Light Duty Efficient Clean Combustion

2008 Semi-Mega Merit Review

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Agenda

- Project Goals and Objectives
- Project Partners
- Technical Approach and Enabling Technologies
- Master Schedule and 2008 Milestones
- Wrap-up and Questions

Project Goals and Objectives

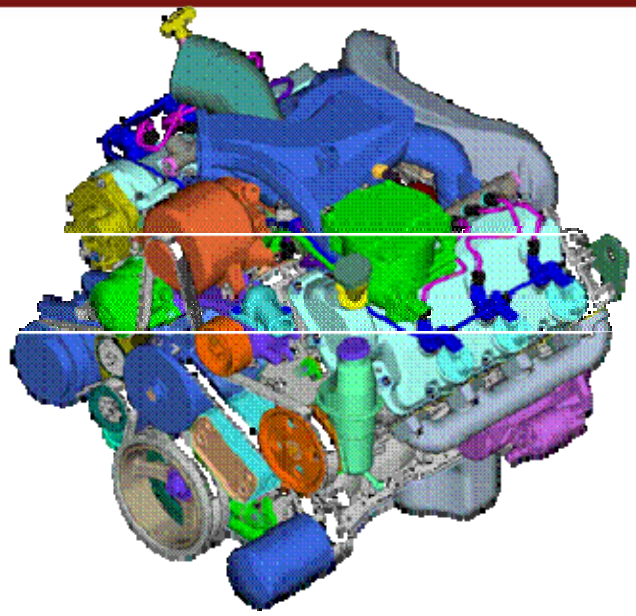
Goal

'Improve the efficiency of diesel engines for light duty applications through technical advances in system optimization and critical subsystem component integration.'

Objectives

- Improve light duty vehicle (5000 lb test weight) fuel efficiency over the FTP city drive cycle by 10.5% over today's state-of-the-art diesel engine.
- Develop & design an advanced combustion system that synergistically meets Tier 2, Bin 5 NOx and PM emissions standards while demonstrating the efficiency improvements.
- Maintain power density comparable to that of current conventional engines for the applicable vehicle class.
- Evaluate different diesel fuel properties and ensure combustion system compatibility with commercially available biofuels.

Project Layout



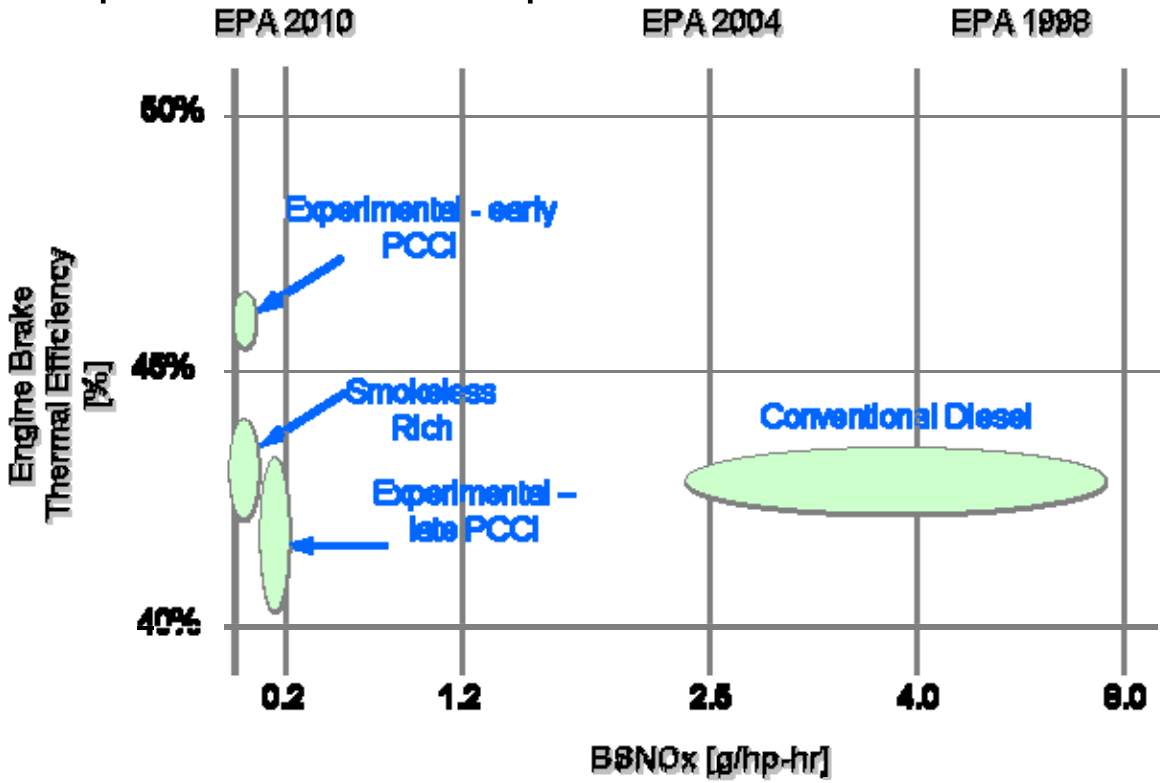
- Budget Period I – October 2007 thru December 2008
  - Applied Research & Exploratory Development
- Budget Period II – January 2009 – September 2009
  - Advanced Development
- Budget Period III – October 2009 – November 2010
  - Engineering Development

Project Partners

- Daimler-Chrysler
  - Definition of Vehicle and Power-train Technical Requirements
  - Packaging Feasibility Study
  - Active Participant in Design Reviews and Program Updates
  - Provide Vehicle for Demonstration
- British Petroleum
  - Evaluation of Future Market Fuels
  - Supply of LDECC Fuel
  - Collaboration on the Evaluation of Fuel Sensing Technologies

Technical Approach

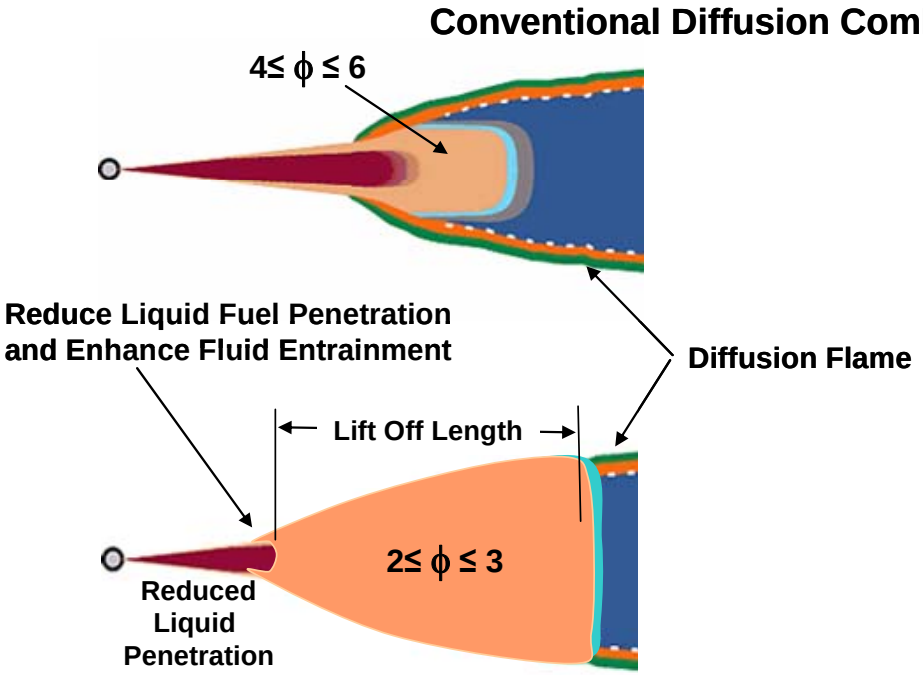
1. Expand Low Temperature Combustion Range



Early PCCI and Smokeless Rich Combustion provide for simultaneous reduction in NOx & PM while maintaining or improving Fuel Economy

Technical Approach

2. Lifted Flame Combustion at High Loads



Mixing Enables:

- Improved NOx vs. PM
- Higher EGR tolerance
- More favorable combustion centroid

Transitioning to Lifted Flame Combustion at intermediate loads will avoid the high noise and cylinder pressures of early PCCI while maintaining excellent fuel economy

Enabling Technologies

Three distinct areas of enabling technologies to drive fuel economy improvements

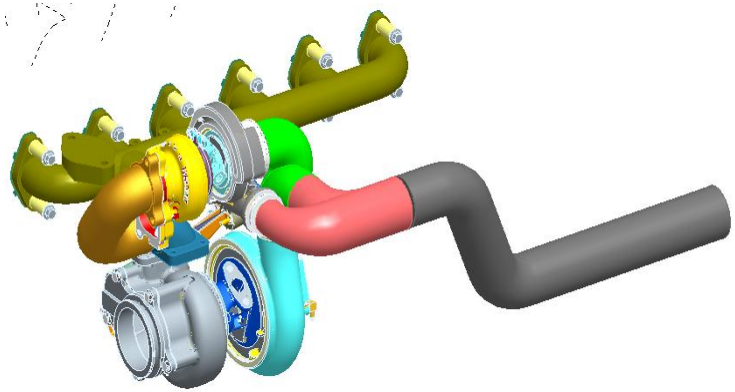
I. Fuel Injection Systems
II. Air Handling System
III. Controls and Sensing System

Enabling Technologies
Fuel Injection System

- High Fuel Injection Pressure
- Improved Small Quantity/Precision Injection Capability
- Increased Number of Injection Pulses
- Variable Spray Pattern Injectors
- Integration of FIE Controls into Closed Loop Combustion Controls

Enabling Technologies
Air Handling System

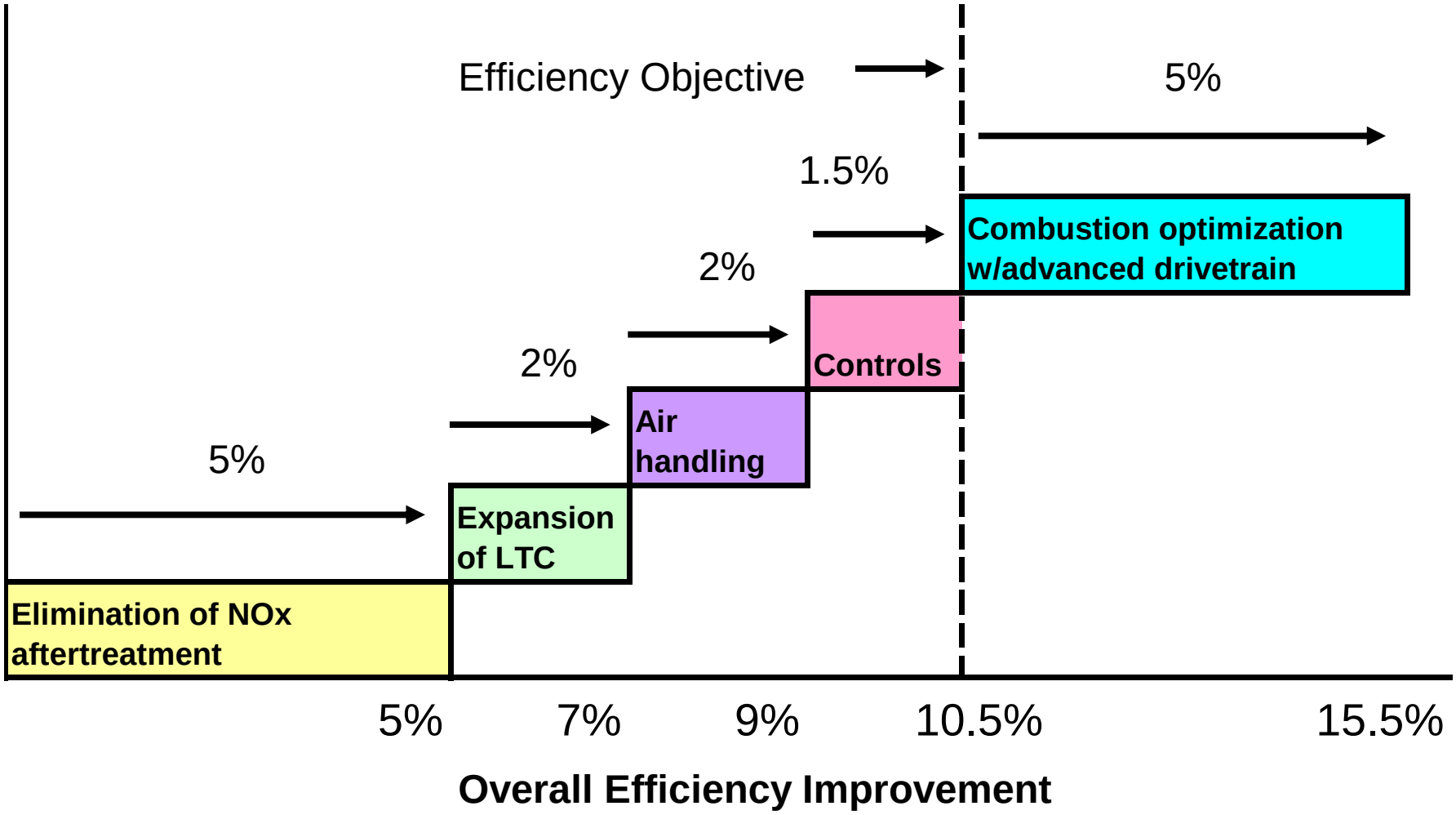
- High Capacity/High Efficiency EGR System
- Fast Response Air Handling Components
  - Variable valve actuation
    - Miller Cycle, Trapped Residual, A/T Regeneration
  - Variable swirl
  - Two stage turbocharger



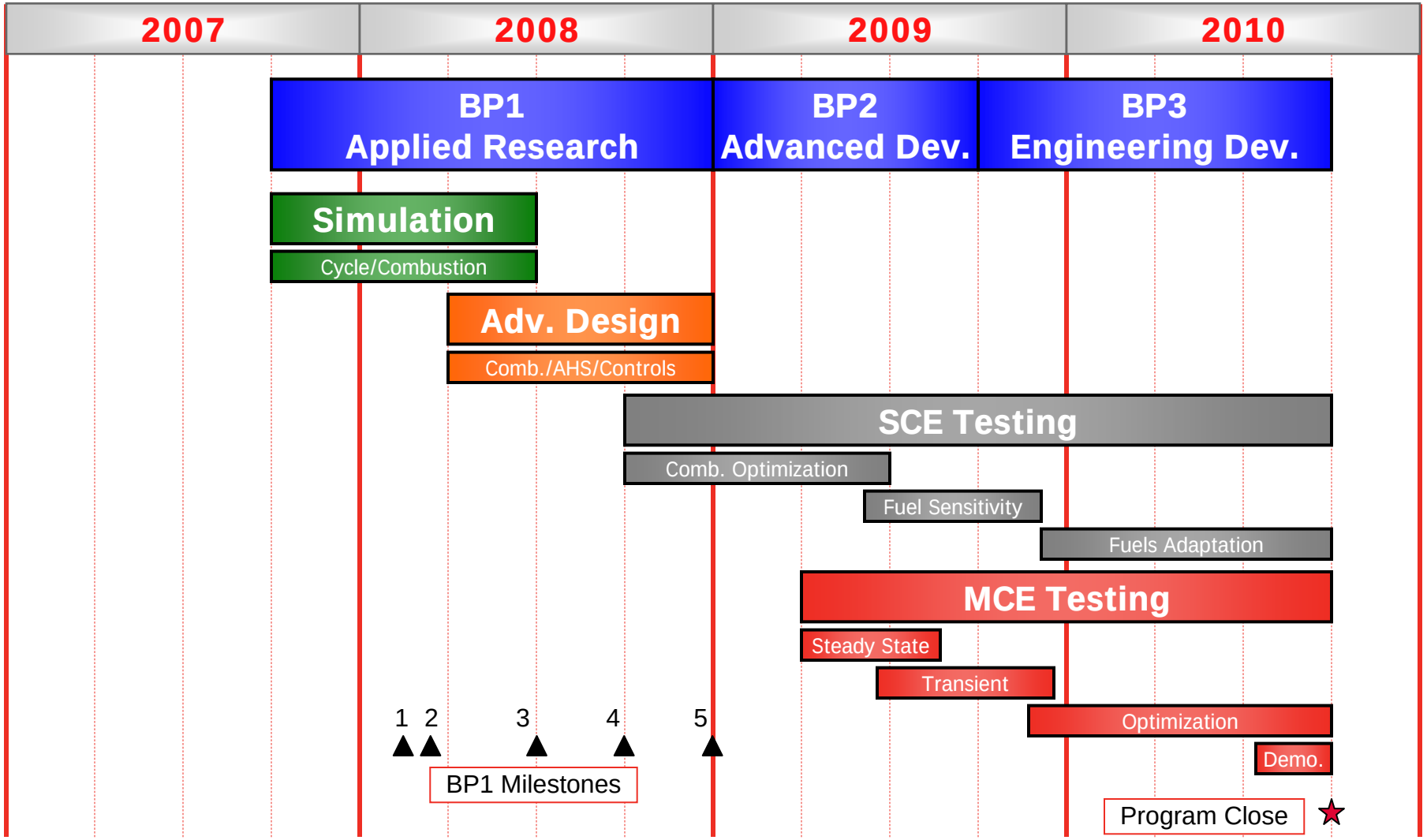
Enabling Technologies
Control and Sensing Systems

- Closed Loop Combustion Control
  - Robust, production viable in-cylinder sensors
  - Piezo actuator feedback for fuel delivery and combustion phasing
- Fuel Quality Sensing
  - Robust, model-based adaptive control
- Charge Management Embedded Models
  - Improved transient charge control
- Drive Cycle Optimization

Path to Fuel Efficiency Target



LDECC Master Schedule



2008 Milestone Descriptions

- **1: Cycle Simulation Model Development** 2/15/08
  GT Power cycle simulation model developed to analyze different system architectures. Work will include the evaluation of EGR system, air handling system, cooling system, and controls system requirements.
- **2: Combustion System Model Calibrated** 3/15/08
  CFD combustion modeling tool validated against mule engine data and LDD VPI data. Key combustion system components will be evaluated and analyzed. Work will include the evaluation of fuel injection system requirements and initial definition of combustion strategy.
- **3: Review Architecture and BP1 Midpoint Review** 6/31/08
  Review modeling results of cycle simulation and combustion modeling to determine status against program targets. GO/NO GO review for continuation of BP 1 work.

2008 Milestone Descriptions

- **4: Single Cylinder Testing** 9/31/08
  Testing of the integrated design configuration will be commenced on a mule single cylinder engine. Combustion system, air handling, and control system components will be evaluated.
- **5: Selection of BP2 Architecture and BP1 Review** 12/31/08
  System combustion system and architecture for Budget Period 2 evaluations will be selected based on estimates of contribution to efficiency improvements, and economic and technical feasibility. Project readiness evaluation and GO/NO GO review to continue with BP 2.

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Cummins Appreciates the Partnership Support of the U.S. Department of Energy.

Thank You!