Enabling High Efficiency Clean Combustion

2008 Semi-Mega Merit Review

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Research & Technology

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This presentation does not contain any proprietary or confidential information

Agenda

- Goals and Objectives
- Approach
- Performance Measures and Accomplishments
- Fuels Impact
- Plans for Next Fiscal Year
- Summary
- Collaborations/Interactions

Statement of Project Objectives

1. Improve brake thermal efficiency by 10% and reduced engine out emissions (2010 compliance)

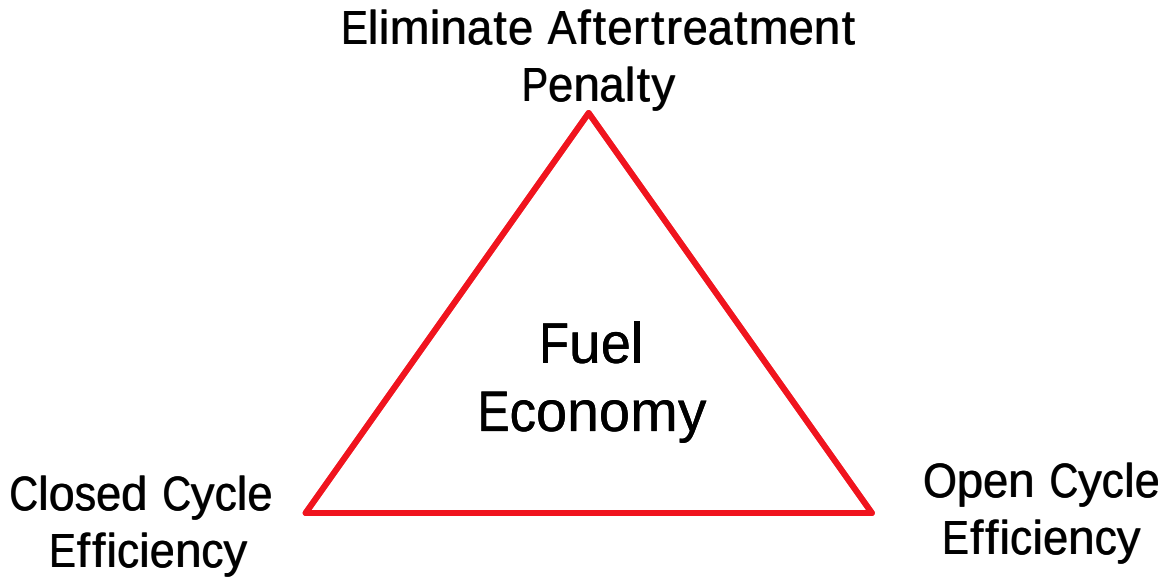
2. Design and develop enabling components and subsystems (air handling, fuel injection, base engine, controls, etc.)

3. Specify fuel properties conducive to improvements in emissions and fuel efficiency

4. System integration for fuel economy optimization (engine and vehicle)

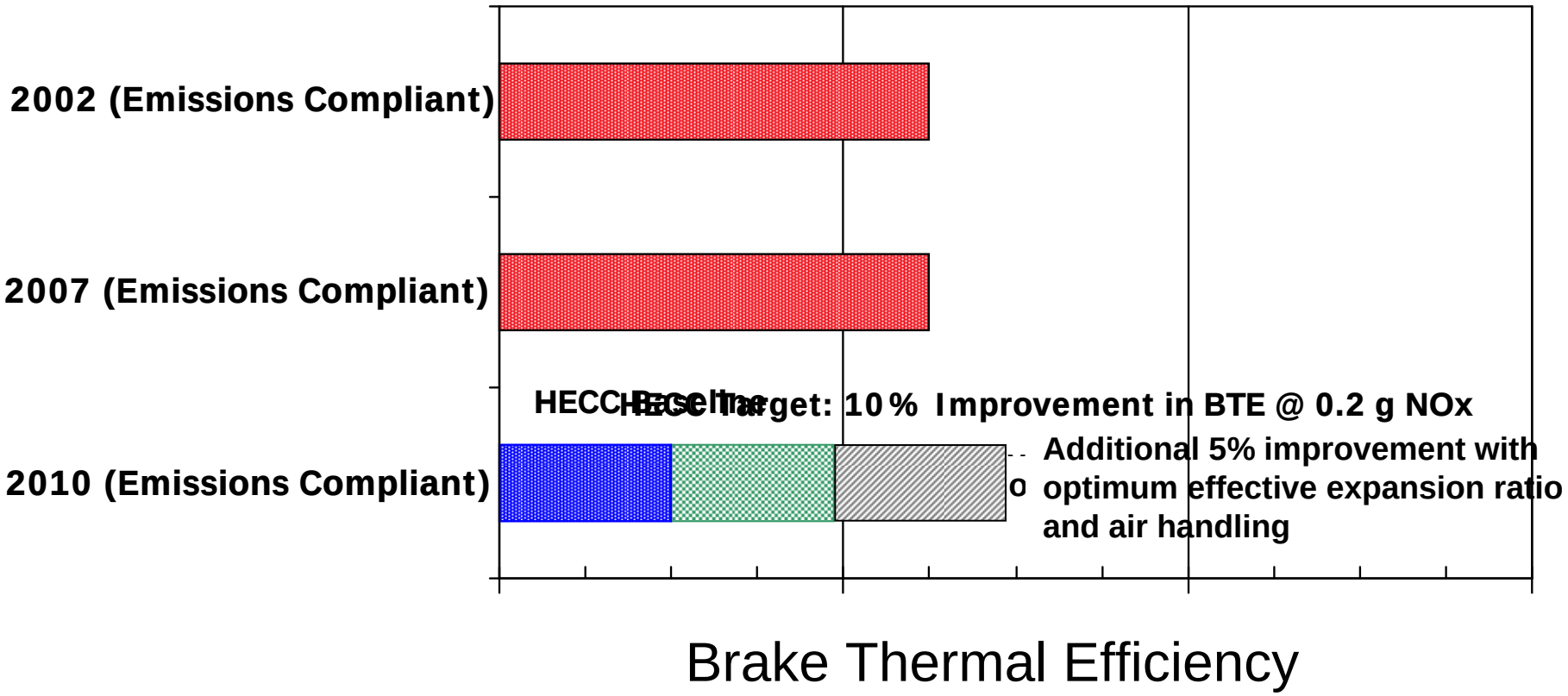
Approach

- A wide variety of low temperature combustion concepts offer potential for low emissions and improved fuel economy.

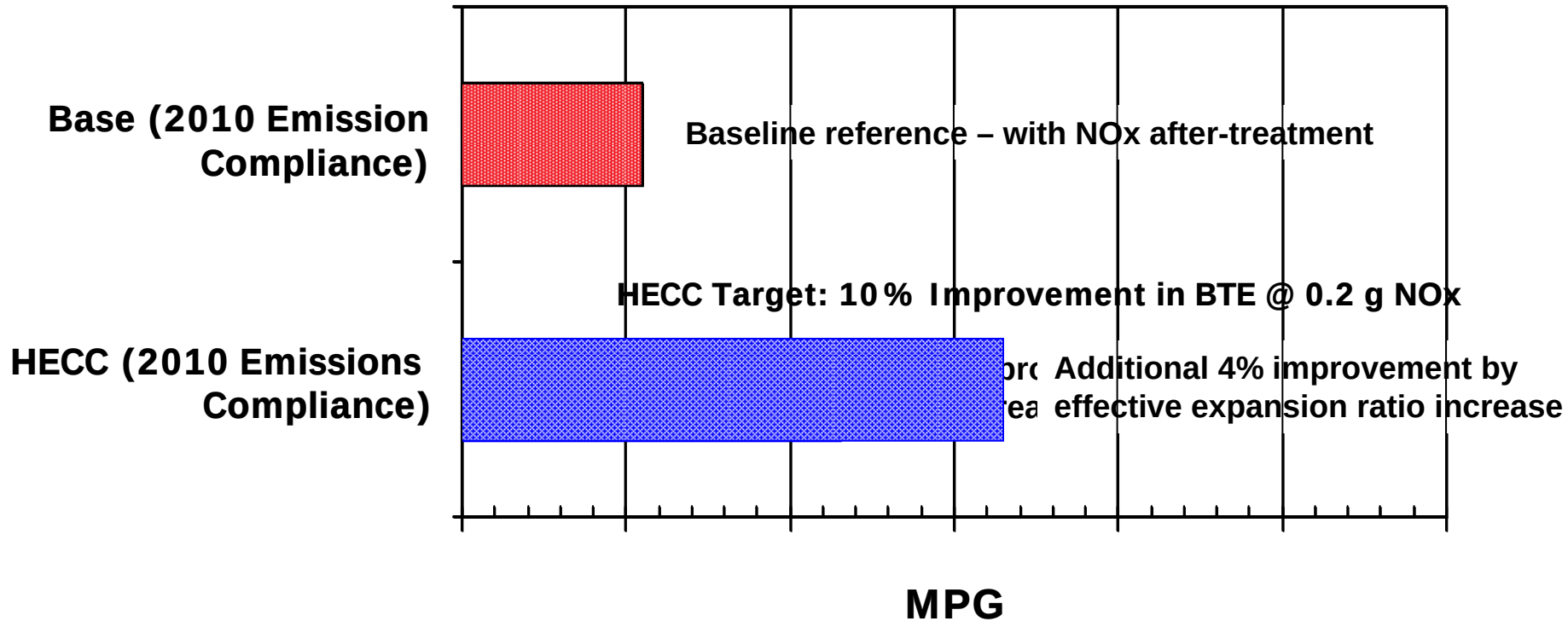


- Leverage Cummins component technologies as enablers for HECC.

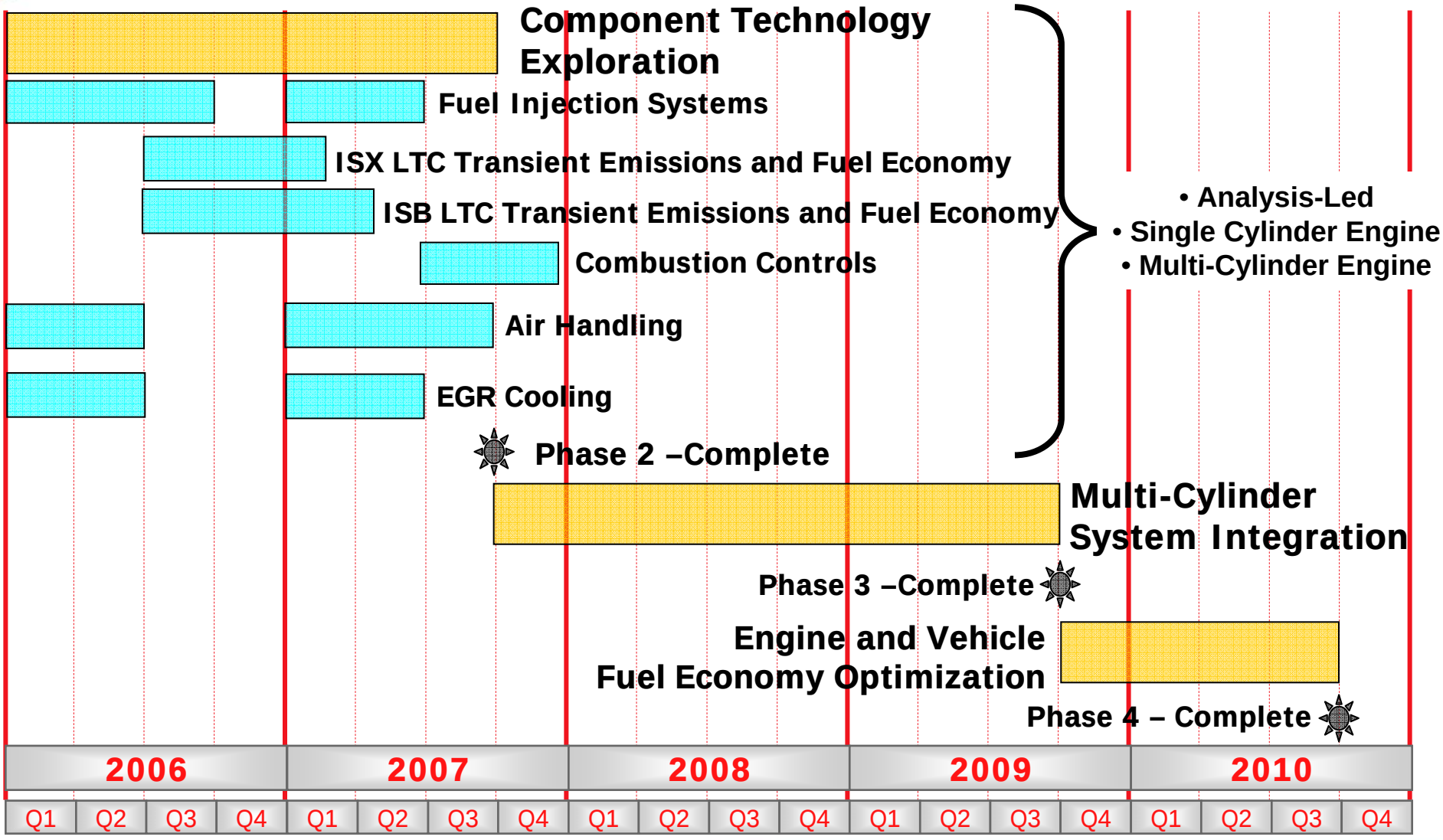
ISX 15L Heavy Duty Engine Fuel Economy



Light Duty 6.7L ISB Fuel Economy



HECC Program Schedule



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ISX Technology Roadmap for Efficiency Improvement

Variable Valve Actuation

Fuel System
-High Injection Pressure
-Piston Bowl/Nozzle
-Multiple injections

Advanced LTC
-Enhanced PCCI
- Mixed Mode Combustion

Variable Intake Swirl

Controls

EGR Loop
- Lower Pressure Drop
- Alternative Cooling

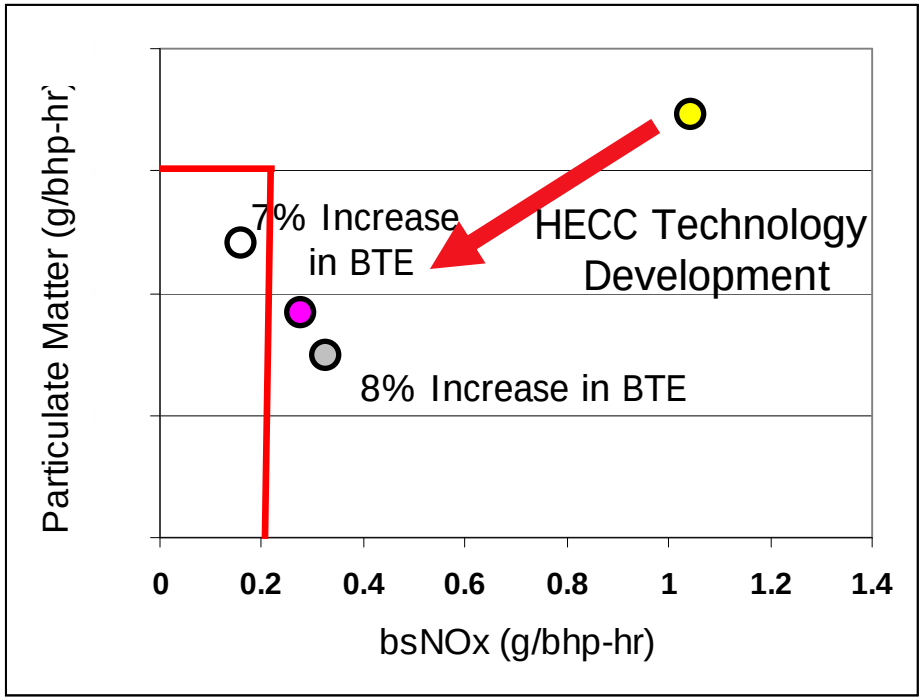
Electrically Driven Components

Turbo Technology

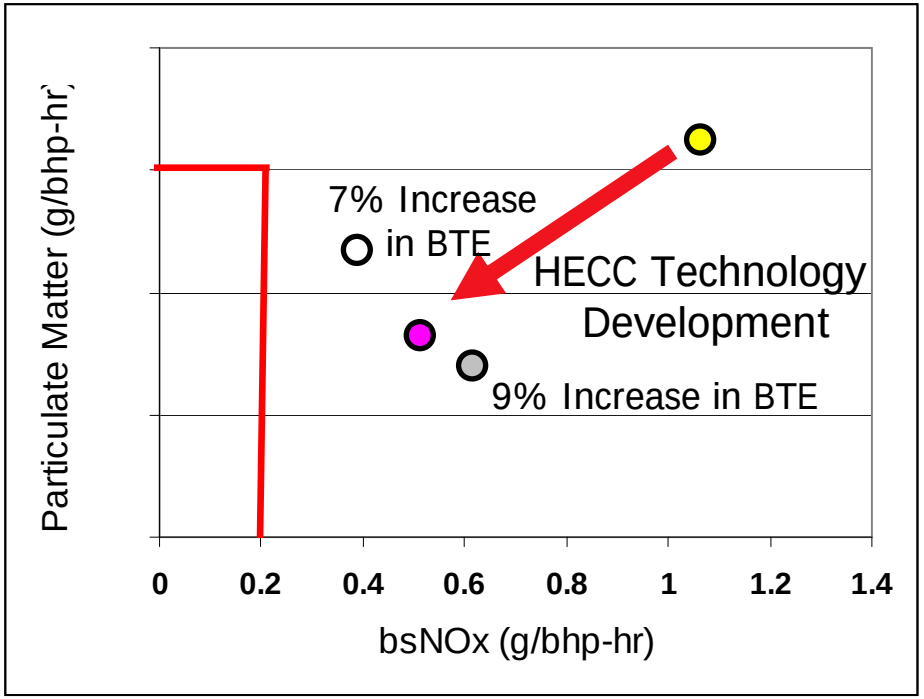
Aftertreatment

Summary of ISX 15L Achievements

Current Status



Steady State Emissions



Transient Emissions

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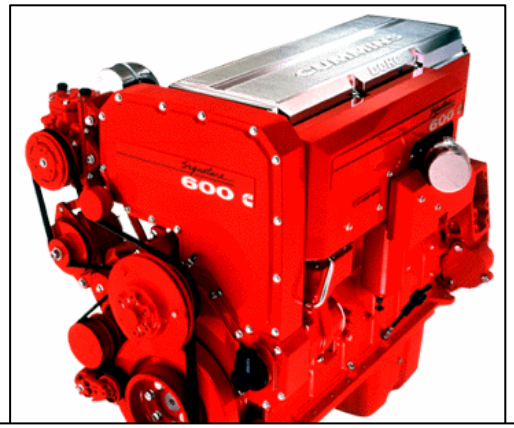


Controls
-Charge Air Manager
-MAF
-Closed Loop Combustion

EGR Loop
- Lower Pressure Drop
- Alternative Cooling

Phase 3: 2007-2008 Work Plan

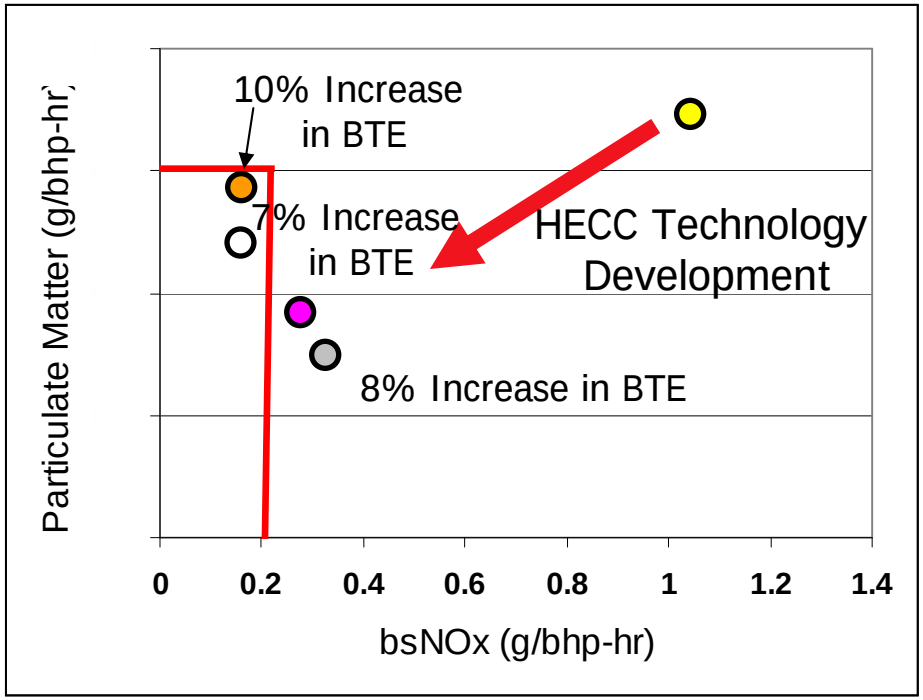
Electrically Driven Components

Turbo Technology
-Electrically Assisted
-2-Stage

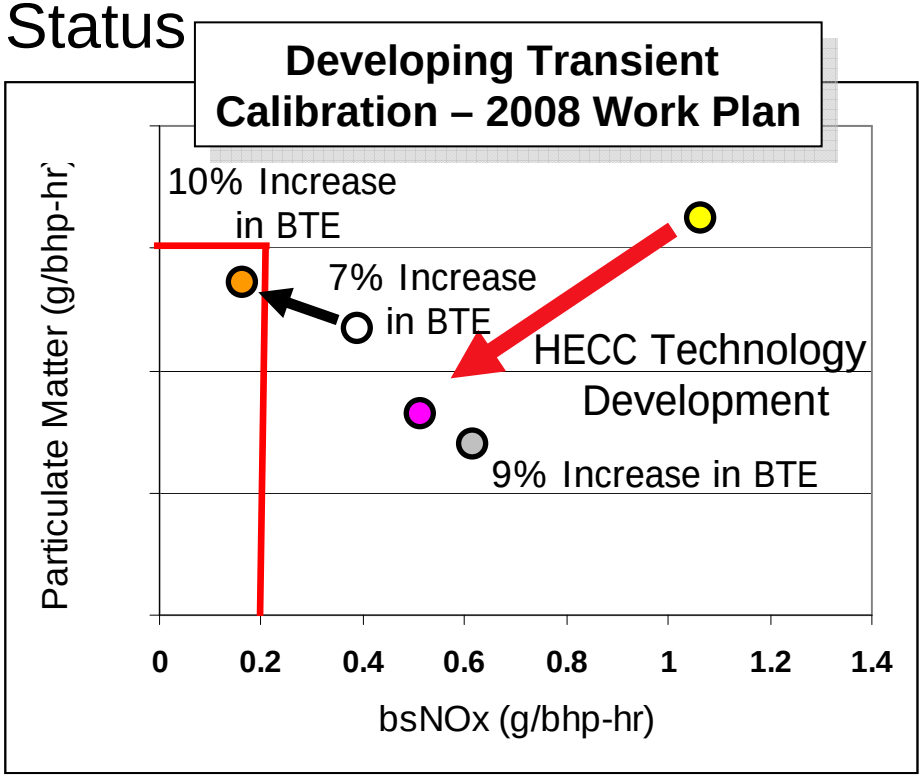
Aftertreatment

Summary of ISX 15L Achievements

Current Status

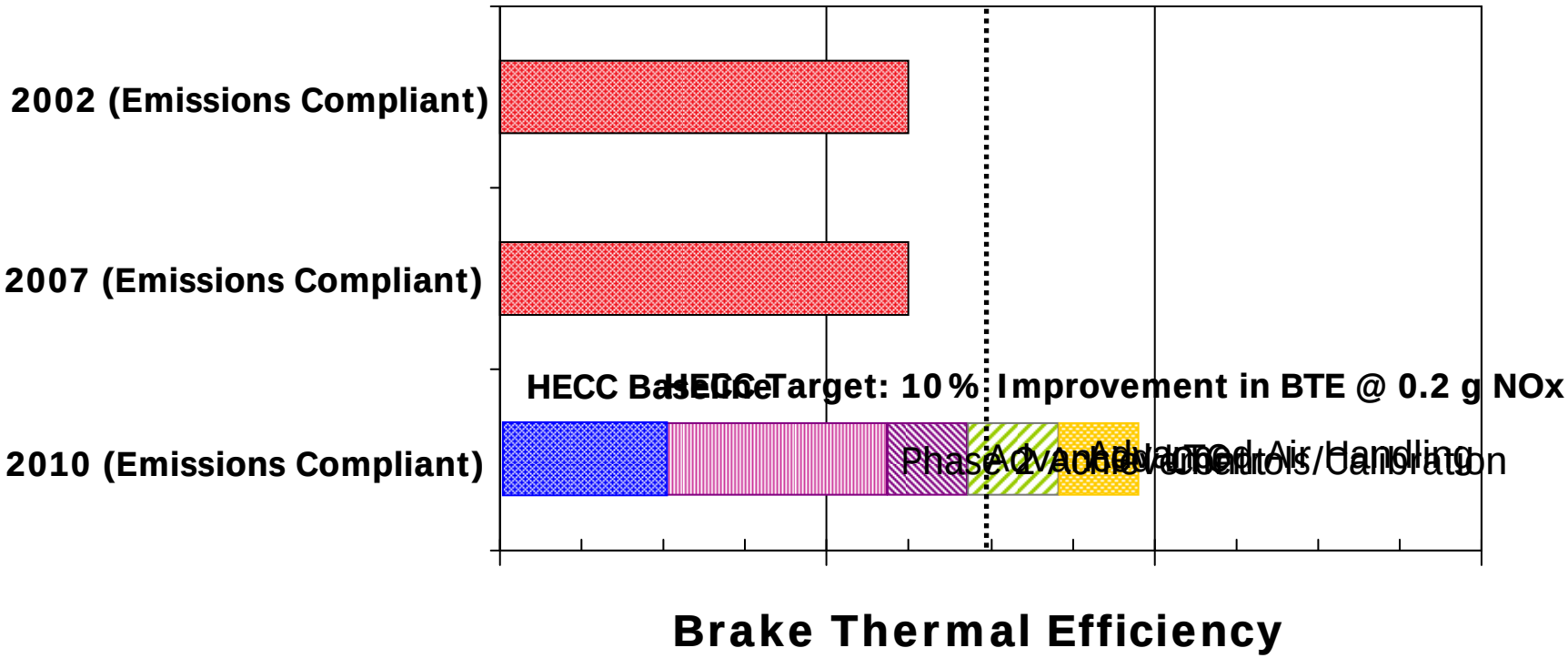


Steady State Emissions



Transient Emissions

2008 Work Plan for ISX Heavy Duty Fuel Economy



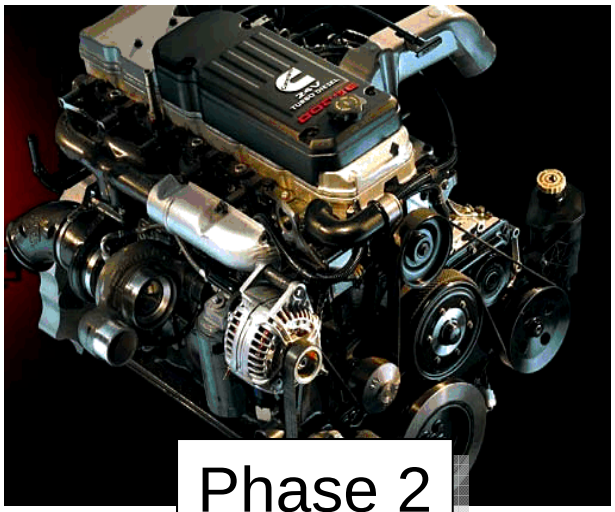
ISB Technology Roadmap for Efficiency Improvement

Variable Valve Actuation

Fuel System
-Piston Bowl/Nozzle
-Multiple injections

Advanced LTC
-Enhanced PCCI
- Mixed Mode Combustion

Variable Intake Swirl



Phase 2

Controls

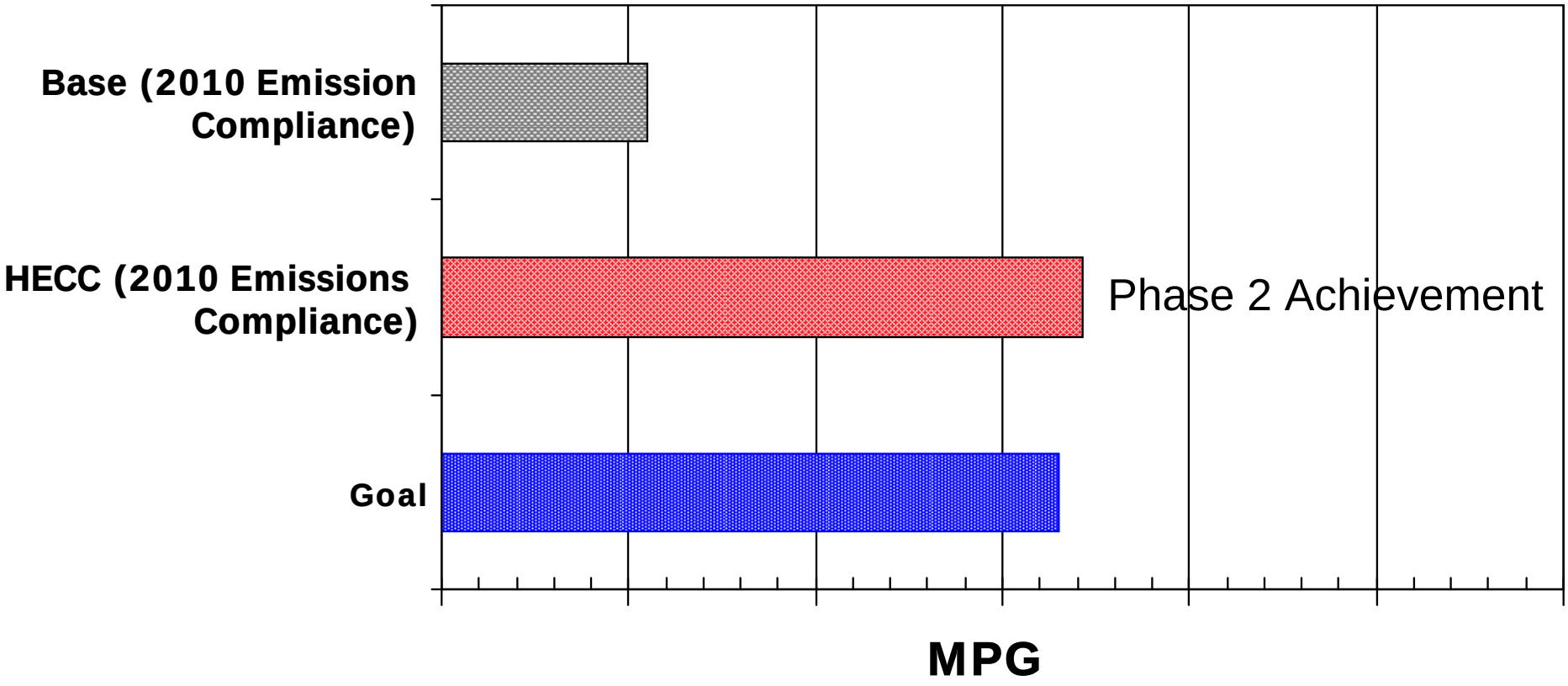
EGR Loop
- Lower Pressure Drop
- Alternative Cooling

Electrically Driven Components

Turbo Technology

Aftertreatment
- HC and CO control

6.7L ISB Efficiency Status



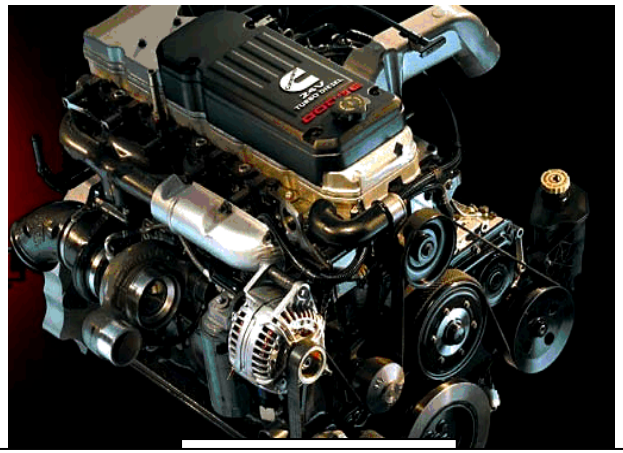
ISB Technology Roadmap for Efficiency Improvement

Variable Valve Actuation

Fuel System
-Piston Bowl/Nozzle
-Multiple injections
-VSP
-High Injection Pressure
-Precision Control

Advanced LTC
-Enhanced PCCI
- Mixed Mode Combustion

Variable Intake Swirl



Controls
-Closed Loop Combustion
-Charge Manager

EGR Loop
- Lower Pressure Drop
- Alternative Cooling

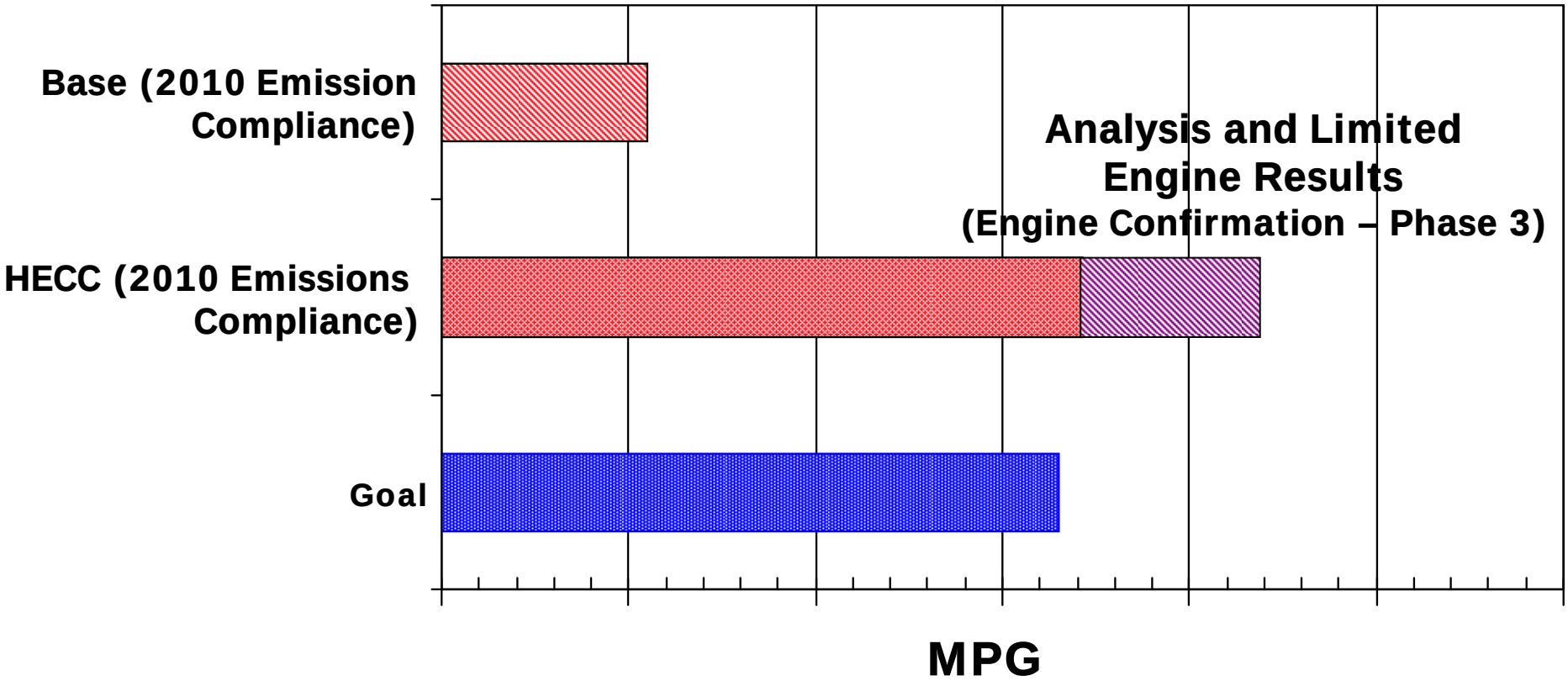
Phase 3: 2007-2008 Work Plan

Electrically Driven Components

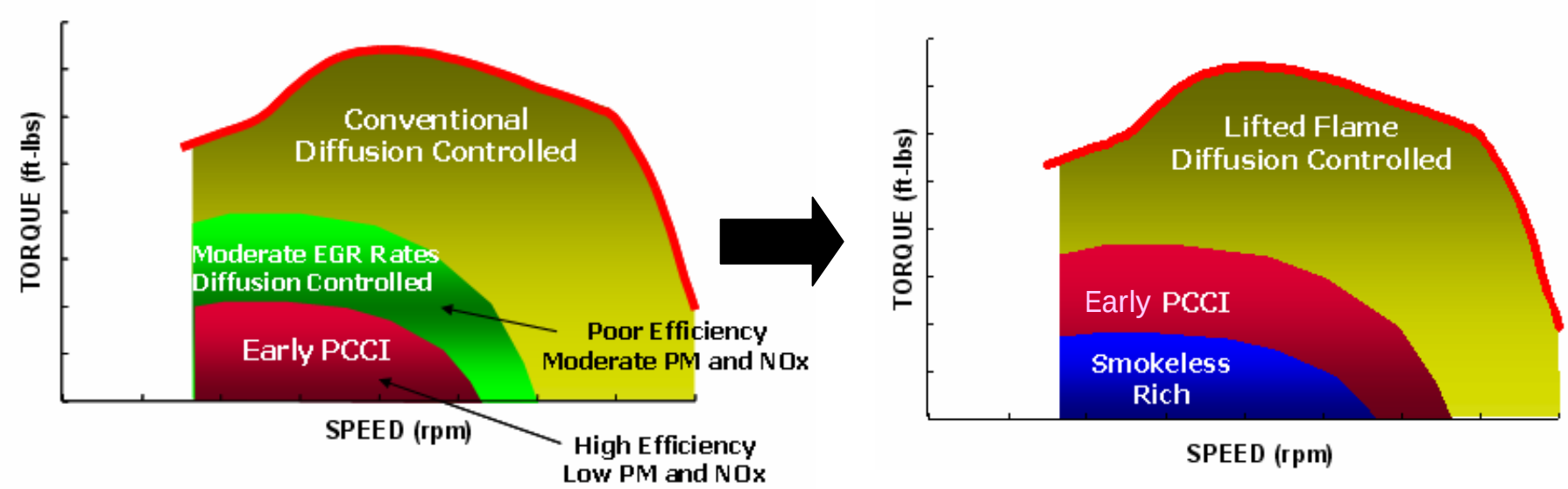
Turbo Technology

Aftertreatment

6.7L ISB Efficiency Status



Combustion Strategy for Additional ISB Fuel Economy Improvements

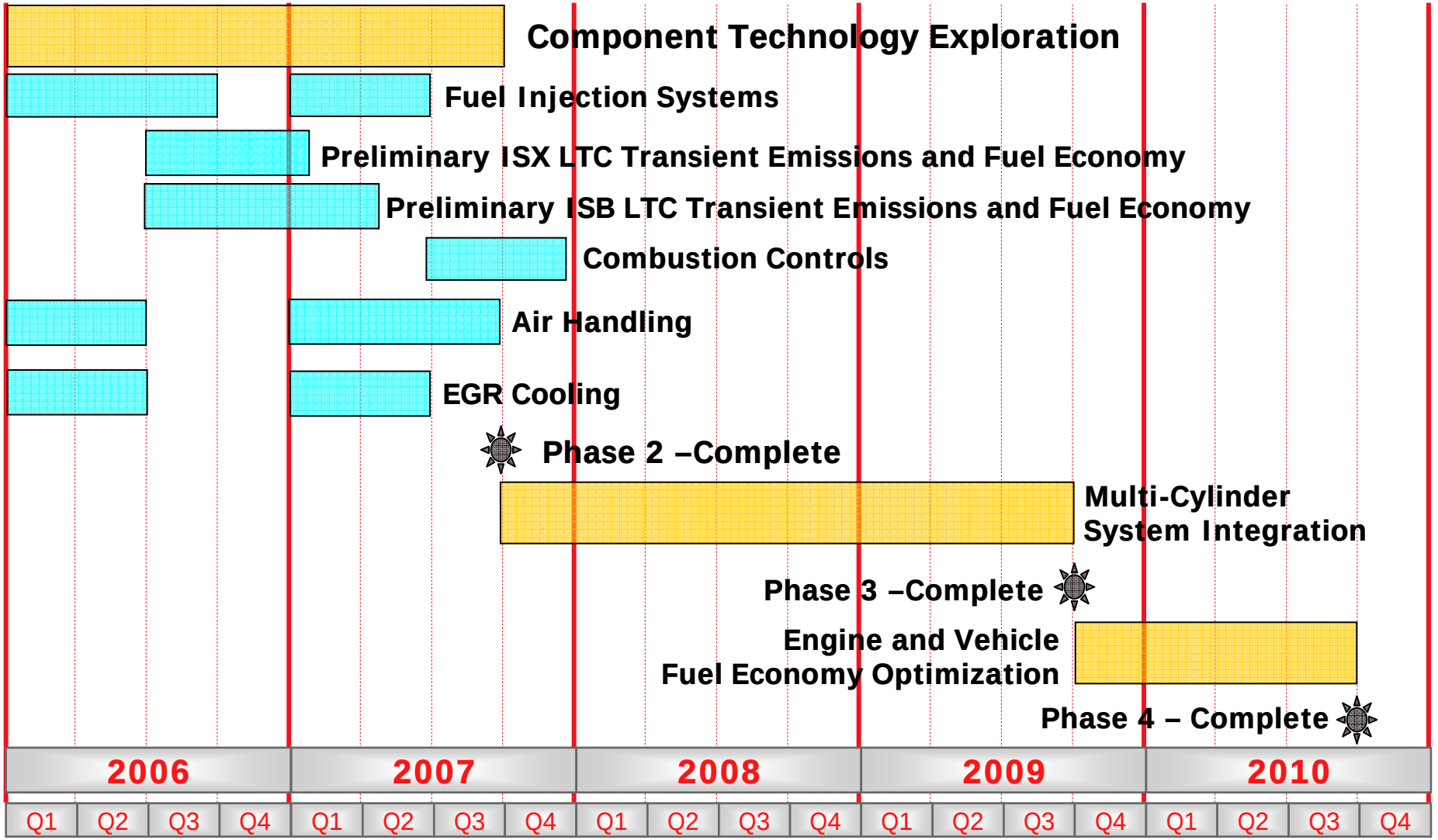


- Demonstrated robust smokeless rich combustion
- Extended the early PCCI mode of combustion with acceptable noise
- Additional work required for lifted flame combustion

Impact of Fuels on HECC

- Completed ISB engine testing of diesel fuel properties along with biofuel blends (SAE 2008-01-0078)
  - Explain observed NOx increase/decrease in published literature
  - Expected NOx emissions impact on Cummins technology
- Developed emissions and fuel economy models as a function of fuel properties for LTC (Cummins and ORNL)
  - Additional testing at ORNL will focus on wider variety of biofuels
- Engine calibration parameters have the largest impact on LTC
  - Higher cetane fuel blends best for PCCI combustion with low T50
  - Problems with off-nominal conditions such as cold operation (HC and CO emissions – significant thermal management required)
- Combustion is robust for the variation in fuel properties studied (fuel economy improvements can be maintained with appropriate changes in engine calibration)
  - Fuel sensing technology would add significant design margin (2008 work plan)
  - Virtual and real fuel sensor technology development
- HECC is robust for variations in biofuel blends (more difficult to maintain fuel economy benefit with lower energy content of biofuels)

HECC Program Schedule



Commercial Viability

- Leverage Cummins Component Business Unit
  - HECC program used to identify research areas
  - Establish investment strategy
- Align HECC program with Cummins Engine Business product plan
  - Phase 2 impact on 2010 engines
  - Beyond 2010
- Comprehensive Total Cost of Ownership (TCO) models used to evaluate commercial viability
- Addressing On-Board Diagnostics (OBD) issues associated with HECC technology

Conclusions

- Program is on path to meet objectives
  - Additional fuel economy is achievable with proper integration of component technology developed in Phase 2.
- Cummins component technologies needed to achieve full emissions compliance and fuel economy targets have been identified via analysis and limited engine testing
  - Phase 3 Multi-cylinder System Integration effort will provide engine confirmation over transient drive cycles
- Additional fuel economy improvements expected during the Phase 4 Engine and Vehicle Optimization efforts.

Collaborations/Interactions

- Oak Ridge National Laboratory
  - Fuels
  - Emission analysis

OAK RIDGE NATIONAL LABORATORY
U. S. DEPARTMENT OF ENERGY

- BP – Global fuels technology

bp

- OEM Partners
  - DaimlerChrysler

DAIMLERCHRYSLER

  - International Truck and Engine Corporation
  - Paccar Inc.

PACCAR

- Supplier Partners
  - Behr
  - Cummins Turbo Technologies
  - Cummins Fuel Systems