Volvo SuperTruck

Powertrain Technologies for Efficiency Improvement

DOE Contract DE-EE0004232

2014 Annual Merit Review
Washington, DC
June 20, 2014

Presenter: John Gibble
Advanced Engineering Chief Project Manager
Volvo Group Truck Technologies

Principal Investigator: Pascal Amar
Volvo Technology of America

This presentation does not contain any proprietary, confidential, or otherwise restricted information
## Project Overview

### Timeline

June 2011 - June 2016  
55% complete to date

### Barriers

- Cost effective & timely evaluation of advanced components and configurations
- Added weight, packaging, and complexity of technologies
- Reduced aftertreatment efficiency at low temperatures
- Integration of interdependent technologies

### Budget

- Total Project Funding: 38M USD
- DOE Cost Share: 19M USD
- Funding received to date $9.1M
- Total project cost to date $18.3M

### Project Partners:

- Lead: Volvo Technology of America
- Volvo Group Truck Technology
- Penn State University
- Grote
- Freight wing
Relevance to Program Goals

Bring technologies that enable lower customer operational cost and reduced environmental impact to market ahead of normal product development time cycle.

Develop more efficient highway transportation technologies to reduce petroleum consumption.

Project Objectives

Objective 1:
Develop powertrain technologies to contribute to 50% freight efficiency improvement in vehicle testing.

Objective 1a:
Develop powertrain technologies capable of 50% engine BTE in vehicle environment.

Objective 2:
Investigate engine technologies capable of 55% BTE through simulation and scoping studies.

Reporting Period Project Objectives

Objective 1:
Test 48% BTE powertrain in concept vehicle.

Objective 1a:
Develop 50% BTE technologies.

Objective 2:
Simulate technologies to achieve 55% BTE.
Projects supporting the objective to develop more efficient highway transportation technologies to reduce petroleum consumption, operating cost, fuel consumption, environmental impact, and time to market for high risk high complexity items are as follows:

- DOE & NETL under Award Number DE-EE0004232
- DOE & NETL under Award Number DE-FC26-07NT43222

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.
Total Powertrain Workflow Approach

55% BTE Combustion Technologies (Objective 2)
- Innovative engine architectures
- Alternative combustion cycles
- Fueling Optimization
- Demonstrate in Simulation and Single Cylinder Scoping

50% BTE Powertrain Technologies (Objective 1a)
- Engine System(s)
  - Combustion
  - WHR
  - Air Handling
  - …
  - Aftertreatment
  - Driveline
- Demonstrate in test cell

50% Freight Efficiency Improvement Technologies (Objective 1)
- Powertrain Improvements
- Aerodynamics
- Light weighting
- Rolling Resistance
- Driver Aides
- Auxiliaries
- …
- Chassis Test

Transfer Technology

Requirements and Feedback

Requirements and Feedback

Requirements

Technology to Customer

+ New Technology
Total Powertrain Workflow Approach

55% BTE Combustion Technologies
(Objective 2)
- Innovative engine architectures
- Alternative combustion cycles
- Fueling Optimization
- Demonstrate in Simulation and Single Cylinder Scoping

50% BTE Powertrain Technologies
(Objective 1a)
- Engine System(s)
  - Combustion
  - WHR
  - Air Handling
  - …
  - Aftertreatment
  - Driveline
- Demonstrate in test cell

50% Freight Efficiency Improvement Technologies
(Objective 1)
- Powertrain Improvements
- Aerodynamics
- Light weighting
- Rolling Resistance
- Driver Aides
- Auxiliaries
- …
- Chassis Test

Technology to Customer

Requirements and Feedback

+ New Technology

Transfer Technology
Approach for 55% BTE Engine (Objective 2)

Optimize gross ITE

Probability Density Function (PDF) is a more accurate method to model combustion behavior during turbulent mixing.

Goal: simulate a powertrain system capable of 55% engine BTE using an integrated computational method.

Currently in Phase II. A 55% BTE engine is conceptualized.

Phase I - Tools & Method Development
Penn State - CFD Development
PDF Diesel Development
PDF PPC Validation
GT Power modelling & Eff. Calculations

"Concept 55" Chosen

Phase II - Concept Development
Concept 55 CFD Simulations
Concept 55 model validation
Concept 55 GT Power
Fuel Mechanism Research
Concept 55 prototype
Progress on 55% BTE Engine (Objective 2)

- For PPC mode, the PDF model matches measured data with improved accuracy compared to common techniques. PDF and 1D multi-cylinder simulations are complete.
- ‘Advanced Concept’ developments are now in progress.
- Work on improving the computational method for ‘Advanced Concept’ thru:
  - Fuel mechanism research
  - Computational speed reduction
  - Heat transfer developments
  - Spray model developments

BTE Improvement Status

- Brake Thermal Efficiency vs Year
- Adv. Concept 1D Analysis
- PPC Final Simulation Result
- Adv. Concept Improvements Via Simulation
- Diesel Baseline

Refined In-cylinder Combustion

1-D CFD GT-Power Engine Model
Total Powertrain Workflow Approach

55% BTE Combustion Technologies (Objective 2)
- Innovative engine architectures
- Alternative combustion cycles
- Fueling Optimization
- Demonstrate in Simulation and Single Cylinder Scoping

50% BTE Powertrain Technologies (Objective 1a)
- Engine System(s)
  - Combustion
  - WHR
  - Air Handling
  - ...
  - Aftertreatment
  - Driveline
- Demonstrate in test cell

50% Freight Efficiency Improvement Technologies (Objective 1)
- Powertrain Improvements
- Aerodynamics
- Light weighting
- Rolling Resistance
- Driver Aides
- Auxiliaries
- ...
- Chassis Test

Technology to Customer

Requirements and Feedback
Strategy for Brake Thermal Efficiency
(Objective 1a)

- Develop and verify powertrain components that enable 50% engine BTE.
- Each family displayed represents many subsets of technologies.
- Integrate systems into concept vehicles and verify on customer duty cycles.
Accomplishments towards 50% BTE (Objective 1a)

- Turbocompound 13liter Engine
- Rankine WHR Generation1
- Reduced Friction PCU
- Improved cooling circuit
- Improved oil circuit
- Improved combustion chamber
- High pressure fuel injection system
- Down-speeded Engine
- Improved aftertreatment system
- Next Generation Axles
- Improved Idle Efficiency
- Dual Clutch Transmission

Testing Completed for Intermediate (48% BTE) Powertrain in Chassis

Suspension, Injection System, Axles and Downspeeding Technology are or will be in production soon
The 50% BTE powertrain is under development, with three engines running and 6 component stands maturing technologies in parallel.

Accomplishments towards 50% BTE (Objective 1a)

- Downsized 13 → 11 Liter Engine
  - 11liter capable of same power as 13liter
  - Powertrain weight reduction >400lbs
55% BTE Combustion Technologies (Objective 2)
- Innovative engine architectures
- Alternative combustion cycles
- Fueling Optimization
- Demonstrate in Simulation and Single Cylinder Scoping

50% BTE Powertrain Technologies (Objective 1a)
- Engine System(s)
  - Combustion
  - WHR
  - Air Handling
  - ...
  - Aftertreatment
  - Driveline
- Demonstrate in test cell

50% Freight Efficiency Improvement Technologies (Objective 1)
- Powertrain Improvements
- Aerodynamics
- Light weighting
- Rolling Resistance
- Driver Aides
- Auxiliaries
- ...
- Chassis Test

Transfer Technology

Requirements and Feedback
Approach to Freight Efficiency Improvement

Two phases of development

- Phase 1 complete
- Phase 2 engine started 6 months ahead of schedule
Powertrain Accomplishments towards 50% Freight Efficiency Improvement (Objective 1)

Completed testing of first generation powertrain system in concept truck

- Tested on road for performance and fuel economy analysis
- Tested in a chassis dynamometer for heat rejection and fuel economy analysis
- Successfully completed missions representative of customer duty cycles
Powertrain Accomplishments towards 50% Freight Efficiency Improvement (Objective 1)

Concept Truck

- Vehicle Test Complete
- 43% Freight Efficiency improvement measured
  - 18% Contribution from Powertrain
  - 48% BTE engine and advanced powertrain tested in vehicle

Final Demonstration Truck

- Initiated testing of engine for Demo Truck 6 months early
- Preparing to deliver mock-up engine to chassis team for fitment studies
Collaborators / Partners

Suppliers and development partners have developed methods to integrate all new technologies in simulation and test phase, striving to deliver an optimized powertrain and chassis for maximum return on investment. Academic partners are assisting in simulations.

<table>
<thead>
<tr>
<th>Collaborator / Partner</th>
<th>Focus</th>
</tr>
</thead>
<tbody>
<tr>
<td>The Customer</td>
<td>Log vehicle data used from thousands of highway vehicles on the market is to define drive cycles and requirements</td>
</tr>
<tr>
<td>Volvo Technology of America</td>
<td>Contract Management and Collaborator Integration</td>
</tr>
<tr>
<td>Volvo Group Trucks Technology</td>
<td>Engine, Transmission, Axles, Light weighting, Chassis Auxiliaries, Integration, Chassis Aerodynamics, …</td>
</tr>
<tr>
<td>Freight Wing, Inc.</td>
<td>Trailer Aerodynamics</td>
</tr>
<tr>
<td>Grote Industries</td>
<td>Advanced Lighting</td>
</tr>
<tr>
<td>Ricardo, Inc.</td>
<td>Rankine WHR Generation 1 Development</td>
</tr>
<tr>
<td>University of Michigan</td>
<td>55% BTE Simulation and Testing</td>
</tr>
<tr>
<td>Drexel University</td>
<td>WHR Topology Simulation</td>
</tr>
<tr>
<td>Pennsylvania State University</td>
<td>55% BTE Simulation and Testing</td>
</tr>
<tr>
<td>Chalmers University of Technology</td>
<td>55% BTE Testing</td>
</tr>
<tr>
<td>Exxon Mobil</td>
<td>Advanced Fuels and Lubrications</td>
</tr>
</tbody>
</table>
Future Plans for Powertrain Development

- 55% BTE (Objective 2)
  - Continue work on applying verified fuel chemistries to the PDF model
  - Optimize the ‘advanced concept’ engine and its sub-models using the integrated computational method with a goal to exceed 55% BTE.

- 50% BTE (Objective 1a)
  - Continue testing and integration of final demonstrator powertrain system in an engine test cell 2014
  - Deliver functional 50% BTE powertrain system to Demo Truck 2015

- 50% Freight Efficiency (Objective 1)
  - Deliver reduced weight powertrain
  - Incorporate 50% BTE methods into 50%+ Freight Efficient chassis
  - Integrate chassis improvements into powertrain system development
Summary of Volvo Supertruck Project Status

- **Timeline:** Project is 55% complete to date
- **Budget:** On track vs. plan
- **Relevance:** Develop more efficient highway transportation technologies to reduce petroleum consumption, reducing operating cost, fuel consumption, environmental impact, and time to market for high risk high complexity items
- **Approach:** Through simulation and testing, develop technologies that meet or exceed 55% BTE scoping, 50% BTE powertrain system in chassis, and 50% Freight Efficiency improvement.
- **Technical Accomplishments:** In 2013/14 Volvo verified combustion simulation for PPC and simulated a 54.5% BTE capable engine. Volvo also tested the 48% BTE powertrain in vehicle with success. The 50% BTE powertrain is under development, with three engines running and 6 component stands maturing technologies in parallel. The first concept vehicle achieved a 45% Freight Efficiency Improvement.
- **Collaborations:** Suppliers and development partners have developed methods to integrate all new technologies in simulation and test phase, striving to deliver an optimized powertrain and chassis for maximum return on investment. Academic partners are assisting in simulations.
- **Future Plans:** Technologies selected as viable and ready will be tested as part of integrated concept powertrain system in 2014 in an engine test cell environment. In 2015 the 50% BTE capable powertrain will be demonstrated in vehicle. Simulation 55% components will progress through upcoming funding year.
End of presentation.

Thank you for your attention.