Exhaust Energy Recovery

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Energy Recovery Agenda

- Program and Goals
- Recovery System
- Technology Challenges
- Customer Benefits
- Summary and Questions
Program Goals

- **Improve fuel efficiency by 10% by recovering waste heat energy**
  - Composite Improvement
  - MY2010 Base Engine Assumed

- Reduce the need for additional heat rejection capacity

- Provide charge cooling capacity to support engine combustion
Recovery System

Proposed Solution -

- Integrate a Rankine Cycle system with the ISX engine to recover waste heat energy from the engine’s CAC and EGR

This solution continues the energy recovery effort initiated under the HDTE program
Program Timeline

May 2005 2006 2007 2008

Phase I
Applied Research
10/14/05

Phase II
Component Development
8/25/07

Phase III
Advanced Development
3/08

Phase IV
Engineering Development
Program End 2/09

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Recovery System Example

HDTE Phase IIB

- 2010 emissions-capable engine
- Operated at Peak Torque Condition - Highest quality heat to recover with best base engine efficiency
- Rankine cycle extracted waste energy from jacket water, charge air, exhaust and EGR

42.5 kWe / 57 Hp Recovered Power

Achieved Program goal of 50.0% BTE

Peak WHR Cycle Efficiency was 21.0%

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Diesel/Rankine Cycle Schematic

Rankine Cycle capturing energy from EGR and combined EGR and CAC (CCAC)

Working fluid is proposed as R245fa
Honeywell Genetron
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
Vehicle Integration

The proposed solution must be integrated into a Class 8 Tractor and be demonstrated on-highway.

We are planning on using the International ProStar for this program.
Technology Pallet

- WHR Turbine Design
- Vehicle/Driveline Integration
- Program Goals
- Electric Power Engineering
- Energy Storage
- System Plumbing
- Power Management And Control

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Turbine/Generator Designs

- Radial inflow turbine
- Axial flow turbine

Both turbine technologies are being evaluated. Partial Admission or Variable Nozzle concepts to broaden operating map width are being considered.

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Power Engineering

- On-Vehicle High Voltage Bus
  Departure from typical 12 VDC
- Incorporates technology common with HEV
  Battery Storage, Power Conditioning, etc.
- Offers opportunities for high voltage accessories
  Driveline Motor/Generator  Electric Fans
  Coolant Pump(s)  Air Compressor
  Power Steering  HVAC
  etc.

*Engine duty cycles and Subsystem duty cycles must be studied and compared for best overall in-vehicle efficiency improvement*

- A comprehensive Energy Utilization study will be performed
Heat Exchanger Technology

- Combined Charge Coolers (Fresh Air and EGR)
  Corrosion/Fouling issues
- Single and 2-Phase Fluid Conditions
  Will require different designs/types at different points
- High Pressure (500 psia) working fluid
  Against lower pressure air/exhaust gases
- Space/weight/performance constraints
- Plumbing and connections similar to current HVAC systems but up-scaled for pressures/temperatures
Vehicle/Driveline Integration

- Driveline motor (/generator)
  - May replace alternator/belt assembly
  - Size depends on power management strategy
  - May influence transmission matching and tuning
  - Active crank damping being investigated

- Electric Cooling Fans
  - Necessary to provide shutdown cooling for WHR system
  - Will supplement mechanical fan and minimize its operation
  - Offers opportunities to further optimize overall cooling system
Customer Benefits

Recovery of Combined Charge CAC/EGR and EGR will achieve the program 10% performance goal and –

*reduce CAC and EGR heat rejection by the recovery cycle efficiency –*

~20% at peak power conditions

This reduction offers a **significant** benefit to the Vehicle OEM
Customer Benefits

A 10% fuel savings represents ~$9000 savings across an 18 month payback to a Class 8, Linehaul end user (at $3/gal and 120,000 miles per year).

- To make this additional system attractive it must cost significantly less than this to purchase and -
  - It must cost significantly less than this to manufacture.

Feasibility must be demonstrated not only in-vehicle but also in-cost
Summary

Going Beyond the Engine –

• New Thermodynamic Cycle
  It’s not just diesel anymore

• Non-Traditional Fluid
  2 Phases and it’s not coolant

• High Voltage Power Engineering –
  Much more than 12V

• System Power Management –
  Parasitics, Vehicle Needs, etc.

A challenging technology development program that will affect how we approach on-vehicle power systems -
Thanks to our Sponsor!

Cummins Inc. thanks –

*The United States Department of Energy*

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