Innovative Approaches to Improving Engine Efficiency

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Deer Conference
August 14, 2007

Agenda

Needs for Diesel Engine Efficiency Increase

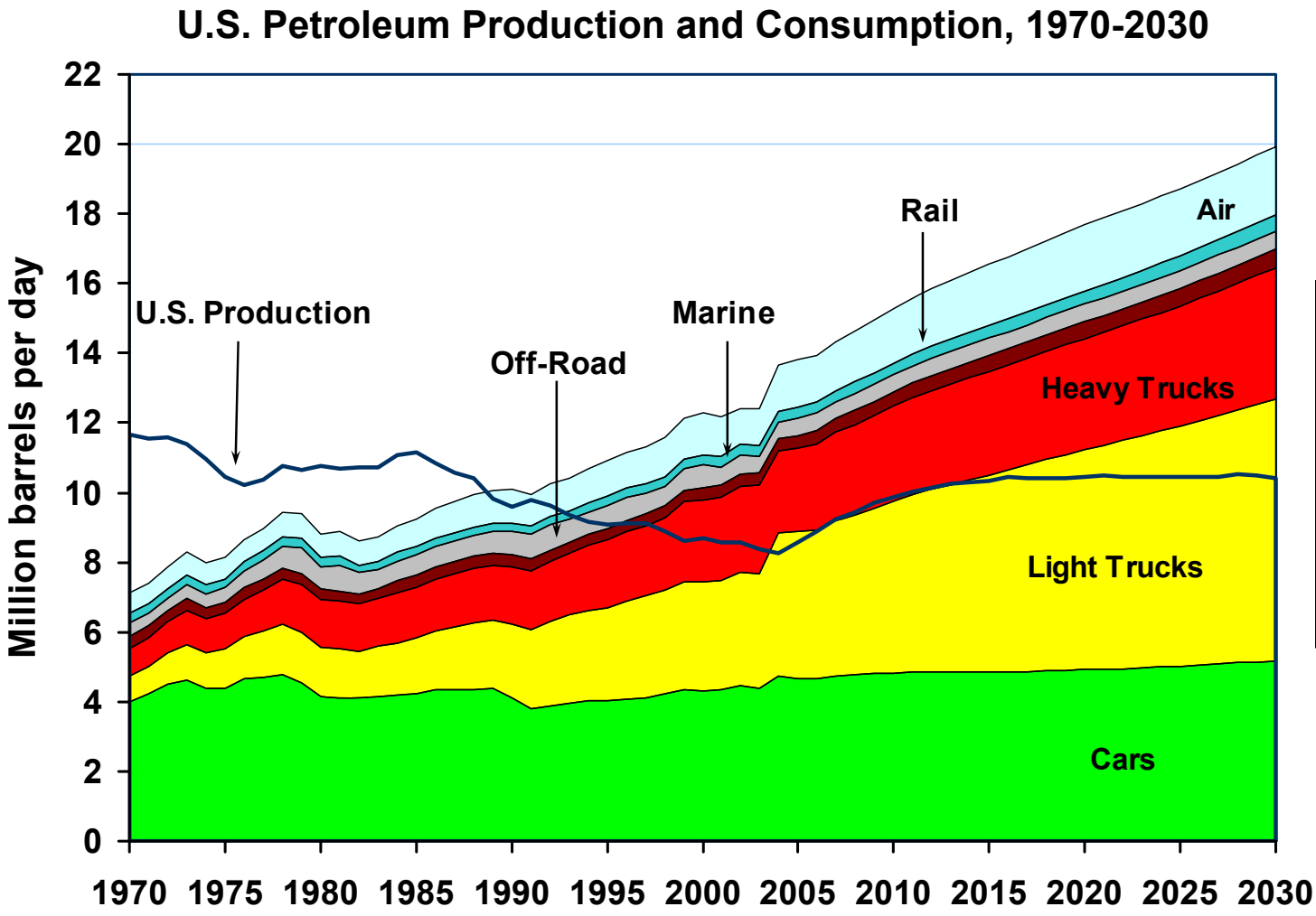
Roadmap for Increasing Heavy Duty Diesel Engine Efficiency

Novel Engine Concepts

Challenges

Conclusions

Petroleum Consumption

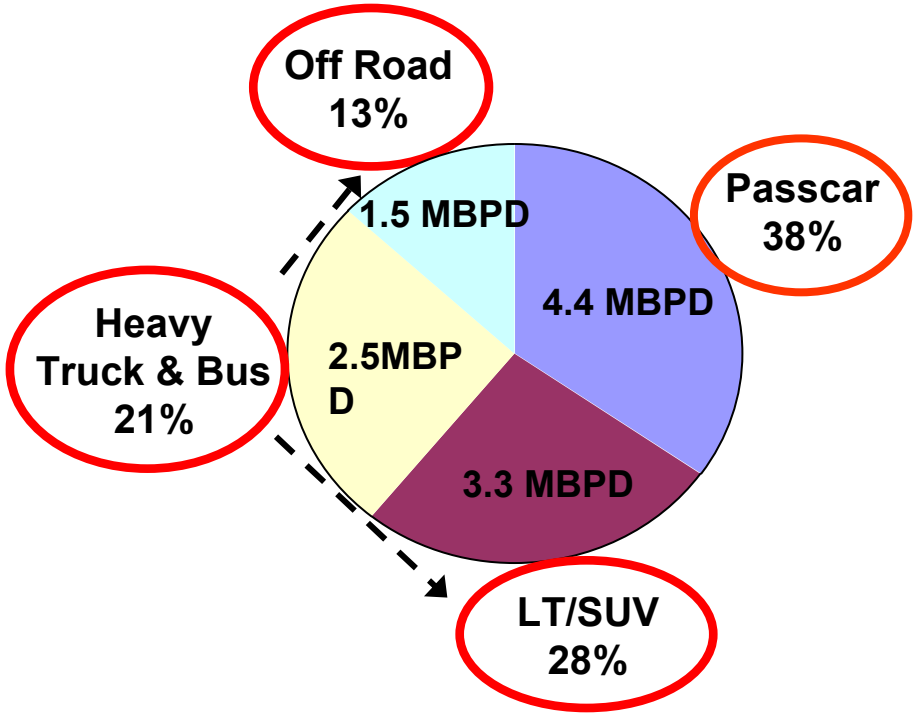


Light and Heavy Duty Trucks Account for Increasing Highway Transportation Energy Use

Sources: *Transportation Energy Data Book: Edition 25* and projections from *Annual Energy Outlook 2006*.

Surface Transportation Fuel Use

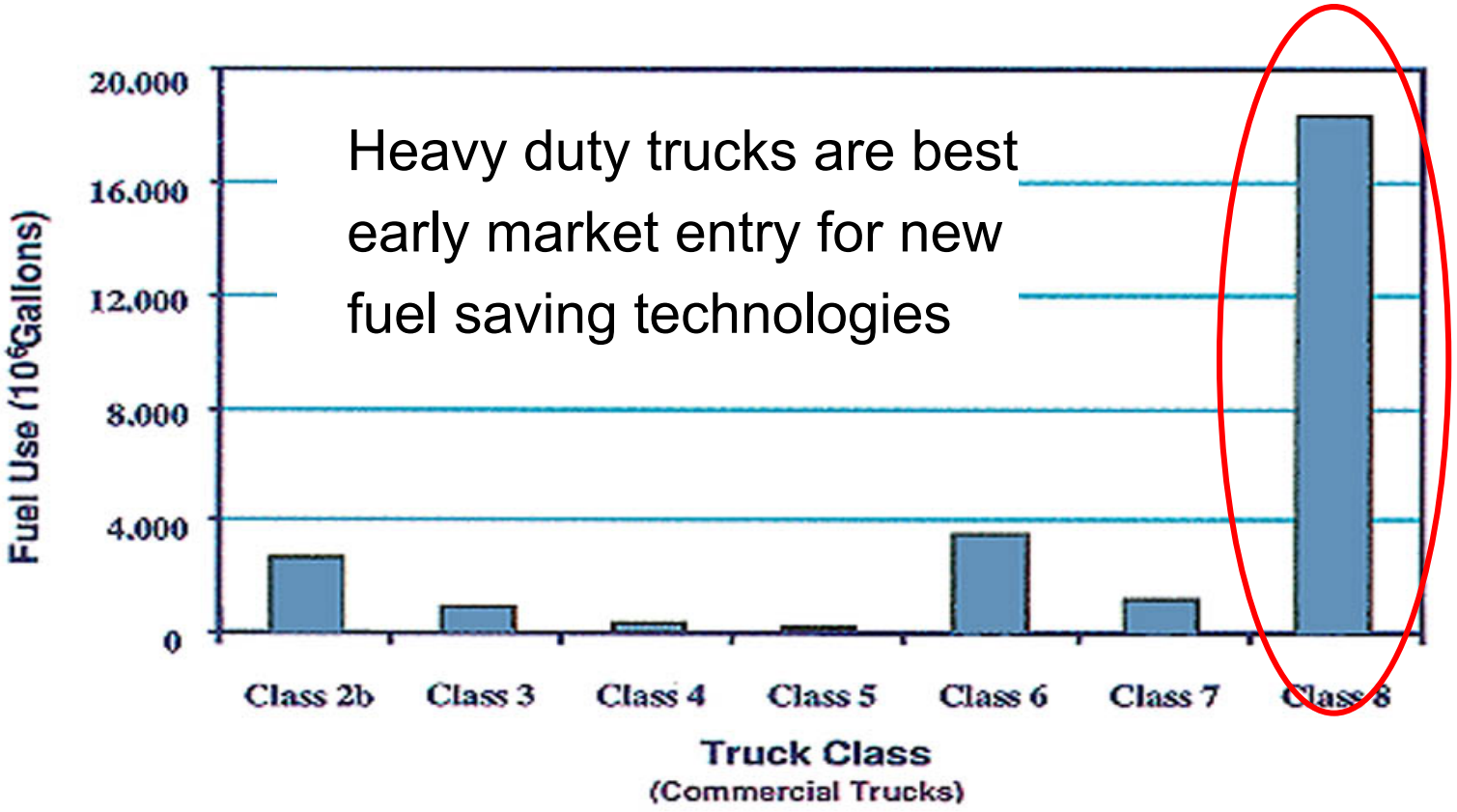
Diesel engines are involved directly in 40% of all surface transportation fuel consumption



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

Source: Trans. Energy Data Book, Edition 25, 2006

Truck Fuel Use

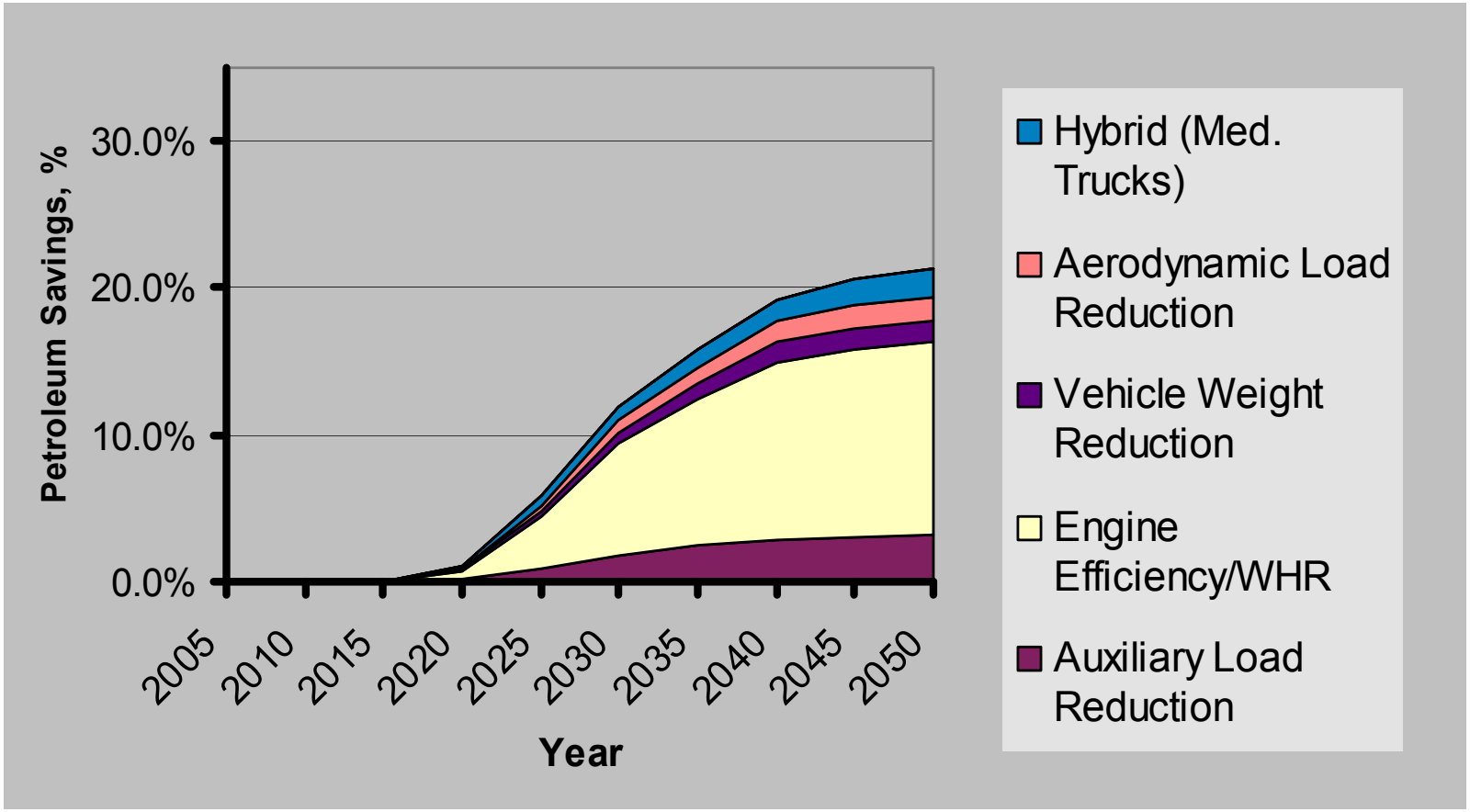


Annual fuel use by commercial trucks (based on VIUS data).

Source: 21st Century Truck Technical Roadmap – 2001, 1993 VIUS data

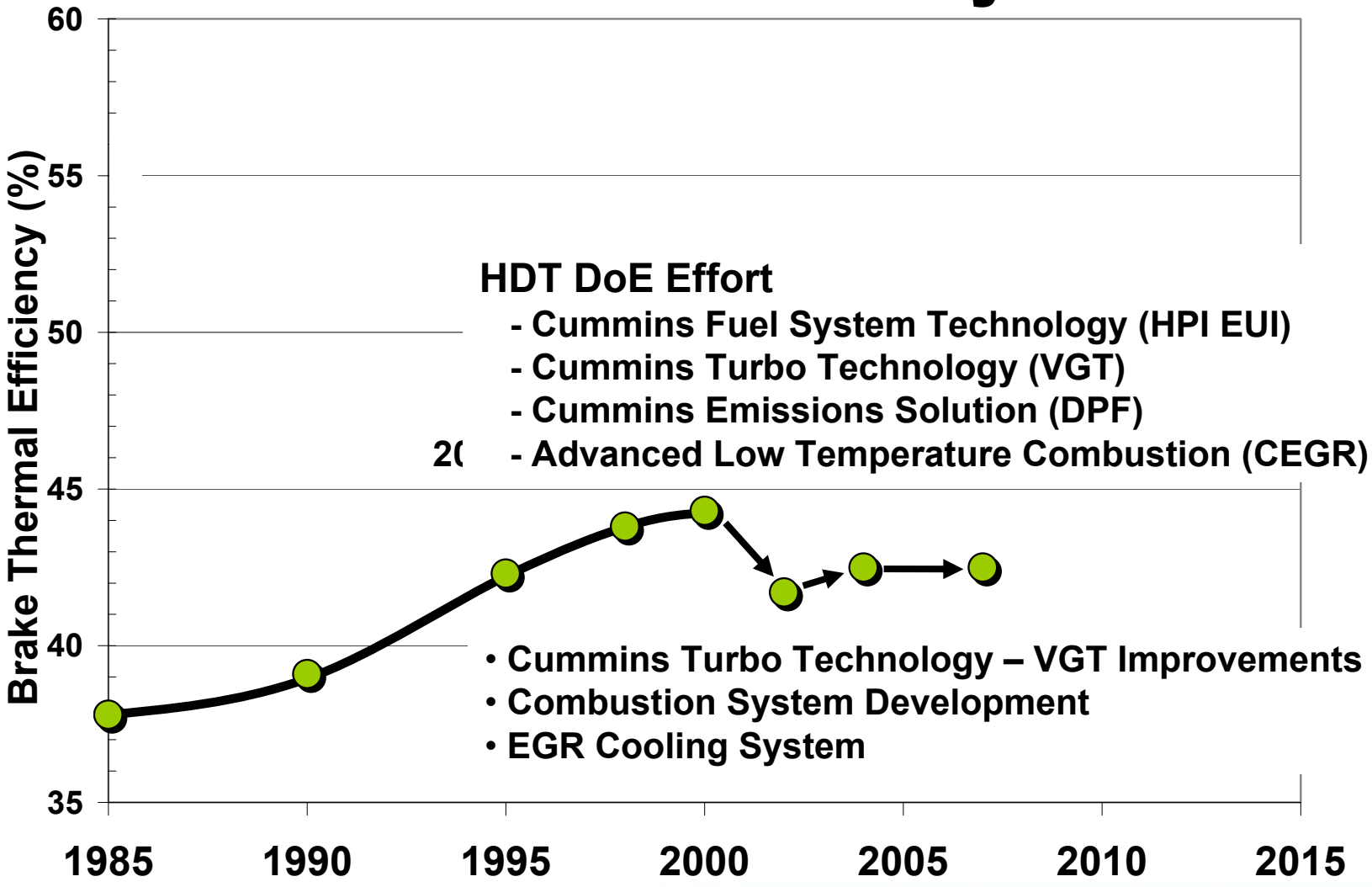
Heavy Duty Truck Technologies for Energy Efficiency

Engine Efficiency is the Biggest Opportunity

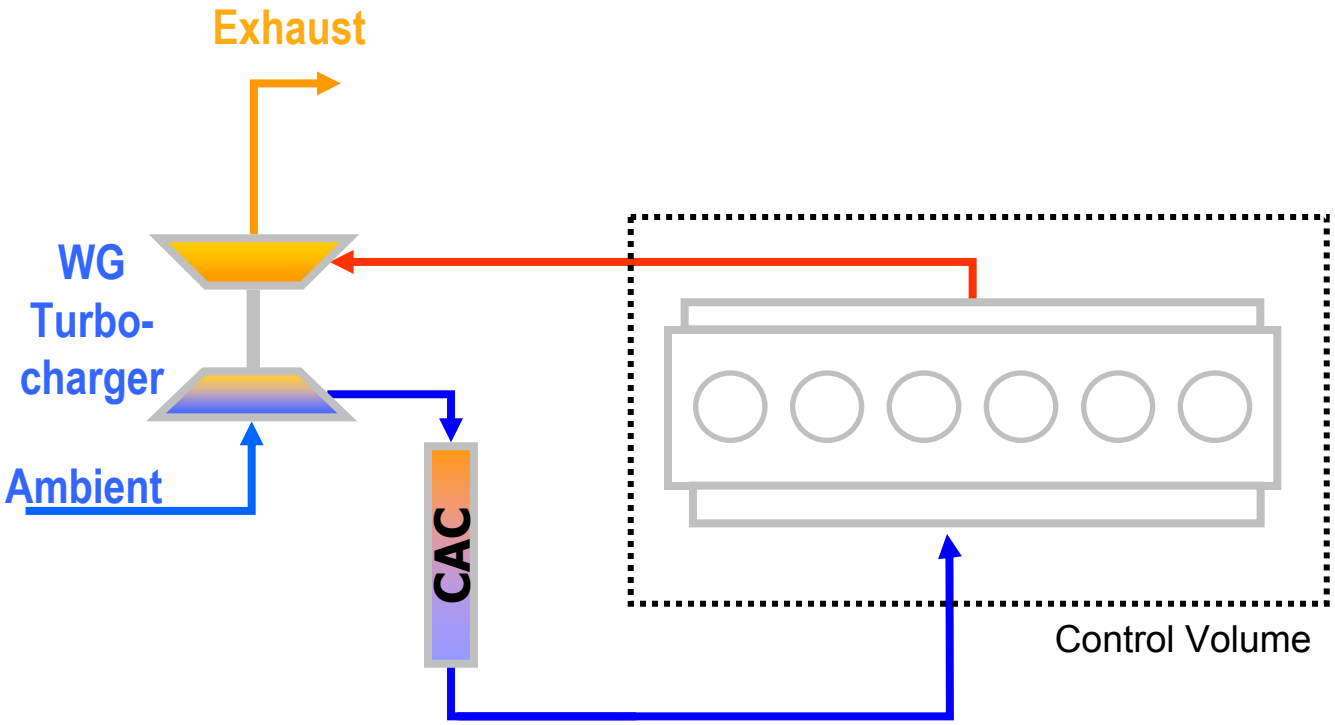


Source: Philip Patterson, Department of Energy projections.

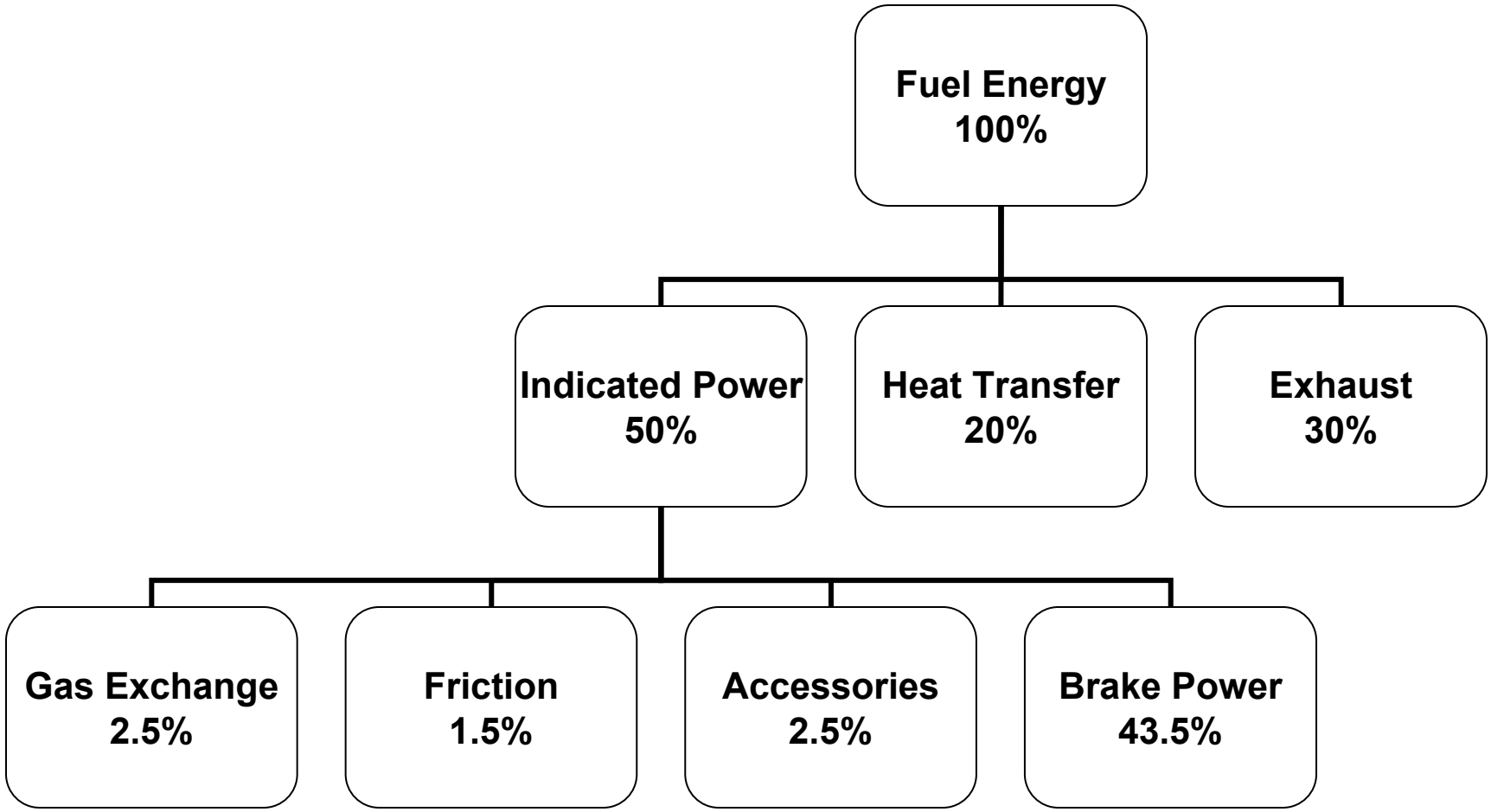
Historical Perspective of HD Brake Thermal Efficiency



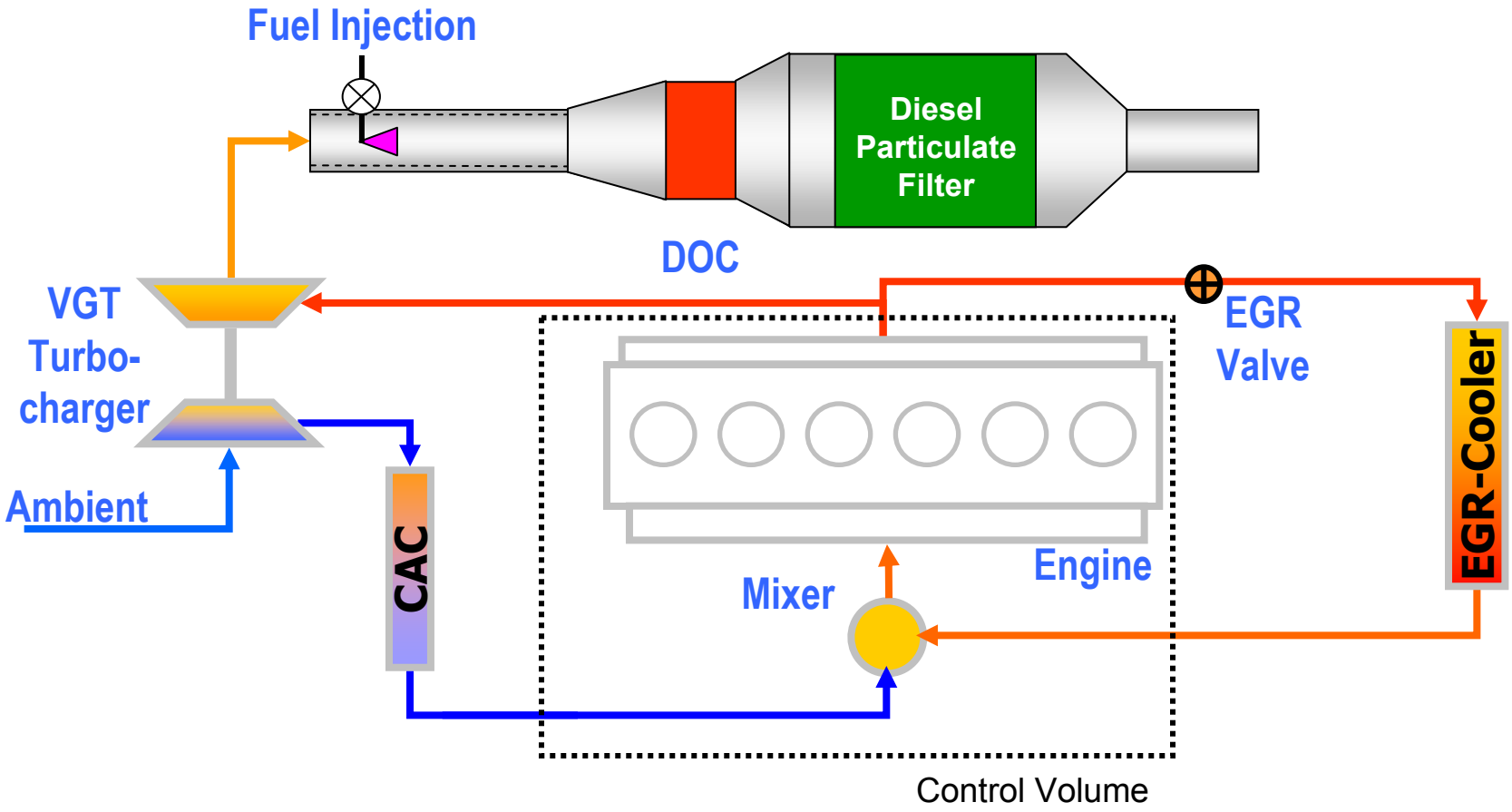
1998 HD Architecture



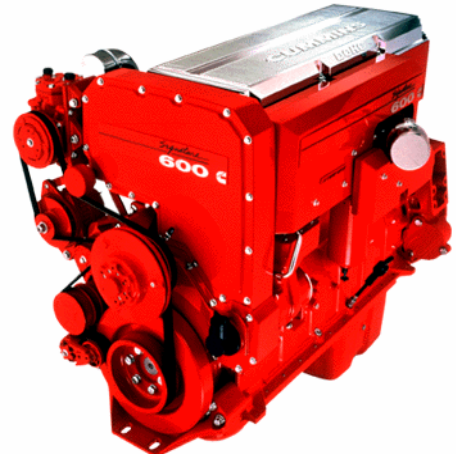
1998 HD Engine Energy Balance



2007 HD Architecture



2007 HD Engine Energy Balance



Advanced Combustion Improvements with CEGR and FIE

Fuel Energy 100%

Indicated Power 50%

Heat Transfer 26%

Exhaust 24%

Increased Coolant Heat Rejection with CEGR

Gas Exchange 4%

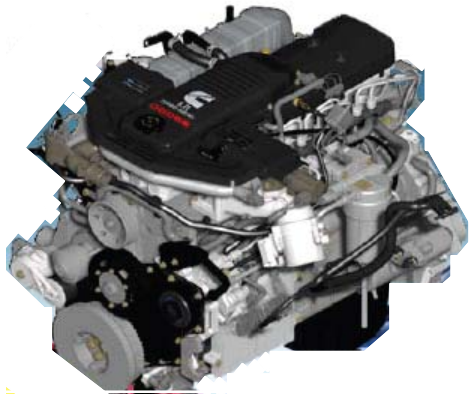
Friction 1.5%

Accessories 2.5%

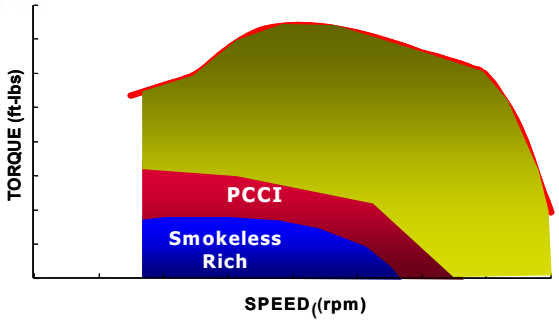
Brake Power 42%

Increased back pressure to drive EGR

Potential Advanced HD Engine Energy Balance

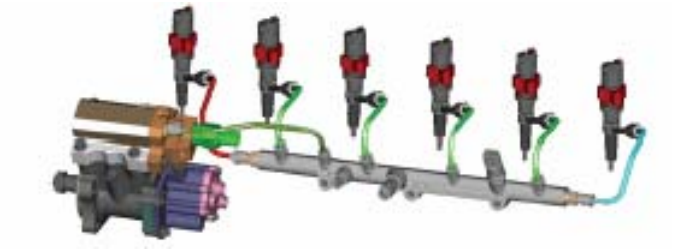


Enabling Technology for Efficiency Improvement



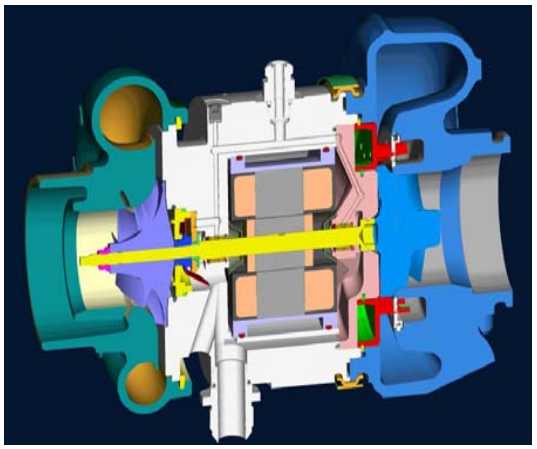
Advanced Combustion
- Early PCCI
- Lifted Flame
- Stoichiometric
- Mixed Mode

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

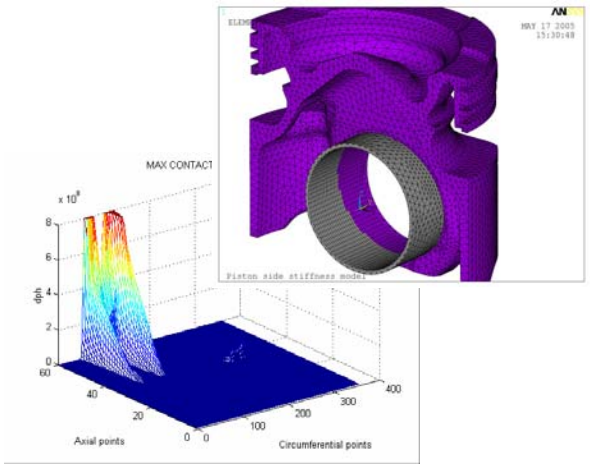
Enabling Technology for Efficiency Improvement



Gas Exchange

- Electrically assisted turbo
- EGR pump
- Variable valve actuation

Enabling Technology for Efficiency Improvement



Fuel Energy
100%

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

Friction Reduction
- Piston and rings
- Bearings
- Surface treatment

Enabling Technology for Efficiency Improvement

Fuel Energy 100%

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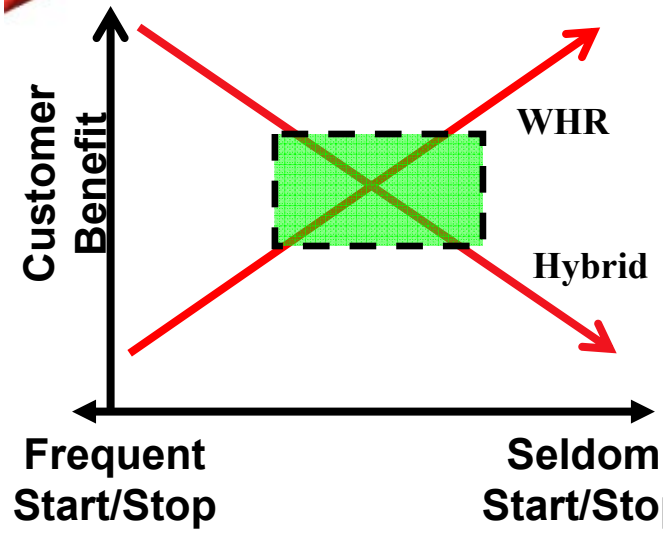
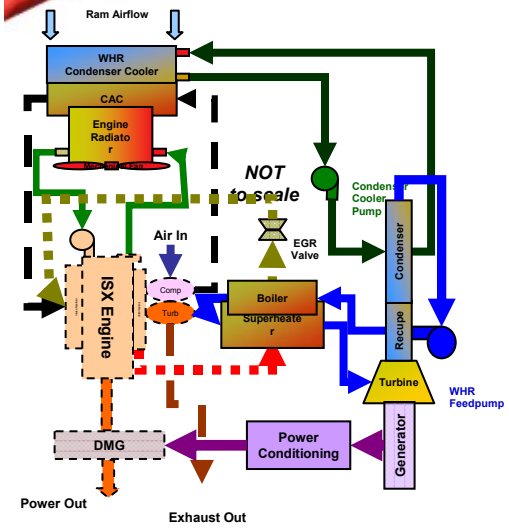
Exhaust Energy Recovery

- Efficient PM Aftertreatment
  - lower soot loading
  - low pressure drop
  - regen controls/strategy
- Exhaust Port Heat Transfer (liners)

Waste Energy Recovery for Advanced HD Engine



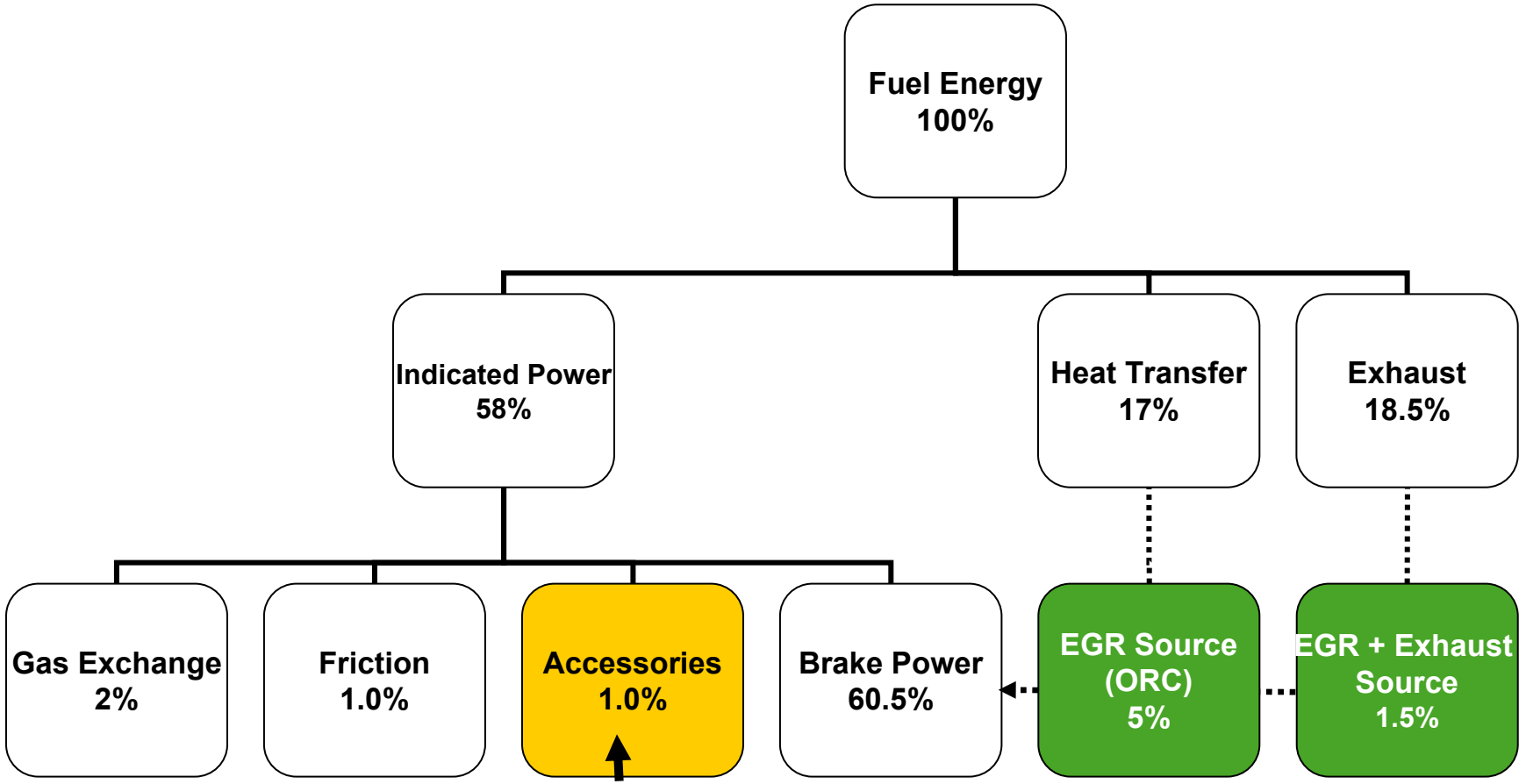
Waste Energy Recovery for Advanced HD Engine



Waste Energy Recovery

- Organic Rankine Cycle
- Turbo compounding
- Brayton Cycle

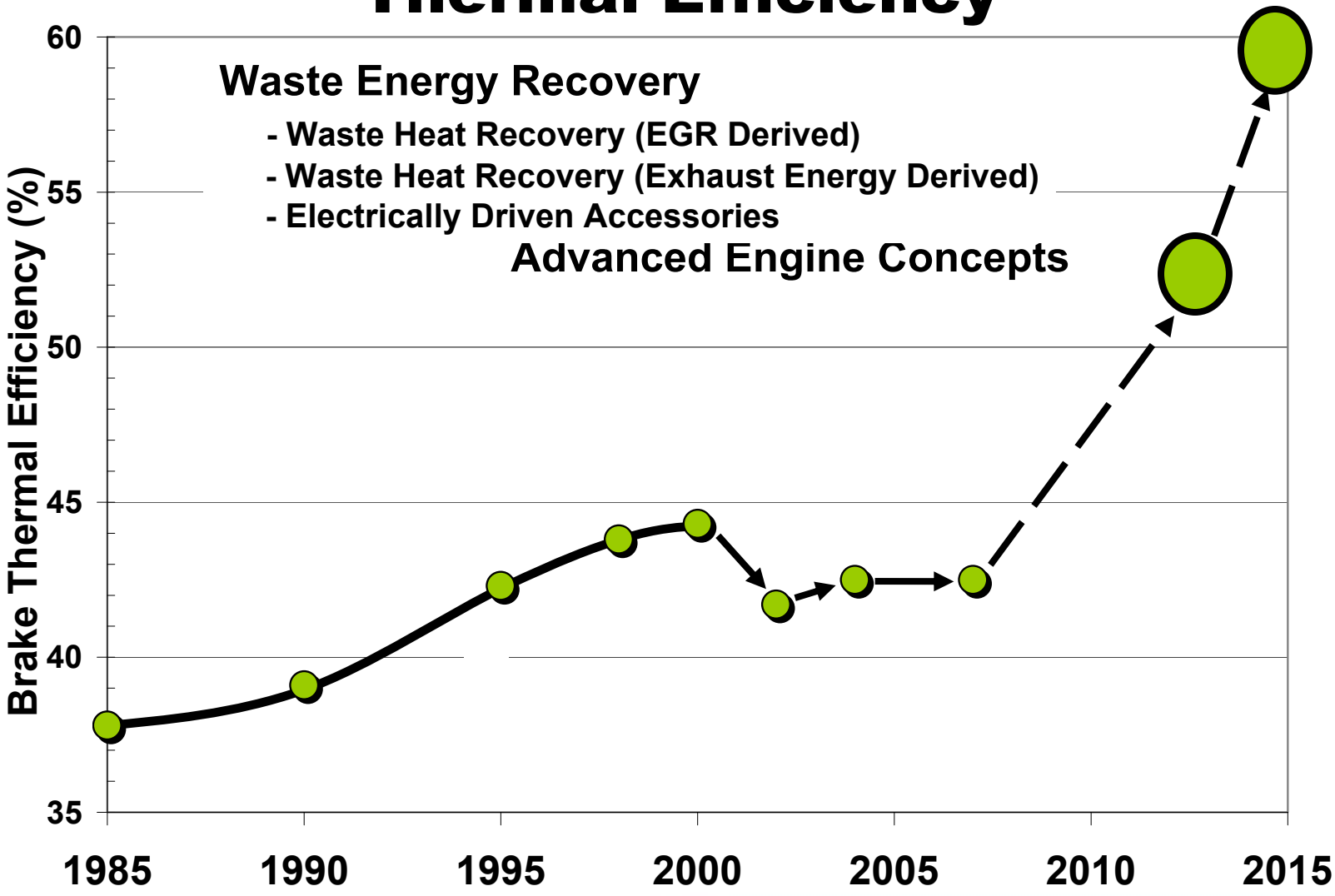
Energy Balance for Advanced HD Engine with Electrification of the Vehicle



Electrified Vehicle

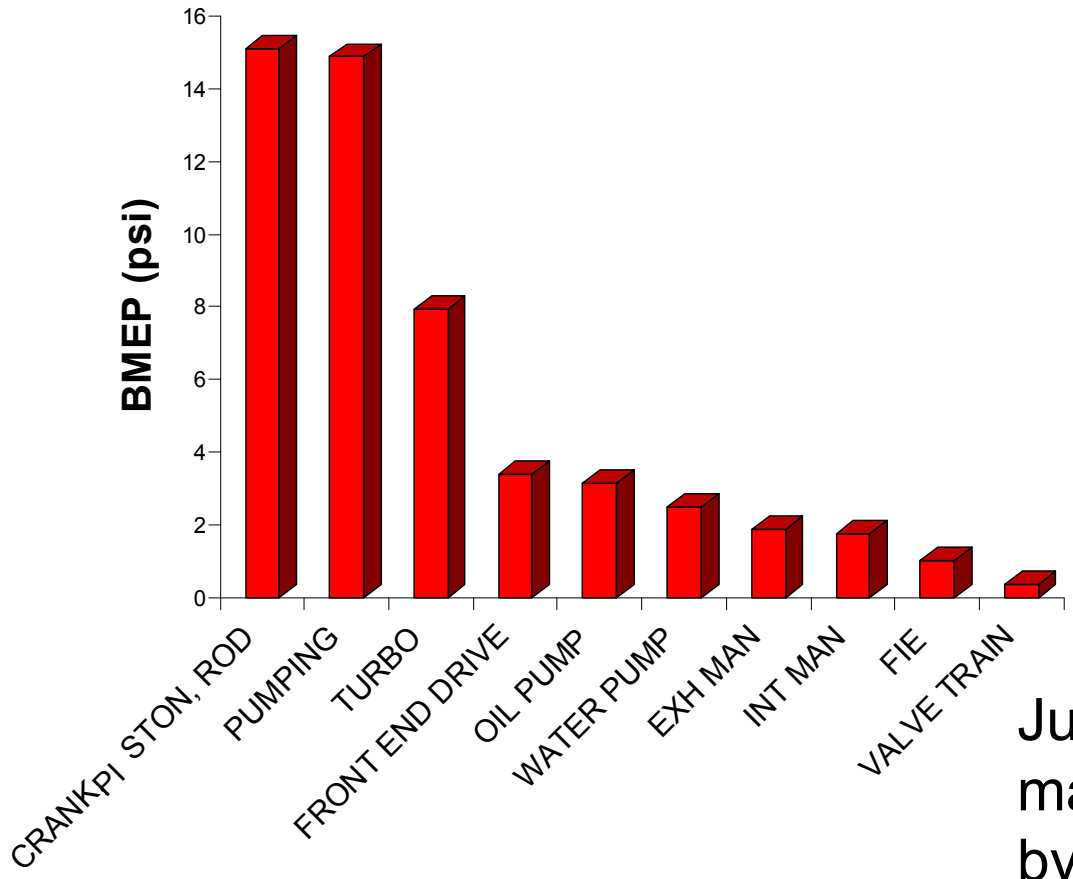
- HVAC
- Water pump
- Oil Pump
- APU

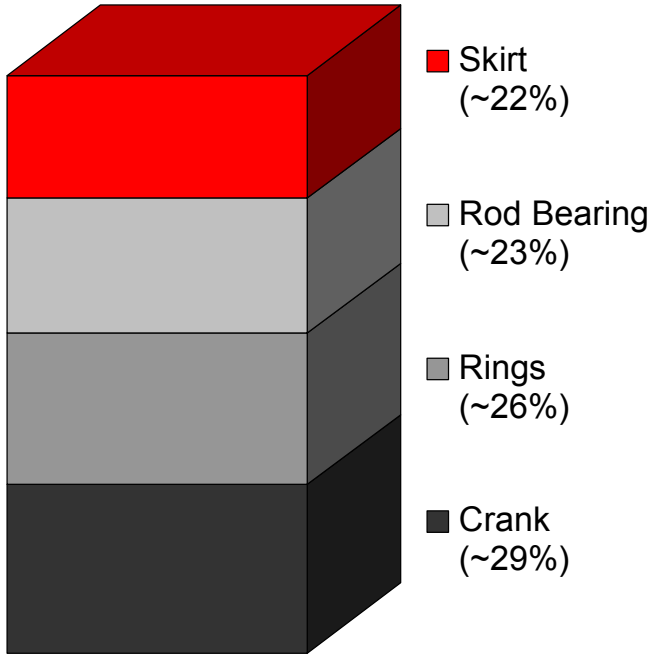
Historical Perspective of HD Brake Thermal Efficiency



Lower Friction to Improve Fuel Efficiency

3600RPM System Motoring BMEP Pareto

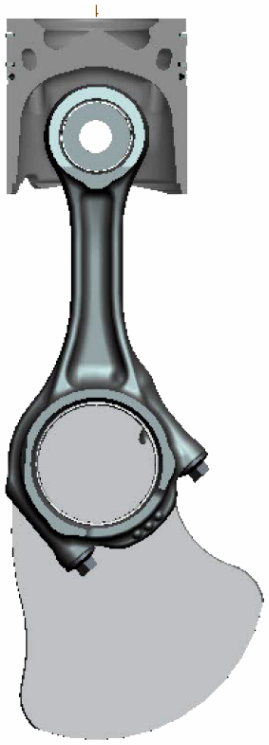


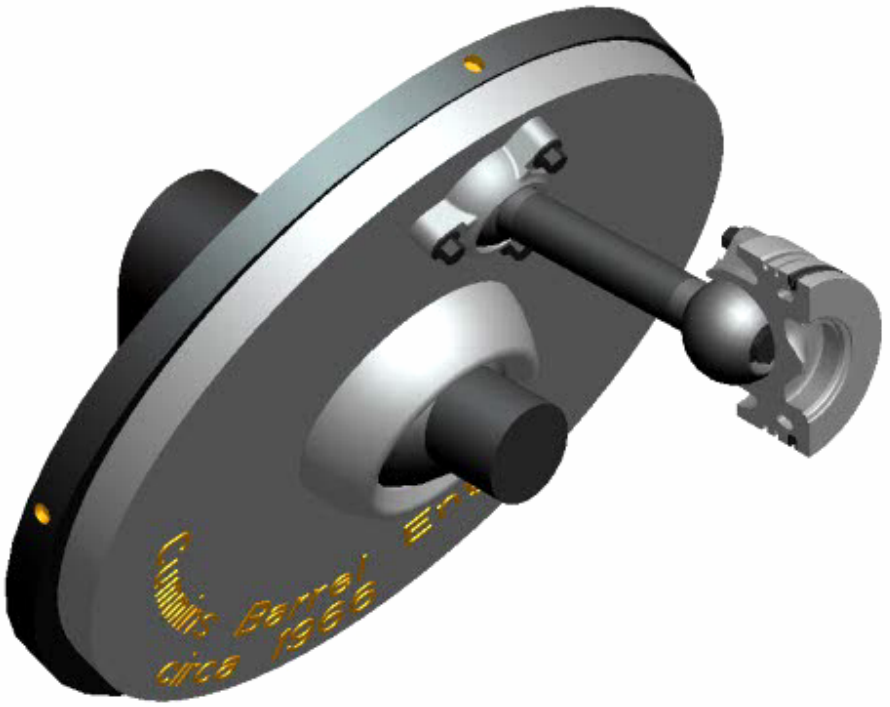


Just reducing piston skirt friction may reduce total friction torque by approximately 6%

Pareto data normalized I6, V6, & V8 motoring friction test results

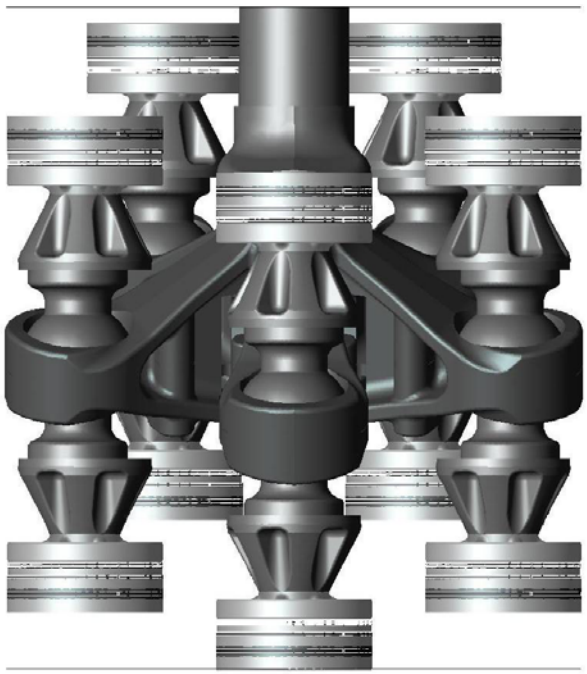
Piston Skirt Friction





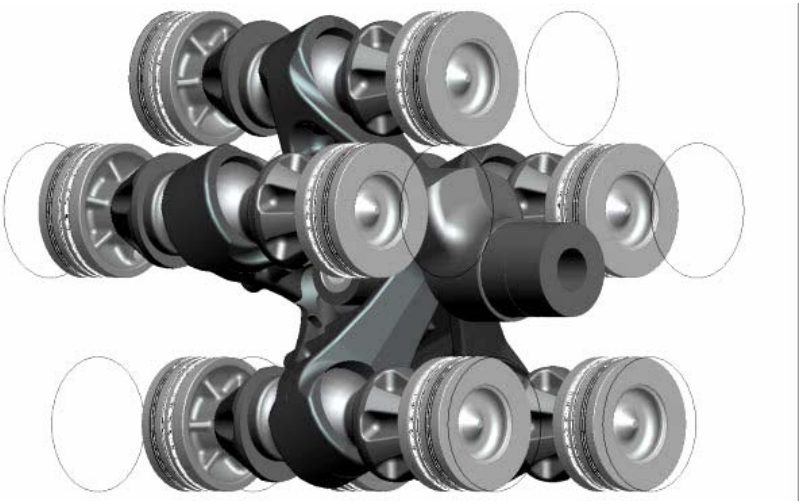
Alternative Engine Architecture

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



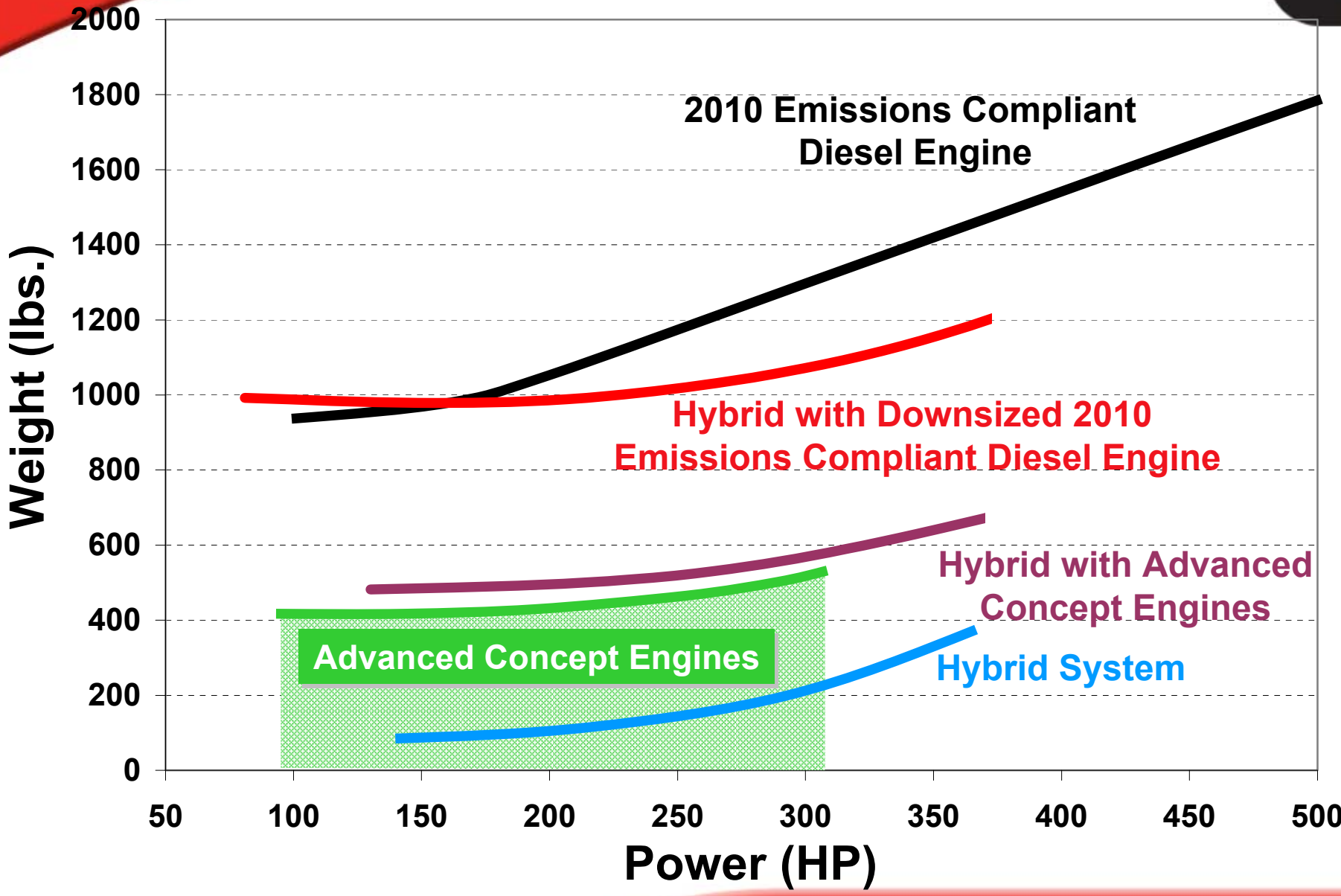
Hybrid pistons
- Hydraulic
- Linear alternator
- Air pump

Conventional pistons



Opportunities for New Engine Concepts

- Reduced Parasitics
- Power Density
  - Weight
  - Size
- Highly Integrated with Power Train System


2000
1800
1600
1400
1200
1000
800
600
400
200
0
Weight (lbs.)
50
100
150
200
250
300
350
400
450
500
Power (HP)
2010 Emissions Compliant Diesel Engine
Hybrid with Downsized 2010 Emissions Compliant Diesel Engine
Hybrid with Advanced Concept Engines
Advanced Concept Engines
Hybrid System

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