Overview of the DOE Advanced Combustion Engine R&D Program

June 16, 2014

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Advanced Combustion Engine R&D
Team Members:
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Outline

- State of technology today for ICE
- Overview of the Advanced Combustion Engine R&D Program
- Combustion and Emission Control Subprogram
  - Engine Combustion Research
    - Low Temperature Combustion
    - Predictive Simulation for ICE Design
  - Emission Control R&D
  - High Efficiency Engine Technologies
- Solid State Energy Conversion Subprogram
- Summary

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.

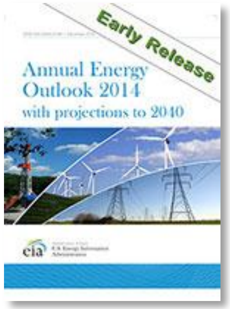
"The performance, low cost, and fuel flexibility of ICEs makes it likely that they will continue to dominate the vehicle fleet for at least the next several decades. ICE improvements can also be applied to both hybrid electric vehicles (HEVs) and vehicles that use alternative hydrocarbon fuels." DOE 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 *AEO 2014*[3] reference case scenario - even by 2040, ***over 99% of vehicles sold will have ICEs***.



DOE 2013

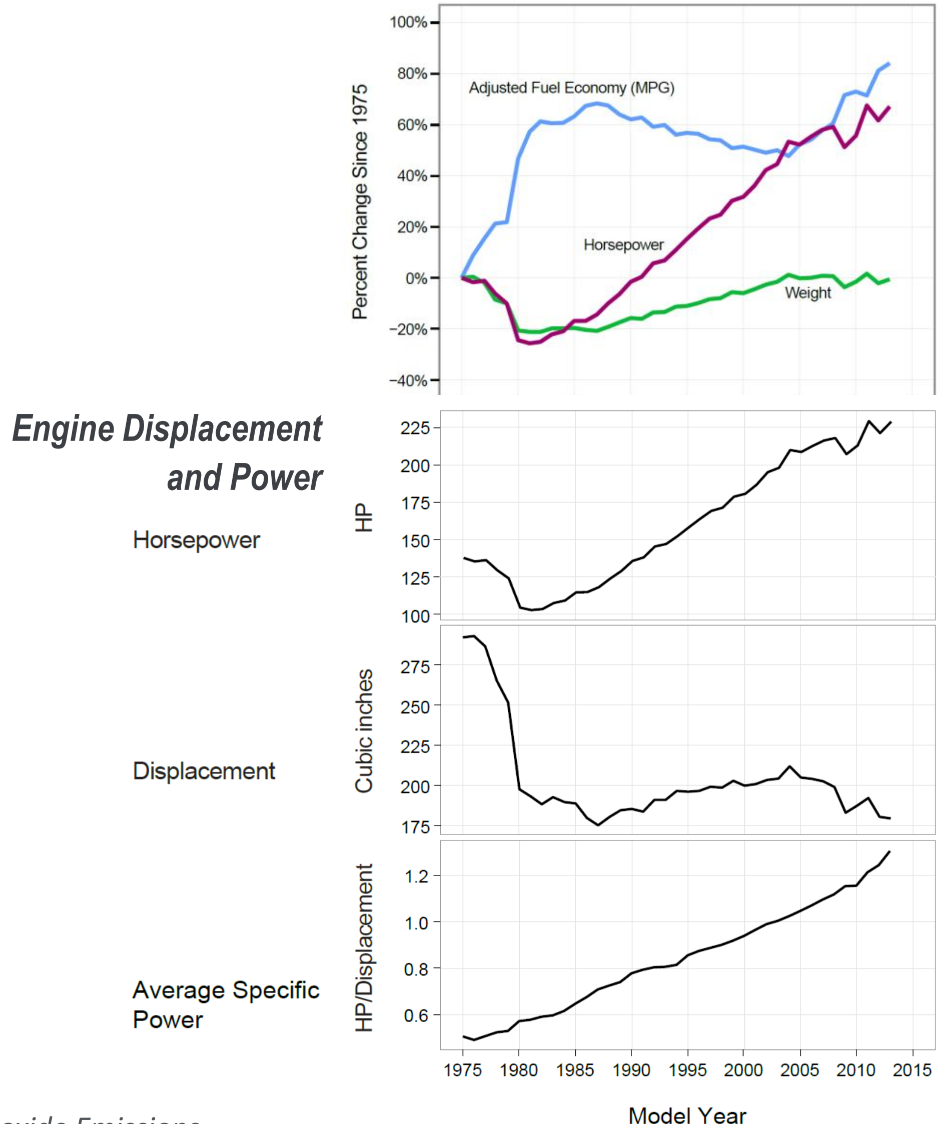
[1] Quadrennial Technology Review, DOE 2011

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

[3] *Annual Energy Outlook 2014*, Early Release, December 2013.

Passenger Vehicle Fuel Economy Trends

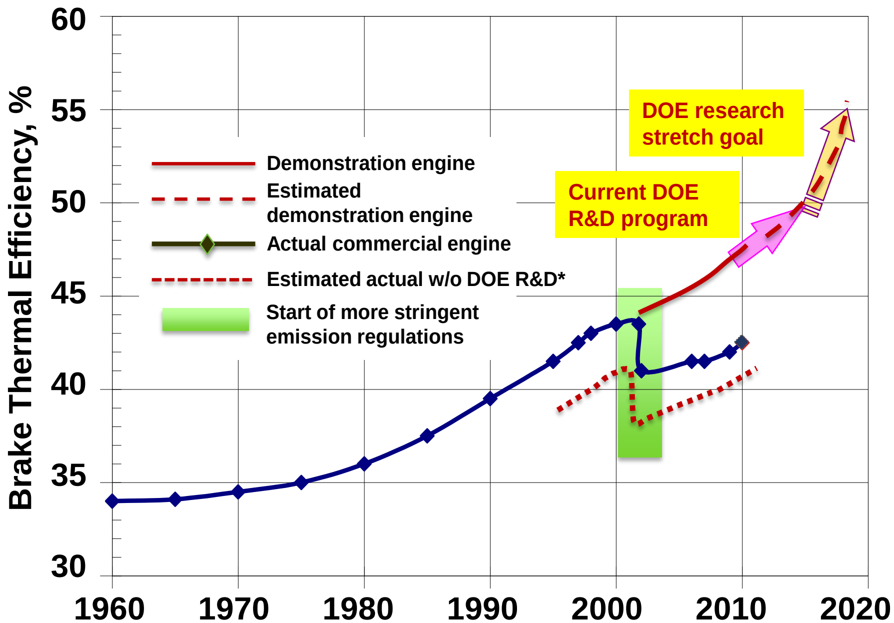
Increase in internal combustion engine performance has been largely responsible for significant fuel economy increases (in spite of increases in vehicle size and weight).

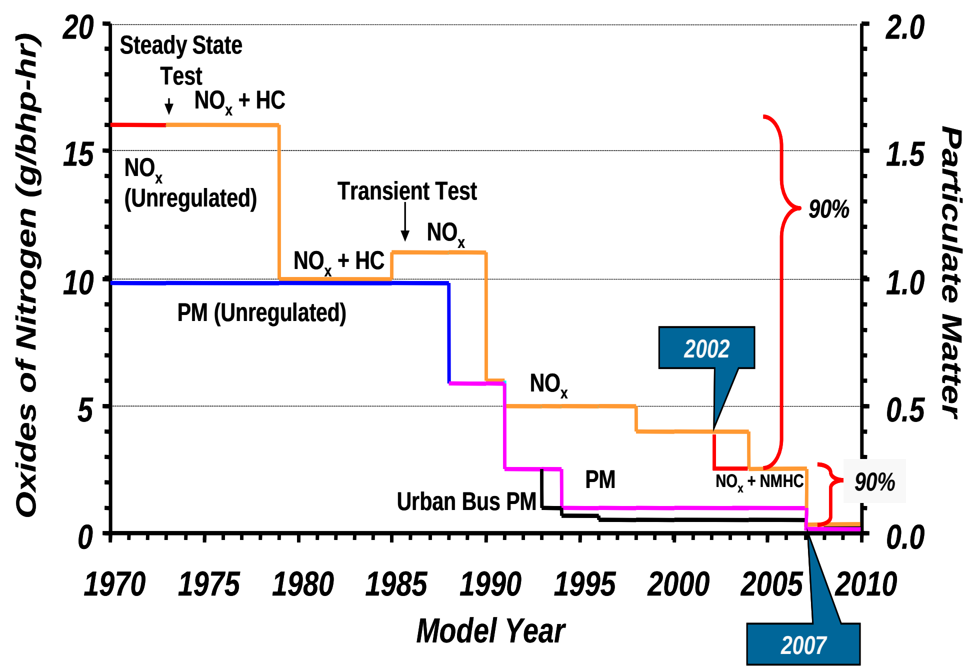


Source: EPA, Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 Through 2013, December 2013

Progress In Heavy-Duty Diesel Engine Efficiency and Emissions

Historical progress in heavy-duty engine efficiency and the challenge of simultaneous emissions reduction, illustrate positive impact from DOE R&D support.





- DOE R&D improved thermal efficiency of over-the-road heavy-duty diesel engines by over 4.5% .
- Benefits from heavy-duty vehicles alone (1995 – 2007) represent an over 70:1 return on investment (ROI) of government funds for heavy-duty combustion engine R&D - total savings of over $70B.

[Source: *Retrospective Benefit-Cost Evaluation of U.S. DOE Vehicle Advanced Combustion Engine R&D Investments: Impacts of a Cluster of Energy Technologies,* U.S. DOE, May 2010]

Historical Trend in Emissions from New Diesel Engines

"We have been working with DOE on clean engine technology for the past 20 years. In fact, many of the technologies used in our engines today were developed in partnership with the DOE, our national labs, universities and other research institutions." – Tim Solso, Cummins Chairman and CEO, June 2010.

Advanced Combustion Engine R&D

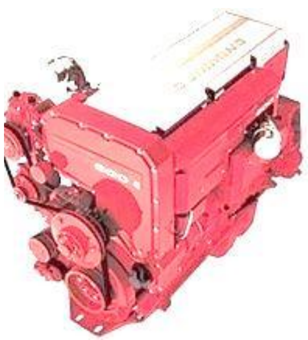
Strategic Goal: Reduce petroleum dependence by removing critical technical barriers to mass commercialization of high-efficiency, emissions-compliant internal combustion engine (ICE) powertrains in passenger and commercial vehicles

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, Bin 2	Tier 3/LEV III	EPA Standards	EPA Standards



*compared to 2009 model year baseline

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Advanced Combustion Engine R&D Program: Budget by Subprogram

Major Activities	FY 2013 Current	FY 2014 Enacted	FY 2015 Request
Advanced Combustion Engine R&D	**$55,004K**	**$49,970K**	**$49,000K**
Combustion and Emission Control	46,804	45,723	49,000
Solid State Energy Conversion	8,200	4,247	0

** FY 2013 full year CR inclusive of SBIR/STTR.

*** FY 2014 budget request inclusive of SBIR/STTR.

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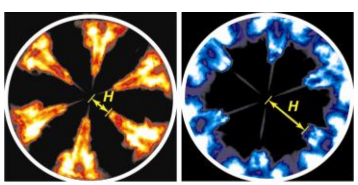
Advanced Combustion Engine R&D

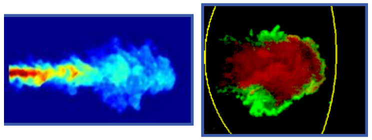
Strategic Goal: Remove critical technical barriers to mass commercialization of high-efficiency, emissions-compliant internal combustion engine (ICE) powertrains in passenger and commercial vehicles

- Advanced Combustion Engines Program
  - Combustion and Emission Control
    - Combustion R&D
    - Emission Control R&D
    - High Efficiency Engine Technologies
  - Solid State Energy Conversion



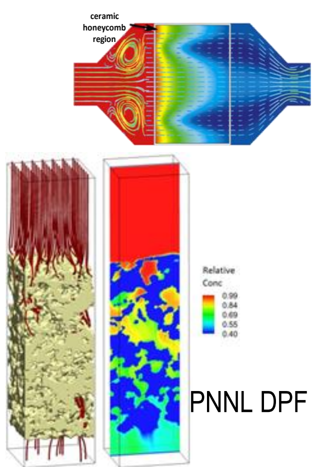
21% O_2
$\phi_{\Omega}(H) = 2.7$

9% O_2
$\phi_{\Omega}(H) = 2.9$

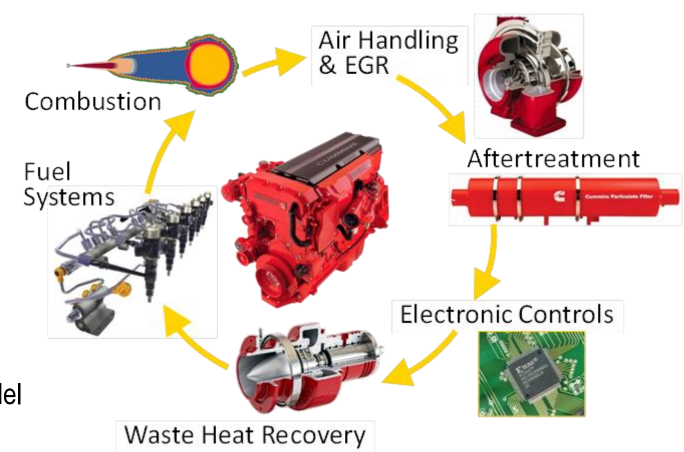


Fuel concentration

Soot (red) and OH (green)



PNNL DPF Model



BMW X6

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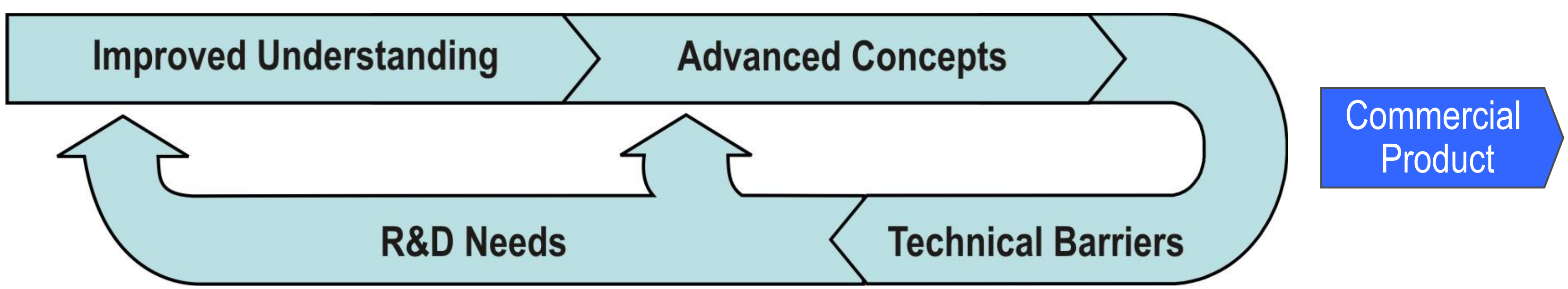
Overall R&D Approach

Fundamental R&D
- SNL – Advanced Combustion Strategies (LTC, lean-burn gasoline, advanced Diesel)
- LLNL – Chemical kinetics models (Combustion, fuels and emissions)
- LANL – CFD modeling of combustion
- ANL – X-ray fuel spray characterization
- PNNL – Catalyst Characterization (NOx and PM Control)
- Universities – Complementary research

Fundamental to Applied Bridging R&D
- ORNL – Experiments and simulation of engines and emission control systems (bench-scale to fully integrated systems)
- ANL – fuel injector design, LTC engine experiments

Competitively Awarded Cost-shared Industry R&D
- Automotive and engine companies,– engine systems
- Suppliers – enabling technologies (sensors, ignition, VVA, WHR)

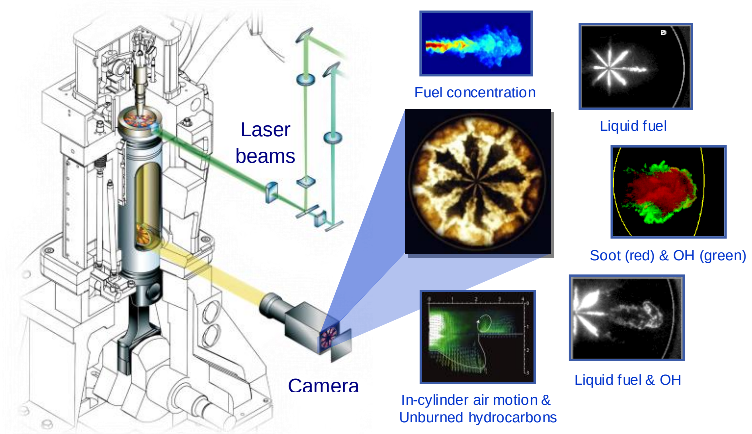


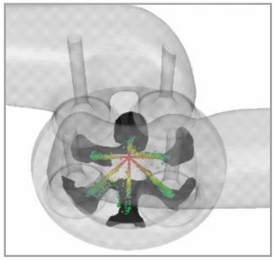
Combustion and Emission Control R&D

Combustion and Emission Control

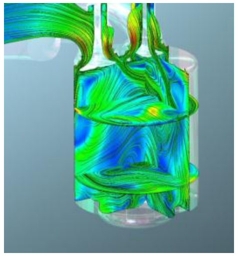
- **Combustion Research**
- Emission Control and Aftertreatment
- High Efficiency Engine Technologies

- Explore low-temperature combustion strategies to achieve higher engine efficiencies with near-zero emissions of NOx and PM.
- Develop greater understanding of engine combustion and in-cylinder emissions formation processes.
- Develop science-based, truly predictive simulation tools for engine design



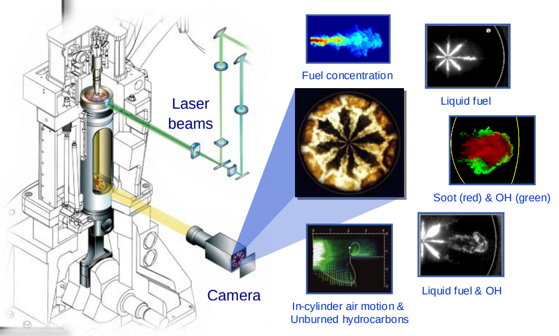


Engine Simulation



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.***

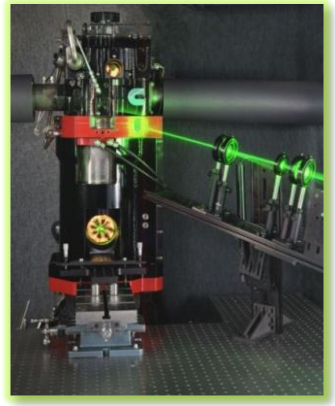


- Cross cuts light-duty and heavy-duty engine R&D
- University research* integrated with MOU

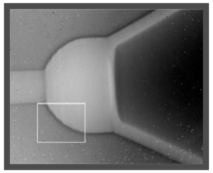
*Funded under the NSF/DOE Partnership on Advanced Combustion Engines

Research Tools Bridge Fundamentals to Application

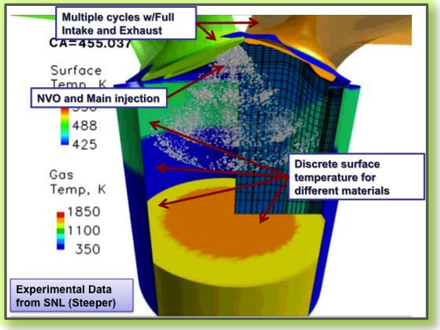
- Close coupled modeling and experiments
  - Advanced diagnostics including optical, laser, x-ray, and neutron based techniques
  - Multi-dimensional computational models and combustion simulators
  - Fuel kinetics
  - Multi- and single-cylinder engines



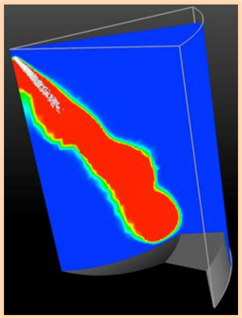
Optical Engine



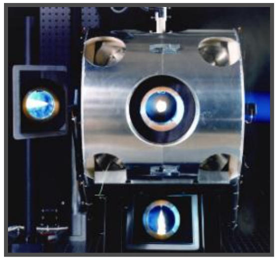
Nozzle Sac X-Ray Image



Engine Simulation

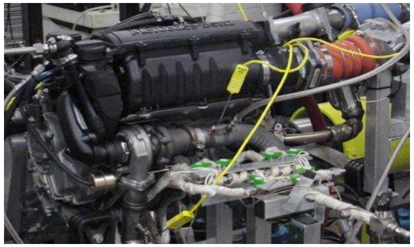


Chemical kinetic solver interfaced to CFD code



LTC Simulator

HCCI & Lean-burn Gasoline



Multi-Cylinder Diesel

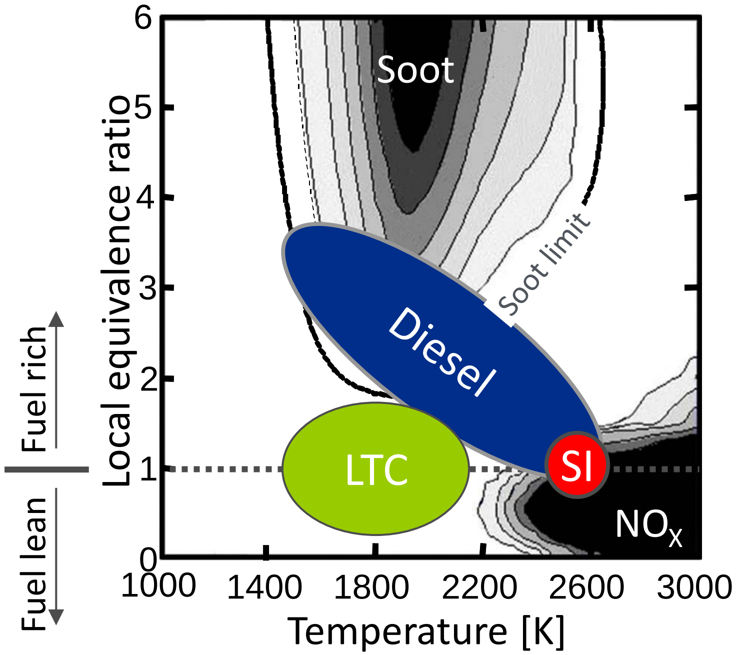
- Close collaboration between industry, national labs and universities
- Cross-cuts light- and heavy-duty engine R&D

Leading to engine CFD modeling tools widely used in industry

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

Diesel and HCCI Combustion

Conventional Diesel Combustion

(movie of hot, glowing soot)

Homogeneous Charge Compression Ignition

(movie of combustion chemiluminescence)

- fuel injector (center) sprays 8 jets of liquid fuel into combustion chamber
- compression-heating ignites fuel
- soot forms in fuel-rich jets, and glows red/orange/yellow
- some soot escapes combustion ⇒ soot emissions
- high-temperature combustion = high NOx
- high efficiency

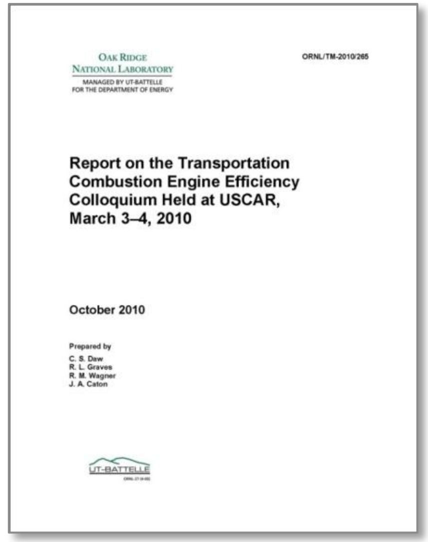
- fuel is vaporized and premixed with air prior to compression
- compression-heating ignites fuel
- mixtures are fuel-lean so no soot forms, but combustion reactions emit light (blue)
- no soot emissions
- low-temperature combustion = low NOx
- high efficiency

Workshops to Identify R&D Needs

Combustion Engine Efficiency Colloquium, USCAR Detroit, MI, March 3 – 4, 2010

Findings

- Achievable peak efficiencies > 60%, "affordable" engines may be lower.
- Possible 2X improvement in fuel efficiency for LD vehicles.



Oak Ridge National Laboratory
Managed by UT-Battelle for the Department of Energy

ORNL/TM-2010/265

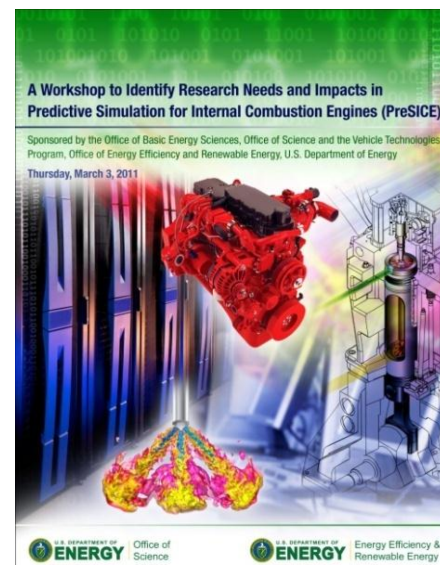
Report on the Transportation Combustion Engine Efficiency Colloquium Held at USCAR, March 3–4, 2010

October 2010

Prepared by
C. S. Daw
R. L. Graves
R. M. Wagner
J. A. Caton

UT-BATTELLE

Workshop on Predictive Simulation of ICE (PreSICE), March 3, 2011



Highest Priority Industry Barriers For Advanced Engines (BES/VTO PreSICE workshop focus)

- Effect of stochastic nature of in-cylinder flow on engine combustion, performance and emissions
- Spray modeling and experimentation in dense spray and nozzle internal flow regions, including physics like cavitation and flash boiling.

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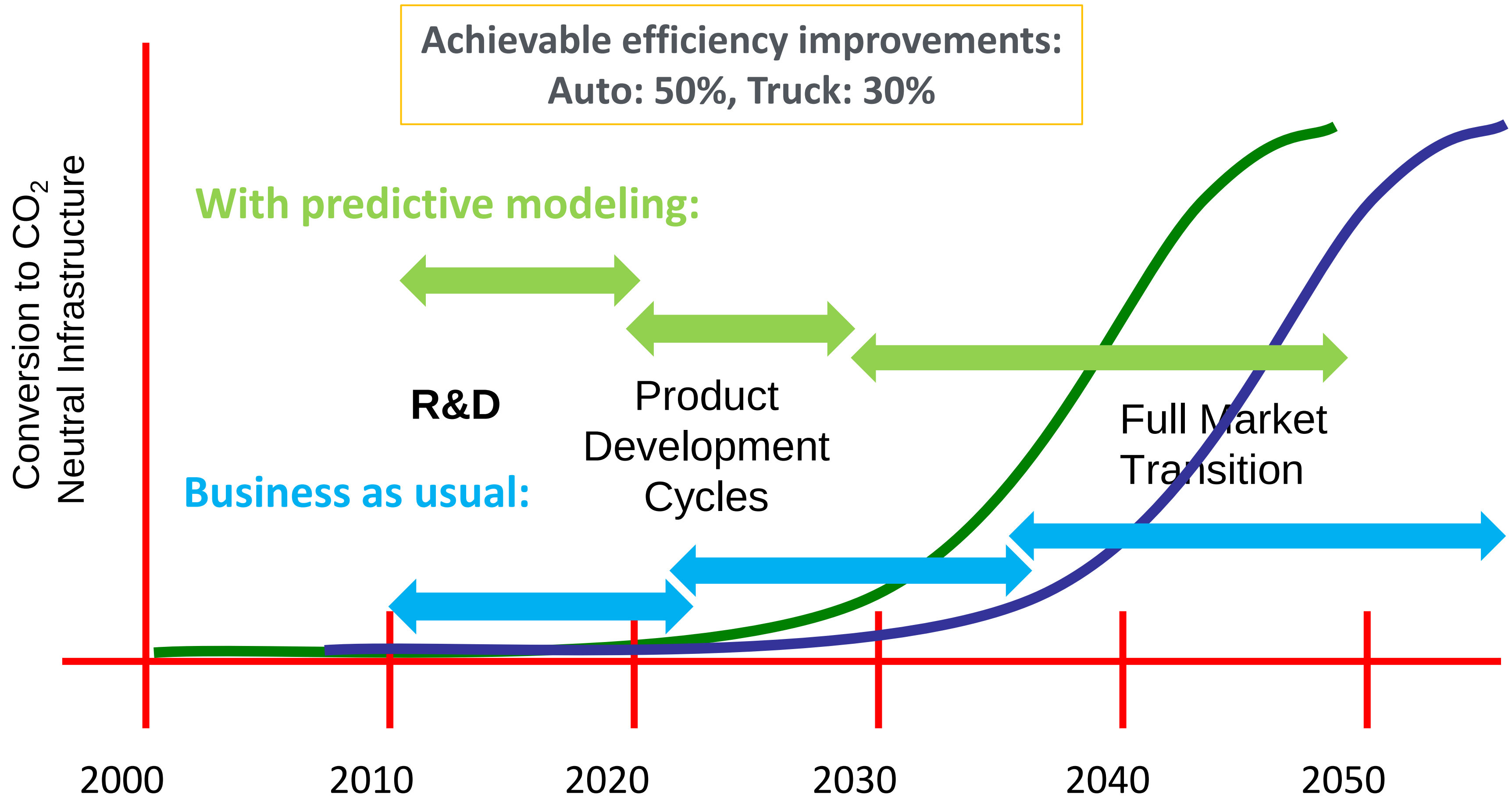
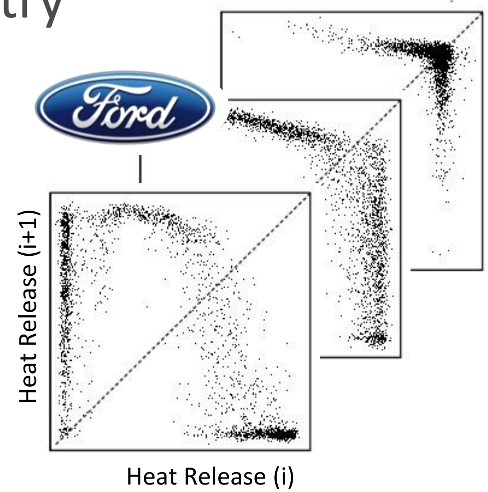
Product Development Must Be Accelerated To Meet Energy Goals

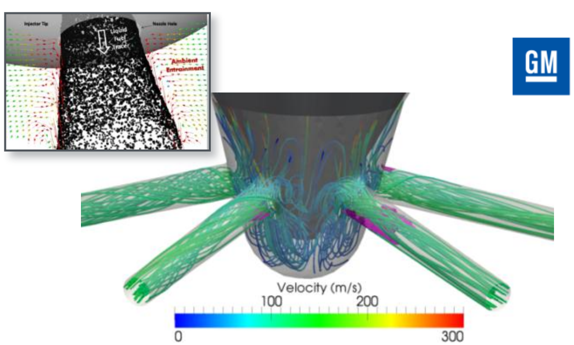


High Performance Computing (HPC) Could Accelerate Development of Advanced Combustion Engines at an Unprecedented Scale

- World-class HPC expertise and resources applied to address engineering challenges (technology barriers) once thought unsolvable
- Example ORNL projects in collaboration with industry
  - **Understanding stochastic and deterministic processes driving cyclic variability in highly dilute SI engines and their impacts on efficiency**
    - Major challenge is scaling serial problem (cycle-to-cycle variations) to parallel computation architecture
  - **Understanding and optimizing fuel injector design for improved efficiency and reduced emissions**
    - Computational framework for coupling models of internal injector flow and cavitation with in-cylinder spray and combustion



ORNL Participants: Dean Edwards, Sreekanth Pannala, Charles Finney, Miroslav Stoyanov, Stuart Daw, Wael Elwasif, Clayton Webster, Robert Wagner

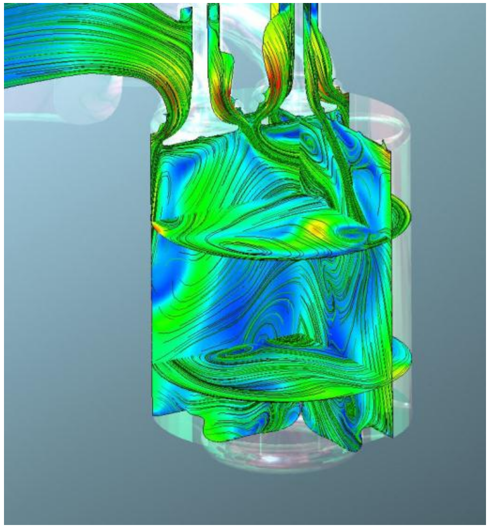


GM RESEARCH & DEVELOPMENT

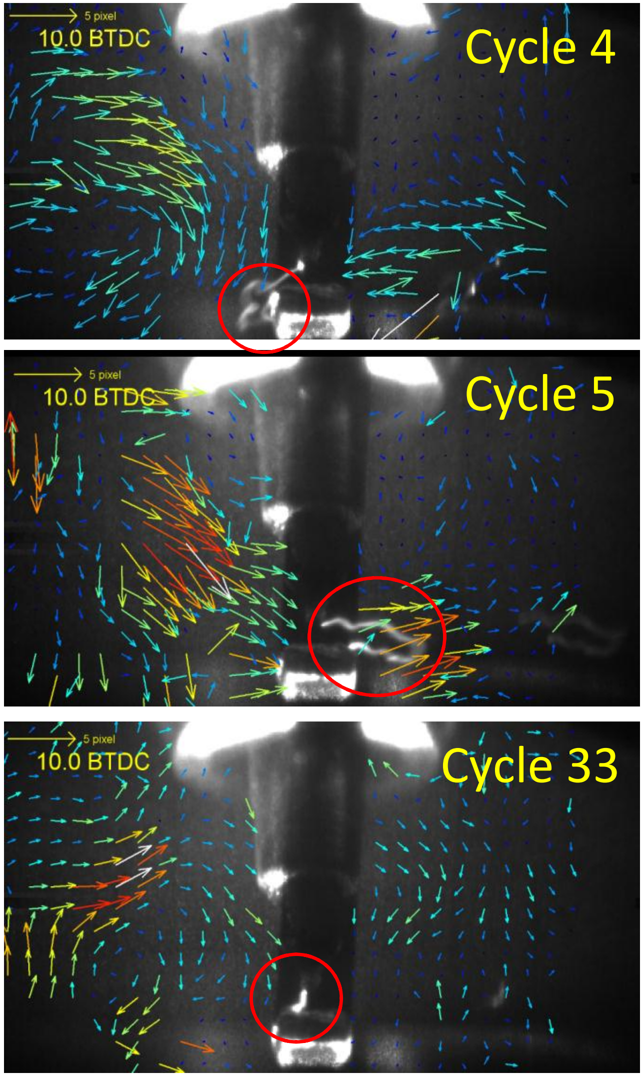
Reference: *Neroorkar, Mitcham, Plazas, Grover, Schmidt, "Simulations and Analysis of Fuel Flow in an Injector Including Transient Needle Effects"*, ILASS-Americas 24th Annual Conference on Liquid Atomization and Spray Systems, San Antonio, TX, May 2012.

Stochastic Processes Priority Research Direction

- Development and validation of models to enable simulation of stochastic processes
  - Sub-grid scale models for unresolved processes
  - Reduced chemical kinetic mechanisms
  - New theoretical frameworks / efficient numerical approaches



Complex in-cylinder flow during intake stroke in diesel engine



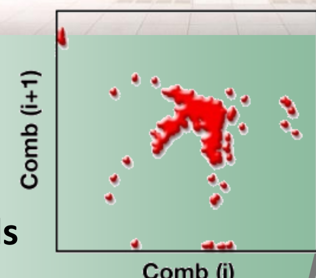
General Motors Research

High Performance Computing Could Accelerate Engine Design and Optimization

Basic Science

DOE Office of Science

Fundamental expertise in combustion instability mechanisms and leadership in high performance computing including the world's fastest supercomputer



TITAN Use Awards

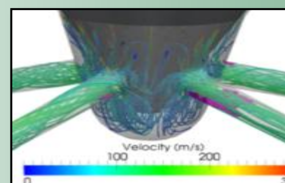
- ALCC 32.5M hrs
- OLCF 17M hrs

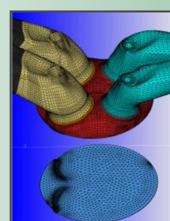
Applied R&D

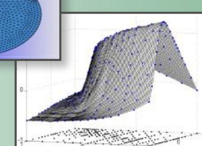
DOE/EERE/VTO

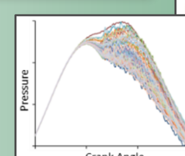
Accelerating high pressure fuel injector design optimization and providing new insights into combustion instability phenomena

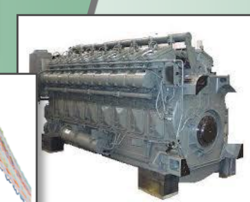
Injector image *(source GM)*











OAK RIDGE National Laboratory

Manufacturing/ Commercialization

GM/Ford/GE

Research in close collaboration with automobile and engine manufacturers will directly impact the development of the next generation of high efficiency engines

GM RESEARCH & DEVELOPMENT

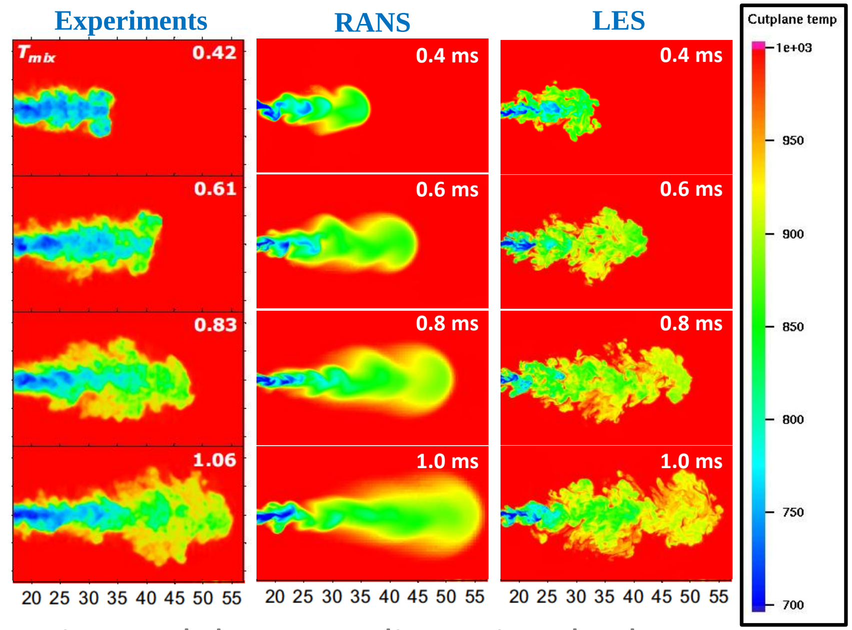
Ford

GE Global Research

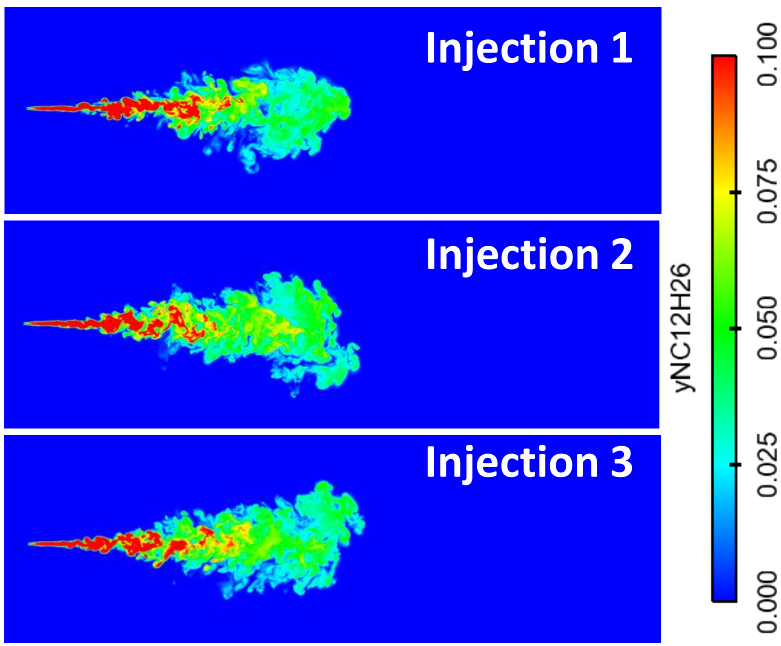
Making use of unique world class resources to address real-world challenges

Cyclic Variability with Large Eddy Simulations

Project Impact
- High-fidelity Large Eddy Simulations (LES) can capture flow structures which lower fidelity (RANS) approaches cannot predict
- LES can predict cycle-to-cycle variations during each injection event. Further research to predict engine misfire!



Experimental data : Sandia National Laboratory



Computational Details
- High-temporal and spatial resolutions results in less sub-grid scale modeling with the LES
- Each cycle: 1 month on 256 cores; need at least 8-10 cycles
- Simulations performed at Fusion cluster at Argonne together with **Cummins Engine Company** and **Convergent Science Inc.**

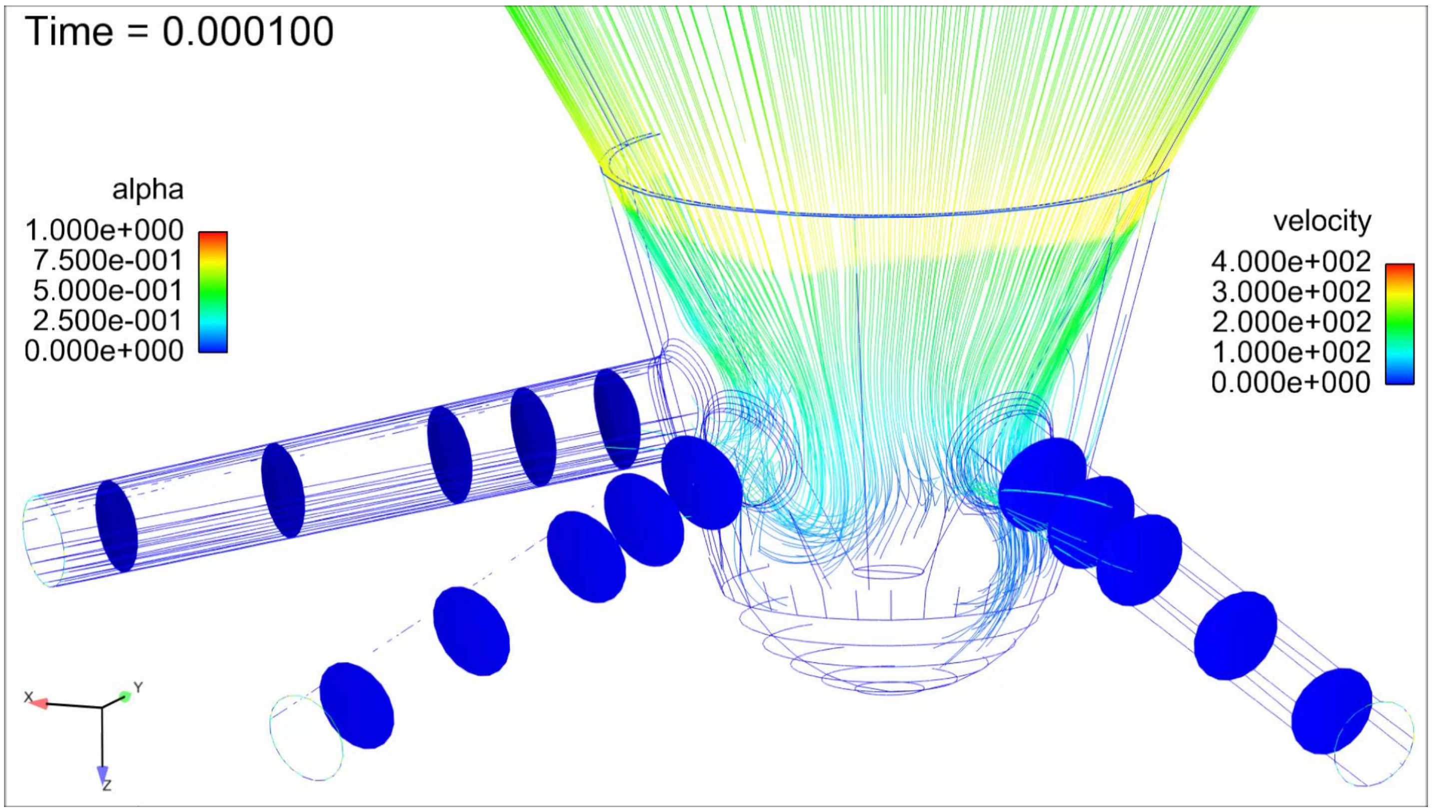
Multi-hole Nozzle Two-phase Flow Simulations

Project Impact

- **Plume-to-plume variations** in Multi-hole nozzles can now be captured
- Influence of **needle transients on fuel spray development** can now be predicted!

Computational Details

- High-temporal and spatial resolutions resulting in **grid-convergent solutions**
- Each Simulation: 1 month on 64 cores; Need 20+ simulations

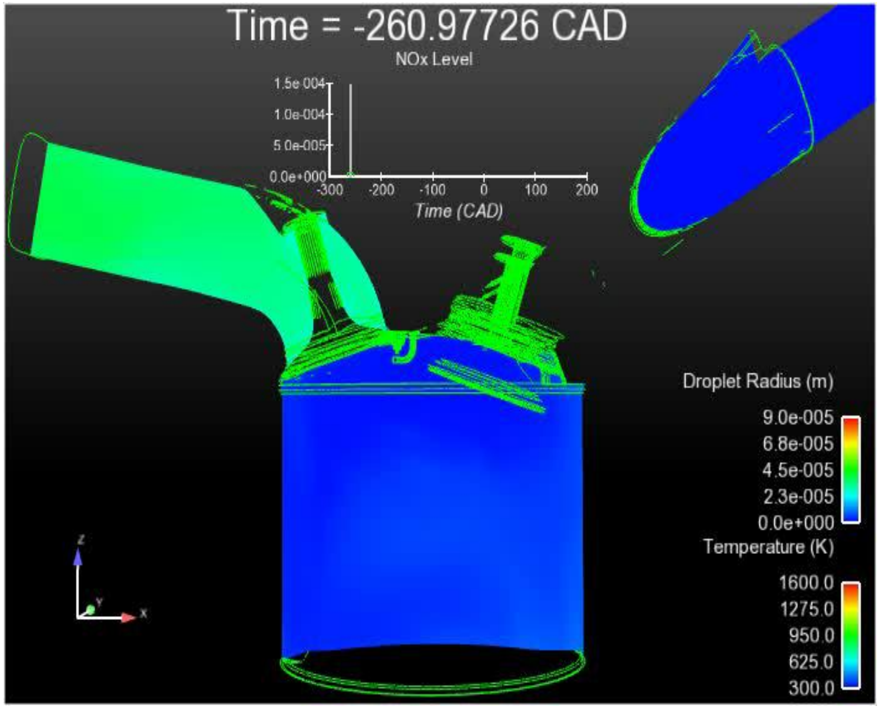


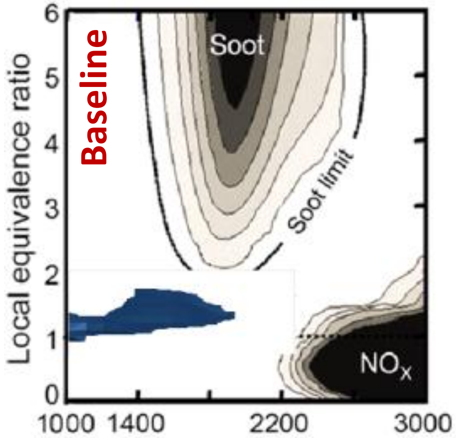
Production GM multi-hole diesel injector simulation at Argonne

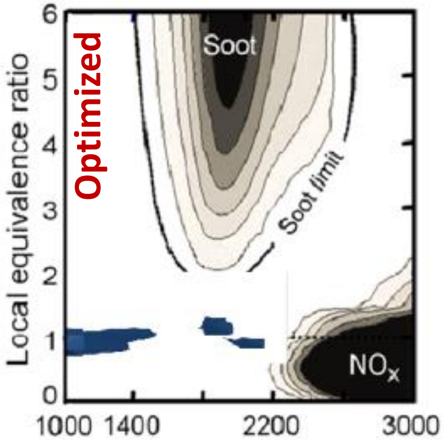
Fuel Economy Optimization with High-Fidelity Simulations

Project Impact

- Specific fuel consumption was **optimized using genetic algorithm** based tools and **CONVERGE** CFD code for **Chrysler LLC**.
- Predicted optimized speed-load conditions corroborated very well with experimental measurements on a Chrysler Dual-fuel combustion engine at Argonne
- The **optimized conditions also showed considerably lower emissions** compared to the baseline







Computational Needs

- 400 engine simulations performed to achieve optimized fuel economy and emissions
- Each simulation generation takes about a week on 24 cores

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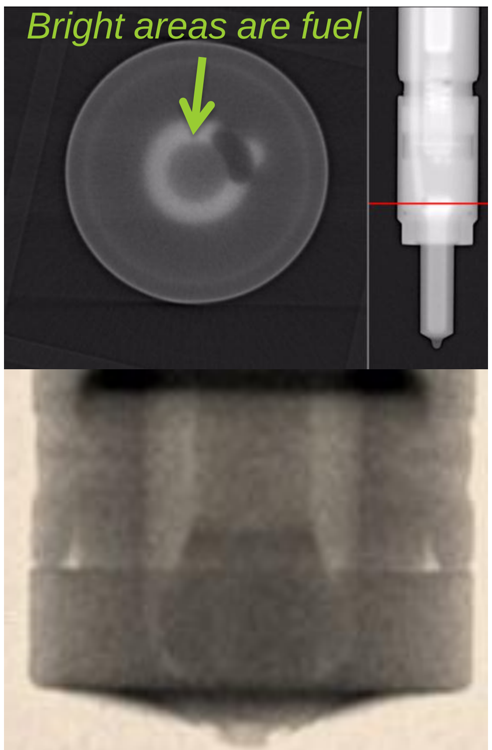
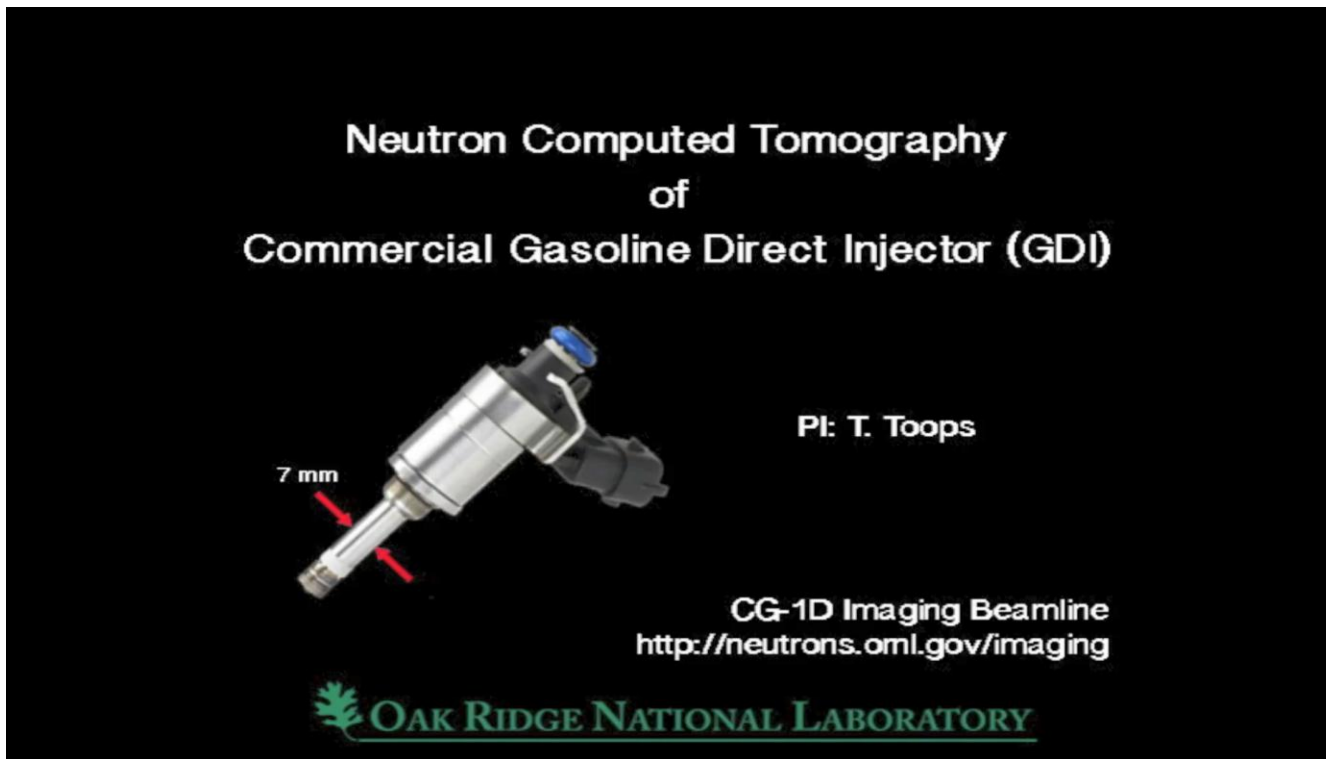
Intra-nozzle Fuel Injector Processes Being Studied Using Neutron Radiography

- Neutrons easily penetrate metal injectors with low interactions and offer opportunity to study critical internal fuel flow dynamics (e.g. cavitation)
- Neutrons readily diffracted/adsorbed by hydrogen containing hydrocarbons, like fuel
  - Complements X-ray and laser-based optical approaches being done in other DOE projects
- Demonstrated tomographic capability; moving towards dynamic image operation
  - 20 micro-second frames and 1 ms injections

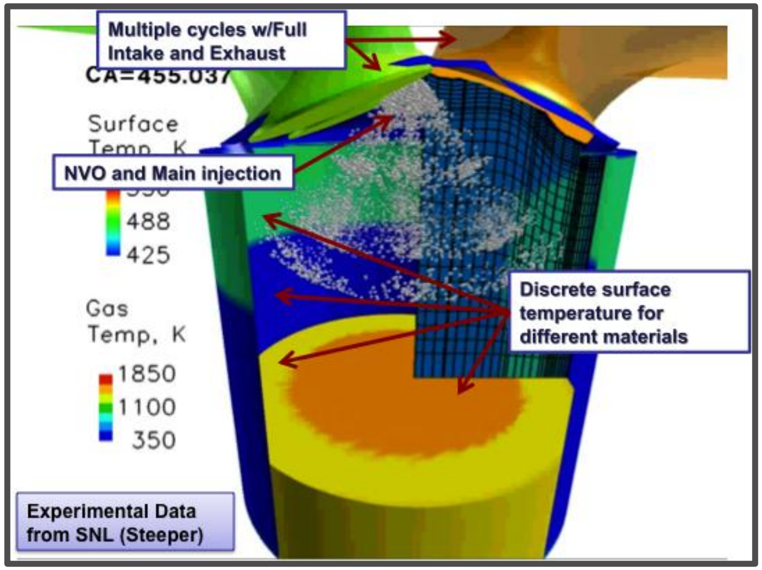


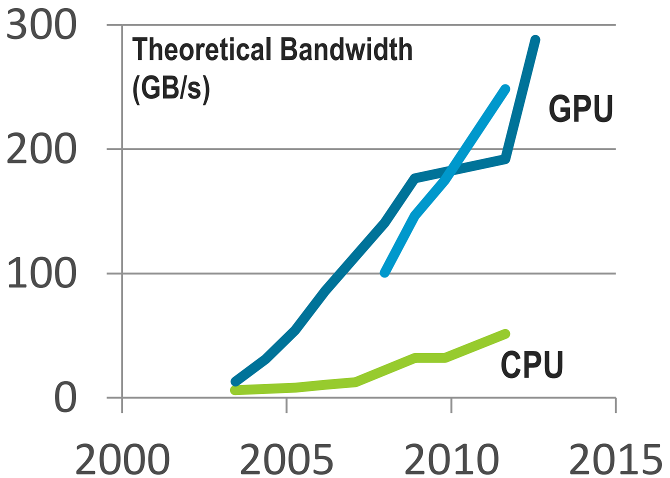


Numerical tools and High Performance Computing (HPC) enable more predictive CFD of Advanced Combustion Regimes (LLNL)

- ❑ Prediction of kinetically controlled combustion and emissions requires simulations with highly detailed chemistry
  - Enabled by multi-zone and adaptive preconditioning work at LLNL
  - HCCI simulations of gasoline surrogate (~1400 species) can now be run in less than 24 hours.
- ❑ HPC provides opportunity to examine experimental and modeling uncertainties systematically
  - Reduces the necessary "tuning" of models to experiments
  - Results in more predictive engine models
- ❑ Incorporating graphics processing unit (GPU) algorithms into CFD codes ensures continued improvement in modeling capability as computing platforms move towards massively parallel architectures.

HCCI engine simulation





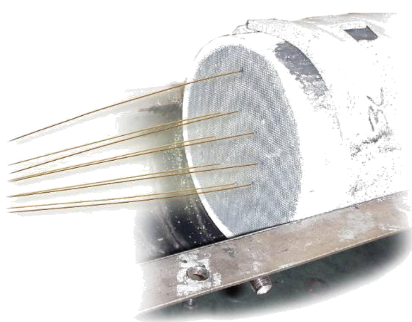
from NVIDIA's *CUDA C Programming Guide v.5.5*

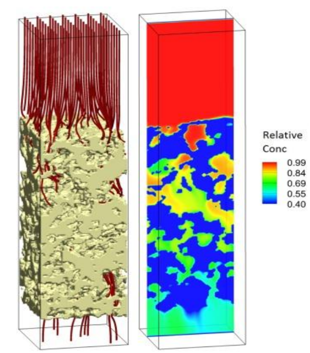
Combustion and Emission Control R&D

Combustion and Emission Control

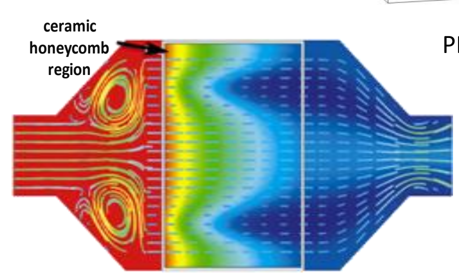
- Combustion Research
- Emission Control and Aftertreatment
- High Efficiency Engine Technologies

- Develop more efficient approaches for reducing NOx, and oxidizing PM, HC and CO in low temperature exhaust (150^{O}C)
- Reduce energy penalty and cost of emission control systems

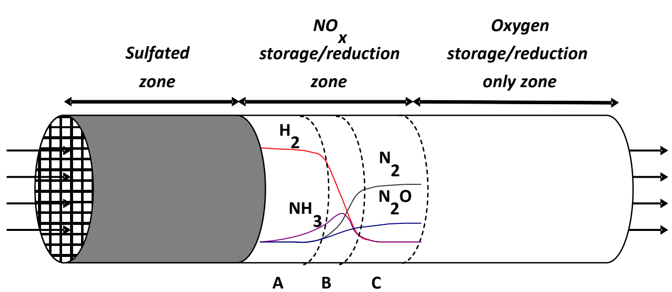




PNNL DPF Model

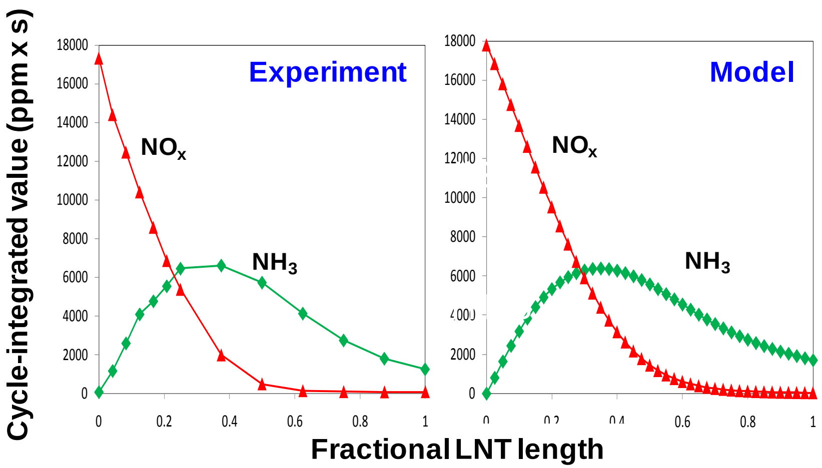


Flow and Temperature Computations during Cold-start of a Catalytic Converter



CLEERS Facilitates Technical Exchange Across Universities, National Labs, and Industry

- Cross-Cut Lean Exhaust Emissions Reduction Simulations (CLEERS) enables technical cross-talk on emission control technology via web meetings, data and model sharing, workshops, and the website www.cleers.org
- More than 100 representatives from industry, national labs, and universities attended the recent workshop in Dearborn, MI



Global model accurately predicts NH_3 formation inside LNT catalyst during regeneration

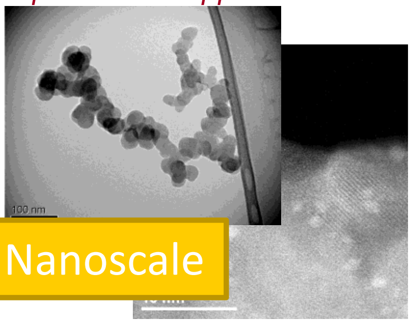
BASF
Bosch
Caterpillar Inc.
Chalmers University
Cummins Inc.
Delphi
Detroit Diesel Corporation
Eaton Corporation
Ford Motor Company
Gamma Technologies
General Motors*
Hilite
John Deere
Johnson Matthey
Mack Powertrain
MECA
Michigan Technological University
Navistar
Northwestern University
Oak Ridge National Laboratory*
Pacific Northwest National Laboratory*
Sandia National Laboratories
Sud-Chemie
Tenneco Inc.
Umicore
University of Michigan
University of Wisconsin
U.S. Department of Energy
U.S. Environmental Protection Agency
Volvo
Organizers

CLEERS

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

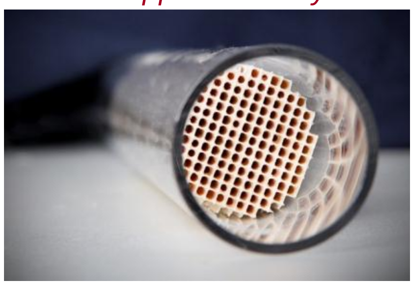
EERE VTO Catalysis Research for Vehicles Spans from Nanoscale to Full Scale

TEM images of PM and PGM dispersed on support



Nanoscale

Monolith supported catalyst core



Engine-catalyst system

Full Scale

Research Areas

Surface Chemistry
Defining surface moieties and intermediates with DRIFTS and other tools

PGM Characterization
Defining Platinum Group Metal (PGM) roles and understanding sintering processes

Poison Effects
Understanding effect of fuel- and oil-borne poisons/fouling agents on aging processes

Reaction Mechanisms
Characterizing reaction processes and measuring kinetics

Characterizing Formulation-Specific Chemistry
Understanding role of components of complex heterogeneous catalyst formulation

Performance and Selectivity
Measuring formulation affect on performance and selectivity (including differentiating regulated vs. unregulated products)

Controlling Unique Advanced Combustion Emissions
Studying combination of advanced catalysts with advanced combustion to achieve overall gains in fuel economy and cost-effective emission compliance

Minimizing Fuel Penalty during Active Regeneration
On-engine studies to minimize fuel use and optimize emission control

Characterizing Combustion-Specific PM and MSATs
Defining morphology, size distribution, and chemical composition of Particulate Matter (PM) and Mobile Source Air Toxics (MSATs)

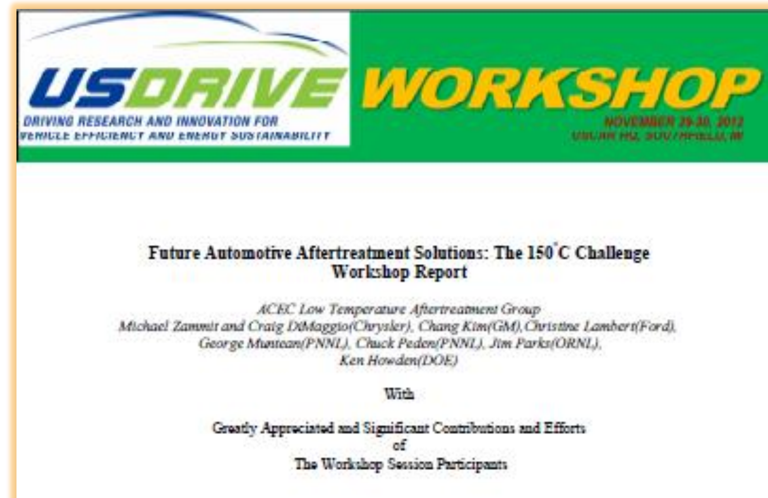
Particulate Filter-Based Control of PM
Studying oxidation kinetics, thermal issues, and fuel penalty for particulate filters

Industry Benefits

- Understanding Catalyst Fundamentals
- Predicting Degradation and Defining Mitigation Strategies
- Developing and Validating Models for Product Design, Controls, and OBD Optimization
- Achieving Cost-Effective Emissions Compliance while Maximizing Fuel Efficiency

Workshop to Identify R&D Needs

U.S.DRIVE workshop conducted to develop a roadmap to address "The 150°C Challenge" related to future automotive emission control in highly efficient engines with low exhaust heat energy and new gas chemistries.


USDRIVE WORKSHOP

DRIVING RESEARCH AND INNOVATION FOR VEHICLE EFFICIENCY AND ENERGY SUSTAINABILITY

NOVEMBER 29-30, 2012

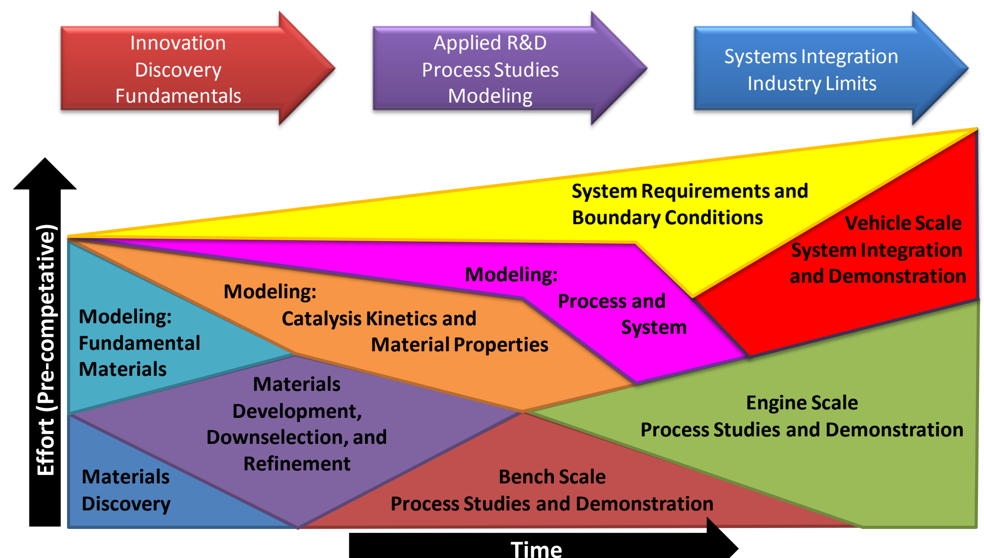
USCAR HQ, SOUTHFIELD, MI

Future Automotive Aftertreatment Solutions: The 150°C Challenge
Workshop Report

ACEC Low Temperature Aftertreatment Group
Michael Zammit and Craig DiMaggio(Chrysler), Chang Kim(GM), Christine Lambert(Ford), George Muntean(PNNL), Chuck Peden(PNNL), Jim Parks(ORNL), Ken Howden(DOE)

With

Greatly Appreciated and Significant Contributions and Efforts
of
The Workshop Session Participants

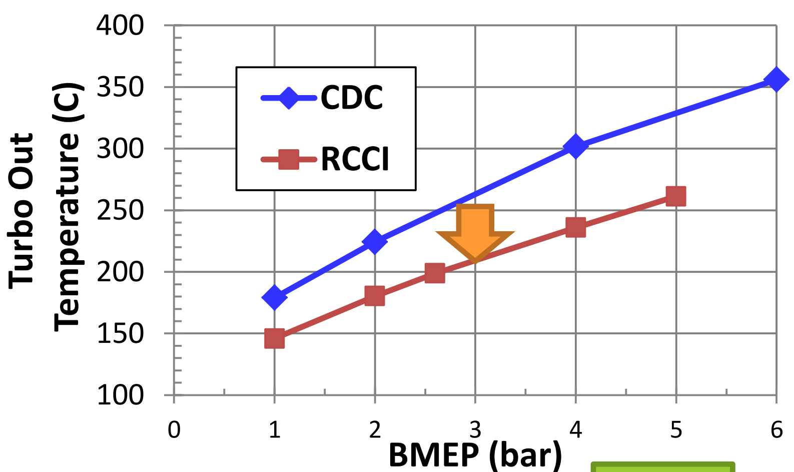


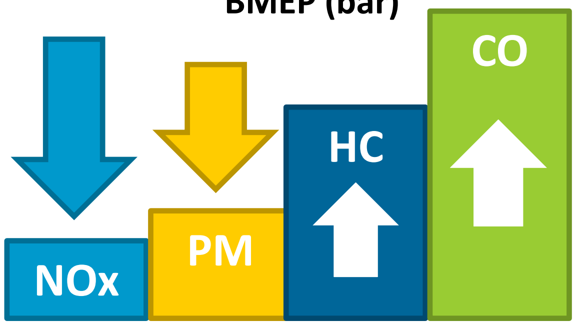
Scope/Resource Timeline (Technical Basis)

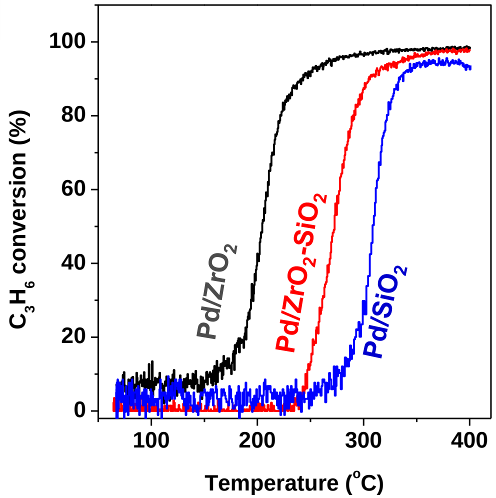
Low Temperature Emission Control Improvements Enabling Commercialization of Advanced Low Temperature Combustion (LTC)

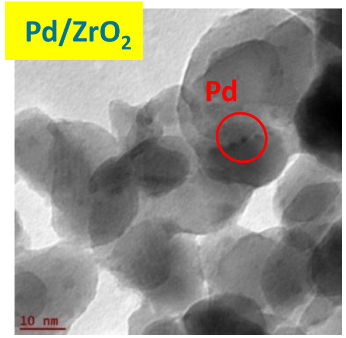
- ***Advanced combustion techniques offer higher fuel efficiency but emission control challenges exist***

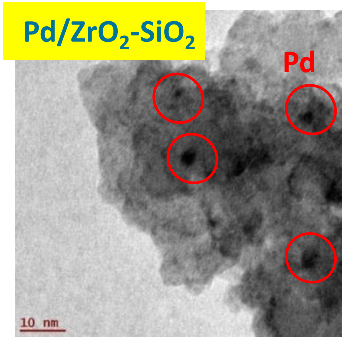
LTC gives lower exhaust temperatures and higher HC and CO emissions relative to conventional diesel combustion (CDC)









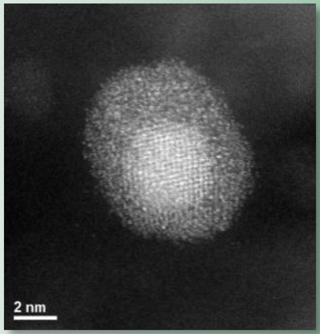


Catalysts with improved low temperature oxidation performance are being developed and studied to enable commercial viability

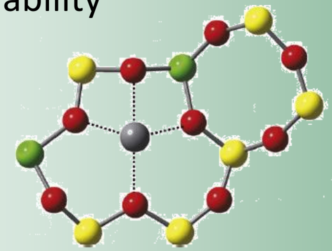
Low Temperature Catalysis Research Addresses New Challenges of Advanced Engines

Basic Science

DOE Office of Science

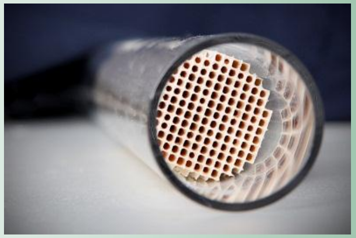


New materials showing excellent low temperature performance and durability

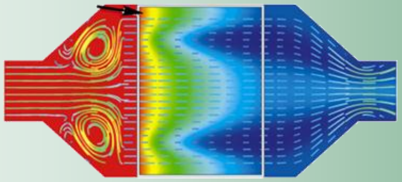


Applied R&D

DOE/EERE/VTO



Materials being evaluated under real-world conditions to understand potential with high efficiency combustion strategies



Manufacturing/ Commercialization

Industry

Supporting automobile and truck manufacturers in the development and execution of a path forward to address this critical enabler for high efficiency engines

Transitioning catalyst material breakthroughs to overcome critical barriers to high efficiency transportation

Low Temperature Emission Control Improvements Enabling Commercialization of Advanced Combustion

Catalyst invented in Basic Energy Sciences (BES) program leading to new discoveries in VTO program that may enable low cost emission control for advanced

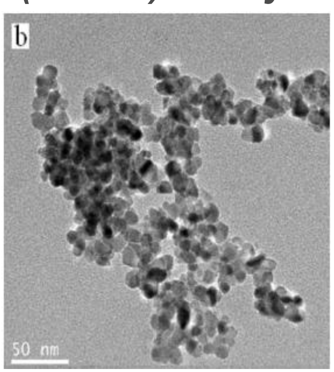
CuO_x-CoO_y-CeO_2 (CCC) catalyst developed in BES program contains no costly Platinum Group Metals


Applied Catalysis A: General 451 (2013) 282–288
Contents lists available at SciVerse ScienceDirect
Applied Catalysis A: General
journal homepage: www.elsevier.com/locate/apcata

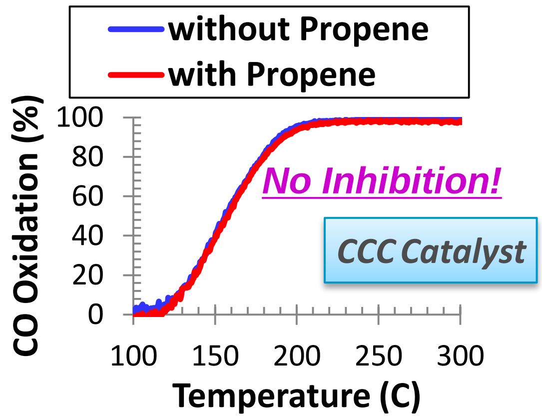
Influence of calcination temperature on the structure and catalytic performance of CuO_x-CoO_y-CeO_2 ternary mixed oxide for CO oxidation

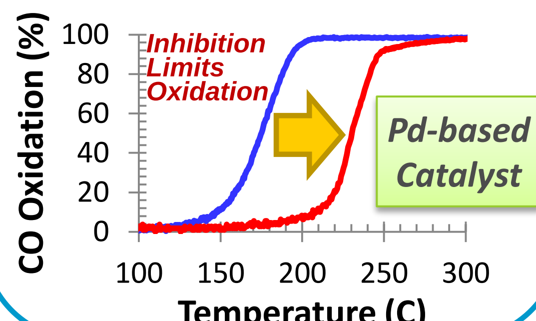
Zhi-Gang Liu[a,*], Song-Hai Chai[b], Andrew Binder[c], Yuan-Yuan Li[a], Lin-Tao Ji[a], Sheng Dai[b,c,**]
[a] School of Chemistry and Chemical Engineering, Hunan University, Changsha 410082, China
[b] Chemical Sciences Division, Oak Ridge National Laboratory, Oak Ridge, TN 37831, USA
[c] Department of Chemistry, University of Tennessee, Knoxville, TN 37996-1600, USA

CuO_x-CoO_y-CeO_2 ("CCC") Catalyst



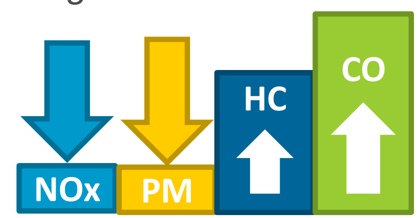
Unlike Pd-based catalysts, VTO studies show CCC's CO oxidation <u>not</u> inhibited by HCs (a unique finding)



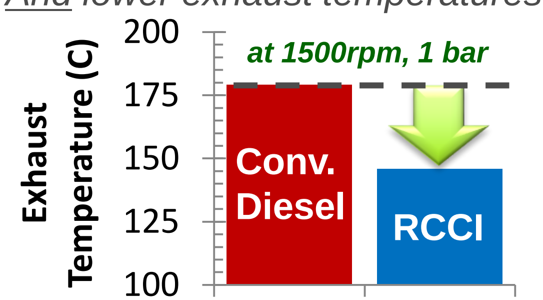


Low-cost catalyst may address higher CO and HC emissions and lower exhaust temperatures of LTC

More Fuel Efficient Low Temperature Combustion (LTC) gives higher CO & HCs**



*<u>And</u> lower exhaust temperatures**



**vs. Conventional Diesel Combustion*

DOE-NSF Engine R&D Grants

$12M over 3 years, equally shared by each agency - *Jointly funded by the DOE Vehicle Technologies Office of the Office of Energy Efficiency and Renewable Energy and the National Science Foundation Division of Chemical, Bioengineering, Environmental, and Transport Systems, Directorate of Engineering*

Combustion Research

- University of California, Berkeley - $1.65M
- Michigan State University - $1.30M
- Michigan Technological University - $0.65M
- University of New Hampshire - $0.60M
- The Pennsylvania State University - $0.60M
- University of Connecticut - $0.80M
- Stanford University - $1.2M
- Clemson University - $1.0M
- Yale University - $0.60M

Emission Control Research

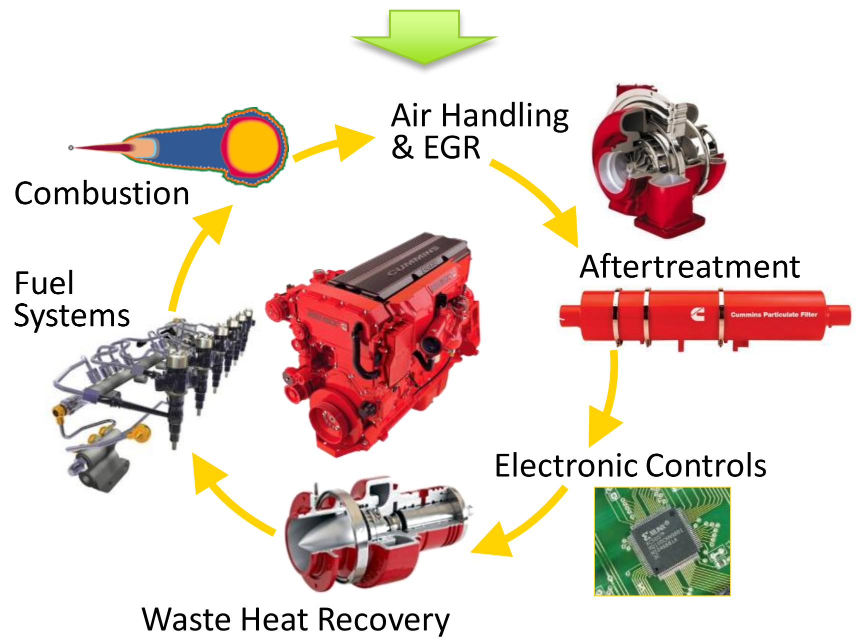
- University of Kentucky - $0.90M
- University of Houston - $1.20M
- Purdue University - $1.50M

Combustion and Emission Control R&D

Combustion and Emission Control

- Combustion Research
- Emission Control and Aftertreatment
- High Efficiency Engine Technologies

- Develop and demonstrate system level technologies to improve vehicle fuel economy through combination of combustion strategies, emission control, fuel injection, air handling, waste heat recovery, and control systems.



Integration of Component Technologies

SuperTruck Initiative

- **June 2009**: Solicitation … develop and demonstrate a 50% improvement in overall freight efficiency on a heavy-duty Class 8 tractor-trailer, measured in ton-miles per gallon; achieve 50% engine thermal efficiency at 65 mph and show a pathway to 55% engine efficiency.

UPI Photo

  - Both engine and vehicle system technologies included
  - Vehicle target for freight efficiency (ton-miles per gallon) improvement based on 65,000 pound GVW
  - 40% of the total improvement is required from engine technologies (50% thermal efficiency) and the remainder from vehicle system technologies.

Daimler Trucks North America VOLVO NAVISTAR®

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

SuperTruck - Develop and Demonstrate System Level Technologies to Improve Long Haul Truck Freight Efficiency

- **Heavy-Duty Engine for Class 8 Trucks**
  - 20% improvement in engine brake thermal efficiency (50% BTE)
  - Modeling and analysis for pathway to 55% brake thermal efficiency

Status of 50% engine efficiency:

- Cummins and Daimler have demonstrated over 50% brake thermal efficiency for *SuperTruck* laboratory engine
- Navistar and Volvo have demonstrated over 48% engine efficiency and are on track to meet goal.

Cummins Daimler Trucks North America VOLVO NAVISTAR®

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

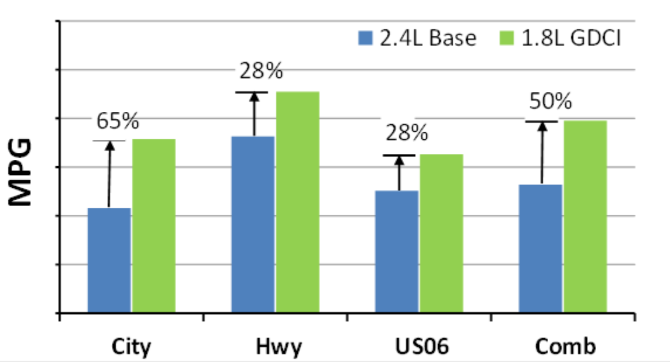
Advanced Technology Powertrain for Light-Duty (ATP-LD) Vehicles

Develop and Demonstrate System Level Technologies to Improve Vehicle Fuel Economy

- **Light-Duty Vehicles**
  - 25% fuel economy improvement for gasoline engines over baseline*
  - 40% fuel economy improvement for diesel engines over baseline*

*Baseline is state-of-the-art port-fuel injected 2009 gasoline engine

- **Status**
  - GM and Chrysler achieved 25% fuel economy improvement.
  - Ford and Bosch are on track to achieve 25% fuel economy improvement.
  - Cummins is on track to achieve 40% fuel economy improvement.
  - Delphi demonstrated potential for 50 percent increase in light-duty vehicle fuel economy

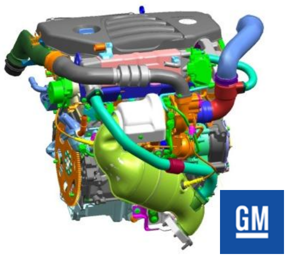


Simulated Vehicle Fuel Economy

- Simulations predict very good fuel economy on U.S. cycles with LTC engine

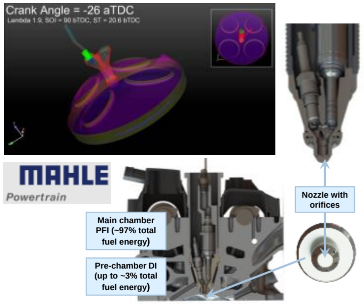
Enabling Technologies for Engine and Powertrain System

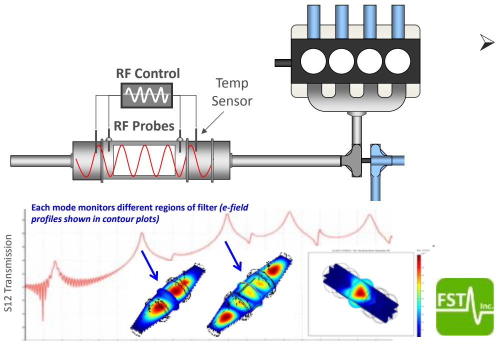
- General Motors LLC completed dynamometer testing and established fuel efficiency at 11 speed-load test points for a production turbocharged engine modified with 11:1 compression ratio, high energy (DCO^{TM}) ignition system, and dedicated low pressure loop (LPL) EGR system.



- Eaton Corporation developed a three stage Roots expander for testing in a heavy duty engine organic Rankine cycle (ORC) waste heat recovery system.

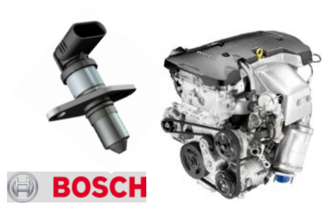
- MAHLE Powertrain LLC validated with pre-chamber simulation, multiple distributed ignition sites with turbulent jet injection for the next-generation ultra lean burn engines.





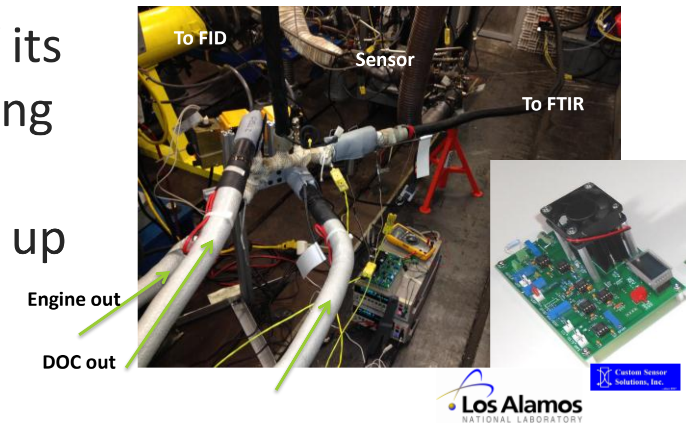
- Filter Sensing Technologies (FST) Inc. demonstrated on-vehicle, a particulate matter (PM) radio frequency sensor and electronic control system that reduces the cost and fuel penalty of diesel particulate filters (DPFs).

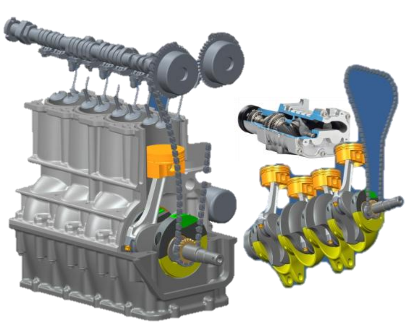
Enabling Technologies for Engine and Powertrain System



- Robert Bosch LLC developed an intake air oxygen (IAO2) sensor that directly and accurately measures the oxygen concentration in the intake manifold for accurate and robust EGR control for future engine concepts.

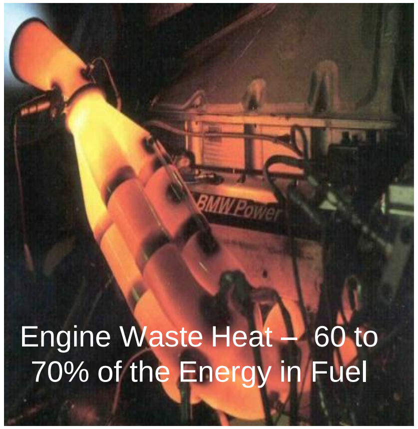
- LANL completed engine dynamometer testing of its robust Nitrogen Oxide/Ammonia Sensors providing quantitative correlation of NOx response to FTIR and HC response to FID THC content during start up and EGR on/off operations.





- Envera LLC completed the design of a variable compression ratio (VCR) engine incorporating variable valve actuation (VVA) and new supercharging technology.

Solid State Energy Conversion



Solid State Energy Conversion

- Develop and demonstrate advanced thermoelectric systems to improve vehicle fuel economy by converting energy in the engine exhaust directly to electricity

Competitively selected cost-shared 2nd Generation TEG projects:

- GenTherm
- General Motors
- GMZ Energy

Develop commercially viable advanced TEGs, improved technology for manufacturing TE devices, and assess feasibility and cost reduction for production volumes of 100,000 units per year

GENTHERM
BMW Group
TENNECO


Ford Explorer


BMW X5

GenTherm TEG Team

GM R&D
marlow industries, inc.
PURDUE UNIVERSITY
DANA
Eberspächer
NASA Jet Propulsion Laboratory California Institute of Technology
DELPHI
Molycorp
MICHIGAN STATE UNIVERSITY
OAK RIDGE National Laboratory
BROOKHAVEN NATIONAL LABORATORY
UNIVERSITY of WASHINGTON

General Motors TEG Team

GMZ ENERGY
BOSCH
HONDA The Power of Dreams
OAK RIDGE NATIONAL LABORATORY
MANAGED BY UT-BATTELLE FOR THE U.S. DEPARTMENT OF ENERGY

GMZ Energy TEG Team

Summary

- Light-duty engine performance improvements have been largely responsible for passenger vehicle fuel economy increases (in spite of vehicle weight, horsepower and size increases).
- Continued improvement in heavy-duty engine efficiency and emissions has been responsible for significant fuel savings in commercial vehicles.
- EERE Advanced Combustion Engine R&D, in collaboration with industry and academia, using unique Federal laboratory expertise and facilities, significantly contributes to dramatic increases in engine efficiency and performance, improvements in vehicle fuel economy, and reduction in emissions and transportation energy use.
- There is still significant potential for further efficiency (fuel economy) improvements using Low-Temperature Combustion and engine optimization:
  - Potential for 50% FE improvement for light-duty vehicles
  - Over 30% FE improvement for heavy-duty vehicles
- Combustion and emission control system modeling and simulation has reduced product development time and improved engine efficiency.

Contact Information

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Web site:

http://energy.gov/eere/vehicles/vehicle-technologies-office