High Efficient Clean Combustion for SuperTruck

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Principal Investigator
September 29, 2010

Work Supported by DoE

DoE Technology Development Manager:
Roland Gravel

Changing the Climate on Climate Change
Outline

- Achievements of HECC and WHR Programs

- SuperTruck Program
  - Objectives
  - Team Members
  - Technologies
  - Schedule

- Summary / Q&A
HECC Program Objectives

(October 2005 – March 2010)

1. Improve brake thermal efficiency by 10% while meeting US EPA 2010 emissions
   • Baseline - engine meeting 2007 US EPA regulations

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

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

4. Vehicle integration for fuel economy optimization
HECC: Achieving In-Cylinder NOx Control with Improved Efficiency

In-Cylinder NOx Control
EGR+DOC+DPF

Robustness remains an issue for In-Cylinder NOx Control

Direct Air to EGR + Combustion System + 2 Stage Turbo + >2600 bar FIE

>2600 bar FIE + Direct Air to EGR + Controls

2 Stage Turbo + Low $\Delta P$ EGR + Calibration

Low $\Delta P$, High Flow Rate EGR + VVA

Engine Out PM Level Assuming DPF

% Change in Fuel Consumption Relative To Baseline

BSNOx [g/hp-hr]

BSDPM [g/hp-hr]

$\Delta$=0.03

Reference: Stanton, 2009 DEER Conference
In-Cylinder NOx Control
EGR+DOC+DPF

Program Baseline
Non – HECC Engine
(2007 Production Engine)

13.5% to 16% Improvement in BTE

10.2% Improvement in BTE

BSNOx [g/hp-hr]

BSNPM [g/hp-hr]

PIPE

% Change in Fuel Consumption Relative To Baseline

0% -3% -6% -9% -12%

Engine Out PM Level Assuming DPF

Non – HECC Engine
(2007 Production Engine)

Reference: Stanton, 2009 DEER Conference
HECC Engine Efficiency Improvements

Class 8 Line Haul Application: Highway Cruise Condition

Brake Thermal Efficiency (%)


HECC+SCR: Lowest CO₂
HECC+SCR: Lowest Operating Cost
In-Cylinder NOx Control
Program Target
10% Improvement

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In-Cylinder NOx Control
Program Target
10% Improvement
Waste Heat Recovery Program Objectives

(October 2005 – March 2010)

1. Improve brake thermal efficiency by 10%
   - Baseline – engine meeting 2007 US EPA regulations

2. Reduce the need for increased vehicle heat rejection capacity for Class 8 line haul applications
   - Helps maintain aerodynamic design of the tractor
6% from EGR energy
+ 2% from Exhaust
+ 2% from Electric Acc.
10% Improvement

- **No NOx Aftertreatment**: 8% fuel efficiency improvement from WHR only with 2007 vehicle cooling capacity
- **SCR NOx Aftertreatment**: 6% fuel efficiency improvement from WHR only with 2007 vehicle cooling capacity

Reference: Nelson, 2009 DEER Conference
Generation 2 WHR: Mechanical ORC

- Sources of energy
  - EGR
  - Charge Air
  - Exhaust heat

- Mechanical coupling of WHR power to engine

- Fuel Economy improvement of ~6% for SCR engine architecture

Reference: Nelson, 2009 DEER Conference
WHR Engine Efficiency Improvements

Class 8 Line Haul Application: Highway Cruise Condition

Gen 1 WHR with No NOx AT Engine Configuration + Electric Accessories
(10% Improvement)

Gen 1 or Gen 2 WHR SCR AT Engine Configuration + No Electric Accessories
(6% Improvement)

Program Target
10% Improvement
Engine Efficiency Improvements

Class 8 Line Haul Application: Highway Cruise Condition

- HECC+SCR: Lowest Operating Cost
- Program Target: 10% Improvement
- Gen 2 WHR SCR AT Engine Configuration + No Electric Accessories
Engine Efficiency Improvements

Class 8 Line Haul Application: Highway Cruise Condition

- Super Truck: 55% BTE Engine Assessment
- Super Truck: 50% BTE Engine Demonstration
- HECC+SCR: Lowest Operating Cost
- Program Target: 10% Improvement

- Gen 2 WHR SCR AT Engine Configuration + No Electric Accessories

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SuperTruck Program Objectives

- 50% increase in vehicle freight efficiency (ton – miles per gallon)

- 20% improvement through engine efficiency development – 50% BTE under highway cruise conditions

- Pathways to 55% BTE in engine lab.
Comprehensive Approach to Fuel Consumption and CO₂ Reduction

- **Engine Losses**
  - Urban: 58-60%
  - Interstate: 58-59%

- **Aerodynamic Losses**
  - Urban: 4-10%
  - Interstate: 15-22%

- **Inertia / Braking**
  - Urban: 15-20%
  - Interstate: 0-2%

- **Rolling Resistance**
  - Urban: 8-12%
  - Interstate: 13-16%

- **Auxiliary Loads**
  - Urban: 7-8%
  - Interstate: 1-4%

- **Drivetrain**
  - Urban: 5-6%
  - Interstate: 2-4%
SuperTruck Program Participants

Cummins Inc.
- Cummins Fuel Systems
- Cummins Turbo Technologies
- Cummins Emissions Solutions
- Cummins Electronics
- Cummins Filtration
- Modine
- VanDyne SuperTurbo Inc.
- Oak Ridge National Lab.
- Purdue University

Program Lead

Peterbilt Motors Company
- Eaton
- Delphi
- Modine
- Utility Trailer Manufacturing
- Bridgestone
- Dana
- U.S. Xpress
Vehicle Demonstrations of Freight Efficiency

- **Vehicle Demonstration #1 – Drive Cycle**
  - 75% at highway cruise
  - Gentle rolling hills
  - 11 hours of driving

- **Vehicle Demonstration #2**
  - 24 hour duty cycle
  - Extended Idle
  - No-idle compliant technology
  - Power demand < 3kW
  - Active power management
# Vehicle Freight Efficiency Path to Target

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<th>24 Hour Duty Cycle Vehicle Demonstration</th>
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Harmonized Tractor – Trailer Aerodynamics

Aerodynamic Improvement Evolution

- Will meet 50% freight efficiency improvement with technology that adheres to current transportation rules, regulations and existing transportation infrastructure
- Explore technologies that leverage changes in existing rules and regulations

1958
Cd = ~0.85

1999
Cd = ~0.55

1958 1999 Model 386 Model 587

SuperTruck Effort
## Vehicle Freight Efficiency Path to Target

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ISX Technology Roadmap for Efficiency Improvement

- Base Engine
  - PCP
  - Friction/Parasitics
- Fuel System
- Advanced LTC
- Variable Valve Actuation
- EGR Loop
- Turbo Technology
- Aftertreatment
- Controls
- Electrically Driven Components
- Waste Heat Recovery

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• Establish requirements for future vehicle communication architecture
• New level of vehicle and powertrain optimization for fuel efficiency
• Provide additional customer value
Acknowledgements

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- SuperTruck work supported by the Department of Energy under Award Number DE-EE0003403

- DoE Technology Development Manager: Roland Gravel