Advances in Diesel Engine Technologies for European Passenger Vehicles

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Content

1. Diesel market in Western Europe
2. Environmental relevant driving forces of vehicle development
3. Powertrain concepts: today and in the future
4. Outlook and conclusions
Diesel Share in Western Europe
Comparison of different prognosis (DRI)

Diesel share of total market [%]

Year: 90 92 94 96 98 00 02 04

Prognosis dated

Actual

European Status
Diesel market in Western Europe
January – June 2002

- Germany 20,5%
- France 23,5%
- Italy 16,9%
- Spain 12,7%
- United Kingdom 9,9%
- Belgien/Lux 6,6%
- Netherlands 2,1%
- Austria 3,5%
- Portugal 1,4%
- Others 2,7%

Diesel market total 3,056 Mio.

Source: Association Auxiliaire de l'Automobile
Western Europe
National Diesel Shares 1990 / 2001 / ½yr 2002

Source: DRI, Association Auxiliaire de l'Automobile

 Olsen 2002
39.4%

 Olsen 2001
36.0%

 Olsen 1990
14.1%
New registrations of Diesel passenger cars
Western Europe: 1990 - 2001

10^3 vehicles

Year

Gasoline

Diesel

European Status
New registrations of Diesel passenger cars
Western Europe: January - June 2002

<table>
<thead>
<tr>
<th>Country</th>
<th>Diesel share [%]</th>
</tr>
</thead>
<tbody>
<tr>
<td>Greece</td>
<td>0,9</td>
</tr>
<tr>
<td>Sweden</td>
<td>6,7</td>
</tr>
<tr>
<td>Finnnland</td>
<td>15,5</td>
</tr>
<tr>
<td>Ireland</td>
<td>15,8</td>
</tr>
<tr>
<td>Norway</td>
<td>16,1</td>
</tr>
<tr>
<td>Switzerland</td>
<td>16,1</td>
</tr>
<tr>
<td>Denmark</td>
<td>18,7</td>
</tr>
<tr>
<td>Netherlands</td>
<td>22,2</td>
</tr>
<tr>
<td>Unit. Kingdom</td>
<td>22,5</td>
</tr>
<tr>
<td>Portugal</td>
<td>32,7</td>
</tr>
<tr>
<td>Germany</td>
<td>37,0</td>
</tr>
<tr>
<td>West. Europe</td>
<td>39,3</td>
</tr>
<tr>
<td>Italy</td>
<td>42,0</td>
</tr>
<tr>
<td>Spain</td>
<td>55,6</td>
</tr>
<tr>
<td>Luxemburg</td>
<td>60,7</td>
</tr>
<tr>
<td>France</td>
<td>62,0</td>
</tr>
<tr>
<td>Belgium</td>
<td>63,5</td>
</tr>
<tr>
<td>Austria</td>
<td>69,0</td>
</tr>
</tbody>
</table>

European Status
New registrations of passenger cars

Germany

Mio. passenger cars

- Gasoline
  - 1980: 95%
  - 1990: 73%
  - 2000: 62%

- Diesel
  - 1980: 5%
  - 1990: 27%
  - 2000: 38%
New registrations of Diesel passenger cars
Germany: January - June 2002

Number in segments (x 10^3)

- Mini car: 11,4
- Small car: 51,2
- Compact car: 164,6
- Medium size car: 200,7
- Full size car: 68,8
- Luxury car: 3,3
- Vans: 90,5
- SUV: 35,4

Share of the segment in %

- Mini car: 9,6
- Small car: 16,9
- Compact car: 36,3
- Medium size car: 49,0
- Full size car: 56,9
- Luxury car: 12,0
- Vans: 57,2
- SUV: 57,8

Ø Diesel share Germany: 38,0%
Diesel share in Germany
January to Juni 2002: German manufacturers

- Audi: 56.5%
- DC: 52.1%
- VW: 48.3%
- Ford: 35.0%
- BMW: 34.7%
- Smart: 34.7%
- Opel: 20.0%
Sure, here is the text representation of the image:

**Diesel share in Germany**

January to Juni 2002: Importers

- Volvo: 47.2
- Skoda: 38.7
- Seat: 38.2
- Citroen: 37.2
- Renault: 32.1
- Mitsubishi: 28.0
- Peugeot: 27.5
- Toyota: 23.4
- Nissan: 21.5
- Fiat: 18.3
- Mazda: 11.3

**European Status**
Why do customers in Europe buy the Diesel?

- The diesel closed the gap to the gasoline engine on:
  - Performance
  - Noise
- The diesel has reduced fuel consumption (CO₂ emissions)
- The diesel has lower operating costs
Operating costs of a Diesel vehicle

- during purchasing
  - vehicle price
  - purchase tax
  - VAT
- during operation yearly
  - annual vehicle tax
- during driving
  - fuel tax
  - maintance costs
- real costs from sophisticated calculation

But: costumers consider mainly the difference in gasoline and diesel fuel costs
Content

1. Diesel market in Western Europe

2. Environmental relevant driving forces of vehicle development
Environmental relevant driving forces of vehicle development

- Energy
- Greenhouse effect (CO₂)
- Exhaust gas emissions (CO, NOₓ, HC, PM)

Importance

EU Member State Tax Incentives for 50 & 10ppm Sulphur fuels

- **National Tax incentives for 50ppm sulphur fuels**
- **National Tax incentives for 50ppm & 10 ppm sulphur fuels (and or availability)**

- 10ppm Petrol (2002)
- 10ppm Diesel (2002)
- 2.5 €/l 50ppm Diesel (1993)
- 0.3 €/l 50ppm Petrol (2001)
- 5.7 €/l 10ppm Diesel (2001)
- 3.9 €/l 50ppm Diesel (2000)
- 2.4 €/l 50ppm Diesel (1999)
- 4 €/l 50ppm Petrol/Diesel (2001)
- 10ppm Diesel Available (2000)
- 0.76 €/l 50ppm Diesel (2001)
- 2 €/l 50ppm Petrol/Diesel (2001)
- 1.5 €/l 10ppm Petrol/Diesel (2003)
- 1.5 €/l 50ppm Petrol/Diesel (2001)
- 3.1 €/l 50ppm Diesel (1993)
- 50ppm Diesel Available (2000)
- 10ppm Petrol/Diesel incentive (2003)
Comparison between EU and US legislation

But in Europe:
- phase-in of only one year
- earlier introduction by tax incentives

European Status

Particulates [g/mi]

NO_x [g/mi]
Scenario EU exhaust gas legislation

Dir 98/69

Euro 3
2000

Euro 4
2005

Euro 5
2010

2015

Dir 98/70

Fuel Sulphur

150/350
50/50

Modification: max 10 ppm

Proposal
Publication
Phase-in

European Status
CO₂ Reduction in Europe
Agreement between ACEA and the EU Commission

ACEA fleet

VW Group

New European driving cycle (Directive 93/116)
Data before 1995: calculated from 1/3-Mix

ACEA:
- 140 g/km in 2008
  (-25% from 1995)
- target in 2003:
  165 - 170 g/km CO₂
- M1 vehicles

European Status
Simulation of CO$_2$ emissions from traffic in Germany

Source: German Ministry of the Environment, 2002
Content

1. Diesel market in Western Europe

2. Environmental relevant driving forces of vehicle development

3. Powertrain concepts: today and in the future
Approaches to maintain individual mobility

- **Powertrains**
  - In production
    - Diesel TDI
  - Alternative
    - Diesel
      - internal engine measures
      - exhaust aftertreatment
Estimate of potential
85 kW vehicle, Golf category, NEDC

- Particle emissions in g/km
  - EU III
  - EU IV

- NO\textsubscript{x} + HC emissions in g/km

- Options:
  - opt. comb. process
  - opt. injection
  - 4 V Technology
  - opt. management
  - improved fuel and lubricants
  - opt. Oxi-cat.

European Status
VW exhaust aftertreatment systems: particle filter system & NOx storage catalytic converter

European Status
Strategies for future diesel development

Version 1

Impact of NOx and HC-Emissions on Particle Emission

- **Euro 3**: Basis
- **Euro 4**: NOx cat with efficiency > 95%
- NOx cat with efficiency > 65% (today technical not feasible)

NOx + HC-Emissions in g/km

Particle emission in g/km

0,05
0,04
0,03
0,02
0,01
0
0 0,1 0,2 0,3 0,4 0,5 0,6

European Status
Strategies for future diesel development

European Status

Version 2

- **Euro 3**
  - NOx:Particle < 10:1

- **Euro 4**
  - NOx:Particle > 10:1
  - EGR, etc.
  - Trap with efficiency > 95%
  - NOx cat with efficiency > 80%
  - Frequent regeneration increase in fuel consumption
Strategies for future diesel development

Version VW

Particle emission in g/km

0,05
0,04
0,03
0,02
0,01
0,0
0
0,1
0,2
0,3
0,4
0,5
0,6

NOx + HC-Emissions in g/km

0,05
0,04
0,03
0,02
0,01
0,0
0
0,1
0,2
0,3
0,4
0,5
0,6

European Status

Engine measures EU-4 strategy

NOx:Particle > 10:1

NOx cat with efficiency > 65%

Trap with efficiency > 95%

NOx:Particle > 10:1

Version VW
VW-Reduction strategy for Euro 4 in combination with improved fuels

- S free fuel + NO\textsubscript{x} cat
- S free fuel + trap
- 4V engine
- 2V engine + internal measures *)

*) incl. Oxi-cat.

European Status
Potential for reduction of emissions

Example for a Golf with manual transmission

<table>
<thead>
<tr>
<th>Particulates [g/mi]</th>
<th>NOx [g/mi]</th>
</tr>
</thead>
<tbody>
<tr>
<td>0</td>
<td>0.01</td>
</tr>
<tr>
<td>0.02</td>
<td>0.03</td>
</tr>
<tr>
<td>0.04</td>
<td>0.05</td>
</tr>
<tr>
<td>0.06</td>
<td>0.07</td>
</tr>
</tbody>
</table>

- **TIER 2, INTERIM**
- **Euro 4**
- **Golf 2000**
- **1998**

**Improvements by conventional measures**

- 90% efficiency Particulate trap
- > 80% efficiency NOx catalyst

**European Status**

[Logo: Volkswagen]
The first 3L vehicle in production
VW Lupo 3L TDI

- 1.2 l TDI engine with unit injection
- 45 kW (61 PS)
- 2.99 l/100 km
- Euro 4 limits
Volkswagen 1-litre car (235 mpg)
four wheels, low height, two seats in tandem
Volkswagen 1-litre car (235 mpg) carbon-fibre-reinforced outer skin over a Mg spaceframe
Volkswagen 1-litre car (235 mpg)
impact and roll-over protection like a GT racing car
Volkswagen 1-litre car (235 mpg)

Technical data

European Status
## Volkswagen 1-litre car (235 mpg)

### Technical data

<table>
<thead>
<tr>
<th>Performance / consumption</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Top speed</td>
<td>120 km/h</td>
</tr>
<tr>
<td>Consumption</td>
<td>0.99 litres / 100 kilometres</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>Body, wheel, tyre dimensions</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Length x width x height</td>
<td>3,646 x 1,248 x 1,110 mm</td>
</tr>
<tr>
<td>Wheelbase</td>
<td>2,205 mm</td>
</tr>
<tr>
<td>Track front / rear</td>
<td>1,000 / 810 mm</td>
</tr>
<tr>
<td>Fuel tank volume</td>
<td>6.5 litres</td>
</tr>
<tr>
<td>Vehicle weight</td>
<td>290 kg</td>
</tr>
<tr>
<td>Luggage space volume</td>
<td>80 litres</td>
</tr>
<tr>
<td>Drag coefficient $c_d / \text{area}$</td>
<td>0.159 / 1.0 m$^2$</td>
</tr>
<tr>
<td>Tyres front / rear</td>
<td>95/80 R 16 / 115/70 R 16</td>
</tr>
</tbody>
</table>
## Volkswagen 1-litre car (235 mpg)

**Technical data**

<table>
<thead>
<tr>
<th>Engine</th>
<th>1-cylinder naturally-aspirated diesel with unit injector, aluminium monobloc</th>
</tr>
</thead>
<tbody>
<tr>
<td>Principle</td>
<td>1-cylinder naturally-aspirated diesel with unit injector, aluminium monobloc</td>
</tr>
<tr>
<td>Volume</td>
<td>299 cc</td>
</tr>
<tr>
<td>Bore x stroke</td>
<td>69 mm x 80 mm</td>
</tr>
<tr>
<td>Compression ratio</td>
<td>16.5: 1</td>
</tr>
<tr>
<td>Valves per cylinder</td>
<td>3</td>
</tr>
<tr>
<td>Valve timing</td>
<td>Twin overhead camshafts</td>
</tr>
<tr>
<td>Engine weight (dry)</td>
<td>26 kg</td>
</tr>
<tr>
<td>Output</td>
<td>6.3 kW (8.5 bhp) at 4,000 rpm</td>
</tr>
<tr>
<td>Torque</td>
<td>18.4 Nm at 2,000 rpm</td>
</tr>
</tbody>
</table>
Volkswagen 1-litre car (235 mpg)

Technical data

An idea for a possible new family of vehicles, which could cover new requirements ranging from the ultra-economical vehicle, through the low-lost everyday touring vehicle for young people to the high-performance sports supercar.
Maintaining individual mobility

Powertrain

- in production
  - Diesel TDI
  - Gasoline FSI
- alternative

European Status
Spark-ignition engine with direct injection
Fuel Economy Potential

Manifold Injector

Injector
Inlet valve
Exhaust valve

Direct Injection
high-pressure injector

fuel economy potential [%]

Relative Air/Fuel Ratio l

European Status
Spark-ignition engine with direct injection
Fuel Economy Potential

Direct injection

High pressure injector

European Status
FSI: Exhaust gas aftertreatment

Main Cat.
NO\textsubscript{X} Adsorption lean

Start Cat.
HC Oxidation lean, 3-Way at ? = 1

EGR
Minimizing NO\textsubscript{X} raw emissions

Temperature sensor
storage control of NO\textsubscript{X} -cat.,
cat. diagnosis

LSU
control at variable ?,
cat. diagnosis

LSF
main control at ? = 1,
cat. diagnosis

control at variable ?,
control regeneration NO\textsubscript{X} -cat.

European Status
Gasoline direct injection
VW Lupo 1.4 l FSI (Fuel Stratified Injection)

- 1.4 l Gasoline FSI
- 77 kW (105 PS)
- 4,99 l/100 km (47 mpg)
- Euro 4 (2005)
Further development of internal combustion engines

Gasoline engine
- Manifold injection
- Direct injection wall guided
- Direct injection spray guided
- Combined Combustion System
- Prechamber
- Direct injection
- High pressure injection
- Direct injection auto-ignition
- Partly homogen spark ignition

Diesel engine
Reduction of exhaust gas emissions by using a SynFuel

1500 rpm / 22 Nm
Reference Diesel

Synfuel A

2000 rpm / 94 Nm
Synfuel A + 5% O₂
Maintaining individual mobility

Powertrain

- in production
  - Diesel TDI
  - Gasoline FSI
  - Transmission
- alternative
  - CVT
  - direct
  - automatic

European Status
Maintaining individual mobility

Powertrain

in production
- Diesel TDI
- Gasoline FSI
- Transmission

alternative
- Electric
- Hydrogen
- CNG
Maintaining individual mobility

Powertrain

in production

Electric

Gasoline reformer + Fuel cell

Hydrogen + Fuel cell

Battery

alternative

Hydrogen

CNG

European Status
Comparison of modern propulsion concepts

Total efficiency incl. fuel production, transport and vehicle operation

Efficiency [%]

- Gasoline
- Diesel
- Methanol FC
- HC FC
- H₂ FC

Potential

2005

European Status