Diesel Engine Fuel Economy Improvement Challenges and Opportunities

Ning Lei

Advanced Technology
Navistar

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About Navistar

North America’s Largest Integrated Truck and Engine Manufacturer
Navistar’s Engine Product Range

- A world wide leader with a full range of Diesel engines for commercial vehicles
- #1 Engine Manufacturer in South America

<table>
<thead>
<tr>
<th>South American Engines</th>
<th>MaxxForce™ 5</th>
<th>MaxxForce™ 7 - Ford V8</th>
<th>MaxxForce™ DT Series 9/10</th>
<th>MaxxForce™ 11/13</th>
<th>MaxxForce™ 15</th>
</tr>
</thead>
<tbody>
<tr>
<td>I-4/I-6</td>
<td>4.5L V-6</td>
<td>6.4L V-8</td>
<td>7.6L/9.3L I-6</td>
<td>11L/13L</td>
<td>15L Big Bore I-6</td>
</tr>
<tr>
<td>100 - 320 hp</td>
<td>150 - 310 hp</td>
<td>200 - 350 hp</td>
<td>210 - 330 hp</td>
<td>310 - 475 hp</td>
<td>450 - 550 hp</td>
</tr>
<tr>
<td>Complete line of 3L-7L products</td>
<td>For Class 4-5</td>
<td>HD diesel Pickup/Vans</td>
<td>Class 6-7 Truck and School Bus</td>
<td>Class 8 Truck</td>
<td></td>
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</tbody>
</table>

Coming
The Diesel Engine Industry Journey

Brake Thermal Efficiency

Hi Injection Pressure
Higher EGR Flow, Cooling, VGT, 2-stage turbo Turbocompounding Aftertreatment


40 – 42%
What Is Coming to Truck Industry

• Legislation Under Discussion for HD & MD Truck
  – GHG emission regulation------ Climate Control
  – Oil Usage ------ Energy Security Act
    • Engine Efficiency improvement, diesel 50% - 55% BTE anticipated
    • Vehicle fuel economy improvements, (DOE Super Truck Solicitation of >50%, measured in (ton-mile/gallon))
    • Japan’s mandatory HD vehicle fuel economy regulation, ~12% by 2015

• General Approach:
  – Low Carbon based fuel usage, “Well to wheel” concept
  – Transportation System Efficiency
Diesel Engine Technology Options

For Efficiency And Emission

- Advanced Combustion
  - Phasing, Flex. Modes, Flex. fuel
- Advanced Fuel Injection System
- Flexible Air & EGR Charging System
- Total Engine and Vehicle Cooling & Thermal Management
- Smart Engine Controls & Sensors
- Variable Valve Technology
- Waste Heat Recovery
- High Efficiency & Low Cost Aftertreatment
- Powertrain Integration
  - Transmission Match
  - Electrification
  - Hybrid and Energy Management

Integrated Solution at Cost, Quality, Timing, Reliability

- Many Opportunities
- Conventional Diesel Engine Becomes Complex
- Doing Business Becomes Costly
FTP HD Emission Cycle vs. Driving Mode

Product Development

- Emission Cycle vs Driving Cycle
- HD Emission Dominant Technology Selection
- Balanced and Trade off
  - Emission
  - BSFC
  - Product cost

Graph showing the relationship between Torque (ft-lb) and Speed (rpm) with points A, B, and C indicating different performance areas. The graph includes a shaded area for the Driving Cycle and another for the Emission Cycle, with points indicating the performance at various speeds and torques.
Approach on Vehicle FE

Truck and Engine Integrated Solutions

- Customer Focus
- Sustainable Solution

Fuel Use by Truck Class

- Class 2B: 10%
- Class 3: 7%
- Class 4: 5%
- Class 5: 15%
- Class 6: 30%
- Class 7: 20%
- Class 8: 40%

TOTAL ENERGY USE
400 kWh (~6.6 mpg)

Aerodynamic Losses
21%

Rolling Resistance
13%

Drivetrain
2%

Auxiliary Loads
4%

Engine Losses
60%

Source: USDOE

Base

Engine Technology

Powertrain Integration

Vehicle Technology
Overall Vehicle Fuel Efficiency Opportunities

Heavy Duty Class 8 Long Haul Truck FE Study

- Road Speed
- Load Management
- Drive Management
- Longer trailer
- Advanced Truck-Cab
- Integrated Truck-Cab
- Bottoming Cycle
- Elec. Turbocompounding
- Parallel Hybrid
- Combustion
- Mech Turbocompounding
- VVA
- Baseline

% Fuel Efficiency Improvements

*** Data from multiple source, NESCCAF, ICCT, Calstart
Truck Hybridisation – The Benefits

- Fuel Economy benefit highly dependent upon drive cycle
- Hybrid Trucks are most efficient in city driving
- Greatest benefit from working trucks is idle engine off operation

Certified FE Improvements
Current Systems

- UDDS (MPG)
- Orange County (MPG)
- Manhattan (MPG)

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<tr>
<th>Truck Type</th>
<th>Stationary Operation</th>
<th>On Highway</th>
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<tbody>
<tr>
<td>Bus (PHEV)</td>
<td>61%</td>
<td>24%</td>
</tr>
<tr>
<td>MD Box Truck</td>
<td>35%</td>
<td>24%</td>
</tr>
<tr>
<td>MD Utility Truck</td>
<td>27%</td>
<td>8%</td>
</tr>
</tbody>
</table>

Work Truck Fuel Consumption

- 80% reduction Stationary Operation
- 20% reduction On Highway
Truck Hybridisation – The Challenges

- Incremental system costs over non Hybrid are extremely high

- Must increase scale through lowering costs and improving functionality
  - Drive technology towards modular and scaleable designs across Passenger Car and Commercial Truck

- EPA needs to address the vehicle certification for MD & HD
  - Fully demonstrate FE and emission benefit
Technology Impact

Challenges and barrier to Commercialization

- Product cost
- Technology maturity and complexity
- Supplier base readiness
- Product development time

Industry Collaboration
- University & Research lab involvement
- Government Funding

![Graph indicating Technology Impact, Cost, FE Gain, and Time](image-url)
Exciting time for engineering

Conventional diesel engine needs **Paradigm shift**
- lower cost, simplicity & efficiency

Focus on technology integration, crossing the **Boundary** for better solution

Greater vertical **Integration** required for truck and engine manufacturing.

Collaboration throughout the entire supply chain is the key, OEMs, fleets, engines, suppliers, universities, labs

Quick to develop technologies with R&D funding