Emerging Engine Technologies for Heavy Duty Vehicle Fuel Efficiency

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SuperTruck Technology Contributions

- Engine: 42%
- Driveline & Tires: 14%
- Vehicle Aero: 44%
- Tractor Aero: 29%
- Trailer Aero: 15%

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Technologies for 50% Engine Thermal Efficiency

Combustion & Air Handling
- Piston bowl size and shape
- Injector specification
- Calibration optimization
- Turbocharger efficiency
- Aftertreatment optimization

Parasitic reductions
- Shaft seal
- Variable flow lube pump and viscosity
- Geartrain
- Cylinder kit friction
- Cooling and fuel pump power

WHR system
- EGR, exhaust, recuperator
- Turbine expander
- Low GWP refrigerant

SuperTruck Efficiency Improvement Results

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## 2020 – 2030 CO₂ Reduction Potential

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<th>Potential % Improvement vs. 2017 Standards (On the Certification Cycle)</th>
<th>Key Technologies</th>
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<td><strong>Engine</strong> 9 - 15</td>
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<td>Turbocharger and EGR Air Handling</td>
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<td>Friction and Parasitic Reductions</td>
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<td>Integration*</td>
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* Not realized on the engine certification cycle
Waste Heat Recovery Technology

Waste Heat Exhausted to Air

Engine Power
Waste Heat Recovery Technology

Exhaust to Air

Pump

Boiler Takes in heat

Waste Heat

Engine Power

Expander

Additional Power

Condenser Releases Unusable Heat

Exhaust to Air

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History of Automotive WHR Development at CMI

- **Gen 0 WHR**
  - Single operating point, test-call demo
  - Working Fluid: Tri-fluoro-ethanol
  - Single-stage turbine expander
  - Coolant, CA, Exhaust, EGR WHR
  - Electric power generation

- **Gen 1 WHR**
  - Vehicle-intent WHR, test-cell demo
  - Working Fluid: R245fa
  - Single-stage turbine
  - EGR, Exhaust WHR
  - Packaged in vehicle
  - Electrically coupled to engine

- **Gen 2 WHR**
  - Vehicle-intent WHR, test-cell demo
  - Working Fluid: R245fa and alternatives
  - Single-stage turbine
  - EGR, Exhaust, CAC WHR
  - Mechanically coupled to engine

- **Gen 3 WHR**
  - Vehicle installation and demo
  - Working Fluid: R245fa (& low GWP fluids)
  - Single-stage turbine expander
  - EGR, Exhaust WHR
  - Mechanically coupled to engine

- **HD Truck Engine Program**
- **Exhaust Energy Recovery Program**
- **SuperTruck**
SuperTruck WHR System Overview

- Extraction of energy from Exhaust & EGR stream
- Extracted energy heats working fluid to a "dry" superheated vapor.
- Superheated vapor expands through a Turbine Expander.
- The resulting power to the turbine output shaft is put back to the engine crankshaft through a gearbox.

Ram Airflow

1. Pump
2. Recuperator
3. EGR Heat Exchanger
4. Turbine Expander
5. Exhaust Heat Exchanger
6. WHR Condenser

CAC
Radiator

Intake Manifold
Exhaust Manifold

Power Out

Aftertreatment

Tailpipe

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WHR FAQ

- What about vehicle impact?

- What about regional haul?
Three WHR equipped Trucks currently operational with a combined ~75k miles
WHR Cycle Sensitivity

WHR Provides Benefit Across Power and Cycle Ranges

WHR Fuel Consumption Benefit (%) vs. Transient Content in Drive Cycle

Range of Engine Power Levels

Line Haul
Regional Haul

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WHR Future

WHR Fuel Consumption Benefit

- Higher Coolant Temp.
- High Efficiency Expander
- High Efficiency Feed Pump
- Mechanical Drive Efficiency Improvement

WHR Cycle Performance

- Variable Geometry Expander
- Improved Heat Exchangers
- Optimized Vehicle Integration

Waste Heat Availability

- Base Engine Efficiency Improvements
- Amount of EGR

4-5%

2014 2021 2024 2029
Engine Connection to Other Technologies

- Hybrid and Stop-Start
- Vehicle Integration
- Connectivity and Telematics
- Transmission Integration
Engine Transmission Integration

Perf Information

AEB’s

Application

Co-development

Improving Fuel Consumption

Eng + Trans + OEM

Co-design

Application

Cooperation

Collaboration

AEB’s

Perf Information

AEB’s

Application
Engine Technology Summary

- Engine technology can provide significant improvement in fuel consumption and CO$_2$ emissions

- System optimization is important

- Waste Heat Recovery technology is progressing

- Optimized powertrain integration will provide significant fuel consumption improvement