

FT01 – APBF Effects on Combustion

(advanced petroleum based fuels, DOE project # 18546)

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Outline

- **Overview**
- **Objectives**
- **Milestones**
- **Approach**
- **Technical accomplishments and progress**
- **Future work**
- **Summary**
- (Response to previous year's review comments)
- (Publications and presentations)
- (Critical assumptions and issues)

Project overview

- **TIMELINE**

- Overall, fuel studies for advanced combustion started in 2004 with advent of APBF and NPBF projects
- Work continuing and evolving to new areas
 - New fuels, engine strategies, optimization, controls, and kinetics
 - Advanced statistical analysis
- Approximately 75% complete

- **BUDGET**

- DOE funding has been in range of \$250K to \$400K per year
- Related industry funding has been in range of \$50K to \$150K per year

- **BARRIERS / TECHNICAL TARGETS**

- Determine fuel characteristics enabling emission compliant, high efficiency engines
- Enable more effective use of LTC and HCCI combustion strategies

- **PARTNERS, PAST AND PRESENT**

- Cummins
- BP, ExxonMobil, and one other
- Reaction Design
- MIT, U. Wisconsin, Mich. State
- University of Tennessee
- CRC
- Rincon Ranch Consulting
- Others, in minor roles

Objectives

- VEHICLE TECHNOLOGIES PROGRAM GOALS
 - Improve energy security, energy options, and energy efficiency
 - Develop cost-competitive fuel options which displace petroleum
 - Develop data and predictive tools for fuel property effects on combustion and engine optimization
- PROJECT OBJECTIVES
 - Determine how fuel chemistry and properties interact with advanced combustion engines to produce optimal performance
 - Study wide range of conventional and emerging fuels on multiple research platforms
 - Determine how to detect, compensate for, and take advantage of fuel changes

Milestone chart by fuel type

	2004	2005	2006	2007	2008	2009	2010
Conventional diesel fuels		XXX	XXX				
FACE diesel fuels					XXX	XXX	
Oil sands derived				XXX			
Oil shale derived					XXX		
Biodiesels			XXX	XXX	XXX		
Conventional gasolines	XXX				XXX	XXX	
FACE gasolines						XXX	
Gasoline surrogates		XXX	XXX		XXX	XXX	XXX
Diesel surrogates					XXX		XXX
Ethanol blends					XXX	XXX	XXX
HVO, bio-algae, etc.							XXX

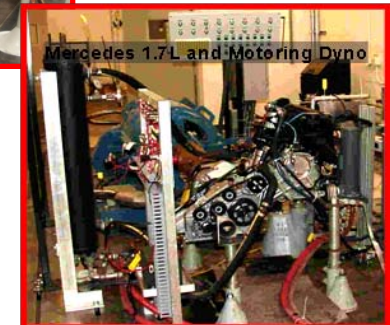
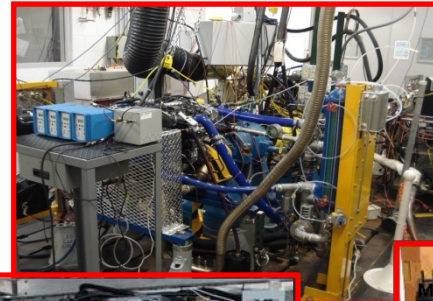
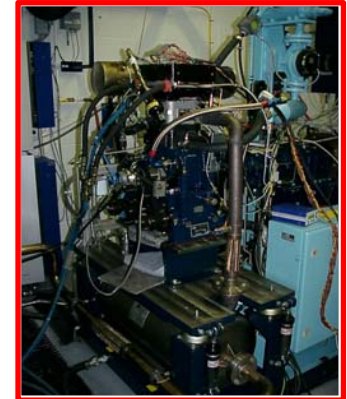
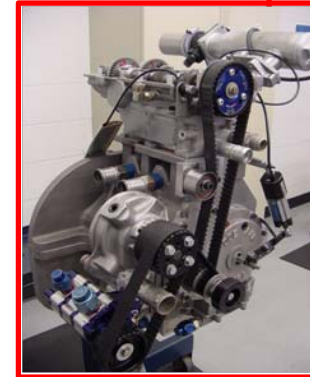
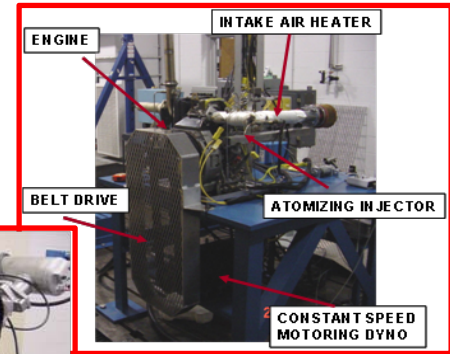
- Table indicates major areas of fuel research by year, additional fuels run as baselines and for efficiency and control studies
- 2008 - 2009 milestones were running FACE diesel fuels in HCCI single and HECC multi-cylinder engines, completed

Approach

- Use a wide range of **fully formulated fuels and surrogate blends** to study effects of fuel properties and chemistry on advanced combustion engines
- Use **multiple research platforms** (single cylinder, multi-cylinder gasoline, and diesel advanced combustion engines) to produce broadly applicable data
- Emphasis on **fuel efficiency, system approach** to understanding of engine and fuel, and on **fuel robustness** of engines
- **Statistical analysis** and modeling of results
- **Collaborations** with industry and universities to leverage capabilities and disseminate results
- APBF fuels include conventionally derived hydrocarbon fuels with normal and modified properties and chemistry for improved operation
 - Separate talk at 1:45pm will cover NPBF fuels

Multiple research platforms

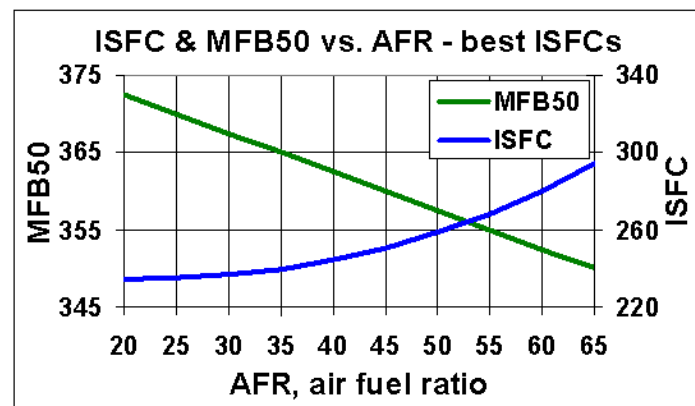
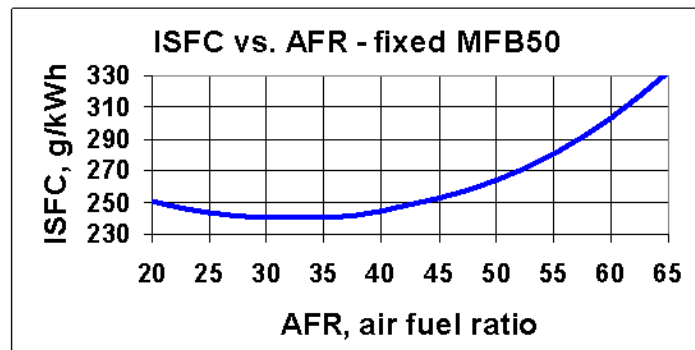
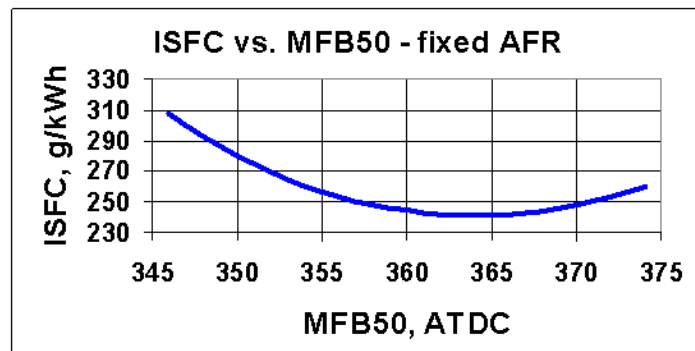
- HCCI single diesel / gasoline
 - PFI, intake heating
 - Adding boosting, throttling, and multiple compression ratios
- Two cylinder VCR gasoline engine
 - Legacy engine from PNGV program
 - Suffered 2 mechanical failures
- AVL VVA GDI / PFI gasoline
- GM 1.9 liter 4 cylinder diesels
 - Open controller
- New engines
 - VVA GDI/PFI



Studies completed and in progress

- **FACE fuels**
 - Fuels run, HCCI and HECC, analyzing results
- **Gasoline and diesel surrogate blends**
 - Four series of fuels completed: gasoline, diesel, ethanol, and detailed chemistry
- **Combustion kinetic studies**
 - Analyzing results of above, comparing to experimental data
- **Statistical analysis of fuel and engine results**
 - Principal components analysis (PCA), applied to all analysis
- **Control and compensation work**
 - In progress, monitoring, correcting for, and taking advantage of fuel changes
- **Many of the studies done in partnership with industry or other research groups**

Response of ISFC regression model at average fuel properties, showing response characteristics of engine



**OPTIMUM ISFC AT ABOUT
365° MFB50**

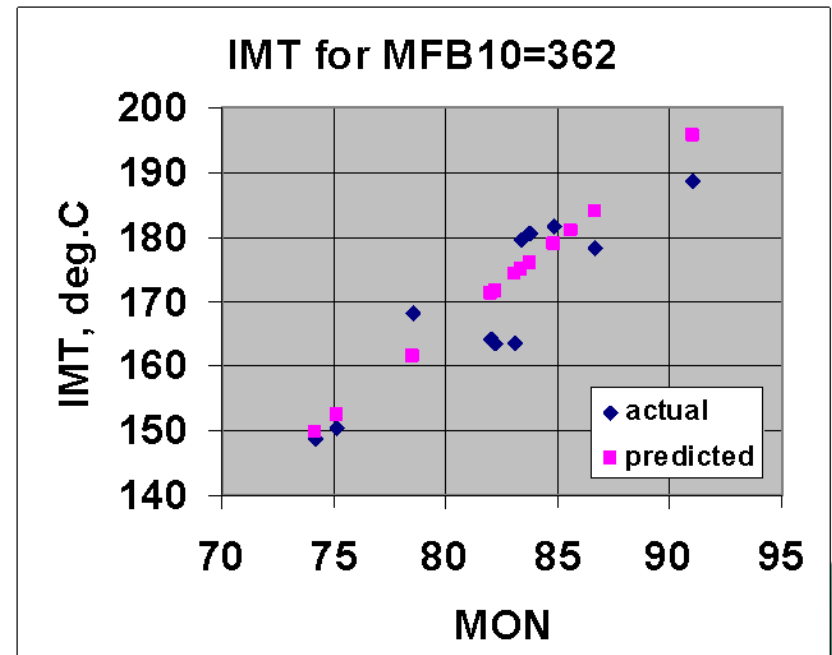
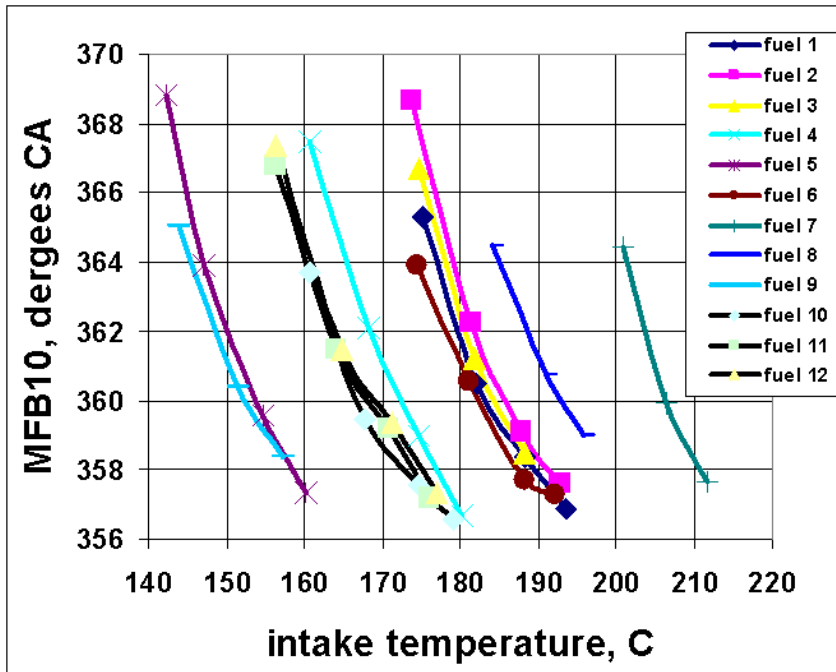
OPTIMUM AFR AT ABOUT 30

**LOWER LOAD OPERATION
(HIGHER AFR) REQUIRES
MORE ADVANCED TIMING
FOR BEST FUEL ECONOMY**

BP diesel fuels

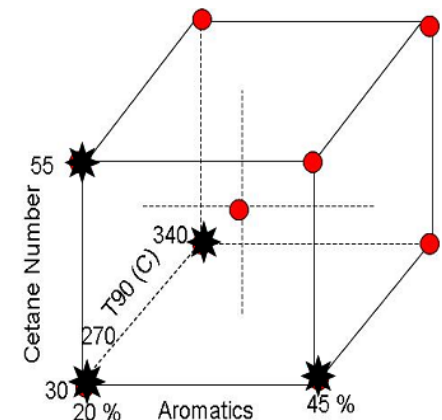
Gasoline surrogates

- 9 surrogate blends + 3 ULR street fuels
- Surrogates designed to 92 RON using octane simulator
- Large differences in ignition characteristics
 - Also pointed out need for better MCH mechanism
- Overall, ignition correlated best to MON
- This data also formed basis for multi-zone modeling



Fuels for advanced combustion engines (FACE) diesel fuels

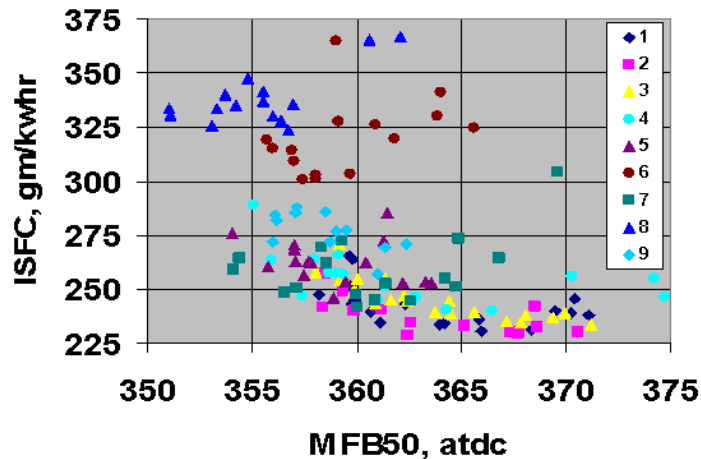
- Joint DOE – CRC effort to design standard reference fuels for the study of combustion in advanced engines
- Nine fuels, targeted to
 - Cetane = 30 or 55
 - Aromatics = 20 or 45%
 - T90 = 270 or 340C
 - Center fuel
- At ORNL, FACE diesel fuels have been run in HCCI engine and 4 cylinder diesel PCCI engine, presenting HCCI results here



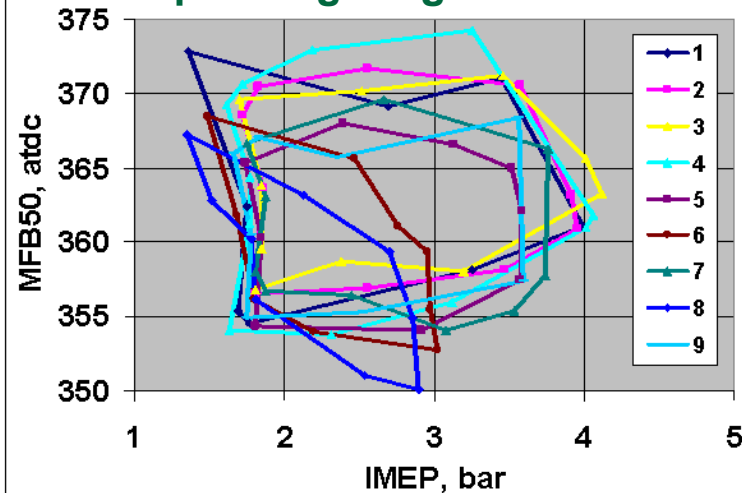
CORRELATION COEFFICIENT MATRIX			
	Cetane	aromatics	T90
Cetane	1.00		
aromatics	-0.22	1.00	
T90	-0.07	-0.24	1.00

FACE diesel fuels – IAFC and operating range both correlate to cetane

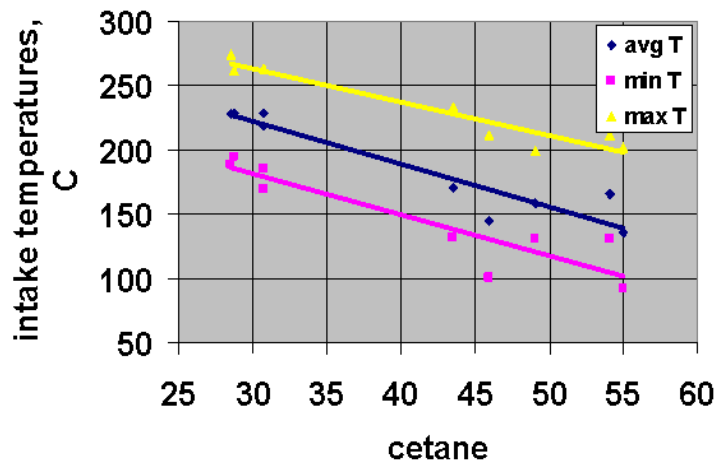
ISFC vs. MFB50



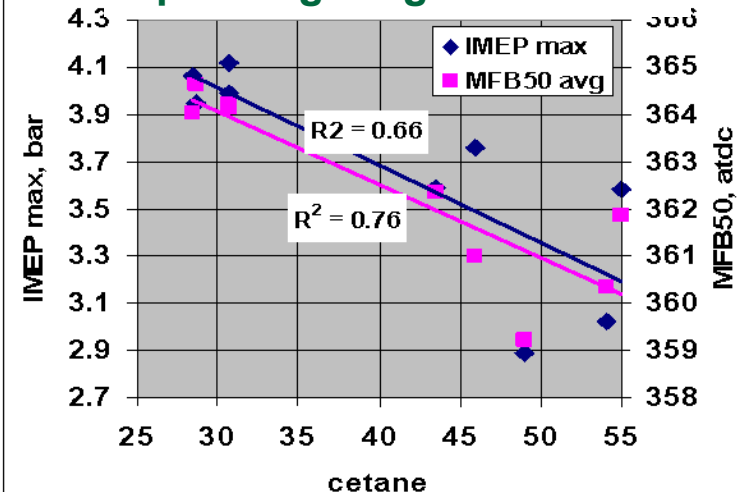
Operating range of fuels



Intake temp. range vs. cetane

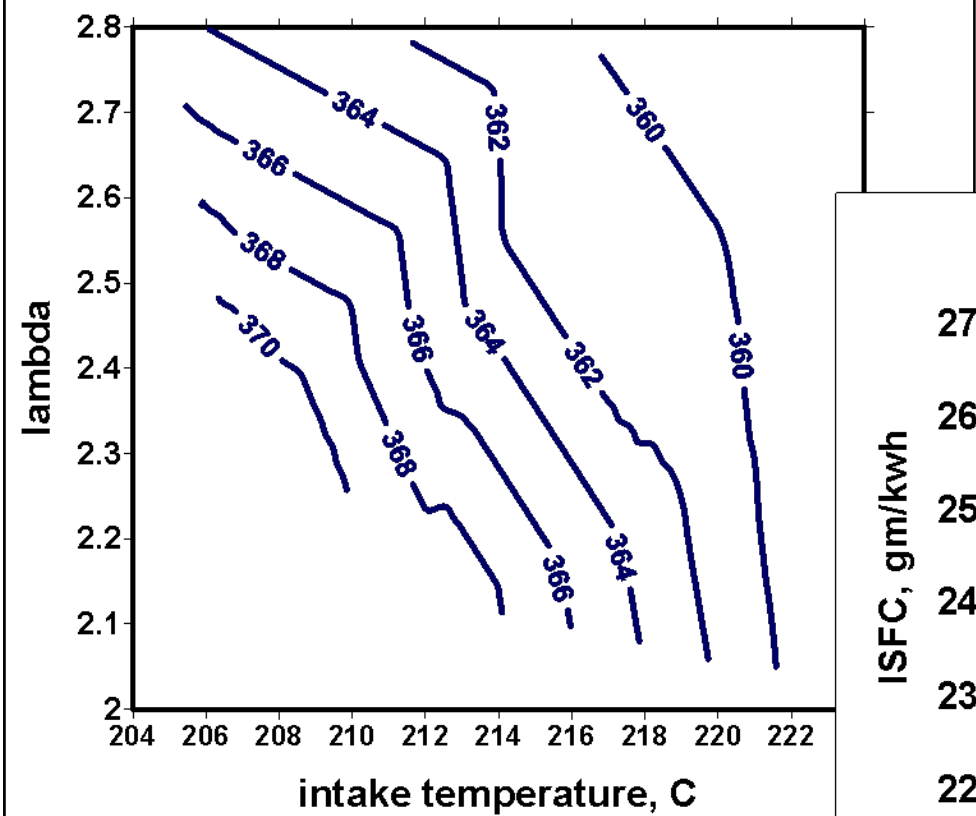


Operating range vs. cetane

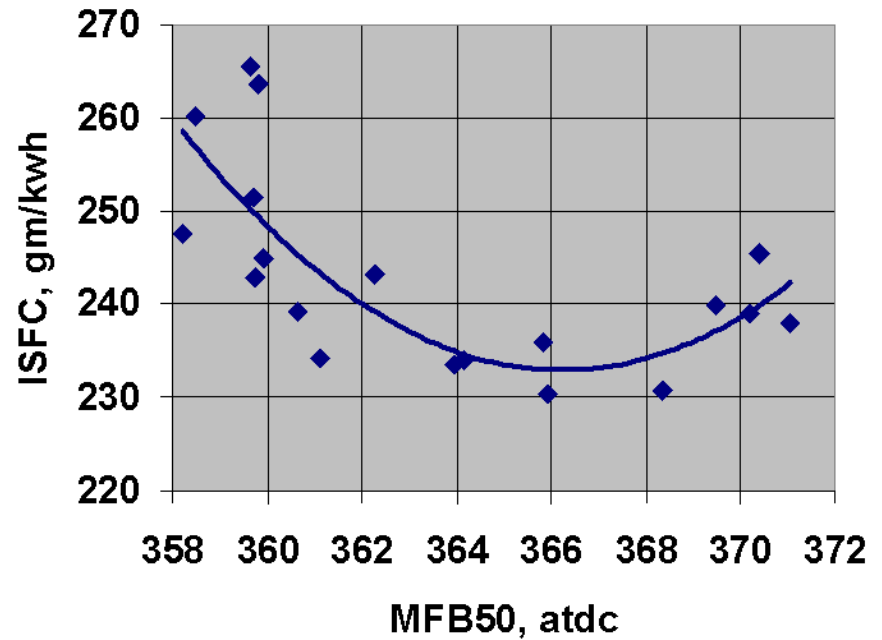


MFB50 can be manipulated by trading off lambda and intake temperature, ISFC is mainly controlled by MFB50

MFB50 vs. lambda and intake T, fuel 1, 10.5 rate



ISFC vs. MFB50, fuel 1, 10.5 rate



PCA analysis of FACE fuels data

- Major fuel variables include cetane, specific gravity, naphthenes, monoaromatics, polyaromatics, T10, T70, and T90
- These are resolved into eigenvectors, which indicate how fuels were blended
 - Vector 1 (49% of variation)
 - Tradeoff of mono and polyaromatics to achieve cetane and T90 targets
 - Vector 2 (19% of variation)
 - Tradeoff of naphthenes and aromatics to achieve cetane targets with low boiling fuels
 - Vector 3 (16% of variation)
 - Tradeoff of naphthenes and monoaromatics with heavy paraffins to achieve T90 targets
 - Fuel vectors combined with engine variables to allow parametric modeling studies of engine response

FACE diesel fuel conclusions

- **Cetane is the major variable correlating to performance and operating range**
- **High T90 is harmful to ISFC and thermal efficiency, but trends are weak**
- **Aromatics appear to have no effect, however we did not measure smoke or particulates**
- **Manipulation of AFR and intake temperature in the range evaluated did not allow the recovery of fuel economy lost by mismatch of fuel and engine**

Future work

- HCCI engine experiments with **detailed exhaust chemistry and particulate characterization**
 - Supports kinetic modeling research
- Evaluation of **compression ratio effects** on HCCI engine with high % ethanol blends
 - Taking advantage of high octane values of ethanol
- Continued development of compression ratio, boosting, and air handling capabilities
 - **Optimization and control of HCCI**
- Adding **new engine capabilities**
 - VVA GDI / PFI
- **Mining of existing data** with focus on performance and engine control
 - Cummins, CRC, and surrogate fuel datasets
- Source and evaluate **new fuels**
 - Hydrotreated vegetable oils, bio- algae fuels

Overall summary

- **A wide range of fuels have been evaluated in HCCI and PCCI combustion**
- **Research platforms continue to evolve to broaden relevance of research**
- **Cetane and octane numbers remain major fuel variables for advanced combustion engines**
- **Lower boiling points / higher volatility improve performance**
- **For fully formulated fuels meeting specifications, chemistry effects are not readily apparent beyond impact on properties**
- **Research is shifting to more detailed chemistry focus and to optimization of engine and fuel as a system**

