Exhaust Energy Recovery
2008 DEER Conference

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Research & Technology

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Agenda

Program Objectives

- WHR Concept and Efficiency Goal Plan
- Program Schedule

First Generation Hardware and Evaluation

- Engine-integrated hardware set
- Performance Testing Results

2nd Generation Hardware Evolution

Summary
Goals and Objectives

Project Goals are:

- **10% Fuel Efficiency Improvement**
- **Reduce the need for increased heat rejection capacity for future heavy duty engines in Class 8 Tractors**

10% increase in fuel efficiency would:

- **Save a linehaul, Class 8 truck over 1800 gallons of fuel per year (120k miles/year at 6mpg)**
- **Reduce exhaust emissions due to less fuel use**

Reduced need for increased heat rejection:

- **Help maintain the aerodynamic advantages of today’s trucks**
Waste Heat Recovery Concept

Organic Rankine Cycle

Converts otherwise wasted thermal energy from the EGR and main exhaust gas streams

Works best for high-EGR flow engine recipes for low-NOx combustion
Recipe for 10% Efficiency Improvement

6% from EGR energy

+ 2% from Exhaust

+ 2% from Electric Acc.

10% Improvement Goal

Our test results to date indicate that our model predictions are feasible and realistic
Phase I
Research and analysis
Completed

Phase II
Component Development

Phase III
Advanced Development per 12/07 Review

2008

2009

2010

1st Gen Hdwr Evaluation

Acquire 2nd Gen Hdwr

2nd Gen Hardware Testing

WHR-Vehicle Testing

Program End – Common with HECC

Innovation You Can Depend On

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Milestones for 2007/2008

Steady Progress -

Design 1st Gen Hardware  
June ’07

Acquire 1st Gen Hardware  
Dec. ’07

1st Gen Engine Build  
Feb. ‘07

First WHR Engine Start –  
April ‘08

WHR Steady State Power Generation –  
June ‘08

Exhaust Recovery and Transients –  
August ‘08

Second-Generation Hardware Design -  
Q3/Q4 ‘08
WHR
First Generation Hardware Design

Condenser
boost pump
rear crossover tube
Flywheel-Motor-Generator

Innovation You Can Depend On
First Generation
Test Cell Installation

WER Gen1
Prototype Layout
3-12-08
ISX with WHR System in Test Cell
International Prostar on HDCC Cycle in VMS (13-Mode)

Engine Speed, RPM

Engine Power, hp

Duty Cycle Fuel Efficiency Improvement

EGR-Only WHR Net benefit for Prostar on HDCC cycle = 6% Predicted

5.0% Observed as modeled with observed data

EGR Only Heat Recovery
Gen1 Test results reflect greater than expected parasitics which may be reduced in future hardware generations

C100 Gen1 Test Result is extrapolated from other Gen1 data

Engine Operating Point
Predicted WHR Power
Observed Gen1 Power

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Electrical Power Flows – B100 Operation

Gross turbine power is based on ‘map-based’ power, ‘measured’ turbine power is 1.4 kW less

- Gross Turbine Power
- Modeled Power Flows
- Measured Power Flows

- 82% of gross
- 71% of gross

Power, kW

0 5 10 15 20 25

Gross Turbine Power
Modelled Power Flows
Measured Power Flows

- Windage/Bearing Loss
- Generator Loss
- PE Loss
- Pump Work
- Unaccounted
- FMG Net Power

Gross turbine power is based on ‘map-based’ power, ‘measured’ turbine power is 1.4 kW less.
Refrigerant Side Pressures

Need to reduce high-side system pressure drop, costs additional pump work

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System Thermal Image Movie

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2nd Generation System Evolution

Air-cooling the condenser will eliminate cost and system complexity

Performance should be slightly improved without the water pump parasitic, making up for windage losses in the turbine

Modine Mfg. has performed modeling of an in-vehicle, air-cooled condenser

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Review and Summary

Significant Progress -

- First Generation evaluation is well underway
- Initial results are promising - we are building our knowledge base
- Now moving to exhaust heat capture in addition to EGR heat
- Development of transient controls for driveability. Initial results look good.

Go Forward Plans

- 2nd Generation system design and analysis is underway
- Continue System refinement and evolution
Cummins Waste Heat Recovery

Cummins Inc. appreciates the partnership support of the U.S. Department of Energy in this highly innovative and unique program –

Thank You!