Future Mobility
Volkswagen Group’s Solutions for Sustainable Mobility

Prof. Dr. Wolfgang Steiger
Global Government Affairs
Future Technologies
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Societal Challenges

Demographic Change and Urbanization
- Noise, Emissions, Accidents

Global Economy and growing Middle Class
- Increasing Traffic

Resource Competition and Climate Change
- Energy Consumption, CO₂

Connectivity and Mobility
- Data Safety and Security

21. Century → Guideline Sustainability
Sustainable mobility: Volkswagen’s fuel and drive train strategy

Renewable energy sources

- CO$_2$-neutral electricity
- CO$_2$-neutral fuels

Conventional energy sources

- Petroleum
- CNG
## Volkswagen XL1

<table>
<thead>
<tr>
<th>Specification</th>
<th>Value</th>
</tr>
</thead>
<tbody>
<tr>
<td>Aerodynamics</td>
<td>$cd = 0.189$</td>
</tr>
<tr>
<td>Curb weight</td>
<td>795 kg</td>
</tr>
<tr>
<td>Top speed</td>
<td>160 km/h</td>
</tr>
<tr>
<td>Fuel consumption (NEDC)</td>
<td>0.83 l/100 km</td>
</tr>
<tr>
<td>CO2 emissions (NEDC)</td>
<td>21 g/km</td>
</tr>
<tr>
<td>All-electric range</td>
<td>50 km</td>
</tr>
<tr>
<td>Total range</td>
<td>approx. 500 km</td>
</tr>
</tbody>
</table>
Carbon dioxide: Conventional drive technologies are not enough

Fleet CO₂ emissions

Technologies to increase CO₂ efficiency

- Optimizing conventional drive trains
- CO₂ efficiency measures in the vehicle
- Using alternative drive technologies
- e-hybrid
- TWIN DRIVE
- e.Motion
- e-tron

Technologies and energy sources

EU27 Fleet value in 2006
166g CO₂/km

EU27 Fleet value in 2012
134g CO₂/km

EU27 Fleet value in 2020
95g CO₂/km
Volkswagen Group: Technologies to suit every need
Interurban Mobility

- Golf TSI BlueMotion
- Jetta Hybrid
- Panamera I Hybrid
- Q5 Hybrid
- Golf TDI BlueMotion
- eco up!
Golf TDI BlueMotion
3.2 l/100km, 85g CO₂/km
Measures to improve CO₂ efficiency

**Engine**

- Combustion system
  - High-performance combustion system
  - Combined turbo- and supercharging
  - Ignition systems
  - Variable valve train
  - Variable compression ratio
- Lightweight design
  - Alternative materials
  - Lightweight design through optimized structures
- Operational strategy
  - Active Cylinder Management
  - Optimizing engine mapping
  - Engine off while coasting
  - Downspeeding
  - NVH at low rpm
- Friction
  - Surface coating
  - Thermal management
  - Utilizing exhaust heat

**Gearbox**

- Dual-clutch gearbox
  - Gear-ratio spread
  - Efficiency
  - Performance when pulling away
  - Low-rpm solution
Evolution of renewable energy pathways

Source/Feedstock

- Solar energy
  - Vegetable oil
  - Glucose
  - Syngas
  - "green" electricity
  - CO₂ + sunlight

Energy carrier for mobility

- Gasoline and Diesel
- Gas
- Battery and fuel cell
**Electrifying the Drive systems at Volkswagen**

- **Micro hybrid/start-stop**
- **Mild hybrid**
- **Full hybrid (HEV)**
- **Plug-in hybrid (PHEV)**
- **Range extender (RE BEV)**
- **Battery vehicle (BEV)**
- **Fuel cell (FCEV)**

**Electric motor**

- **Boost**
- **Internal combustion engine**

**Electric range**

- 2 km
- 20–80 km
- 50–120 km
- 80–200 km
- 400–600 km

**Electric vehicle**

1) > 2020 Internal combustion engine

1) > 2020

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Volkswagen Group: Technologies to suit every need
Urban Mobility

- Golf TSI BlueMotion
- Golf TDI BlueMotion
- Jetta Hybrid
- eco up!
- Panamera 1 hybrid
- Q5 Hybrid
- Golf blue-e-motion
- e-up!
Volkswagen e-up!
## Development in 2010 to 2013 e-up!

<table>
<thead>
<tr>
<th></th>
<th>e-up! 2010</th>
<th>e-up! 2013</th>
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</thead>
<tbody>
<tr>
<td>Material Cost</td>
<td>-16 %</td>
<td></td>
</tr>
<tr>
<td>Battery Size</td>
<td>-21 %</td>
<td></td>
</tr>
<tr>
<td>Energy Consumption*</td>
<td>-23 %</td>
<td></td>
</tr>
<tr>
<td>Range</td>
<td>160 km</td>
<td></td>
</tr>
<tr>
<td>Weight</td>
<td>1.139 kg</td>
<td></td>
</tr>
<tr>
<td>Aerodynamic $cw \times A$</td>
<td>-6 %</td>
<td>0.644 m²</td>
</tr>
<tr>
<td>Rolling-Resistance</td>
<td>-6 %</td>
<td>7.2 %</td>
</tr>
</tbody>
</table>

| Battery Size     | 18.7 kWh           |
| Energy Consumption* | 11.7 kWh/100km  |

* incl. Recharging
The electric drive system of the e-Golf

Electric machine
Permanent magnet synchronous motor

<table>
<thead>
<tr>
<th>Feature</th>
<th>Specification</th>
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<tbody>
<tr>
<td>Max. power output</td>
<td>85 kW</td>
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<tr>
<td>Constant power output</td>
<td>50 kW</td>
</tr>
<tr>
<td>Max. torque</td>
<td>270 Nm</td>
</tr>
<tr>
<td>Constant torque</td>
<td>160 Nm</td>
</tr>
<tr>
<td>Range</td>
<td>180 km</td>
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</tbody>
</table>
Roadmap for high-energy batteries

All-electric range in km **

Conventional lithium-ion technology

- 150 km 140 kWh/kg*
- 190 km 170 kWh/kg*
- 250 km 220 kWh/kg*

Lithium-sulfur batteries

- 300 km 500 kWh/kg*

Lithium-air batteries

- 520 km 1000 kWh/kg*

New battery technologies

** Based on Golf blue e-motion with constant battery volume

* Energy density per cell
Range Improvement –
More than just Battery Size

- Energy consumption
- Weight
- Aerodynamic
- Rolling Resistance

Range [km]

Battery Capacity [in kWh]
### Outlook Mileage e-up! and e-Golf

<table>
<thead>
<tr>
<th>Battery Cells [Ah]</th>
<th>Battery Capacity [kWh]</th>
<th>Range NEDC [km]</th>
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</thead>
<tbody>
<tr>
<td>Status: 25</td>
<td>18.7</td>
<td>160</td>
</tr>
<tr>
<td>Outlook: 28</td>
<td>21.0</td>
<td>185</td>
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<tr>
<td>34</td>
<td>25.5</td>
<td>220</td>
</tr>
<tr>
<td>36</td>
<td>26.9</td>
<td>230</td>
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### Outlook Mileage e-up! and e-Golf

<table>
<thead>
<tr>
<th>Battery Cells [Ah]</th>
<th>Battery Capacity [kWh]</th>
<th>Range NEDC [km]</th>
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</thead>
<tbody>
<tr>
<td>Status: 25</td>
<td>24.2</td>
<td>180</td>
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<tr>
<td>Outlook: 28</td>
<td>27.1</td>
<td>205</td>
</tr>
<tr>
<td>34</td>
<td>32.9</td>
<td>250</td>
</tr>
<tr>
<td>36</td>
<td>34.9</td>
<td>265</td>
</tr>
</tbody>
</table>
Combined Charging System – One System for All

Easy-Handling and Widely Spread User Acceptance
Uniform, open and standardised solution as future-proof investment

Simple – Safe – Flexible
No need for variants

Charging Time
- Ultra Fast: 15 min
- Fast: 1 h
- Basic: 8 h

Speed of Charging
- High Power
- DC

Type 2 Core
Volkswagen Group: Technologies to suit every need
Unlimited Mobility

- Golf TSI BlueMotion
- Jetta Hybrid
- Golf PHEV
- Golf blue-e-motion
- e-up!
- Panamera S e-hybrid
- AUDI A3 e-tron
- Panamera 1 hybrid
- Audi A3 e-tron
- Q5 Hybrid
- eco up!
- Panamera S e-hybrid
- Audi A3 e-tron
- Panamera 1 hybrid
- Golf TDI BlueMotion
- Golf TDI BlueMotion
- Panamera S e-hybrid
- Audi A3 e-tron
- Panamera 1 hybrid
- Golf TSI BlueMotion
- Jetta Hybrid
- Golf PHEV
- Golf blue-e-motion
- e-up!
- XL1
Audi A3 e-tron

1.4 l 110 kW TSI engine with aluminum cylinder block and crankcase

Lithium-ion battery
96 cells, 352 V, 8.8 kWh

Power electronics including DC-DC converter

Dual clutch gearbox DQ400E with integrated electric machine (80 kW)
The MQB plug-in drive train with the DQ400E gearbox

Technical specifications

<table>
<thead>
<tr>
<th>Component</th>
<th>Specification</th>
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</thead>
<tbody>
<tr>
<td>IC engine</td>
<td>110 kW / 250 Nm</td>
</tr>
<tr>
<td>Electric motor</td>
<td>80 kW / 330 Nm</td>
</tr>
<tr>
<td>System output</td>
<td>150 kW</td>
</tr>
<tr>
<td>System torque</td>
<td>350 Nm</td>
</tr>
<tr>
<td>HV battery capacity</td>
<td>8.8 kWh</td>
</tr>
<tr>
<td>All-electric range</td>
<td>approx. 50 km</td>
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</table>
Assembly kit for hybrid drive systems

<table>
<thead>
<tr>
<th>Engine</th>
<th>Electric machine</th>
<th>Gearbox</th>
<th>Battery</th>
<th>Power electronics</th>
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<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></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>
Competition of Technologies

- Customer requirement: Range > 500 km
- Both Technologies have specific Challenges
Fuel Cell Technology – HyMotion

- **Power Fuel Cell**: 85 kW
- **Battery Capacity**: 1.1 kWh
- **Coaxial Drivetrain**
  - **Power E-Motor**: 85 kW
  - **Torque E-Motor**: 270 Nm
- **Range**: 420 km
- **Max Speed**: 160 km/h
- **Acceleration 0-100 km/h**: 12 s
Fuel Cell Technology – HyMotion

- Fuel Cell Stack
- Fuel Cell Controller
- Air Cooler
- Fuel Cell peripherals
- Fuel Cell System
- Triport DC/DC Transformer
- Hybrid-Battery
- Hydrogen Tanks
- Power Electronics
- E-Motor
Volkswagen is electrifying all vehicle classes

<table>
<thead>
<tr>
<th>Year</th>
<th>BEV</th>
<th>PHEV</th>
<th>PHEV</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>VW e-up!</td>
<td>Audi A3</td>
<td>Audi A6</td>
</tr>
<tr>
<td>2011</td>
<td>VW Jetta</td>
<td>VW Golf</td>
<td>Audi A8</td>
</tr>
<tr>
<td>2012</td>
<td>VW e-Golf</td>
<td>Porsche Cayenne</td>
<td>Derivatives of other Group brands</td>
</tr>
<tr>
<td>2013</td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>2014 → beyond</td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

- HEV: Hybrid Electric Vehicle
- BEV: Battery Electric Vehicle
- PHEV: Plug-in Hybrid Electric Vehicle

Derivatives of other Group brands:
- Audi Q7
- VW Passat
- Porsche Panamera

Vehicles:
- Volkswagen Touareg
- Audi Q5
- Volkswagen Jetta
- Volkswagen e-Golf
- Volkswagen e-up!
- Porsche Panamera S
- Porsche Cayenne S
- Porsche 918 Spyder
- Audi A6
- Audi A8
- Audi A3
- Audi Q7
- Volkswagen Golf
- Volkswagen Passat
- Audi A8
- Volkswagen Panamera
Power to Fuel - Opportunities to Access Renewable Power

- **Electricity Grid** "Green Electricity"
- **Power Station** to **H₂ Storage**
- **Electrolysis** to **Electricity**
- **H₂ Storage** to **H₂ Filling Station**
- **Direct Injection** to **C₀Hₐ**
- **Fischer-Tropsch-Synthesis** to **H₂**
- **Methanisation** to **CO₂**
- **Power Station** to **Methane Storage**
- **Natural Gas Pipeline** to **CNG Filling Station**

Charging Station

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Electric Mobility – a Systems Approach

Source: Nationale Plattform Elektromobilität (NPE)
Thank you for your Attention!
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Volkswagen Group’s Solutions for Sustainable Mobility

Prof. Dr. Wolfgang Steiger
Global Government Affairs
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