Sustainable TRANSPORTATION

U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy

Overview of the DOE Advanced Combustion Engine R&D Program

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Vehicle Technologies Office

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DOE Vehicle Technologies Office
Washington, DC
May 14, 2013

ACE00A

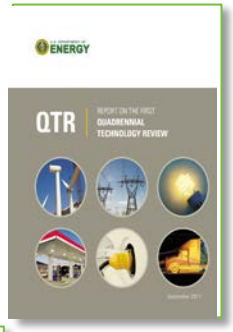
The Federal Role

- Facilitate development of precompetitive technical knowledge base through investments in fundamental and applied R&D
- Undertake high-risk mid- to long-term research
- Utilize unique national lab expertise and facilities
- Help create a national consensus
- Enable public-private partnerships to integrate R&D into industrially useful design tools

Opportunity for Increased ICE Efficiency

Increasing the efficiency of internal combustion engines (ICEs) is one of the most promising and cost-effective approaches to improving the fuel economy of the U.S. vehicle fleet in the near- to mid-term.

"The performance, low cost, and fuel flexibility of ICEs makes it likely that they will continue to dominate the vehicle fleet for at least the next several decades. ICE improvements can also be applied to both hybrid electric vehicles (HEVs) and vehicles that use alternative hydrocarbon fuels." DOE QTR 2011[1]

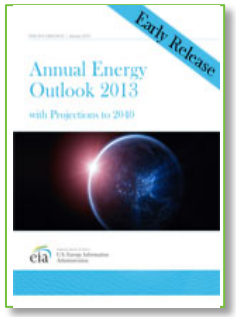


DOE 2011

"…ICEs … are going to be the dominant automotive technology for decades, whether in conventional vehicles, hybrid vehicles, PHEVs, biofueled or natural gas vehicles. …better understanding of the combustion process and emissions production can help to overcome a major barrier to more advanced ICEs, this work is important to the country. …" NRC Report 2013[2]


NRC 2013

EIA AEO2013 reference case scenario - even by 2035, ***over 99% of vehicles sold will have ICEs***. EIA *AEO 2013*[3]



DOE 2013

[1] Quadrennial Technology Review, DOE 2011

[2] *Review of the Research Program of the U.S. DRIVE Partnership: 4th Report,* NRC 2013

[3] *Annual Energy Outlook 2013*, Early Release, DOE 2012.

Advanced Combustion Engine R&D

Strategic Goal: Reduce petroleum dependence by removing critical technical barriers to mass commercialization of high-efficiency, emissions-compliant internal combustion engine (ICE) powertrains in passenger and commercial vehicles

Primary Directions

- Improve ICE efficiency through advanced combustion strategies
- Develop aftertreatment technologies
- Explore waste energy recovery with mechanical and advanced thermoelectric devices

Performance Targets

	Light-Duty		Heavy-Duty	
	2015	2020	2015	2020
Engine brake thermal efficiency			50%	55%
Fuel economy improvement	25 – 40%	35 – 50%	20%	30%
NOx & PM emissions	Tier 2, Bin2	Tier 2, Bin2	EPA Standards	EPA Standards

Advanced Combustion Engine R&D

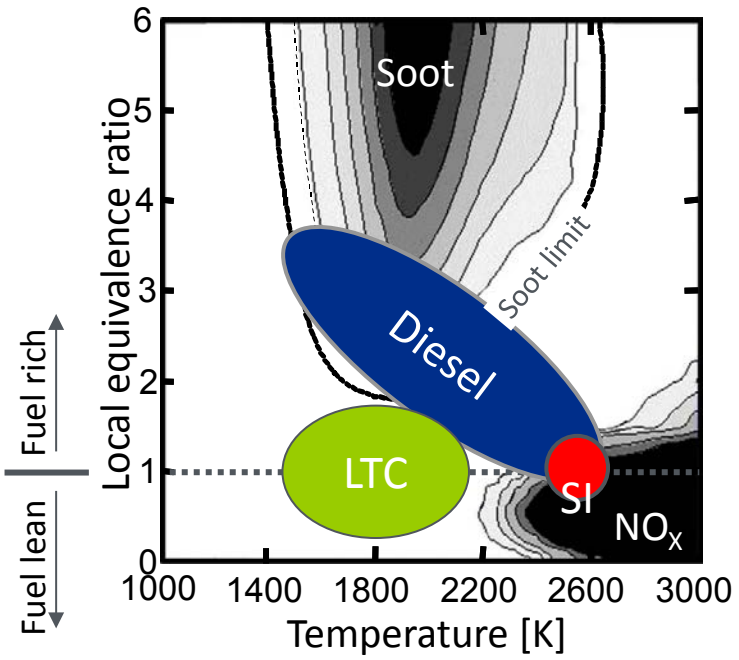
Key Subprograms

- **Combustion and Emission Control R&D**
  - Combustion Research
  - Emission Control R&D
  - High Efficiency Engine Technologies
- **Solid State Energy Conversion**

Combustion Research Directions and Challenges

Combustion Strategies Enabling Improved Efficiency and Very-Low Emissions

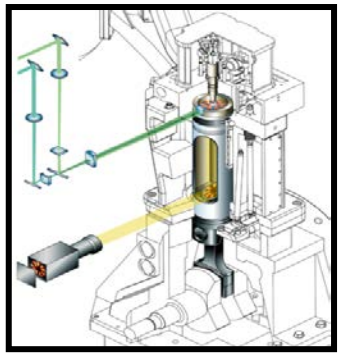
- Low-Temperature Combustion (LTC):
  - Premixed-Charge Compression-Ignition (PCCI) (PPCI, PCI, MK, …) – "mixed enough"
  - Homogeneous-Charge Compression-Ignition (HCCI) – "heterogeneous enough"
  - Reactivity Controlled Compression Ignition (RCCI) – "dual fuel" combustion
- Dilute Gasoline Combustion: Fuel-air mixing, ignition and flame propagation in stratified mixtures, stochastic misfire and knock challenges, fuels, emissions…
- Clean Diesel Combustion: EGR, high-pressure and multi-pulse injection, lifted-flame combustion, post injections for in-cylinder and aftertreatment emission control...



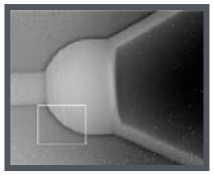
- LTC Challenges:
  - Combustion phasing
  - Load range
  - Heat release rate
  - Transient control
  - HC and CO emissions
  - Fuel characteristics

Research Tools Bridge Fundamentals to Application

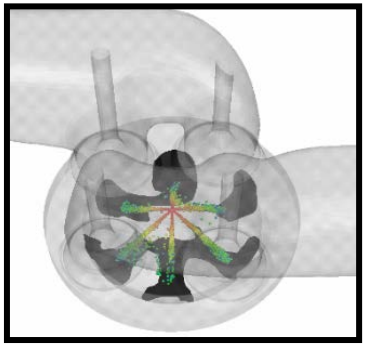
- Close coupled modeling and experiments
  - Advanced diagnostics including optical, laser, x-ray, and neutron based techniques
  - Multi-dimensional computational models and combustion simulators
  - Fuel kinetics
  - Multi- and single-cylinder engines



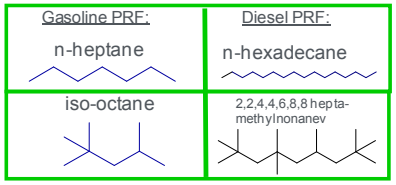
Optical Engines



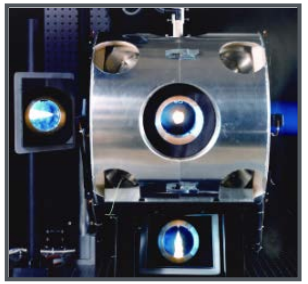
Nozzle Sac X-Ray Image



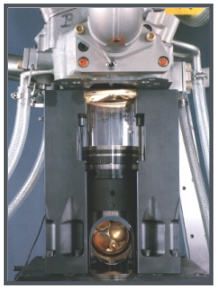
Engine Simulation



Gasoline and Diesel Surrogates



LTC Simulator



HCCI & Lean-burn Gasoline

Multi-Cylinder Diesel

- Close collaboration between industry, national labs and universities
- Cross-cuts light- and heavy-duty R&D

Leading to engine CFD modeling tools widely used in industry

Advanced Engine Combustion Research

- **Goal:** To develop the knowledge base for low-temperature combustion (LTC) strategies and carry research results to products.
  - Science-base for advanced combustion strategies
  - Computational tools for combustion system design and optimization
  - Identify potential pathways for efficiency improvement and emission compliance
- Close collaboration with industry through the Advanced Engine Combustion MOU led by Sandia National Labs ***carries research to products.***

- Cross cuts light-duty and heavy-duty engine R&D
- University research integrated with MOU

University Solicitation with National Science Foundation (2012)

NSF/DOE PARTNERSHIP ON ADVANCED COMBUSTION ENGINES

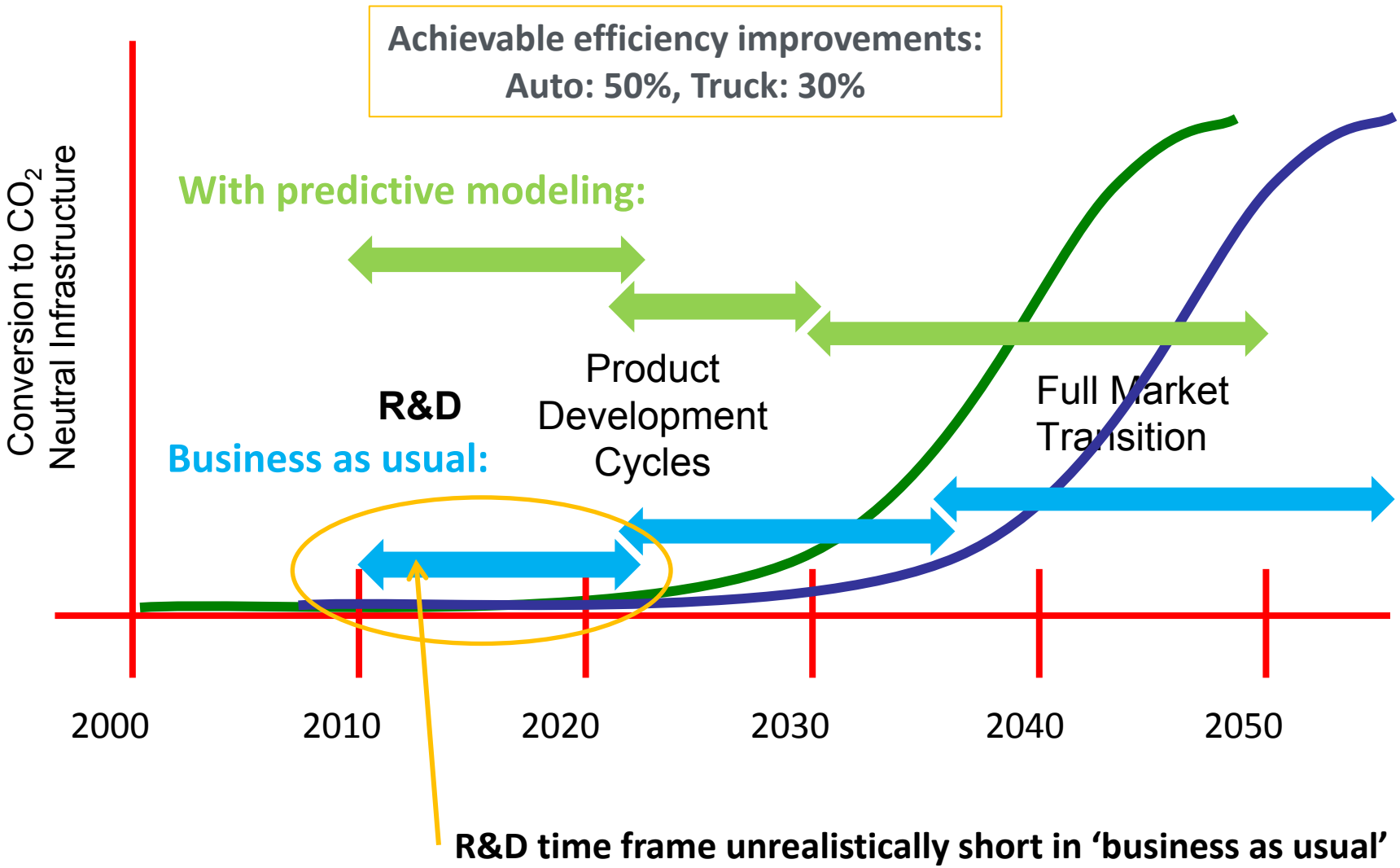
National Science Foundation
Directorate for Engineering
Division of Chemical, Bioengineering, Environmental and Transport Systems

U.S. Department of Energy, Vehicle Technologies Program

- A Partnership to leverage the complementary DOE and NSF missions[1].
- Two broad areas: *Advanced Combustion Engines*; and E*missions Control Strategies*
- Research to focus on understanding the fundamental thermal/fluid/chemical processes and how improved understanding will enable ICE efficiency gains.
- Collaborations with industry, and other academic and/or national laboratories that provide complementary experimental/ modeling/facility capabilities.

[1]DOE Mission - Deployment and Commercialization
NSF Mission - Fundamental Research and Education

Product Development Must Be Accelerated To Meet Energy Goals

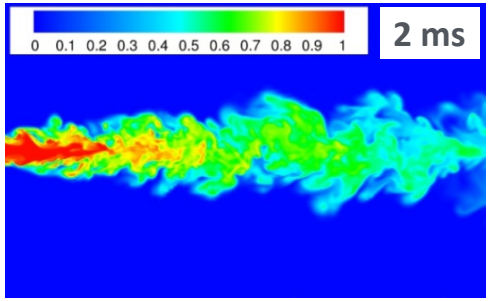


Providing New Breakthroughs with HPC: High-Fidelity, Large Eddy Simulation (LES) Coupled with Engine Experiments (SC/BES and EERE/VTO Collaboration)

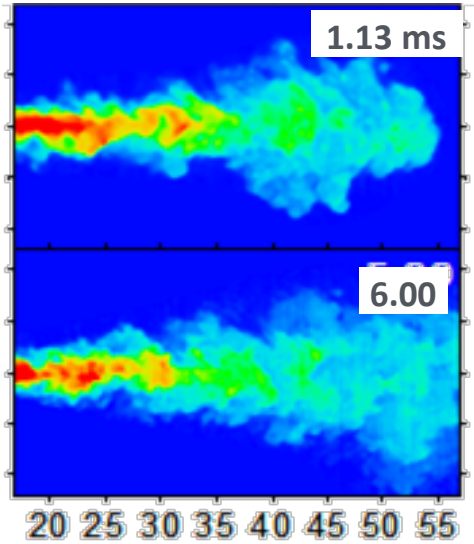
❑ Currently simulating a progression of fuel injection sprays for direct injection engines.

- Validated high-fidelity LES is run on DOE supercomputer platforms
- Results providing insights for improving engineering CFD models

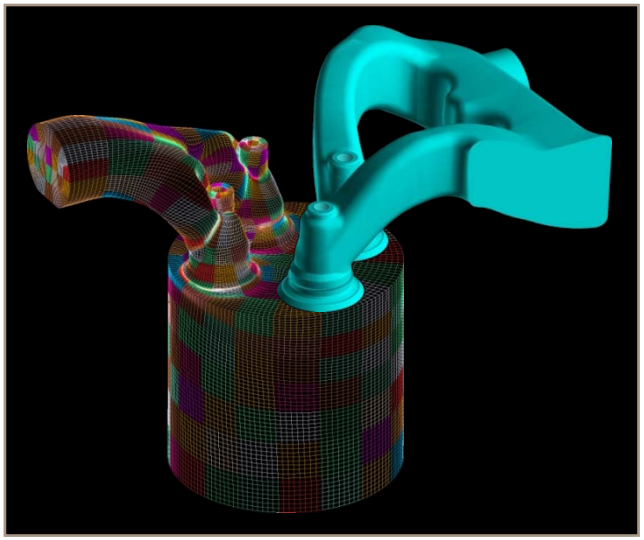
Large Eddy Simulation of fuel concentration



Rayleigh Scattering images of fuel concentration



Sandia HCCI Engine grid for LES



❑ HCCI engine LES in progress:

- Demonstrated LES can capture physics
- Now focused on improving grid fidelity (advanced gridding)
  - Intake flow with anti-swirl plate
  - Valve seat indentations and piston crevice
  - Detailed heat transfer model for walls
- Simulations will explore thermal stratification effects on heat release rate to improve understanding and engineering models

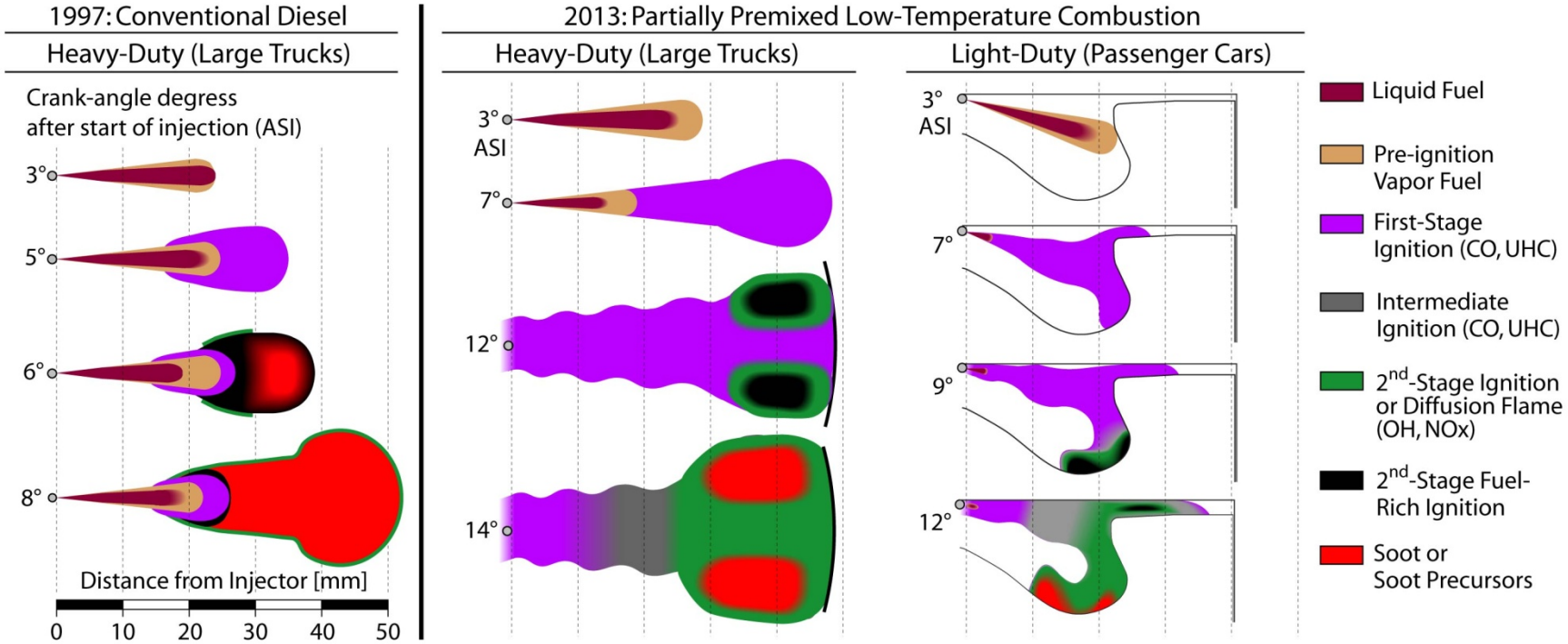
Newly developed conceptual model for diesel LTC combustion describes in-cylinder processes *(SNL)*

Motivation:

- 1997: Conventional diesel conceptual model (left) is foundation of understanding for industry
- 2013: Need new conceptual model to aid development low-temperature combustion (LTC)

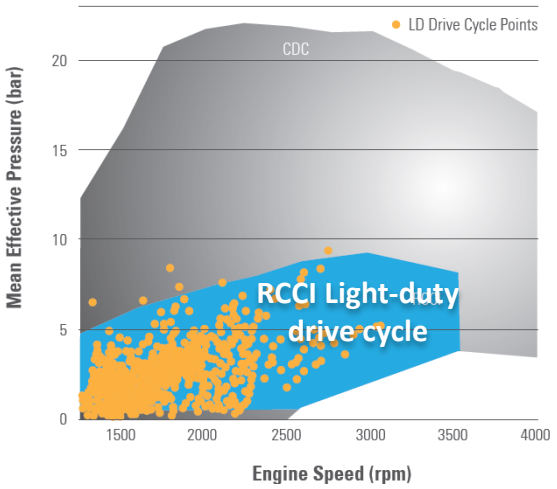
Impact of new LTC conceptual model:

- Describes LTC operating condition effects on spray, mixing, combustion, efficiency, emissions
- Supported by years of optical data and simulations in heavy-duty (left) and light-duty (right)



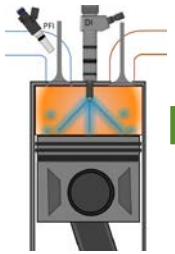
Multi-Mode RCCI Engine Map Used to Demonstrate Potential Improvements in Modeled Fuel Economy (ORNL)

- Reactivity controlled compression ignition (RCCI) combustion
  - In-cylinder blending of two fuels (diesel and gasoline) with differing reactivity is used to tailor the reactivity of the fuel charge for improved control of the combustion process.
  - Allows stable, low-temperature combustion to be extended over more of the light-duty drive cycle load range.
- RCCI mapped on multi-cylinder light-duty engine
  - A multi-mode RCCI strategy was employed (i.e., engine switches from RCCI to conventional diesel combustion when demanded speed and load fall outside of the RCCI range)

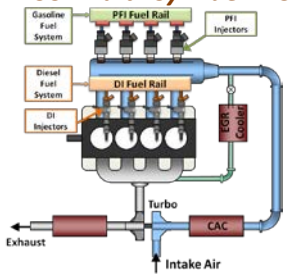


Drive cycle simulations of multi-mode RCCI combustion demonstrate greater than 15% drive cycle fuel economy improvement compared to a gasoline engine baseline.

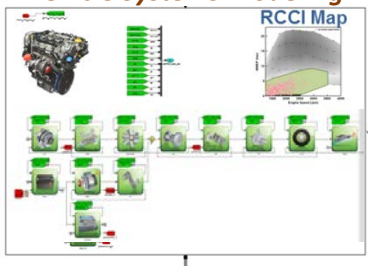
Dual-Fuel RCCI



ORNL RCCI Multi-Cylinder 1.9L GM



Vehicle Systems Modeling



Modeled Fuel Economy

Advanced Combustion Engine R&D SBIR/STTR Topics for FY 2012

Small Business Innovation Research (SBIR) and
Small Business Technology Transfer (STTR) Programs Topics
FY 2012 Phase I (Release 3)

- Topics Released: Monday, March 5, 2012
- Funding Opportunity Announcement Issued: Monday, April 3, 2012
- Pre-Application Due Date: Tuesday, May 1, 2012
- Feedback Provided on Pre-Applications: Tuesday, June 5, 2012
- Application Due Date: Tuesday, July 3, 2012

Vehicle Technologies Program topics:

(a) High-energy, high-power electric drive vehicle batteries
(b) Catalyst materials for exhaust aftertreatment
(c) Engine boosting technologies
(d) Differential compression and expansion technologies
(e) Subsystem component technologies
(f) Thermoelectric technologies
(g) Materials for traction drive motor laminations, cores, or structures.

SBIR/STTR FY 2012 Phase I (Release 3) Awards announced 2/20/2013

Advanced Combustion Engine R&D Program: Budget by Subprogram

Major Activities	FY 2012* Enacted	FY 2013** Full Year CR	FY 2014*** Request
Advanced Combustion Engine R&D	**$58,027K**	**$56,725K**	**$59,500K**
Combustion and Emission Control	49,320	48,216	54,500
Solid State Energy Conversion	8,707	8,509	5,000

* FY 2012 SBIR/STTR removed.
** FY 2013 full year CR inclusive of SBIR/STTR.
*** FY 2014 budget request inclusive of SBIR/STTR.

Questions?

Thank You!

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Web site:

http://www.eere.energy.gov/vehiclesandfuels