Development and Demonstration of a Fuel-Efficient HD Engine
(Dept of Energy Supertruck Program)

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Navistar

Technical Session: High-Efficiency Engine Technologies Part 1

DOE DEER CONFERENCE
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Industrial Partners: Bosch, ARGONNE, Federal Mogul, WERC
Outline

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  – Milestone 2: Turbocompounding
  – Milestone 3: Base Engine Technologies
  – Milestone 4: Rankine Cycle Selection

• Advanced Engine Concept
  – Impact of Fuel Reactivity
  – Challenges and Opportunities

• Summary

• Acknowledgements
Project Goals: Approach for Fuel Economy

**Baseline**
2010 ProStar with MAXXFORCE 13L

**Engine**
Combustion-Emissions
Base Engine
Heat recovery

**Vehicle**
Hybrid
Dual-Mode Drive
Electrified Accessories

**Aero**
Gap reduction
Aero Drop
Camera Mirrors

**Light Weight**
SMART tandem axles
Composite cab, trailer
Wide base single tires

**Driveline**
SMART tandem axles
Composite cab, trailer
Wide base single tires

Supertruck Concept

20% improvement in freight efficiency

30%
Engine Baseline and Targets

MY 2010
MAXXFORCE 13

Rated Power 475hp
Best BTE 42%
Engine out NOx 0.35g/bhp-hr

2200 bar Common Rail
2-Stage turbocharger
2-stage EGR cooling

Advanced Combustion Concepts
- Advanced Simulation
- Combustion feedback

Fuel Reactivity
- 3000bar capability

Variable Valve Actuation
High Efficiency Turbochargers

Advanced EGR cooling

PF

Base Engine
- Friction reduction, PCP
- Electrification of accessories

Pushing the technology frontier

4. WHR
3. Base Engine Accessories
2. Air System
1. Combustion

Base efficiency

Supertruck Targets

Rated Power 475hp
Best BTE 50%
Emissions HD

EPA 2010

Bottoming Cycles
- Electric Turbo-compound
- Rankine Cycle, Thermo-electrics
Development Facilities

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Combustion Development, Emissions Performance Benchmark

Heat Recovery Technology

BOSCH

High-injection pressure capability

CFD-Engine correlations

Argonne National Labs

Fuel Reactivity

Cylinder head redesign with PFI system installation

Federal Mogul

Friction Benchmark
Efficiency at road load condition

- Comb
- TUCO
- VVA
- Friction
- ORC

2010: currently 46.5%

MAXXFORCE 13

Combustion / Aftertreatment

Heat Recovery

Base engine improvements

Advanced Concepts: Fuel Reactivity

50% BTE and Vehicle Demonstration

55% BTE dyno demonstration
Efficiency Roadmap

Target a combined 50%
At road load condition

Supertruck Technologies towards 50% BTE
Milestone 1: Engine Thermal Efficiency

Road Map

Currently demonstrated
+3% BTE gain (to 45%)

✓ Minimize engine out NOx – Soot

✓ Maximize BTE

✓ Optimize:
  Injection timing
  Fuel pressure
  Injection events

✓ Optimize Hardware:
  Compression ratio
  Cooling system

<table>
<thead>
<tr>
<th></th>
<th>BTE (CR)</th>
<th>BTE (Inj Press)</th>
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<tbody>
<tr>
<td>A75</td>
<td>+1.3%</td>
<td>+0.5%</td>
</tr>
<tr>
<td>B50</td>
<td>+1.3%</td>
<td>+1.0%</td>
</tr>
<tr>
<td>C100</td>
<td>+1.2%</td>
<td>+1.2%</td>
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</table>
Milestone 2: Turbocompounding

Recover exhaust energy

Criteria
- highest efficiency opportunity
- best opportunity for system optimization
- synergistic with Supertruck hybridization

Support Systems¹

System integration²

Demonstrated at road load condition:
+1.4% BTE gain
(46.4% BTE)
Milestone 2: Turbocompounding (TuCo)

Optimizing work
- Load distribution across turbine wheels
- Couple hardware with flow targets (emissions)
- Leverage simulation tools

Current test results
✓ Broader range of improvement from mechanical turbocompounding

Challenges of optimization

Varying emissions at fixed hardware configuration

Two hardware configurations at same emission level
Milestone 3: Base Engine

- Up to 2% BTE gain possible across base engine improvements
- Target is 1.5% BTE gain.

<table>
<thead>
<tr>
<th>Categories</th>
<th>Friction</th>
<th>Increased Cylinder Pressure</th>
<th>Thermal Management</th>
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</thead>
<tbody>
<tr>
<td>Power Cylinder</td>
<td>+</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Power Transfer</td>
<td>++</td>
<td>+</td>
<td></td>
</tr>
<tr>
<td>Crankcase</td>
<td>+++</td>
<td></td>
<td>++</td>
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</tbody>
</table>

- Piston and liners
- Bushings
- Low friction camshaft
- Light weight crank
- Coolin system
- Lube oil system
Milestone 4: Rankine Cycle

Cycle Criteria:
Achieve target intake manifold temperature;
Package in the vehicle;
Produce fuel economy benefit;
Safety and crashworthiness;
Cost and cost/performance ratio;
Reliability, durability, and product life;
Serviceability and service intervals;
Minimal weight increase.

Evaluation of Fluids
Critical temperature, pressure
Triple point temp, Psat at -40°C, 25°C
Flammability (in air)
Decomposition temp (°C), products
GWP, ODP
Cost/L (Approx)
Specific gravity at 25°C

Alternative Concepts

BSFC Improvement*          | HTR Cooled Condenser
----------------------------|---------------------------
Road Cycle [1]               | 3.1%                      
Road Cycle [2]               | 3.9%                      
USSET                       | 4.9%                      

*Estimates
The High Efficiency Diesel MAXXFORCE13:

✓ Engine operates at gross thermal efficiencies of 51-55% 

Single Cylinder Research engines with advanced or two fuels:

✓ Engines have shown similar efficiencies (e.g. PPC [1], RCCI [2])
✓ Fuel reactivity shows significantly improved engine out emissions
✓ Challenges exist to make this “feasible”

MAXXFORCE13 has been reworked to operated in Dual Fuel mode

[1] Path to High Efficiency Gasoline Engines, Bengt Johansson, DEER 2010
Fuel Reactivity
Challenges and Opportunities

EPA regulations

<table>
<thead>
<tr>
<th>NOx</th>
<th>soot</th>
<th>gross eff</th>
<th>EGR%</th>
<th>Tintake (°C)</th>
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</thead>
<tbody>
<tr>
<td>0.20g/kW-hr</td>
<td>0.07</td>
<td>0.010</td>
<td>54%</td>
<td>52%</td>
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</tbody>
</table>

Diesel Fuel
- Challenging in-cylinder
- Costly aftertreatment
- Retains high efficiency
- In production

Fuel Reactivity
- Reduce engine out emissions to 2010 levels
- High Efficiency
- Challenging conditions to attain in production

Enablers with the MAXXFORCE13 Dual Fuel and Advanced EGR

VVA Combustion Feedback
Variable Geometry Turbos

EGR driving capability

PPC [1] 21bar
RCCI [2] 16bar

- 20
- 30

- EPA regulations
- NOx
- soot
- gross eff
- EGR%
- Tintake (°C)

- Fuel Reactivity
- Diesel Fuel
- Emissions
- Efficiency
- Engine Technologies

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Project is focused on assessing and developing engine and vehicle technologies to improve freight efficiency for class 8 truck and trailer.

The MAXXFORCE 13L engine is well posed to deliver 50% BTE

The work to date includes:

- **Milestone 1**: Combustion optimization demonstrated efficiency improvement of 3% BTE
- **Milestone 2**: Demonstrated turbocompounding improvement of 1.4% BTE
- **Milestone 3**: Base Engine Technologies selection targeting 1.5% BTE gain
- **Milestone 4**: Rankine Cycle Selection (including hardware, refrigerant) targeting 1.5% BTE gain

**In addition:**

- Engine has been prepared to examine the impact of Fuel Reactivity
Acknowledgements

Engine Project Partners

Thank You

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