Fuel Effects on Advanced Combustion: Optical Heavy-Duty Engine Research

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2010 DOE Vehicle Technologies Annual Merit Review
Washington Marriott Wardman Park, Washington, DC
June 8, 2010

Project ID#: FT004

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Overview

Timeline

- Project provides fundamental research to support DOE/ industry fuel-technologies projects
- Project directions and continuation are evaluated annually

Budget

- Project funded by DOE/VT:

  FY09 – $600K

  FY10 – $730K

Barriers*

- Cost-competitive heavy-duty engines with >50% thermal efficiency, 2010/Tier-4-compliant emissions, and using fuels that can give at least 15% petroleum replacement by 2030 currently do not exist
- Lack of adequate combustion understanding and simulation capability, especially for new combustion regimes and emerging fuels

* Sources: *Draft DOE/VT MYPP (March 18, 2010) and 21st Century Truck Partnership Roadmap*

Partners

- Project lead: Sandia – C.J. Mueller (PI)
  B.T. Fisher, C.J. Polonowski (post-docs)
- 15 industry, 6 univ., and 6 nat'l lab partners in Advanced Engine Combustion MOU
- Coordinating Research Council (CRC)
- Caterpillar Inc.

Relevance – Objectives

Develop the fuel-effects and engine-combustion science-base to enable high-efficiency, clean-combustion (HECC) engines using fuels that improve US energy security

- Specific objectives of work since FY09 Annual Merit Review
  - Understand fuel effects on liquid length under unsteady conditions
    - In-cylinder fuel-film formation degrades efficiency and emissions
  - Develop capabilities to study mixing-controlled HECC strategies
    - Could be attractive alternative to HCCI-like approaches
  - Contribute to development of surrogate diesel fuels
    - To understand fuel effects and facilitate computational engine optimization

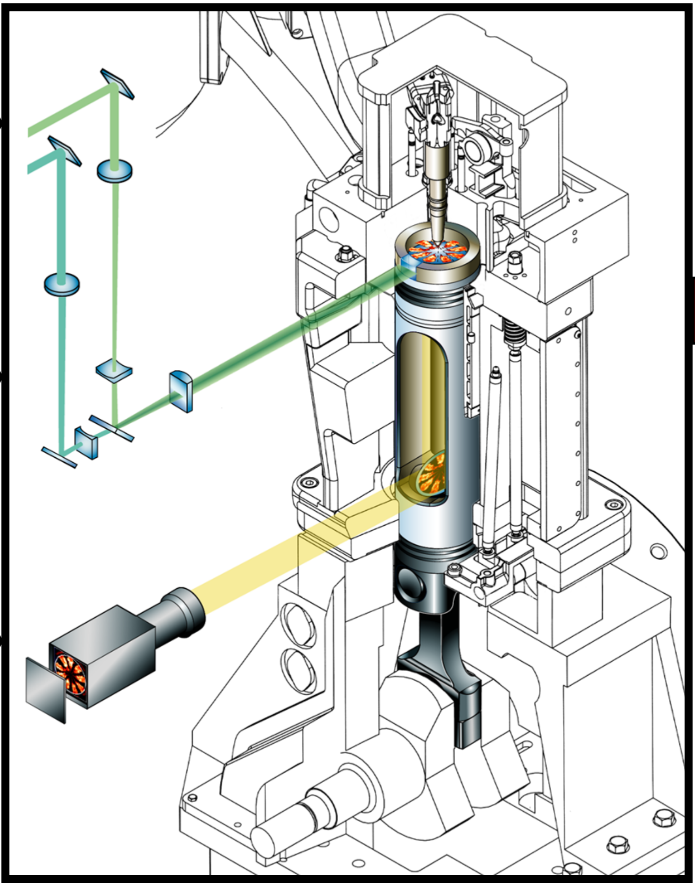
Approach – Experimental

Use optical engine and advanced diagnostics to understand fuel effects on in-cylinder processes

Modern Engine Hardware

Advanced Fuels

Collaboration with Industry, Academia, National Labs



Science-Base to Increase Efficiency and Reduce Emissions

Approach – Milestones

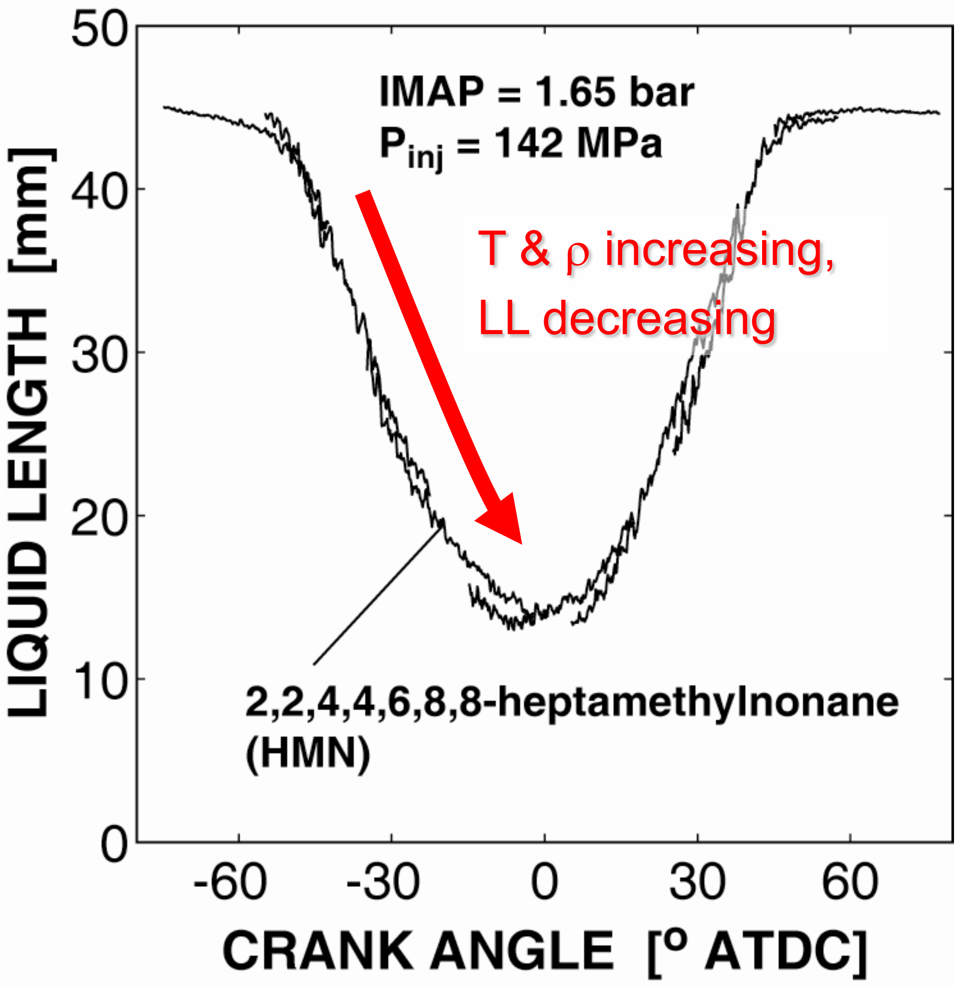
- ✓ **September 2009**
  Acquire in-cylinder liquid-length (LL) data for biodiesels from different feedstocks and #2 ULSD under early- and late-DI operating cond's
- ✓ **December 2009**
  Implement and test in optical engine: 1) new fuel-flexible high-pressure common-rail fuel-injection system, and 2) new dual-camera simultaneous high-speed imaging system
- **August 2010**
  Acquire in-cylinder liquid-length data for a range of well-characterized petroleum-based fuels (FACE diesels)
- **September 2010**
  Complete mixing-controlled HECC experiments with an oxygenated diesel fuel
- **October 2010**
  Summarize CRC surrogate diesel fuel research activities

Technical Accomplishments and Progress

- **Measured liquid lengths under unsteady in-cylinder conditions for a range of fuels:**
  - Liquid films on in-cylinder surfaces degrade efficiency and emissions
  - Single-component fuels (*iso*-octane and heptamethylnonane), biodiesels from different feedstocks, #2 ULSD certification fuel
- **Implemented new systems for studying mixing-controlled high-efficiency clean combustion (HECC)**
  - This advanced combustion strategy is an alternative to HCCI
  - 3000-bar common-rail fuel-injection system
  - Simultaneous dual-camera high-speed imaging system
- **Co-led CRC team of experts in surrogate diesel fuel research**
  - Enhances understanding of fuel effects on advanced combustion, supports computational engine optimization
  - Literature review completed
  - Project completion expected later this year

Q1: How Do Single-Component Fuel Properties and Unsteadiness Affect the Liquid Length (LL)?

- **Answer: Primary effects**
  - In-cylinder T and ρ ↑, LL ↓



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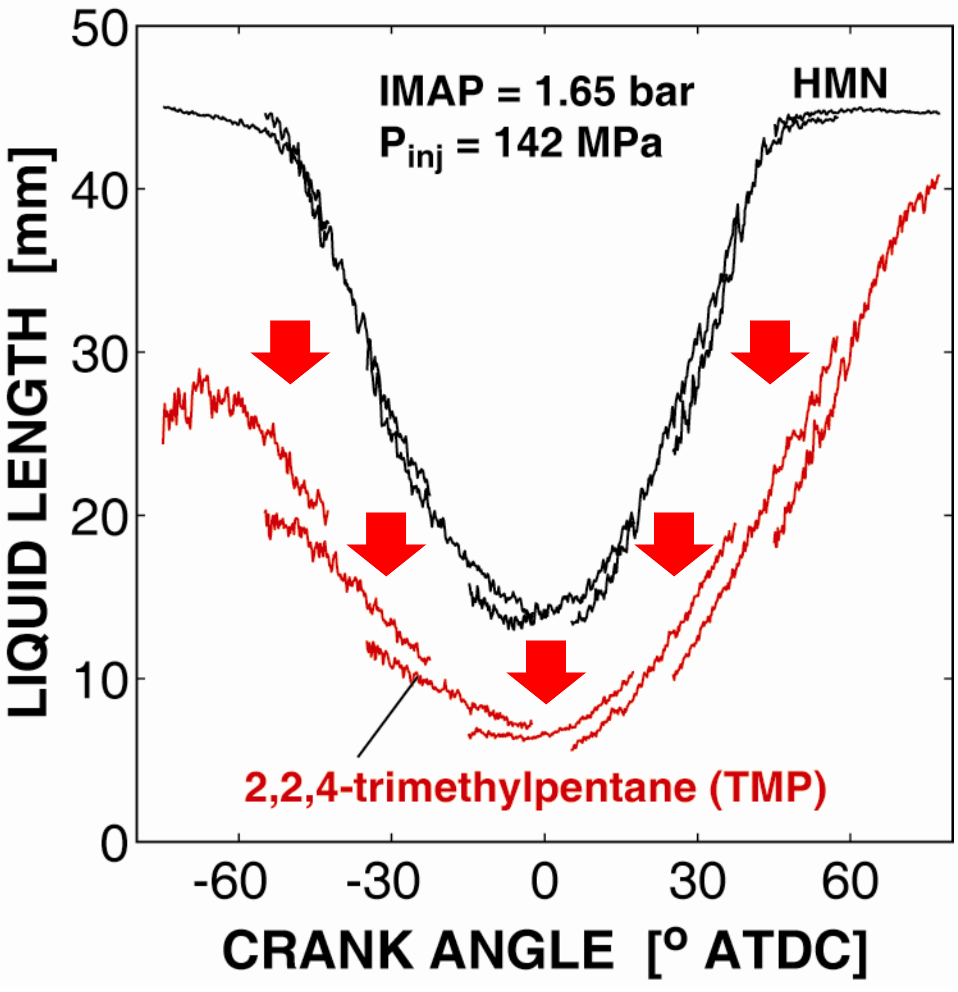

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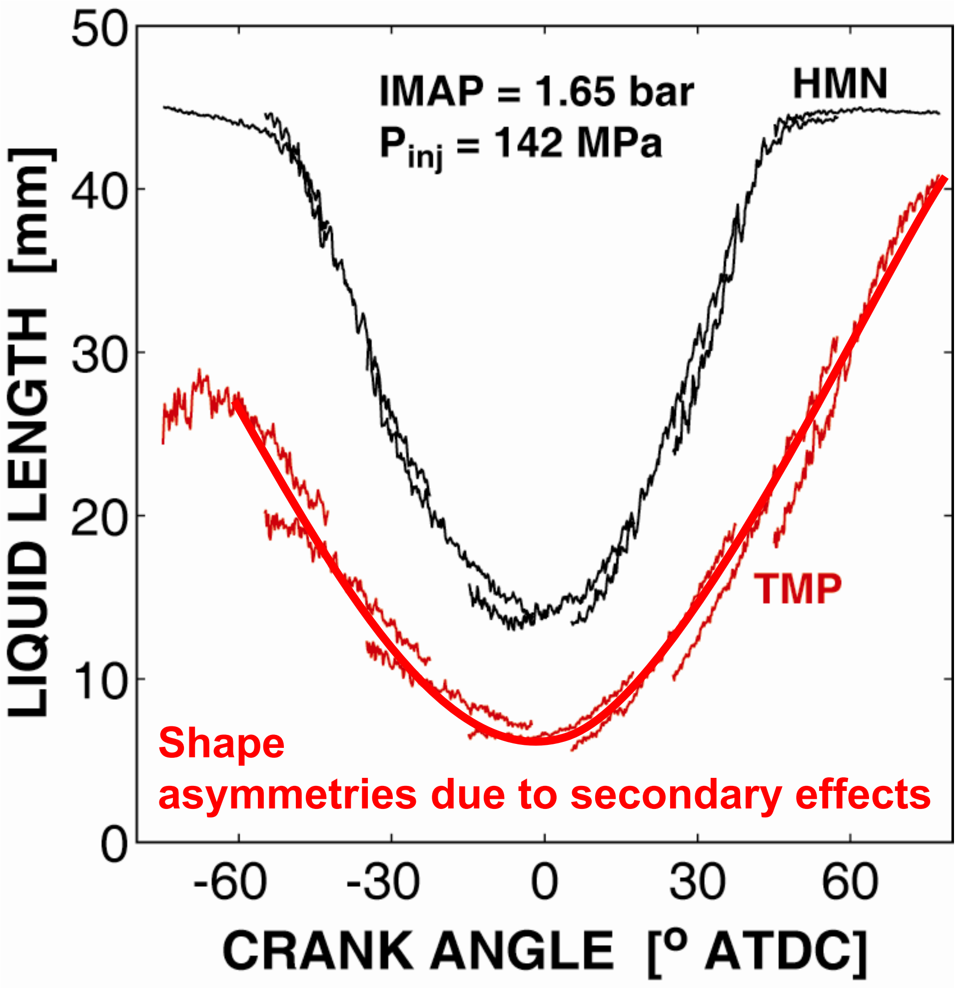
  - Local charge cooling due to fuel vaporization ↑, LL ↑



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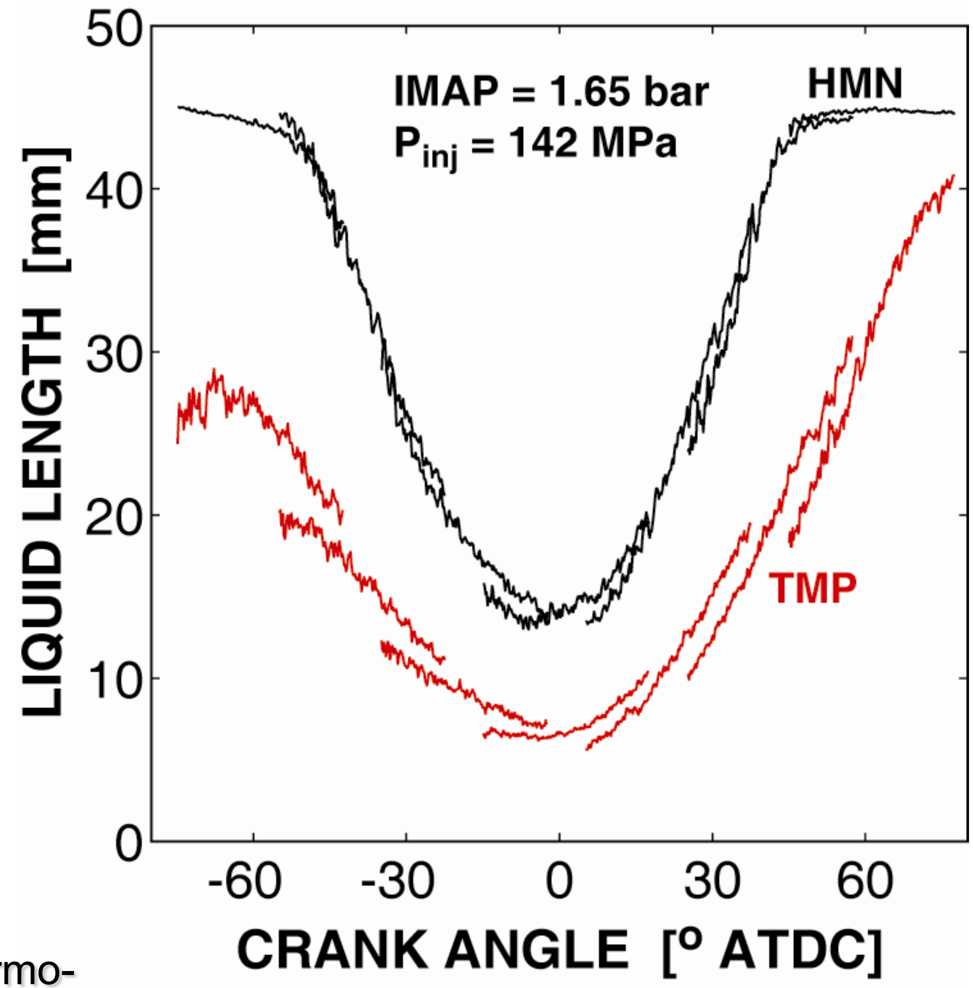
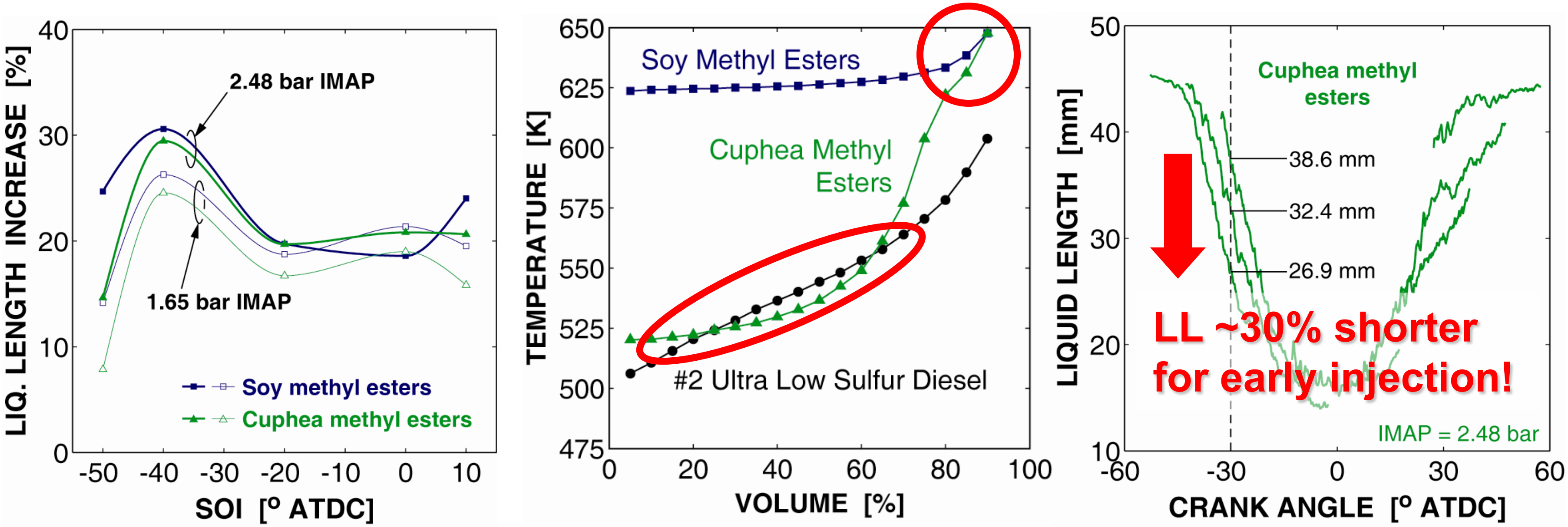
  - In-cylinder T and ρ ↑, LL ↓
  - Fuel volatility ↑, LL ↓
- **Secondary effects**
  - Heat losses ↑, LL ↑
  - Local charge cooling due to fuel vaporization ↑, LL ↑
- **Little to no effect**
  - Injection rate / pressure
  - Unsteadiness
    - Residence time of liquid fuel in jet is short relative to in-cyl. ΔT, Δρ timescales
  - History
    - I.e., instantaneous local thermo-dynamic conditions determine LL



Q2: How Does Fueling with Biodiesel Affect LL Relative to Fueling with #2 ULSD?



Cuphea biodiesel provided by G. Knothe (USDA)

Advanced Distillation Curve data provided by T. Bruno (NIST)

- **Answer: Biodiesel LLs are ~20% longer than those for #2 ULSD**
  - Helps explain lube-oil dilution with late post-injections of biodiesel
  - True even for cuphea biodiesel, which has T10 – T70 similar to ULSD
- **Least-volatile components appear to determine LL**
- **History, other effects important for multi-component fuels**

Q3: Could Mixing-Controlled HECC Strategies Be Attractive Alternatives to HCCI?

- **We are developing the capabilities to answer this question**
  - New 3000-bar fuel-flexible common-rail fuel-injection system with custom injector tips (injectors and tips provided by Caterpillar)
  - Dual-camera high-speed imaging system

Click to play video

Soot Incandescence *OH Chemiluminescence*

- **Goal is to identify key barriers to achieving mixing-controlled HECC with emerging fuels, and overcome them**

Q4: What Should Be the Methodology for Formulating Accurate Surrogate Diesel Fuels?

- **Answer: CRC Advanced Vehicles, Fuels, and Lubricants (AVFL) Project 18 is addressing this question**
  - Team led by Chuck Mueller (Sandia) and Bill Cannella (Chevron)
- **CRC policy forbids discussion of details before public release**
- **A surrogate fuel** "accurately reproduces the ignition, combustion, emissions, and other relevant characteristics of a full-boiling-range real diesel fuel, but consists of approximately a dozen [or fewer] pure compounds"
- **Goal is to formulate accurate surrogates by using** "compounds that represent the major chemical classes found in real diesel fuels"
- **Literature review complete, available on web**
- **Lot of interest in this work, team is making good progress**
- **Final report expected near end of this year**

CRC Report No. AVFL-18a

RECENT PROGRESS IN THE DEVELOPMENT OF DIESEL SURROGATE FUELS

December 2009

CRC

COORDINATING RESEARCH COUNCIL, INC.
3650 MANSELL ROAD·SUITE 140·ALPHARETTA, GA 30022

Collaborations and Coordination with Other Institutions

- **Liquid-length work conducted with guidance from Advanced Engine Combustion Memorandum of Understanding (MOU)**
  - 10 engine OEMs, 5 energy companies, 6 national labs, 6 universities
  - Semi-annual meetings
- **Surrogate diesel fuel research conducted under auspices of CRC; AVFL-18 includes participants from**
  - 3 energy companies, 1 Canadian + 7 US national labs, 1 auto OEM
  - Tri-weekly teleconferences, quarterly meetings
- **Work-for-others contract**
  - Funds in from Caterpillar Inc.
  - Bi-weekly teleconferences, semi-annual meetings
- **Biodiesels from novel feedstocks**
  - Fuel and characterization data provided by USDA (G. Knothe)
  - Joint publication in process

Proposed Future Work (through FY11)

- **Quantify liquid lengths of multi-component hydrocarbon and/or bio-derived fuels under unsteady in-cylinder conditions**
  - FACE diesels and/or oil-sands diesel
  - Pure and/or blended methyl esters
- **Study mixing-controlled HECC using a diesel / oxygenate blend, < 40% EGR, and small injector orifices**
  - May use biodiesel and/or a high-molecular-weight ether
- **Complete current phase of diesel surrogate fuel development efforts (AVFL-18), propose / conduct follow-on research**
  - Summarize results in publication (CRC technical report, SAE paper)
  - Surrogate- and target-fuel testing in optical engine
- **Continue other active collaborations**
  - Advanced Engine Combustion MOU
  - CRC Advanced Vehicles, Fuels and Lubricants activities
  - Work-for-Others with Caterpillar

Summary

- **This research effort is dedicated to an improved understanding of fuel effects on advanced combustion strategies**
  - Tight focus on DOE objectives of achieving HECC with blends of advanced petroleum-based fuels and non-petroleum fuels
  - Includes close collaboration and guidance from engine manufacturers, energy companies, academia, and other national laboratories
- **Significant technical accomplishments have been made during this reporting period, including:**
  - Measured liquid lengths under unsteady in-cylinder conditions for single-component and biodiesel fuels to help avoid detrimental effects of liquid films on in-cylinder surfaces
  - Implemented new fuel-injection and high-speed imaging systems for studying mixing-controlled HECC, a potential alternative to HCCI
  - Co-led CRC team of experts in surrogate diesel fuel research to enhance understanding of fuel effects on advanced combustion and to support computational engine design / optimization