Transmission potential to contribute to CO2 reduction

2020 and beyond line haul perspective

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HD Transmission Technology Trends

Higher performance and complexity and deep integration

Manual

MT

AMT

Automated

Integration

Optimization

Evolution

Revolution

CVT?

EV?

Hybrid?

Dual-Clutch

Look-ahead

Time

Complexity / Performance

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Transmission Optimization

Still opportunity to improve component efficiency

- In-Gear efficiency [0.5%-1%]
- Dry sump & lubricants [1%]
- Bearing losses [.25%]

- Light weighting is important:
  Potential to eliminate 300-500 lbs
  drives 0.3-0.5% fuel and 1% – 1.5% freight efficiency
  - Architecture
  - Materials (shafts and gears 60% of gearbox weight)

Steel torque carrying elements
Lightweight filling (polymer/C-fiber or Al)
Automation
Transition from Manual to AMT driven by fuel economy, shift to regional haul and driver demographics

Automated Mechanical Transmissions
- **2-4%** fleet average improvement based on average driver skill
- Allows small ratios in high gears **[1-2%]**
- Effortless shifts allow higher shift density: key enabler to downspeeding
- Rapid adoption in market: SmartAdvantage, Volvo XE, DT-12. 8% in 2010, 15% in 2013, +20% in 2014.
- Expecting 55-60% market penetration of AMT by 2018

Example: Eaton-Cummins SmartAdvantage
- Fully integrated engine & transmission
- 3-6% improvement over base engine (ISX 15L) and base transmission (UtraShiftPLUS LAS)
Powertrain integration

Automated Mechanical Transmissions
- AMT and mild engine downspeeding will be baseline line haul powertrain by 2020
- 3-6% improvement is shared between engine and transmission

Dual Clutch Technology
- reducing the power excursions in engine, eliminating 0-torque condition at shifts [1%-3%]
- Significantly better drivability
- Enable further engine optimization by narrowing operating band (eg turbo optimization)
- Enable aggressive downspeeding due to drivability, eg 900-1000 rpm at cruise, additional 2%
- Lower cruise speed or higher productivity [.5-2%]

Eaton-Cummins SmartAdvantage
- 3-6% improvement
- 1.5-3%: engine downspeeding from 1350 rpm to 1100 rpm at cruise
- 1.5-3%: special ratios, shift logic and integrated controls

Eaton DCT proof-of-concept transmission
- 11 ratios, progressive gearing
- Eliminate torque interrupt
- Maintains engine at full load during shifts
- 20% faster acceleration
Look-Ahead technologies

Improve driver performance for fuel economy: 3-4% fleet average improvement

• Unique features: accounts for
  • Driver behavior
  • Real time traffic conditions
  • Non-intrusive in cabin, shaves unnecessary acceleration peaks

• Seamless integration
  • With and without cruise control
  • Terrain and route (GPS, grade)
  • Route specifics (speed limits)

• Compatible with eco-roll type features
**Long-term: Low-CD increases HD hybrid potential**

**Competing trends: eco-roll, platooning, base engine efficiency**

<table>
<thead>
<tr>
<th>Cd</th>
<th>0.8</th>
<th>0.65</th>
<th>0.55</th>
<th>0.35</th>
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<tr>
<td>2% grade power</td>
<td>522</td>
<td>479</td>
<td>450</td>
<td>391</td>
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<tr>
<td>MPG (65mph)</td>
<td>6.5</td>
<td>7.6</td>
<td>8.6</td>
<td>11.4</td>
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<tr>
<td>-2% grade power</td>
<td>-29</td>
<td>-72</td>
<td>-102</td>
<td>-160</td>
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<tr>
<td>HD hybrid (50% brake regen)</td>
<td>507</td>
<td>442</td>
<td>399</td>
<td>311</td>
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</tbody>
</table>

**Simplifying Assumptions**
- 50% BTE engine
- Mild grades
- Constant speed 65mph
- 80,000 lbs truck

**Fuel burn [gals]**
- 2010: 13158
- 2014: 8772

**Hybrid benefit**
- 2010: 2.6%
- 2014: 9.9%

**Hybrid fuel save [gals]**
- 2010: 336
- 2014: 867

**Hybrid fuel save $**
- 2010: $1,343
- 2014: $3,468

**20kWh battery pack**
- Today $10-20k, future = $5-8k??
Key points

Line haul entitlement: 4.5–8% from advanced transmission, 1.5-5% from engine, 2-4% from driver improvement and 2-10% hybrid

• **NRC 2010 study** attributed 2% improvement entitlement to driveline, focused on mechanical efficiency of gears in transmissions and axles.
  • SuperTruck and other developments relevant to 2020 timeframe go well beyond that number.
  • Preliminary 2014 NRC report recognizes potential of transmission and engine-transmission integration but does not quantify it.

• **Four sources of CO2 reduction associated with transmissions**
  • More efficient transmissions, minimizing mechanical losses and light weighting. [2%-3%]
  • Optimized gear rations and automation that reduces driver variability and misuse [1.5%-3%]
  • Transmission integrated with engine: enabling downsizing, downsizing, reduced engine transients, excursions [1.5%-5%]
  • Transmission integrated with the vehicle: reducing power loss [1%-2%], hybrids [2%-10%], shifting based on driving environment (aka making average drivers better) [2%-4%]

• **Key transmission technologies**
  • Gearbox enhancements
  • Transition from manual to automation to dual clutch
  • Deep integration with engine enabling powertrain optimization: downspeeding and narrow-banding engine operations
  • Integration with the driving environment: Look-Ahead
  • Hybridization and related technologies