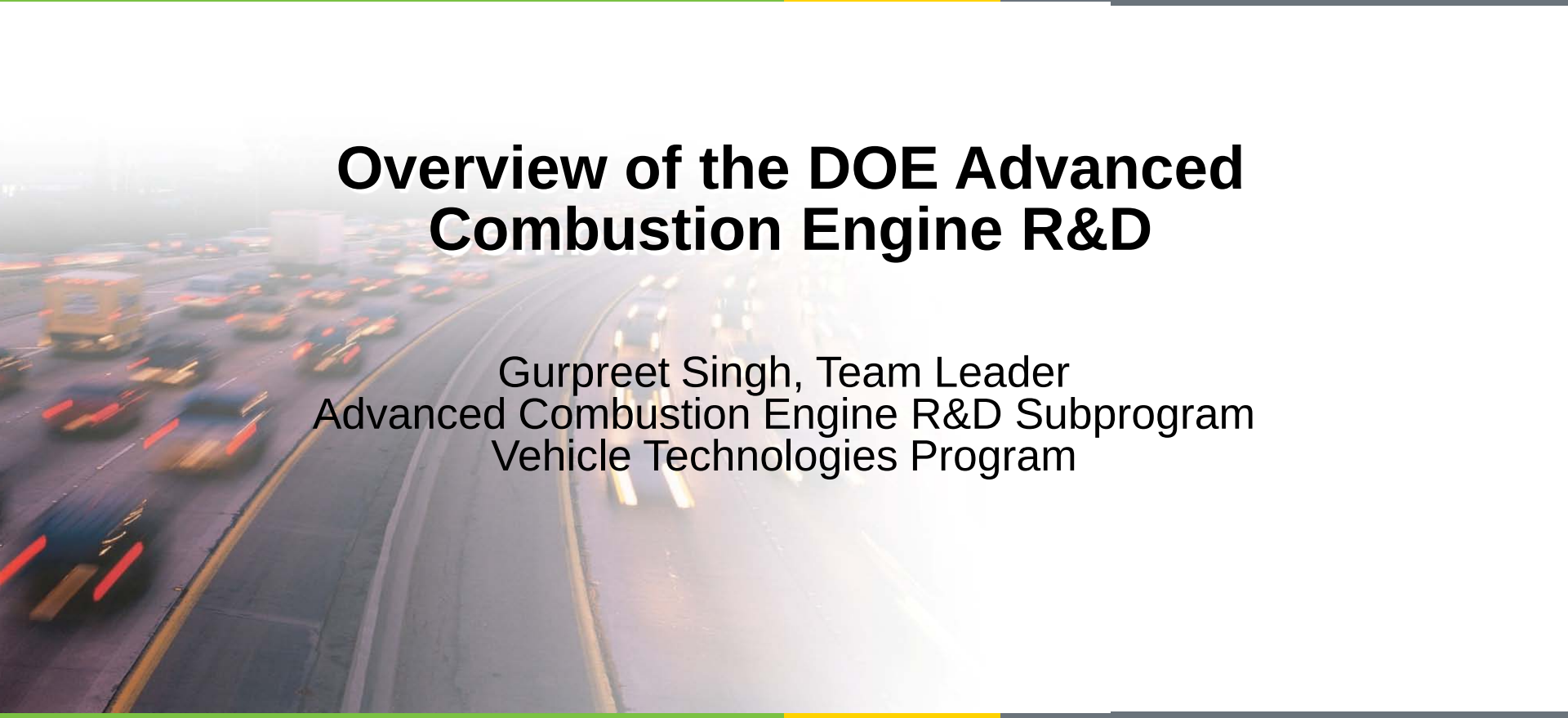
U.S. DEPARTMENT OF ENERGY | Energy Efficiency & Renewable Energy



Overview of the DOE Advanced Combustion Engine R&D

Gurpreet Singh, Team Leader
Advanced Combustion Engine R&D Subprogram
Vehicle Technologies Program

Presented at the
2011 Annual Merit Review
DOE Hydrogen and Fuel Cells Program
and Vehicle Technologies Program
Washington, DC
May 9-13, 2011

Vehicle Technologies Program Mission

To develop more energy efficient and environmentally friendly highway transportation technologies that enable America to use less petroleum.

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

DOE Vehicle Technologies Program Strategy

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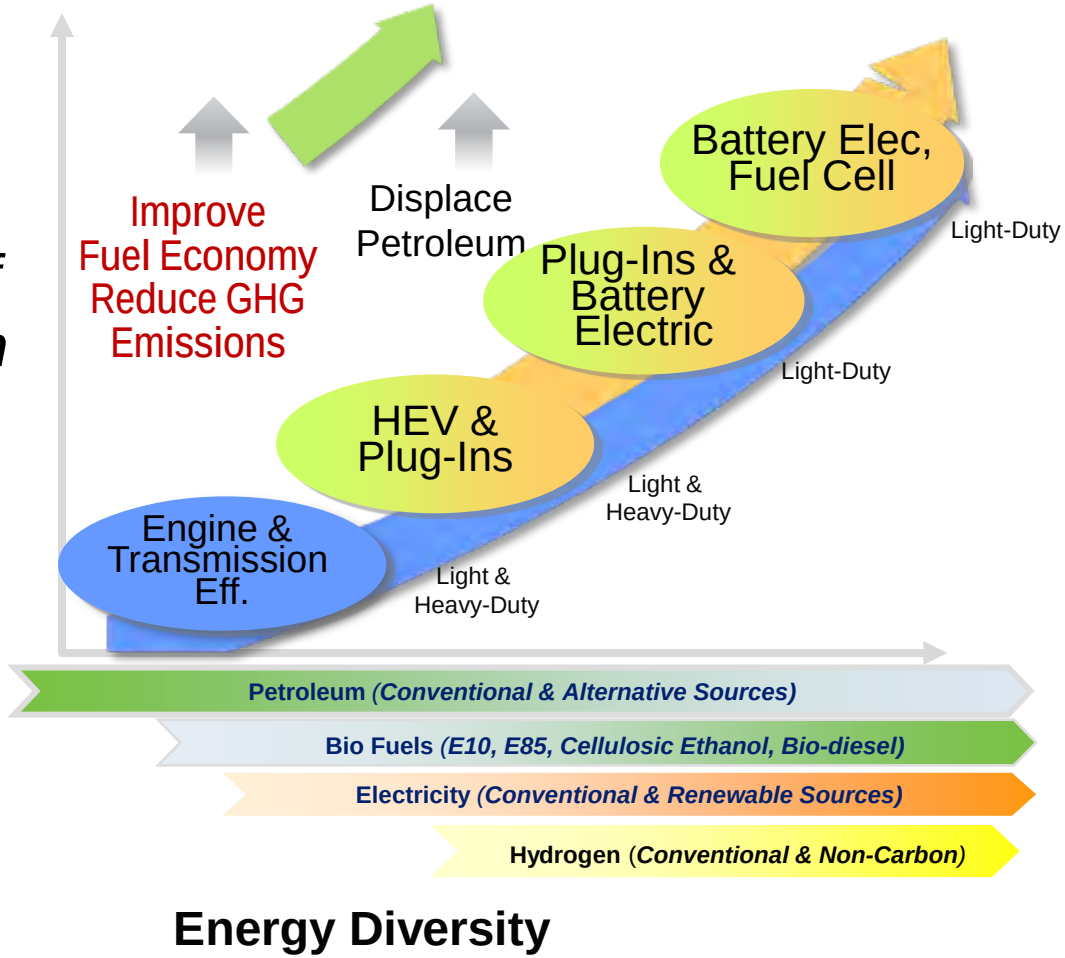
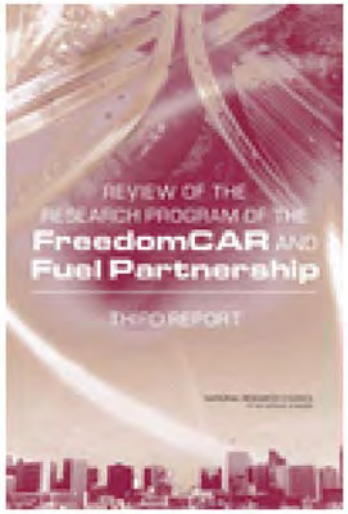
Increasing the efficiency of ICEs is the most promising and cost effective approach to improving the fuel economy of the Nation's fleet of vehicles in the near- to mid-term. … with their relatively low cost, high performance, and ability to utilize renewable fuels, ICEs will likely dominate the market for at least the next 30 years. …advanced engines in hybrid electric and plug-in hybrid electric vehicles will enable even greater fuel savings.



Energy Diversity



The National Research Council expressed full support for advanced combustion engine R&D in their 2010 report -

"There seems to be little doubt that, regardless of the success of any pathways discussed, **the internal combustion engine (ICE) will be the dominant prime mover for light-duty vehicles for many years, probably decades**.

"Thus it is clearly important to perform R&D to provide a better understanding of the fundamental processes affecting engine efficiency and the production of undesirable emissions. …to maintain an active ICE and liquid fuels R&D program at all levels, namely, in industry, government laboratories, and academia, to expand the knowledge base to enable development of technologies that can reduce the fuel consumption of transportation systems powered by ICEs. …"

Source: *Review of the Research Program of the FreedomCAR and Fuel Partnership: Third Report,* Committee on Review of the FreedomCAR and Fuel Research Program, Phase 3, National Research Council, 2010.

Advanced Combustion Engine R&D

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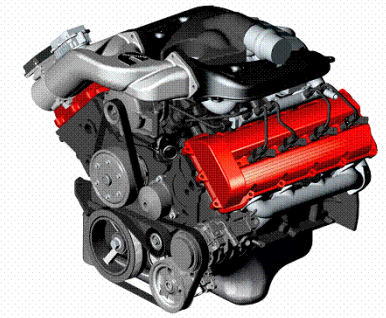
Strategic Goal: Reduce petroleum dependence by removing critical technical barriers to mass commercialization of high-efficiency, emissions-compliant internal combustion engine (ICE) powertrains in passenger and commercial vehicles



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 (BTE)	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%

Key Activities

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

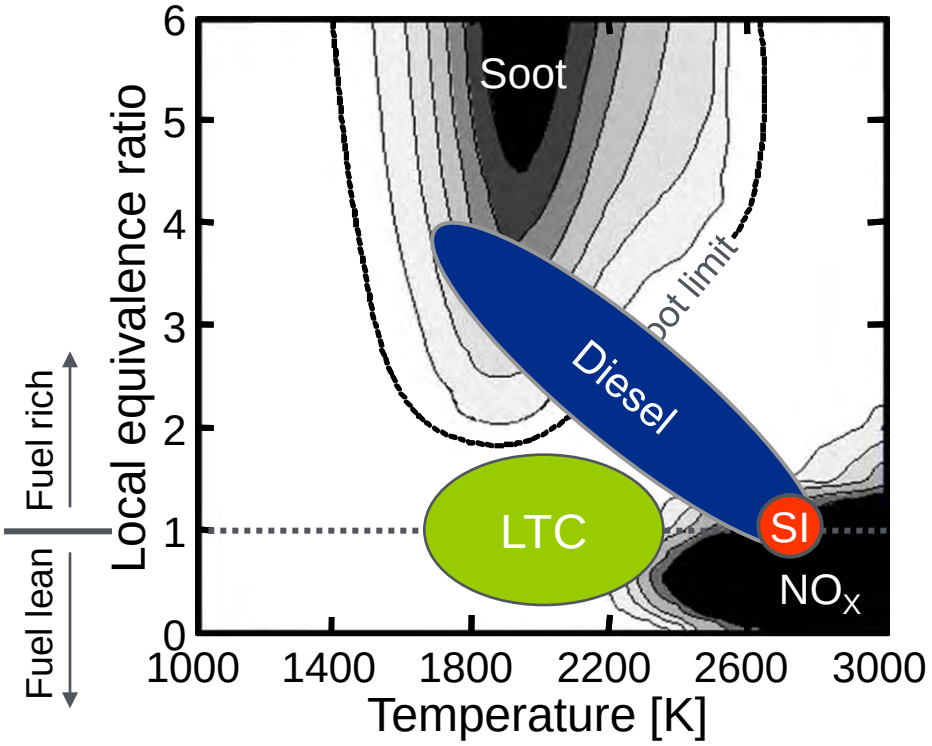
Advanced Engine Combustion Research Supports DOE/Industry High-efficiency, Clean Engine Goals

- **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)

Focus On Low-Temperature Combustion (LTC) Strategies

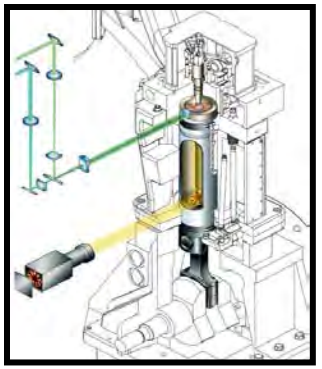
Potential to enable high-efficiency and low-emission operation



- LTC used generically to represent many processes
  - Homogeneous-Charge Compression-Ignition (HCCI)
  - Premixed-Charge Compression-Ignition (PCCI), SCCI, HECC, MK, PCI, UNIBUS, …
- Challenges
  - Combustion phasing
  - Load range
  - Heat release rate
  - Transient control
  - HC and CO emissions
  - Fuel characteristics

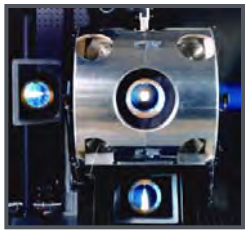
Research Tools Bridge Fundamentals to Application and Support Model Development

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

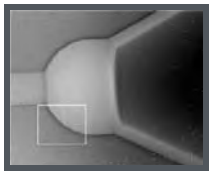


Optical Engines

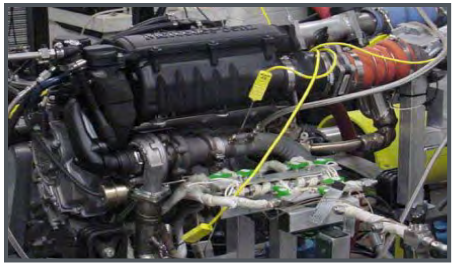
HCCI & Lean-burn Gasoline



LTC Simulator

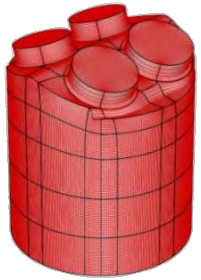


Nozzle Sac X-Ray Image

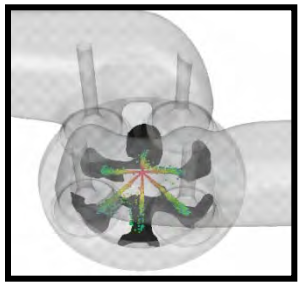


Multi-Cylinder Diesel, LTC and Lean-burn Gasoline

Gasoline PRF:	Diesel PRF:
n-heptane	n-hexadecane
iso-octane	2,2,4,4,6,8,8 hepta-methylnonanev



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

University Research

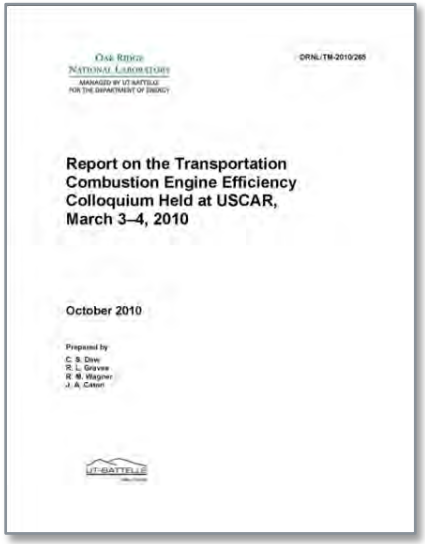
- University Research in Advanced Combustion and Emission Control
  - 2 – 3 years
  - Research Areas of Interest:
    - Lean-burn and low-temperature combustion strategies
    - Reduce nitrous oxide and particulate matter emissions in lean-burn combustion
    - Reduce combustion inefficiencies
    - Reduce hydrocarbon and carbon monoxide emissions for low temperature and lean-burn combustion
- Universities selected:
  - *Michigan State*
  - *Regents of the U. of Michigan*
  - *Board of Regents of the U. of Wisconsin*
  - Michigan Tech
  - U. of Houston
  - U. of Connecticut

Combustion

Emission Control

Workshops to Identify R&D Needs

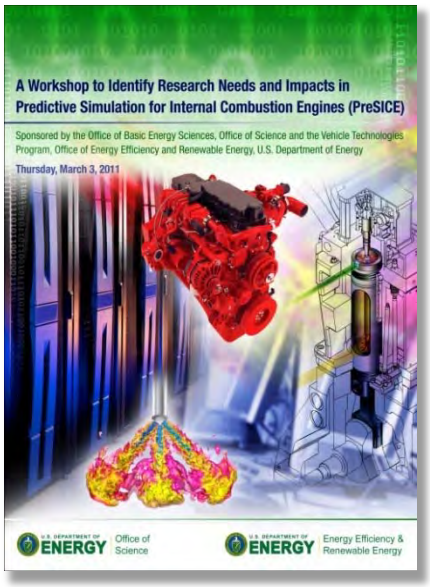
Combustion Engine Efficiency Colloquium, USCAR Detroit, MI, March 3 – 4, 2010



Findings

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

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



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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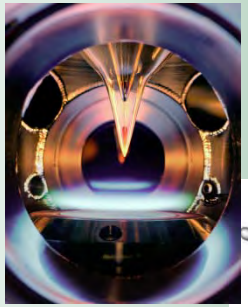
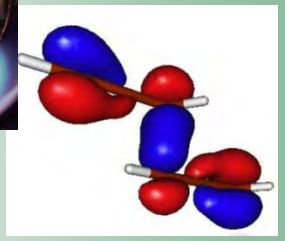
Basic Science

BES
Sustained support in 2 areas

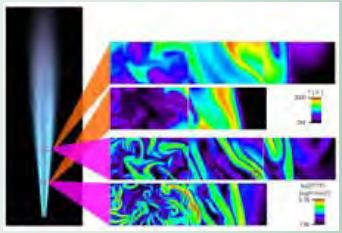
Development of predictive chemistry in model flames



Computational kinetics and experiments



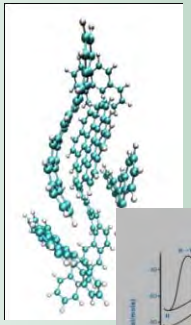
Advance laser diagnostics applied to model flames

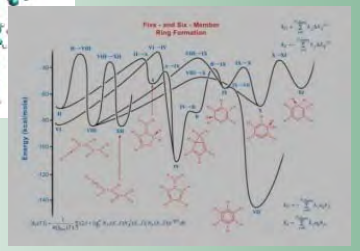


Laser-based chemical imaging

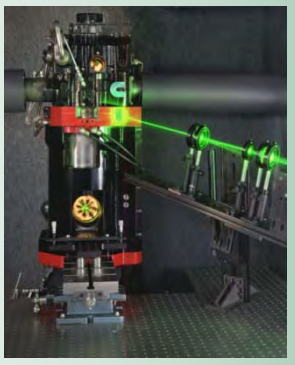
Applied R&D

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

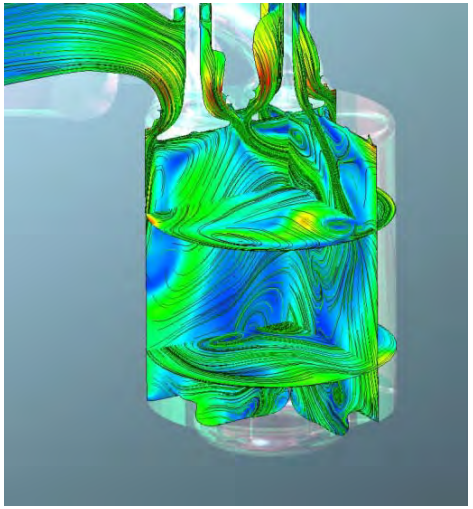
Cummins and Dodge

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

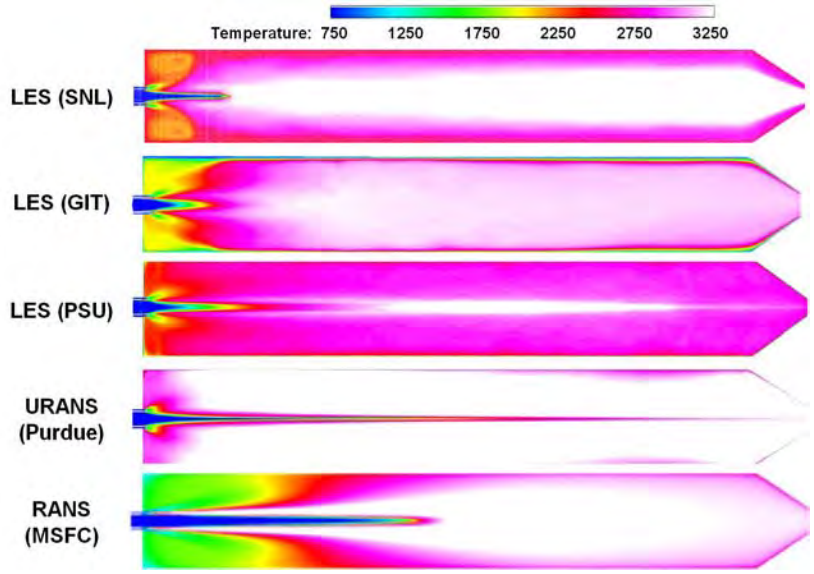
Stochastic Processes Priority Research Directions

- **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



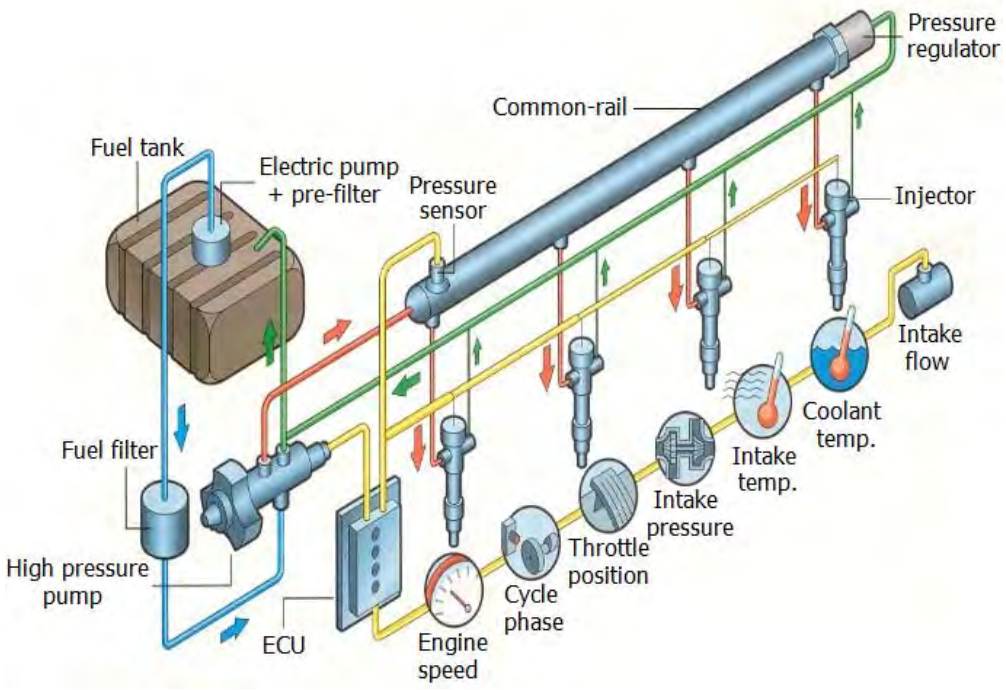
Complex in-cylinder flow during intake stroke in diesel engine

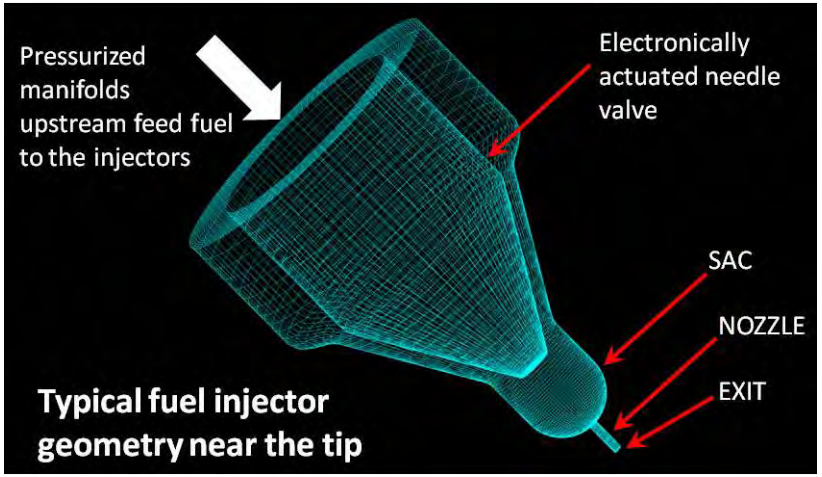
- **Improved accuracy and minimization of uncertainty**
  - Ability to tune model complexity to necessary accuracy level
  - Impact of uncertainty in initial conditions, boundary conditions, parameters
  - Propagation of uncertainties and errors reduction



Spray Dynamics Priority Research Directions

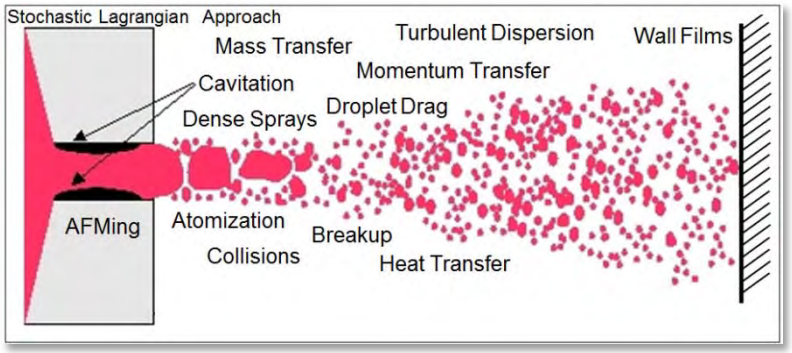
- **Detailed treatment of fuel-delivery systems (fuel rail and internal injector flows)**
  - Geometric complexities of flow passages upstream of injector
  - High pressure internal flow dynamics and transients
  - Turbulence and cavitation within injector sac and nozzle(s)

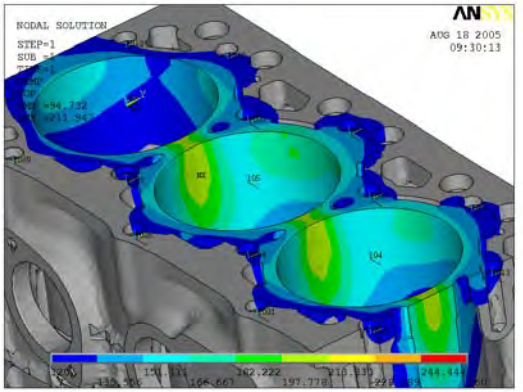


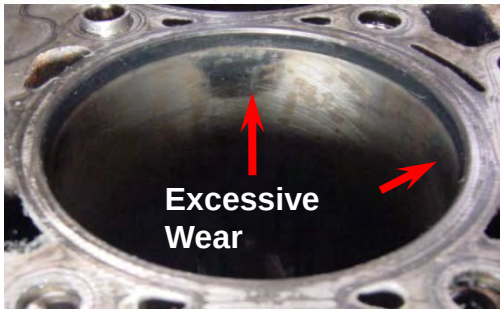


Spray Dynamics Priority Research Directions (cont'd)

- **Optimization of fuel-preparation strategies (in-cylinder injection, mixing and combustion)**
  - Injection timing and strategy (single/multiple-pulse, etc.)
  - Primary-breakup, atomization, dense spray dynamics
  - Secondary-breakup, particle deformation, coalescence
  - Dilute drop dynamics, vaporization, combustion
  - High-pressure thermodynamically supercritical flow
- **In-cylinder fluid-wall interactions, heat transfer**
  - Fuel impingement on cylinders degrades performance, emissions and durability
  - Surface temperature variations create similar problems
  - Improved modeling of near-wall effects is required for advanced systems



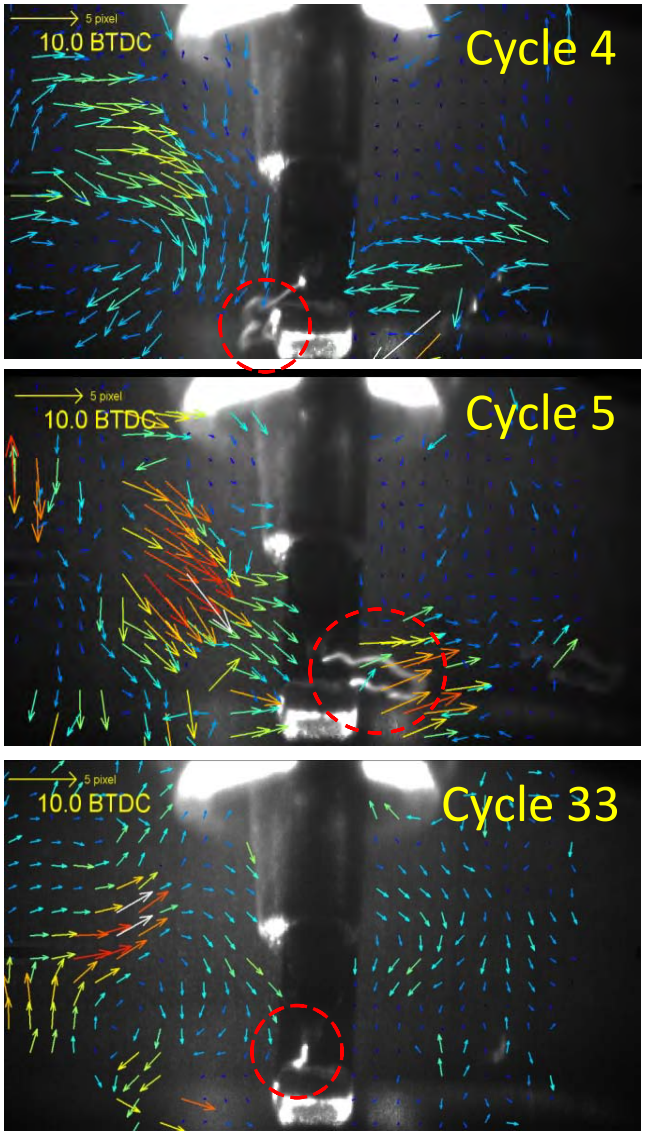




Calculated heat load from wall impingement and observed wear

Cross Cutting Research Needs

- **Development of tailored discovery and validation experiments**
  - Spatially and temporally-resolved, multi-parameter diagnostics
  - High pressure chemistry of complex mixtures
  - High pressure spray facilities with advanced diagnostics
  - Standard optical engine for advanced combustion strategies



High frame rate, in-cylinder velocity field measurements

Future Awards

Funding Opportunity Announcement (FOA) - for near and mid-term projects in technology areas that support the vehicle technologies mission and goals.

- Area of Interest 6A - Solid State Thermoelectric Energy Conversion Devices

- Area of Interest 6B - Enabling Technologies for Engine and Powertrain System

Advanced Combustion Engine R&D Budget by Activities

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Major Activities	FY 2009 Appropriation	FY 2010 Appropriation	FY 2011 Request	FY 2012 Request
Advanced Combustion Engine R&D	**$40,800K**	**$57,600K**	**$57,600K**	**49,000K**
Combustion and Emission Control *	35,089	47,239	47,239	40,824
Solid State Energy Conversion	4,568	8,748	8,748	6,804
SBIR/STTR	1,143	1,613	1,613	1,372

**Includes Heavy Truck Engine and Health Impacts.*

Questions?

Thank You!

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