Diesel Efficiency and Associated Fuel Effects

Stuart Johnson
Senior Manager, Engineering and Environmental Office, Volkswagen Group of America

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VW GROUP PRODUCTS: NINE INDEPENDENT BRANDS

### Automotive Division

**Passenger Cars**

- Volkswagen
- Audi
- Bentley
- Skoda
- SEAT
- Bugatti
- Lamborghini
- Porsche
- Porsche

Also: VW Commercial, Scania, MAN
DIESEL IS AN IMPORTANT DIFFERENTIATOR FOR THE VOLKSWAGEN GROUP

Volkswagen Group Diesel volume Passenger Cars (PC) 2012

- Volkswagen Group: ~78%
- Competitors: ~22%

Volkswagen Group US market share diesel PC ~ 78%

Constant growth since its introduction

Source for competitor sales: Polk
VW PASSAT TDI SETS NEW WORLD RECORD FOR FUEL ECONOMY

Volkswagen of America announced today that it has set a new GUINNESS WORLD RECORD® achievement for the “lowest fuel consumption—48 U.S. states for a non-hybrid car” category.

- **77.99 mpg** more than **10 mpg** better than the previous mark of 67.9 mpg
- The achievement also beats the **hybrid vehicle** record of **64.6 mpg** by more than **13 mpg**
- **8,122 miles** on just **104.94 gallons** of fuel

“We felt we had a good chance of beating the existing record with the Passat TDI,” Gerdes said, “but to smash it by averaging **77.99 mpg** is really impressive and a testament to the potential of Volkswagen’s TDI Clean Diesel vehicles.
WORLDWIDE EMISSION PROGRAMS

Volkswagen Group targeting 10 million units per year Worldwide in 2018

NAR ≈ 1,000,000 units

SAR ≈ 1,000,000 units

20% of Worldwide Volkswagen sales comply with US Standards for emissions, the remaining 80% comply with ECE
# AGENDA

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- VW Group overview
- Importance of diesel engine technology
- Regulatory challenges

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- First generation BIN 5/Clean Diesel engine in the Jetta
- Second generation BIN5/Clean Diesel engine in the new US Passat
- Third generation Clean Diesel: MDB modular EA 288 TDI®

## Fuel effects on modern diesel engines
- Cetane influence on modern closed loop engines
- Other fuel properties – energy density, volatility, fuel density
- Biodiesel influence

## Summary of fuel effects
VOLKSWAGEN’S DIESEL HISTORY

1976 1.5l-2V-SD 50 HP
1983 1.7l-2V-SD 54 HP
1993 1.9l TDI 90 HP TIER1
2000 1.9l-2V-TDI –PD 100 HP BIN10
2006 5.0l 2V-TDI-PD DPF 310 HP BIN10
2008 2.0l-4V-TDI-Common Rail 140 HP BIN5

Audi A3 TDI Clean Diesel “Green Car of the Year 2010”
THE FIRST GENERATION BIN5 ENGINE FOR THE JETTA CLEAN DIESEL

Optimized and newly developed components of the BIN5 engine

- Improved injector design with optimized nozzle - multiple injections
- Cylinder pressure control – closed loop cylinder control
- High and low pressure exhaust gas recirculation (EGR) with high-performance EGR cooler
- Turbocharger system with low pressure EGR inlet nozzle
- Intake pipe with controllable swirl valves
- Exhaust gas aftertreatment with NOx storage catalyst
THE SECOND GENERATION BIN5 ENGINE FOR THE NEW US PASSAT

2011
2.0l-4V-TDI-CR 140 HP BIN5
THE SECOND GENERATION BIN5 ENGINE FOR THE NEW US PASSAT

- Cylinder head with integrated HP-EGR channel and optimised port geometry
- Thermodynamical improved turbocharger design
- Optimized dual-circuit exhaust gas recirculation
- Indirect water cooled charge air cooling
- Exhaust gas aftertreatment with SCR
THE SECOND GENERATION BIN5 ENGINE FOR THE NEW US PASSAT

The dual-circuit exhaust gas recirculation system
THE NEW MODULAR TDI® GENERATION FROM VOLKSWAGEN – MDB EA 288
TARGETS FOR TIER 3/EURO 6 ENGINES IN THE MDB

- Using the modular diesel system
- CO₂ neutral reduction of NOₓ raw emission
- Scalable NOₓ aftertreatment
- Considering Euro 6 level 2 (RDE)
- High synergy between Tier 3 and Euro 6 engines
- Continuing module solutions for engine control
THE MODULES OF THE BIN5 ENGINE IN THE MDB

Modules basic engine

- HP EGR w/o cooler
  (channel through cylinder head)
- Variable valve train (VVT)
- Cylinder pressure control 2nd generation
- 2000 bar high-pressure injection system

Modules exhaust gas aftertreatment

- Close-coupled NO$_x$ aftertreatment
DUAL-CIRCUIT EXHAUST GAS RECIRCULATION - COMPONENTS

- Intake manifold with integrated intercooler
- HP EGR valve
- Air control valve
- HP EGR channel
- LP EGR
- LP EGR cooler
VVT CONCEPT – PORTS AND VALVES IN ROTATED POSITION
VVT OPERATING MODE - VALVE TIMING

Adjustment range max. 50° crank angle

Variable camshaft

Fixed camshaft

Valve lift

BDC  TDC  BDC
HIGH-PRESSURE INJECTION SYSTEM - INJECTOR

- Max. injection pressure 2000 bar
- Mini rail
- 3-part welded nozzle needle with close-to-seat guide
- Nano blind hole
MODULES OF THE TIER 3/EURO 6 ENGINE IN THE MDB

Modules basic engine

NOx raw emissions - 40%

Modules exhaust gas aftertreatment

Scaleable emissions aftertreatment for various levels up to EU 6.2 and LEV III/ Tier 3
CLOSE COUPLED EXHAUST GAS AFTERTREATMENT

BIN5/Euro 6 exhaust system design with Selective Catalytic Reduction (SCR)

- NOx sensor
- Lambda sensor
- Temperature sensor T4
- Temperature sensor T6
- Differential pressure sensor LP-EGR
- SCR dosing module (water-cooled)
- Oxidation catalyst
- Mixer
- Diesel particulate filter with SCR coating
- Diesel particulate filter with Cu/Zeolite
DIESEL PARTICULATE FILTER WITH SCR COATING

Characteristics of the integrated component

- Cu/Zeolite coating
- Filter substrate

- DPF with optimised porosity
- High SCR washcoat amounts
- Thermally stable SCR coating
- Low exhaust back pressure and high filtration efficiency
DIESEL PARTICULATE FILTER WITH SCR COATING

Development of mixture preparation

- Mixture preparation in transfer tunnel
- Low exhaust back pressure with uniform NH$_3$ distribution
- Avoiding urea deposits
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### Fuel effects on modern diesel engines

- Cetane influence on modern closed loop engines
- Other fuel properties – energy density, volatility, fuel density
- Biodiesel influence

### Summary of fuel effects
FUEL EFFECTS

It’s not easy…
INFLUENCE OF FUELS ON EMISSIONS – TEST MATRIX

5 test fuels covering wide range of cetane number

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<tr>
<td>ULSD</td>
<td>47</td>
</tr>
<tr>
<td>ULSD</td>
<td>42</td>
</tr>
<tr>
<td>ULSD</td>
<td>54</td>
</tr>
<tr>
<td>B30</td>
<td>54</td>
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<td>SynFuel</td>
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2.0L mass production engine
3 engine load points
  - low load (LL)
  - medium load (ML)
  - high load (HL)
Engine emission sensitivity dependent on fuel and load point
Inhomogeneous fuel related differences
Effect on exhaust aftertreatment system (DPF + SCR)
FUEL INFLUENCE ON EMISSIONS – HC / CO

- Engine emission sensitivity dependent on fuel and load point
- Inhomogeneous fuel related differences
- Risks of insufficient conversion at oxidation catalysts
DIFFERENTIAL HEAT FLOW AT 2000 RPM

2000 rpm, 2 bar SWC1 and USLC, with smoothed oscillation

Volkswagen Group of America EEO
- Confidential -
FUEL EFFECTS OF OTHER FUEL PROPERTIES

- Energy density
  - Less impact on emissions but a greater impact on efficiency
  - Energy density also important when considering heat delivered to the after treatment systems
- Volatility
  - Important aspect for post injection, crankcase dilution, and heat delivered to the after treatment system
  - Also some new evidence indicates volatility may be more important than originally thought for the combustion process
- Fuel density
  - Also important when modelling the amount of fuel delivered for both combustion and after treatment
- Biodiesel
  - Properties dependent on feedstock
  - Differences in volatility, cetane, energy density
  - Heat flow curves are different
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Summary of Fuel Effects

- Closed loop cylinder control can compensate for some differences in fuel properties
- Despite this, cetane and energy density still influence efficiency and emissions
- Volatility also seems to be more important than originally thought and is being further investigated
- Biodiesel properties, especially FAME, is feedstock dependent and adds additional variations to cetane, energy density and volatility
- Fuel influence is a complex picture - additional study is on-going
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