BMW Diesel.
12th DEER Conference, August 20-24, 2006, Detroit

BMW Diesel Engines – dynamic, efficient and clean
Wolfgang Mattes
BMW Diesel.

Contents

• BMW Diesel history

• Engine portfolio and market success

• What do Diesel customers like?

• Challenges in the US-market

• Emission concept for TIER2 BIN5

• Conclusions
BMW Diesel.

Dramatic evolution.

- Torque: +160%
- Power: +135%
- Consumption: -20%
- Emissions: -99%
- Particulates
BMW Diesel.
Two decades of diesel competence.

1983
- First inline 6 BMW diesel
- 524td, fastest diesel car of its time

1987
- First Digital Diesel-Electronic (DDE)

1990
- First BMW diesel with Oxidation-CAT

1995
- Introduction of DI technology by BMW
- BMW 320d wins the 24 Hours of Nürburgring

2000
- Variable Twin Turbo
- Particulate filter 2nd generation

1998
- First V8 diesel with direct injection within the premium car segment

2001
- DI with 2nd generation Common Rail, 1600 bar

2004
BMW Diesel.
Production Volumes.

<table>
<thead>
<tr>
<th>Year</th>
<th>1st Generation</th>
<th>2nd Generation</th>
<th>3rd Generation until end 2005</th>
</tr>
</thead>
<tbody>
<tr>
<td>1983</td>
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<td>1984</td>
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<tr>
<td>2005</td>
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</tr>
</tbody>
</table>

- **1st Generation**: Total 262,000 engines
- **2nd Generation**: Total 635,000 engines
- **3rd Generation until end 2005**: Total 2,324,000 engines
### BMW Diesel.

#### Diesel Models in Europe.

<table>
<thead>
<tr>
<th></th>
<th>Mini</th>
<th>1er</th>
<th>3er</th>
<th>5er</th>
<th>7er</th>
<th>X3</th>
<th>X5</th>
</tr>
</thead>
<tbody>
<tr>
<td>4-Cylinder</td>
<td>One D</td>
<td>118d 120d</td>
<td>318d 320d 320cd</td>
<td>520d</td>
<td>X3 2.0d</td>
<td></td>
<td></td>
</tr>
<tr>
<td>6-Cylinder</td>
<td></td>
<td>330d 330cd 330xd</td>
<td>525d 530d 530xd 535d</td>
<td>730d</td>
<td>X3 3.0d</td>
<td>X5 3.0d</td>
<td></td>
</tr>
<tr>
<td>8-Cylinder</td>
<td></td>
<td></td>
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<td>745d</td>
</tr>
</tbody>
</table>
BMW Diesel.
Development of 6-Cylinder Diesel-Engines.

<table>
<thead>
<tr>
<th>Year</th>
<th>Power [kW]</th>
<th>Torque [Nm]</th>
</tr>
</thead>
<tbody>
<tr>
<td>1983</td>
<td>85</td>
<td>210</td>
</tr>
<tr>
<td>1991</td>
<td>105</td>
<td>410</td>
</tr>
<tr>
<td>1998</td>
<td>135</td>
<td>500</td>
</tr>
<tr>
<td>2002</td>
<td>160</td>
<td>500</td>
</tr>
<tr>
<td>2004</td>
<td>200</td>
<td>560</td>
</tr>
</tbody>
</table>

* since 03/2005 170 kW / 520 Nm
### BMW Diesel.

#### Engine Line up.

<table>
<thead>
<tr>
<th>Engine Displacement [l]</th>
<th>4-Cylinder 2.0 l</th>
<th>6-Cylinder 2.5 l / 3.0 l / 3.0 l VVT</th>
<th>8-Cylinder 4.4 l</th>
</tr>
</thead>
<tbody>
<tr>
<td>1.5</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2</td>
<td></td>
<td></td>
<td></td>
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<tr>
<td>2.5</td>
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<tr>
<td>3</td>
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<tr>
<td>3.5</td>
<td></td>
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<td></td>
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<tr>
<td>4</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>4.5</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- **Power [kW]**
  - 100
  - 125
  - 150
  - 175
  - 215
  - 250
BMW Diesel.

BMW Diesel–Mix in Western Europe.

Per August 2005:

- 1er: 58%
- 3er: 56%
- 5er: 73%
- 7er: 70%
- X3: 88%
- X5: 89%

Overall (gesamt):
- 63%

(2004: 54%)
BMW Diesel.
Australia – development of X5 Diesel-share.

- Overall Diesel Share PC+ LDV
  - 2004: 10%
  - 2005: 11%
  - 2006 forecast: 1708 units

- Diesel share [%]
  - 2004: 1387 units
  - 2005: 1830 units
  - 2006 forecast: 1708 units
BMW Diesel.
Success factors for Diesel engines.

- **Fun to drive, outstanding torque characteristic**
  - relaxed cruising
  - torque on demand
  - good NVH due to low engine speed

- **Low fuel consumption**
  - 20-30 % below comparable Petrol cars
  - cost saving, sometimes supported by low fuel costs
  - high cruising range

→ **BMW focus: Sports Diesel**
High power output and sporty drivability combined with low FC under all driving conditions
BMW Diesel.
Efficient Dynamics.

Dynamics

Weight reduction

Fuel-Consumption and Emissions
BMW Diesel.
Clean Diesel – Introduction of Particulate Filter.

<table>
<thead>
<tr>
<th>2007</th>
<th>2004</th>
<th>2005</th>
<th>2006</th>
</tr>
</thead>
<tbody>
<tr>
<td>118d, 120d</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>318d, 320d</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>330d</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>525d, 530d</td>
<td>03/04</td>
<td></td>
<td></td>
</tr>
<tr>
<td>535d, 520d</td>
<td>09/04</td>
<td></td>
<td></td>
</tr>
<tr>
<td>730d, 745d</td>
<td></td>
<td></td>
<td>03/05</td>
</tr>
<tr>
<td>X3 2.0d, X3 3.0d</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>X5 3.0d</td>
<td></td>
<td></td>
<td>10/05</td>
</tr>
</tbody>
</table>
BMW Diesel.
Leading edge engine technology.
BMW Diesel.
Variable Twin Turbo technology –
a new milestone in diesel history.
BMW Diesel.
Variable Twin Turbo technology - even more powerful.
BMW Diesel.
Variable Twin Turbo technology combines V8-dynamics with R6 fuel consumption.
BMW Diesel.
Technology proofed in Rally Sport.

Engine: BMW inline 6 cylinder diesel with Variable Twin Turbo
Power: about 270 HP
Torque: over 600 Nm

→ First Diesel to win a special stage
BMW Diesel.
The package for EU4 emission regulations.
BMW Diesel.
The package for EU 4 emission regulations.
BMW Diesel.
Combustion Chamber Configuration.

6-Cylinder
- central injector position
- 4 valves
- symmetrical combustion chamber
- variable air control

8-Cylinder
Particles are filtered and burnt off in the ceramic filter with its catalytic coating.

- No power loss
- No significant increase in FC
- Reduced HC/CO-emissions
- No maintenance necessary
- Reduced system effort
When I buy a new car, the fuel consumption is very important for me, even if it means spending more money for this lower fuel consumption. I couldn't imagine life without a car.

A car has to be at the cutting edge of technology.

A car's eco-friendliness is of the greatest importance for me.

For me a car is simply a functional object.

For me a car is of particular interest if it is a very innovative and advanced model.

Cars are a major problem for the environment.

When I buy a car, the price is the absolutely decisive criterion.

I can get really enthusiastic about cars.

---

General Attitude towards Driving & Cars

**Data in %**

**Petrol drivers (n=598)**

- Diesel drivers (n=420)

**Petrol drivers (n=676)**

- Diesel drivers (n=329)

---

Source: BOSCH
What do Diesel customers like.

Timing of Engine Choice

<table>
<thead>
<tr>
<th>Decision Timing</th>
<th>Petrol drivers (n=598)</th>
<th>Diesel drivers (n=420)</th>
<th>Petrol drivers (n=676)</th>
<th>Diesel drivers (n=329)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Decided right at the beginning</td>
<td>37</td>
<td>55</td>
<td>37</td>
<td>52</td>
</tr>
<tr>
<td>Before going to the dealership</td>
<td>14</td>
<td>16</td>
<td>18</td>
<td>22</td>
</tr>
<tr>
<td>I listen to the dealer’s advice and then decide between petrol and diesel</td>
<td>21</td>
<td>13</td>
<td>16</td>
<td>8</td>
</tr>
<tr>
<td>After going to the dealership</td>
<td>17</td>
<td>8</td>
<td>11</td>
<td>11</td>
</tr>
<tr>
<td>Don’t know / No answer</td>
<td>11</td>
<td>8</td>
<td>12</td>
<td>4</td>
</tr>
</tbody>
</table>

Petrol drivers (n=598)

Diesel drivers (n=420)

Petrol drivers (n=676)

Diesel drivers (n=329)

Data in %

Source: BOSCH
BMW Diesel.

What do Diesel customers like.

Spontaneous Associations with Diesel

<table>
<thead>
<tr>
<th>Petrol drivers (n=598)</th>
<th>Diesel drivers (n=420)</th>
<th>Petrol drivers (n=676)</th>
<th>Diesel drivers (n=329)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Positive aspects</td>
<td>Negative aspects</td>
<td>Makes/models</td>
<td>Others</td>
</tr>
<tr>
<td>46</td>
<td>40</td>
<td>10</td>
<td>9</td>
</tr>
<tr>
<td>3</td>
<td>18</td>
<td>16</td>
<td>16</td>
</tr>
<tr>
<td>No specific image</td>
<td>No answer</td>
<td></td>
<td></td>
</tr>
<tr>
<td>8</td>
<td>7</td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

Data in %

Source: BOSCH
### Spontaneous Associations with Diesel

#### Positive aspects

<table>
<thead>
<tr>
<th>Aspect</th>
<th>Petrol drivers (n=598)</th>
<th>Diesel drivers (n=420)</th>
<th>Petrol drivers (n=676)</th>
<th>Diesel drivers (n=329)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Consumption level</td>
<td>24</td>
<td>42</td>
<td>15</td>
<td>42</td>
</tr>
<tr>
<td>Performance (hp, acceleration, torque)</td>
<td>18</td>
<td>36</td>
<td>8</td>
<td>22</td>
</tr>
<tr>
<td>Eco-friendly technology</td>
<td>6</td>
<td>10</td>
<td>3</td>
<td>7</td>
</tr>
<tr>
<td>Strongly improved diesel technology</td>
<td>7</td>
<td>6</td>
<td>6</td>
<td>13</td>
</tr>
<tr>
<td>Smooth engine</td>
<td>4</td>
<td>9</td>
<td>5</td>
<td>12</td>
</tr>
<tr>
<td>For longer distances / high mileage</td>
<td>3</td>
<td>3</td>
<td>3</td>
<td>1</td>
</tr>
<tr>
<td>Diesel engine lasts longer</td>
<td>1</td>
<td>3</td>
<td>2</td>
<td>3</td>
</tr>
<tr>
<td>Reliability</td>
<td>1</td>
<td>3</td>
<td>3</td>
<td>18</td>
</tr>
</tbody>
</table>

Data in %

Source: BOSCH
What do Diesel customers like.

**Willingness to change – Germany 2002/2004/2005**

<table>
<thead>
<tr>
<th>Year</th>
<th>Petrol Drivers</th>
<th>Diesel Drivers</th>
</tr>
</thead>
<tbody>
<tr>
<td>2002</td>
<td>24</td>
<td>35</td>
</tr>
<tr>
<td>2004</td>
<td>36</td>
<td>41</td>
</tr>
<tr>
<td>2005</td>
<td>40</td>
<td>37</td>
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<tr>
<td>2002</td>
<td>17</td>
<td>29</td>
</tr>
<tr>
<td>2004</td>
<td>24</td>
<td>41</td>
</tr>
<tr>
<td>2005</td>
<td>27</td>
<td>45</td>
</tr>
</tbody>
</table>

- **Convertible** (= wechselbereit)
- **Shallow** (= schwankend)
- **Average** (= verbunden)
- **Entrenched** (= verwurzelt)

Source: BOSCH
BMW Diesel.
Challenges in the US market.

- Stringent emission legislation (orientation on gasoline engine)
- High requirements to OBD
- Various fuel quality with large dispersions
- Intensified climatic edge conditions

→ Robust, sustainable solutions are required
→ New technologies are needed
BMW Diesel.

NOx challenge BIN 5.

X5 3.0d with EU4 technology incl. DPF
BMW Diesel.
TIER2 BIN 5 concept.

- Modified combustion
- Advanced EGR- system
- Adapted fuel injection system
- Electrical control devices
- Additional sensors
- OBD functions
- Diesel Particulate Filter (DPF)
- SCR-System (Selective Catalytic Reduction)
BMW Diesel.
Fuel Consumption – Diesel efficiency.
BMW Diesel.
DPF + SCR-system layout.

Additional requirements:
- heated tank with fluid-level indicator (OBD)
- heated Urea pipes from tank to dosing unit
BMW Diesel.

SCR system – chemical reactions

\[
\text{NO} + \frac{1}{2} \text{O}_2 \rightarrow \text{NO}_2
\]

\[
\text{NO} + \text{NO}_2 + 2 \text{NH}_3 \rightarrow 2 \text{N}_2 + 3 \text{H}_2\text{O}
\]

\[
4 \text{NO} + \text{O}_2 + 4 \text{NH}_3 \rightarrow 4 \text{N}_2 + 6 \text{H}_2\text{O}
\]

\[
6 \text{NO}_2 + 8 \text{NH}_3 \rightarrow 7 \text{N}_2 + 12 \text{H}_2\text{O}
\]

\[
(\text{NH}_2)_2\text{CO} \rightarrow \text{NH}_3 + \text{HNCO}
\]

\[
\text{HNCO} + \text{H}_2\text{O} \rightarrow \text{NH}_3 + \text{CO}_2
\]

BMW Diesel.

SCR system – chemical reactions
Advantages

- High NO\textsubscript{x}-efficiency up to high engine loads
- Long term emission stability
- No increase in fuel consumption

Challenging requirements

- UREA infrastructure $\rightarrow$ common efforts necessary
- OBD

SCR systems are available for trucks in Europe and Japan

$\rightarrow$ BMW judgement: long term solution for diesel engines
BMW Diesel.

Conclusion.

• Portion of BMW Diesel passenger cars in Europe has significantly increased within the last decade

• BMW Diesel philosophy is “efficient dynamics”

• BMW at leading edge of diesel technology

• BMW target for US is to fulfil 50 state legislations

• Technology concept for BIN 5 defined, but still challenging

• Compromises to Diesel necessary (i.e. phase-in`s)

→ BMW Diesels: dynamic, efficient and clean
Thank you very much for your attention!

BMW Diesel.
Ready for the future.