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DOE Transportation Strategy: Improve Internal Combustion Engine Efficiency

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Advanced Combustion Engine Technologies
Vehicle Technologies Program
U.S. Department of Energy

Presented at the
DOE Quadrennial Technology Review
Knoxville, TN
May 4, 2011

DOE/QTR- ICE Team
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- Johney Green, *ORNL*

Outline

- Current state of the technology including costs and performance trends over time
- Headroom to improve the technology that could include a breakdown of the supply chain
- Future technical pathways, with description, potential impact, and potential cost
- DOE's current strategy in pathways and along the supply chain

Opportunity for Increased Internal Combustion Engine Efficiency

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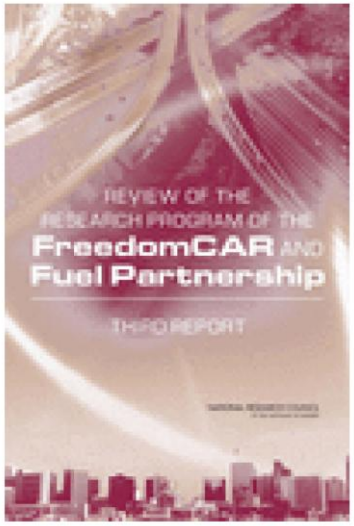
Increasing the efficiency of internal combustion engines (ICEs) is one of the most promising and cost-effective approaches to improving the fuel economy of the U.S. vehicle fleet.

- "…***The internal combustion engine will be the dominant prime mover for light-duty vehicles for many years, probably decades …"*** NRC Report[1]
- Advanced engines in conventional, hybrid electric vehicles (HEVs) and plug-in hybrid electric vehicles (PHEVs) will maintain significant market share for several decades
- Medium-duty and heavy-duty commercial vehicles account for a quarter of the fuel used (mostly diesel fuel)
  - **No obvious alternative to ICE for over-the road trucks in the foreseeable future**



[1] *Review of the Research Program of the FreedomCAR and Fuel Partnership: Third Report,* NRC, 2010

ICEs Can Use a Variety of High Energy Density Fuels

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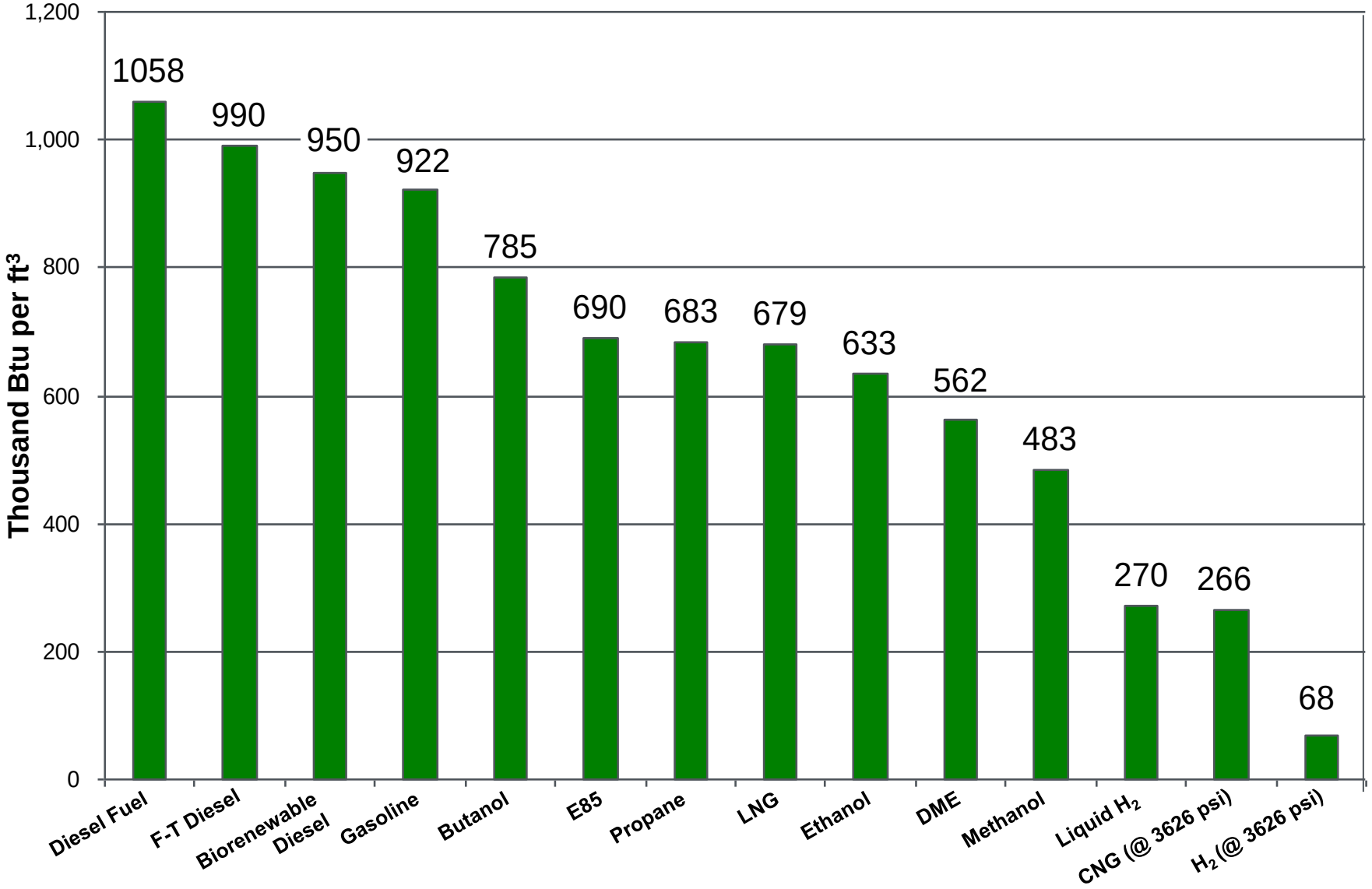

Passenger Vehicle Fuel Economy Trends

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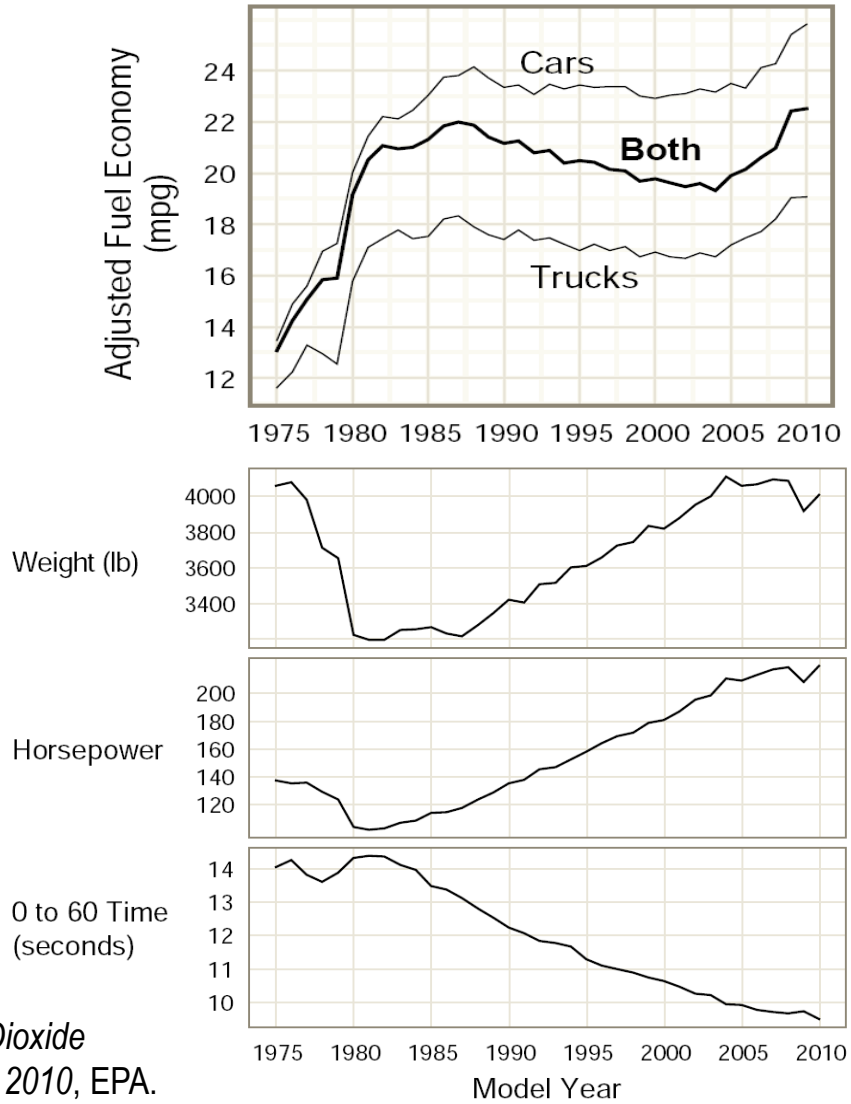
Significant fuel economy increases (***in spite of increases in vehicle weight, size and performance)*** can be largely attributed to increase in internal combustion engine performance



Source: *Light-Duty Automotive Technology, Carbon Dioxide Emissions, and Fuel Economy Trends: 1975 through 2010*, EPA.

Progress In Heavy-Duty Diesel Engine Efficiency and Emissions

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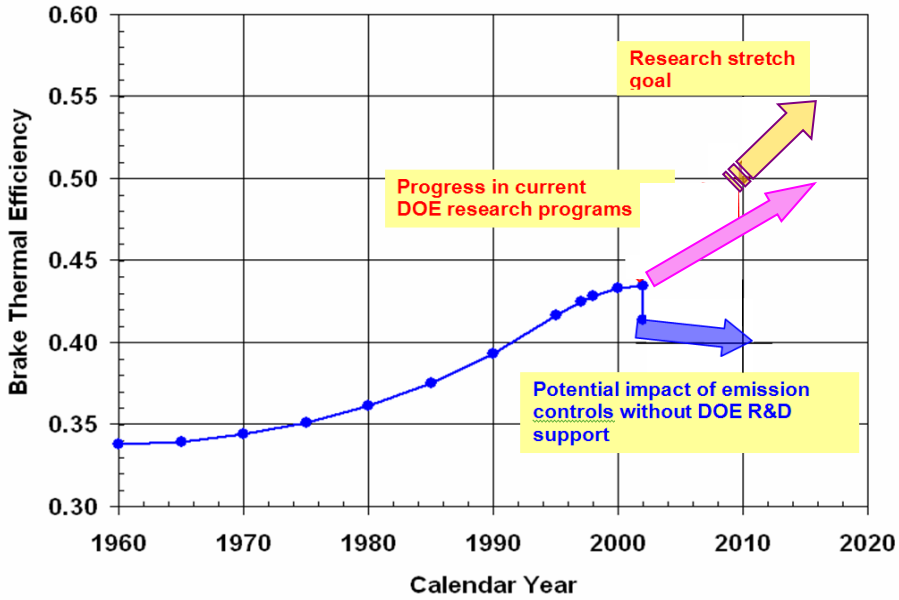
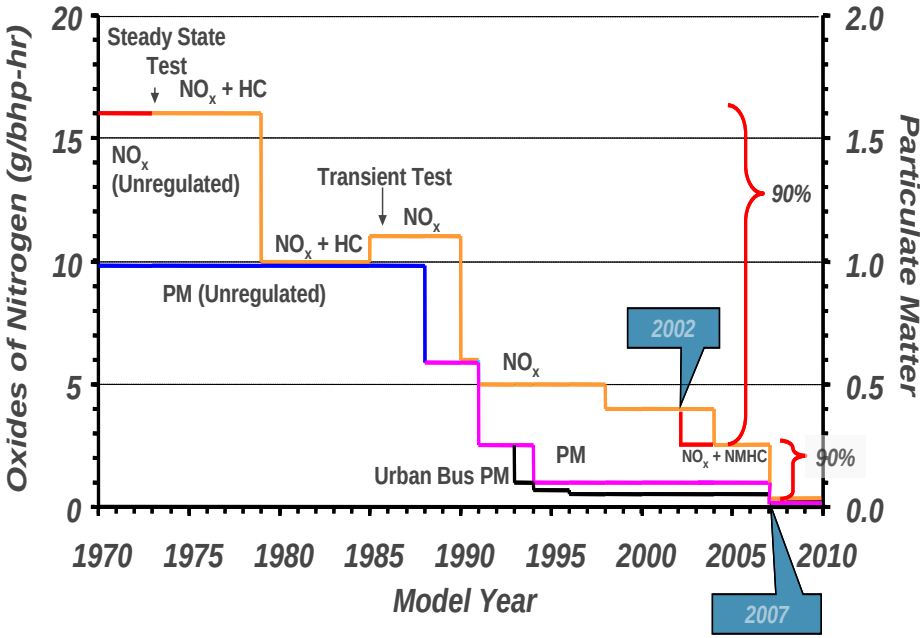


Historical progress in heavy-duty engine efficiency and the challenge of simultaneous emissions reduction, illustrate positive impact from DOE R&D support. (Adapted from DEER presentation, courtesy of Detroit Diesel Corporation).

Oil savings from heavy-duty vehicles alone (1997 – 2005) represent an over 35:1 return on investment (ROI) of government funds for heavy-duty combustion engine R&D.

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

Workshops to Identify R&D Needs

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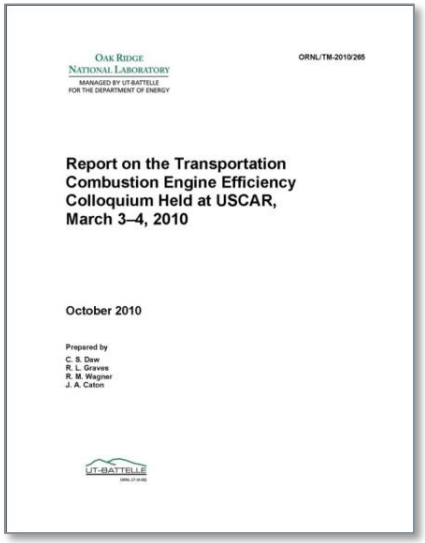
Combustion Engine Efficiency Colloquium, USCAR Detroit, MI, March 3 – 4, 2010

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
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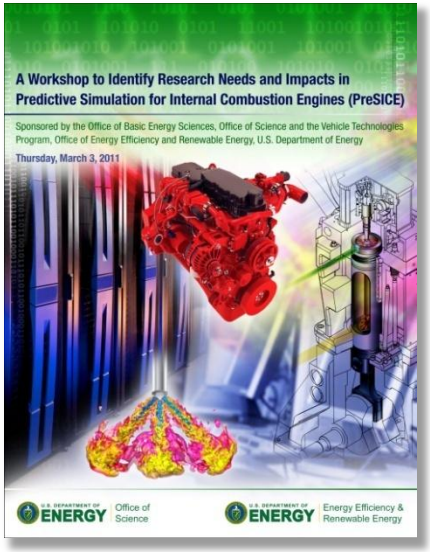
J. A. Caton

UT-BATTELLE

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



A Workshop to Identify Research Needs and Impacts in Predictive Simulation for Internal Combustion Engines (PreSICE)

Sponsored by the Office of Basic Energy Sciences, Office of Science and the Vehicle Technologies Program, Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy

Thursday, March 3, 2011

U.S. DEPARTMENT OF ENERGY Office of Science | U.S. DEPARTMENT OF ENERGY Energy Efficiency & Renewable Energy

Highest Priority Industry Barriers For Advanced Engines (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.

Science-Based Engine Design - An early example

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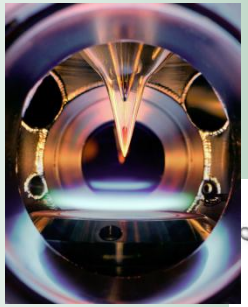
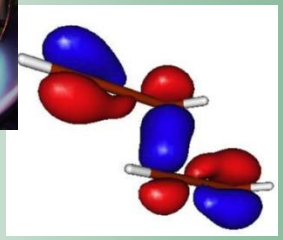
Basic Science

BES
Sustained support in 2 areas

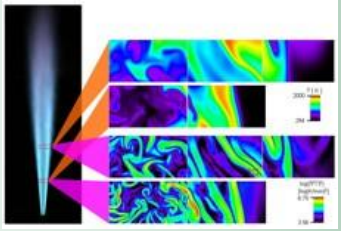
Development of predictive chemistry in model flames



Computational kinetics and experiments



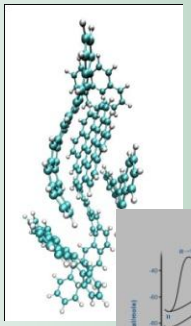
Advance laser diagnostics applied to model flames

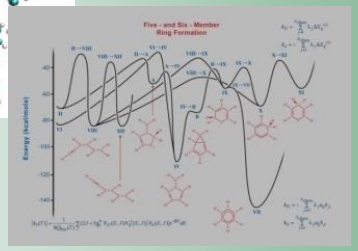


Laser-based chemical imaging

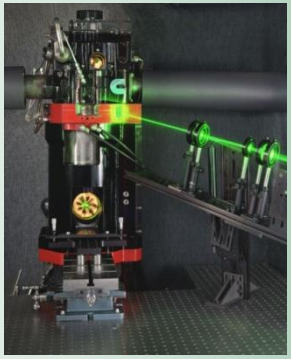
Applied R&D

BES → EERE
Applications of chemistry and diagnostics to engines





Predictive chemical models under realistic conditions

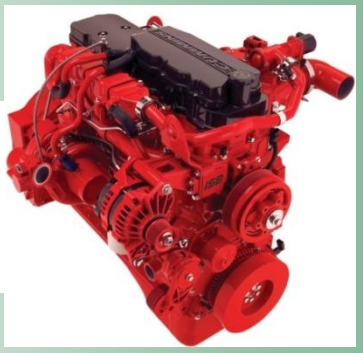


Laser diagnostics of diesel fuel sprays in engine cylinders

Manufacturing/ Commercialization

Cummins and Dodge

Cummins used simulation tools and improved understanding of diesel fuel sprays to design a new diesel engine with reduced development time and cost and improved fuel efficiency.



ISB 6.7 liter Cummins diesel engine first marketed in the 2007 Dodge Ram pickup truck; more than 100,000 sold/year

Advanced Combustion Engine R&D

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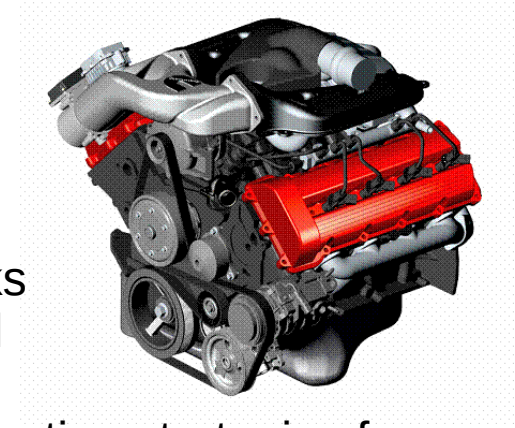
Strategic Goal: Reduce petroleum dependence by removing critical technical barriers to mass commercialization of high-efficiency, emissions-compliant internal combustion engine (ICE) powertrains in passenger and commercial vehicles



Primary Directions

- Improve ICE efficiency for cars, light- and heavy-duty trucks through advanced combustion and minimization of thermal and parasitic losses
- Develop aftertreatment technologies integrated with combustion strategies for emissions compliance and minimization of efficiency penalty
- Explore waste energy recovery with mechanical and advanced thermoelectrics devices
- Coordinate with fuels R&D to enable clean, high-efficiency engines using hydrocarbon-based (petroleum and non-petroleum) fuels and hydrogen

Performance Targets

	Light-Duty		Heavy-Duty	
	2010	2015	2015	2018
Engine brake thermal efficiency	45%		50%	55%
Powertrain cost	< $30/kW			
NOx & PM emissions	Tier 2, Bin5	Tier 2, Bin2	EPA Standards	EPA Standards
Fuel economy improvement		25 – 40%	20%	30%

Research Tools Bridge Fundamentals to Application and Support Model Development

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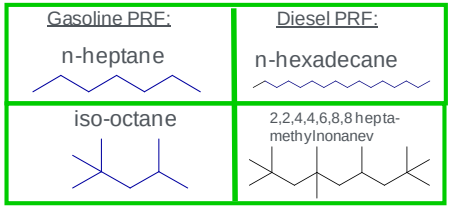
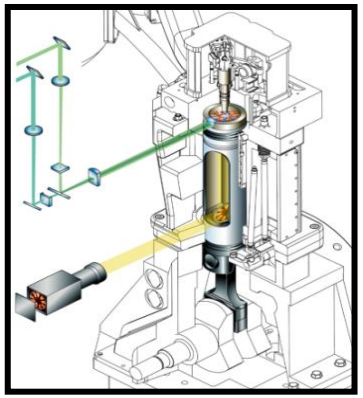
- Close coupled modeling and experiments
  - Advanced diagnostics including optical, laser, x-ray, and neutron based techniques
  - Combustion simulators
  - Multi-dimensional computational models
  - Fuel kinetics

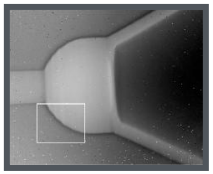


  - Multi- and single-cylinder engines

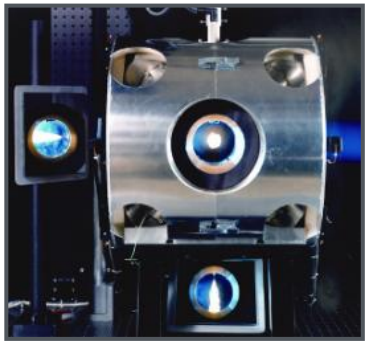


Optical Engines

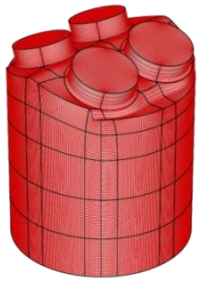
HCCI & Lean-burn Gasoline



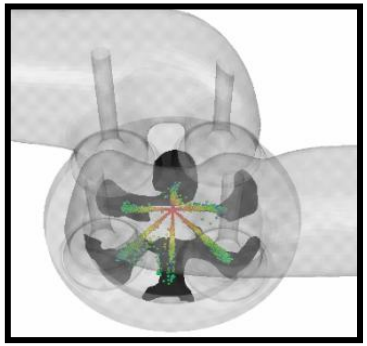
Nozzle Sac X-Ray Image



LTC Simulator



3-Million Cell LES Grid



Engine Simulation

- 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 Supports DOE/Industry High-efficiency, Clean Engine Goals

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- **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 (Wisconsin, Michigan, MIT, UC Berkeley, and Michigan State)

LTC in Heavy- and Light-Duty Engines (UW)

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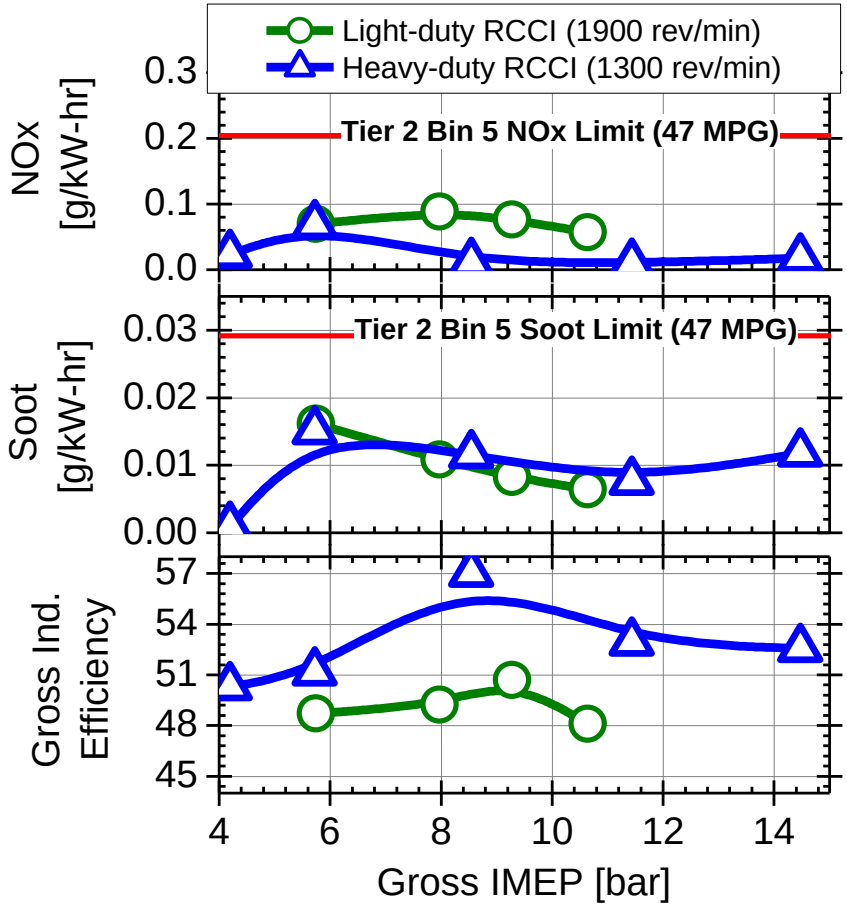
- Engine efficiency improvement could increase LD fuel economy by over 75 percent compared to current gasoline engine.
- Dual fueling (with gasoline and diesel fuel) has shown indicated efficiency between 50% and 59%.



CLEERS Working Group

Crosscut **L**ean **E**xhaust **E**missions **R**eduction **S**imulation

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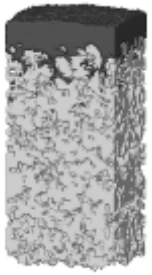
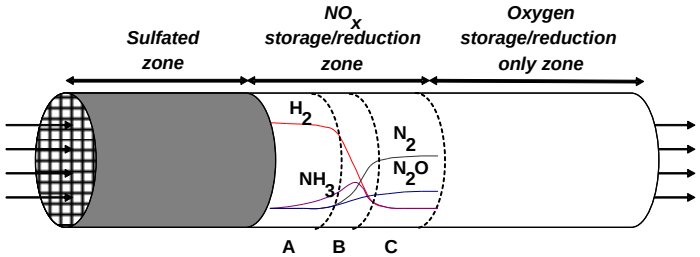
Supports DOE Research on Engine Emission Control:

- Promotes development of improved computational tools for simulating realistic full-system performance of lean-burn diesel/gasoline engines and associated emissions control systems
  - Emphasis on engine-aftertreatment system efficiency
  - Integration with advanced combustion processes
  - Identification of new catalyst materials to reduce need for precious metals (i.e., costs)
- Coordinated by subcommittee of industry, government, and academic representatives
  - Workshops and monthly focus groups discussions
  - Industry surveys provide recommendations for R&D directions
  - CLEERS website (www.cleers.org) includes data and forum for model and data exchange



PNNL DPF Model



ORNL LNT Model

Function Integration Is Next Major Hurdle for Aftertreatment Technology

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Fundamental understanding of SCR & DPF behavior leads to better integration into a single monolithic device, which will help with efficiency, packaging, weight and cost.

On-going PNNL CRADA with PACCAR achieves:

- Better understanding of coupling SCR-DPF and trade-offs
- Determined requirements & limitations for on-board packaging and integration with engine management
- Proper thermal management of the system for regenerating the DPF without negative impacts on the SCR catalyst

PACCAR Inc

DOE also supporting SuperTruck and Advanced Technology Powertrain Projects

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Systems Level Technology Development, Integration, and Demonstration for Efficient Class 8 Trucks (SuperTruck) and Advanced Technology Powertrains For Light-Duty Vehicles

- Objectives are to develop and demonstrate advanced engine and vehicle technologies:

- Heavy-Duty Class 8 Trucks
  - 20% improvement in engine brake thermal efficiency (50% BTE)
  - 50% improvement in freight efficiency (ton-miles/gallon)
  - Modeling and analysis for pathway to 55% brake thermal efficiency
- 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 gasoline engine

Solid State Energy Conversion

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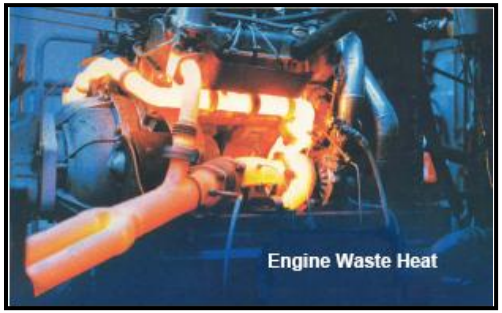
By 2015, **increase fuel economy** of passenger vehicles by at least 5% with thermoelectric generators that convert waste heat to electricity



- Develop advanced thermoelectric systems that directly convert waste heat from engine exhaust to electricity for improved vehicle fuel economy.
- Develop advanced thermoelectric systems for energy efficient heating/cooling of vehicle occupants for improved vehicle fuel economy.

Questions?

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Thank You!

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Web site:

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