Light-Duty Diesel Engine Technology – What’s New?

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Maintaining individual mobility

Powertrain

in production
- Diesel TDI
- Gasoline FSI
- Transmission

alternative
- Electric
- Hydrogen
- CNG
Means of maintaining individual mobility

- Powertrain
  - Conventional
    - Diesel TDI
  - Alternative
    - Diesel
      - engine modification
      - Exhaust gas aftertreatment
Question

• Can light-duty diesels meet emission standards and compete in the marketplace?
Diesel emissions

- High confidence diesels can meet final Tier 2 and LEV II emissions standards
  - HC, CO levels already low
    - Oxidation catalyst effective
  - NOX, PM emissions to be reduced through:
    - Improved combustion process, lower engine out emissions
    - Addition of NOX and particulate matter (PM) aftertreatment
      - Breaks NOX/PM trade-off dilemma
Estimate of potential
85 kW vehicle, Golf category, NEDC

Particle emissions in g/km

NOx + HC emissions in g/km
Estimate of potential 85 kW vehicle, Golf category

Particle emissions in g/km

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

- Opt. comb. process
- Opt. injection
- 4 V Technology
- Opt. management

Basis
Diesel technologies

Swirl chamber (IDI)  Direct injection (DI)
Development potential of diesel engines

Today's direct injection engine characteristics

2 Valve

4 Valve
High pressure injection systems

- Distributor Injection Pump
- Common-Rail System
- Unit-Injector
4V Cylinder head with Unit Injector

Environmental related advantages

- Low combustion noise
- Low fuel consumption
- Low exhaust gas emissions
Characteristics of high pressure diesel injection

- **Duration**: 1.5 ms
- **Injection Event**: $\triangle \geq 1.5$ ms
- **Pressure**: 2000 bar
- **Quantity**: 1 mm$^3$
Future high pressure injection systems; injection event

Injected mass per time

time
Estimate of potential
85 kW vehicle, Golf category

Particle emissions in g/km

EU III

EU IV

NO$_x$ + HC emissions in g/km

- opt. comb. process
- opt. injection
- 4 V Technology
- opt. management
- Improved fuel and lubricants
- opt. Oxi-cat.
Comparison between EU and US legislation

Graph showing the comparison between EU and US legislation for particulates and NOx emissions. The graph includes data for Euro 4, Tier 2 BIN 5, and Interim TIER2 BIN 9 standards.
Exhaust gas aftertreatment for particulate

- Periodic regenerating systems
- Continuous regenerating systems

(Pre cat.)

Oxidation catalytic converter
Particulate trap
Ceramic particulate trap

Engine exhaust

Filtered exhaust gas

Filtered exhaust gas
CRT-System (Continuous Regeneration Trap)

Oxi cat: \[2 \text{ NO} + \text{ O}_2 \rightarrow 2 \text{ NO}_2\]

Trap: \[2 \text{ NO}_2 + \text{ C} \rightarrow 2 \text{ NO} + \text{ CO}_2\]
VW exhaust aftertreatment systems

VW particle filter system

- EDC
- Temperature
- Δp sensor
- Oxi-cat.
- NO₂ cat.
- Particulate filter
VW exhaust aftertreatment systems

The VW particle filter system

- No extreme component temperatures
- No increase in emissions during regeneration
- No increase in fuel consumption caused by high exhaust back-pressure
VW exhaust aftertreatment systems
VW particle filter system and NOx storage catalytic converter
Strategies for future diesel development

Particle emission in g/km

NOx:Particle > 10:1

Engine measures EU-4 strategy

NOx:Particle > 10:1

NOx cat with efficiency > 65%

Trap with efficiency > 95%

Version VW
Potential for reduction of emissions
Example for a Golf with manual transmission

Particulates [g/mi]

0,06
0,05
0,04
0,03
0,02
0,01
0

0
0,1
0,2
0,3
0,4
0,5
0,6

NOx [g/mi]

90% efficiency
Particulate trap

>80% efficiency
NOx catalyst

Improvements by conventional measures
Diesel Market

• Qualified yes.
  – Diesels can compete in the US market but many external factors will influence success.
  – Biggest factors will be cost of fuel and initial cost of vehicle
  – New diesel technology has other attractive attributes in addition to good fuel economy
    • Both US and European customers like the performance, torque characteristics
    • Purchase decision not totally influenced by fuel economy
Volkswagen Diesel Background

- Introduced high-speed, light-duty diesel in 1976
- Today is the biggest diesel engine producer in the world
- In 2001-2003, VW produced about 5 million vehicles/year
  - 1.8 million vehicles/year were diesel
- The main diesel market is Europe
Recent US diesel experience

- Offered direct injection diesel engines in the US since 1996
  - Tier 1 emission level through 2003
  - Offered most recently in Golf, Jetta, New Beetle
- In 2004 will sell Bin 9 and 10 diesel engines in Golf, Jetta, New Beetle, Passat and Touareg
Volkswagen Diesel Vehicle Sales 1996-2003
US Market

• About 8% of our total sales are diesel
• In Canada 30% of total sales are diesel
• Fuel economy is major purchase decision, but not only factor
  – Customers cite torque, driveability, fewer refueling stops, CO2 reduction, low operating cost
    • Some customers do not pay back initial purchase
  – Same observations in Europe
    • Tax and price structure favor diesel even more
European Market Perspective

• Why do customers in Europe buy the diesel?
  – The diesel has closed the gap on gasoline engines in performance and noise
  – The diesel has reduced fuel consumption
  – The diesel has lower operating cost
Operating costs of Diesel Vehicle in Europe

• Initial purchase
  – Vehicle price
  – Purchase tax
  – VAT
• Yearly operation
  – Annual vehicle tax
• Daily operation
  – Fuel tax
  – Maintenance costs
• But customers mainly consider the difference between diesel and gasoline fuel cost
Diesel Share in Western Europe
Comparison of different prognosis (DRI)
Future Share of Engines in Europe

Boundary Conditions:
* new vehicles
* tax legislation
* future emission regulation
* system costs
* progress
* fuel costs
* promotion
in exhaust gas aftertreatment and actuator technology

In some countries Diesel share could be up to 45%

Source: RWTH Aachen (modified)
New registrations of passenger cars
Germany

![Graph showing new registrations of passenger cars in Germany from 1980 to 2000. The graph compares gasoline and diesel registrations. Gasoline registrations peak at 3.5 million in 1992 and decrease to 1.2 million in 2000. Diesel registrations rise from 0.1 million in 1980 to 1.8 million in 2000.]
New registrations of Diesel passenger cars
Western Europe: January-June 2002
Additional Factors in Europe

• Voluntary fuel economy agreement of manufacturers with EU
• CO2 reduction strategies
Global driving forces of vehicle development

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

Importance

- 1990
- 1995
- 2000
- 2005
- 2010
- 2015
- 2020
- 2025
ACEA Commitment

CO$_2$-Emissions [g/km]

M1-New Car Fleet

Target 2008 140 g/km

-25%
Summary of European Factors
Stimulating Diesel Sales

• High fuel prices
• Engine performance benefits
• Tax incentives for diesel fuel
• Voluntary fuel economy agreement of manufacturers
• CO2 reduction strategy
• Achievable emission standards
Will US customers pay for fuel economy?

• Even in Europe customers will not pay for best fuel economy
  – Trade initial cost vs. operating cost
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
The most fuel efficient vehicles in the European market

**Diesel-PKW**

- **VW Konzern**
  - VW 3,0l Lupo 61 PS
  - Audi A2 1,2 TDI 61 PS
  - Seat Arosa 1,2 TDI 61 PS
  - Smart cdi 41 PS
  - Seat Arosa 1,4 TDI 75 PS
  - VW Lupo 1,4 TDI 75 PS
  - Audi A2 1,4 TDI 75 PS
  - Opel Astra ECO 4 75 PS
  - Seat Arosa 1,7 SDI 60 PS
  - VW Lupo 1,7 SDI 60 PS
  - VW Polo 1,4 75 PS
  - VW Polo 1,9 SDI 60 PS
  - Mercedes A16 60 PS

- **Competitors**
  - VW Polo 1,4 75 PS
  - Audi A2 1,2 TDI 61 PS
  - Seat Arosa 1,2 TDI 61 PS
  - Smart cdi 41 PS
  - Seat Arosa 1,4 TDI 75 PS
  - VW Lupo 1,4 TDI 75 PS
  - Audi A2 1,4 TDI 75 PS
  - Opel Astra ECO 4 75 PS
  - Seat Arosa 1,7 SDI 60 PS
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  - VW Polo 1,4 75 PS
  - VW Polo 1,9 SDI 60 PS
  - Mercedes A16 60 PS

Fuel consumption in l/100 km
New Registrations of Diesel passenger cars
Germany: January-June 2002

Number in segments ($\times 10^3$)

- 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%
Situation in US less attractive

- No tax incentives
- Diesel fuel more expensive
- More technology added to vehicle
- Biggest influence in the future will be fuel cost
Volkswagen 1-litre car (325 mpg)
Technical data
Volkswagen 1-litre car (235 mpg)
Four wheels, low height, two seats in tandem