Daimler roadmap to sustainable mobility

- High-tech combustion engines
- Consequent hybridization
- Electric vehicles with battery and fuel-cell
Fuel cell technology: Worldwide experience for highest technological know-how

Mercedes-Benz B-Class F-CELL

Mercedes-Benz Citaro FuelCELL-Hybrid

More than 8 million km customer experience
More than 4,000 h fuel cell durability

More than 4 million km of regular line operation
More than 10,000 h fuel cell durability
Mercedes-Benz F-CELL World Drive 2011

3 B-CLASS F-CELL
125 DAYS
14 COUNTRIES
30,000 KM
Mercedes-Benz F-CELL Lessons Learned: Fast Refueling is validated

Result of 36,000 refuelings in real-life operation:
**2.8 minutes refueling time** in average
Mercedes Benz F-CELL Lessons Learned for Next Generation

**Fleet Operation (Customers)**
- Different customer profiles
- User behaviour
- Different climate
- Different H2-Infrastructure
- Reliability in daily use

**Powertrain-Testing**
- Load distribution
- Degradation
- Statistics & Prognosis

**GLC-Fuel Cell System Learnings**
- Apply learnings from Fleet and test benches e.g. to reduce stress on stack components
- More stable components (e.g. catalysts)
- Implement recovery procedures
- Improved component specifications
DAIMLER: Next Generation Fuel-Cell System

Huge technological progress

2010: Underfloor package

2017: Compartment package

- 30% reduction fuel cell engine size
- 90% reduction of Platinum
- 30% higher electric range in future vehicles
- 40% higher system performance
The V Model of Product Development

Requirement/Development Cascade (top-down) & Validation/Testing Cascade (bottom-up)
Durability test distribution on different integration levels:

![Durability test distribution table]

<table>
<thead>
<tr>
<th>Hardware-Stages Integration Level</th>
<th>Stage 1</th>
<th>Stage 2</th>
<th>Stage 3</th>
<th>Stage 4</th>
</tr>
</thead>
<tbody>
<tr>
<td>Component Level</td>
<td>![Component Level Stage 1]</td>
<td>![Component Level Stage 2]</td>
<td>![Component Level Stage 3]</td>
<td>![Component Level Stage 4]</td>
</tr>
<tr>
<td>System Level</td>
<td>![System Level Stage 1]</td>
<td>![System Level Stage 2]</td>
<td>![System Level Stage 3]</td>
<td>![System Level Stage 4]</td>
</tr>
<tr>
<td>Powertrain Level (Test Bench)</td>
<td>![Powertrain Level Stage 1]</td>
<td>![Powertrain Level Stage 2]</td>
<td>![Powertrain Level Stage 3]</td>
<td>![Powertrain Level Stage 4]</td>
</tr>
<tr>
<td>Vehicle Level (Road Testing)</td>
<td>![Vehicle Level Stage 1]</td>
<td>![Vehicle Level Stage 2]</td>
<td>![Vehicle Level Stage 3]</td>
<td>![Vehicle Level Stage 4]</td>
</tr>
</tbody>
</table>

→ Good correlation of results on different integration levels required!
Stack (component) Testing Philosophy: Transfer failure mode from Vehicle/Powertrain to Components

Requirements Definition → Conformity to Requirements

Fundamental Understanding

Component Verification

Stack Verification/Validation

- Materials Tests
- Subscale Tests
- Module Tests
- System & Vehicle Tests
- Usage Data

Material Requirements & Testing
Component/Stack Requirements & Testing
Stack Module Requirements & Testing

Failure Mode Identification and Feedback to Design Process
Key Success Factor: Fast Material Tests that correlate with Stack testing for Prediction of Stack Behaviour in System/Vehicle


Performance & Durability Prediction → Performance & Durability Validation

**Material Characteristics:**
Tests in wide range of operating conditions
Failure mode specific test protocols

**MEA and Subcomponent Interaction:**
Tests in specified operating conditions and window around System conditions

**Integrated Stack:**
Tests in specific conditions derived from vehicle including drive cycles

**Fuel Cell System/Powertrain Vehicle:**
Performance & Durability validation addressing fuel cell specific needs
Example: Testing for Start/Stop in the driving cycle

**Hydrogen-Air Start**

- Short stops: Negligible degradation
- Long stops: After shutdown air diffuses to anode

**Air-Air Start**

- At start-up, air-hydrogen front at anode
- Oxygen is reduced at anode $\Rightarrow$ Corrosion of C-support

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Example: RDE and Stack Measurement Results

- Catalyst RDE test results are comparable with In-situ Test Result in Stacks, but 10 times faster.

  => Component Testing (RDE) can be used to predict catalyst durability and to design fuel cell system and operating strategy to optimize durability.
Komponenten-Entwicklung BZ-System: Beispiel ETC

- Verdichter-Rad
- Magnet im Rotor
- Turbine
- Radiales Luftlager
- Axiales Luftlager

- Ölfreie Lagerung notwendig => Luftlager
- Reibungsarme Beschichtung für axiale und radiale Lager notwendig für An- und Abschaltvorgänge
- Mehr als 200.000 Start – Stopp Zyklen erfolgreich getestet

- Herausforderung: Vereinfachung der Fertigungstechnologie um Kosten zu senken
DAIMLER: Next Generation Fuel-Cell System

**GLC F-CELL Facts**

- Approx. 500 km combined electric range NEDC
- < 50 km ranges in battery-electric mode alone
- 700 bar hydrogen refueling in approx. 3 min
- Battery with an energy content of approx. 9 kWh
- 2 carbon fibres coated tanks with ~4 kg capacity
Starting 2017: Mercedes-Benz GLC F-CELL with plug-in-technology
Starting 2017: Mercedes-Benz GLC F-CELL with plug-in-technology
Keep it simple and utilize interfaces experience from current standard!
One coupling for each pressure regime is sufficient!
Volatile energy supply due to feed-in of renewable electricity

The feed-in of wind energy already causes significant peaks in the energy supply.

Increasing Feed-in of renewable electricity

The supply of wind energy may exceed the aggregate demand temporarily.

In the future, peaks in energy supply and demand become normal.

Time-dependent over- or under-supply of renewable electricity requires highly-efficient and large-scale electricity storages. → Opportunity: H₂-storage
Excess electricity can be stored in different storage systems

- Hydrogen is the ideal mid- to long-term storage for large amounts of energy from excess electricity.

Central long-term storage

- Today only readily controllable fossil power plants are able to compensate long-term (days or weeks) fluctuations (e.g.: lack of wind).
- Replacing these fossil power plants with energy storage systems helps to speed up the Energiewende.
- H2 cavern storage systems have the highest energy density.
Comparison of WTW greenhouse gas emissions and power consumption of the EUCAR reference vehicle 2020+

**Sources:** JRC/EUCAR/CONCAWE (2013): WW report, version 4a, Daimler-internal calculations

* GHG: Green House Gas
H2-Mobility
Build up a H2-infrastructure network until 2023 in Germany

Putting Hydrogen on the map

By 2018/19 as many as 100 Hydrogen stations across Germany should provide the world’s densest network

H2-Mobility Signing Ceremony in Berlin
13th October 2015

* By 04/2017 there are 33 HRS are completed, 22 HRS are under construction
Brennstoffzellentechnologie bei Daimler

Seminar erneuerbare Energien
Uni Karlsruhe
10. Mai 2017

Dr. G. Frank, Daimler AG,
Fuel Cell Component Development & H2 Infrastructure