Super Truck Program: Engine Project Review

Recovery Act – Class 8 Truck Freight Efficiency Improvement Project

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Project ID: ACE058

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Overview

Timeline

• Project start: April 2010
• Project end: March 2015
• Percent complete: 40%

Barriers

• High efficiency SCR unit had higher than desired pressure drop. Design being iterated.
• Integrate electric power generating systems with hybrid power bus and controls

Budget

• Total project $79,119,736
• Engine Budget $31,633,001
  – DOE Share(*) $4,494,000
  – DTNA Share(*) $9,042,000

(*): Program total through Dec 2011 for engine R&D expenses only, vehicle R&D expenses reported separately

Partners

• Department of Energy
• Oak Ridge National Laboratory
• Massachusetts Institute of Technology
• Atkinson LLC
• Daimler Trucks North America
• Daimler Advanced Engineering
# Objectives and Milestone

**Develop and Demonstrate a 50% total increase in vehicle freight efficiency:**
- At least 20% improvement via a heavy-duty diesel engine capable of achieving a 50% brake thermal efficiency
- Identify key pathways towards achieving a 55% brake thermal efficient engine through modeling and analysis

<table>
<thead>
<tr>
<th>Timeline</th>
<th>Phase Description</th>
<th>Milestones</th>
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<tbody>
<tr>
<td>4/10–3/11</td>
<td>(1) Technology Modeling/Analysis and Initial Component Development and Demonstration</td>
<td>Develop analytical roadmap:</td>
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<td>• 50% vehicle freight efficiency improvement</td>
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<td>• 50% engine brake thermal efficiency</td>
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<td>4/11–3/12</td>
<td>(2) Experimental Demonstration of Technology Building Blocks for Intermediate Goals</td>
<td>Experimentally demonstrate technology building blocks:</td>
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<td>• 25% vehicle freight efficiency improvement (system level test)</td>
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<td>• 46% engine brake thermal efficiency</td>
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<td>4/12–5/13</td>
<td>(3) Technology Identifications and Final Component Development and Demonstration</td>
<td>Identify and initially develop technology building blocks:</td>
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<td>• 50% vehicle freight efficiency improvement (system level test &amp; analysis)</td>
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<td>• 50% engine brake thermal efficiency</td>
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<td>6/13–6/14</td>
<td>(4) Experimental Demonstration of Technology Building Blocks for 50% Engine Thermal Efficiency and 50% Vehicle Efficiency</td>
<td>Experimentally demonstrate technology building blocks:</td>
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<td>• 50% vehicle freight efficiency improvement (system level test)</td>
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<td>• 50% engine brake thermal efficiency</td>
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<td>7/14–3/15</td>
<td>(5) Final System Integration and Demonstration</td>
<td>Experimental demonstration:</td>
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<td>• 50% vehicle freight efficiency improvement (entire vehicle test)</td>
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<td>• 50% engine brake thermal efficiency (engine test)</td>
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<td>• 55% engine brake thermal efficiency (engine analysis)</td>
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Demonstrate 50% brake thermal efficiency via:
- Engine downsizing (higher BMEP)
- Higher compression ratio
- Air system optimizations, reduced EGR
- Reduced parasitic
- Waste heat recovery
**Higher Peak Firing Pressures**

- Raised peak firing pressure by 10% in test. Will increase by 20% over baseline this year.
- Increase compression ratio by 2 points over the baseline
- Re-matching injector tip to new piston bowl

**Air System Rematch**

- Leveraging higher SCR conversion efficiency to reduce EGR rates
- Higher airflow rates requires a turbo rematch
- Prototype turbocharger on order
- Prototype turbocompound unit on order
Increased Engine Out NOx

- Significantly reduced EGR
- Calibration adjusted to maintain good SCR temperatures
- Significant bsfc benefit measured

Aftertreatment

- Thinner wall DPF showed very low dP. DPF will benefit from higher NOx/PM ratio (low soot load)

- Increased SCR cell density and alternative catalyst material. Testing showed high SCR conversion efficiency (95 to 100%), but high SCR dP.

- Iterating SCR design
Engine Parasitic Reduction via Downsizing

- 40% motoring power reduction at cruise RPM
- Higher BMEP at road load

Engine Downsizing Via Cylinder Deactivation

- Cylinder deactivation was evaluated as a way to increase BMEP
- Measurable BSFC benefit at low loads
- Limiting factors (namely exh. temperature and airflow) necessitate turbocharger rematch.
- Not being pursued further
SuperTruck Engine Controls – Objective

- Develop a **predictive** engine controller
- Include a fuel efficiency optimizer
- Integrate predictive vehicle information
- Reduce calibration complexity

Extensive engine mapping is used in neural network model training

Emissions & fuel economy models enable on-board BSFC optimization

Calibration Constraints
- Drivability
- Durability
- Fuel economy
- Life-cycle cost
- NOx / PM / NMHC / CO2
- OBD
- Exhaust temperature
- GPS / Route / Traffic info.
Engine Mapping

- Engine controller relies on extensive engine mapping
- Data is obtained under transient conditions

Controller Evaluation Over Transient Cycles

- Extended number of controlled variable
- Evaluated controller on SuperTruck routes (20 and 40-minute dyno cycles)
- Controller response is predictable and repeatable
Integrate With Super Truck’s Predictive Capabilities

- Demonstrated controller’s ability to modulate NOx in real-time
- 5% lower BSFC over highway ST cycle
- 4.8% lower BSFC over urban ST cycle
- Will use route information (GPS, terrain, traffic, etc.) to leverage the engine controller’s ability to optimize the engine in real-time
Reduced Engine Parasitics

- Water pump improvements completed, 0.5% BSFC improvement
- Development work on lower friction kit (piston, rings, liner) continues. Initial bench testing was positive, engine testing did not show same results. Development continues.
- Evaluating alternative oils

MIT Friction

- Evaluated where potential for friction improvement was largest with special attention to oil temperatures
- Looking at component optimizations for oil temperature control within system for friction reduction
- Significant modeling completed and effort continues
Waste Heat Recovery Test Bed

- Test fixture designed, and built
- Allowance for additional instrumentation and easy installation in a test cell
- Component location relative to each other same as planned for vehicle

Waste Heat Recovery Control System

- Test bed control system designed and functional
- Further refinement in process to allow for running on vehicle
Waste Heat Recovery Modeling

- Modeling of waste heat recovery continues for both component sizing and overall system optimization
- Multiple models being utilized; Daimler in-house model and Oak Ridge National Laboratory model

Working Fluid

- Selection criteria considered:
  - Low environmental impact, thermodynamic performance, acceptable operating pressures, high thermal stability, etc.
- Ethanol selected
Technical Accomplishments and Progress

Waste Heat Recovery Testing

- Test fixture installed in dedicated waste heat recovery test cell
- Successful shakedown of fixture and controls
- Boiler and condenser evaluations in process
- Expander/generator in final assembly

Waste Heat Recovery Packaging

- Current system using exhaust gas recovery only. Packaging and design of EGR recovery in process
- Packaging studies in vehicle underway. Significant studies into cooling system impact completed (DTNA lead)
Generator

- Partnered with Oak Ridge National Laboratory (ORNL) for development of generator
- Utilized low cost wound field generator as opposed to permanent magnet machine.
- Prototype build in process with delivery expected April 2012. ORNL will perform performance testing.

Expander

- Scroll expander selected as primary option for WHR
- Magnetic coupling to allow hermetic sealing of expander and simple interface to generator
- Expander in final assembly. Supplier will perform basic testing. Delivery expected April 2012.
Vehicle Only Benefits (not Thermal Efficiency)

- High NOx/PM → Passive only particulate filter regeneration
- Predictive engine controls
- Weight neutral design; added waste heat system, downsized the engine
- Engine geared for low rpm operation
- Clutched air compressor
Collaboration and Support

- Department of Energy Head Quarters
  - Gurpreet Singh
  - Roland Gravel

- National Energy Technology Laboratory
  - Carl Maronde

- Oak Ridge National Laboratory
  - Waste heat recovery system

- Massachusetts Institute of Technology
  - Low friction technologies

- Atkinson LLC
  - Advanced engine controls
Summary and Future Work

- Second year of Super Truck program complete
- Engine has demonstrated 46.2% brake thermal efficiency
- Plans firmly in place for next level of performance improvement:
  - Higher compression ratio including new piston bowl and injector tip
  - Iterate SCR design for lower pressure drop
  - Reduced engine parasitics
  - Continue controls development and refinement
  - Waste heat regeneration development
    - Expander and generator
    - Add EGR waste heat recovery
    - Integrate onto vehicle