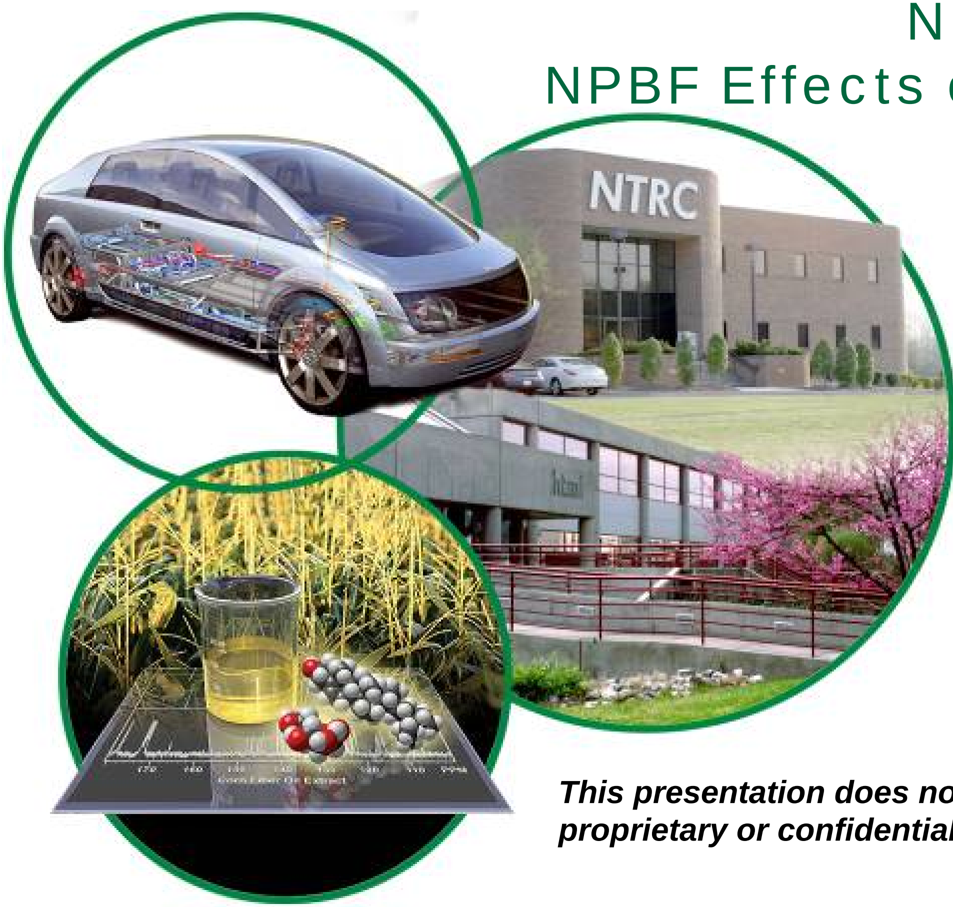
Non-Petroleum-Based Fuels: Effects on Emissions Controls
Agreement Number 13425

NPBF Effects on PM Oxidation
NPBF Effects on EGR System Performance



Presented by **Scott Sluder**

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This presentation does not contain any proprietary or confidential information

2008 Office of Vehicle Technologies Annual Merit Review
Bethesda, Maryland

The purpose of this work is to identify potential barriers and benefits to emissions control systems associated with use of NPBFs.

Goals

- **By 2007, identify fuel formulations optimized for use in 2007-2010 technology diesel engines that incorporates use of non-petroleum-based blending components with the potential to achieve at least a 5 percent replacement of petroleum fuels by 2015.**
- **By 2010, identify fuel formulations optimized for use in 2010-2020 advanced combustion regime engines providing high efficiency and very low emissions, which incorporate use of a non-petroleum-based blending components with the potential to achieve at least a 10 percent replacement of petroleum fuels by 2025.**

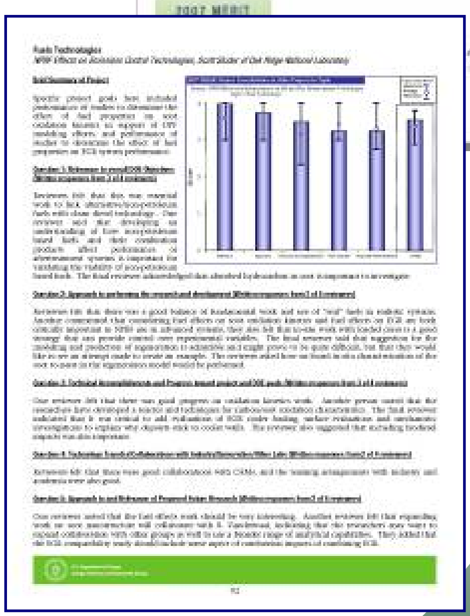
Barriers

- **Inadequate data and predictive tools for fuel property effects on combustion and engine optimization.**
- **Inadequate data and predictive tools for fuel effects on emissions and emission control system impacts.**
- **Long-term impact of fuel and lubricants on engines and emissions control systems.**

Feedback from the FY 2007 review underscored the importance of these topics.

(EGR study was initiated just prior to the review last year.)

- **Relevance:**
  - **Reviewers felt that this was essential work to link alternative/non-petroleum fuels with clean diesel technology.**
- **Approach:**
  - **Reviewers felt that there was a good balance of fundamental work and use of "real" fuels in realistic systems.**
  - **…fuel effects on soot oxidation and fuel effects on EGR are both critically important in NPBF use in advanced systems…**
- **Technical Accomplishments and Progress:**
  - **Good progress on oxidation kinetics work.**
- **Tech Transfer / Collaboration**
  - **Reviewers felt that there were good collaborations with OEMs, and the teaming arrangements with industry and academia were also good.**
- **Approach to and Relevance of Future Research:**
  - **One reviewer noted that the fuels effects work should be very interesting. Another reviewer suggested that the EGR study should include some aspect of combustion impacts of EGR fouling.**



There have been several technical accomplishments this year.

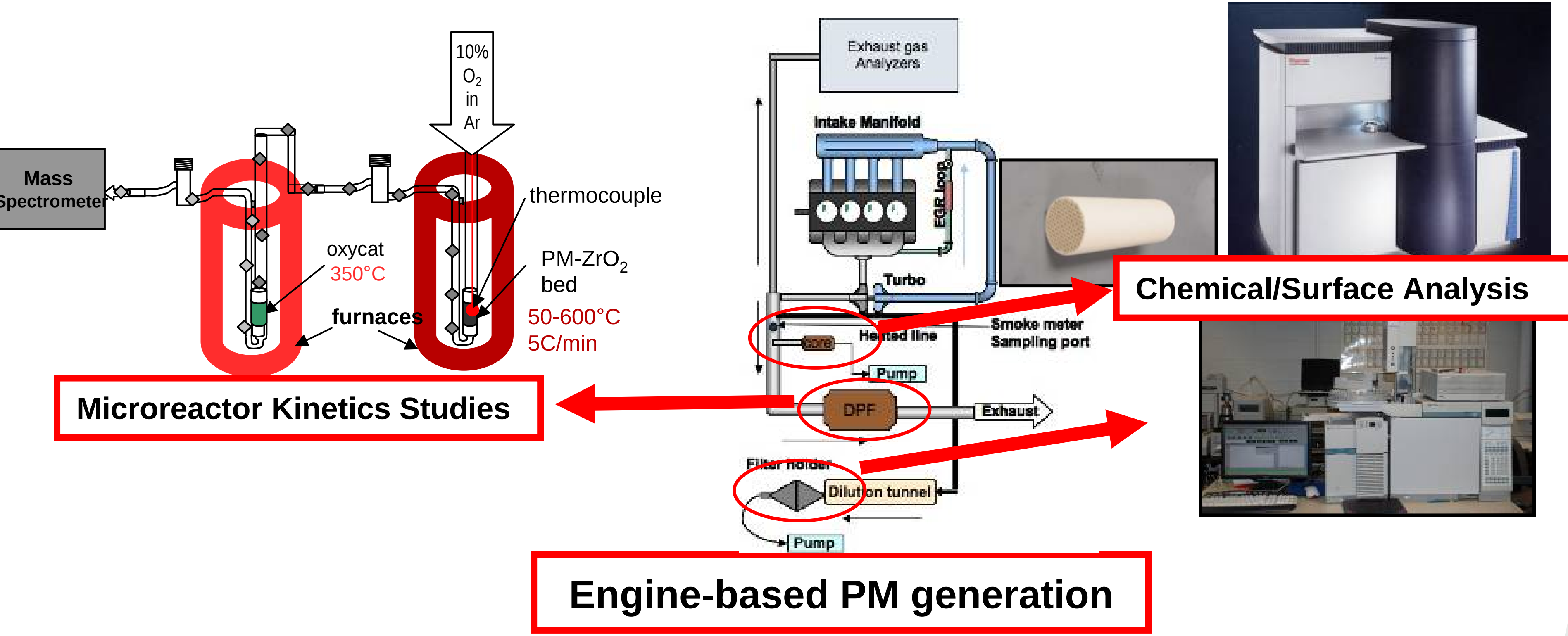
PM oxidation project showed:

- ✓ Increased PM surface oxygen content reduces ignition temperature.
- ✓ Higher biodiesel blends form PM with higher surface oxygen content.
- ✓ Biofuel HCs adsorbed in DPF PM may be one source of increased surface oxygen content.

EGR cooler fouling project showed:

- ✓ Capability for using surrogate EGR cooler tubes to investigate fouling fundamentals.
- ✓ Mass accumulation and effectiveness degradation in coolers are not worse for biodiesel blends than for ULSD at low-HC conditions.
- ✓ Thermal conductivity of fouling layer for B20 is 0.027 – 0.034 W/mK.
- ✓ Completed experiments investigating EGR fouling at lower coolant temperatures relevant for warm-up operation. (Not discussed)

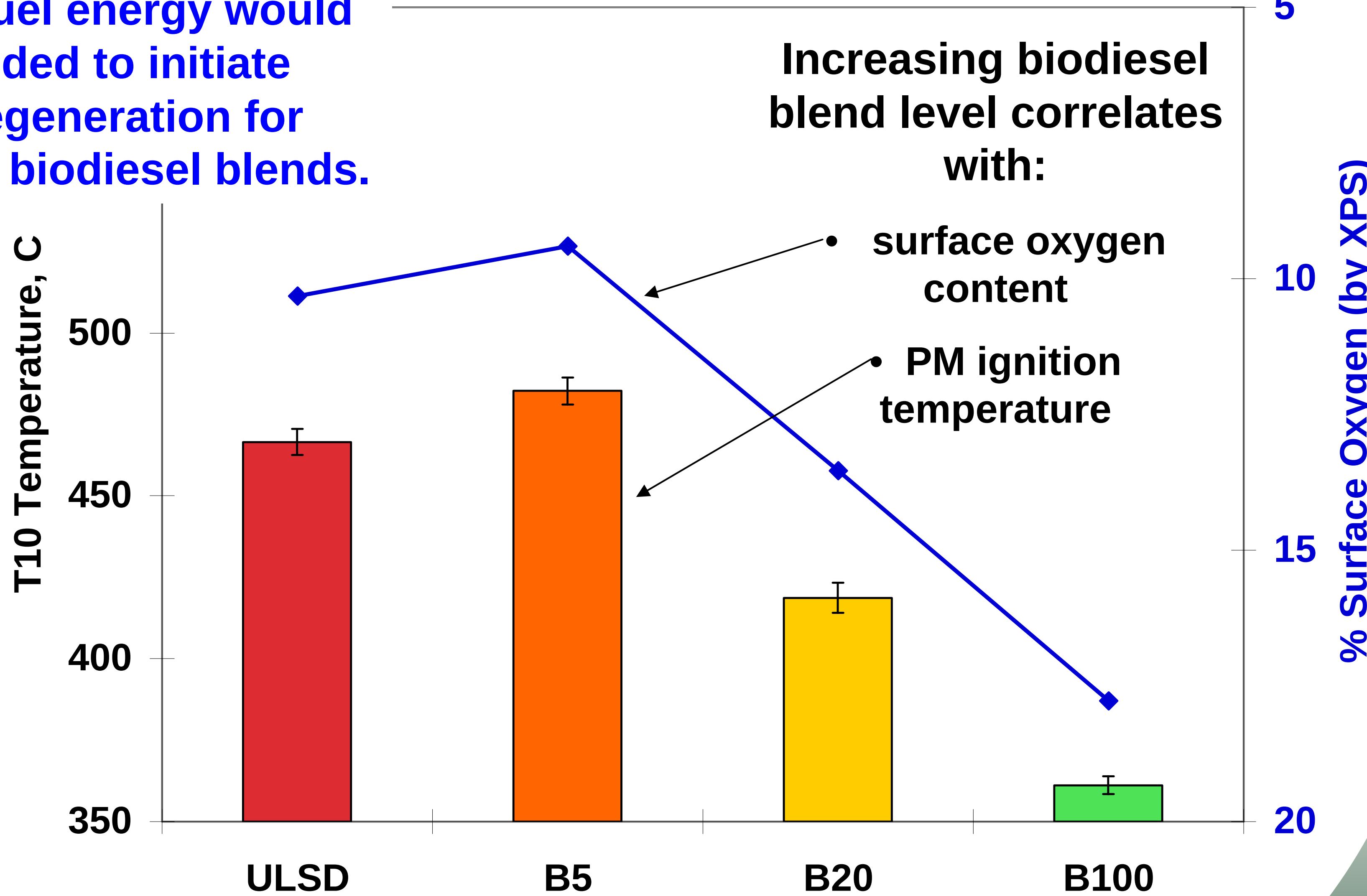
Approach for investigating NPBF effects on soot oxidation combines engine-based sample generation with off-engine experiments and analyses.



- **Oxidation kinetics, HC desorption, and reactive surface area of PM samples and surrogates are investigated in a differential microreactor equipped with a mass spectrometer.**
- **Identification of HC species in fuels and adsorbed in DPFs are investigated through solvent extraction and GC/MS analysis; ORNL HTML provides many useful surface analysis capabilities.**

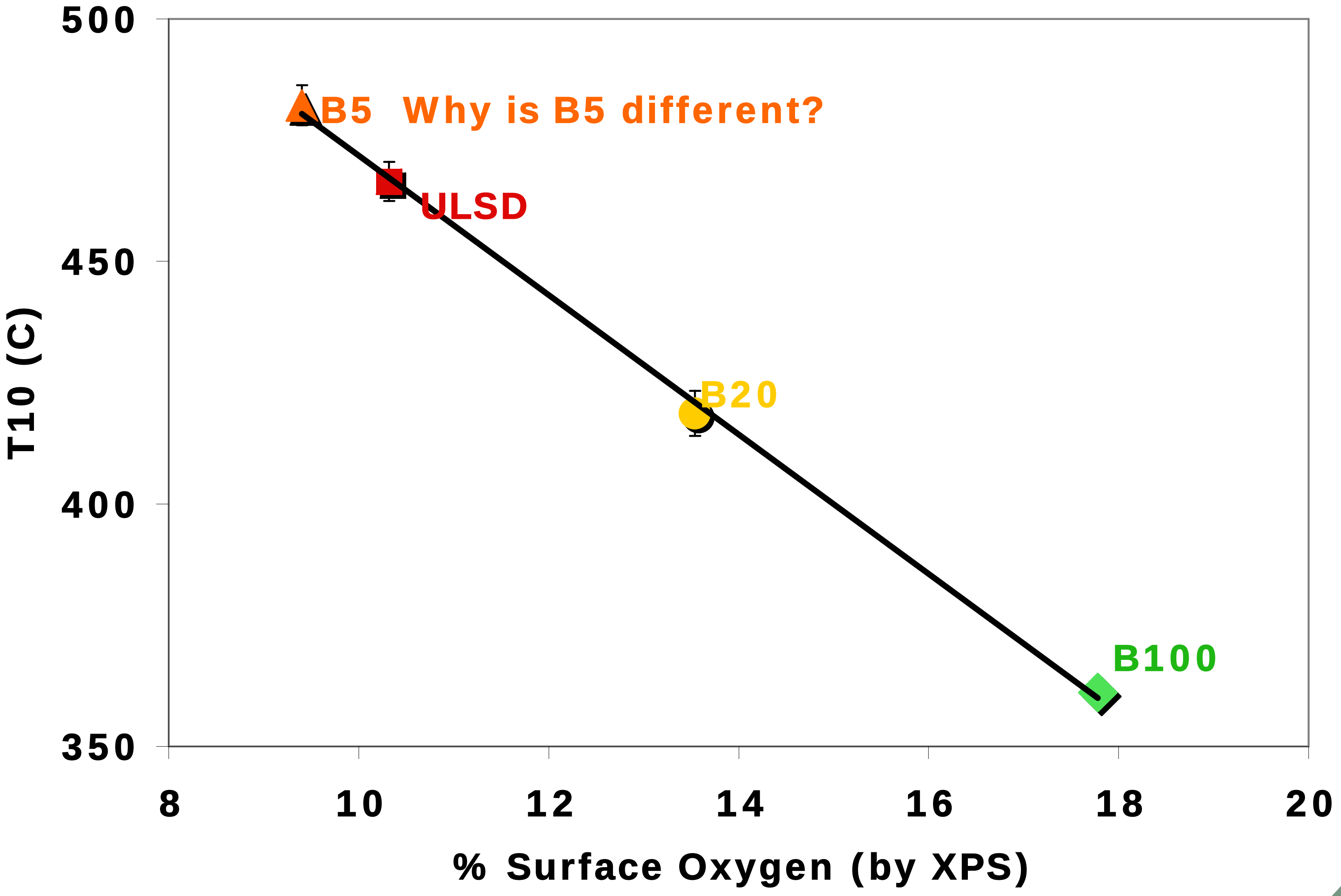
Lower PM ignition temperatures for biodiesel-derived PM were observed.

Less fuel energy would be needed to initiate DPF regeneration for higher biodiesel blends.

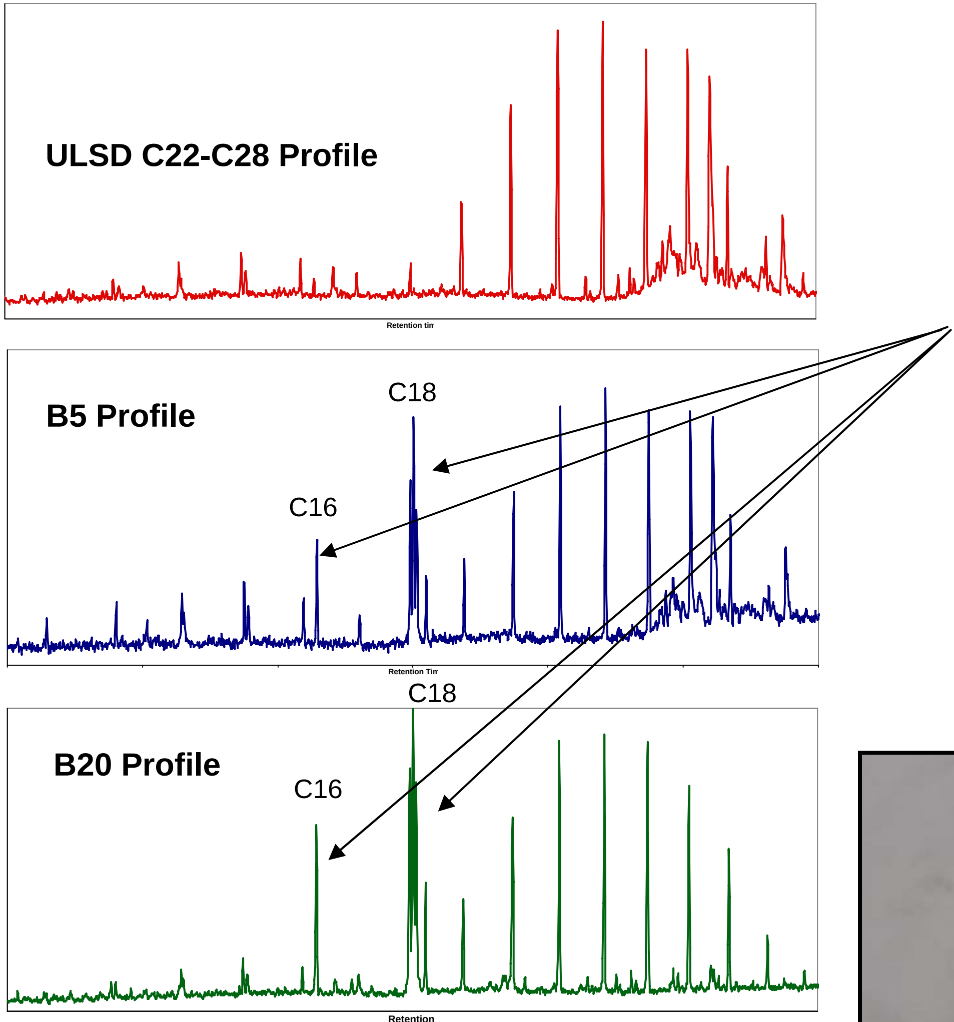


Data are shown for PM generated at one engine condition: 1,500 RPM 2.6 Bar BMEP.

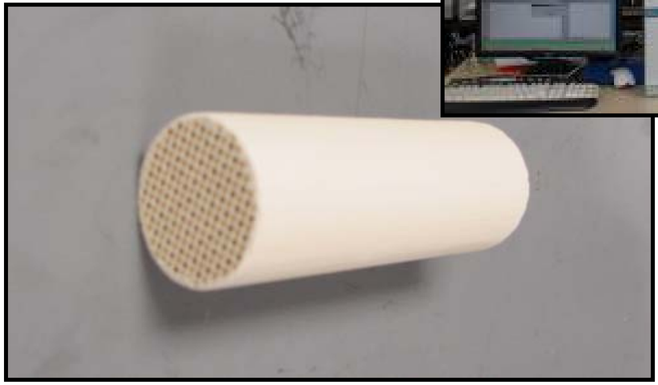
Results suggest that biofuels enhance PM reactivity by increasing surface oxygen content.



Fuel esters adsorbed in DPF soot cake may represent one source of the surface oxygen content.



- **Need to understand the magnitude of contribution of HCs to oxidation behavior. (Experiments underway.)**
- **Relatively high fuel ester content, even at low blend levels.**



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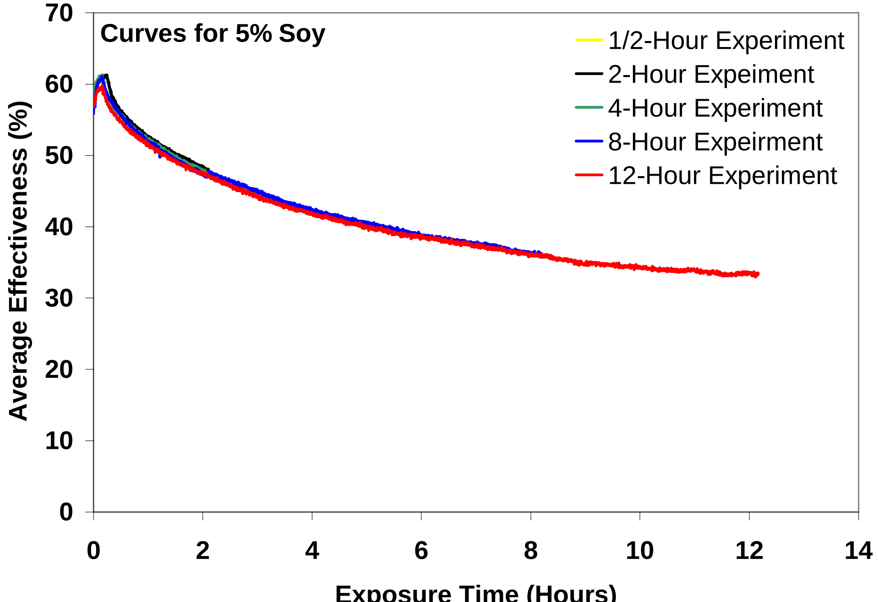
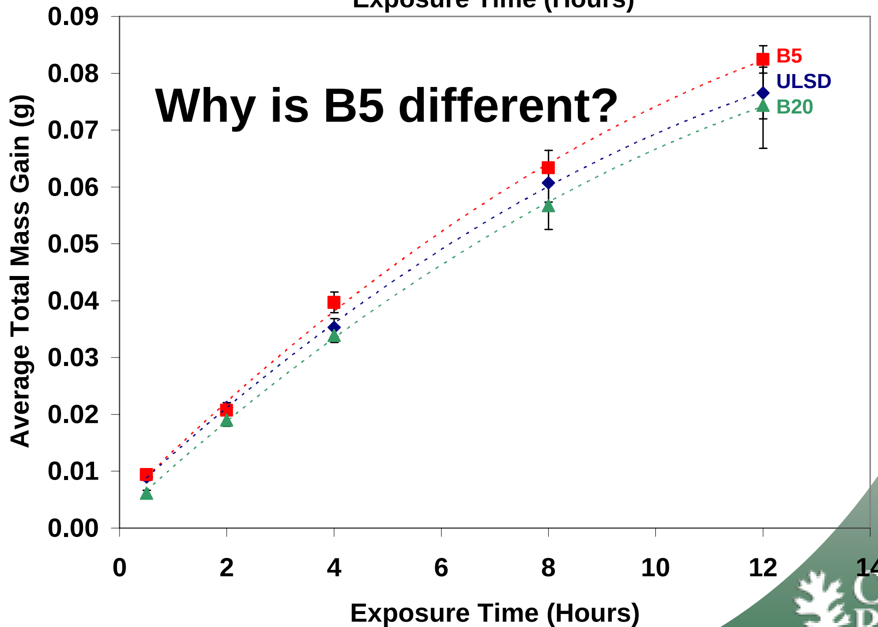
Approach to investigating NPBF effects on EGR cooler fouling is based on studying surrogate EGR cooler tubes.

- **Ford 6.4-L V-8 used as exhaust generator.**
- **Surrogate tubes provide more accessible samples for study than full-size coolers.**
- **Exhaust passed through surrogate EGR cooler tubes at constant flow rate and coolant temperature.**
  - **Tubes were ¼ inch square cross-section stainless tubes.**
  - **Thermal effectiveness of tubes is assessed during exposure.**
- **Subsequent analyses of tube deposits:**
  - **Total mass of deposits**
  - **Volatile / non-volatile deposit mass**
  - **GC/MS characterization of the deposit HCs**
  - **Deposit layer thermal properties**

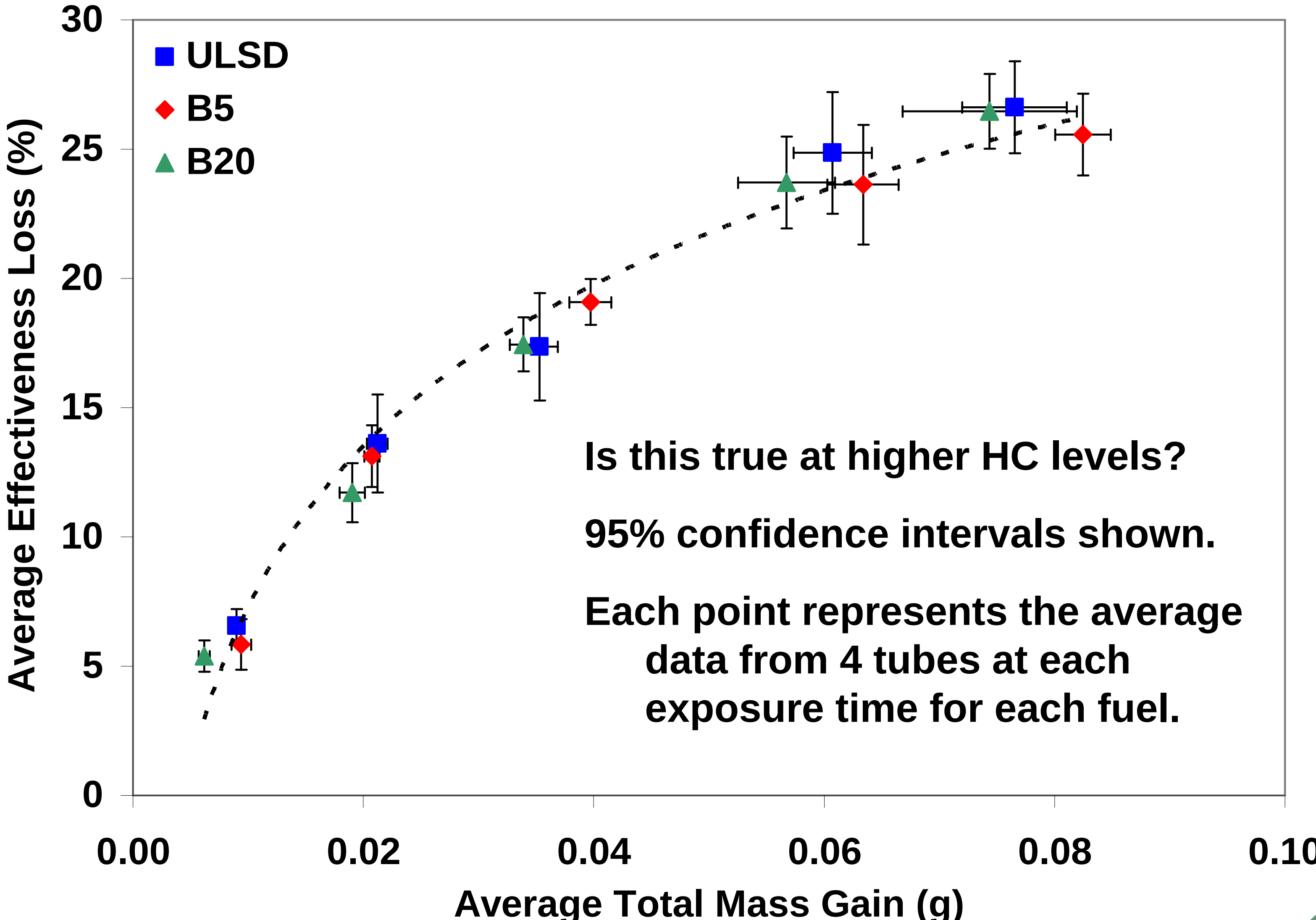
Results show that significant thermal effectiveness loss due to deposit formation occurs within a few hours.

- **Feedgas conditions:**
  - **1.5 Smoke Number**
  - **50 PPM HC (as C_1)**
- **Tube Conditions**
  - **90 °C Coolant**
  - **30 SLPM per-tube gas flow**
- **Steady-flow, time-of-exposure experiments showed very good repeatability.**
- **Mass accumulation in the tubes showed similar profiles for ULSD, B5, and B20 fuels.**
  - **95% confidence intervals shown.**





Examination of the effectiveness loss as a function of deposit total mass gain shows no significant difference between ULSD, B5, and B20 fuels.



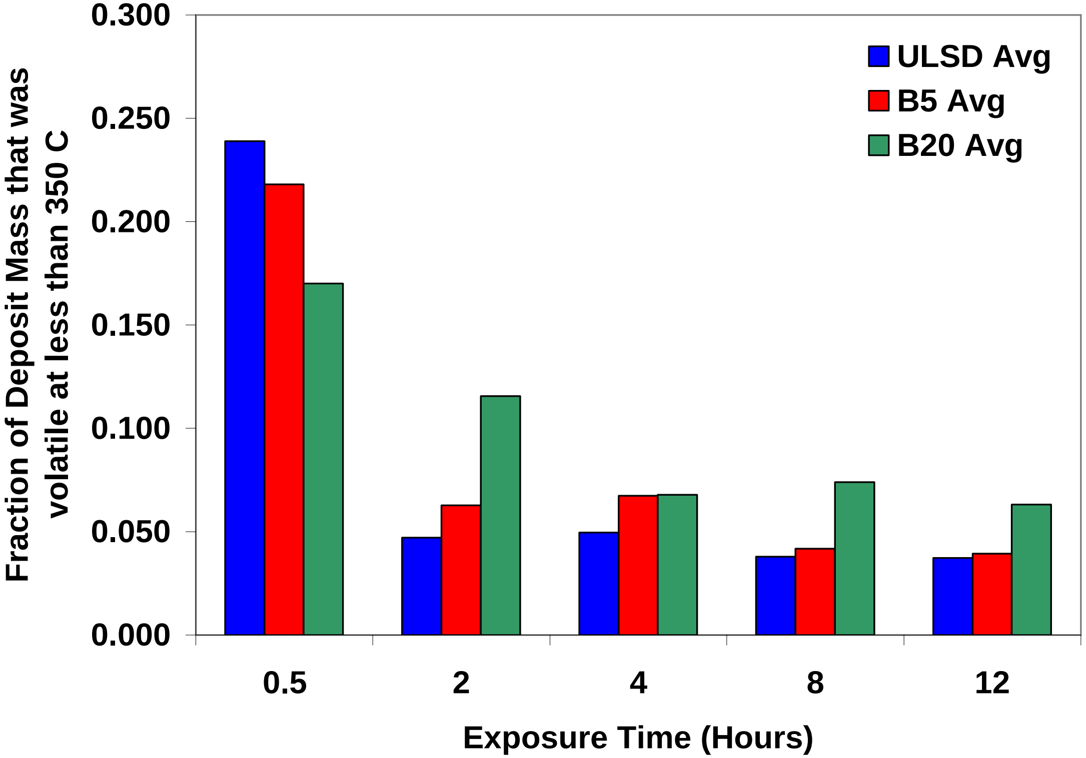
Is this true at higher HC levels?

95% confidence intervals shown.

Each point represents the average data from 4 tubes at each exposure time for each fuel.

Fractionation of the deposit mass suggests that most of the volatile deposit mass is deposited early in exposure.

- **Deposit mass fractionation:**
  - **Total mass**
  - **< 350 °C Volatile mass**
  - **350 – 550 ° C Volatile mass**
  - **Non-volatile mass**
- **Values of < 350 °C volatile mass suggest a nearly constant level for each fuel.**
- **350 – 500 °C volatile mass were very low and essentially constant.**
- **GC/MS analysis**
  - **Bio-esters more prevalent than other fuel compounds.**
  - **Tailored extraction methods needed for some analyses.**

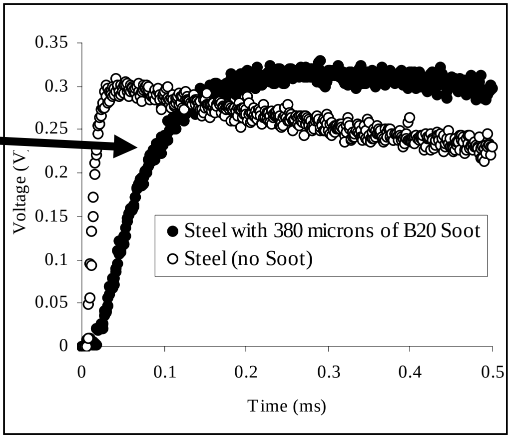


How does the presence of HCs impact the cooler performance in the longer term as the deposits age?

Direct measurements of the deposit layer thermal properties were successfully developed. The deposit layer is a very effective insulator.

How does this work?

Time required for heat flow through fouling layer and tube wall is measured.



$$K = \alpha\rho C_p$$

where K is thermal conductivity, α is thermal diffusivity, ρ is density and C_p is heat capacity

- Thermal Diffusivity (α) was measured using the Xenon Flash Method
- Density was measured at ~0.04 g/cm^3
- Deposit thickness was ~380 µm
- Cp for soot was taken to be 0.79 J/gK.

- **Thermal Conductivity of B20 deposit layer = 0.027 - 0.034 W/mK**
  - **Very similar to air (0.025 W/mK)**
  - **Stainless steels ~14.0 W/mK**
- **Deposit layer porosity is greater than 90%.**
- **This means that the deposit layer is a nearly ideal thermal insulator!**

How do the deposit layer thermal and physical properties change with HC level, fuel type, and time of exposure?

Information from these projects are shared with researchers from other interested organizations.

PM Oxidation Studies:

- Industry collaborators
  - Ford, GM, Cummins
- Academia, Labs
  - Univ. Wisconsin – Madison
  - NASA Glenn
  - PNNL
- Publications, Presentations
  - 2007 DOE Merit Review
  - 2 Posters at DEER 2007
  - CLEERS 2007
  - 2007 North American Symposium on Chemical Reaction Engineering
  - Planned publications at the2008 CLEERS workshop and the 2009 SAE Congress.

EGR System Studies:

- Industry collaborators
  - Ford, GM
- Academia
  - Univ. Michigan
- Publications, Presentations
  - 2007 DOE Merit Review
  - Planned for the SAE 2008 Powertrain, Fuels, and Lubricants Meeting and the 2009 SAE Congress.

Future plans include additional analyses, experiments, and fuel formulations.

PM Oxidation Studies

- **Measure impact of adsorbed HCs (for each fuel) on**
  - soot surface area
  - oxidation kinetics
  - surface oxygen content
  - surface structure
- **Compare engine operating conditions**
  - PM physical parameters
  - PM chemical parameters
- **Make recommendations as to kinetic correlations for DPF modelers that reflect the impact of fuel and operating conditions.**
- **Investigate other NPBF streams**
  - Oil sands
  - Oil shale

EGR Cooler Studies

- **Publish current data and ongoing analyses. (Planned for SAE 2008 PF&L, 2009 Congress)**
- **Study a condition with higher HC level.**
- **Expand surface analysis to further investigate deposit thickness, density, thermal properties.**
  - Publish results so that the modeling community can use the data.
- **Investigate deposit aging. How do deposits react to thermal cycling, changes in gas concentrations, condensation, etc?**
- **Investigate fouling behavior during controlled transient exhaust exposures.**

Why is B5 different?

NPBF Fuel Effects on Emissions Control Systems: Summary

- **Purpose**

  Provide more information on the effects of NPBF formulations on the performance of emissions control systems, in support of DOE goals for petroleum displacement.

- **Approach**

  This activity capitalizes on synergies gained through the combination of off-engine analyses and experiments using samples generated during engine dynamometer studies using a range of engine technologies and fuel formulations.

- **Technical Accomplishments**

  Showed that use of biodiesel blends promotes PM oxidation at lower temperatures because of the increased surface oxygen content of the PM. Showed that use of biodiesel blends do not promote more rapid EGR cooler fouling than petroleum-derived fuel at a low-HC condition.

- **Technology Transfer**

  Results and data from this activity are conveyed to government and industry stakeholders through publication and presentations (CLEERS, DEER, and SAE) as well as individual communications with industrial partners.

- **Future Plans**

  Future plans include further analyses of samples and data from current and upcoming experiments as well as inclusion of other NPBF formulations (such as oil sands and oil-shale-derived fuels).