European Diesel Engine Technology: An Overview

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Contents

- Market Factors
  - Legislation
  - Customer Requirements
  - Europe vs. US
- Current Trends
- Future Technologies
- Summary
Legislation

- Emissions
- CO$_2$
Comparison of NOx Emission Standards (Diesel)

- Fed NOx
- Cal NOx
- Euro HC+NOx
- Euro NOx

Fed Tier 2, Bin 2 = 0.02 g/mi
Cal SULEV 2 = 0.02 g/mi
Comparison of PM Emissions Standards

PM Emissions [g/mi]

- Fed PM
- Cal PM
- Euro PM

Model Year

CO₂ Emissions - European Fleet Average and Required Reductions

<table>
<thead>
<tr>
<th>Model Year</th>
<th>CO₂ Fleet Average - g/km</th>
</tr>
</thead>
<tbody>
<tr>
<td>1995</td>
<td>200</td>
</tr>
<tr>
<td>2000</td>
<td>180</td>
</tr>
<tr>
<td>2005</td>
<td>160</td>
</tr>
<tr>
<td>2010</td>
<td>140</td>
</tr>
<tr>
<td>2015</td>
<td>120</td>
</tr>
</tbody>
</table>

1998 Fleet Average

ACEA and EU Commission Goals

-26%  
-37%

X---X Actual
US CAFE Standards

- Car
- Truck

Model Year

- US Senate Proposal
- Kyoto Protocol

Fuel Consumption [l/100 km]

- 5.9
- 6.7
- 7.8
- 9.4
- 11.8
- 15.7
- 23.5
- 47.1

CAFE [MPG]

- 0.0
- 5.0
- 10.0
- 15.0
- 20.0
- 25.0
- 30.0
- 35.0
- 40.0
CO₂ Emissions Potential - Diesel vs. Gasoline Engines

Source: Kraftfahr-Bundesamt (KBA), 7/1999
Customer Requirements

- Costs
  - Fuel Costs
  - Initial Purchase vs. Operating Costs

- Performance
European Fuel Prices

unleaded petrol, prices in EU Member States, October 2000

- VAT
- excise duty
- cost price

Source: Eurostat, 2001

Only Country With Lower Gasoline Price
Source: Eurostat, 2001; EIA 2002
Cost Comparison

- **VW Golf 1.9l TDI vs. 1.8l T**
  - ≈ 1500 Euro Difference in Purchase Cost
  - 5.4 vs. 7.9 l/100 km
  - 15000 km /year
  - 0.89 vs 1.03 Euro/l
  - 720 vs. 1220 Euro Annual Operating Costs
  - 3 Year Payback Period

- **M-B E 270 CDI vs. E 240**
  - ≈ 700 Euro Difference in Purchase Cost
  - 6.5 vs. 10.7 l/100 km
  - 15000 km /year
  - 0.89 vs 1.03 Euro/l
  - 870 vs. 1650 Euro Annual Operating Costs
  - 1 Year Payback Period
## Performance: Diesel vs. Gasoline

<table>
<thead>
<tr>
<th></th>
<th>VW Golf 1.8T</th>
<th>VW Golf 1.9TDI</th>
<th>M-B E240</th>
<th>M-B E270 CDI</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Power [kW]</strong></td>
<td>130</td>
<td>130</td>
<td>130</td>
<td>130</td>
</tr>
<tr>
<td><strong>Torque [N-m]</strong></td>
<td>240</td>
<td>400</td>
<td>240</td>
<td>400</td>
</tr>
<tr>
<td><strong>Vmax [km/h]</strong></td>
<td>236</td>
<td>230</td>
<td>236</td>
<td>236</td>
</tr>
<tr>
<td><strong>0-100km/h [s]</strong></td>
<td>8.9</td>
<td>9.0</td>
<td>8.9</td>
<td>9.0</td>
</tr>
<tr>
<td><strong>City [l/100km]</strong></td>
<td>15.8</td>
<td>9.1</td>
<td>15.8</td>
<td>9.1</td>
</tr>
<tr>
<td><strong>Hwy [l/100km]</strong></td>
<td>7.9</td>
<td>7.9</td>
<td>7.9</td>
<td>7.9</td>
</tr>
<tr>
<td><strong>Comb [l/100km]</strong></td>
<td>10.7</td>
<td>6.5</td>
<td>10.7</td>
<td>6.5</td>
</tr>
<tr>
<td><strong>CO2 [g/km]</strong></td>
<td>257</td>
<td>172</td>
<td>257</td>
<td>172</td>
</tr>
</tbody>
</table>
Elasticity: Diesel vs. Gasoline

<table>
<thead>
<tr>
<th></th>
<th>M-B C180</th>
<th>M-B C200 CDI</th>
</tr>
</thead>
<tbody>
<tr>
<td>Power [kW]</td>
<td>122</td>
<td>114</td>
</tr>
<tr>
<td>Torque [N-m]</td>
<td>178</td>
<td>250</td>
</tr>
<tr>
<td>Vmax [km/h]</td>
<td>213</td>
<td>204</td>
</tr>
<tr>
<td>0-100km/h [s]</td>
<td>12.83</td>
<td>12.06</td>
</tr>
<tr>
<td>60-100km/h (4th) [s]</td>
<td>12.83</td>
<td>9.92</td>
</tr>
</tbody>
</table>

+40% vs. -23%
Europe vs. US

Diesel “Gap”

Fuel Economy

"High-Tech"

Environment (CO2)

Cost

Emissions

Noise

Performance

Europe

North America

Japan

Rest of World
Contents

- Market Differences
  - Legislation
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Specific Torque of HSDI Diesels

- VW
- BMW
- AUDI

Specific Torque [Nm/l]

Curb Weight (Kg)

- 3, 4 and 5 cyl. PC engines
- 6, 8 and 10 cyl. PC engines
- All SUVs

All SUVs = USA, Japan and Europe
Specific Power of HSDI Diesels

Curb Weight (kg) vs. Specific Power [kW/l]

- VW
- BMW
- AUDI

- 3, 4 and 5 cyl. PC engines
- 6, 8 and 10 cyl. PC engines
- All SUVs

All SUVs = USA, Japan and Europe
Specific Torque vs. Specific Power

Passenger Car Engines Certified to EURO III or Better

Source: Kraftfahr-Bundesamt (KBA), 03/2000; mot 11/2000; Automobil Revue 2000
Assessment of Technologies to Meet Future Emissions Standards

EURO V, US Tier 2, CARB LEV II Standards

“Conventional” Combustion Systems

- DPF
- 4way cat ? = 65/95 %
- Alternative Combustion Systems plus Aftertreatment

Alternative Combustion Systems

- DPF ? > 85%
- 4 way cat

Vehicle ITW (kg)

1000 2000 3000 4000
Contents

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Most Promising Options for SUV / LDT
Effect of Charging Systems on Full Load Characteristics

6 Cylinder HSDI, 0.5 l/cylinder Class

Transmission Torque Limitation

Low end torque

Specific power

Engine speed [rpm]

BMEP [bar]

- 65 kW/l, Torque demand
- 65 kW/l, Real compressor map
- 55 kW/l, Real compressor map
- 55 kW/l, VGT + E-Booster
- 70 kW/l, 2stage TC
Specific Power vs. Peak Firing Pressure and Compression Ratio

3l V6 at Constant Compression Ratio

Lower Compression Ratio Allows:
• Reduction of PFP
• Higher specific power (kW/l)
• Lower fuel consumption, and
• Lower emissions

About 10 bar / CR Unit
Variable Swirl: Effect on Exhaust Emissions

- 0.5l/Cyl Class, TCI engine
- CR FIE; 4.1 bar/1500 RPM
- Constant Injection Timing

**Smoke (BSU):**
- Swirl 1.2 (swirl flap opened)
- Swirl 2.8 (swirl flap closed)

**CO-Emission (ppm):**
- ~Const CO
- Increasing EGR

**NOx:**
- ~Const CO

**Air Excess Ratio:**
- Spec. NOx-Emission (g/kWh)
- Spec. NOx-Emission (g/kWh)
Alternative Combustion Systems

AVL Combustion: Single Cylinder Engine - 0.5 l/cyl.
EU III & EU IV Data: Multicylinder Engine - 0.40 l/cyl.

1250 RPM
1.6 bar BMEP

KNOx_S (g/kg)

HC (ppr)

Soot (g/kg)

AVL Comb. EL8 EU4 AVL Comb. EL8 EU4 AVL Comb. EL8 EU4

0.02 6.1 4.7 1924 421 586 0.532 0.25 0.33

0.01 0.532 0.526 0.05

DEER 2002 Conference - 27
Summary and Conclusion

- Specific Performance Will Reach
  - 60-65 kW/l
  - 180 Nm/l

- Engine Fuel Consumption Will be Reduced by:
  - Friction Reduction
  - Faster Engine Warm Up
  - Reduced Compression Ratio
  - Cylinder Deactivation, and
  - Start-Stop Operation
Summary and Conclusion (2)

Emissions Reductions to Very Low Levels by:
- Increased Sophistication
- Exhaust Aftertreatment
- Improved Fuels
- Alternative Combustion Systems

Most Solutions Too Expensive or Not Ready for Mass Production
“Mainstream” HSDI Diesel Technology Will be Cost Competitive With Gasoline Engines

High-Tech Diesels Most Appropriate for Markets With Strong Emphasis on Fuel Consumption, i.e.

- Europe
- North America (Pick-Ups, SUVs, etc.)