AUTOMOTIVE FUELS AND EMISSIONS: Policies, Compliance & Potential Impact on Future Technologies

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VW GROUP PRODUCTS: NINE INDEPENDENT BRANDS

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<th>Automotive Division</th>
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<td><strong>Passenger Cars</strong></td>
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<td><strong>Remaining companies</strong></td>
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- Volkswagen
- Audi
- Škoda
- SEAT
- Bentley
- Bugatti
- Lamborghini
- Porsche
- Ducati
Volkswagen Group targeting 10 million units per year Worldwide in 2018

20% of Worldwide Volkswagen sales comply with US Standards for emissions, the remaining 80% comply with ECE
OVERVIEW OF US LEGISLATION

**CO2 (Green-house gas + CAFE)**
- **Agency**: EPA, NHTSA, CARB
- **California + Sec.177**

**Emissions (Federal: TIER, California: LEV Low Emission Vehicle)**
- **Agency**: EPA, CARB
- **California + Sec.177**

**ZEV (Zero Emission Vehicle)**
- **Agency**: CARB
- **California + ZEV States**

**EPA**
- **Tier 2**
- **Tier 3 (with Phase in)**
- **LEV II**
- **LEV III (with Phase in)**

**CARB**
- **ZEV I**
- **ZEV II**

**National GHG / CAFE Legislation**
- **2014**
- **2015**
- **2016**
- **2017**
- **2018**
- **2019**
- **2020**
- **2021**
- **2022**
- **2023**
- **2024**
- **2025**

**National GHG/ CAFE regulation**
- **2040 = 0 gram CO₂**

**VW has to fulfil ZEV Legislation from 2018**
TIER 3/LEV III FLEET AVERAGE PHASE-IN

Fleet average NMOG+NOx (g/Mile)

Tier 2 / LEV II Registration still possible

LEV II

LEV III / Tier 3

NMOG = Non-Methane Organic Gas
With extended warranty of 150k Miles / 15 years of emission relevant parts, agencies grant a bonus of 5mg/Miles. For example SULEV30 turns to SULEV25 because of that for the fleet calculation.
The NPRM (Notice of Proposed Rule Making) is 1450 pages

- FUL (Full Useful Life) extended from 120K to 150 K
- More stringent FUL SFTP standards
  - SFTP = Supplemental Federal Test Procedures – two additional test cycles for “off-cycle” emissions
    - US06 test cycle for high speed/high load
    - SC03 for air conditioning testing/micro-transients
  - Option for fleet average NMOG + NOX with similar FTP compliance curve
- New “Zero” evaporative emission standards
  - Fleet average compliance to very low whole vehicle emission levels
  - New canister bleed test to check evaporative emission system
- Lower PM standards on both the FTP (3mg/mile) and the US06 cycle (10 mg/mile)
  - Potential measurement/compliance issue
  - Potential disagreement with California – FTP (1mg/mile), US06 (4 mg/mile)
- Part 1066: New CFR section to handle revised testing and measurement techniques
- New certification fuel with ethanol content
- New market fuel with reduced sulfur

MANY ADDITIONAL ASPECTS TO THE TIER 3 REGULATION!!!
US TEST CYCLES

**2 Cycle test**

Used for:
- CAFE mpg targets
- NMOG + NOx FTP fleet average
- GHG fleet average

**5 Cycle test**

Used for:
- Monroney sticker (EPA mileage)
- NMOG + NOx SFTP average (excluding FTP-Cold Ambient Cycle)
Three engines will be central to VW Group powertrain strategy – all four cylinder engines

- Recently developed for worldwide deployment
- Modular construction and adaptable to various emissions concepts
- Two gasoline engines, one diesel engine
- All three have direct injection, turbocharging and innovative valve timing/actuation
TECHNOLOGIES: EA 211 ENGINE

CO$_2$-optimization - iAGK cylinder head

4-valve cylinder head
- Integral exhaust manifold
- Cross-flow cooling
- 5 mm valve guide
- Faster engine heat-up
- Faster cabin heat up
- Reduction of exhaust temperature by 100 K
- Reduction of fuel consumption by up to 2l / 100km at Top Speed
TECHNOLOGIES: EA 211 ENGINE

Cylinder shutdown - Rocker cover module

Assembly & function

• Installed space compatible with basic version
• Double-pin actuators for cylinders 2/3
• Inlet and exhaust camshaft adjusters
• Integral HDP drive
• Integral water pump drive
• Splined shafts and cam sections manufactured by VW
• Anti-friction bearing on drive side
• Reduced braking torque when coasting
• Engine start-stop function when vehicle is at a standstill
TECHNOLOGIES (EA 888) – Roadmap for direct injected engines
TECHNOLOGIES EA 888: US VOLUME VERSION

Thermostat
- Integrated Exhaust Manifold: significant Increase of customer mpg
- 200 bar High Pressure Injection
- Weight reduction on turbine housing
- Electric wastegate

Cylinder Head
- Simple Exhaust Camshaft
- Intake Manifold without MPI Injectors

US-specific Components
To be updated with future stringency of GHG Rules

Lightweight Crank
- Thinwall crankcase
- Plastic lower oil pan
- Crankshaft with 4 counterweights
- Aluminum Screws

Friction Reduction
- Balance shaft roller bearing
- Smaller main bearings
- Reduced Oil pressure level
- Reduced tensioner forces

Crankcase
- Thinwall crankcase
- Plastic lower oil pan
- Crankshaft with 4 counterweights
- Aluminum Screws
THE MODULES OF THE EA 288 TIER 3 ENGINE

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\textsubscript{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

Variable camshaft

Fixed camshaft

Adjustment range max. 50° crank angle

Valve lift

BDC  TDC
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

- Nano blind hole
- Close-to-seat guide
- Mini rail
- 3-part welded nozzle needle
THE MODULES OF THE TIER 3 EA-288 ENGINE

Modules basic engine

Modules exhaust gas aftertreatment

NOx raw emissions - 40%

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

Tier 3 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
- Cu/Zeolite
**DIESEL PARTICULATE FILTER WITH SCR COATING**

Characteristics of the integrated component:

- **Cu/Zeolite coating**
- **Filter substrate**

- DPF with optimized 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
VW Group is converging towards three 4-cylinder concepts as our volume leaders

- EA888, EA211, and EA288 will comprise 95% of volume in the coming years
- Modular design of engines will permit use in multiple markets while meeting local cost targets

New engine technologies are focusing on:

- Reduced weight – up to 30% reduction
- Improvements in friction, and warm-up strategies
- Advanced, cost-effective valve trains
- Advanced turbo-charging with integrated cooling and faster response
- Optimized fuel injection
- Optimized combustion
- Reduced engine out emissions – emissions compliant in all markets
- Reduced CO2 emissions – 10 to 20%
GEARBOX TECHNOLOGIES – CONTINUED DSG DEVELOPMENT

- Cost reduction
- Increase of Efficiency
- Quality Improvement
- Use of Synergies
- Standardization
- CO2 Reduction

Short gear set
Long gear set

MGB

DQ250
DQ500
DQ200
DQ101
DQ231
DQ381
DQ501
Concept Guidelines:

- Successor of 6-speed AQ450-6F/A
- For US market cars Tiguan, B-SUV und CC NF
- Optimized efficiency
- Optimized NVH
- For Gasoline and Diesel Engines
- Torque range from 280 to 500 Nm
**GEARBOX TECHNOLOGY: TRANSVERSE AT ≥ 8 Gears, NAR Market**

**Specification:**

<table>
<thead>
<tr>
<th>Aisin AQ 450-8F/A</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Gears</td>
<td>8</td>
</tr>
<tr>
<td>Spread</td>
<td>7,8</td>
</tr>
<tr>
<td>Final drive ratios</td>
<td>3,33 – 2,561</td>
</tr>
<tr>
<td>Max. power</td>
<td>220 kW</td>
</tr>
<tr>
<td>Torque capacity</td>
<td>500Nm</td>
</tr>
<tr>
<td>Weight</td>
<td>95 kg</td>
</tr>
<tr>
<td>Source</td>
<td>Aisin AW</td>
</tr>
<tr>
<td>Expected efficiency improvement</td>
<td>5 - 8 g CO2</td>
</tr>
</tbody>
</table>
GEARBOX TECHNOLOGY: CONSUMER ACCEPTANCE

- DQ200 updates produced **incremental improvements** to overall acceptability: “completely acceptable” scores increase (not significantly) by 6% (from 45% to 51%)

- However, AQ is preferred to DQ200 by U.S. customers (69% “completely acceptable”)

> How **acceptable** would this **transmission** be in a vehicle you would **consider purchasing**?
GEARBOX TECHNOLOGY: DQ400E PHEV TRANSMISSION

Specifications:

- Torque capacity: 400 Nm
- max. ICE-Torque: 350 Nm
- Integrated E-motor and clutch K0
- Oil supply on demand
- 2 circuit hydraulic control (High-/Low pressure)
- Friction optimized
- High efficient synchronizer system
- 6 forward gears
# ELECTRIFICATION – VW GROUP HYBRID TOOLBOX

<table>
<thead>
<tr>
<th>Engine</th>
<th>Electric motor</th>
<th>Gearbox</th>
<th>Battery</th>
<th>Power electronics</th>
</tr>
</thead>
<tbody>
<tr>
<td>2-cylinder in-line TDI</td>
<td>HEM 20</td>
<td>DQ200E</td>
<td>HEV</td>
<td></td>
</tr>
<tr>
<td>3-cylinder in-line TSI/TDI</td>
<td>HEM 60</td>
<td></td>
<td></td>
<td>Power electronics</td>
</tr>
<tr>
<td>4-cylinder in-line TSI/TDI</td>
<td>HEM 80</td>
<td>DQ400E</td>
<td>PHEV</td>
<td></td>
</tr>
</tbody>
</table>
## ELECTRIFICATION – VW XL1 HYBRID DRIVETRAIN

### TDI engine

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Displacement</td>
<td>830 cm³</td>
</tr>
<tr>
<td>Output/at rpm</td>
<td>35 kW/4,000 rpm</td>
</tr>
<tr>
<td>Torque/rpm</td>
<td>120 Nm/2,000 rpm</td>
</tr>
<tr>
<td>Weight:</td>
<td>72 kg</td>
</tr>
</tbody>
</table>

### Electric motor

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>Synchronous, permanent magnet</td>
</tr>
<tr>
<td>Output</td>
<td>20 kW</td>
</tr>
<tr>
<td>Torque</td>
<td>140 Nm</td>
</tr>
<tr>
<td>Weight</td>
<td>30 kg</td>
</tr>
</tbody>
</table>

### DSG gearbox

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Type</td>
<td>7 forward gears</td>
</tr>
<tr>
<td>Clutch</td>
<td>Dry clutch</td>
</tr>
<tr>
<td>Casing</td>
<td>Magnesium casing</td>
</tr>
</tbody>
</table>
VOLKSWAGEN’S APPROACH TO SUSTAINABLE MOBILITY

Renewable energy sources
- CO₂-neutral electricity
- CO₂-neutral fuels

Conventional energy sources
- Petroleum

TSI
TDI
TGI
DSG
TWIN DRIVE
BLUEMOTION
g-tron
e-tron
e-hybrid
# Alternative Fuel Development

<table>
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<tr>
<th>Year</th>
<th>2013</th>
<th>2014</th>
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<tr>
<td><strong>Hybrid vehicle (PHEV)</strong></td>
<td>Volkswagen XL1</td>
<td>Audi A3 e-tron</td>
</tr>
<tr>
<td></td>
<td>Porsche 918 Spyder</td>
<td>Volkswagen Golf TwinDrive</td>
</tr>
<tr>
<td></td>
<td>Porsche Panamera S E-Hybrid</td>
<td>Volkswagen e-Golf</td>
</tr>
<tr>
<td><strong>Battery vehicle (BEV)</strong></td>
<td>Volkswagen e-up!</td>
<td>Volkswagen e-up!</td>
</tr>
<tr>
<td><strong>Compressed Natural Gas</strong></td>
<td>Audi A3 g-tron</td>
<td>SEAT León TGI</td>
</tr>
<tr>
<td></td>
<td>Volkswagen Golf TGI</td>
<td>ŠKODA Octavia Sedan</td>
</tr>
<tr>
<td></td>
<td></td>
<td>ŠKODA Octavia Combi</td>
</tr>
<tr>
<td><strong>Ethanol</strong></td>
<td>Volkswagen Saveiro</td>
<td>Volkswagen CrossFox</td>
</tr>
<tr>
<td></td>
<td>Volkswagen Golf Rallye</td>
<td>Volkswagen SpaceFox</td>
</tr>
<tr>
<td></td>
<td>Volkswagen Fox Bluemotion</td>
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SUMMARY

• Tier 3/LEV 3 regulations, combined with the GHG/CAFÉ regulation, will drive many changes to powertrains
• Engine downsizing and down speeding will occur
• Four cylinder gasoline engines will dominate the market and must achieve Bin 20 and Bin 30 performance
• Six cylinder engines must also achieve Bin 30 emissions performance
• Larger engines and diesels must ultimately achieve Bin 50 and 70 performance when the regulations are fully phased-in
• Engine development will be focused on optimized combustion, fuel injection systems, variable valve timing, downsizing and charging
• Transmission technology will continue to evolve
• Increased hybridization of all types and in all market segments
• Continued controversy around PM standards and PM measurement
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