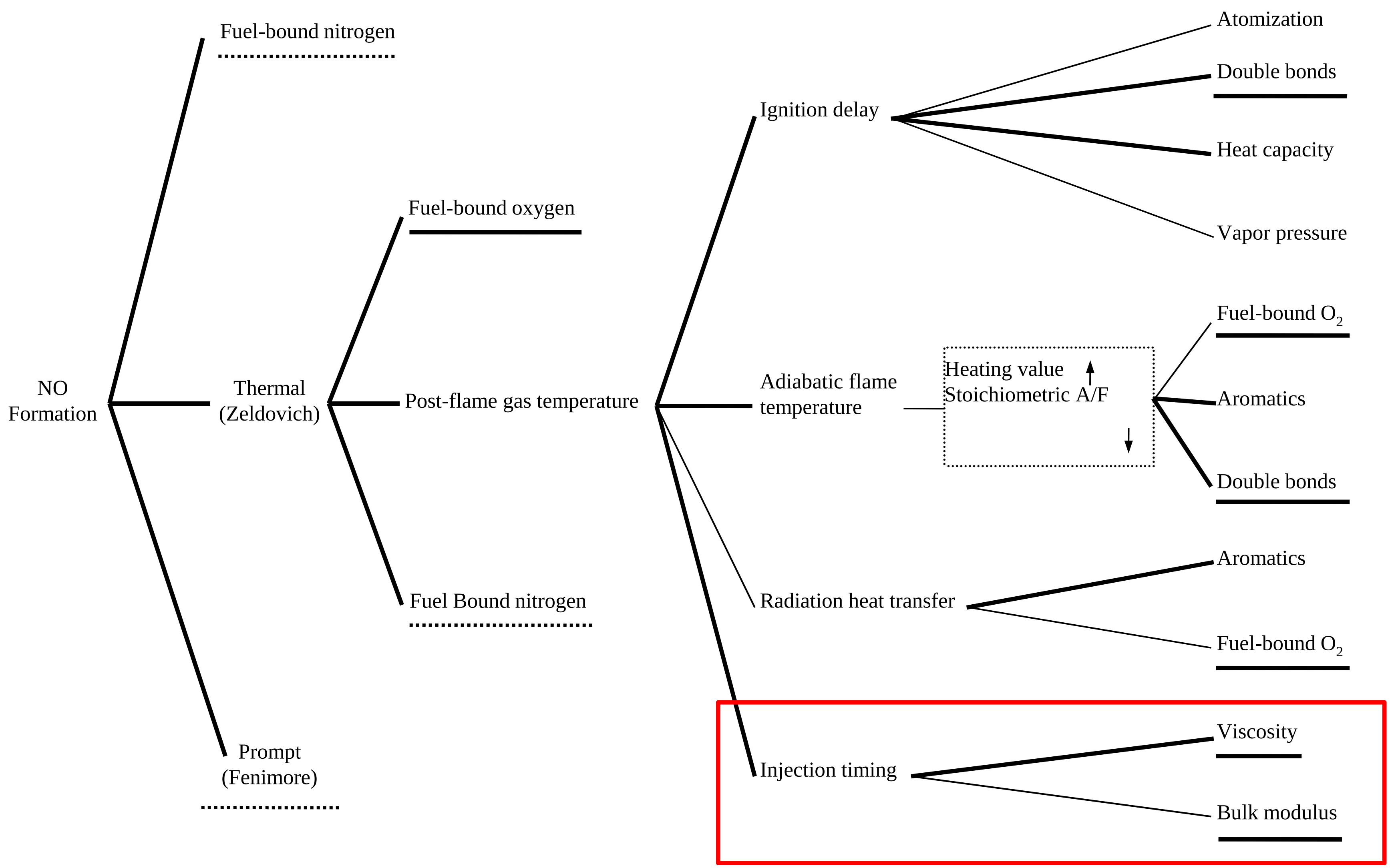
- All controlled parameters could be adjusted, including, a) injection timing, b) rail pressure (if applicable), c) EGR level (if applicable), and d) VGT vane setting (if applicable).

Background (Fundamental Responses)

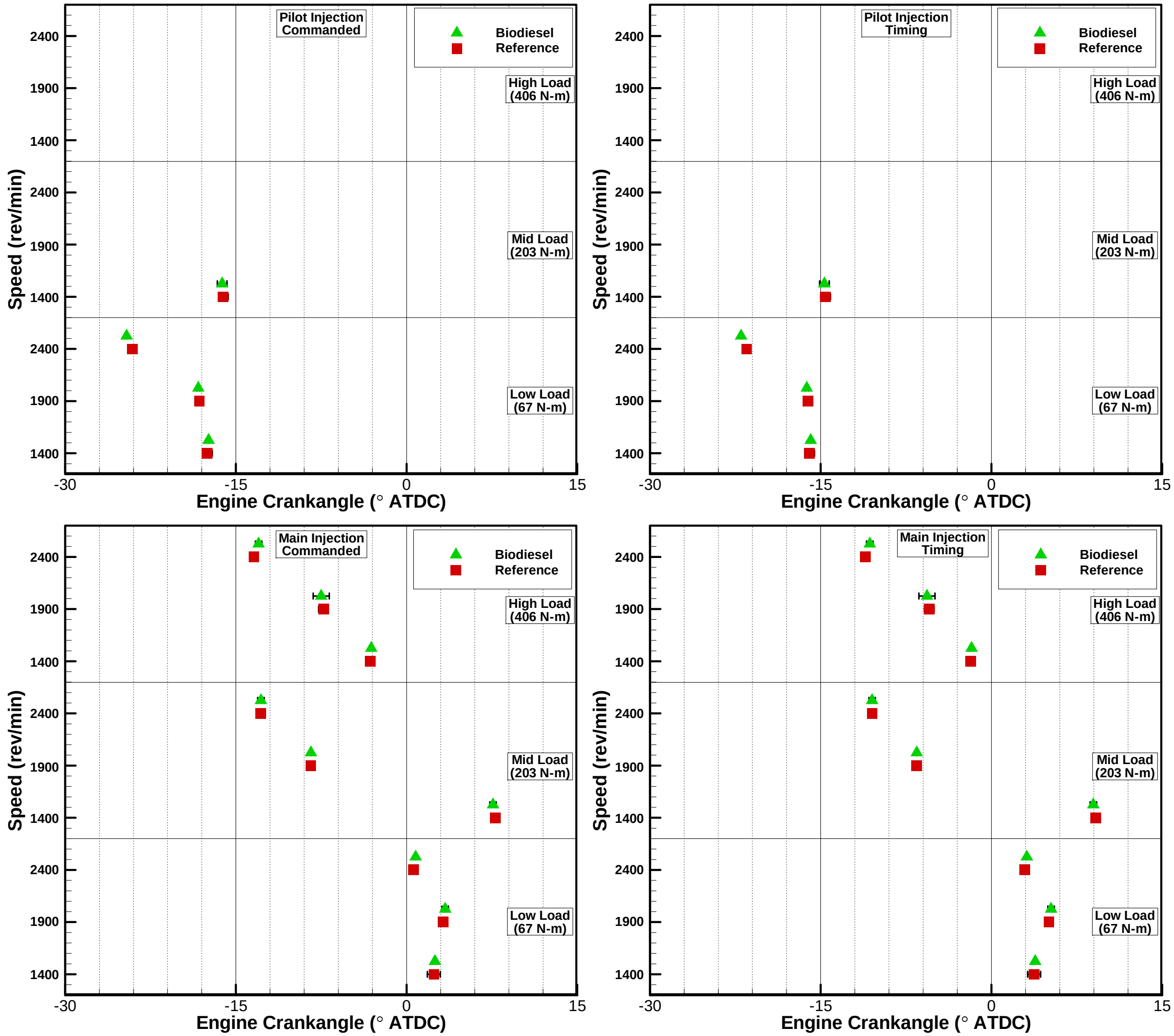
A fundamental response is that manifested by a difference in fuel property directly on the in-cylinder fundamental processes (such as combustion, emissions formation, and thermodynamics); fundamental responses depend on the “design” of the fuel.

Origins of NO Changes

“Biodiesel NOx penalty” provides a good example for describing the basis of a system response versus a fundamental response.

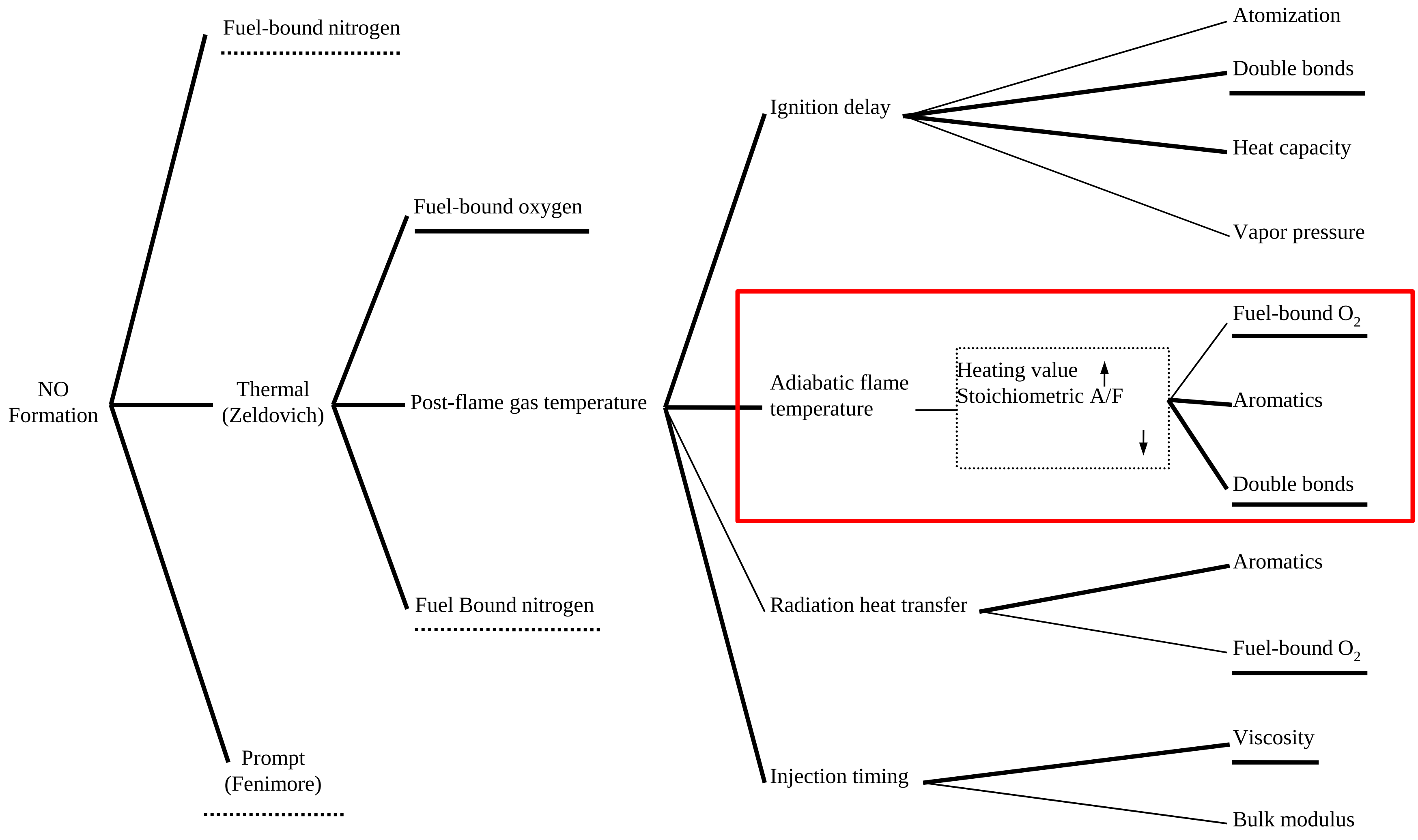


Influence of Injection Timing

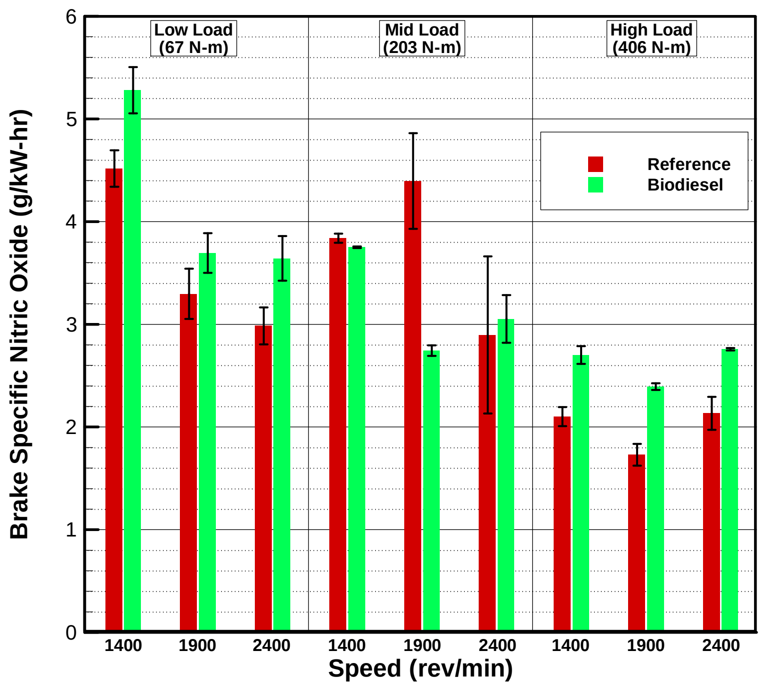


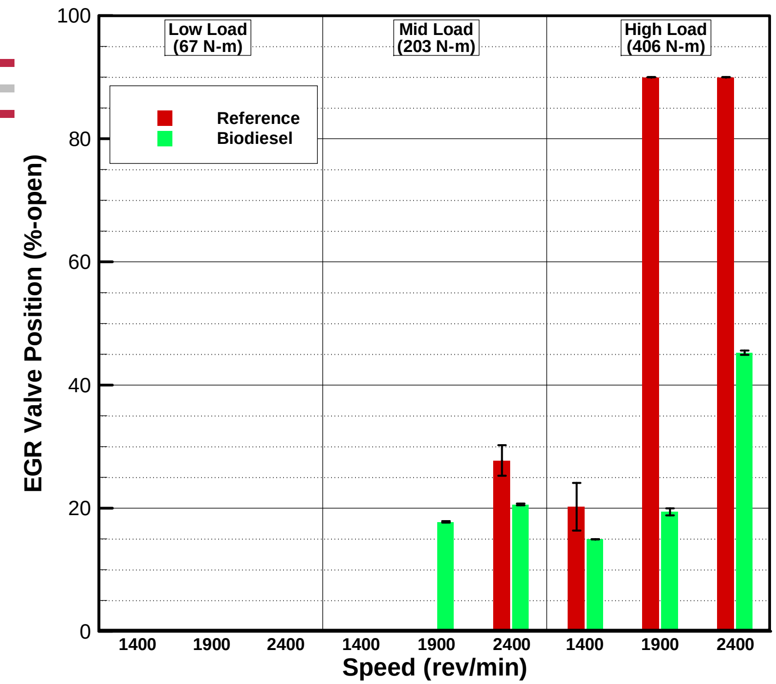
A parameter such as injection timing is really a “system-response” since it depends on the design of the system.

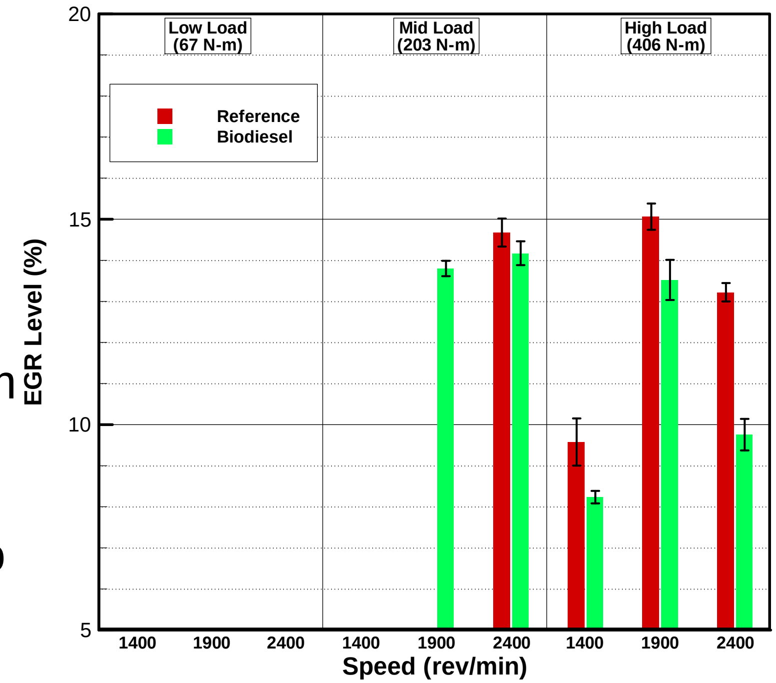
Origins of NO Changes



Biodiesel and Petroleum Diesel



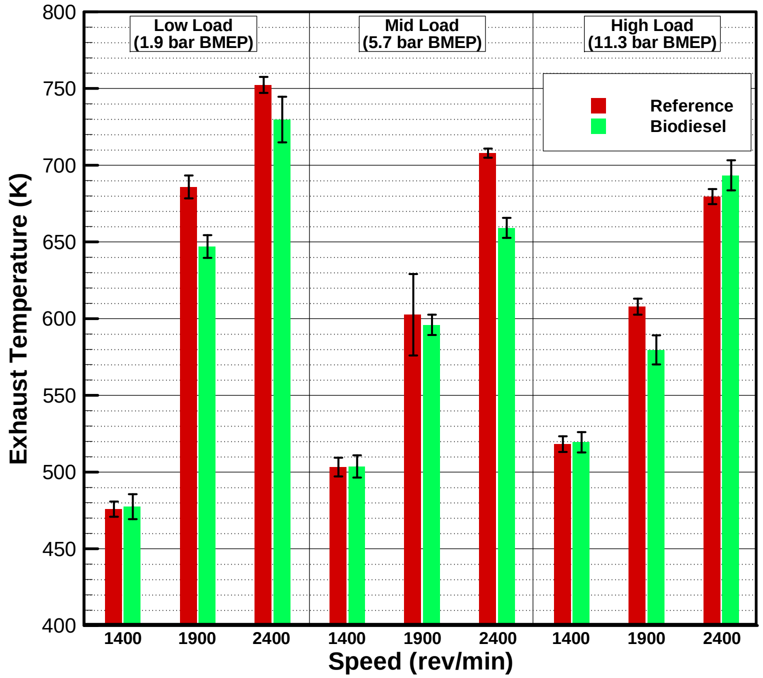


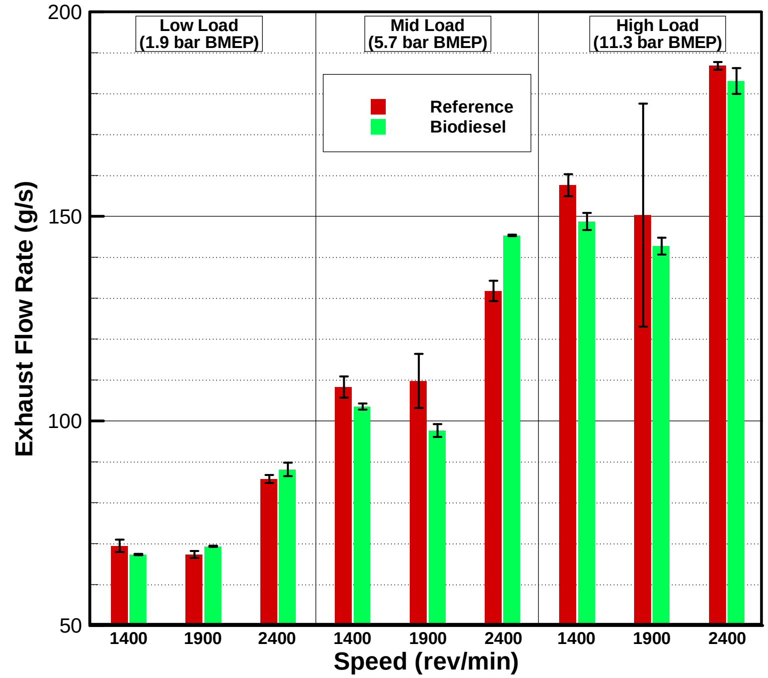


Biodiesel NO tends to be higher, due to the fundamental response of relatively leaner premix reaction zones of biodiesel compared to petroleum diesel.

In this engine, however, system responses tend to cause lower NO emissions with biodiesel.

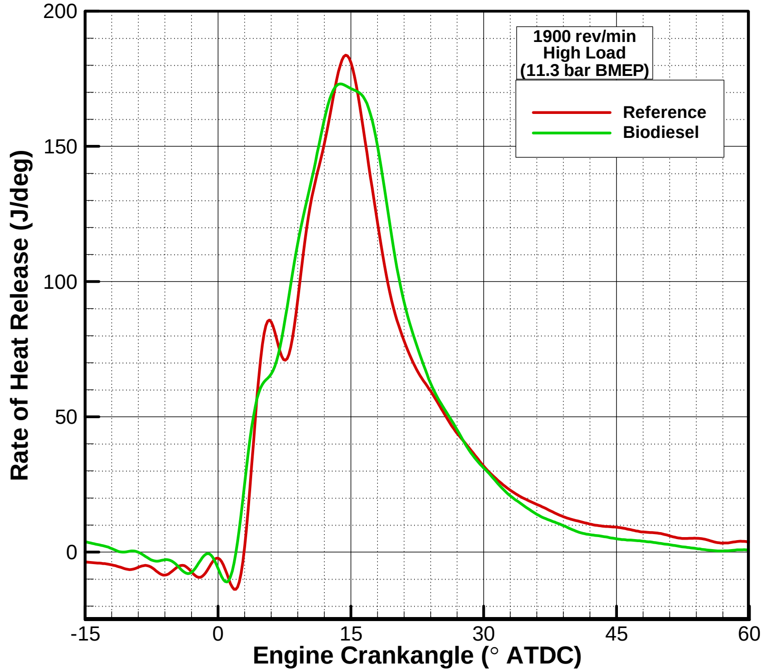
Biodiesel and Petroleum Diesel

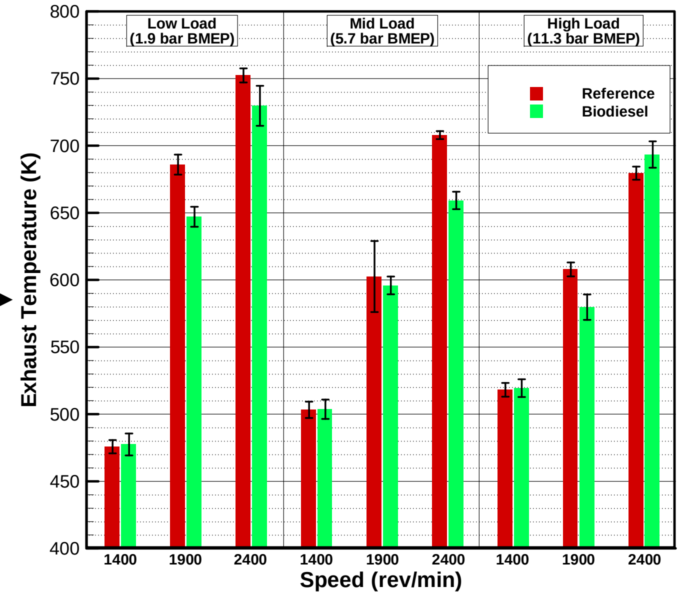


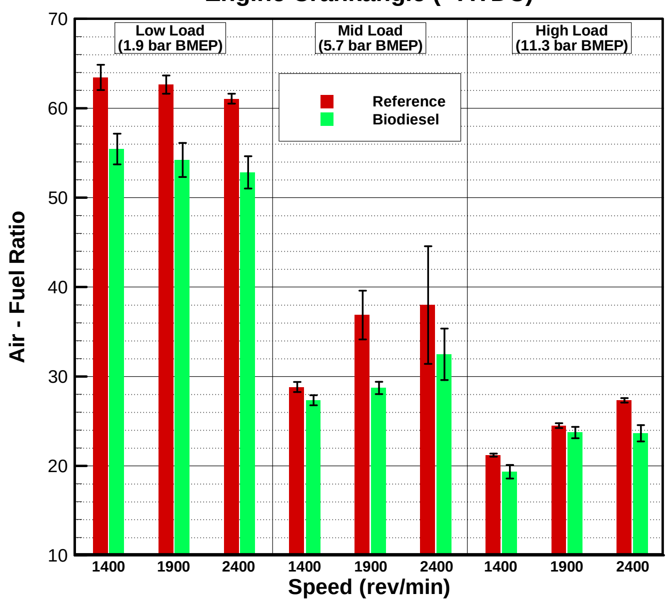


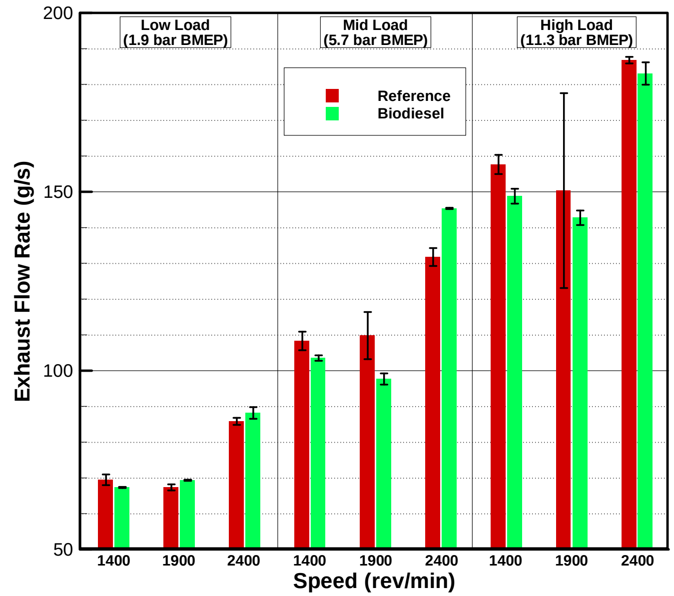
Typically, biodiesel will tend to have lower exhaust temperatures, but perhaps roughly the same the same exhaust flow rates. This may translate to slightly lower exhaust enthalpy.

Biodiesel and Petroleum Diesel

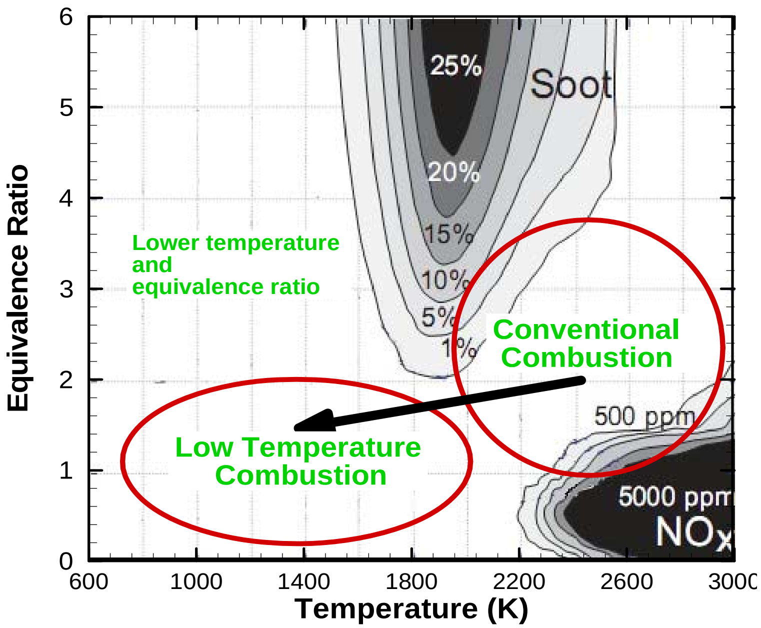


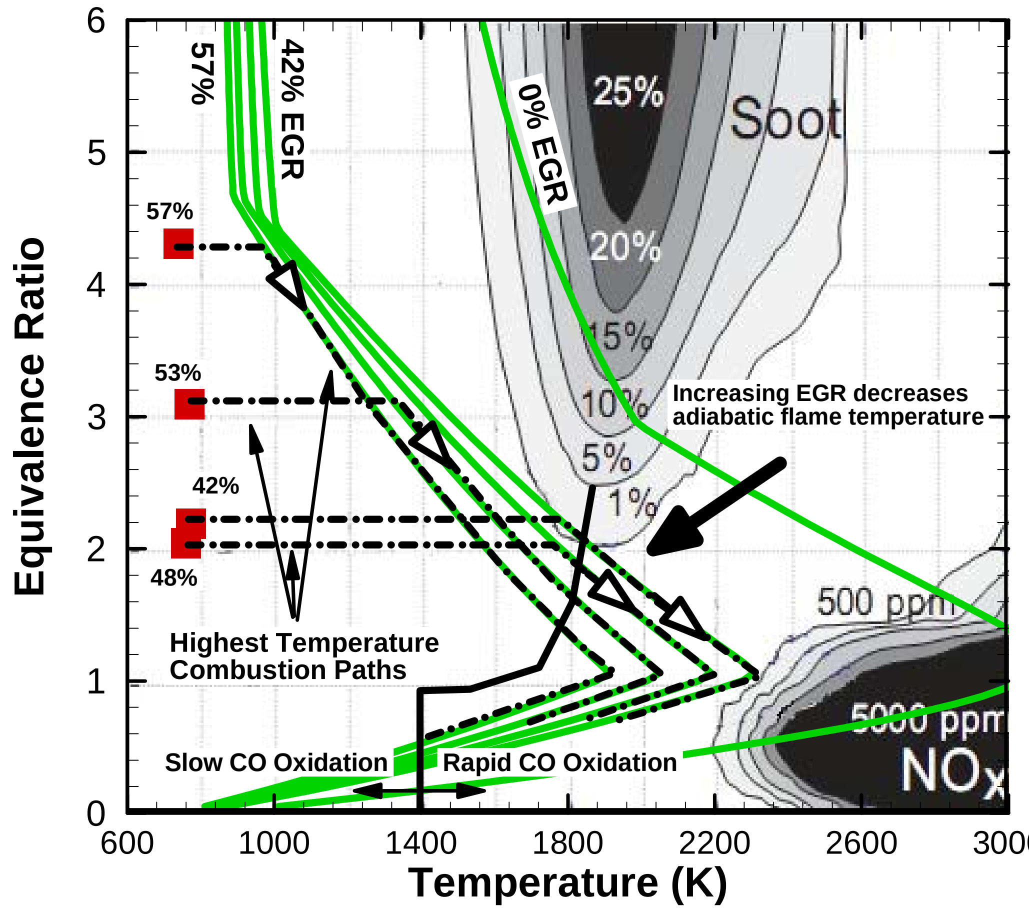






Background (Low Temperature Combustion)

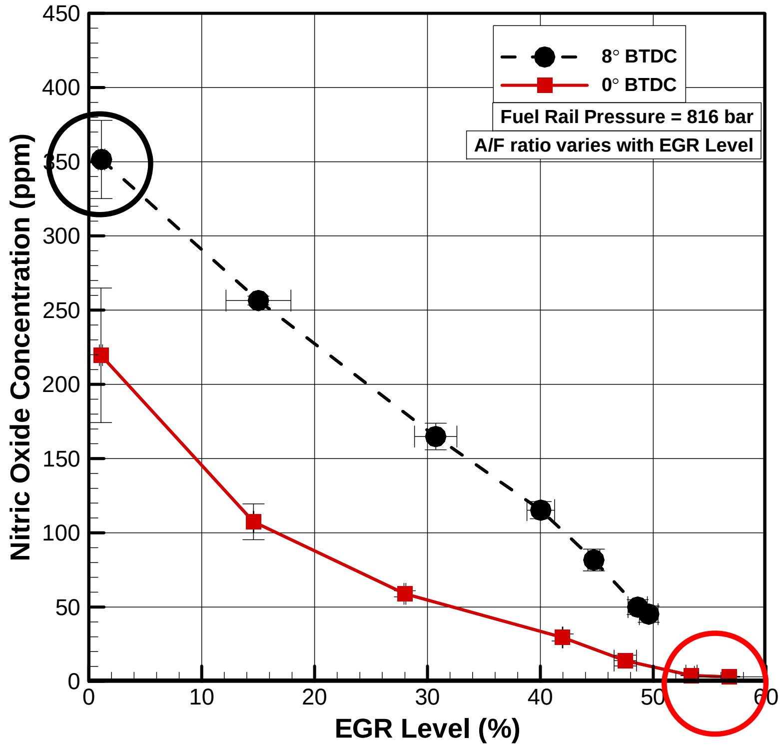


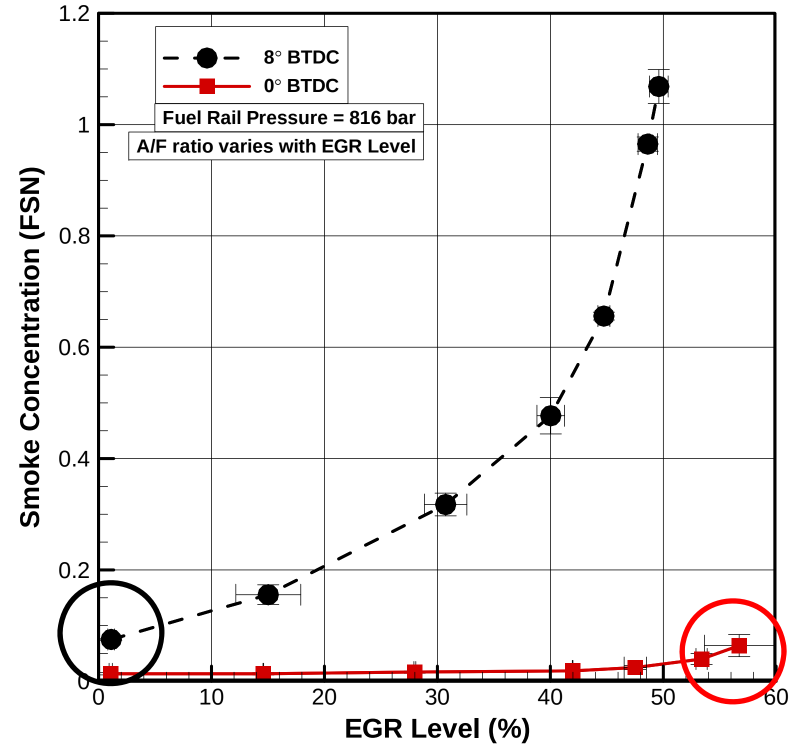


Data overlaid on work adapted from [1] based on work done by [2].

[1] Kitamura, T. et al., 2003, SAE Transactions - Journal of Fuels and Lubricants, 112(SAE Paper No. 2003-01-1789).
[2] Kamimoto, T. et al., 1988, SAE Transactions – Journal of Engines, 97(SAE Paper No. 880423).

Low Temperature Diesel Combustion



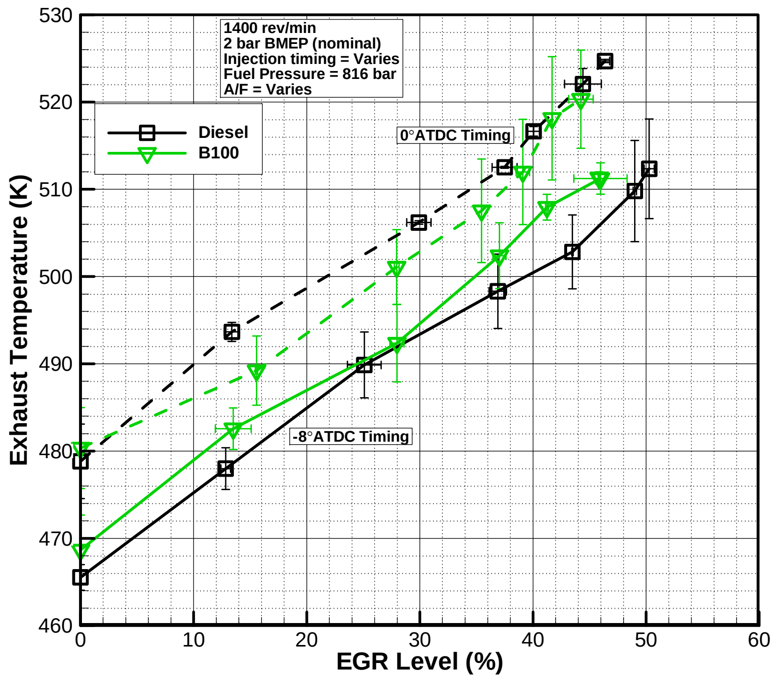


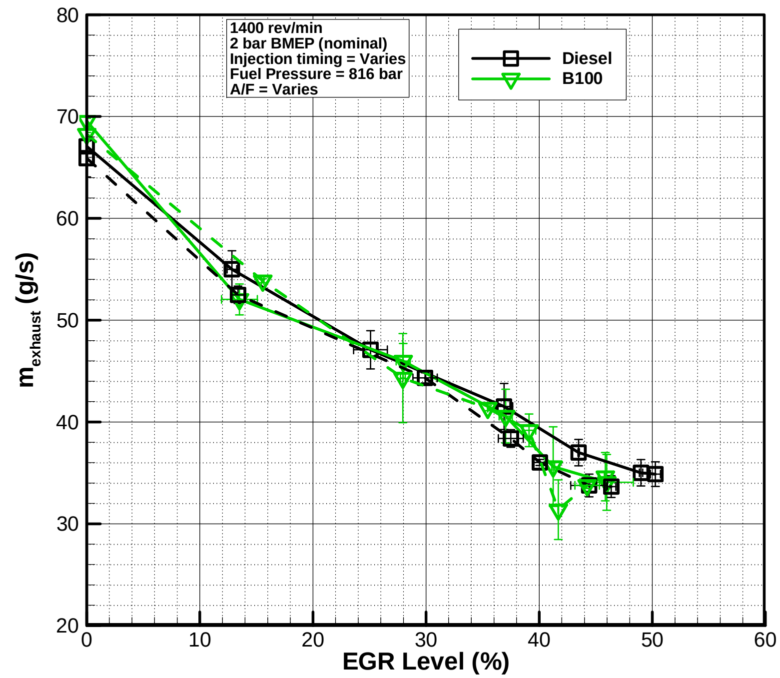
- Conventional Diesel Combustion

- Low Temperature Diesel Combustion

Low temperature combustion is able to simultaneously reduce NO and soot concentrations, the latter of which is the "building block" for PM.

Combustion Effect



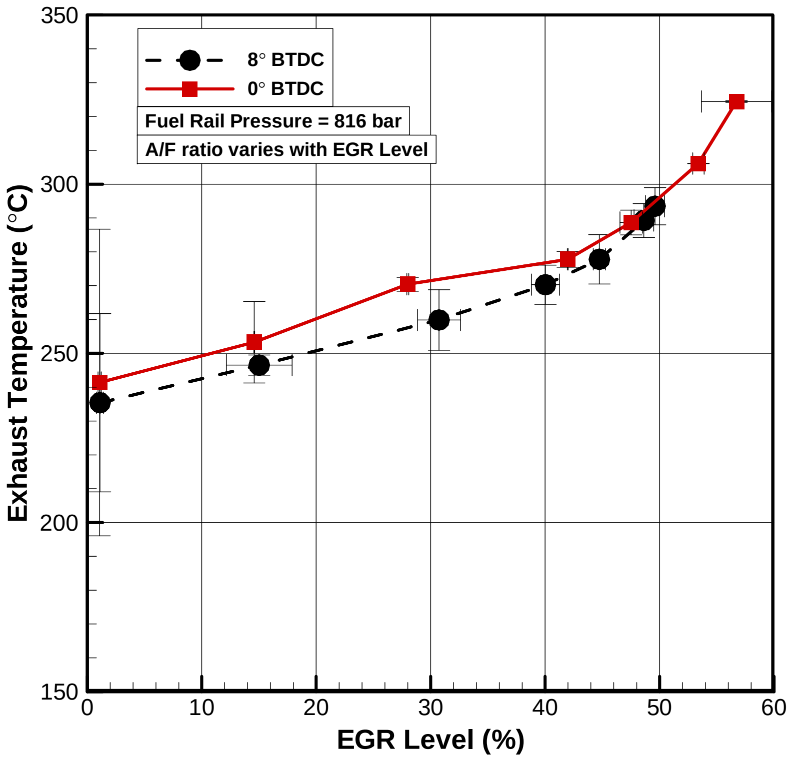


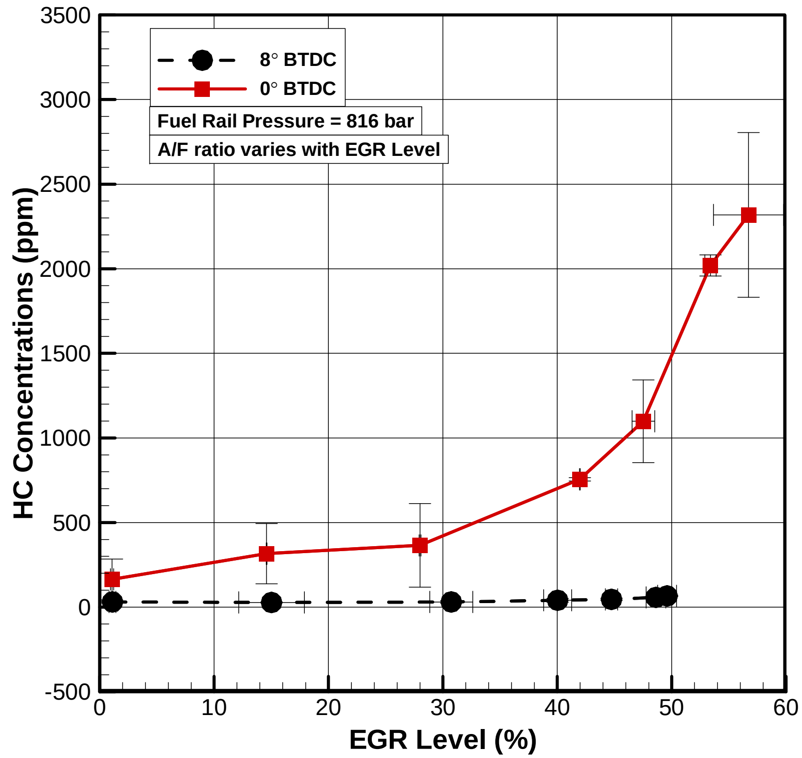
Generally, approaching “ultra-clean” combustion modes results in a decrease in exhaust energy (although temperature increases, exhaust flow rate decreases).

In the case of EGR, exhaust temperature increases (later phased combustion), but exhaust energy flow rate decreases as mass flow rate decreases.

A Challenge and an Opportunity

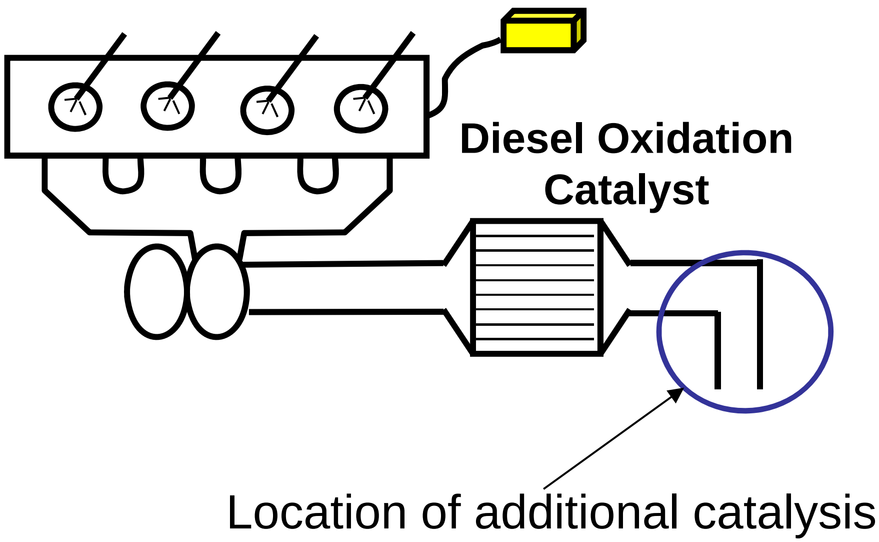
- Mostly due to combustion phasing, and in spite of its name, low temperature diesel combustion may actually yield higher exhaust temperatures (but lower exhaust flow rates) than conventional combustion.
- One challenge facing low temperature diesel combustion is its excessively high HC (and CO) concentrations. But this may create an opportunity. . .

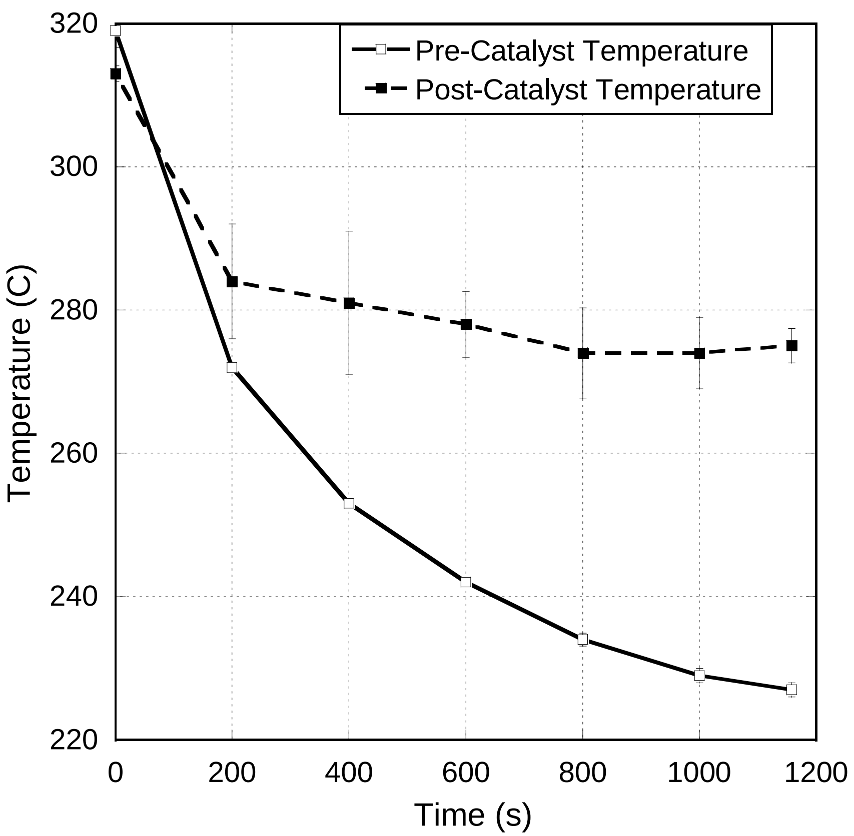




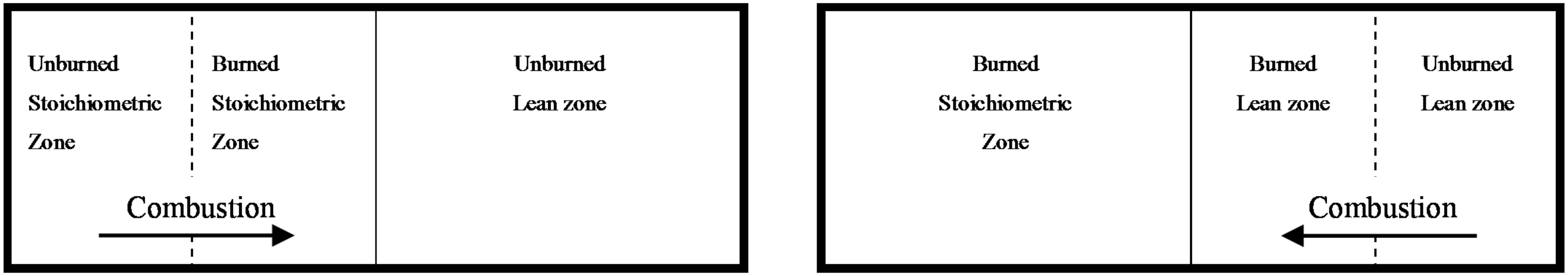
Exhaust Exotherm to Support Catalysis

- The use of a diesel oxidation catalyst, with primary purpose to reduce low temperature diesel combustion hydrocarbon and carbon monoxide concentrations, also provides exothermic heating of the exhaust.
- Such action could improve the combination efficiency of a clean low temperature diesel engine / after treatment system.





Model Description(Assumptions)



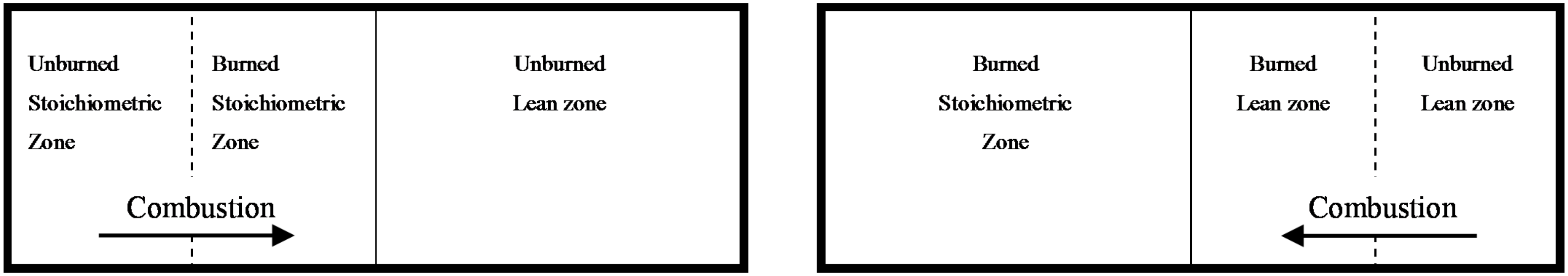
(a) (b)

Figure 1: Schematic of combustion at each stage: (a) the first stage; (b) the second stage

- Model is based on Szekely and Alkidas[1]
- Cylinder is divided into two main zones, each with two sub-zones. Heat release occurs in two stages. During the burning of a stage, one zone transfers between its two sub-zones while the second zone remains inactive (acts like a non-participating ideal gas zone).
- When one stage of burning is complete, the heat release occurs in the second zone with the second stage burning.
- The scheme is meant to improve mixture temperature prediction for NO calculation; it's not meant to physically represent diesel combustion.

[1] Szekely, G., Alkidas, A. (1986). SAE 861272

NO Modeling via Two-Stage Heat Release



(a) (b)

Figure 1: Schematic of combustion at each stage: (a) the first stage; (b) the second stage

- In Szekely and Alkidas[1], what is here called the "stoichiometric zone" they called the rich zone (but took phi = 1). Variation of phi above 1 for the "rich zone" results in diverging solutions.
- Consequently, $\text{phi}_{\text{stoichiometric zone}} = 1$, and $\text{phi}_{\text{lean zone}}$ is given by the following correlation[1]:

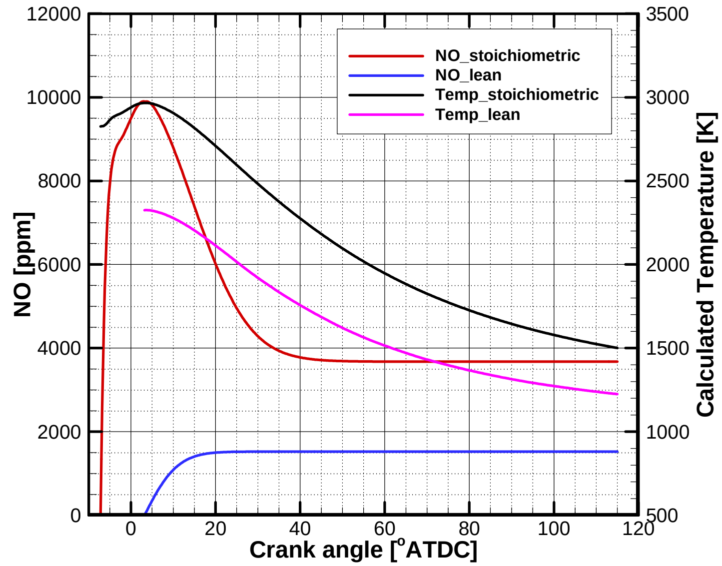
$$\Phi_l = 1.035 \cdot \Phi_{avg} - 0.0917$$

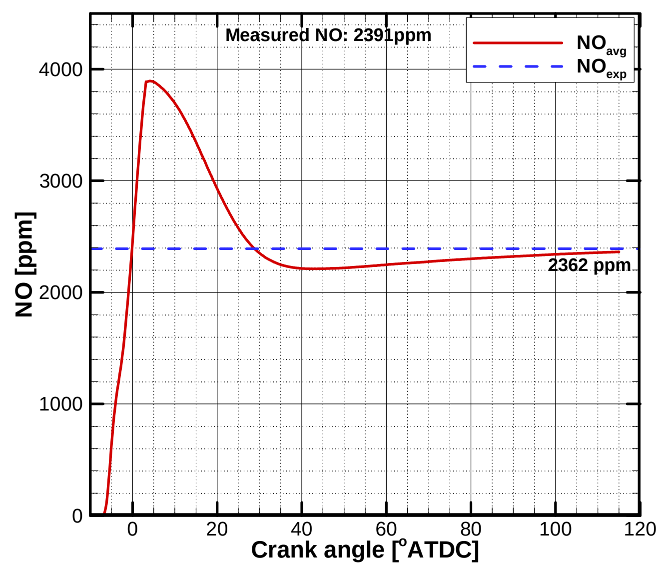
- The calculation (and ultimately NO prediction) is very sensitive to this correlation, and will require future work.

[1] Szekely, G., Alkidas, A. (1986). SAE 861272

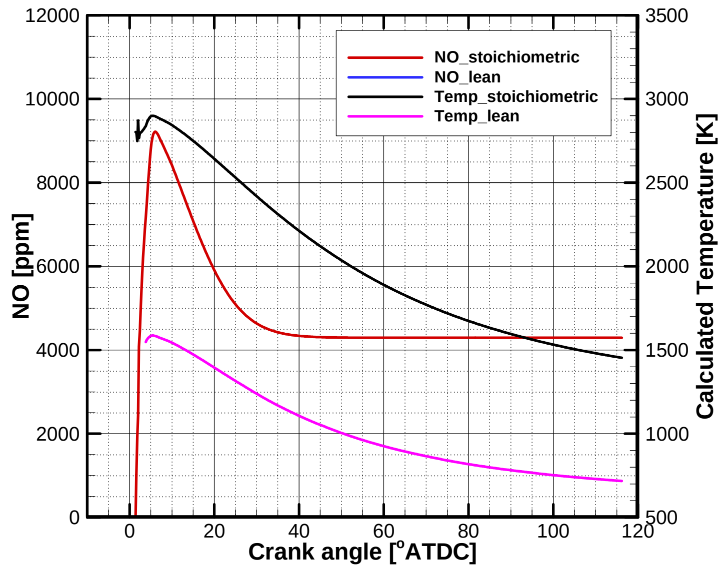
NO Modeling via Two-Stage Heat Release

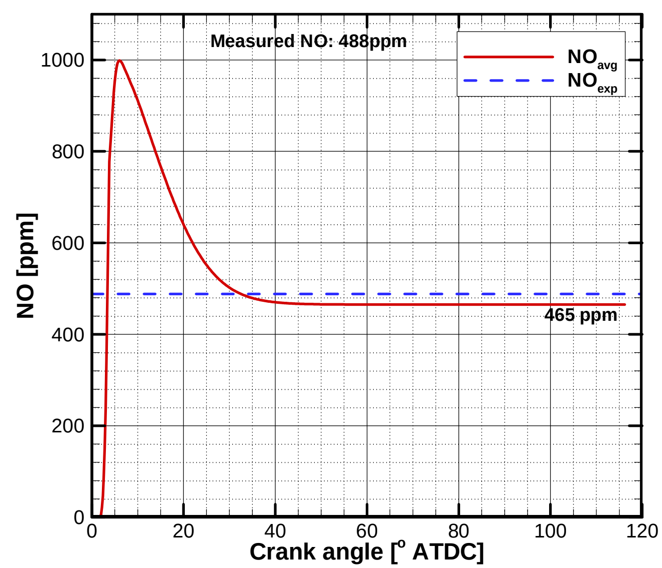
1400 rev/min
“High Load”





1400 rev/min
“Low Load”





Conclusions

- Depending on the design of the system or the “design” of the fuel, exhaust conditions may be more or less favorable (from a temperature, flow rate, and species perspective) with alternative fuels (such as biodiesel).

- Advanced modes of combustion such as later-phased low temperature combustion are likely to render lower exhaust enthalpy, due mostly to a decrease in exhaust flow rate. Exhaust constituents could, however, create an opportunity for exhaust exothermic heating.

- Simple “real-time capable” models may enable direct control of certain emissions (such as nitric oxide) to help support after treatment catalysis.

Thank you!

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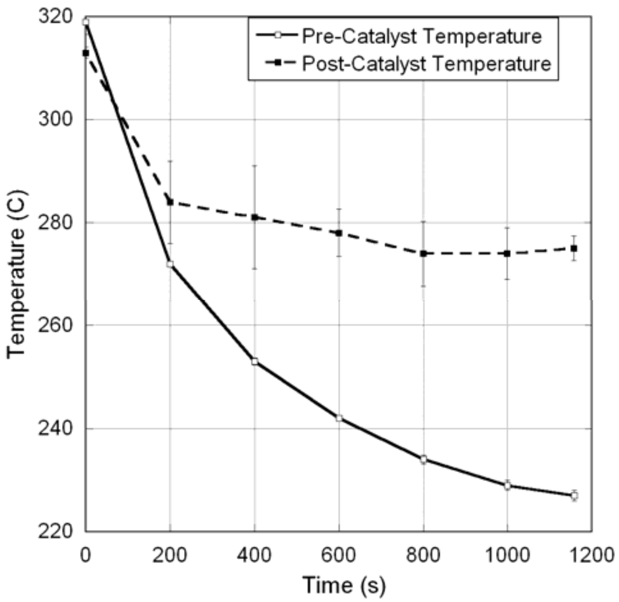
Thank you for your attention!

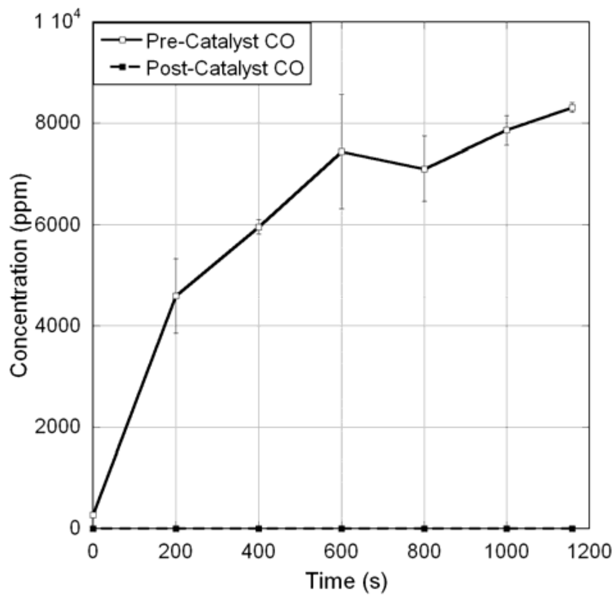
Acknowledgements:

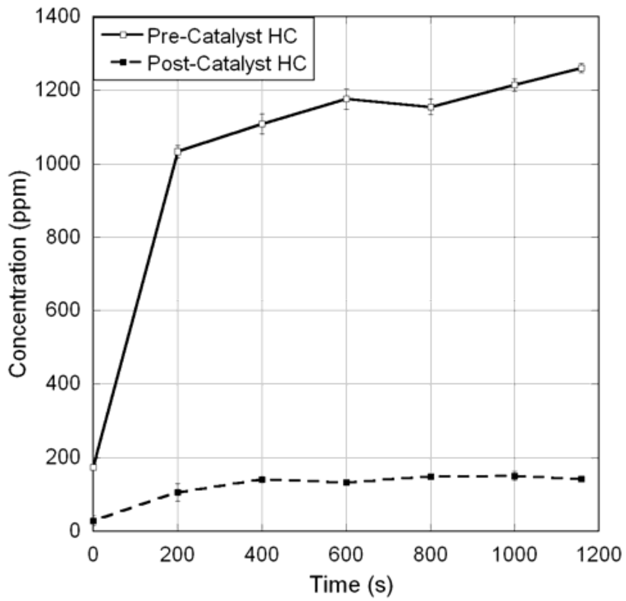
- Department of Energy for the opportunity to present.
- Some of the data shown in this presentation resulted from research sponsored by the Texas Commission on Environmental Quality through the New Technology Research and Development program.
- Some of the data shown in this presentation is collected by graduate students (Brandon Tompkins, Josh Bittle, Bryan Knight).

Transient Feed-Gas Testing

- To evaluate reduced temperature as the leading cause, the catalyst was exposed to high temperature exhaust prior to “mode switching” to rich PCI.
- First evaluations were conducted with lean PCI (data herein shown)

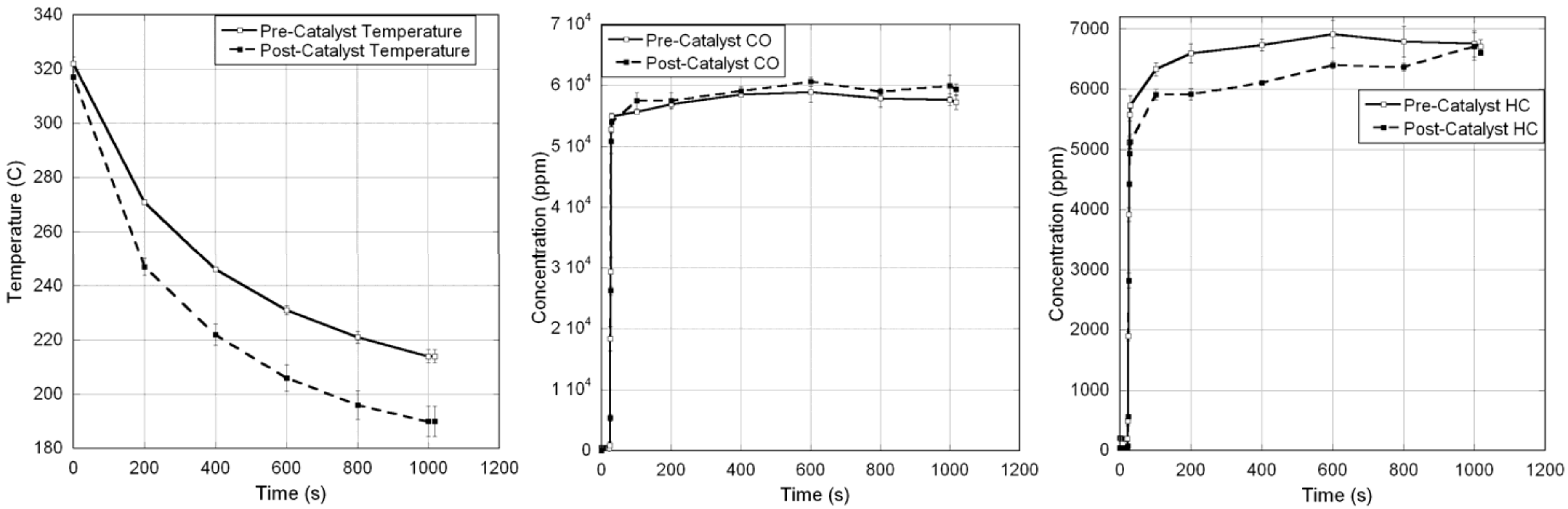






Transient Feed-Gas Testing

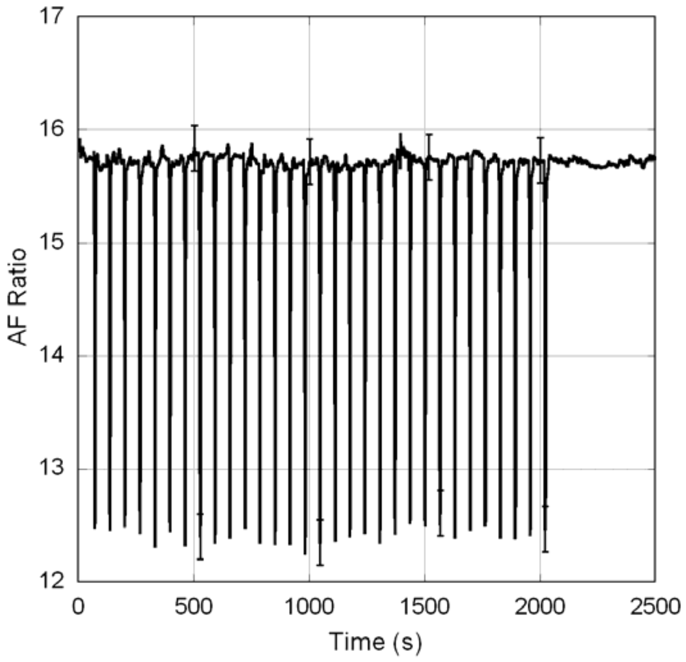
- Evaluations at rich PCI reveal that an established in-catalyst exotherm "dies" nearly instantly upon mode switching.



Combustion Mode Switching

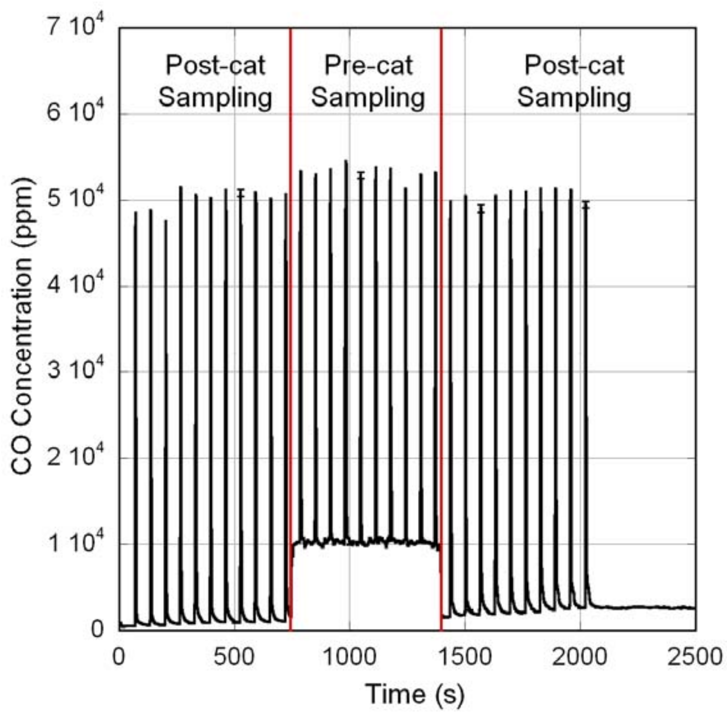
- Will the DOC stay “suitably” active during temporal rich excursions?
- How will temporal rich excursions affect DOC activity as time goes on?

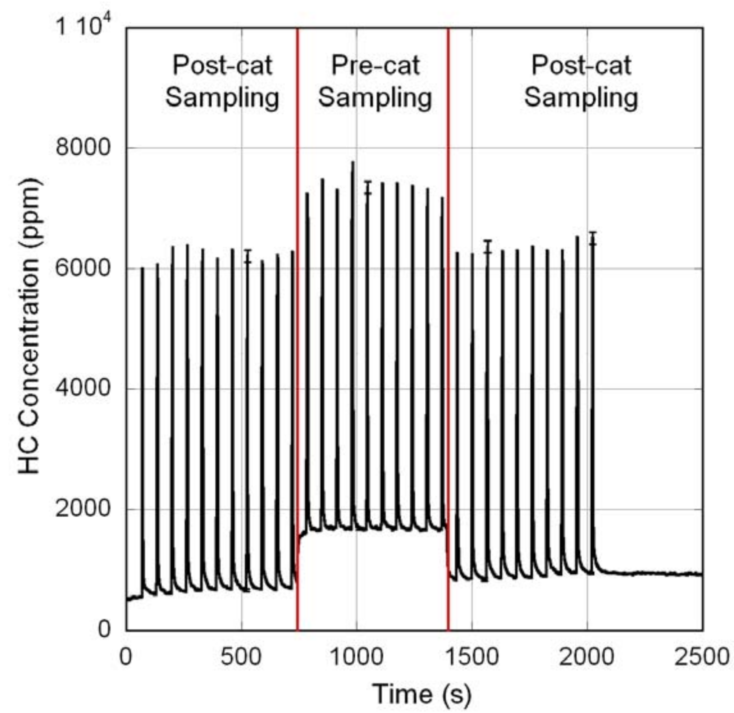
- t = 0 seconds to t ~ 2000 seconds:
  - Lean PCI for 60 seconds
  - Rich PCI for 5 seconds
  - Lean PCI for 60 seconds, etc.
- t ~ 2000 seconds:
  - Engine returned to lean PCI for eventual stabilization.



Combustion Mode Switching

- DOC never maintains effectiveness during rich PCI excursions.





Combustion Mode Switching

- DOC could be exhibiting decreased activity as time goes on with mode switching.