VSS140

Impacts of Advanced Combustion Engines

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2015 U.S. DOE Hydrogen Program and Vehicle Technologies Program Annual Merit Review and Peer Evaluation Meeting

June 9, 2015

OVERVIEW

Timeline

- Project start date: Oct. 2013
- Project end date: Continuing
- Activity scope changes to address DOE & industry *needs*

Barriers for VSS* and ACE*

- Constant advances in technology (VSS)
- Computational models, design, and simulation methodologies (VSS)
- Lack of modeling capability for combustion and emission control (ACE)
- Lack of actual emissions data on future engines (ACE)

**from 2011-2015 VTP MYPP*

Budget (DOE share)

- FY14 funding: $150k
- FY15 funding: $250k

Partners

- DOE ACE and FLT research projects
- DOE Advanced Engine Crosscut Team
- CLEERS Collaborators
- Oak Ridge National Laboratory
  - Fuels, Engines, & Emissions Research Center
  - Center for Transportation Analysis

OBJECTIVE: Evaluate the benefits and challenges of advanced combustion concepts on a vehicle systems basis

"WHY"

- **Advanced combustion achieves high thermal efficiency with low engine-out emissions**
- **Transient/drive cycle benefits and challenges of advanced combustion in light-duty vehicles is not well understood**
- **Evaluation and analysis are important for supporting U.S. automakers to meet 2025 CAFE standards and EPA Tier III emissions regulations**

"HOW"

- **Generate experimental steady-state advanced engine maps**
- **Integrate engine maps into transient vehicle models along with full aftertreatment-trains**
- **Evaluate fuel economy and emissions of multi-mode combustion using vehicle systems simulations over realistic light-duty drive cycle conditions**
- **Identify promising paths for improving LD energy efficiency, fuel mileage and emissions with advanced combustion modes in conventional and hybrid-electric vehicle powertrains**

> "Without aftertreatment constraints in the simulation, the model might allow engine system operation outside the emission-constrained envelope."
>
> – National Academy of Science study on reducing fuel consumption from MD and HD vehicles (ISBN: 0-309-14983-5)

RELEVANCE (1)*

- **Directly supports ACE R&D program goals including a JOULE level milestone**
- **Directly supports FLT R&D program goals including a JOULE level milestone**
- **Directly supports 3 VSS cross-cutting activities:**
  - Modeling and simulation; component & systems evaluations; vehicle systems optimization.
- **Directly supports US Drive ACEC/VSATT activities**
- **Addresses the following VSS Barriers (2.2.1 e,f):**
  - **Computational models, design and simulation methodologies**
  - **Constant advances in technology.**
- **Addresses the following ACE/FLT Barriers (2.3.1 a,c,d,f):**
  - **Lack of fundamental knowledge of advanced combustion regimes**
  - **Lack of modeling capability for combustion and emission control**
  - **Lack of effective engine controls for LTC**
  - **Lack of actual emissions data on future engines**

*Reference: Vehicle Technologies Multi-Year Program Plan 2011-2015:
http://www1.eere.energy.gov/vehiclesandfuels/pdfs/program/vt_mypp_2011-2015.pdf

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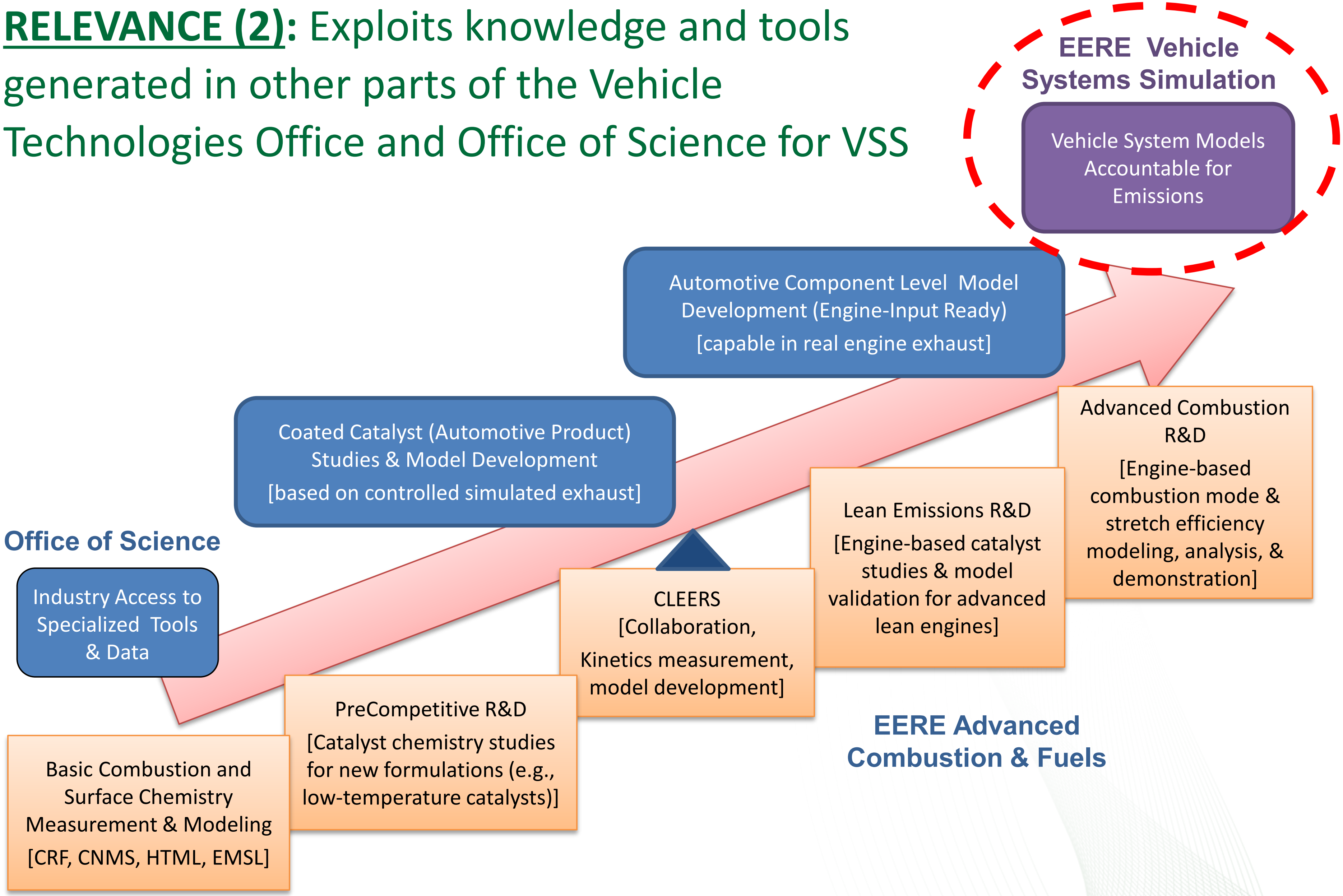
RELEVANCE (2): Exploits knowledge and tools generated in other parts of the Vehicle Technologies Office and Office of Science for VSS



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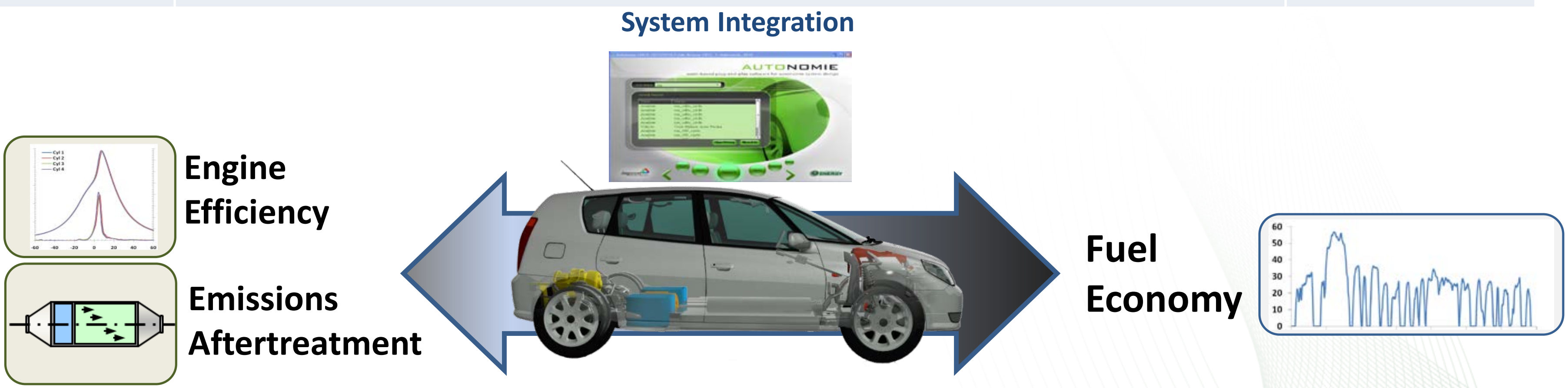
Milestones

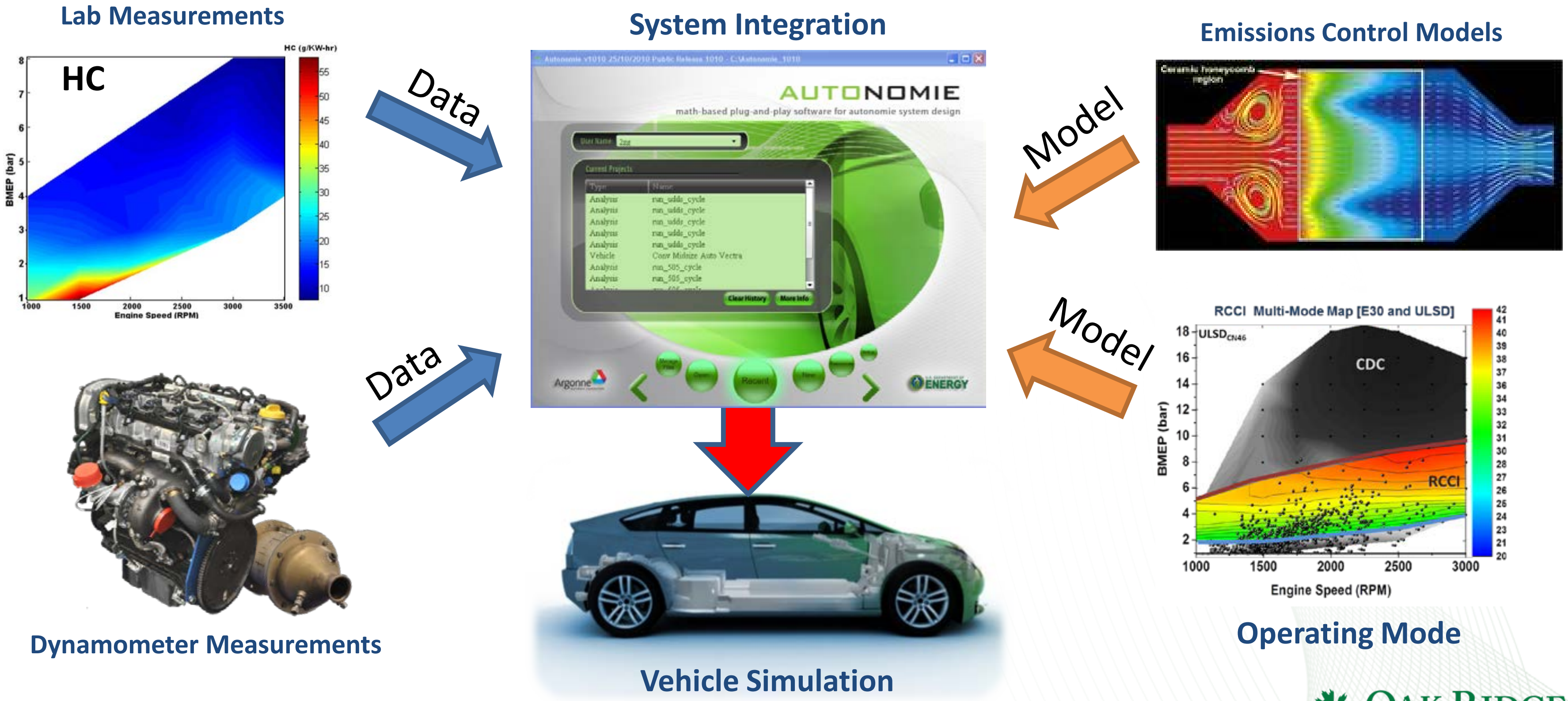
All Milestones Completed or On-Track

Date	Milestone/Deliverables	Status
Dec 2014	Hardware-in-the-loop transient support for ACE and FLT advanced combustion projects	**Completed**
April 2015	Vehicle level simulation support for advanced combustion including after treatment modeling including multi-mode operation	**Completed**
June 2015	Vehicle level simulation support for octane optimized vehicle for renewable super premium project	**On track**



APPROACH (1): Vehicle Systems Simulations with Advanced Combustion

- **Advanced combustion engine maps for use in vehicle systems simulations**
  - Steady-state advanced combustion engine maps from dynamometer measurements with exhaust species
- **Evaluate advanced combustion engine operation in conventional and hybrid LD powertrains**
  - Fuel economy potential of advanced combustion engine multi-mode concepts
- **Evaluate the effect of fuels on advanced combustion engine drive cycle coverage**
  - Complete drive-cycle coverage has implications on aftertreatment requirements for multi-mode operation



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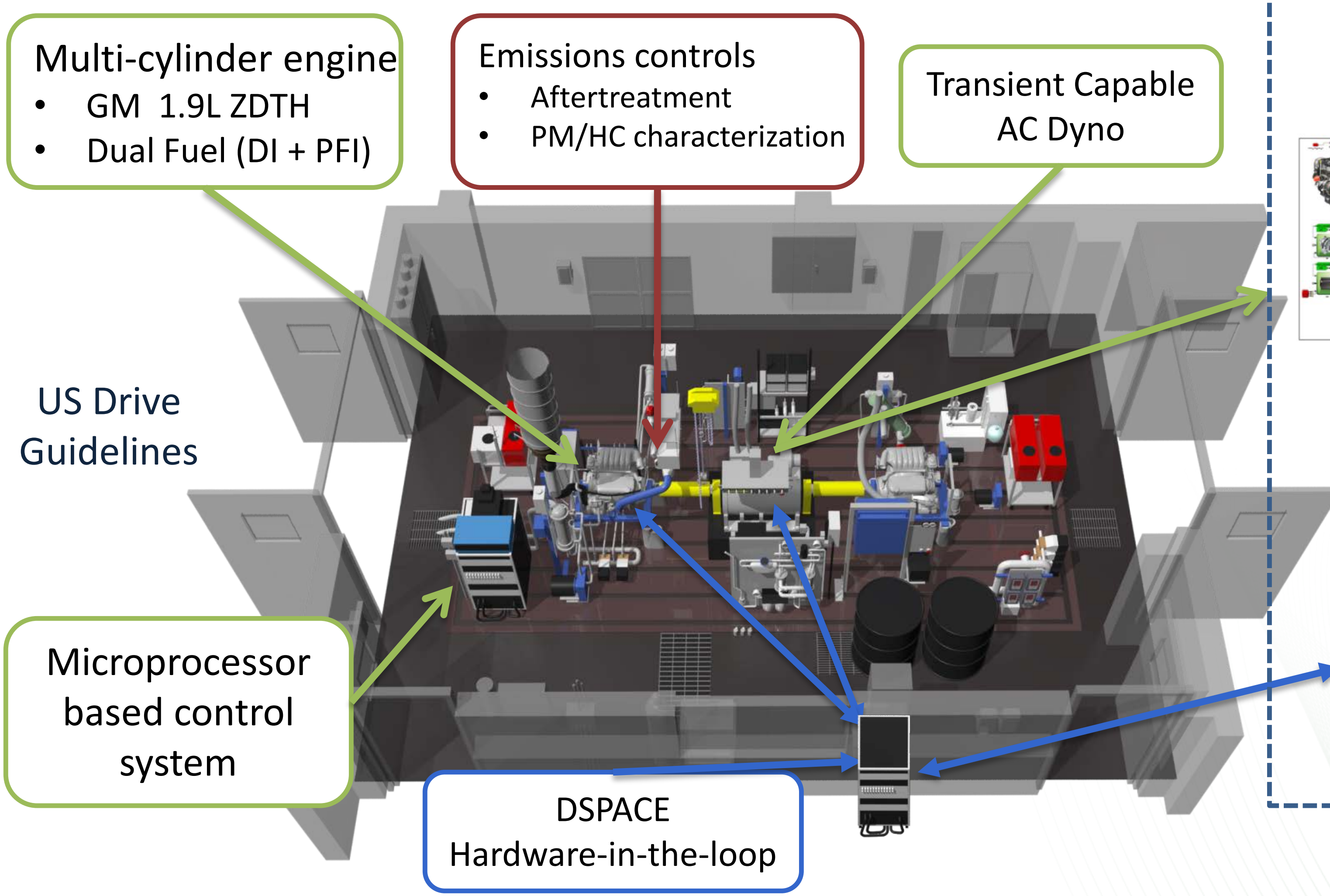
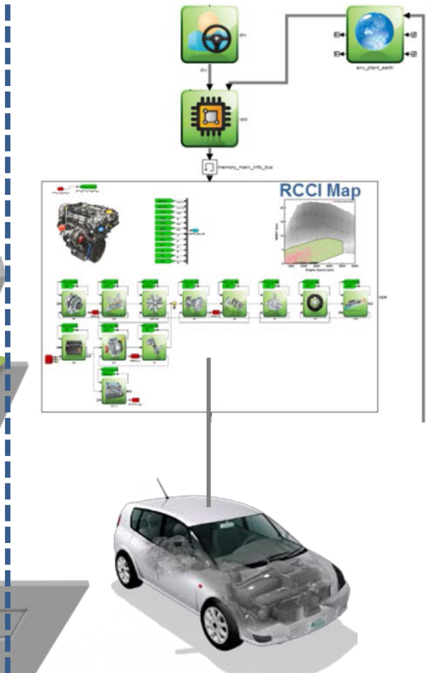
Approach: Multi-cylinder investigations of LTC including aftertreatments leading to vehicle systems simulations

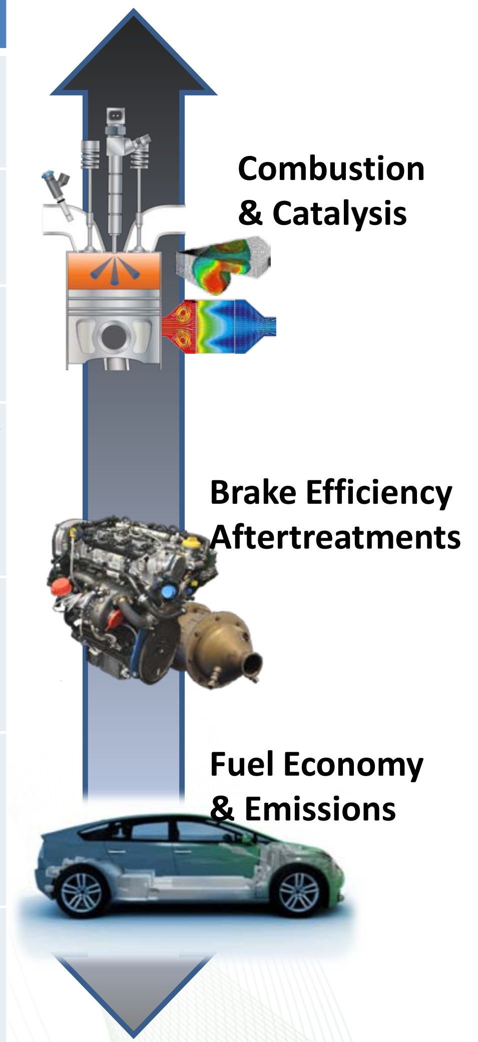
- GM 1.9 ZDTH Diesel Engine with dual-fuel system
- Emissions characterization and aftertreatment evaluation
- Vehicle systems simulations using experimental data/ HIL experiments





Technical Accomplishments – Summary 2014

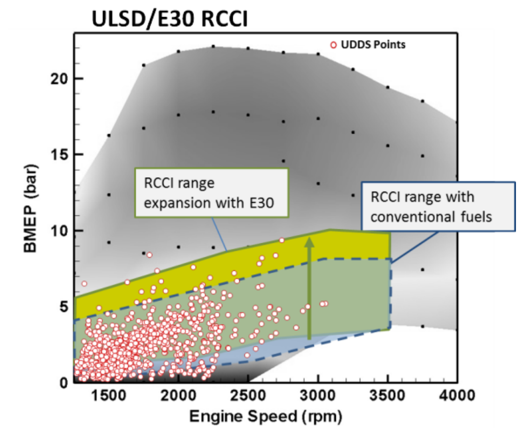
	Tasks
1	Model fuel economy potential of RCCI using vehicle systems simulations
2	Update and refine multimode CDC/RCCI engine maps in collaboration with ACE
3	Conduct fuel economy simulations of RCCI-enabled HEVs in city and highway cycles
4	Compare and evaluate fuel economy and emissions control among RCCI and other HECC engines in HEVs/PHEVs
5	Update DOC catalyst models for multi-mode RCCI combustion for both CDC and RCCI conditions
6	Estimations for the Aftertreatment efficiency needed for EPA Tier III standards for RCCI, CDC, lean-GDI
7	FY 15 Model fuel economy potential of RCCI using vehicle systems simulations (on-track)



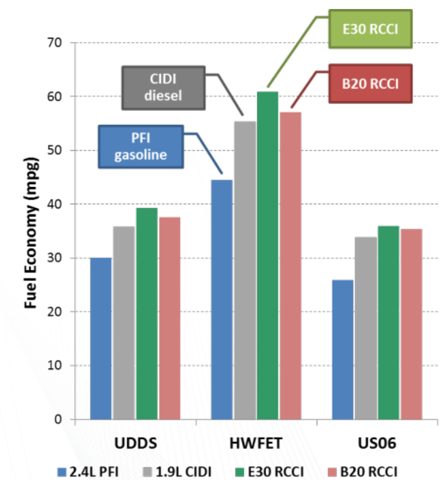
Accomplishment (1.1) FY 14 Supporting Accomplishments: ACE/FLT

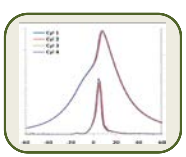
This project supports other VTO programs leveraging activities in meeting VTO goals

- **Support FLT R&D Program FY 14 Q2 JOULE Milestone**
  - **Drive Cycle Expansion Enabled by Biofuels – Completed**
  - Demonstrate an increase in the RCCI operating range due to the use of renewable fuels allowing 75% coverage of non-idling portions of the city (UDDS) and highway (HWFET) light-duty federal drive cycles
  - Vehicle systems simulations used to model drive cycle coverage



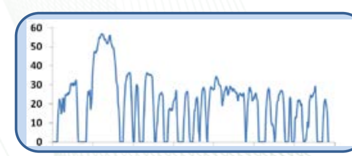
- **Support ACE R&D Program FY 14 Q4 JOULE Milestone**
  - **RCCI Fuel Economy Modeling - Completed**
  - Demonstrate improved modeled fuel economy of **25%** for passenger vehicles solely from improvements in powertrain efficiency relative to a 2009 PFI gasoline baseline
  - Vehicle systems simulations used to model fuel economy





Engine Efficiency

Fuel Economy



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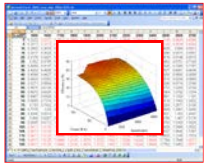
Accomplishment (1.2) Vehicle Systems Simulation Using Experimental Engine Data

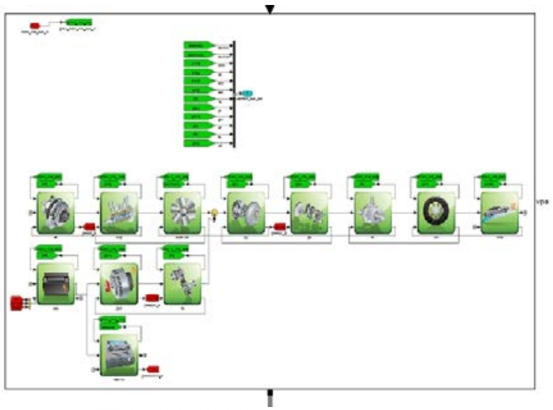
Vehicle system modeling using experimental/ industry engine maps on same vehicle in Autonomie.

- **Base vehicle**
  - Mid-size passenger sedan, 1580kg, Automatic transmission
  - Transmission shifting optimized for fuel economy for each engine (BackUp)
- **Engine maps based on steady state experimental data**
  - 1.9L, Q3 RCCI Map – ORNL Experimental map from **Q3 Joule milestone**
  - 1.9L , Diesel Map (CDC) Experimental ORNL map
  - 1.8L, 2.4L, 2.7L and 4.0L , 2009 PFI Maps– Automotive OEM supplied
- **Multi-mode RCCI/Diesel strategy used**
  - RCCI map covers most of light-duty drive cycles
  - Must switch to diesel mode outside of RCCI envelope
  - Mode switching behavior not accounted for in this study (perfect step change)

AUTONOMIE

Engine map includes:
- **Fuel consumption**
- **E/O temperature**
- **E/O NOx, HC, CO,**





Gross indicated efficiency

Brake (shaft) efficiency

Drive cycle efficiency

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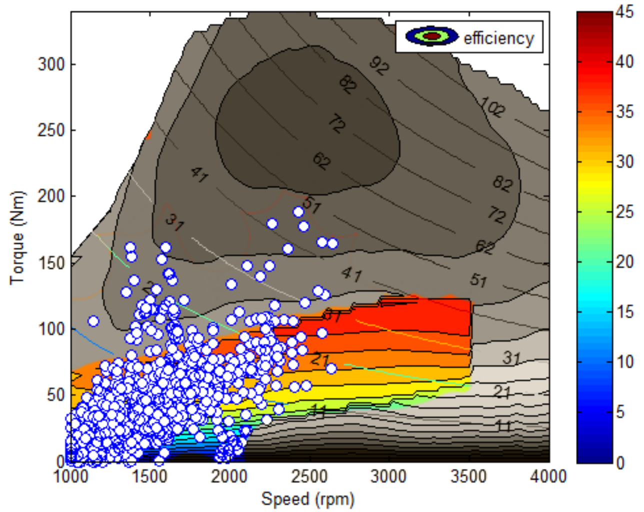
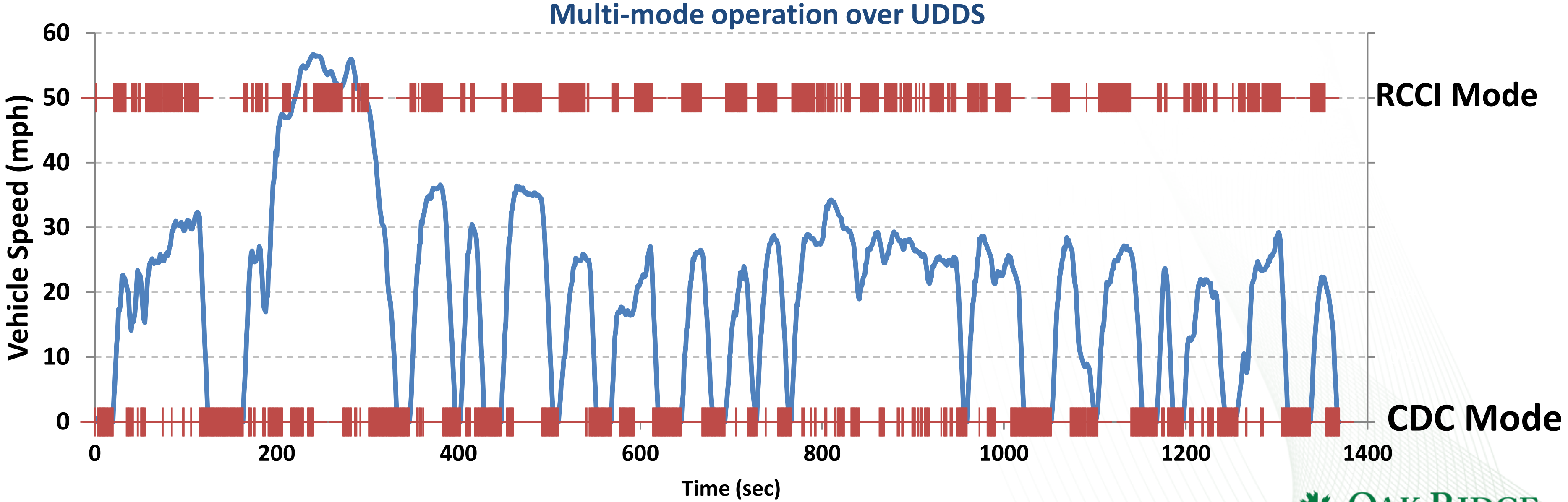
Accomplishment (1.3) Developed Multi Mode Strategy

- **Combustion mode switching may be required for complete map coverage**
- **Self-imposed boundary conditions used to keep implementations realistic**
  - High Load – cylinder pressure raise rate
  - Low Load – CO and HC limit
- **First order lag approximations used to model mode switching**

UDDS – City Cycle

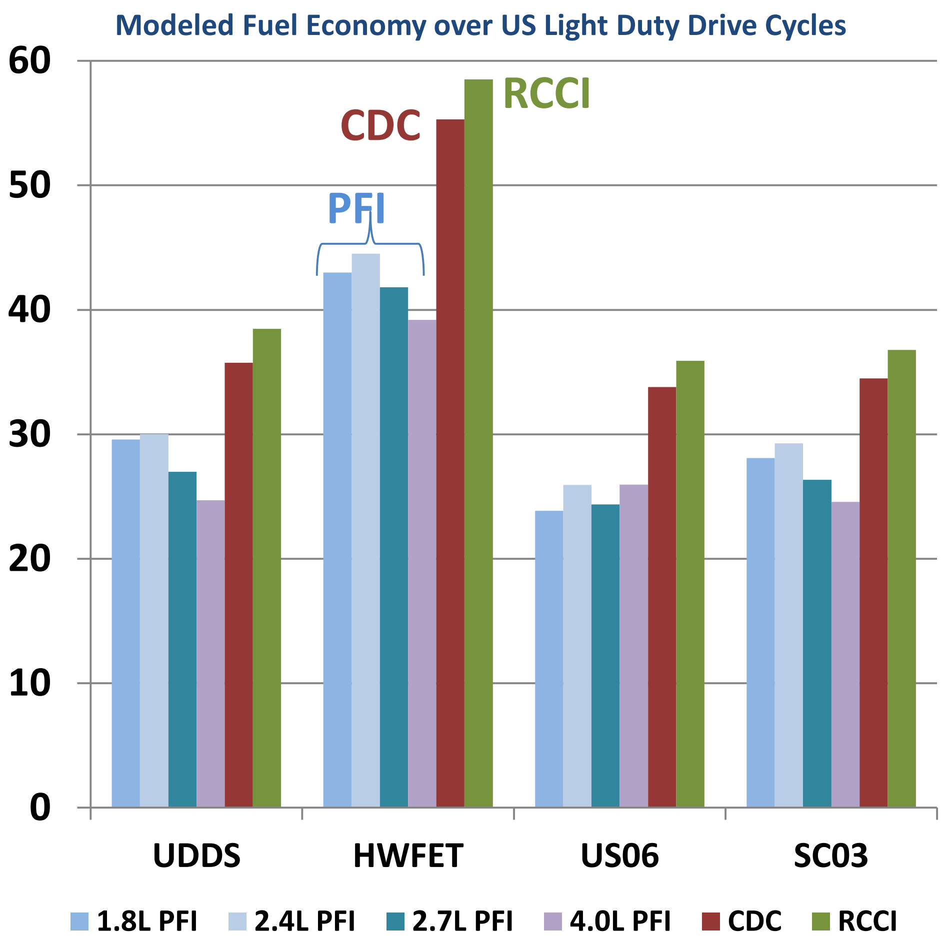


Multi-mode operation over UDDS

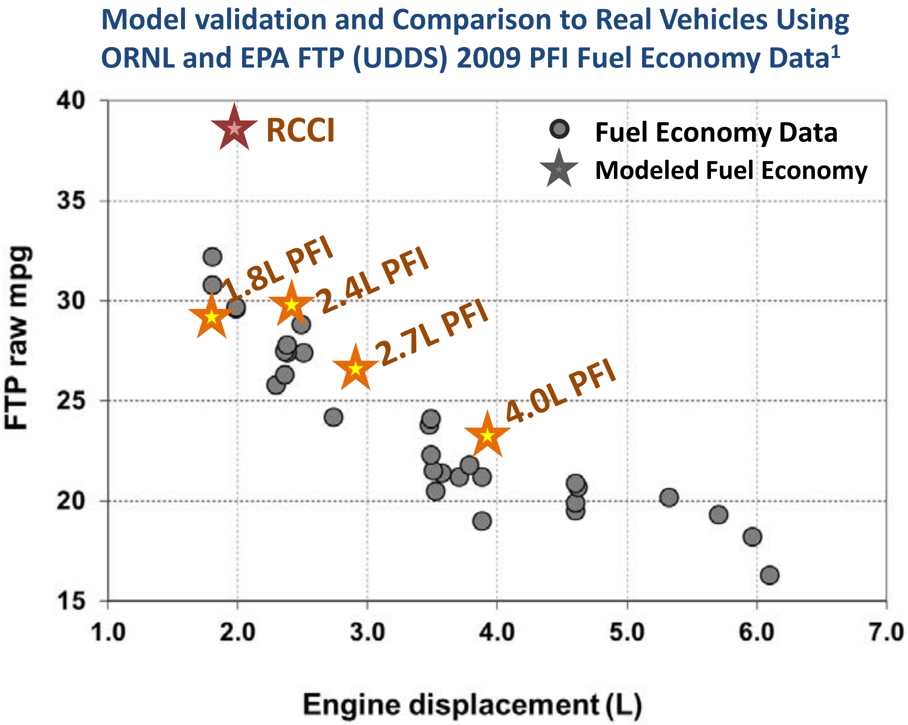


Accomplishment (1.4) Modeled RCCI Drive Cycle Fuel Economy

- Modeling results show up to a 22 - 28% improvement in fuel economy with RCCI over UDDS compared to 2009 PFI baseline on same vehicle
- ORNL chassis dyno and EPA fuel economy data mined for other PFI engine sizes



PFI MAPS from OEM collaboration



1 Data for small to full-size passenger cars with varying vehicle weight

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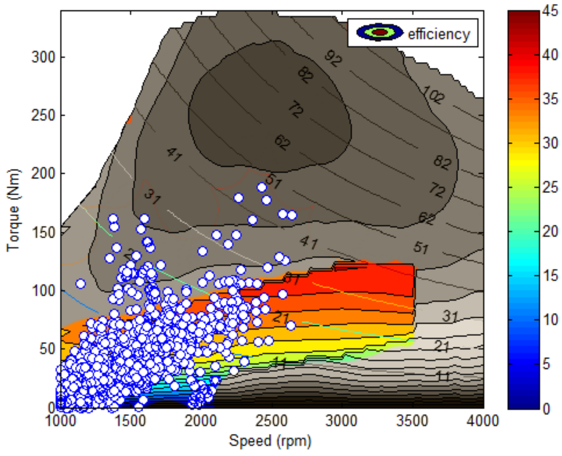
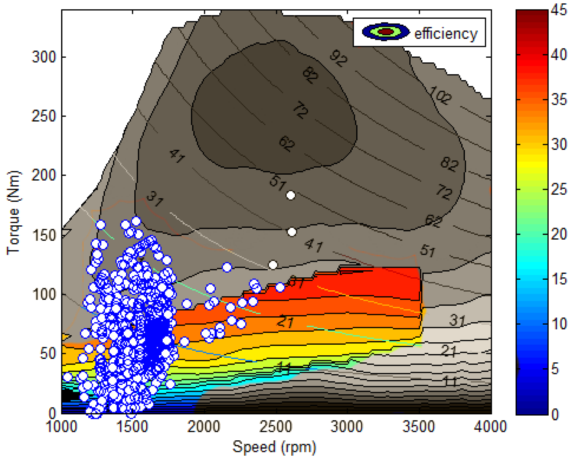
ACCOMPLISHMENT (1.5) Q4 RCCI Fuel Economy Modeling Providing Insights Into Drive Cycle Coverage + Fuel Economy

- **RCCI fuel economy improvements despite lack of complete drive cycle coverage** (Further development possible)
  - **UDDS = 62.7% drive cycle coverage by distance**
  - **HWFET = 62.8% drive cycle coverage by distance**
  - Hardware changes being considered (FY 15)
- **Results based on steady state engine data**
  - Does not currently address transient operation (FY 15)
- **Does not address aftertreatment effectiveness**
  - Ongoing research at ORNL

UDDS – City Cycle



HWFET – Highway Cycle



Modeled RCCI fuel economy improvements compared to PFI baselines

Cycle/ PFI Baseline	1.8L	2.4L	2.7L	4.0L
UDDS RCCI improvement	30.1%	28.1%	42.6%	55.7%
HWFET RCCI improvement	36.1%	31.5%	40.0%	49.3%

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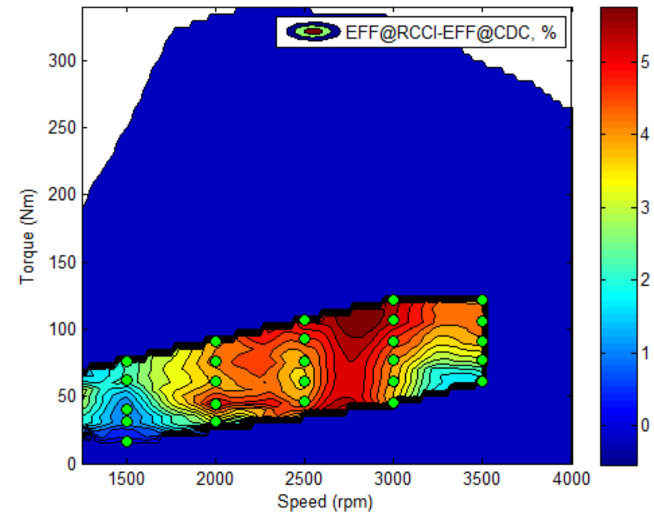
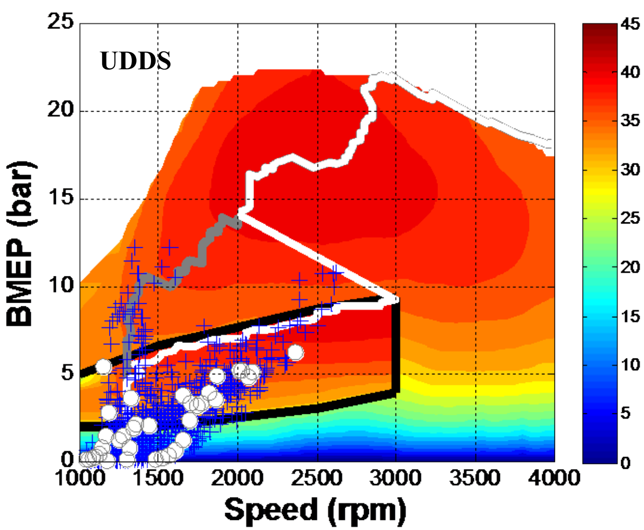
Accomplishment (2.1) Simulations show high potential for RCCI to further improve fuel economy with hybrid configurations

- **Though power density of RCCI is limited requiring multi-mode strategy for full drive cycle coverage**
- **There may be opportunities for decoupling engine speed and load from drive cycle requirements through vehicle electrification**
  - Help ensure engine operates in efficiency "sweet spot"
- **Could allow RCCI multi-mode to maximize fuel economy and minimize NOx emissions (next slide)**

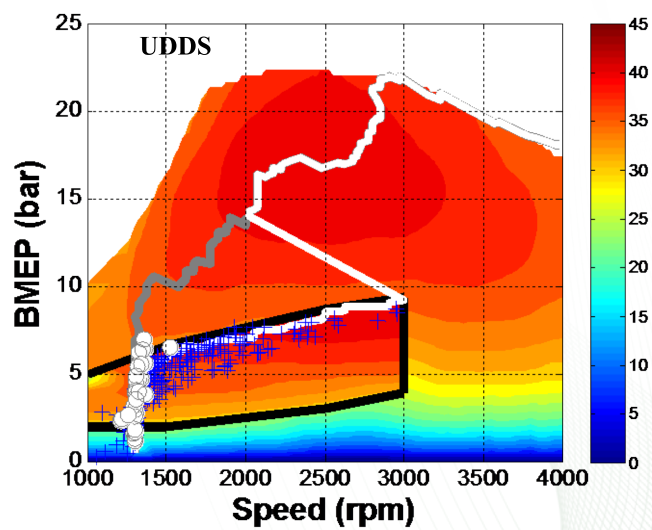


BTE Delta with RCCI compared to CDC



39MPGGE

Conventional Powertrain



72MPGGE

Hybrid Powertrain

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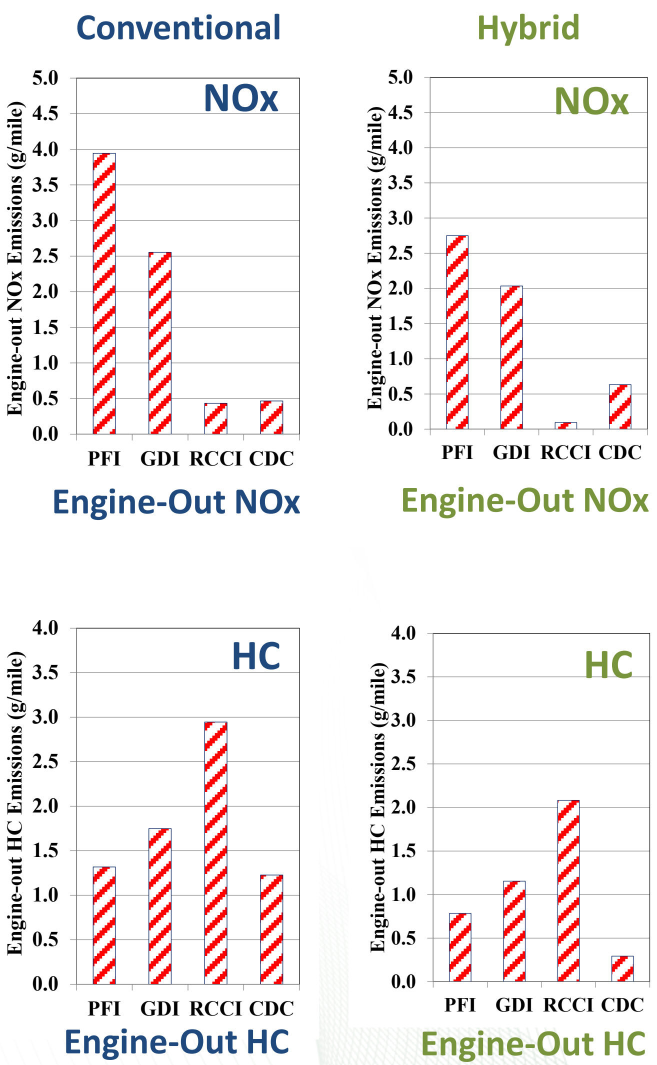
Accomplishment (2.2) Engine-out emissions simulations provide insight in integration challenges

- **RCCI compared to stoich-PFI, CDC and lean-GDI**
  - Better representing ACEC technology portfolio
  - Conventional powertrains and hybrid powertrain considered
- **Simulated conventional vehicle drive-cycle engine-out emissions. Compared to PFI, lean GDI achieves substantially less NOx and CO emissions while producing higher HC and PM emissions.**
  - Thus, enabling RCCI to meet Tier 3 regulations will require high HC oxidation efficiency by catalysts while lean GDI engines will require high NOx reduction efficiency in lean operation



Vehicle	Conventional	Power-split HEV
Engine	PFI/GDI/CDC/RCCI*	PFI/GDI/CDC/RCCI*
Motor	N/A	PM Motor, 78kW@6500rpm, 275V
Battery	Std. ignition battery only	NiMH 275 V/ 1.5 kWh
Transmission/Gear	6-speed manual	Planetary Gear[30/78]
Final drive ratio	3.56	3.56
Wheel radius	0.332 m	0.332 m
Front area	2.25 m^2	2.25 m^2
Mechanical accessory load	200 W	50 W
Electrical accessory load	100 W	200 W

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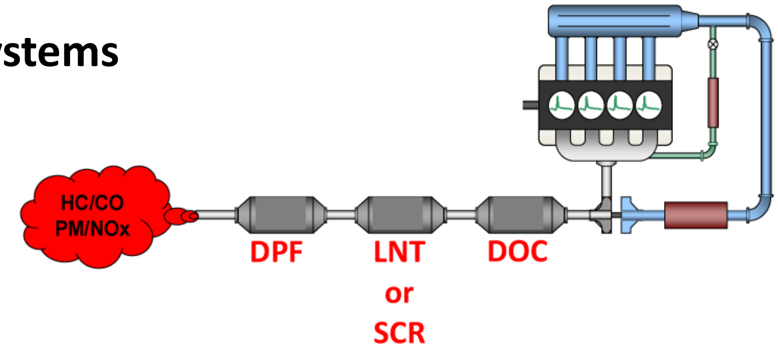
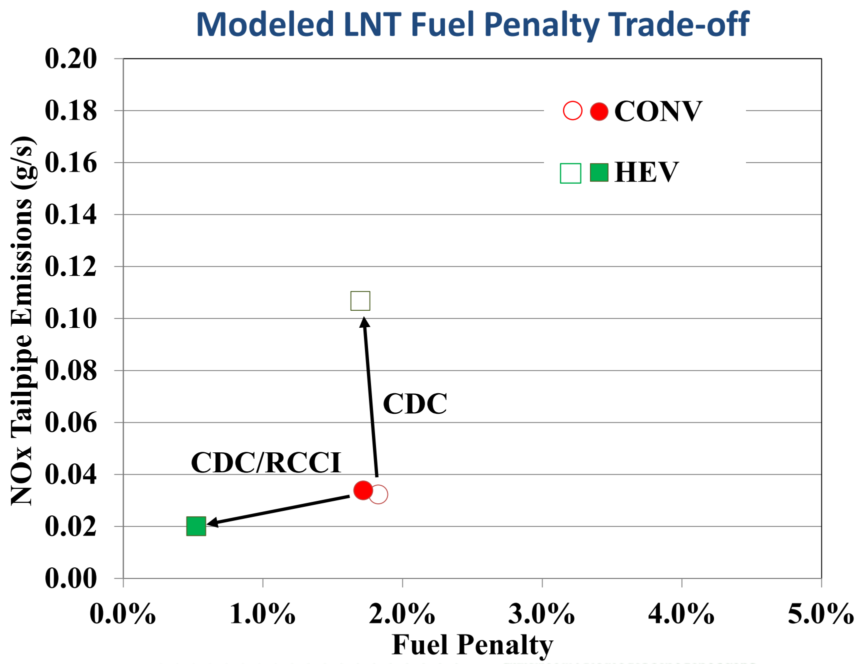
Accomplishment (2.3) Impact of aftertreatment systems on emissions control in RCCI-enabled HEVs/PHEVs

- **Simulated ORNL aftertreatment devices and systems**
  - CO and HC oxidation: DOC
  - NOx reduction: LNT or SCR
  - PM trapping and oxidation: DPF
  - Aftertreatment systems: DOC/LNT/DPF or DOC/SCR/DPF



- **Simulated driving cycle for emissions control: FTP75**
  - Cold start transient phase
- **Modeling results of the potential tradeoff between the LNT regen fuel penalty and NOx tailpipe emissions**
  - The solid markers are CDC/RCCI and the open markers are CDC.



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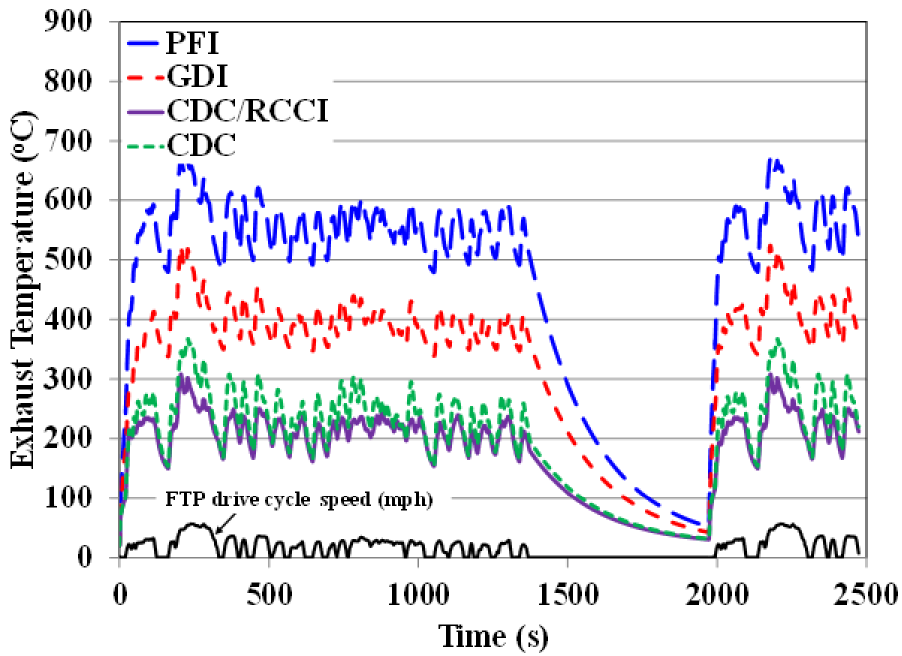
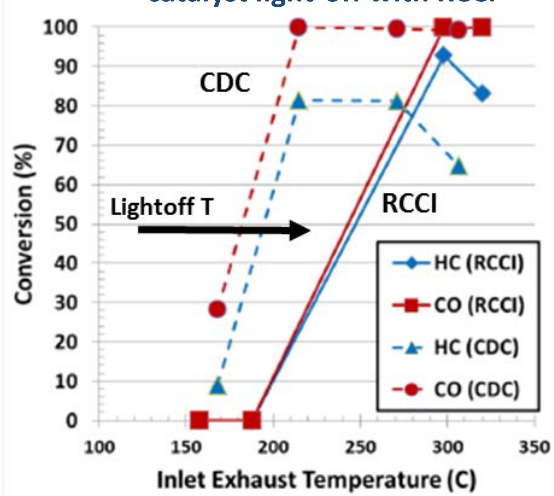
Accomplishment (2.4) Exhaust Temperature effects

- **Improved Fuel Economy via improved fuel efficiency results in lower engine out temperatures**
- **Particular challenge for competing needs for advanced combustion**
  - Enthalpy needed to drive turbo-machinery
  - Sufficient temperatures needed to maintain catalyst effectiveness
  - Anticipates direction for LT Catalyst Research - ACEC report to be issued soon



Conventional Powertrain Exhaust Temperature Simulations From Steady-State Engine Maps

Leveraging ACE research into catalyst light-off with RCCI



Model DOC

Prikhodko, V., et al., "Effectiveness of Diesel Oxidation Catalyst in Reducing HC and CO Emissions from Reactivity Controlled Compression Ignition," *SAE Int. J. Fuels Lubr.* 6(2):329-335, 2013,

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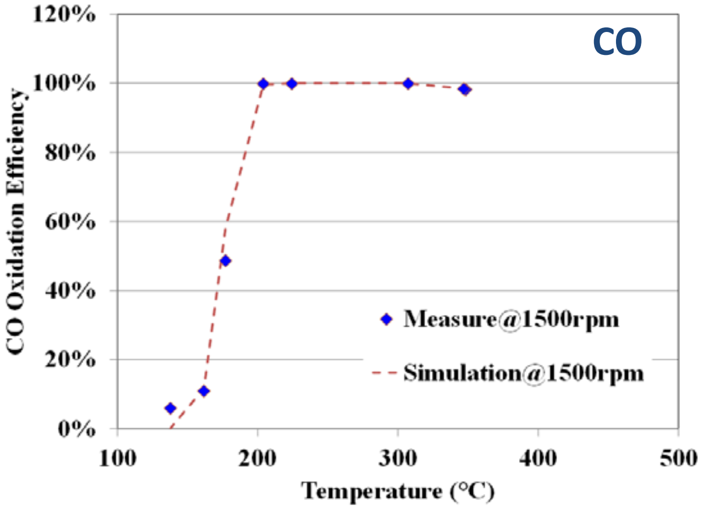
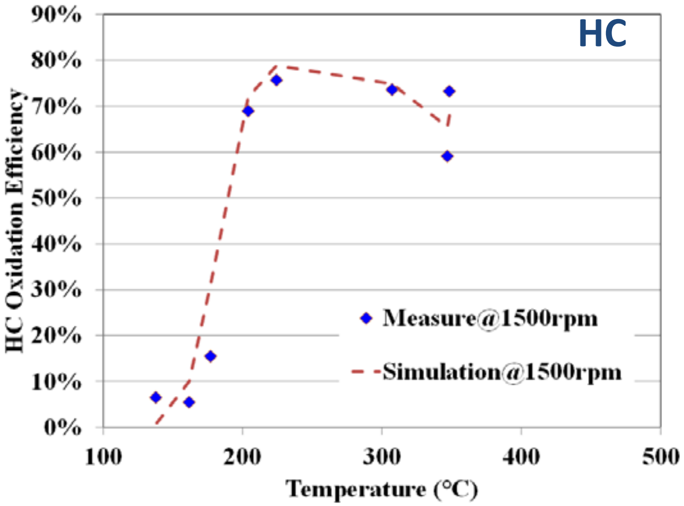
Accomplishment 5: Update DOC catalyst models for multi-mode RCCI combustion

- **Fitted reaction rates of CO/HC/NO oxidation as a function of the DOC operating temperature***
  - The reaction rates were optimized using MATLAB® optimization functions for each DOC performance at 1500rpm and 3000rpm engine series operations
  - The slope and intercept can be used as active energy and pre-exponential factor
- **Critical to update moving forward simulating aftertreatment effectiveness with RCCI multimode (CDC complete – currently working on RCCI data)**
  - Simultaneously high HC and CO with lower temperatures effects with RCCI not well understood for DOCs (competing)
  - Not only the amount of HC and issue but the composition of RCCI HC for DOCs developed for CDC HC, CO and Temps
  - DOC light-off criteria being incorporated into next multi-mode control strategy (critical for Tier III standards HC+NOx)

Comparison of the simulated and measured CO/HC oxidation efficiency with CDC





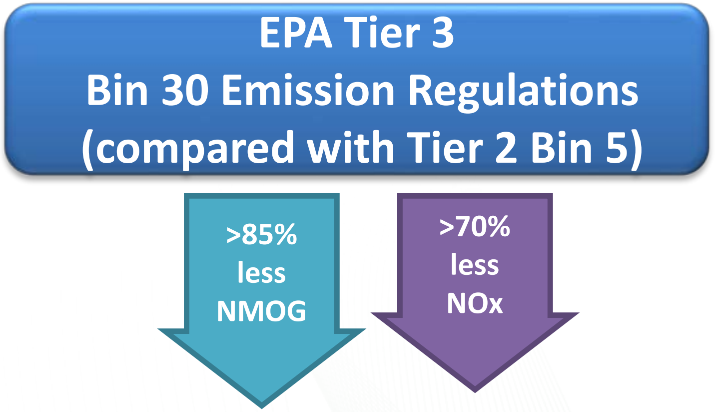
**In coordination with CLEERS Activity*

ACE022 CLEERS Analysis and Coordination

Accomplishment 6: Estimations for the Aftertreatment efficiency needed for EPA Tier III standards

- **Examine how these technologies compare in their achievement of the new U.S. EPA Tier 3 emission**
- **These standards require the fleet average CO, non-methane organic gases (NMOG)+NOx, and PM emissions to reach 1.0 g/mile, 30 mg/mile, and 3.0 mg/mile (i.e., Tier 3 Bin 30), respectively, by 2025.**

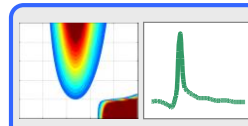
Combustion	Type	CO reduction	NMOG+NOx reduction	PM reduction
PFI	Conv.	87.2%	99.4%	0.0%*
	Hybrid	79.2%	99.2%	0.0%*
Lean GDI	Conv.	81.0%	99.3%	34.3v
	Hybrid	74.0%	99.1%	0.0%*
CDC/RCCI	Conv.	84.2%	99.1%	-
	Hybrid	66.8%	98.6%	-
CDC-only	Conv.	75.1%	98.2%	82.6%
	Hybrid	0.0%*	96.8%	85.9%

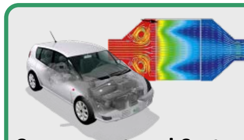


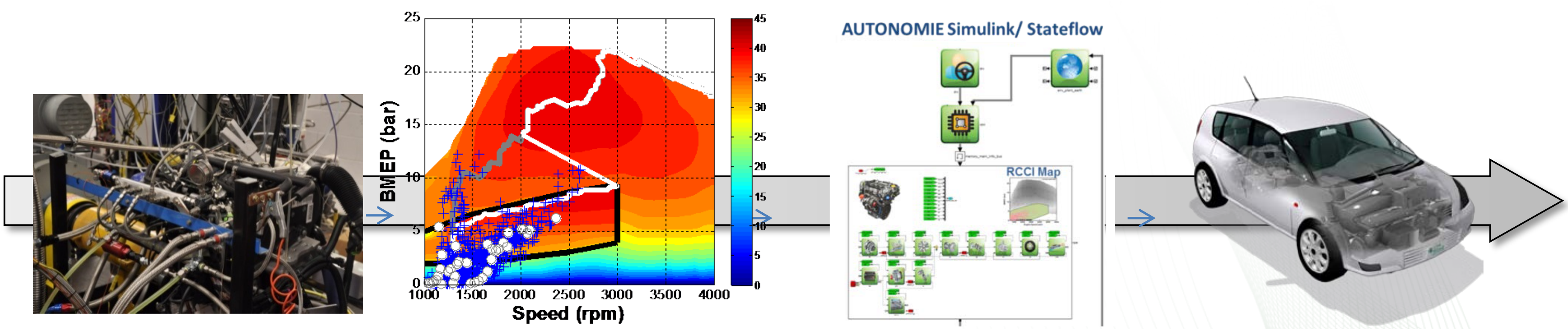
* meets the emission standard without aftertreatment.

Accomplishment (7) FY 15 Supporting Simulations On Track Supporting Advanced Combustion Engines Milestones

- **Q3 Milestone – High Efficiency RCCI Mapping**
  - Develop RCCI multi-mode combustion map on a multi-cylinder engine suitable for light-duty drive cycle simulations
    - Transient effects on light-off effects
- **Q4 Milestone – RCCI Vehicle Systems Modeling**
  - Demonstrate modeled fuel economy improvement of **30%** for passenger vehicles solely from improvements in powertrain efficiency relative to a 2009 PFI gasoline baseline
    - Perform drive cycle simulations on same vehicle platform to estimate fuel economy and engine out emissions


Advanced (HECC) Combustion


Component and System Modeling



Mapping Experiments

RCCI Map

Vehicle Systems Simulations

Modeled Fuel Economy

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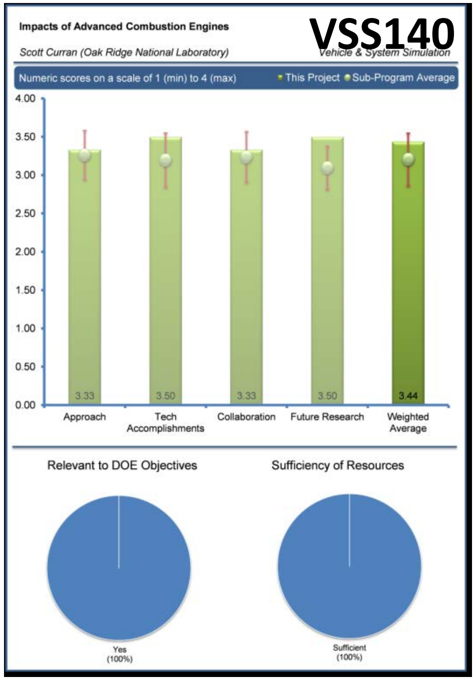
Responses to Previous Year Reviewer Comments

Positive Comments

- Reviewers noted the project demonstrates excellent coordination and collaboration with VTO Advanced Combustion Engines, Fuels & Lubricant Technologies and VSST
- Reviewer stated that the ideal activity for a national laboratory is to explore and define advanced technology and transfer to industry.
- Reviewers noted strong technical approach and growth strategy with good relevance to industry with cooperative relationships through crosscut committee
- Sound approach taken in support of 2025 CAFE standards
- Excellence relevance of work, excellent progress has been made for the funding level of the project



Addressing Questions/ Recommendations from 2014 Reviewers

- **Reviewers noted that there should be more parallel validation of the model against advanced systems under test at OEMs or at DOE labs**
  - **Very good point – first step was taken to evaluate an RCCI hybrid at ORNL and FORD chassis dyno labs to validate models under ACE subprogram**
- **Reviewers encouraged more OEM/ Powertrain suppliers as partners to enable model verification and validation**
  - **Already working with OEM on baseline PFI maps – starting to work with more on model validation**
  - **Slide 17 shows model validation to real vehicles + AEJ paper did more comparisons (ANL D3 Database)**
- **Reviewer requested acronym list**
  - **FY 15 Slides include in backup**

Comments cited above were paraphrased as appropriate from 2014 Annual Merit Review document, http://www1.eere.energy.gov/vehiclesandfuels/pdfs/merit_review_2012/2012_amr_04.pdf

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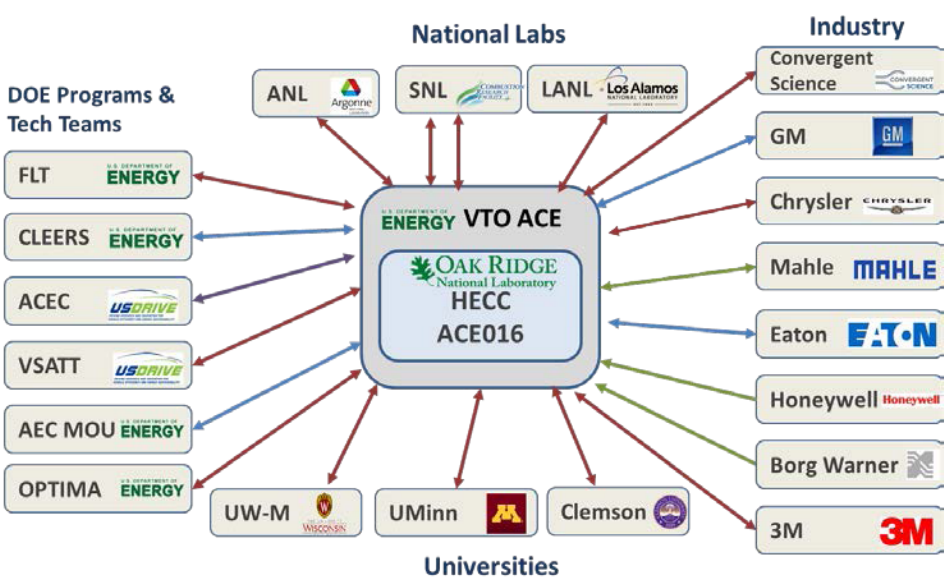
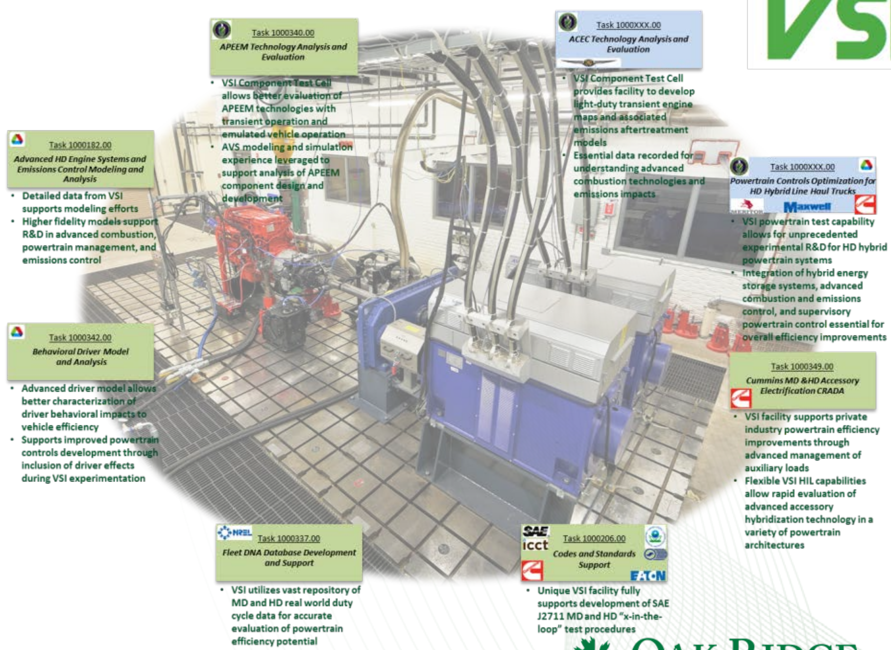
COLLABORATION AND COORDINATION

- **USDRIVE Advanced Combustion and Emissions Control Technical Team**
- **DOE Advanced Engine Crosscut Team**
  – Crosscut Lean Exhaust Emissions Reduction Simulation (CLEERS) Focus Group Collaborators
- **VTO and BES programs at ORNL supporting basic emission control component R&D**
- **Large network of industry and university partners**
- **Related ORNL Activities**
  – Advanced LD Engine Systems and Emissions Control Modeling and Analysis (VSS041)
  – High Efficiency Clean Combustion in Multi-Cylinder Light-Duty Engines (ACE016).
  – Fuel Effects on Emissions Control Technologies (FT007).
  – Gasoline-like Fuel Effects on Advanced Combustion Regimes (FT008).

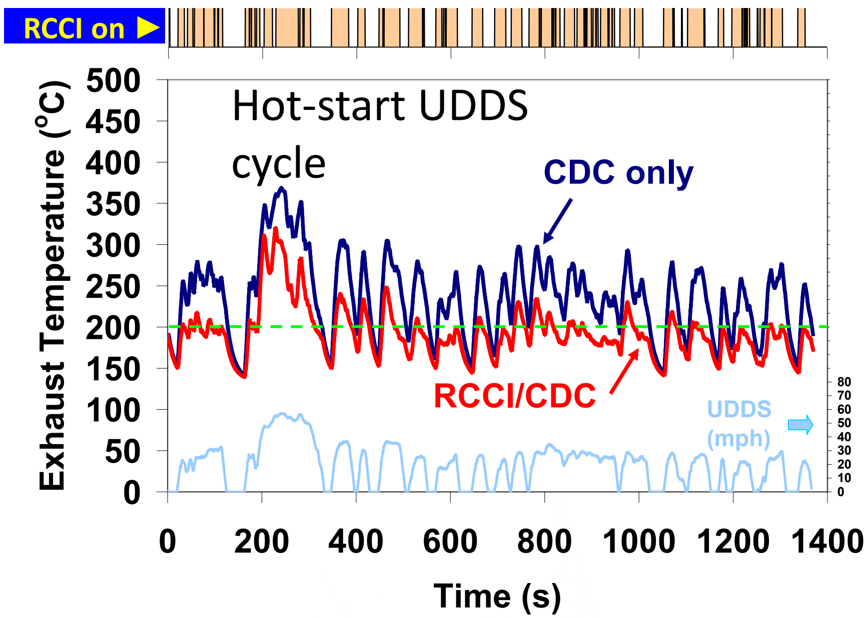




Remaining Challenges and Barriers

Challenges

- **Need for transient LTC validation for approach**
- **Need to validate exhaust emissions against actual transient LTC operation**
  - Current collaboration with the university of Wisconsin RCCI Hybrid team for test validation
- **Applicability of current aftertreatment models to LTC exhaust including PM**
  - Being addressed at ORNL with ACE research on multi-cylinder engines



Barriers

- **Lack of production LTC modes being addressed by this project on a vehicle systems basis**

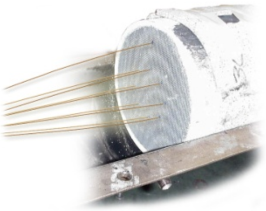
PROPOSED FUTURE WORK

- FY2015
  - Continue working closely with the ORNL-FEERC experimental teams to improve the low-temperature and RCCI exhaust HC/CO response of DOC catalyst models and NOx reduction device models based on the latest available experimental catalyst and device data
  - Continue improving and validating the ORNL methodology for adjusting steady-state engine-out emissions maps to account for drive cycle transients using the most recently available dynamometer data.
  - Refine simulations of fuel economy, engine-out, and tailpipe-out emissions for RCCI-enabled HEVs and PHEVs in city and highway driving.
  - Utilize experimental data for refinement of aftertreatment component models including low-temperature catalyst in support of ACEC goals
  - Integration of transient engine data for refinement of multi-mode engine model

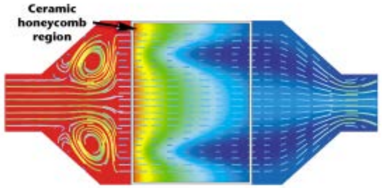
Vehicles

Components

Data



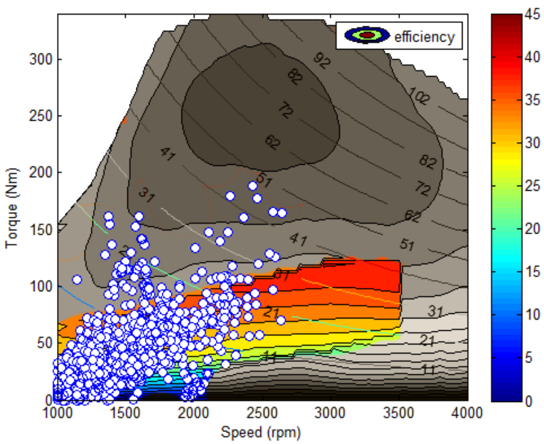
Modeling



SUMMARY: VSST collaboration with the VTO ACE and FLT programs enhances the U.S. DOE mission of improving vehicle energy efficiency within emissions constraints

- **Significant progress has been made toward simulating fuel consumption and emissions for advanced combustion**
- **Focused on investigating fuel economy potential of LTC using comprehensive engine systems approach**
  - Multi-cylinder advanced combustion experiments
  - Aftertreatment integration
  - Vehicle systems level modeling
- **Collected and integrated 1.9L GM dual-mode CDC/RCCI engine map into transient engine model enabled to switch CDC and RCCI**
- **Simulated LD hybrid vehicle powered by an RCCI-enabled engine over realistic driving cycles**
- **We continue to expand the capabilities of our engine and aftertreatment models to enhance their accuracy, flexibility, and relevance to the most advanced engine and emissions technology**

Advanced Combustion

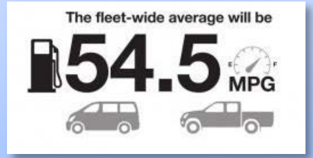


System Integration

FUEL ECONOMY

2025 CAFE Standards

(U.S. EPA and U.S. NTSA standards)



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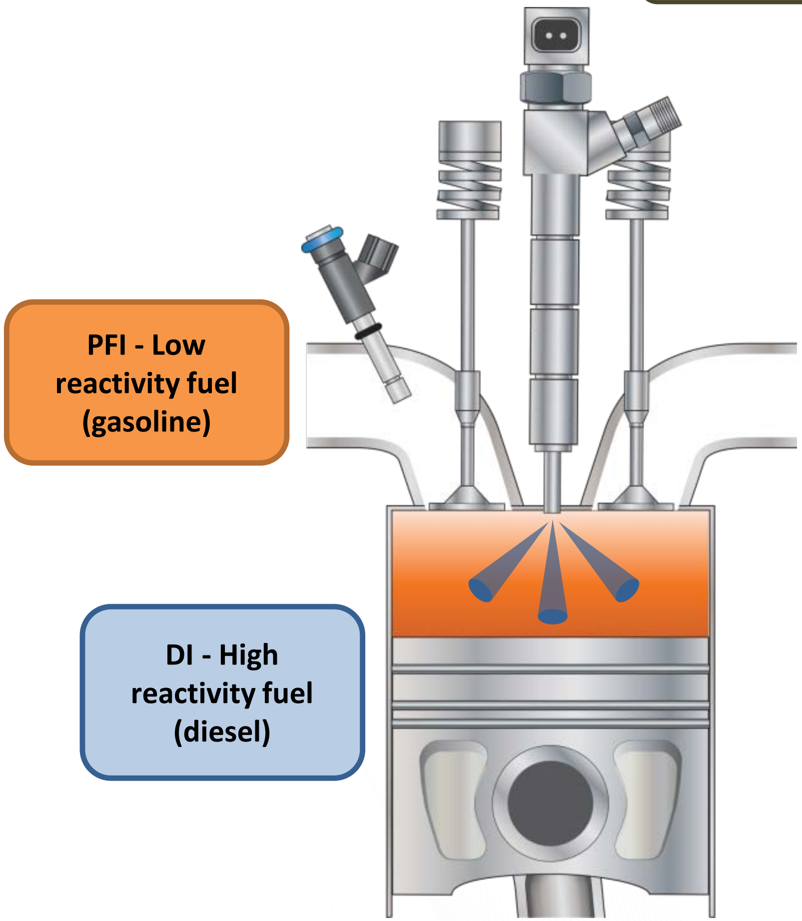
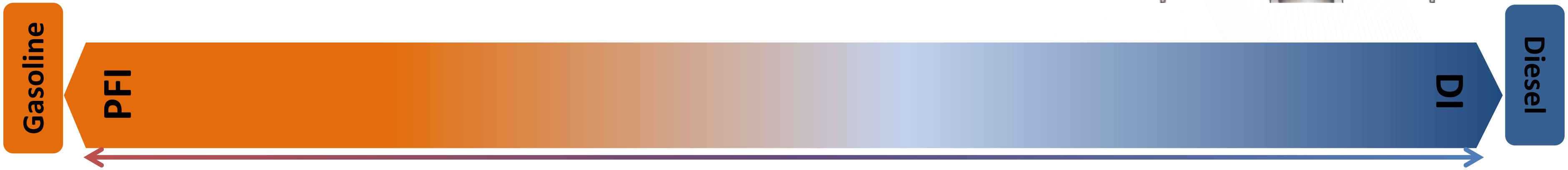
Backup Slides

Background: Dual-fuel Reactivity Controlled Compression Ignition (RCCI)

Back-Up 1

- **Reactivity controlled compression ignition (RCCI) allows precise reaction and heat-release control**
  - A low-reactivity fuel is introduced early and premixed with air.
  - A high-reactivity fuel is injected into the premixed charge before ignition.
- **RCCI increases engine operating range for premixed combustion**
  - Global fuel reactivity (phasing)
  - Fuel reactivity gradients (pressure rise)
  - Equivalence ratio and temperature stratification
- **RCCI offers both benefits and challenges to implementation of LTC**
  - Diesel-like efficiency or better
  - Low NOx and soot
  - Controls and emissions challenges





Low = Prevents Auto-Ignition **Fuel Reactivity** **High** = Promotes Auto-Ignition

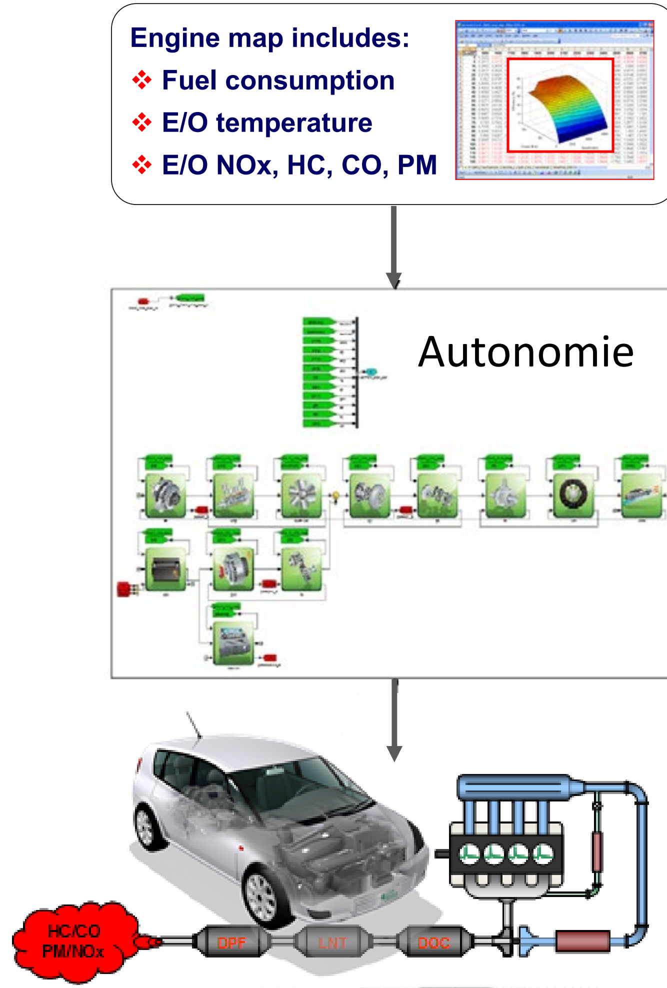
APPROACH Details : ORNL's comprehensive approach to vehicle systems research

Back-Up 2

- 2007 GM 1.9-L multi-cylinder diesel engine
  - OEM (CR 17.5) and modified RCCI pistons (CR 15.1)
  - Dual-fuel system with PFI injectors
- Aftertreatment integration & emissions characterization
  - Modular catalysts / regulated and unregulated emissions
- Vehicle systems simulations using Autonomie
  - Create multi-mode engine maps and controls
  - Experimental engine maps used for drive cycle simulations
  - Comparison between 2009 PFI, diesel and diesel/RCCI
  - Multi-mode (RCCI to conventional diesel combustion) used for areas of the drive cycle outside the RCCI operating range

– Model Details

- Simplified low-order correction methodology to estimate transient exhaust properties from steady-state engine maps *(Gao et.al., Int. J. Engine Res., 11(2), 2010)*
- Other simulation details available from Gao et. al., "Light-Duty Drive Cycle Simulations of Diesel Engine-Out Exhaust Properties for an RCCI-Enabled Vehicle," 8th U. S. National Combustion Meeting (& backup slide)



Modeled Fuel Economy & Emissions

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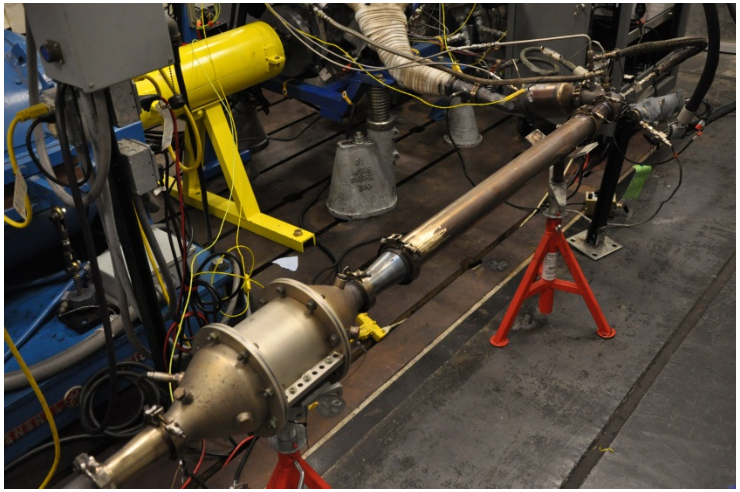
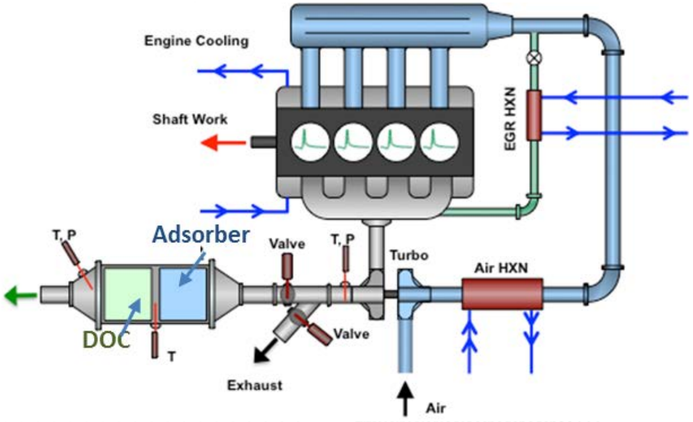
Assess benefits of using passive sorbent traps to reduce NOx and HC emissions in RCCI-enabled LD hybrids

Back-Up 3

- **Cold start and repeated engine off delay catalyst heat-up, leading to significant CO, HCs, and NOx emissions**
  - Significant cold start impact in HEVs and PHEVs
  - HEVs and PHEVs engine intermittent operation
- **Significant HCs released from RCCI**
  - Lower-load exhaust temps < 260°C
- **Sorbent trapping is an innovative technology**
- **Our approach and plan for this simulation**
  - Update our previously published passive sorbent trap models
  - Implement and demonstrate adsorber model in Autonomie
  - Simulate the potential benefits of using a passive adsorber device to reduce the NOx and HC tailpipe emissions during initial cold-start and repeated engine restarts



ORNL ACE Aftertreatment Research Setup



List of References for the VSST models

Back-Up 4

- Transient Engine Simulation Methodology
  - Z. Gao et.al., A Proposed Methodology for Estimating Transient Engine-out Temperature and Emissions from Steady-State Maps, Int. J. Engine Res., 11(2), 2010.
- DOC/DPF/SCR Component models
  - Z. Gao et.al., Simulation of Catalytic Oxidation and Selective catalytic NOx Reduction in Lean-Exhaust Hybrid Vehicles, SAE paper 2012-01-1304 (DOC and SCR modeling).
  - Z. Gao et.al., Simulating the Impact of Premixed Charge Compression Ignition on Light-Duty Diesel Fuel Economy and Emissions of Particulates and NOx, Proc. IMechE - Part D: J. Automobile Engineering, 227(1), 2013 (DPF modeling).
  - C.S. Daw et.al., Simulated Fuel Economy and Emissions Performance during City and Interstate Driving For a Heavy-Duty Hybrid Truck, SAE paper 2013-01-1033 (DOC/DPF/SCR and new SCR parameters).
- HD Hybrid Truck Simulation
  - C.S. Daw et.al., Simulated Fuel Economy and Emissions Performance during City and Interstate Driving For a Heavy-Duty Hybrid Truck, SAE paper 2013-01-1033.
- Advanced Diesel Combustion Simulation
  - Z. Gao et.al., Using a phenomenological Computer Model to Investigate Advanced Combustion Trajectories in a CIDI Engine, Fuel, 90, 1907–1918, 2011.

Acronym list

Back-Up 5

- ACE = Advanced Combustion Engines Subprogram
- ACEC = Advanced Combustion and Emissions Controls Technical Team
- CAFE = Corporate Average Fuel Economy
- CDC = Conventional Diesel Combustion
- DI = Direct Injection
- DOC = Diesel Oxidation Catalyst
- DPF = Diesel Particulate Filter
- FLT = Fuels and Lubricant Technologies Subprogram
- GM = General Motors
- FEERC = ORNL Fuels Engine and Emissions Research Center
- HEV = Hybrid Electric Vehicle
- PFI = Port Fuel Injection
- PM = Particulate Matter
- LD = Light-Duty
- LTC = Low Temperature Combustion
- LNT = Lean NOx Trap
- LT = Low Temperature
- ORNL = Oak Ridge National Laboratory
- RCCI = Reactivity Controlled Compression Ignition
- SCR = Selective Catalytic Reduction
- UDDS = Urban Dynamometer Driving Schedule
- VSI = ORNL Vehicle Systems Integration Laboratory
- VSS = Vehicles Systems & Simulations
- VTO = Vehicle Technologies Office

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