A Vision for Future Mobility – Volkswagen’s Fuel and Powertrain Strategy

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Seven Mega Trends

1. Climate Change and Sustainability
2. Shortage in Energy and Resources
3. Seamless Mobility
4. Urbanization and Mega Cities
5. Globalization and Individualization
6. Demographic Change
7. Health and Security
Environmental Impact

... in Sacramento

... in Bangkok
Peak of Oil

Source: Energy Watch Group/Ludwig Bölkow Stiftung, „Zukunft der weltweiten Erdölversorgung“, S. 13, Mai 2008
## Availability of Non-Renewable Energies

<table>
<thead>
<tr>
<th>Resource</th>
<th>Proven</th>
<th>Resource</th>
</tr>
</thead>
<tbody>
<tr>
<td>Crude Oil</td>
<td>58</td>
<td>84</td>
</tr>
<tr>
<td>Natural Gas</td>
<td>61</td>
<td>577</td>
</tr>
<tr>
<td>Hard Coal</td>
<td>129</td>
<td>2680</td>
</tr>
<tr>
<td>Lignite</td>
<td>285</td>
<td>4275</td>
</tr>
<tr>
<td>Uranium</td>
<td>43</td>
<td>387</td>
</tr>
</tbody>
</table>

(source: BGR 2008)

*Note: ("Peak-Oil")*
Mega Cities: Urbanization Leads to Worldwide Growth of Mega Cities

* Mega Cities = Cities with more than 10 million inhabitants in 2020, counted with agglomerations

source: UNPD 1999, 2003
CO₂ Emission Challenge

- Increased efficiency
- Biofuels
- New technologies
Customer Wishes

- Quality
- Costs
- Environment
- Individuality
- Comfort
- Driving Pleasure
Global Challenge

- Customer Wishes
- Different Markets & Competition
- Global Change
- International Legislation
Volkswagens Powertrain- and Fuel Strategy

- Renewable Energy Sources
  - SunFuel®
  - Hydrogen
  - Electricity
  - Electrotraction Fuel Cell
  - Electrotraction Battery

- Fuel Options
  - Natural Gas
  - SynFuel (CNG)
  - Diesel Fuel
  - Gasoline
  - Oil
  - Energy Storage Solutions
    - Battery
  - Engine Technologies
    - Hybrid
      - TSI®
      - TDI®
      - DSG®
### Modular Design System – Module Management

<table>
<thead>
<tr>
<th>Modular Toolbox</th>
<th>Drivetrain</th>
<th>Suspension</th>
<th>Equipment</th>
<th>Electric</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>A000</td>
<td>A00</td>
<td>A0</td>
<td>A</td>
</tr>
<tr>
<td></td>
<td>A</td>
<td>A</td>
<td>B</td>
<td>C</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td>D</td>
<td>E</td>
</tr>
</tbody>
</table>

- **Modular Design System**
- **Established Markets**
- **Emerging Markets**

Segments (vehicle classes)
MQB – Variety of Today's and Future Drivetrains

**Conventional drivetrains**
- Gasoline engines
  - TSI
  - CNG
  - LPG
  - E85

- Diesel engines
  - TDI
  - Clean Diesel
  - Bi-TDI

- Transmission
  - DSG
  - manual gearbox
  - emerging Markets

**Alternative drivetrains**
- Hybrid
  - μ-Hybrid
  - Mild-Hybrid
  - Full-Hybrid
  - Plug In-Hybrid

- Electricity
  - Range Extender
  - Electrical Vehicle

- Fuel Cell
  - HT-PEM
The New 1.6l TDI Engine from Volkswagen

Vehicle results

<table>
<thead>
<tr>
<th>Power output [kW]</th>
<th>55 *</th>
<th>66 **</th>
<th>77 **</th>
</tr>
</thead>
<tbody>
<tr>
<td>at [1/min]</td>
<td>4000</td>
<td>4200</td>
<td>4400</td>
</tr>
<tr>
<td>Torque [Nm]</td>
<td>195</td>
<td>230</td>
<td>250</td>
</tr>
<tr>
<td>at [1/min]</td>
<td>1500 to 2000</td>
<td>1500 to 2500</td>
<td>1500 to 2500</td>
</tr>
<tr>
<td>Top speed [km/h]</td>
<td>170</td>
<td>178</td>
<td>189</td>
</tr>
<tr>
<td>Acceleration 0 - 100 km/h [sec]</td>
<td>14.0</td>
<td>12.9</td>
<td>11.3</td>
</tr>
<tr>
<td>Elasticity 80 - 120 km/h (4.5) [sec]</td>
<td>14.0</td>
<td>12.5</td>
<td>11.0</td>
</tr>
<tr>
<td>MVEG consumption [l/100 km]</td>
<td>4.2</td>
<td>4.5</td>
<td>4.5</td>
</tr>
<tr>
<td>CO₂ emissions [g/km]</td>
<td>109</td>
<td>118</td>
<td>119</td>
</tr>
<tr>
<td>Emissions standard [-]</td>
<td>EU5</td>
<td>EU5</td>
<td>EU5</td>
</tr>
</tbody>
</table>

* Polo  ** Golf
### The New 1.2l TSI Engine from Volkswagen

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Concept</td>
<td>4 Cyl. In-Line</td>
</tr>
<tr>
<td>Valves per Cylinder</td>
<td>4</td>
</tr>
<tr>
<td>Capacity</td>
<td>1197 cm³</td>
</tr>
<tr>
<td>Bore/Stroke</td>
<td>71.0 / 75.6 mm</td>
</tr>
<tr>
<td>Stroke/Bore Ratio</td>
<td>1.064</td>
</tr>
<tr>
<td>Distance Between Cylinder Axes</td>
<td>82 mm</td>
</tr>
<tr>
<td>Conrod Length</td>
<td>144 mm</td>
</tr>
<tr>
<td>Compression Ratio</td>
<td>10</td>
</tr>
<tr>
<td>Rated Power Output</td>
<td>77 kW at 5000 1/min</td>
</tr>
<tr>
<td>Specific Power Output</td>
<td>64.3 kW/l</td>
</tr>
<tr>
<td>Max. Torque</td>
<td>175 Nm at 1500-3500 1/min</td>
</tr>
<tr>
<td>Specific Torque</td>
<td>146 Nm/l</td>
</tr>
<tr>
<td>Fuel</td>
<td>ROZ 95</td>
</tr>
<tr>
<td>Engine Control</td>
<td>Simos 10</td>
</tr>
<tr>
<td>Exhaust-Gas Optimisation</td>
<td>EU5</td>
</tr>
<tr>
<td>Gearbox</td>
<td>Manual 6G., DSG 7G.</td>
</tr>
<tr>
<td>Power Output</td>
<td>77 kW</td>
</tr>
<tr>
<td>Acceleration 0 – 100 km/h [MQ / DQ]</td>
<td>10.5 / 10.3 s</td>
</tr>
<tr>
<td>Consumption [MQ / DQ]</td>
<td>5.7 / 5.4 l/100 km</td>
</tr>
<tr>
<td>CO₂ Emissions [MQ / DQ]</td>
<td>134 / 129 g/km</td>
</tr>
</tbody>
</table>
New generation of fuel efficient engines: the 1.4 TSI engine

Monoturbo 90 kW
Twincharger 103 / 110 / 118 / 125 kW
Benchmark Fuel Consumption – Gasoline Engines
Power Range 77-150 kW

Fuel consumption [l/100 km] NEDC

Engine power [kW]

<table>
<thead>
<tr>
<th>Competitors</th>
</tr>
</thead>
<tbody>
<tr>
<td>Golf TSI</td>
</tr>
<tr>
<td>Golf TSI - TC</td>
</tr>
<tr>
<td>Golf GTI</td>
</tr>
<tr>
<td>Golf VI - M6 - EU5</td>
</tr>
<tr>
<td>Golf VI – DSG- EU5</td>
</tr>
</tbody>
</table>

Golf 1,2l TSI

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AKTIENGESELLSCHAFT
TSI® plus CNG – The Perfect Volkswagen Combination

- TSI® + CNG is the optimal starting position for creating an engine optimized for low fuel consumption and driving performance

- The Twincharger concept avoids the otherwise obligatory Turbo lag

- Performance of a large displacement natural aspirated engine with both minimal fuel consumption and emissions

- 1.4 TSI-CNG 110 kW
- 110 kW/150 PS
- 210 km/h
- 4.4 kg/100 km
- CO₂ emissions 119 g/km
- Total range: 940 km
BlueMotion Measures for Further Reduction in Fuel Consumption

- **55 kW w/o DPF**
- **59 kW with DPF**
- **1.4l TDI EU4 with manual gearbox**
- **4.4 Base 4+E gearbox**

**NEDC [l/100km]**
- **-0.2**
- **-0.1**
- **-0.1**
- **-0.4**
- **+0.2**
- **3.8**

- Engine measures
- Diesel-particulate filter
- Aerodynamic measures and optimized generator
- Tires with less roll resistance

**Target**
BlueMotion Technologies: Product Strategy

BlueMotion 1. generation

KJ 2006

7 models 2007

9 models 2008

BlueMotion 2. generation;
TSI EcoFuel; BlueTDI

40 models

TSI
TDI
DSG
Start-Stop
recuperation
NOx-exhaust-
after treatment

29 models

TSI
TDI
DSG
Start-Stop
recuperation
NOx-exhaust-
after treatment

Hybrid

... 2009

2010
BlueMotion 2nd Generation

Golf BlueMotion
99 g CO₂/km – Euro 5

1,6l TDI
Common-Rail

Passat BlueMotion BlueTDI
109 g CO₂/km – Euro 6

2,0l TDI
Common-Rail
Polo BlueMotion 87gCO₂/km
Consumption-Optimized Models in the Group

VOLKSWAGEN

4 models
≤ 100 g CO₂/km

33 models
≤ 120 g CO₂/km

132 models
≤ 140 g CO₂/km

132 models ≤ 140 g CO₂/km
2nd Generation Biofuels SunFuel®
Basic Requirements for New Fuels

• Compatibility with existing car fleet
• Blending with conventional fuels
• Compliance of sustainability criteria
Characteristics of Different Biofuels

1\textsuperscript{st} Generation
- biodiesel (rapeseed)
- ethanol (wheat, sugar beet)

2\textsuperscript{nd} Generation
- SunDiesel\textsuperscript{®} (Biomass to Liquid, BtL)
- SunEthanol\textsuperscript{®} (Cellulose Ethanol)

- high potential for CO\textsubscript{2} reduction
- no interference in the food chain
- high hectare yields
State of the Art: Production of Biogas
Fuel Yield per Hectare Cultivated Area

- Biomethane (maize)
- BtL
- Biodiesel (RME)
- Ethanol (sugar beet)
- Ethanol (cereal-wheat)
- Ethanol (straw)

Source: Fachagentur Nachwachsende Rohstoffe (FNR) 2009

1 \text{t}_{\text{gasoline.äq.}} = 43.2 \text{ GJ}
Well-To-Wheel CO₂-Reduction of Biofuels

Feedstock ↔ Residue, Cellulose

1st Generation

2nd Generation

CO₂-Reduction Potential [%]

State of the Art
CO₂-optimized

Ethanol, Biodiesel, Hydreated Vegetable Oil, Biogas, Ethanol 2nd Generation, BtL
**Comparative Life Cycle Assessment (Well-to-Wheel)**

Petrol Car – EcoFuel – EcoFuel with Biomethane

<table>
<thead>
<tr>
<th></th>
<th>CO$_2$ [g/km] Tank-to-Wheel</th>
<th>CO$_2$eq [g/km] Well-to-Wheel</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Petrol car</strong></td>
<td>157 g/km</td>
<td></td>
</tr>
<tr>
<td><strong>EcoFuel</strong></td>
<td>119 g/km</td>
<td></td>
</tr>
<tr>
<td><strong>EcoFuel/100% Biomethane</strong></td>
<td>119 g/km</td>
<td>-79%</td>
</tr>
</tbody>
</table>

Petrol car: Passat 1,4 TSI DSG  
EcoFuel: Passat 1,4 TSI EcoFuel DSG

Source: Volkswagen
First Electric Car by Porsche
Presentation on April 14th 1900 at the World Exhibition in Paris

2 wheel-hub electric motors

\[ P_{\text{max}} = 2 \times 7 \text{ PS} \]
\[ P_{\text{rated}} = 2 \times 2.5 \text{ PS} \text{ (at 120 rpm)} \]

44 cells for a 300 Ah battery with 80 V

\[ v_{\text{max}} = 50 \text{ km/h} \]

Range 50 km

Stops preventing rollback

Electric brake in the front, mechanical brake in the rear

Total weight 980 kg

Battery weight 410 kg

1 front wheel 115 kg

Approx. 300 vehicles sold
Volkswagen Electric and Hybrid Vehicles

HEVs
- Typ2 City Taxi
- Golf I Hybrid
- Chico Hybrid
- Audi Duo
- Bora SUVA Hybrid
- Golf TwinDrive II

EVs
- Typ2 Electric
- Golf I Electric
- T2 Electric
- Jetta CitySTROMer
- Golf III CitySTROMer
- Golf Electric
- Space up! blue
- Golf I Electric CitySTROMer
- Golf II Hybrid
- Golf III Hybrid
- Golf ECO.Power
- Touran TSI Hybrid
- Bora Electric
- Touareg Hybrid
Touareg Hybrid

- Power electronics with DC/DC-converter
- Electric motor
- 8 speed automatic transmission
- High voltage
- Hybrid battery

3,0l TFSI V6
Requirements on Future Electrical Energy Storages

Range

2008 2012 2017

Availability prototype cell

Evolutionary development

Technology leap

Technology change

Technological vision

Limit of Lithium-ion-technology

*energy density based on battery cell

120 Wh/kg* 600 W/kg
170 Wh/kg* 800 W/kg
200 Wh/kg* 1000 W/kg
200-600 Wh/kg* 1000 W/kg
1500 Wh/kg* 1000 W/kg
Requirements on Electrical Energy Storage Devices

- **energy**
  - electrical range, availability of electric comfort consumer

- **cost**
  - economic viability, market acceptance, recycling

- **power**
  - performance, dynamic

- **lifetime**
  - cycles, durability

- **safety**
  - fault, crash, misuse, service

Technology today: Nickel-metal-hydride
Technology tomorrow: Lithium-ion
Energy Storage Systems: The Dilemma

Battery system
68 kg
Energy content 0.5 kWh

Chocolate
85 g
Energy content 0.5 kWh

Gasoline
55 ml
Energy content 0.5 kWh
2-Way Roadmap for "Sustainable Drives"

- **Focus: combustion engine**
  - Combustion engine
  - Mild hybrid
  - Integrated hybrid
  - Zero-impact powertrain

- **Focus: electric drive**
  - Electric drive with range extender
  - Electric drive with FC range extender
  - Long distance electric drive
  - Full hybrid
  - Plug-in hybrid
## twinDRIVE: Concept Ideas

### Electrical

**Short Range Mobility**
- use of alternative & regenerative energy forms for short range mobility
- next step to independence of fossil resources
- fill up with cheap power @ 220V- electrical grid
- emission free driving in restricted city centers
- grid stabilization by EVU

### Combustion Engine

**Long Range Mobility**
- use of conventional fuels for long range mobility
- consumption optimized powertrain by full-hybrid-functionality (start/stop, E-Drive, recuperation)
- drivability, performance, fuel consumption and range as full-hybrid-powertrain
twinDRIVE®: Basic Concept of Drive Train

Vehicle:
- Golf Estate
- Driving power: ~ 80 kW
- Electric cruising range: @ 18 kWh/100 km: ~30...50 km
Volkswagen’s Efficiency Kit for the Future

- Further optimization of powertrain technologies (TDI/TSI/TFSI)
- Extension of new gearbox technology (DSG / S tronic)
- Electrification of powertrains (Start/Stop, Hybrid)
- Alternative mechanical and hydraulic accessories
- Reduction of mechanical resistances
- Further development of alternative fuels
- Improvement of energy management
- Broadening competence in light weight construction
- Optimization of aerodynamics
- Further development of driver-assistance systems

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