Fuel Consumption Potential of Medium- and Heavy-Duty Applications

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Introduction

• Several ways to improve vehicle fuel efficiency
• Each component of the powertrain can be improved more or less aggressively
• Impact on vehicle fuel efficiency is different whether:
  • Component improvements are considered separately
  • Advanced technologies are combined
• Supported the National Academy of Science report “Technologies and Approaches to Reducing the Fuel Consumption of Heavy Duty Vehicles”
Medium Duty Application
Vehicle Characteristics

- Pickup Truck Class 2b
- Based on a GMC Sierra 2500 HD
- Vehicle simulated on UDDS and HWFET cycles

<table>
<thead>
<tr>
<th>Component</th>
<th>Model Characteristics</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine</td>
<td>Diesel: Cummins 6.7 L, 272 kW</td>
</tr>
<tr>
<td></td>
<td>Gasoline: GM LM7 5.3 L, 276 kW</td>
</tr>
<tr>
<td>Transmission</td>
<td>Automatic 6-speed</td>
</tr>
<tr>
<td>Tire</td>
<td>P245/75/R16 - Radius = 0.387 m - Rolling Resistance = 0.007</td>
</tr>
<tr>
<td>Vehicle Losses</td>
<td>Drag Coefficient = 0.44 - Frontal Area = 3.233 m²</td>
</tr>
<tr>
<td>Curb Weight</td>
<td>2659 kg</td>
</tr>
<tr>
<td>GVWR</td>
<td>4172 kg</td>
</tr>
<tr>
<td>Max. Payload</td>
<td>1513 kg</td>
</tr>
</tbody>
</table>
## Individual Technologies Summary

<table>
<thead>
<tr>
<th>Advanced Technology for...</th>
<th>Percent Fuel Saved (Conventional)</th>
<th>Percent Fuel Saved (Hybrid)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine&lt;sup&gt;(1)&lt;/sup&gt;</td>
<td>+8.6%</td>
<td>+8.9%</td>
</tr>
<tr>
<td>Aerodynamic&lt;sup&gt;(2)&lt;/sup&gt;</td>
<td>+3.0%</td>
<td>+3.8%</td>
</tr>
<tr>
<td>Tires&lt;sup&gt;(3)&lt;/sup&gt;</td>
<td>+1.2%</td>
<td>+1.6%</td>
</tr>
<tr>
<td>Transmission&lt;sup&gt;(4)&lt;/sup&gt;</td>
<td>+1.7%</td>
<td>+1.4%</td>
</tr>
<tr>
<td>Vehicle Weight&lt;sup&gt;(5)&lt;/sup&gt;</td>
<td>+1.4%</td>
<td>+1.4%</td>
</tr>
<tr>
<td>Hybridization&lt;sup&gt;(6)&lt;/sup&gt;</td>
<td>+14.8%</td>
<td>N/A</td>
</tr>
</tbody>
</table>

(1) From 34.7 to 38% peak efficiency (inc. VVL, VVT, direct injection)
(2) From Cd = 0.44 to 0.34
(3) From Crr = 0.007 to 0.0063
(4) From 6 to 8 speed transmission
(5) 136 kg reduction (baseline = 2659 kg)
(6) Pre-transmission full HEV with 50kW electric machine
Combined Technologies

- Fuel Consumption reduction is greater for the hybrid baseline
  - Components more efficient AND
  - Less charging required for the battery

- Only the gasoline version is used for the simulation
Combined Technologies

Aerodynamics + Weight

∑ 4.4 %

∑ 5.2%
Combined Technologies

Aerodynamics + Weight + Tires

∑ 5.6%

∑ 6.8%
Combined Technologies
Aerodynamics + Weight + Tires + Transmission

∑ 7.3%
∑ 8.2%
Combined Technologies
Aerodynamics + Weight + Tires + Transmission + Engine

∑ 15.9%
∑ 17.1%
Combined Technologies

All Technologies

Percent Fuel Saved

Each technology

Combination

∑ 30.7%

28.4%

14.8%

8.6%

1.7%

1.2%

3.0%

1.4%

Hybrid CS

Engine

Transmission

RR

Cd

Weight

Hybrid improvements

Baseline improvements

0.0%

5.0%

10.0%

15.0%

20.0%

25.0%

30.0%

35.0%
Heavy Duty Application
Vehicle Characteristics

- Line Haul Class 8
- Five cycles considered:
  - HHDDT65, HHDDT Cruise, HHDDT high speed, HHDDT Transient and UDDS truck

<table>
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</tr>
</thead>
<tbody>
<tr>
<td>Engine</td>
<td>Cummins ISX 14.9L 317 kW (425hp)</td>
</tr>
<tr>
<td>Transmission</td>
<td>Manual 10 gear (EATON FRO, 11.06 to 0.75 ratios)</td>
</tr>
<tr>
<td>Tire</td>
<td>P295/75R22 - Radius = 0.515m</td>
</tr>
<tr>
<td>Final Drive</td>
<td>2:64:1</td>
</tr>
<tr>
<td>50% Load</td>
<td>26,000 kg</td>
</tr>
<tr>
<td>100% Load</td>
<td>36,300 kg</td>
</tr>
</tbody>
</table>
Two Hybrid Configurations Considered

**Starter-alternator**
- Baseline + 50 kW Motor + 2.5 kWh Battery
- Start/Stop: engine is OFF when the truck idles and battery is not depleted
- Torque assist, regenerative braking (limited)
- No shifting time reduction

**Series-Parallel**
- Baseline + 200 kW Motor (MG1) + 50 kW Motor (MG2) + 25 kWh Battery
- Accessories electrification: 3 kW elec. / 1 kW mech. (vs. 0.3 / 5.2 for the conv.)
- Start/Stop, EV capability at low speeds
- Torque assist, regenerative braking
- Shifting time reduction
Fuel Savings on Standard Drive Cycles

- In percentage of fuel saved, hybridization is most beneficial on urban cycles
- Full HEV gets higher fuel savings
Regenerative Braking and Engine Efficiency Are the Main Factors Behind Fuel Savings

- Smaller motor on the mild HEV reduces regen braking
- Longer shifting times on the mild HEV also reduces regen braking

Mild HEV has no EV capability: at low speeds, engine must be ON, and then works in inefficient areas
Driving without Stops Reduces the Fuel Savings of the Hybrid

- Full HEV loses half of its fuel savings “improvement” when the cycle does not include stops!
- HEV has no benefits when cruising: less transients means less advantage for the HEV
Conclusion

• Medium and heavy duty vehicles can achieve significant fuel reduction in the future through technology advances
• Engine, hybridization and aerodynamics technologies will lead to the greatest fuel consumption reductions
• Line haul hybridization offers significant fuel saving when considering the total distances driven.
• However, particular attention has to be paid to drive cycle selection, including grade
• Vehicle system approach is critical to properly assessing the benefits of any technology or set of technologies
Argonne Vehicle Simulation Tool development was funded by Lee Slezak and David Anderson from the U.S. DOE Vehicle Technologies Program.

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