The Viability of Sustainability: The Role of Clean Diesel

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Diesel Systems Development
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reduced by Bosch

University of Michigan Transportation Research Institute
“Focus on the Future”
Automotive Research Conferences
“Focus on the Future” UMTRI conference 13 Feb. 2013

Topics:

- Market Trends and Regulations
- Future approach
  - Air & Fuel management
  - Exhaust Gas Management
  - Tolerance Reduction
  - Combustion Process
  - Powertrain
- Summary
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Changing Requirements

- CO\(_2\) / Fuel Economy
- Emissions (HC, CO, NO\(_x\), Particulates)
- Power / Comfort
- Renewable Fuels
- Fossil Fuels

Resources

- ACEA-Selbstverpflichtung 2008: 140g/km (-25%)

Bosch Innovations

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US PC/LD Emissions Evolution:

More than 90% reduction in criteria emissions in 10 years

2009 Clean Diesel Vehicles

2006 vehicles

1999 vehicles

Tier 1

Tier 2

Bin 2

Bin 8

Bin 9

Bin 10

2009 Clean Diesel Vehicles

D/EIS-NA | 02.06.2013 | 1382_046.ppt © 2013 Robert Bosch LLC and affiliates. All rights reserved.
Development CO₂ fleet targets

<table>
<thead>
<tr>
<th>g CO₂ / km</th>
<th>l/100 km</th>
<th>mpg</th>
<th>km/l</th>
</tr>
</thead>
<tbody>
<tr>
<td>250</td>
<td>10,5</td>
<td>22,3</td>
<td>9,5</td>
</tr>
<tr>
<td></td>
<td>9,4</td>
<td>24,9</td>
<td>10,5</td>
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<tr>
<td>200</td>
<td>8,4</td>
<td>27,9</td>
<td>11,9</td>
</tr>
<tr>
<td></td>
<td>7,5</td>
<td>31,2</td>
<td>13,3</td>
</tr>
<tr>
<td>150</td>
<td>6,3</td>
<td>37,2</td>
<td>15,9</td>
</tr>
<tr>
<td></td>
<td>5,7</td>
<td>41,5</td>
<td>17,5</td>
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<tr>
<td>100</td>
<td>4,2</td>
<td>55,7</td>
<td>23,8</td>
</tr>
<tr>
<td></td>
<td>3,8</td>
<td>62,3</td>
<td>26,3</td>
</tr>
<tr>
<td>50</td>
<td>2,1</td>
<td>113</td>
<td>47,6</td>
</tr>
</tbody>
</table>

US CAFE

Cars

\[35.5 \text{ mpg}^*\]

LT

\[54.5 \text{ mpg}^*\]

* Combined fleet average

CAFE = Corporate Average Fuel Economy  PC = Passenger Cars  LT / LDT = Light Trucks (pick-ups, vans, SUVs)  CARB = California Air Resources Board  mpg = miles per gallon

Stringent requirements by 2025
MY2011 Passenger Car CAFE Fleet Data

Bosch Footprint Based Segments

Source: Martec 2011/Bosch

MY2017 - MY2025 targets based on corrected NPRM 11/30/11
**MY2011 Passenger Car CAFE Fleet Data**

**Gasoline and Diesel Passenger Cars**

<table>
<thead>
<tr>
<th>Model</th>
<th>MY2016</th>
<th>MY2021</th>
<th>MY2025</th>
</tr>
</thead>
<tbody>
<tr>
<td>Jetta Sportwagon Diesel</td>
<td>14%</td>
<td>18%</td>
<td>25%</td>
</tr>
<tr>
<td>Golf Diesel</td>
<td>15%</td>
<td>4%</td>
<td>23%</td>
</tr>
<tr>
<td>Jetta Sedan Diesel</td>
<td>2%</td>
<td>62%</td>
<td>48%</td>
</tr>
<tr>
<td>BMW 3-Series Gasoline</td>
<td>0%</td>
<td>23%</td>
<td>7%</td>
</tr>
<tr>
<td>BMW 3-Series Diesel</td>
<td>23%</td>
<td>94%</td>
<td>11%</td>
</tr>
<tr>
<td>Audi A3 Diesel</td>
<td>25%</td>
<td>11%</td>
<td>66%</td>
</tr>
</tbody>
</table>

**MY2017 - MY2025 targets based on corrected NPRM 11/30/11**

Source: Martec 2011
### U.S. Clean Diesel Vehicle Launch Calendar

<table>
<thead>
<tr>
<th>Year</th>
<th>2013</th>
<th>2014</th>
<th>2015</th>
<th>2016≤</th>
</tr>
</thead>
<tbody>
<tr>
<td>PC</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Audi A6 (3.0L)</td>
<td>Audi A7 (3.0L)</td>
<td>Audi A8 (3.0L)</td>
<td>BMW 325 (2.0L)</td>
</tr>
<tr>
<td></td>
<td>Chevrolet Cruze (2.0L)</td>
<td>Mazda 6 (2.2L)</td>
<td>MB E250 (2.2L)</td>
<td></td>
</tr>
<tr>
<td></td>
<td>VW Beetle Conv. (2.0L)</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>SUV</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Audi Q5 (3.0L)</td>
<td>Jeep Grand Cherokee (3.0L)</td>
<td>MB GLK 250 (2.2L)</td>
<td>MB ML 250 (2.2L)</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Truck/Van</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>Ford Transit (3.2L)</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

**Announced by OEM**

**Not Announced by OEM**
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➢ Market Trends and Regulations

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  ➢ Exhaust Gas Management
  ➢ Tolerance Reduction
  ➢ Combustion Process
  ➢ Powertrain

➢ Summary
Powertrain diversification for Today and the Future

- Gasoline
- Diesel
- Alternative fuels
- Hybrid
- EV / range extender
- EV / battery
- EV / fuel cell
- EV (battery / fuel cell)

Variety of Technical solution needed to address energy reduction
New powertrains: Estimated world market volumes

- ICE (gasoline / diesel / FlexFuel)
- Full Electric Vehicles
- Hybrid Vehicles (w/ ICE Engine)
- Others (CNG, LPG)

Source: Internal

Internal Combustion Engines will remain the predominant power train for the near future
Optimizing the Diesel System

Air Management
- Swirl-/Throttle Valve
- Turbo Charger/VGT*

Combustion Process
- Reduction of compression ratio
- Combustion strategies

Fuel Injection System
- New Generations
- Multiple Injections
- Reduced Tolerance
- Optimized Nozzle

Exhaust gas management
- Fast Catalyst Light-Off (reduce thermal losses)
- Diesel Particulate Filter
- NOx storage catalyst
- Catalyst temp control

Tolerance Reduction
- Zero Fuel Calibration
- Fuel Balancing Control
- Individual Cylinder Control

*VGT= Variable Geometry Turbo
Optimizing the Diesel System

**Combustion Process**
- Reduction of compression ratio
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- NOx storage catalyst
- Catalyst temp control

*VGT= Variable Geometry Turbo
Hybrid: No longer a gasoline story

Fuel Consumption in g/kWh

Disadvantage Area

NO\textsubscript{X}

Soot

Engine Speed [rpm]

BMEP [bar]

Engine Speed [rpm]

BMEP [bar]

Engine Speed [rpm]

BMEP [bar]

NO\textsubscript{X}

Soot

CO

HC

Low

High

Low

Low

High

Low

High

Low

Low
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<table>
<thead>
<tr>
<th></th>
<th>Mild Hybrid</th>
<th>Strong Hybrid w/ mech. drive</th>
<th>Strong Hybrid w/o mech. drive</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Electrical Power demand</strong></td>
<td>Low</td>
<td>Mid</td>
<td>High</td>
</tr>
<tr>
<td><strong>Recuperation Potential</strong></td>
<td>Low</td>
<td>High</td>
<td>High</td>
</tr>
<tr>
<td><strong>Performance in Electric Driving</strong></td>
<td>Very Low</td>
<td>High</td>
<td>Very high</td>
</tr>
<tr>
<td><strong>Efficiency Chain of Drivetrain</strong></td>
<td>Mid</td>
<td>High</td>
<td>Mid</td>
</tr>
<tr>
<td><strong>CO₂ Potential</strong></td>
<td>Mid</td>
<td>High</td>
<td>Mid</td>
</tr>
<tr>
<td><strong>Architectures</strong></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Diesel Systems</td>
<td></td>
<td></td>
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</tr>
</tbody>
</table>

- Elimination of engine low load area requires pure electrical driving
- Parallel architecture with a single clutch is a smart solution with low complexity
Parallel Strong Hybrid – Single Clutch

- Diesel Engine: DI 1.6l, Pmax = 85 kW
- Gearbox: 6-speed AMT
- E-Motor: IMG, Pmax = 25 kW
- Battery: Li-Ion, Capacity = 1.5 kWh

AMT: Automated Manual Transmission
IMG: Integrated Motor Generator
SES: Standard Electric Starter

Elimination of engine low load area requires pure electrical driving
Parallel architecture with a single clutch is a smart solution with low complexity
**Split Test:**
Battery balance is also forced at the end of UDC.

CO₂ emission reduction by combining urban with extra urban driving.

* Basis: CO₂ Emission in g of Conventional Vehicle in NEDC
Basis: CO₂ Emission in g/km of Conventional Vehicle* in NEDC

*Conventional Vehicle: 1470 kg IW, 1.6 l Diesel Engine, Euro 5; HEV: 1590 kg IW, 1.6 l Diesel Engine + 25 kW E-Motor

Reduced CO₂ emission difference between urban and extra urban driving with hybrid
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Summary:

- Cont. work ongoing to further improve fuel economy
- Diesel will maintain advantage compared to gasoline
- LEV III work ongoing
- New Technologies provide emissions benefit
- GHG reduction work ongoing
- New Technologies provide GHG benefit
- Full system approach required to meet
  - FE and criteria emission targets
Thank You