Waste Heat Recovery for Heavy Duty Vehicles

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“This presentation does not contain any proprietary or confidential information”
Goals and Objectives

Concept from final phase of Cummins’ HDTE project

Project Goals are:
- 10% Fuel Efficiency Improvement
- Reduce or eliminate the need for increased heat rejection capacity for future heavy duty engines in Class 8 Tractors

A 10% increase in fuel efficiency would:
- Save a linehaul, Class 8 truck over 1800 gallons of fuel per year
- Reduce exhaust emissions due to less fuel use

Reducing the need for increased heat rejection:
- Helps maintain the aerodynamic advantages of today’s trucks
Approach

Incorporation of a Rankine Cycle Waste Heat Recovery System with Cummins ISX Engine

Recovered energy is converted to electricity which supplements the engine’s output power via a Flywheel Motor Generator

Pathway to Program Efficiency Goal -
- EGR Heat Recovery: 6% Improvement
- Selective Exhaust Heat Recovery: 2% Improvement
- ‘More Electric’ Accessories: 2% Improvement

10% Achievement

Recovery of Waste Heat will provide additional engine power and mitigate the increased EGR heat load required to meet stringent emission requirements
ISX Technology Roadmap for Efficiency Improvement

- Variable Valve Actuation
- Fuel System
- Advanced Combustion
- Variable Intake Swirl
- EGR Loop
  - Lower Pressure Drop
  - Alternative Cooling
- Controls
- Electrically Driven Components
- Turbo and Air Handling
- Aftertreatment
- Waste Heat Recovery

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Approach - EGR Only WHR

~6% efficiency benefit across drive cycle

>6% benefit at level cruise

Initial architecture

On-engine system

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Performance Measures and Accomplishments - Phase I - Applied Research - Heat Input Analysis

- WHR heat input is limited by the capability of the vehicle’s cooling package
  - Quantity of heat rejection is reduced with WHR, however…
  - Smaller $\Delta T$ to ambient requires increased cooling package size
  - Dictates the use of highest quality (temperature) heat input only

<table>
<thead>
<tr>
<th>Heat Source</th>
<th>Selection Rationale</th>
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<tbody>
<tr>
<td>Jacket Water</td>
<td>Fluid temperature is too low to be useful. Offers limited pre-heating potential.</td>
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<tr>
<td>Charge Air</td>
<td>Vehicle heat rejection limitations prevent efficient utilization. Would also add significant $\Delta P$ to CA system.</td>
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<tr>
<td>EGR</td>
<td>Highest temperature source enables higher cycle efficiency with reasonably sized heat exchangers.</td>
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<tr>
<td>Exhaust Gas</td>
<td>High temperature heat source, however, required engine cooling already fully utilizes vehicle’s heat rejection capacity.</td>
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<tr>
<td>Recuperator</td>
<td>Allows significant preheating to occur internal to the WHR cycle. Reduces condenser heat rejection load.</td>
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Approach - WHR On-Engine

Condenser

boost pump

rear crossover tube

Flywheel-Motor-Generator
Working Fluid – R245fa

Main Advantages of R245fa
- Hydrofluorocarbon
  - Not a chlorinated fluorocarbon
- Non Ozone Depleting
- Low Global Warming Potential
- Non-Flammable

- Also –
  - Good heat transfer ability
  - Excellent Thermal Stability
  - Low viscosity

- It can work with the existing AC tool set in service shops
- It runs above atmospheric in its cycle
  - Similar in behavior to R134a
Turbine Generator

30 Hp Max. Continuous Power

17” long x 6” dia

84k rpm Operating Speed

340VAC, Permanent Magnet Alternator, 2-pole, 3 Phase

SmCo Magnets

Inconel Retention Sleeve

Hybrid-Ceramic Ball Bearings
Boost/Feed Pumps

Boost Pump –
- 60 psid
- 3-9krpm
- 7.5 lbs
- Hermetically Sealed
- Variable Speed
- CAN Bus Control Interface

Feed Pump –
- 300 psid
- 0.7-1.7 lbm/sec flow
- 25krpm
- 8 lbs
- Ball Bearing
- Hermetically Sealed
- CAN Bus Control Interface
Flywheel Motor/Generator

Stators – assembled around water jacket core and installed into Flywheel Housing
Flywheel Motor/Generator

Assembled FMG on test at CGT

Half of Rotor Assembly showing magnet mounting details
Stator/Cooling Jacket are assembled into Flywheel Housing – extended by 93mm

Standard Ring Gear and Starter are used
Coolant Pump and Controller

EMP C26 Pump
Low Temperature Cooling Loop pump for Condenser and Electronics

Nearly off-the-shelf item from EMP, pre-production prototype at 24VDC

340VDC version available
Extracts Waste EGR Heat primarily -

Takes in Waste Exhaust Heat when off-peak

WHR Loop kept at peak power as much as possible

~8% efficiency benefit across the drive cycle.

>8% improvement at cruise

‘More Electric’ Accessories will add 2% benefit
Summary

Cummins Rankine Cycle Waste Heat Recovery –

A clear path to the 10% Efficiency Improvement Goal and mitigates cooling system size increases

Directly aligned with the Goals of:

- Enhancing energy efficiency
- Bringing clean, reliable and affordable energy technology to the marketplace

Thank You!