Innovative Approaches to Improving Engine Efficiency

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Agenda

Needs for Diesel Engine Efficiency Increase

Roadmap for Increasing Heavy Duty Diesel Engine Efficiency

Novel Engine Concepts

Challenges

Conclusions
Light and Heavy Duty Trucks Account for Increasing Highway Transportation Energy Use
Diesel engines are involved directly in 40% of all surface transportation fuel consumption.

Total U.S. Surface Transportation Diesel + Gasoline Fuel Use = 11.7 MBPD (Million Barrels Per Day)

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Truck Fuel Use

Heavy duty trucks are best early market entry for new fuel saving technologies

Heavy Duty Truck Technologies for Energy Efficiency

Engine Efficiency is the Biggest Opportunity

Source: Philip Patterson, Department of Energy projections.
Historical Perspective of HD Brake Thermal Efficiency

HDT DoE Effort
- Cummins Fuel System Technology (HPI EUI)
- Cummins Turbo Technology (VGT)
- Cummins Emissions Solution (DPF)
- Advanced Low Temperature Combustion (CEGR)

• Cummins Turbo Technology – VGT Improvements
• Combustion System Development
• EGR Cooling System

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1998 HD Engine Energy Balance

Fuel Energy 100%

Indicated Power 50%
- Gas Exchange 2.5%
- Friction 1.5%
- Accessories 2.5%

Heat Transfer 20%
- Brake Power 43.5%

Exhaust 30%

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2007 HD Engine Energy Balance

Fuel Energy 100%

Indicated Power 50%

Heat Transfer 26%

Exhaust 24%

Gas Exchange 4%

Friction 1.5%

Accessories 2.5%

Brake Power 42%

Increased Coolant Heat Rejection with CEGR

Advanced Combustion Improvements with CEGR and FIE

Increased back pressure to drive EGR

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Potential Advanced HD Engine Energy Balance

- Fuel Energy 100%
  - Indicated Power 58%
  - Heat Transfer 22%
  - Exhaust 20%
  - Gas Exchange 2%
  - Friction 1.0%
  - Accessories 2.5%
  - Brake Power 52.5%
Enabling Technology for Efficiency Improvement

Advanced Combustion
- Early PCCI
- Lifted Flame
- Stoichiometric
- Mixed Mode

Indicated Power 58%

Fuel Energy 100%

Heat Transfer 22%

Exhaust 20%

Gas Exchange 2%

Friction 1.0%

Accessories 2.5%

Brake Power 52.5%
Enabling Technology for Efficiency Improvement

Advanced Combustion
- FIE (Inj. Pressure, Multiple Injection)
- CEGR Cooling Systems
- Air Handling (Electrically assisted turbo)
- Increased Peak Cylinder Pressure
- Closed Loop Combustion Control

Fuel Energy 100%

Indicated Power 58%

Heat Transfer 22%

Exhaust 20%

Gas Exchange 2%

Friction 1.0%

Accessories 2.5%

Brake Power 52.5%
Enabling Technology for Efficiency Improvement

Fuel Energy 100%

Indicated Power 58%
Heat Transfer 22%
Exhaust 20%

Gas Exchange 2%

Gas Exchange
- Electrically assisted turbo
- EGR pump
- Variable valve actuation

Friction 1.0%
Accessories 2.5%
Brake Power 52.5%
Enabling Technology for Efficiency Improvement

Fuel Energy 100%

Indicated Power 58%
Heat Transfer 22%
Exhaust 20%

Gas Exchange 2%
Friction 1.0%
Accessories 2.5%
Brake Power 52.5%

Friction Reduction
- Piston and rings
- Bearings
- Surface treatment

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Enabling Technology for Efficiency Improvement

Fuel Energy 100%

Indicated Power 58%

Heat Transfer 22%

Exhaust 20%

Gas Exchange 2%
Friction 1.0%
Accessories 2.5%
Brake Power 52.5%

Exhaust Energy Recovery
- Efficient PM Aftertreatment
  - lower soot loading
  - low pressure drop
  - regen controls/strategy
- Exhaust Port Heat Transfer (liners)
Waste Energy Recovery for Advanced HD Engine

- Fuel Energy 100%
- Indicated Power 58%
- Heat Transfer 22%
- Exhaust 20%
- Gas Exchange 2%
- Friction 1.0%
- Accessories 2.5%
- Brake Power 52.5%

Customer Benefit

Frequent Start/Stop

Seldom Start/Stop

WHR

Hybrid

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Waste Energy Recovery for Advanced HD Engine

Waste Energy Recovery
- Organic Rankine Cycle
- Turbo compounding
- Brayton Cycle

Fuel Energy 100%

- Indicated Power 58%
- Heat Transfer 17%
- Exhaust 18.5%

Gas Exchange 2%
Friction 1.0%
Accessories 2.5%
Brake Power 59%
EGR Source (ORC) 5%
EGR + Exhaust Source 1.5%

Waste Energy Recovery

Fuel Energy

- Indicated Power
- Heat Transfer
- Exhaust

Indicated Power 58%

Heat Transfer 17%

Exhaust 18.5%

Gas Exchange 2%
Friction 1.0%
Accessories 2.5%
Brake Power 59%
EGR Source (ORC) 5%
EGR + Exhaust Source 1.5%

Waste Energy Recovery
- Organic Rankine Cycle
- Turbo compounding
- Brayton Cycle

Waste Energy Recovery

Fuel Energy

- Indicated Power
- Heat Transfer
- Exhaust

Indicated Power 58%

Heat Transfer 17%

Exhaust 18.5%

Gas Exchange 2%
Friction 1.0%
Accessories 2.5%
Brake Power 59%
EGR Source (ORC) 5%
EGR + Exhaust Source 1.5%

Waste Energy Recovery
- Organic Rankine Cycle
- Turbo compounding
- Brayton Cycle
Energy Balance for Advanced HD Engine with Electrification of the Vehicle

Fuel Energy 100%

- Indicated Power 58%
- Heat Transfer 17%
- Exhaust 18.5%
- Gas Exchange 2%
- Friction 1.0%
- Accessories 1.0%
- Brake Power 60.5%
- EGR Source (ORC) 5%
- EGR + Exhaust Source 1.5%

Electrified Vehicle
- HVAC
- Water pump
- Oil Pump
- APU

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Historical Perspective of HD Brake Thermal Efficiency

Waste Energy Recovery
- Waste Heat Recovery (EGR Derived)
- Waste Heat Recovery (Exhaust Energy Derived)
- Electrically Driven Accessories

Advanced Engine Concepts
Lower Friction to Improve Fuel Efficiency

3600RPM System Motoring BMEP Pareto

Just reducing piston skirt friction may reduce total friction torque by approximately 6%

Pareto data normalized I6, V6, & V8 motoring friction test results
Piston Skirt Friction
Alternative Engine Architecture

- Axial, barrel-type piston configuration
- Allows for integrated hybrid

Hybrid pistons
  Hydraulic
  Linear alternator
  Air pump

Conventional pistons
Opportunities for New Engine Concepts

- Reduced Parasitics

- Power Density
  - Weight
  - Size

- Highly Integrated with Power Train System
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2010 Emissions Compliant Diesel Engine

Hybrid with Downsized 2010 Emissions Compliant Diesel Engine

Hybrid with Advanced Concept Engines

Advanced Concept Engines

Hybrid System

Power (HP)

Weight (lbs.)
Challenges

- Emissions
- Design Constraints
- Controls
- Total Cost of Ownership
Conclusions

- Diesel Engine efficiency improvements are a significant lever for controlling petroleum consumption

- Efficiency levels beyond 55% are feasible
  - System integration is critical to control cost and provide additional system improvements
    - Waste energy recovery
    - Electrification

- New engine concepts are providing interesting possibilities