Future Directions in Engines and Fuels

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DEER 2010
Detroit, October 27, 2010
Future Directions in Engines and Fuels
Market Trend Observations – Past Year Review

Source: www.bts.gov; www.eia.doe.gov; www.automotivenews.com

Presented DEER 2009
Light Duty Diesel – Quo Vadis?
Future Directions in Engines and Fuels
Global Market Development Diesel – PC & LD

- Emission Standards
- Client Acceptance
- Fuel Prices

- Fuel Prices
- Fuel Quality

- Client Acceptance
- Fuel Prices
- Fuel Quality

- Fuel Prices
- FuelQuality

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## Future Directions in Engines and Fuels

### Future Diesel Drivetrain Scenarios

<table>
<thead>
<tr>
<th>Technology</th>
<th>Segment</th>
<th>Small</th>
<th>Medium</th>
<th>Large</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Downsizing</strong></td>
<td>Not feasible? (1.3l) → (1l)?</td>
<td>(2l) → (1,6l) -20%</td>
<td>(3IV6) → (2,2l I6/I4) -30%</td>
<td></td>
</tr>
<tr>
<td><strong>Boosting</strong></td>
<td>Optimized VNT</td>
<td>1/2-stage</td>
<td>2-stage</td>
<td></td>
</tr>
<tr>
<td><strong>FIE</strong></td>
<td>1450..1800 bar</td>
<td>1800-2000 bar (Piezo)</td>
<td>&gt;2000 bar Piezo</td>
<td></td>
</tr>
<tr>
<td><strong>EGR-System</strong></td>
<td>HP/HP&amp;LP-EGR</td>
<td>HP&amp;LP-EGR</td>
<td>HP&amp;LP-EGR</td>
<td></td>
</tr>
<tr>
<td><strong>Aftertreatment</strong></td>
<td>DPF / LNT</td>
<td>DPF / SCR or DPF / LNT</td>
<td>DPF / SCR</td>
<td></td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Transmission</th>
<th>Diesel</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Engine</td>
<td>Manual / Automated</td>
<td>AMT, DCT</td>
<td>AMT, DCT, AT</td>
</tr>
<tr>
<td>Gears</td>
<td>5-6</td>
<td>6-8</td>
<td>6-8</td>
</tr>
<tr>
<td>Clutches Dry / Wet</td>
<td>Dry</td>
<td>Wet, Dry</td>
<td>Wet</td>
</tr>
<tr>
<td>Hybrid</td>
<td>Start/Stop</td>
<td>BISG</td>
<td>BISG &amp; ISG</td>
</tr>
<tr>
<td>Rekuperation</td>
<td>Restricted, 3KW</td>
<td>Enhanced</td>
<td>Full</td>
</tr>
<tr>
<td>Optimized Operation</td>
<td>Limited</td>
<td>Limited</td>
<td>Yes</td>
</tr>
<tr>
<td>Electric Drive (&lt;20mi)</td>
<td>-</td>
<td>-</td>
<td>Yes</td>
</tr>
</tbody>
</table>

**Boundary Conditions: U.S. Tier 2 Bin 5**
### FEV HECS Engine Specifications

<table>
<thead>
<tr>
<th>Specification</th>
<th>HECS Engine</th>
</tr>
</thead>
<tbody>
<tr>
<td>BoreXStroke</td>
<td>75x88.2 mm</td>
</tr>
<tr>
<td>Displacement</td>
<td>1.6L (4x390 cm³)</td>
</tr>
<tr>
<td>Compression ratio</td>
<td>15.5</td>
</tr>
<tr>
<td>Valves per cylinder</td>
<td>4</td>
</tr>
<tr>
<td>Max. valve lift</td>
<td>8 mm</td>
</tr>
<tr>
<td>Maximum cylinder peak pressure</td>
<td>220 bar</td>
</tr>
<tr>
<td>Fuel injection equipment specifications:</td>
<td>Piezo Common Rail System (CP4.1, CRI 5.1)</td>
</tr>
<tr>
<td>Max. injection pressure</td>
<td>2000 bar</td>
</tr>
<tr>
<td>HFR</td>
<td>310 cm³/60s@100bar</td>
</tr>
<tr>
<td>Max. boost pressure</td>
<td>3.75 bar (2-stage)</td>
</tr>
<tr>
<td>Charge air cooling level</td>
<td>Advanced</td>
</tr>
<tr>
<td>Variable swirl</td>
<td>Yes (with VVL)</td>
</tr>
<tr>
<td>Glow plug</td>
<td>Yes</td>
</tr>
<tr>
<td>EGR</td>
<td>Internal, HP and LP EGR</td>
</tr>
<tr>
<td>Combustion control</td>
<td>Center of combustion, maximum burning rate, IMEP Control</td>
</tr>
<tr>
<td>Emission level</td>
<td>Euro 6+</td>
</tr>
</tbody>
</table>
## Future Directions in Engines and Fuels

### FEV HECS Diesel Concept Car

#### Specification HECS I (current)
- 1.6l 4-Cyl. Diesel Engine
- 60 kW/l spec. Power (limited PFP)
- Euro 6 w/o DeNOx (<1700 kg)
- ~130g/km CO₂ (1590 kg)
- 2-stage boosting system
- High (cooled) and Low Pressure EGR
- Advanced Cooling Concept
- 2000 bar Piezo FIE
- Optimized Bowl with CR 15:1
- Exhaust Cam Phaser
- Model based Air path control
- Closed loop combustion control

#### Specification HECS II
- 1.6l 4-Cyl. Diesel Engine
- 80 kW/l spec. Power (200 bar PFP)
- Euro 6 w/o DeNOx (<1700 kg)
- ~120g/km CO₂ (1590 kg)
- 2-stage boosting system
- High and Low Pressure EGR
- Advanced Cooling Concept
- Split&intelligent cooling engine
- 2000 bar Piezo FIE
- Optimized Bowl with CR 15:1
- Variable Swirl Concept (VVL)
- Exhaust Cam Phaser
- Model based Air path control
- Closed loop combustion control
- Start & Stop
Calculation Results Series-TC:

- Power target at n=1000 rpm not reached (larger HP-turbine), torque slightly above baseline engine; further H/W optimization feasible
- All other power targets can be reached, but LP-compressor is very close to choke line at high engine speeds
- At n=4500 rpm quite high exhaust back pressure rise due to decreasing LP-compressor efficiency (could be optimized)
- Advantage of exhaust back pressure due to higher LP-turbine efficiency

<60kW/L
Future Directions in Engines and Fuels
Heat Exchanger and Coolant Circuit

**HP-EGR Cooler:**
- Shell and tubes heat exchanger with optimised gas tube design
- High thermal exchange and resistance to fouling
- High permeability
- U-flow design for additional heat exchange
- Stainless steel for high resistance to corrosive gases

**Intercoolers:**
- Liquid cooled aluminium plate heat exchanger
- Reduction of gas volume
- High permeability
- High thermal performance
- Higher degrees of freedom respect to packaging

**LP-EGR Cooler:**
- Aluminium plate and fin heat exchanger
- Compact and permeable design
- High thermal conductivity
- Low density
Comparison of EGR Concepts @ 2000 rpm – 12 bar

- Intake Temperature [°C]
- Air Fuel Ratio [-]
- BSFC [g/kWh]
- Smoke Number [-]

Specific NOx-Emission [g/kWh]

- Only HP-EGR
- Only LP-EGR

-4.3%
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Map of HP – LP EGR Distribution

![Map of HP – LP EGR Distribution](image-url)
Future Directions in Engines and Fuels

Efficiency Potential

2000 rpm, 12 bar BMEP

η = 44.0%

η = 40.3%

η = 43.9%

EGR point for split of losses
Future Directions in Engines and Fuels
Emission Potential of Advanced Fuel Compositions

Part Load Operation Point: 2300 rpm, high load (HECS)

<table>
<thead>
<tr>
<th>Fuel</th>
<th>Description</th>
</tr>
</thead>
<tbody>
<tr>
<td>Fuel 1</td>
<td>Standard EN590 Diesel Research Fuels</td>
</tr>
<tr>
<td>Fuel 2</td>
<td>Diesel with reduced aromatic content</td>
</tr>
<tr>
<td>Fuel 3</td>
<td>Diesel with reduced cetane number</td>
</tr>
<tr>
<td>Fuel 4</td>
<td>Diesel with higher volatility</td>
</tr>
<tr>
<td>Fuel 5</td>
<td>Diesel with reduced aromatic content and higher volatility</td>
</tr>
<tr>
<td>Fuel 6</td>
<td>Octane/Heptane blend (CN44)</td>
</tr>
<tr>
<td>Fuel 7</td>
<td>Toluene/Heptane blend (CN44)</td>
</tr>
<tr>
<td>Fuel 8</td>
<td>Gasoline/Diesel blend (CN44)</td>
</tr>
<tr>
<td>Fuel 9</td>
<td>Octane/Heptane blend (CN35)</td>
</tr>
<tr>
<td>Fuel 10</td>
<td>Octane/Heptane blend (CN30)</td>
</tr>
<tr>
<td>Fuel 11</td>
<td>Octane/Heptane blend (CN25)</td>
</tr>
<tr>
<td>Fuel 12</td>
<td>Octane/Heptane blend + E10 (CN44)</td>
</tr>
</tbody>
</table>

Smoke Number [FSN]

- Euro 5 ISNOx-level: 1.2 g/kWh
- Euro 6 ISNOx-level: 0.6 g/kWh
- Euro 7 ISNOx-level: 1.8 g/kWh
Light Duty Gasoline Development Trends
Future Directions in Engines and Fuels
Full Load – State-of-the-Art 3-Cylinder Engine

Target 3 Cylinder

Scatter Range
Future Low End Torque
TC Engines

Brake Mean Effective Pressure
- Standard engines
- Turbocharged
Future Directions in Engines and Fuels

FEV *EDE* (Extreme Downsized Engine)

- Homogenous $\lambda = 1.0$ concept
- Multihole solenoid injector
- Assymetric spray pattern
- Single piston pump 200 bar
- Pump is driven by camshaft

$\Rightarrow 100 \text{ kW} / \text{l} - 0.7 \text{l}$
Future Directions in Engines and Fuels

Full Load – State-of-the-Art 3-Cylinder Engine

- Base PFI 1.4 l-I4-4V, N.A.
  - 65 kW
  - 120 km/h

- EDE engine DI 0.7 l-I3-2V, T.C.
  - 65 kW
  - 120 km/h

- Driving resistance
  - 5th gear
  - 3rd gear

- Fuel consumption reduction: 10%

- Brake mean effective pressure / bar
  - 0
  - 5
  - 10
  - 15
  - 20
  - 25
  - 30

- Engine speed / rpm
  - 1000
  - 2000
  - 3000
  - 4000
  - 5000
  - 6000
Final Thoughts

Fuel Economy [mpg]

Vehicle Weight [lbs]

Displacement Downsized Engine

Base Engine

Variance in Transmission Technology

1000 lbs opportunity

10% FE

28 29 30 31 32 33 34 35 36 37 38 39 40 41 42

2000 2500 3000 3500 4000 4500 5000
Thank you