High Efficiency Clean Combustion in Multi-Cylinder Light-Duty Engines

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High Efficiency Clean Combustion Project Overview

PROJECT OVERVIEW (1/1)

Activity evolves to address DOE challenges and is currently focused on milestones associated with Vehicle Technologies efficiency and emissions objectives

Timeline

- Consistent with VT MYPP
- Activity scope changes to address DOE & industry *needs*
- *FY 17-19 project plan*

Barriers (MYPP 2.3 a,b,f)*

a) Lack of fundamental knowledge of advanced combustion regimes

b) Lack of effective emissions controls for LTC

f) Lack of emissions data on future engines

Budget

FY 2014 – $500k

FY 2015 – $430k

FY 2016 – $400k

FY 2017 – $310k

Partners / Interactions

Regular status reports to DOE

Industry technical teams, DOE working groups, and one-on-one interactions

Industry: GM, MAHLE, Honeywell, and many others

Universities: U. Wisconsin, U. Minnesota, Clemson

DOE Labs: SNL, ANL, LANL

VTO: Other ACS projects, Fuel Lube Tech./Co-Optima

ORNL: fuels, emissions, vehicle systems, others

Consortia: CLEERS (DOE), DERC (U. Wisc)

*http://www1.eere.energy.gov/vehiclesandfuels/pdfs/program/vt_mypp_2011-2015.pdf

Relevance and Project Objectives

RELEVANCE (1/1)

- **Overall Objectives**
  - **Develop and assess the potential of single- and dual-fuel advanced combustion concepts on multi-cylinder engines (MCE) for improved efficiency and emissions**
  - **Address barriers to meeting VTO goals** of reducing petroleum energy use (engine system) including potential market penetration with efficient, cost-effective aftertreatments
  - **Minimize fuel penalties for aftertreatments** (Tier 3 goal)
  - **Characterize MCE LTC implementation losses** on thermodynamic basis including hardware effects
  - **Interact in industry/DOE tech teams and CLEERS** to respond to industry needs and support model development

Objectives March 2016–March 2017

1. RCCI Development – Mapping - FY16 Q3 Milestone
2. Low Delta Reactivity Stratified Development
3. RCCI Fuel Economy - FY 16 Q4 Milestone
4. Advanced airhandling study
5. Mixing controlled noise collaboration SNL
6. Thermodynamic analysis of loss mechanisms

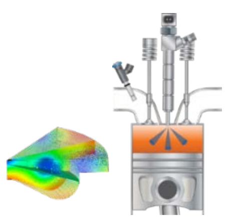
Relevance to DOE VTO MYPP 2.3X

A. Lack of fundamental knowledge of advanced engine combustion regimes
B. Lack of cost-effective emission control.
C. Lack of modeling capability for combustion and emission control
D. Lack of effective engine controls.
F. Lack of actual emissions data on pre-commercial and future combustion engines.
H. Market perception

Milestones and Go/No-Gos for FY 16 and 17

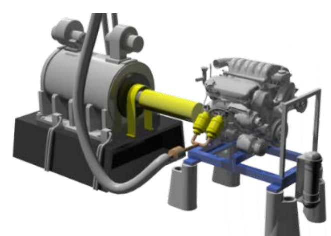
Milestones (1/1)

- **Complete** — FY 16, Q3: Develop experimental multi-mode RCCI map suitable for drive cycle simulations with transient effects
- **Complete** — FY 16, Q4 SMART: Demonstrate 25% increase in dyno fuel economy with RCCI over LD drive cycle on transient experiments
- **On Track** — FY 17, Q4 SMART: Demonstrate the ability to achieve efficiency parity for range of low- and high-delta reactivity stratification advanced combustion approaches including zero-delta approaches (single fuel)



Combustion

Metric: Indicated efficiency



Engine System

Metric: Brake efficiency

Full Vehicle

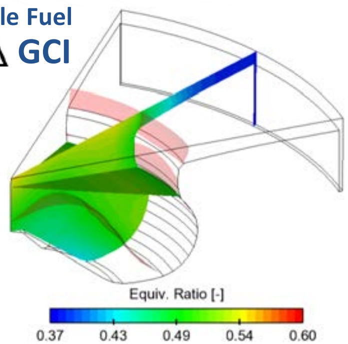
Metric: Fuel Economy

Long term Objective: Develop and assess the potential of reactivity stratified combustion concepts on MCEs [FY 17-19 Plan]

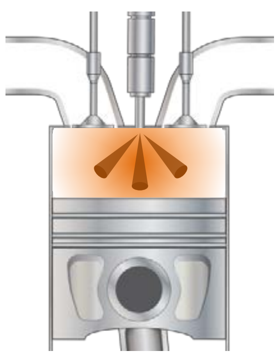
APPROACH (1/4)

- Dual-fuel/ single-fuel LTC approaches where reactivity stratification is achieved through fuel composition stratification in addition to equivalence ratio and temperature stratification
  - High-delta reactivity stratified combustion (e.g., gasoline and diesel fuel)
  - Single-fuel or zero-delta reactivity stratified combustion (Injection timing controlled auto-ignition)
  - Low-delta reactivity stratified combustion (e.g., low octane gasoline range fuel and diesel fuel)

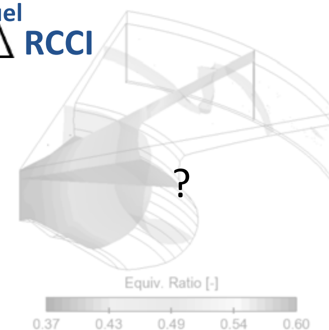
Single Fuel
0Δ GCI



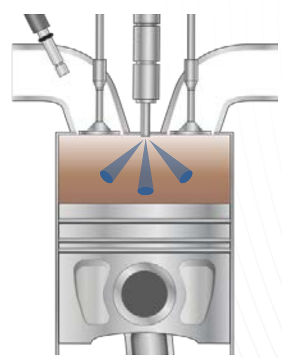
Low RON Gasoline



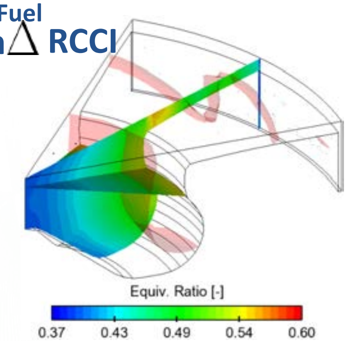
Dual Fuel
LowΔ RCCI



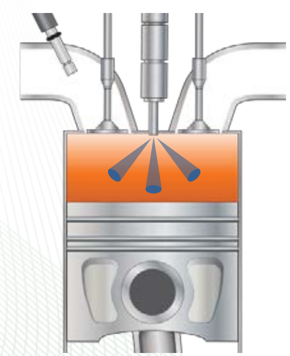
High RON Gasoline + Low RON Gasoline
Low RON Gasoline + Diesel



Dual Fuel
HighΔ RCCI



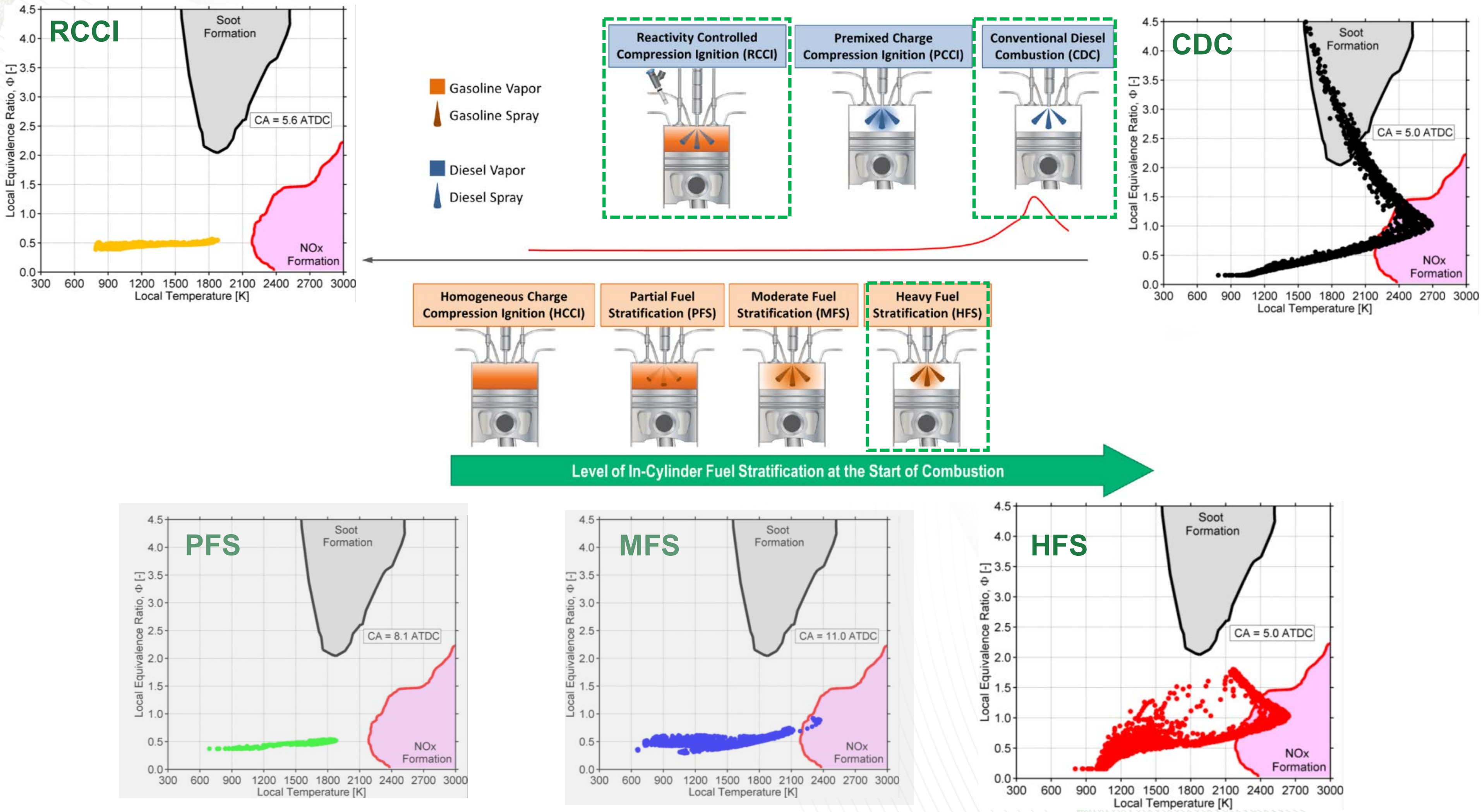
High RON Gasoline + Diesel



Different LTC approaches dominated by differences in fuel/air stratification

APPROACH (2/4)

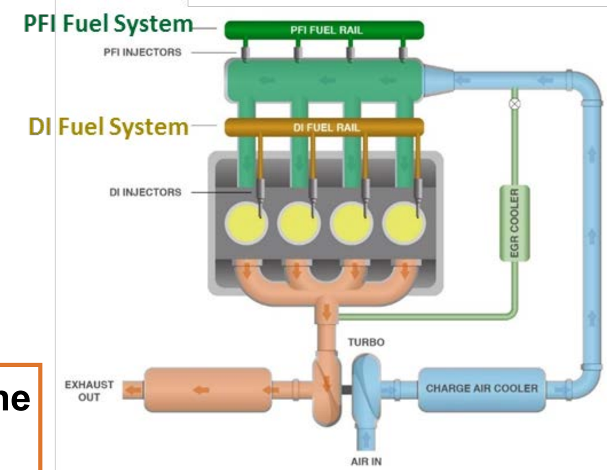
- GCI landscape explored in other activities at ORNL but included here for reference
  - CFD using KIVA3V-Release 2 – RANS Simulations with a Lagrangian Drop/Eulerian Fluid Framework



Approach: Multi-cylinder advanced combustion with production-viable hardware and aftertreatment integration

APPROACH (3/4)

- **GM 1.9 DTH multi-cylinder diesel engine with dual-fuel system**
  - **Single-fuel and dual-fuel LTC modes + mixing controlled modes**
- CFD and 1-D modeling for guidance and insight
- Emissions characterization and aftertreatment integration
- Vehicle systems simulations using experimental data/ HIL experiments to address barriers for LTC

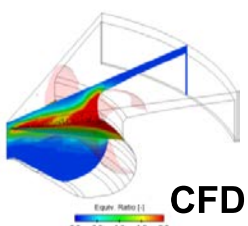


CFD & 1D Modeling

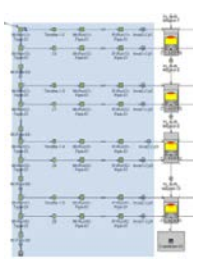
Transient AC Dyno

Emissions controls
- Aftertreatments
- PM/HC characterization

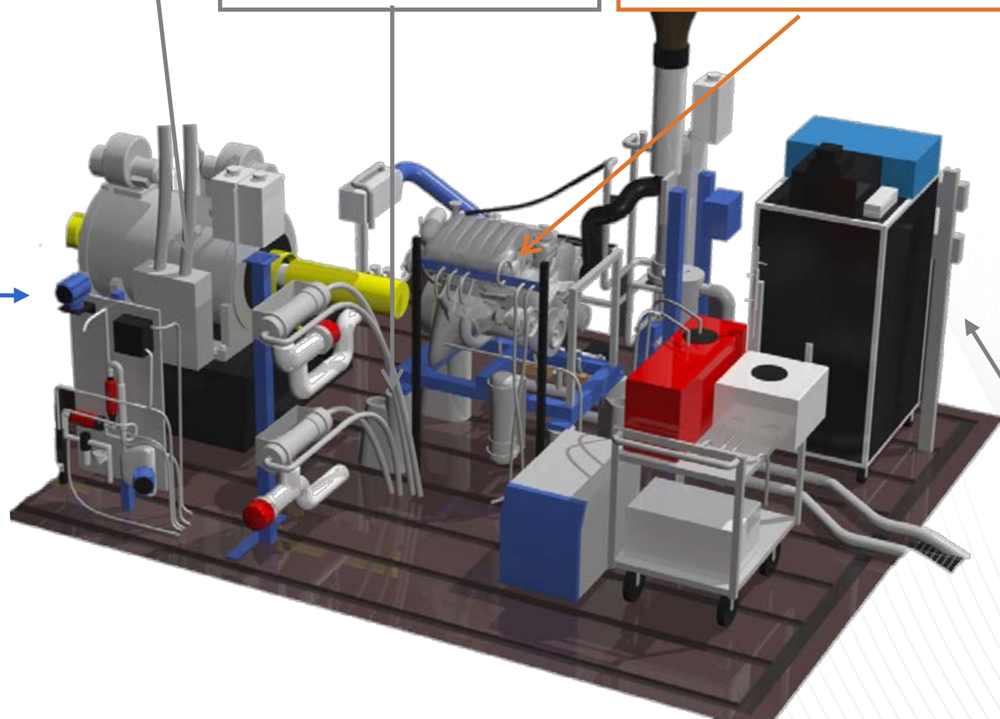
Multi-cylinder engine
- GM 1.9L DTH
- Dual Fuel (DI + PFI)



CFD



1D Models



Rest of Vehicle Simulated

DSPACE
Hardware-in-the-loop

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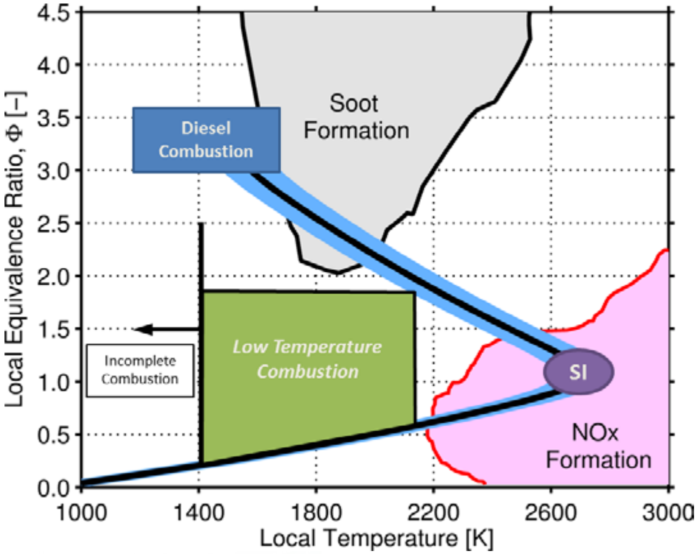
Technical accomplishments overview

Accomplishments (0/10)

Focus: Develop and assess the potential of reactivity stratified combustion concepts from an engine systems perspective

- FY 16 Q3 milestone low delta RCCI Map [Slide 9]
- Low delta RCCI development [Slide 10]
- FY 17 Q4 milestone progress low-delta CFD [Slide 11]
- LTC/ mixing controlled multi-mode [Slides 12-13]
- Multi-mode transitions + fast FID [Slide 14]
- FY 16 Q4 milestone – transient dyno study [Slide 15-16]
- Advanced air handling study LTC/ GCI [Slide 17-18]



ACE [ACS] Sub Program Primary R&D Directions
(from 2015 VTO AMR Report Chapter 4*)

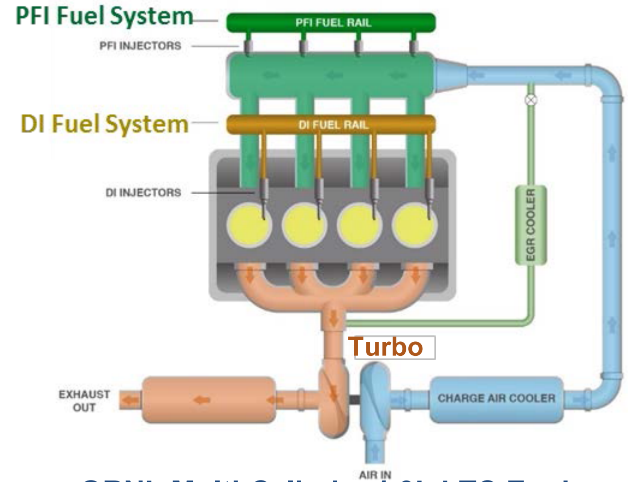
1. **Developing advanced combustion strategies** that **maximize energy efficiency** while **minimizing the formation of emissions** within the engine.
2. Developing **cost-effective aftertreatment technologies** that further reduce exhaust emissions at a **minimum energy penalty**.
3. **Reducing losses** and recovering waste energy.

* http://energy.gov/sites/prod/files/2015/12/f27/04%20-%20Advanced%20Combustion%20Engines.pdf

Reactivity stratified combustion development: Mapping

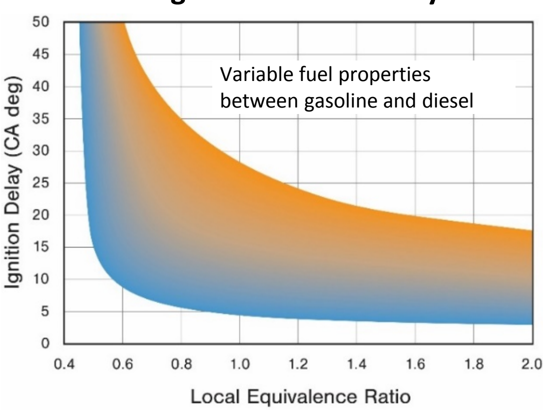
ACCOMPLISHMENTS (1/10)

- **FY 16 Q3 Milestone Met:** Develop experimental multi-mode RCCI map
- **1.9L GM diesel engine modified for both single- and dual-fuel LTC**
  - Stock-GM re-entrant piston used for FY 15/ 16 (premixed piston before)
- **PFI Fuel= 70 RON gasoline range fuel, DI Fuel = ULSD**
  - 96 RON cert gasoline and ULSD used in for FY 15 milestone
- **Jointly developed (ORNL/ANL) advanced combustion mapping guidelines**
  - US DRIVE ACEC Noise and Efficiency Guidelines followed
- **Previous maps available on CLEERS database [ACS 022]**



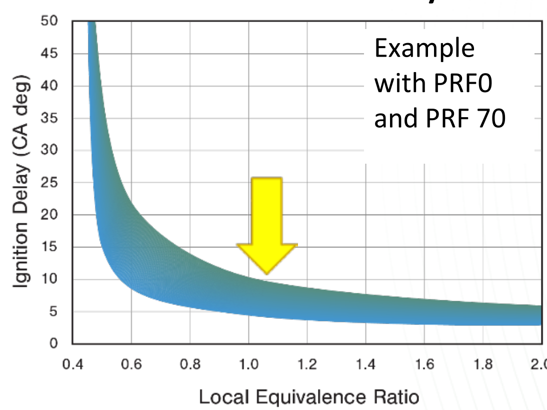
ORNL Multi-Cylinder 1.9L LTC Engine

High Δ Fuel Reactivity



Two fuels - e.g. gasoline and diesel fuel

Low Δ Fuel Reactivity



Two fuels TBD – several options

Figure Source: *Adapted from* Klos, D., Janecek, D., and Kokjohn, S., SAE 2015-01-0841.

ORNL/ANL LTC Mapping Guidelines

Oak Ridge National Laboratory [ACS016]

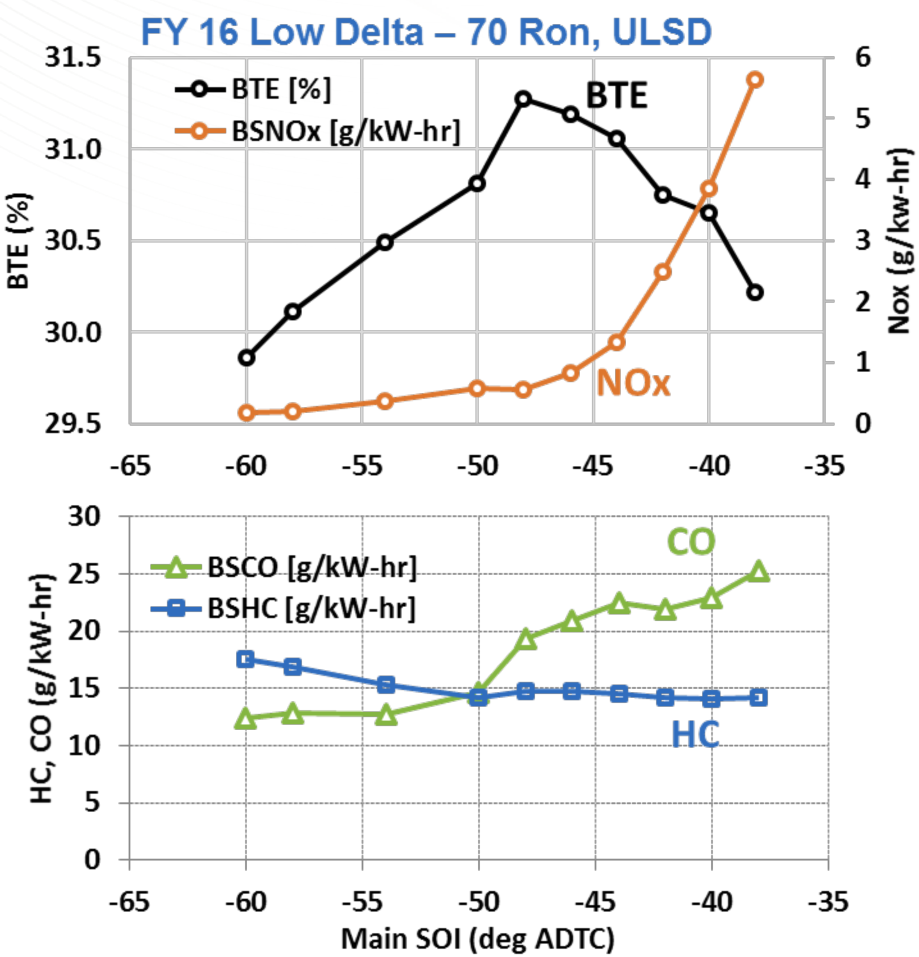
Argonne National Laboratory [ACS011]

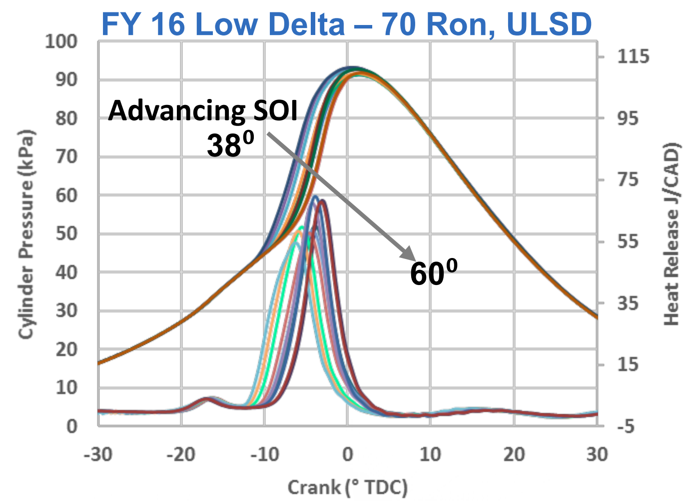
Newly implemented advanced combustion guidelines co-developed by ORNL and ANL
[*under continuing development*]

Exploring RCCI combustion performance with the narrowing of fuel reactivity

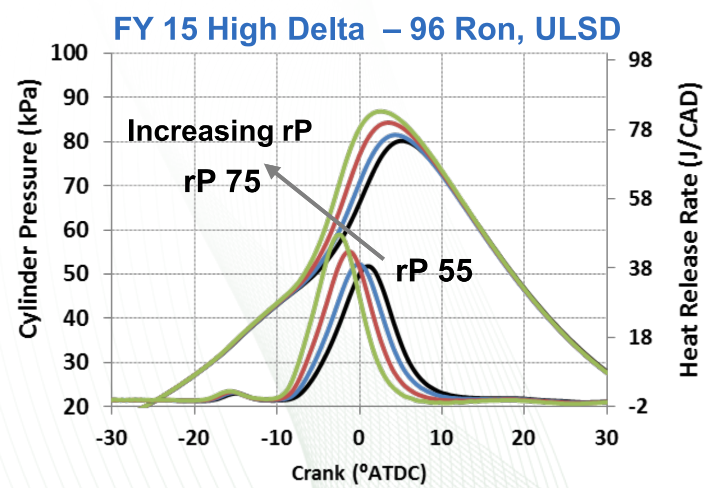
ACCOMPLISHMENTS (2/10)

- 70 RON PFI /ULSD DI, 2000rpm, 3.0bar BMEP
  - Main diesel SOI Sweep with matched conditions 96 RON case FY 15 map





Fixed 75% premixed ratio (rP) **Best BTE = 31.2%**



Fixed Main SOI = -48⁰ ATDC **Best BTE = 31.6%**

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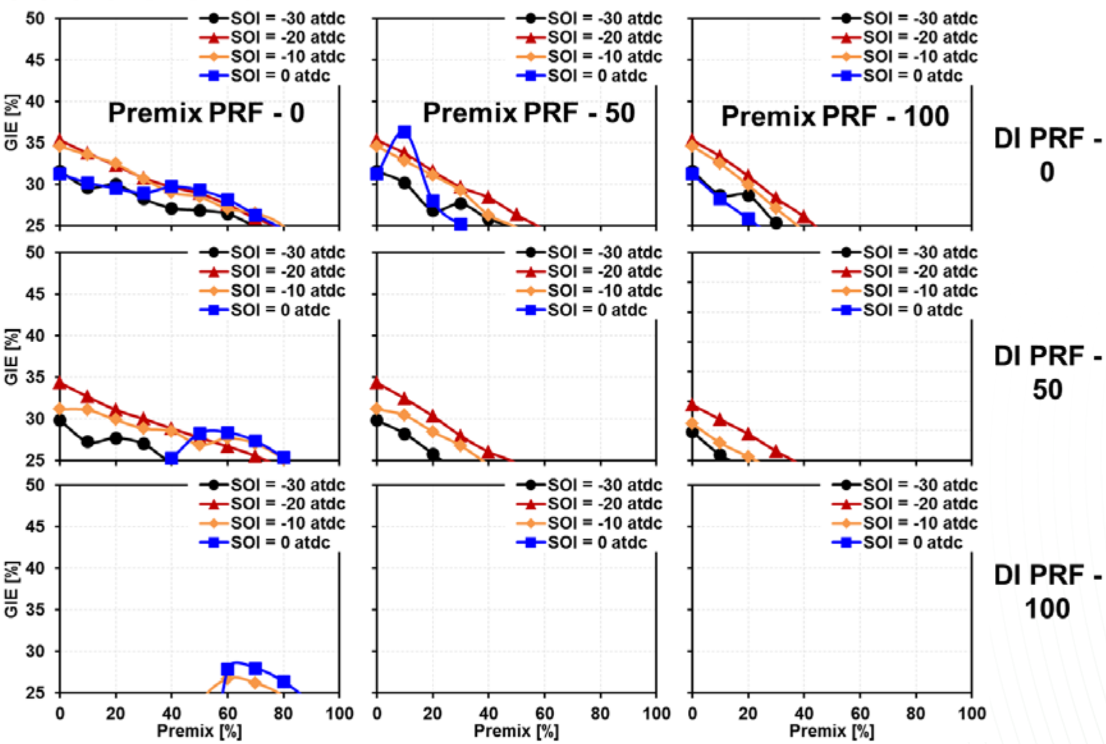
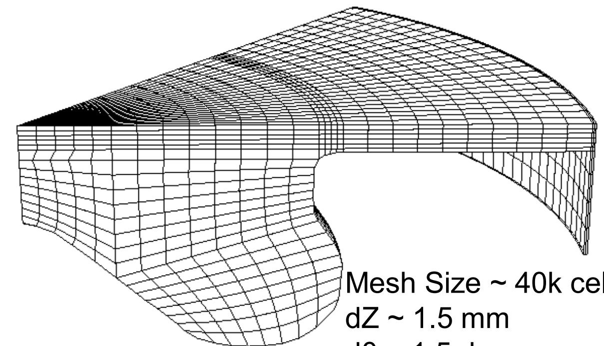
FY 17 Q4 milestone investigation low-delta RCCI being guided by CFD modeling: Collaboration with U. Wisc

ACCOMPLISHMENTS (3/10)

- **FY 17 Q4 Milestone eff. parity with low delta- Underway**
- Large parameter space to explore
- Large matrix of PFI and DI reactivity being explored in CFD to guide experiments





Mesh Size ~ 40k cells at BDC
dZ ~ 1.5 mm
dθ ~ 1.5 deg

Mechanism	Sub-Model
Combustion	Reduced PRF Mechanism (80 species, 351 reactions)
Emissions	• Reduced NOx Model (4 species, 12 reactions) • 2-Step Phenomenological Soot Model
Spray	• KH-RT Spray Breakup • Gasjet Model • Droplet Collision • Wall Film
Turbulence	RNG k-ε model

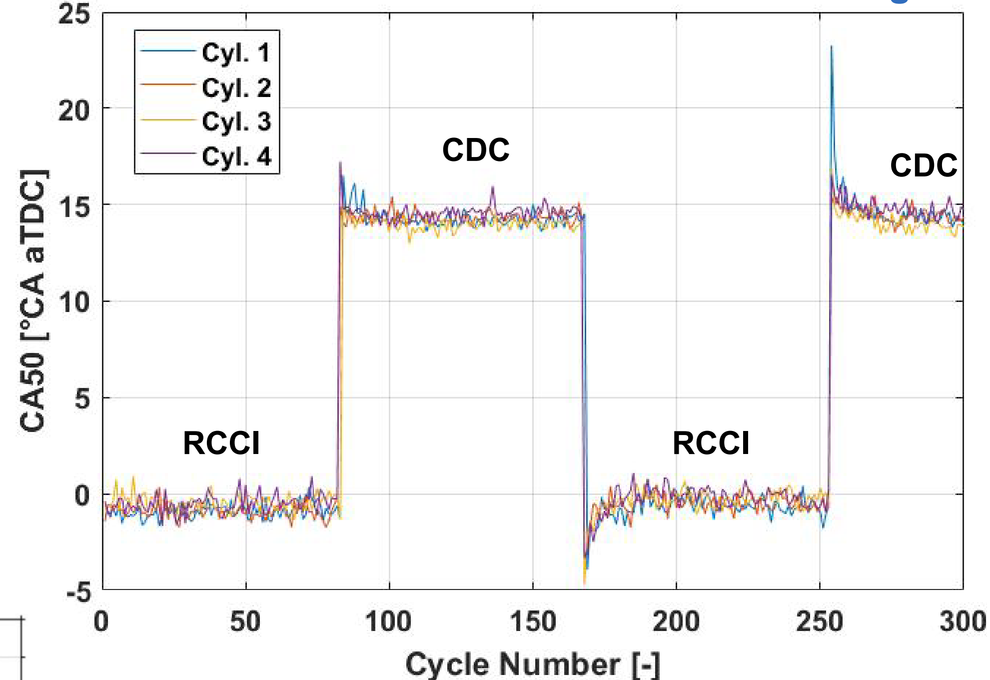
Chaitanya Kavuri and Sage Kokjohn
Engine Research Center, UW-Madison

Control authority of RCCI allows for rapid and stable mode switches between RCCI and mixing controlled combustion modes

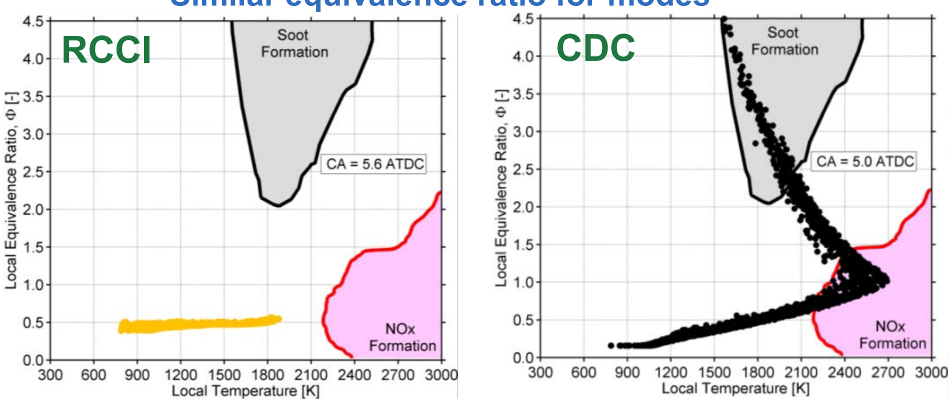
ACCOMPLISHMENTS (4/10)

- **High Delta RCCI - UTG96 PFI, USLD DI**
- Open controller modified to allow for step change between multiple points
  - DI SOI, DI duration, boost, PFI duration, swirl, etc…
  - No other controls implemented
  - Area for future development
- Step change experiments– CDC and RCCI
  - Zero EGR mode switching, **different boost levels**
  - Zero EGR mode switching, **matched boost levels**
  - **CDC + PFI dual fuel** mode switching to RCCI
  - **Matched noise** mode switching [backup slide]

3.5 BAR BMEP – RCCI/CDC Mode Switching



Similar equivalence ratio for modes



	RCCI	CDC/ CDC + PFI
Main SOI	50 degBTDC	1.86 degBTDC
Boost	1.05	1.05-1.21
Premixed Ratio	70%	0 – 5%

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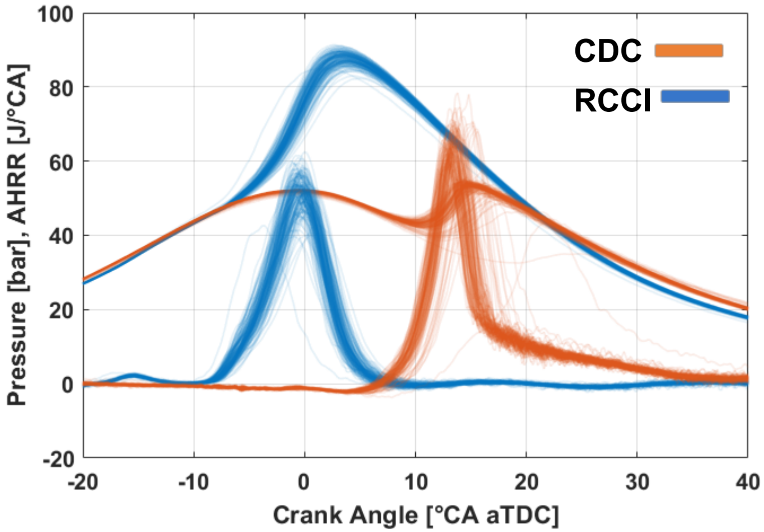
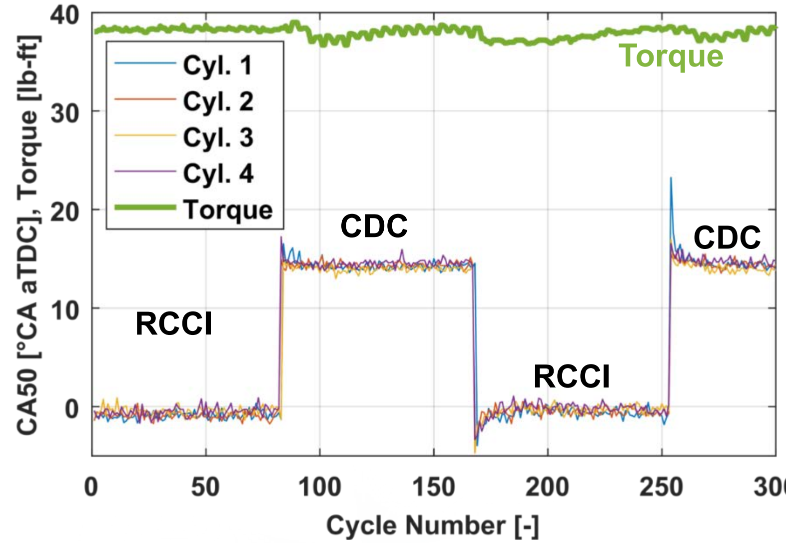
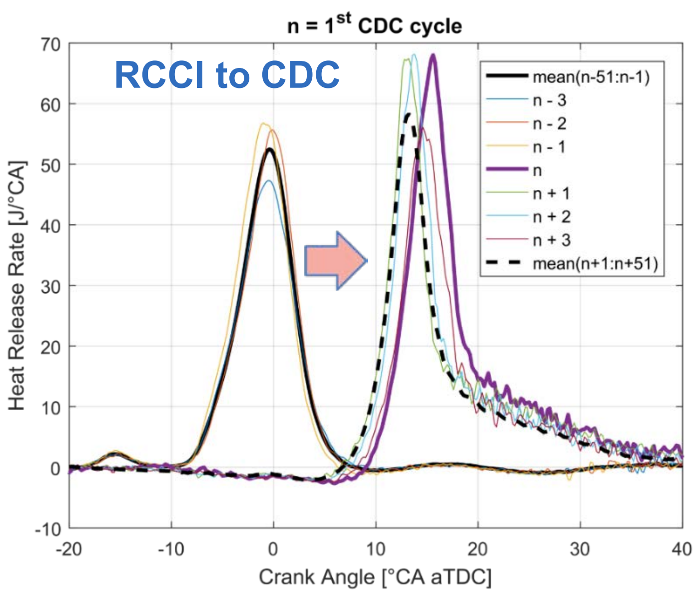
Control authority of RCCI allows for rapid and stable mode switches between RCCI and mixing controlled combustion modes

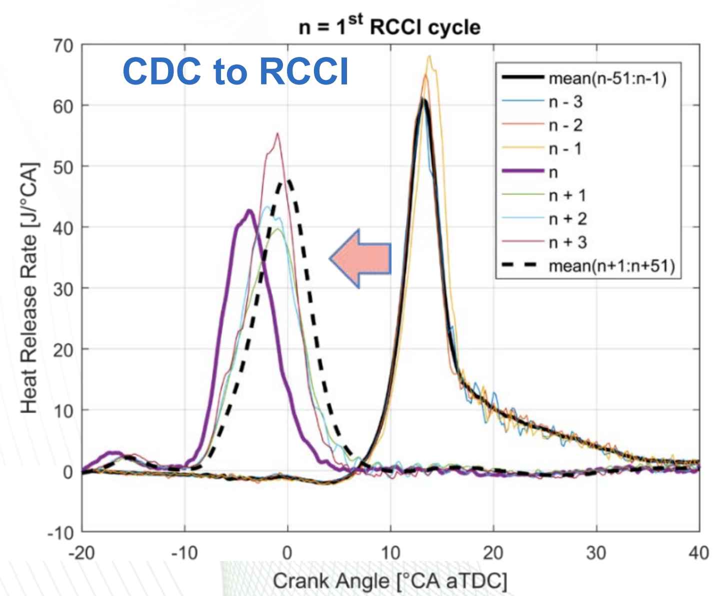






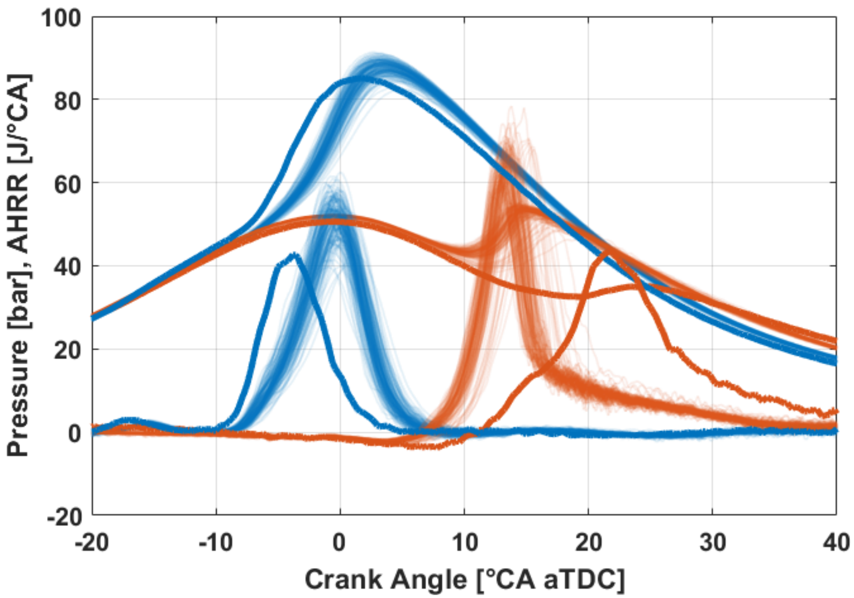
Observations

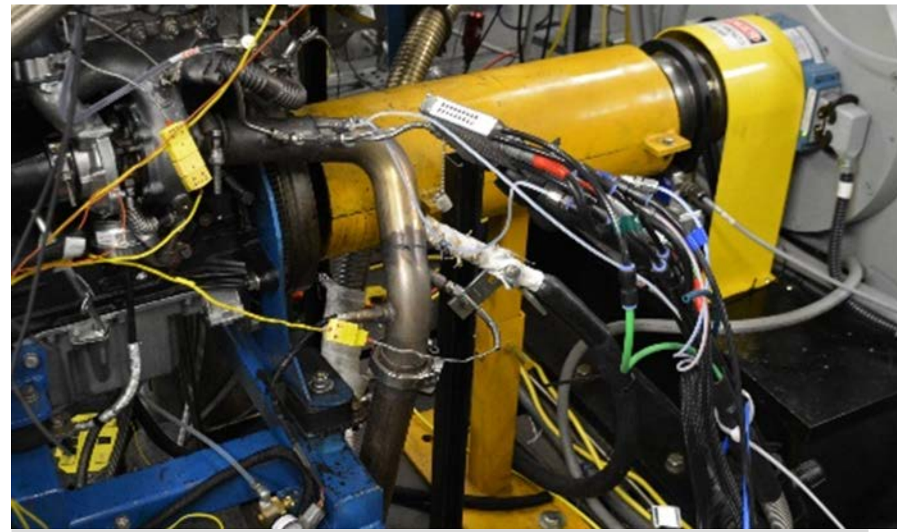
- Stable mode transition in both directions with small variations in initial subsequent cycles
- Allowed by similarities in both equivalence ratio and boost levels



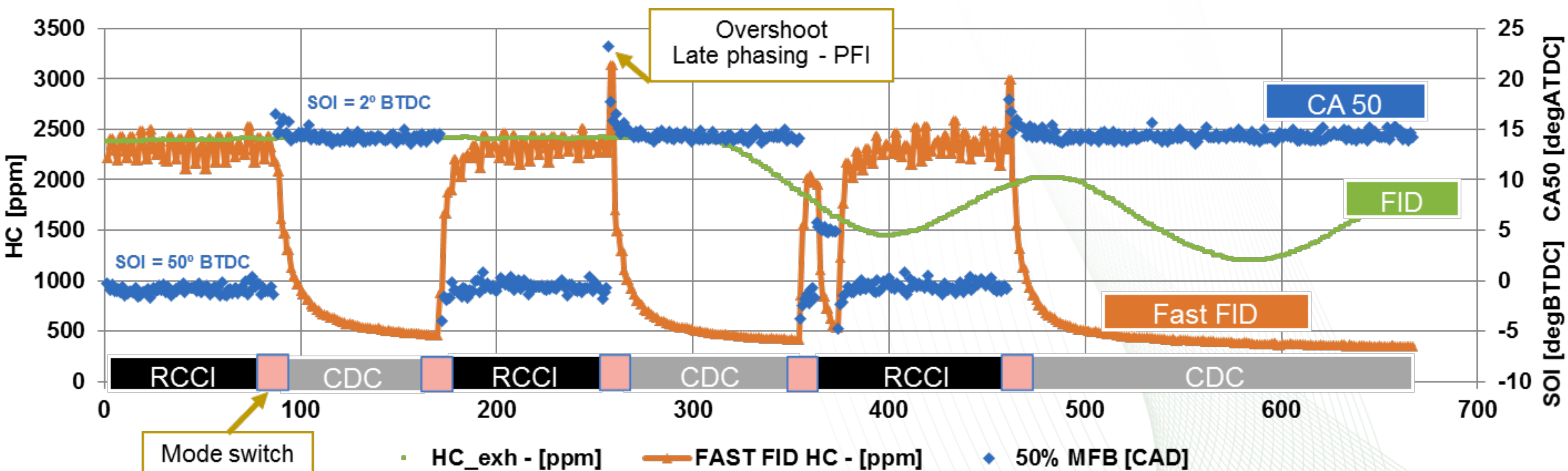
Phasing excursions seen without feedback controls: options include dual-fuel conventional combustion modes

ACCOMPLISHMENTS (6/10)



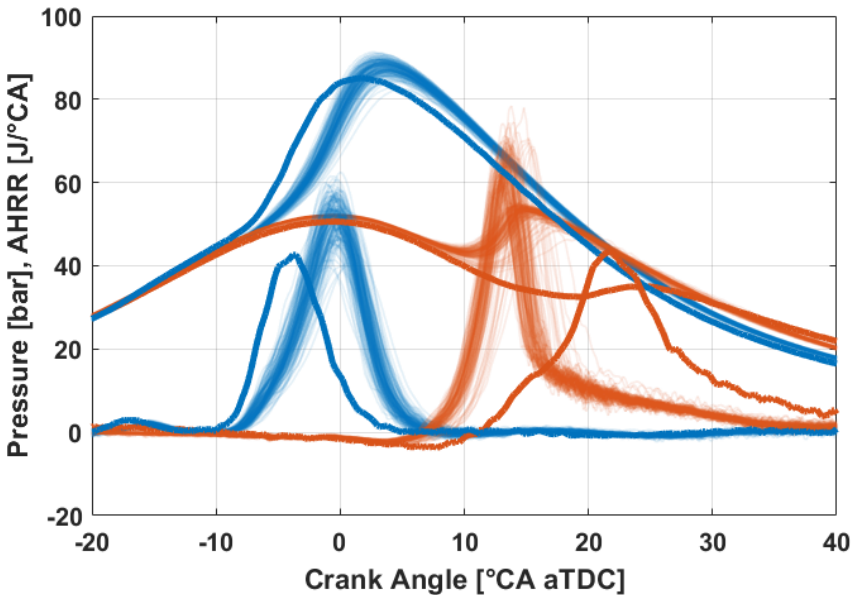


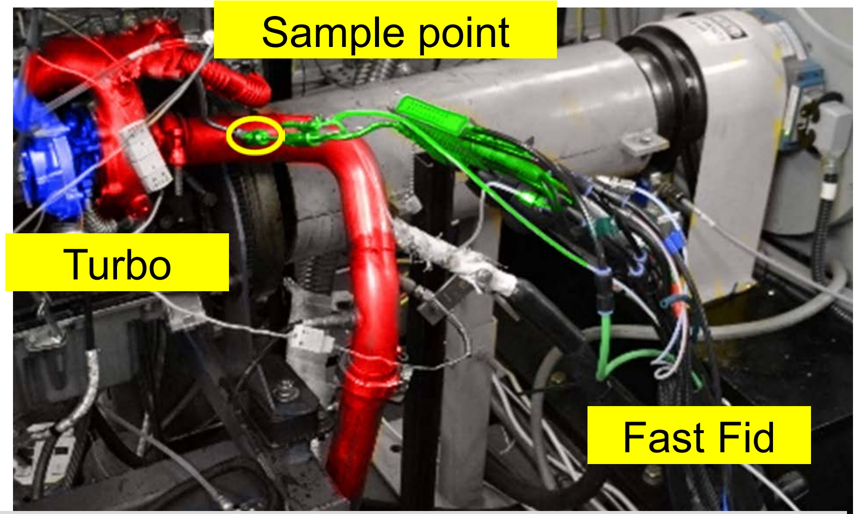
–Fast FID enabled HWFET dyno experiments in progress



Phasing excursions seen without feedback controls: options include dual-fuel conventional combustion modes

ACCOMPLISHMENTS (6/10)





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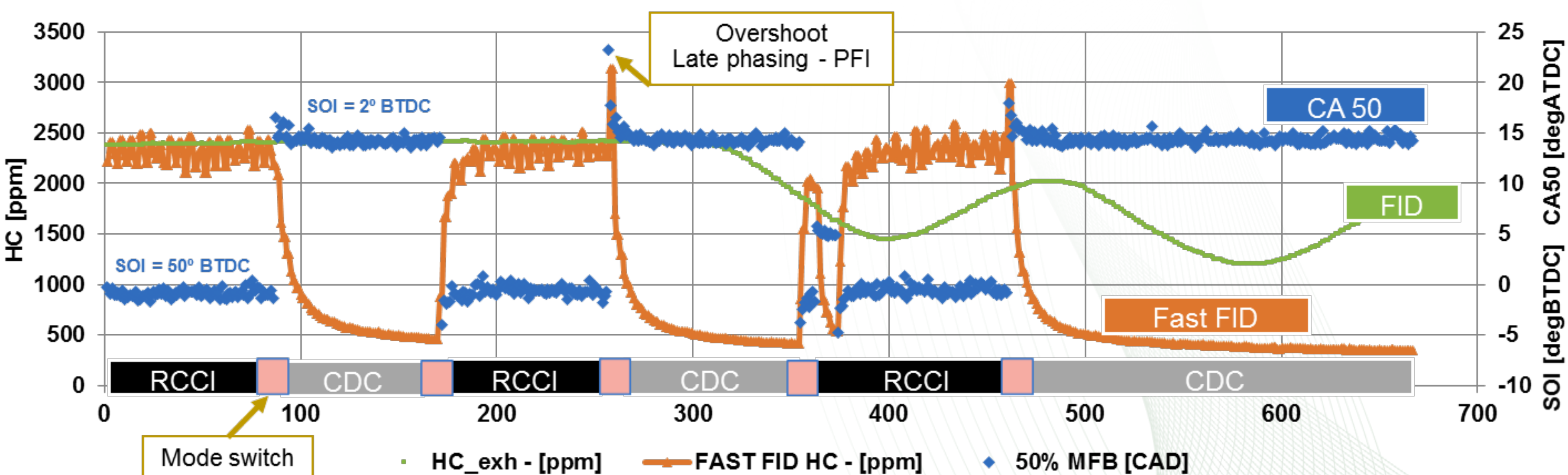
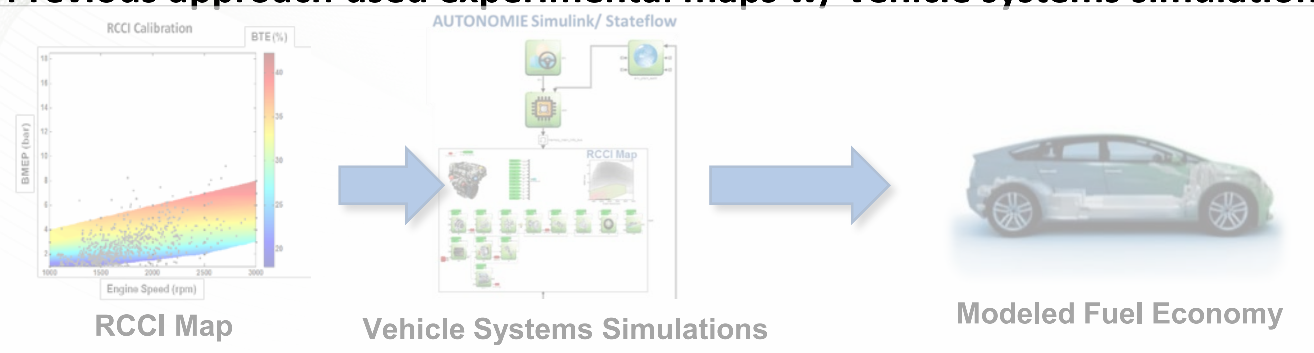


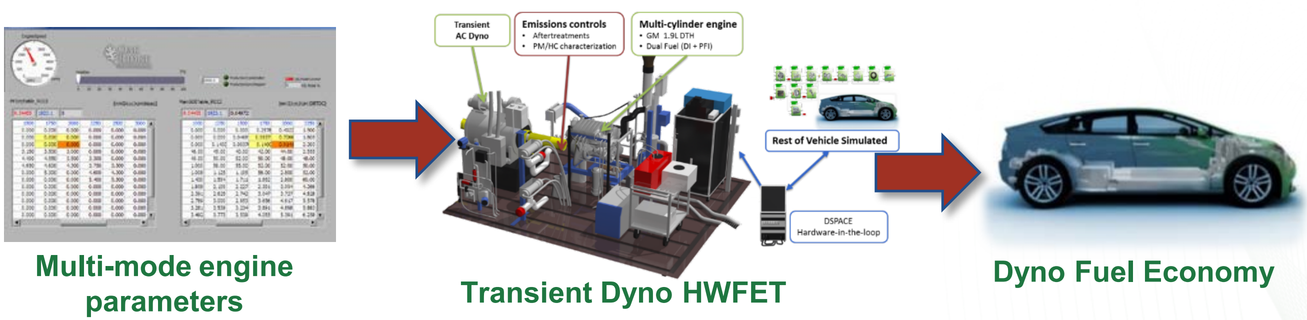
Multi-mode reactivity stratified combustion development: leading towards better understanding of drive cycle implications

Accomplishments (7/10)

Previous approach used experimental maps w/ vehicle systems simulations

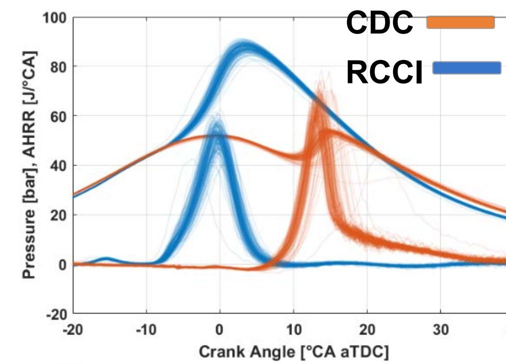


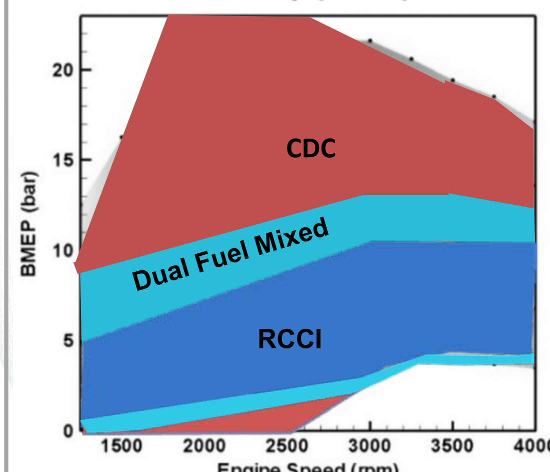
FY 16-17 Transient Dynamometer Drive cycles with Multi-Mode RCCI



- **Lookup table interpolation in simulations shows directionality of trends**
- **Transient results on engine systems level shows new challenges and opportunities for early stage R&D**

Dual fuel mixed mode (CDC + PFI) implemented in transient study to minimize excursions

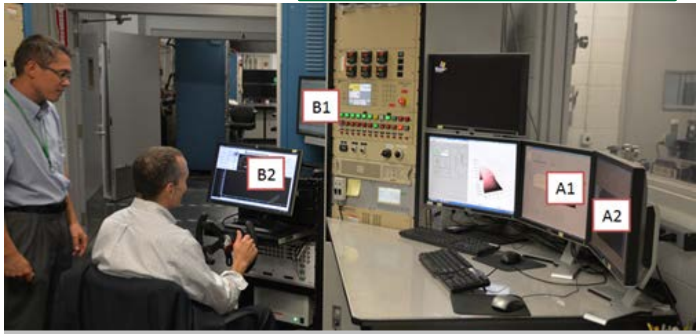




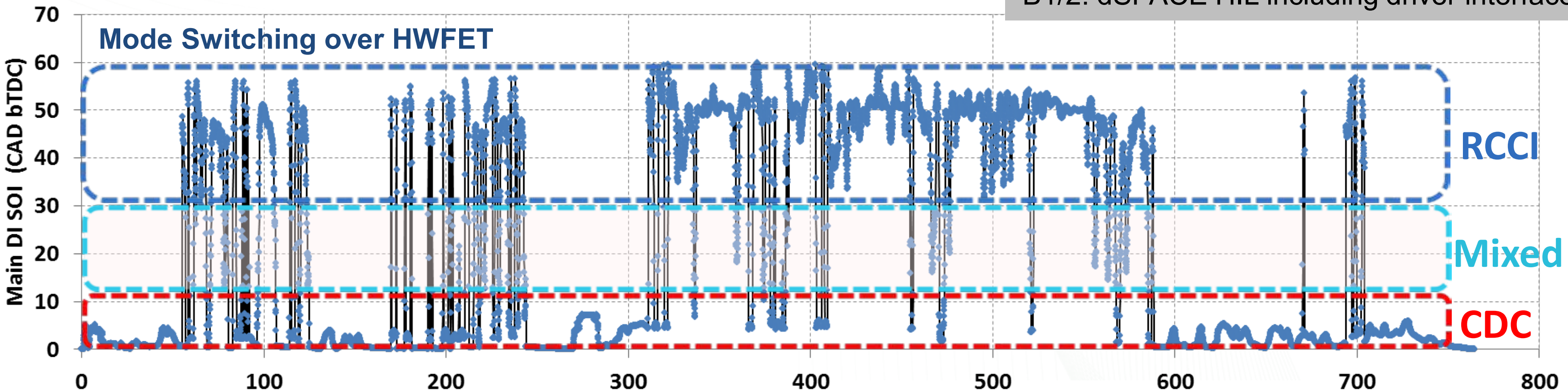
FY 16 Q4 Milestone demonstrating - 25% increase in dyno fuel economy with RCCI over light-duty drive cycle on transient experiments

- Multi-mode RCCI-CDC maps programed into controller
  - Based on FY 15 DOE milestone RCCI map (ULSD + UTG96)
  - The engine controller automatically switches in and out of LTC mode back to conventional diesel combustion for areas outside the RCCI speed and load operating window

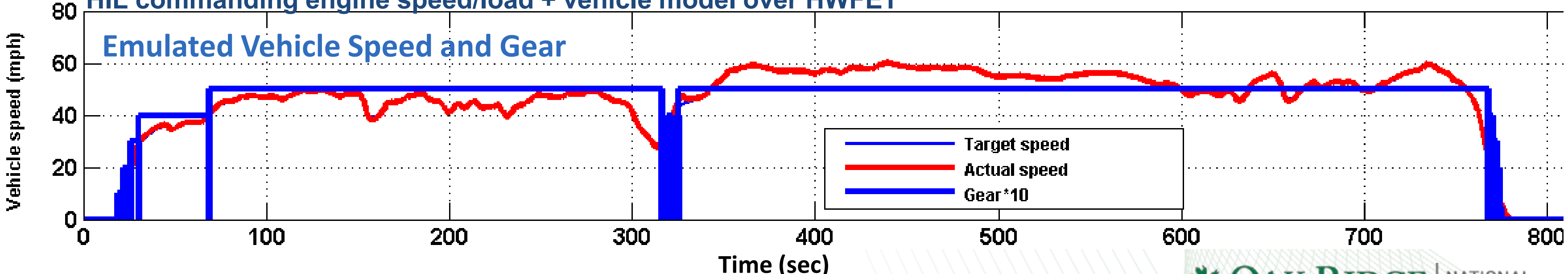
- Unique capability enables ability to investigate barriers to implementation for early stage combustion modes (RCCI/ GCI +) and different powertrains configurations (hybrid)
- Enables future aftertreament investigations over various mixing controlled and LTC modes including multi-mode operation



A1/2: Combustion analysis and engine settings
B1/2: dSPACE HIL including driver interface



HIL commanding engine speed/load + vehicle model over HWFET

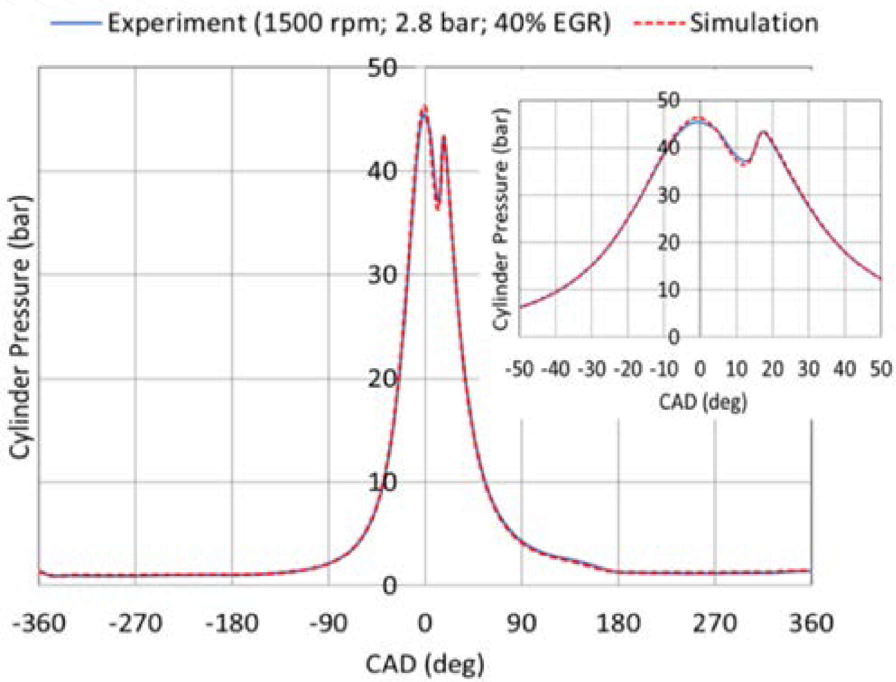


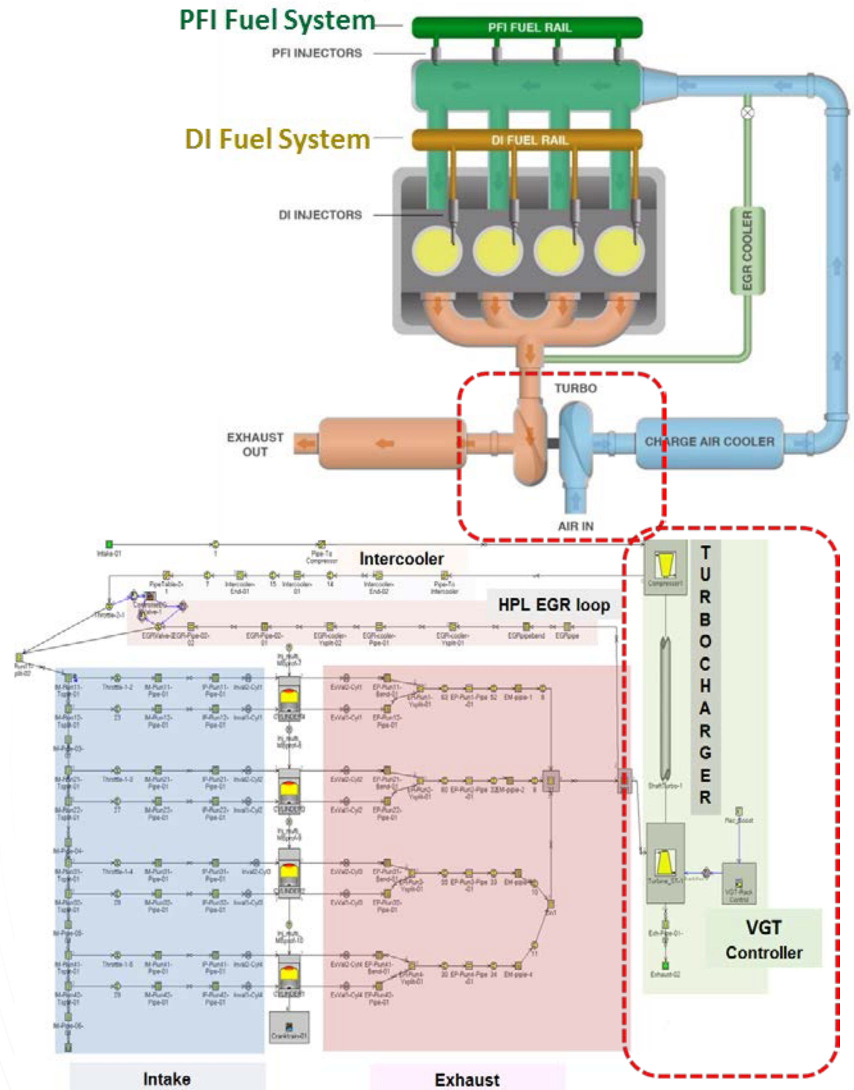
More details on HIL in backup slides

LTC Air Handling Challenges: 1D model developed to inform decision on next generation air handling system

Accomplishments (9/10)

LTC barrier – advanced air handling: Working within constraints for RCCI combustion, effects on efficiency and emissions





GT Power Model: 1.9L Diesel Engine

Being used to inform decisions on next generation air handling systems – validated against CDC/ RCCI/ GCI

Nandini, Dempsey, Curran – ASME ICEF2016-9459

More details in backup slides + thermodynamic analysis

Multi-mode strategies with single or dual-fuel modes with DI gasoline range fuels: Air handling implications

ACCOMPLISHMENTS (10/10)

- Engine was operated in the heavy fuel stratification (HFS) GCI operating strategy using a gasoline boiling range fuel
- At 2000 rpm, the load was increased progressively while using EGR level to maintain NOx emissions below 0.3 g/kWh on a brake-specific basis (VGT vanes closed for max boost)

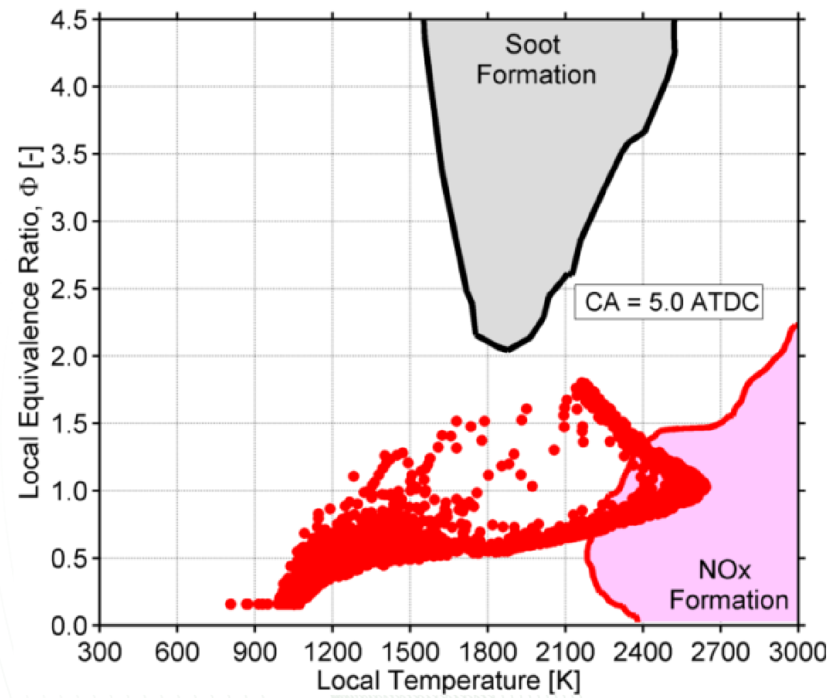
Increasing Load →

High NOx and PM

Experimental Results			
BMEP (bar)	5.70	5.77	6.17
EGR (%)/Intake Pressure (bar)	40%/ 1.20	39%/ 1.21	37%/ 1.22
Global Equivalence Ratio (-)	***0.83***	***0.84***	***0.86***
Main SOI (ATDC)	-16.7	-18.2	-17.1
BSNOx (g/kWh)	0.22	0.22	0.23
AVL Filter Smoke Number (-)	***0.11***	***0.11***	***0.48***
BSCO/BSHC (g/kWh)	22.3/ 1.0	27.2/ 1.2	34.7/ 1.1

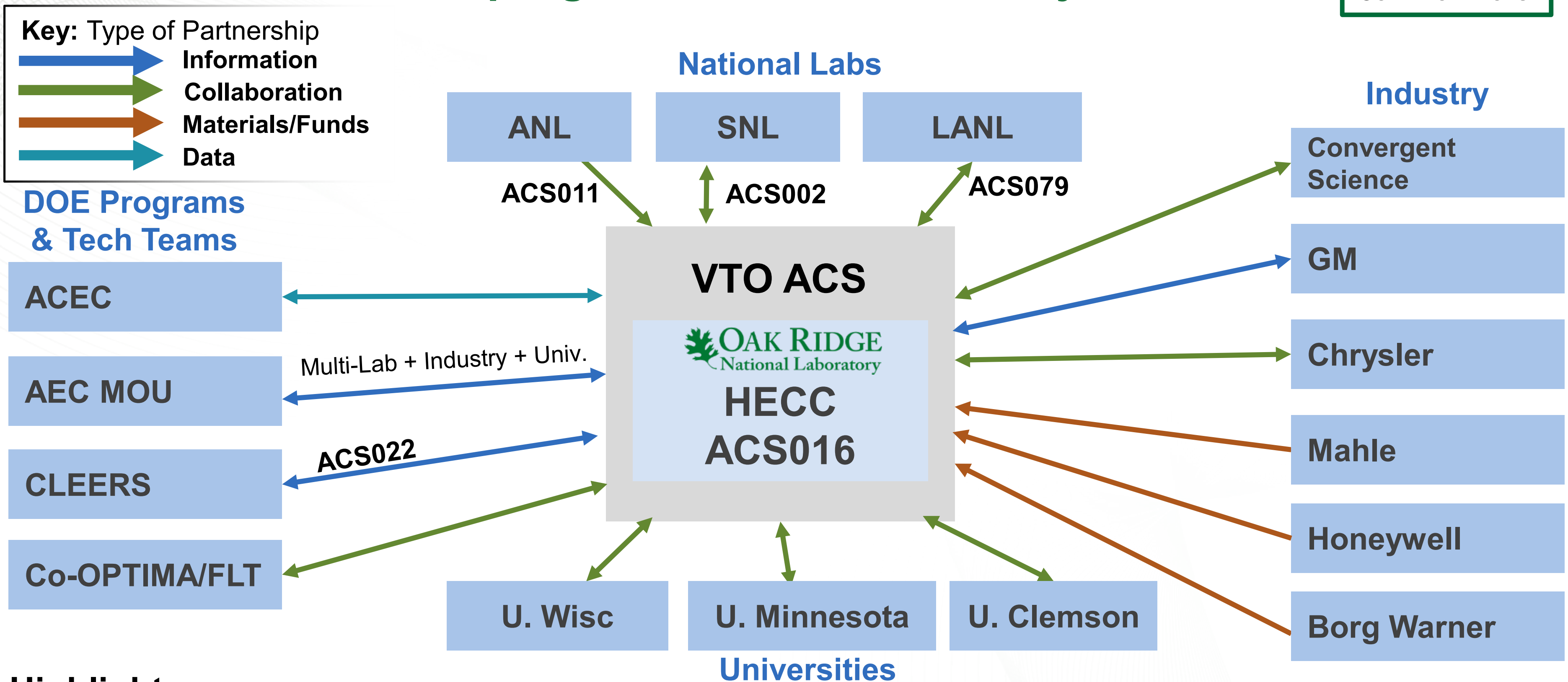
Maximum load is just over 6 bar BMEP before the smoke emissions increased due to the global equivalence ratio increasing to 0.86.

HFS – GCI combustion



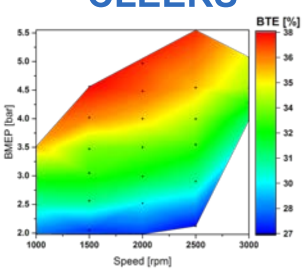
ACS016 project leverage resources and expertise across industry, universities and DOE programs to meet these objectives

COLLABORATIONS



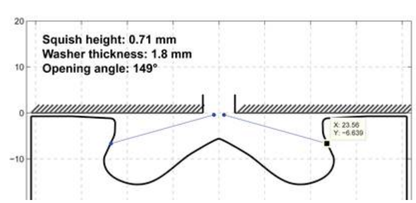
Highlights

CLEERS



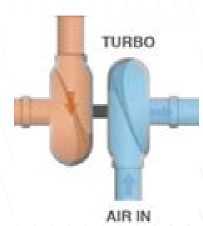
RCCI/ CDC Data

SNL



Mixing controlled noise

BorgWarner



Advanced airhandling

Others presented

- ANL – Mapping Guidelines
- U. Clemson – Airhandling
- U. Wisc – CFD

IEA Combustion Task

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Reviewer Comments from FY 2016 – ACE016 - HECC

Reviewer Comments

Addressing Significant Questions/ Recommendations

–**Reviewer advised** understanding transients will be a key to the researchers' success. The reviewer stated that knowing the transient behavior of the entire engine system, including air handling, EGR, and boosting system, and matching those conditions with the optimal RCCI control algorithm will be a large technical challenge

- Agreed and effort has been accelerated Response

Reviewer noted results of the simulation on top of the experimental results that were shown. The reviewer questioned if the simulation is being used for suggesting optimal operating conditions with the many variables they must control, and if not, it should be

- New collaboration in FY 17 with U. Wisc better utilizing for low-delta RCCI

–**Reviewer** suggested that rather than continue to push the efficiency benefits higher, it is time to focus on minimizing HC and CO emissions while retaining efficiency. The reviewer said the researcher should attack key barriers first

- New capabilities allowing investigations into engine system effects – continue collaborating with emissions controls projects to address barriers + future work

Positive Comments

- **Reviewers noted** **"**project took an excellent experimental approach, combining 1D and 3D, multi-cylinder, and transient dyno hardware-in-the-loop capability. The reviewer commented that this is a very good and practical approach to measuring virtual in-vehicle fuel economy of advanced combustion concepts**"**
- **A reviewer noted** The reviewer said that conducting a fundamental investigation of the discrepancies between measured and modeled efficiencies to look for areas of efficiency loss is a sound scientific approach. The reviewer commented that contributions at this level will be more valuable to industry than optimizing a given set of hardware.

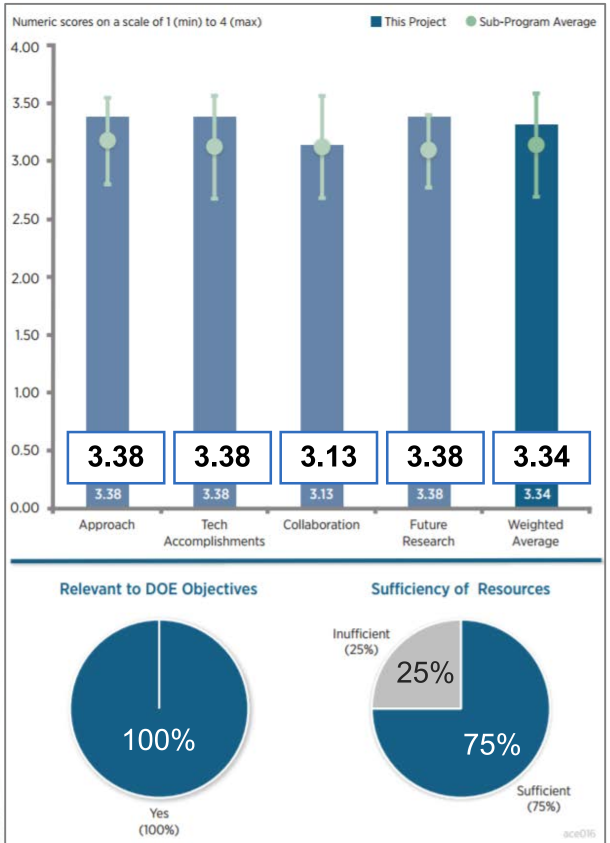


Figure 4-13 – High-Efficiency Clean Combustion in Multi-Cylinder Light-Duty Engines: Scott Curran (Oak Ridge National Laboratory) - Advanced Combustion Engines

Comments cited above were paraphrased as appropriate from 2016 Annual Merit Review document https://energy.gov/sites/prod/files/2016/12/f34/Chapter%204%20Advanced%20Combustion%20Engines_0.pdf ,

Remaining Challenges and Barriers

CHALLENGES/ BARRIERS

Remaining challenges and barriers being addressed in three year plan

- LTC development: understanding and tailoring reactivity stratification in cylinder
  - Dual-fuel: challenges of dual diesel/gasoline fuel systems and aftertreatments needed for multi-mode operation (being addressed in future work)
- Engine Systems
  - Emissions: After-treatment synergies for high engine systems efficiency
    - Lean NOx aftertreatment studies currently underway
    - Higher efficiency with lifting NOx constraint?
    - Air handling matching to help further drive down NOx
  - Transients: transient LTC operation and multi-mode transients
    - Implementation of feedback controls
  - Air-handling: matching air handling to LTC and multi-mode strategies

Challenges still exist with:

Full speed/load range coverage

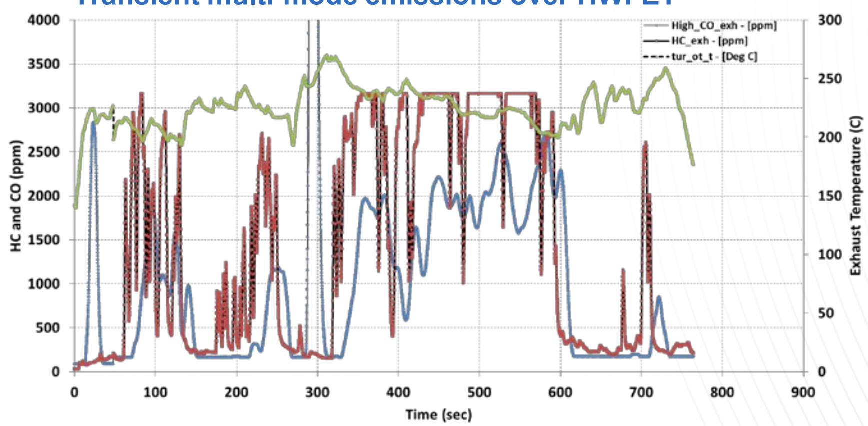
Air handling requirements

Emission controls

Combustion noise at high load

Combustion efficiency at low load

Transient multi-mode emissions over HWFET



New capabilities enable precompetitive research and development on engine systems basis to address challenges/barriers

Drive cycle implications
- Transient emissions
- Mode switching emissions
- Others

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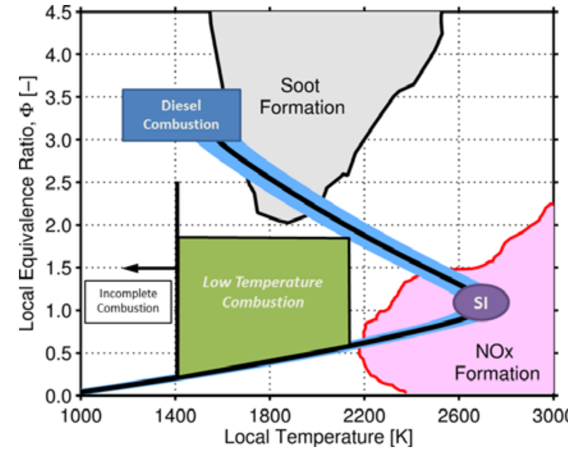
Future Work - FY 17 and FY 18 - 19

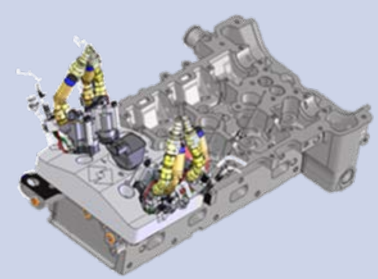
FUTURE WORK (1/2)

Addressing barriers to implementation with GDI platform

- Motivation for investigating with GDI platform [barriers]
  - **GDI platform offers both advanced CI and advanced SI options**
  - Combustion chamber and DI system designed for volatile fuels
  - VVT options including fully flexible hydraulic single cyl system
  - Full time LTC coverage – options for multi-mode



Single and multi-cylinder engines already installed at ORNL

	GM 1.9L DTH	GM 2.0L LNF	Ford 1.6L EcoBoost
Platform	**CI**/ Multi Cyl	**GDI**/ Multi Cyl/ Single Cyl	**GDI**/ Multi Cyl/ Single Cyl
Injection System	High press. Center +PFI	Med. press. Side + PFI	Med. press. Center
Airhandling System	Boosted/ HPEGR	Boosted/ HP/LP EGR	Boosted
Comp. Ratios	15-17.5 + others	9-14 + others	9-14 + others
RCCI and GCI Possible with Each Platform			

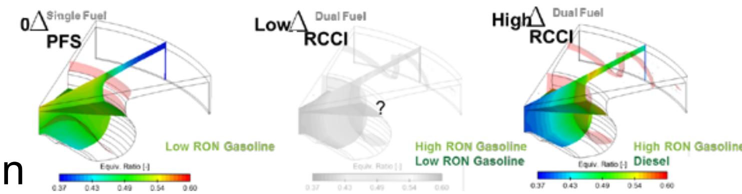
Any proposed future work is subject to change based on funding levels

Future Work - FY 17 and FY 18 - 19

Future Work (2/2)

FY 17 Remainder -High Efficiency Clean Combustion in Multi-Cylinder Light-Duty Engines

- Transient HIL experiments continue
- Q4 DOE Milestone – Low Delta RCCI efficiency parity
- Collaboration with SNL on injector studies for combustion noise reduction (ACS002 – Busch)
    - Important with new focus on noise constraints and finding solutions that are decoupled from dilution

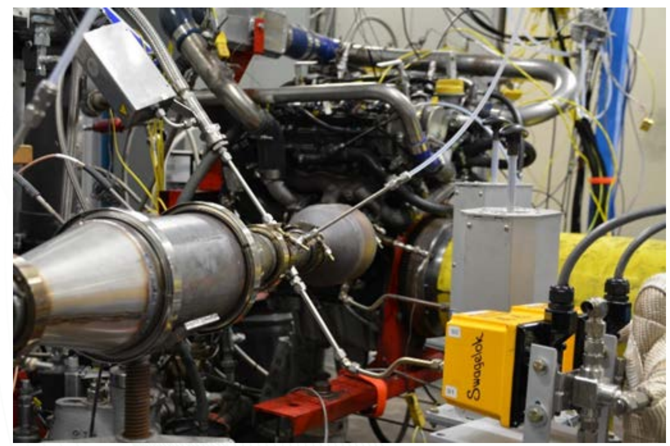


Low Delta RCCI - GCI

FY 17 – 19, Reactivity Stratified Combustion Development

Long term Objective. Develop and assess the potential of reactivity stratified combustion concepts on MCEs

- Dual-fuel/ single-fuel LTC approaches where reactivity stratification is achieved through equivalence ratio and temperature stratification
- Experiments and high-fidelity simulation of high-delta reactivity (e.g., gasoline and diesel) and low-delta reactivity (e.g., low octane and high octane gasoline) combustion



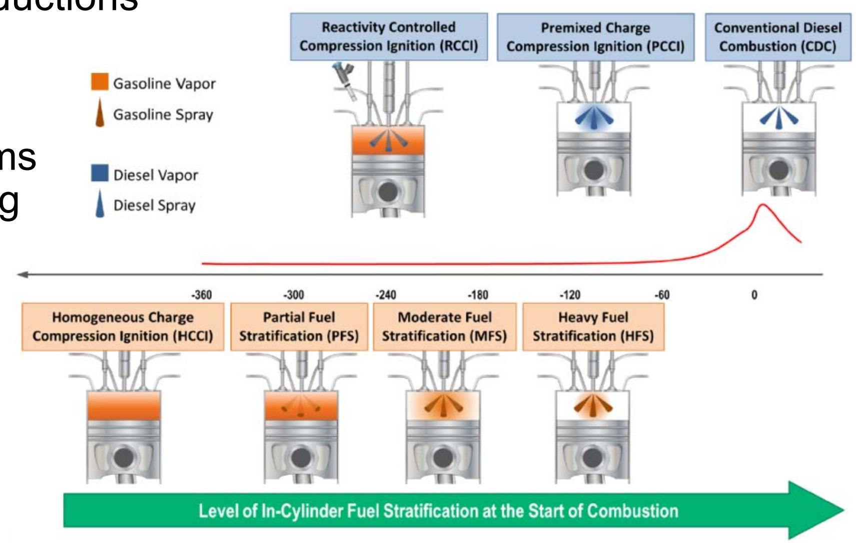
NOx aftertreatment studies underway

Any proposed future work is subject to change based on funding levels

Summary

SUMMARY

- Relevance
  - Results focused on implementation challenges with LTC related to VTO ACS goals to show engine system and fuel economy benefits leading to petroleum reductions
- Approach/Strategy
  - Multi-cylinder engine research with coupled aftertreatment integration using vehicle systems simulations, CFD and thermodynamic modeling
- Technical Accomplishments
  - Low delta RCCI
  - Transient combustion behavior
  - Transient dyno fuel economy
  - CFD Guidance for LTC
  - Advanced airhandling
- Collaboration and Coordination
  - Industry and Tech Teams
  - University and National lab partners
- Proposed future work
  - Combustion development on CI and SI platforms
  - Transient combustion research for advanced combustion/ multi-mode + emission controls

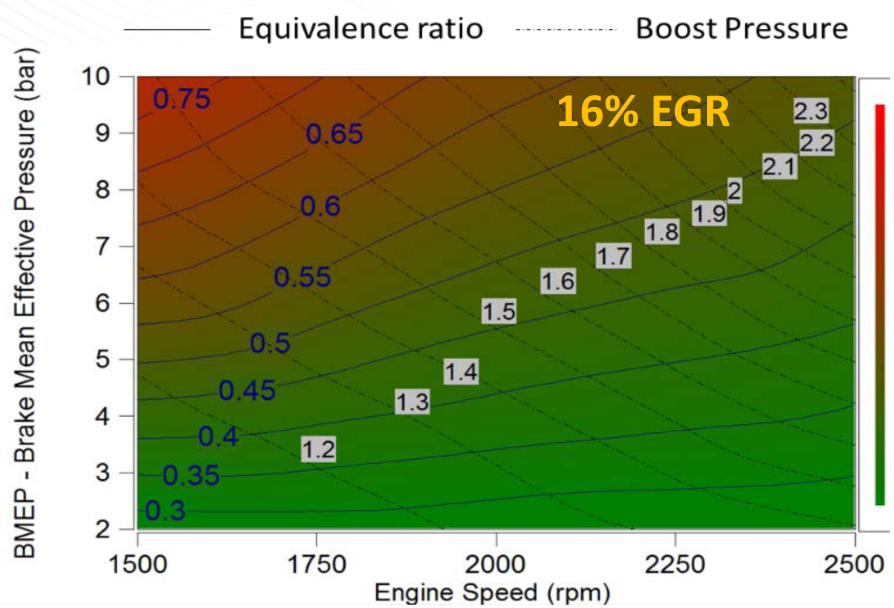


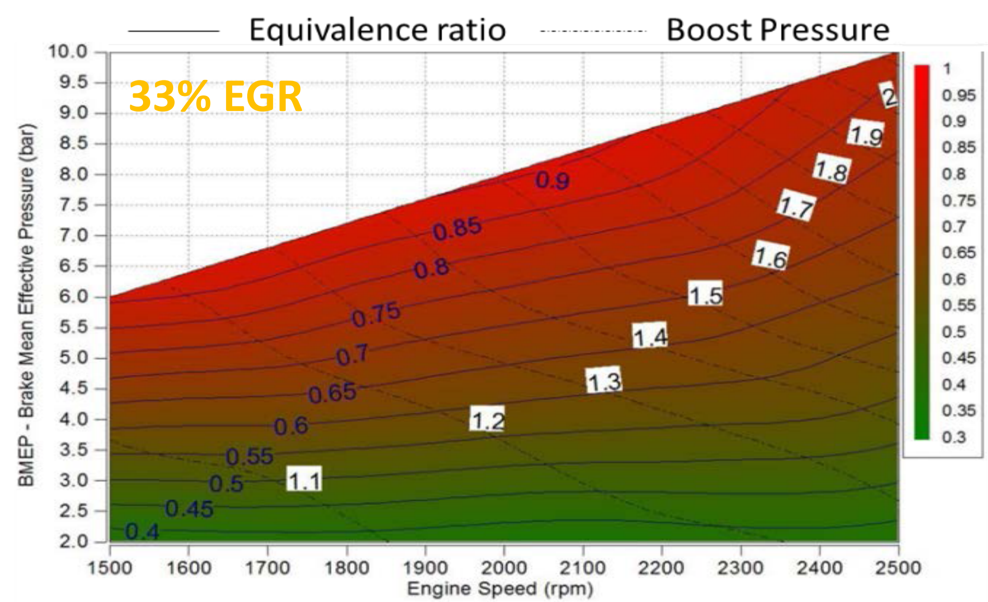
Any proposed future work is subject to change based on funding levels

Backup Slides

Equivalence Ratio and Boost Pressure Variation as EGR Level is Increased – Important for Heavy Fuel Stratification Approaches

- At 16% EGR, the maximum boost capability reduces from 2.6 bar to 2.3 bar at high speed/load
- This is due to the reduced mass flow rate through the turbine resulting in reduced work generated by the turbine





- At 16% EGR, the maximum boost capability reduces from 2.6 bar to 2.3 bar at high speed/load
- This is due to the reduced mass flow rate through the turbine resulting in reduced work generated by the turbine

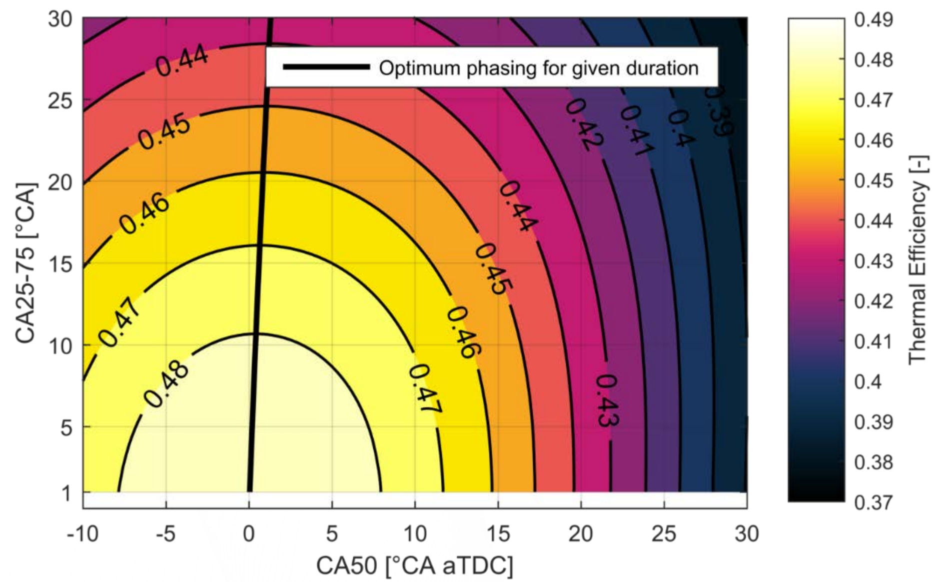
Model being used to guide next air handling system
3 options moving forward

- As the EGR level is increased further to 33%, the engine reaches global stoichiometric operation at high loads
- The maximum load that the engine can produce is limited to 6 bar BMEP at 1,500 rpm due to lack of available intake oxygen
- The intake manifold absolute pressure has dropped to ~1.15 bar at this condition causing reduction in maximum load attainable

Back-Up 1

Effect of combustion phasing and duration on thermal efficiency

LNF, rc = 11.85:1, Φ = 1, iso-octane, no EGR, T(-180°CA) = 40° C



Heat Release

Volume Change

Mass Change

Molecular Weight Change

$$\frac{dp}{d\theta} = \left(\frac{dp}{d\theta}\right)_Q + \left(\frac{dp}{d\theta}\right)_V + \left(\frac{dp}{d\theta}\right)_m + \left(\frac{dp}{d\theta}\right)_M$$

$$\left(\frac{dp}{d\theta}\right)_Q = \left(\frac{\gamma - 1}{V}\right)\dot{Q}$$

$$\left(\frac{dp}{d\theta}\right)_V = -\frac{\gamma p}{V}\frac{dV}{d\theta}$$

Otto Cycle (instantaneous $\dot{Q}$ at TDC, constant γ)

$$\left(\frac{dp}{d\theta}\right)_m = \left[\frac{\gamma p}{m} - \left(\frac{\gamma - 1}{V}\right)(h - h_f)\right]\frac{dm}{d\theta}$$

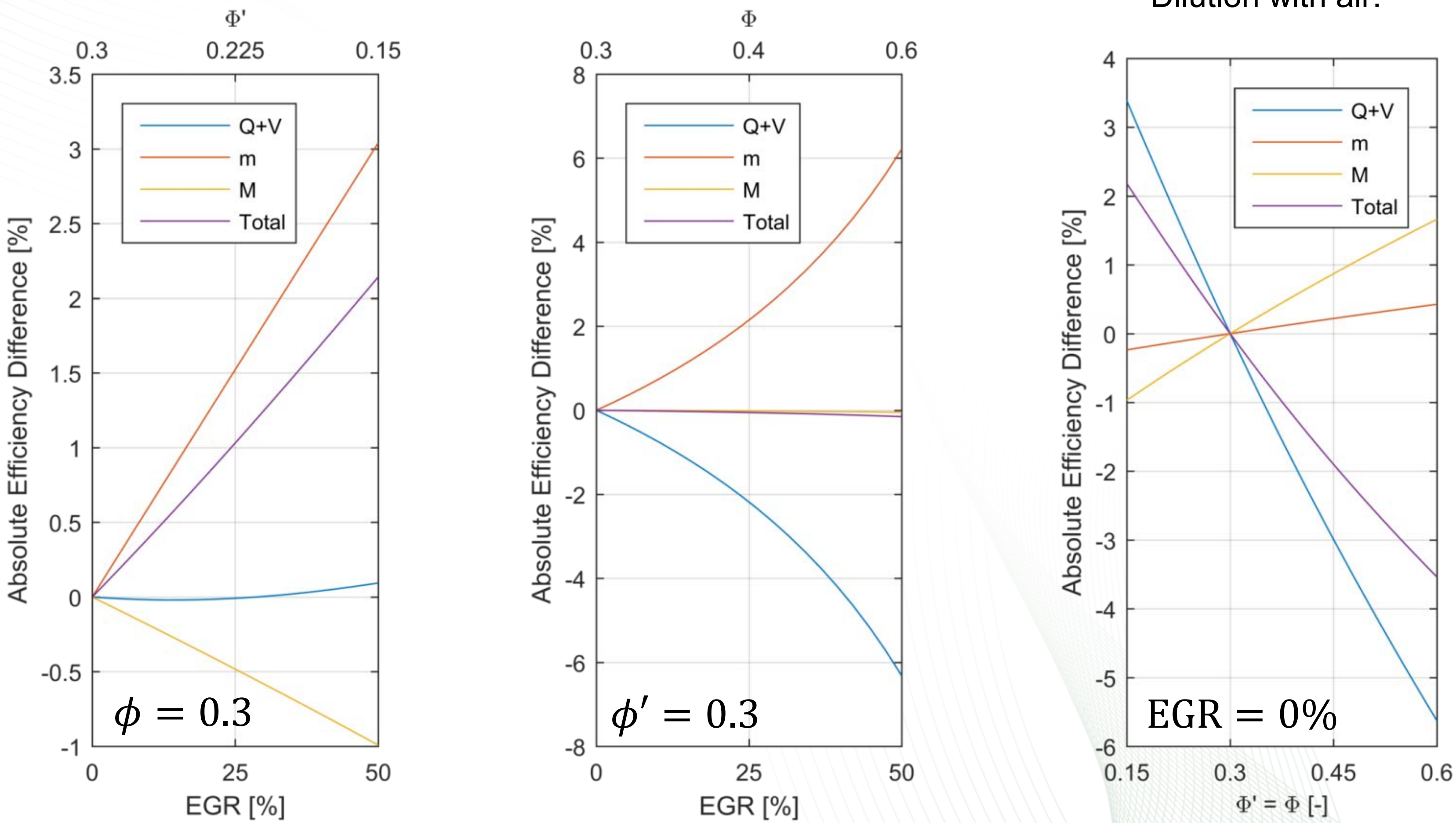
$$\left(\frac{dp}{d\theta}\right)_M = -\frac{p}{M}\frac{dM}{d\theta}$$

Efficiency Contributions from Individual Terms Help to Understand EGR with lean DI+CI

$$\phi' = \phi \times \left(1 - \frac{\text{EGR\%}}{100}\right)$$

SOI = -20°CA aTDC

Dilution with air:



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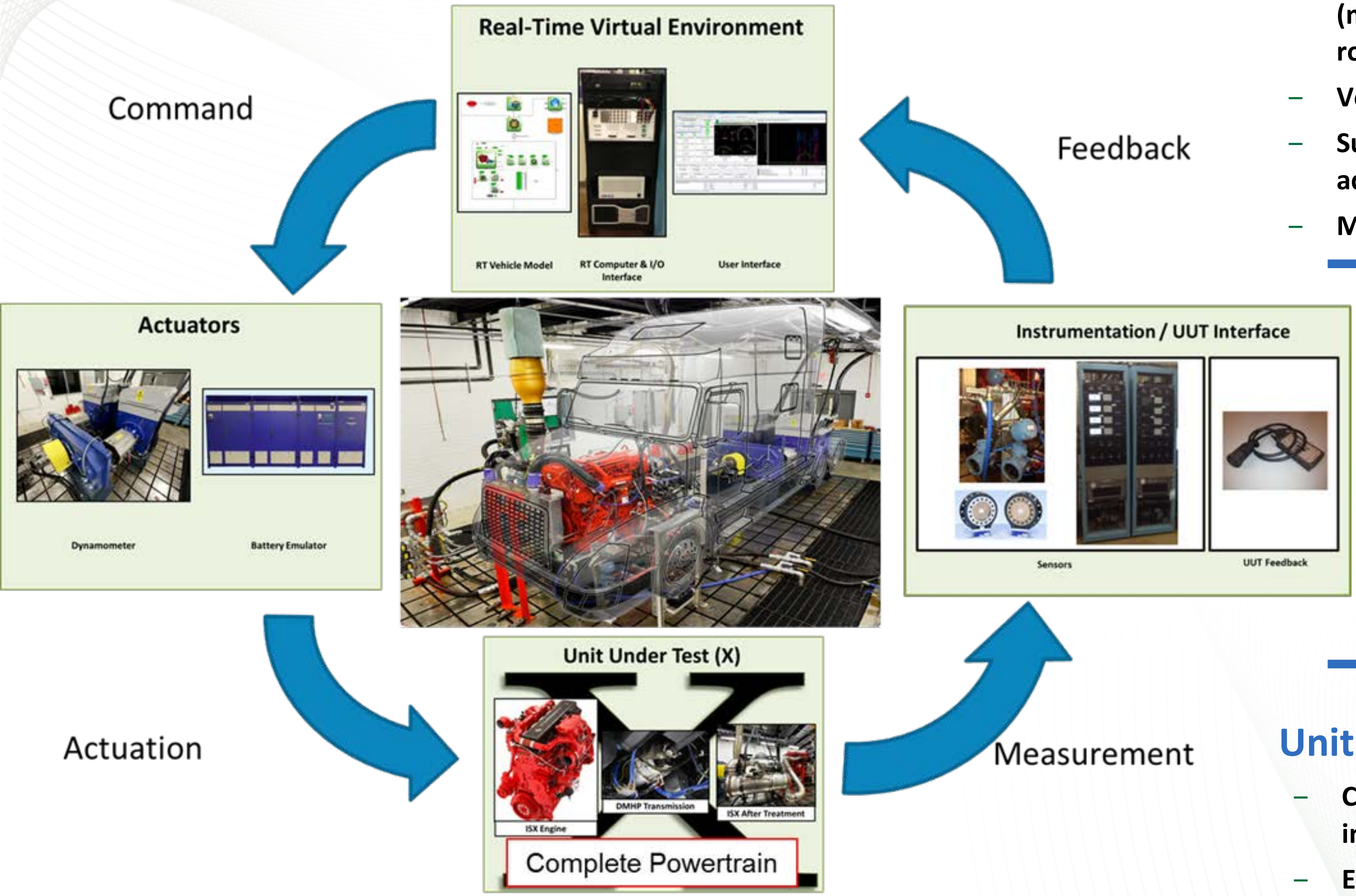
Hardware-In-the-Loop (HIL) Architecture: Example ORNL VSI



Real-Time Virtual Environment

- Emulated "rest of vehicle" real-time model (multiple powertrain architectures, masses, road loads, etc.).
- Vehicle communication network emulation
- Supervisory controls development for advanced powertrains
- Measurement and data acquisition

Actuators

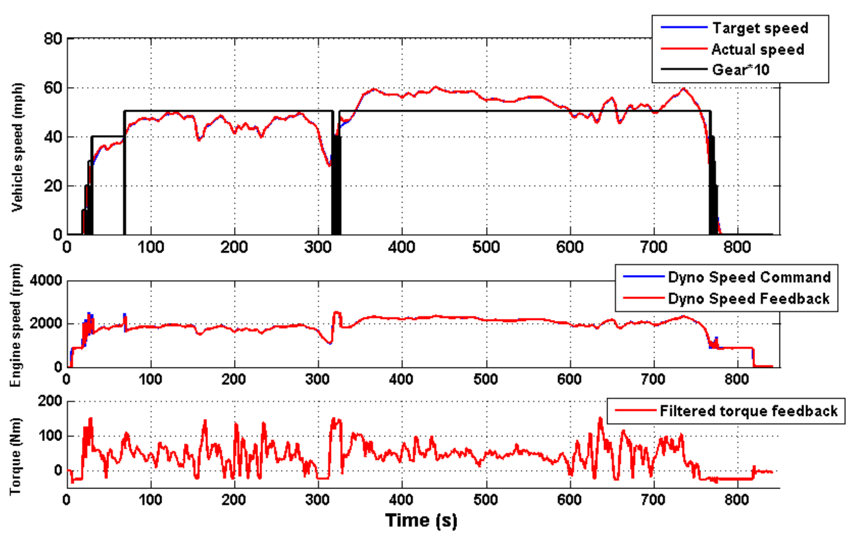
- Battery emulator for electrical Energy Storage System (ESS) emulation
- Dynamometers for road load emulation

Unit Under Test

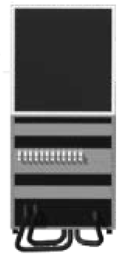
- Controller, component, sub-system, or integrated powertrain
- Engines, electric machines, energy storage systems, transmissions
- Light-, medium-, and heavy-duty

The Unit Under Test "thinks" it is installed in a vehicle and driven on real-world roads.

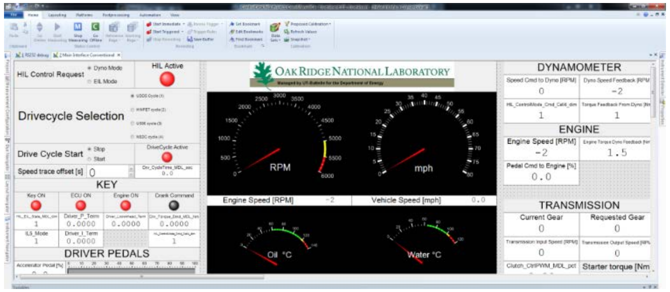
Advanced Combustion – Transient Experiments with HIL Functionality



HIL system emulates vehicle/ controls engine speed and load



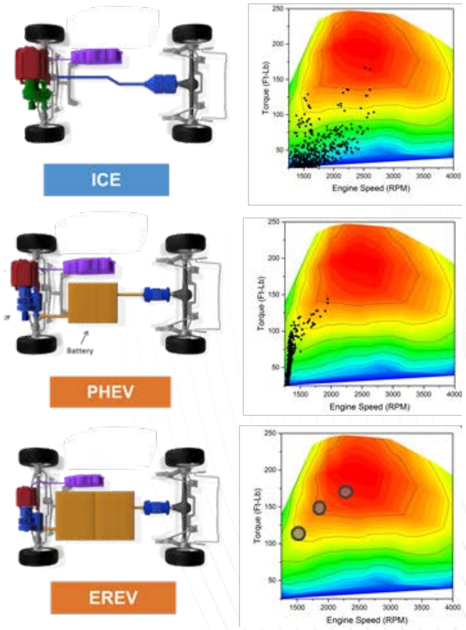
HIL Platform

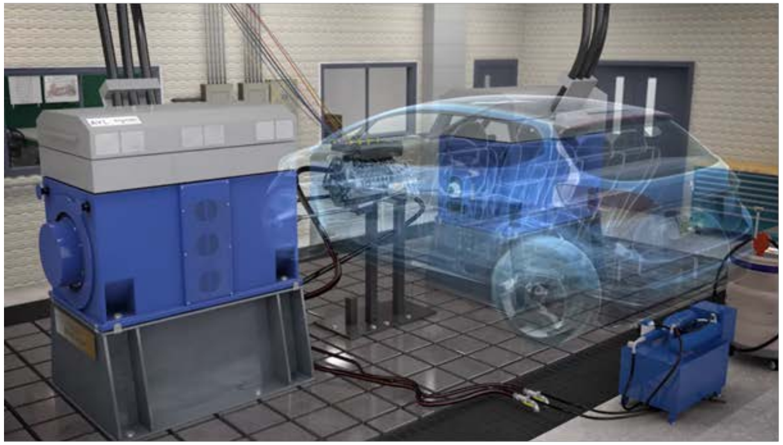


dSPACE Interface

Vehicle Model

Vehicle model can be set to conventional powertrains or hybrid configurations





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