Fuel cell electric vehicles – outlook on market potential and industry challenges

Dr. Martin Linder, McKinsey & Company
F-CELL, Stuttgart, September 27th, 2011
Major driver for alternative powertrains is tightening CO₂ regulation – significant reductions announced until 2020, but uncertainty of outlook

Converging emission regulations across the globe

- Future powertrain market penetration will be mainly driven by CO₂ regulations, TCO, and fit with customer needs
- Regional differences are projected to be substantial (e.g., speed of adoption, public incentives)
- To be in line with the “2°C global warming” target, CO₂ emission reduction to 10 g/km are required in the private road transport sector by 2050

Future tightening by expected switch from “tank-to-wheel” to “well-to-wheel”

"Below 40" and "below 10" not feasible with pure ICE

1 Regulation under review by the European Parliament: 2015, 2020, 2025 targets will be determined by 2015

SOURCE: European Commission; McKinsey
A global industry group is evaluating the commercialization of a H₂-infrastructure and fuel cell electric vehicles

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**Objective**

- Fact-based evaluation of the market potential of FCEV compared to BEV, PHEV, ICE
- Development of an integrated perspective across the H₂ value chain based on proprietary industry data
- Assessment of hydrogen retail infrastructure roll-out in GER
- Definition of an integrated roll-out scenario for FCEV market penetration with major car OEMs
- Establishment of a future consortium for the H₂ infrastructure roll-out
- Implementation of a business case
27 private companies, 1 NGO, and 2 GOs across the value chain evaluated the potential of alternative power-trains for passenger cars in Europe.

**Core questions**

- How do FCEVs, BEVs, and PHEVs compare to ICEs on
  - Cost
  - Emissions
  - Energy efficiency
  - Driving performance?
- What are viable production and supply pathways?
- What are the potential market segments for the different power-train technologies?

**Approach and principles**

- 3 reference car segments
- Well-to-wheel
- >10,000 company data in a “clean room” environment
Proprietary data were collected on all drive trains and at a granular level

<table>
<thead>
<tr>
<th>Reference vehicle</th>
<th>Power-trains</th>
<th>Evaluation criteria</th>
</tr>
</thead>
<tbody>
<tr>
<td>Small (A/B)</td>
<td>ICE - gasoline</td>
<td>Total cost of ownership</td>
</tr>
<tr>
<td></td>
<td>ICE - diesel</td>
<td>Purchase price</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Running cost</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Payoff time</td>
</tr>
<tr>
<td>Medium (C/D)</td>
<td>PHEV</td>
<td>Overall sustainability¹</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Production</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Operation</td>
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<tr>
<td></td>
<td></td>
<td>End-of-life</td>
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<tr>
<td>SUV (J)</td>
<td>BEV</td>
<td>Performance</td>
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<td>FCEV</td>
<td>Performance</td>
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</table>

- Potential for biofuels not assessed. Biofuels are assumed to be blended up to 24% CO₂ reduction in 2050
- Power sector will gradually decarbonize from 2010 to 2050
- Oil price slowly increasing to USD 119/bbl in 2030 (IEA)
- No taxes on purchase price and fuels, no subsidies in base case
- No cherry picking of 'best data'. Frozen input data before sharing results
- Impact of potential technology breakthroughs not included

¹ Note: Overall sustainability is a measure of the environmental impact of the vehicle over its entire life cycle.
Key insights

- Electric driving has clear benefits over the combustion engine on CO$_2$ and local emissions.

- Within electric driving, battery electric vehicles are suited for urban driving – small cars and shorter driving ranges.

- Plug in hybrids and fuel cell vehicles are suitable for medium and larger cars with higher annual driving distance.

- For this segment amounting for 50% of the fleet and 70% of the CO$_2$ emissions, fuel cell vehicles are an attractive low carbon solution.

- After 2025, the total cost of ownership of electric vehicles is comparable to ICEs.

- To drive the uptake of fuel cell vehicles, significant infrastructure investments are required in the first decades (~ EUR 3 billion up to 2020).
There is not one technology outperforming others across all dimensions

<table>
<thead>
<tr>
<th></th>
<th>FCEV</th>
<th>BEV</th>
<th>PHEV</th>
<th>ICE</th>
</tr>
</thead>
<tbody>
<tr>
<td>Performance</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Environment</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Economics¹</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>

1 Consumer economics can be different, dependent on tax region
2 Fast charging for BEVs implies reduced battery lifetime, lower battery load and higher infrastructure costs than included in this study

SOURCE: Study analysis
BEVs and FCEVs can achieve significantly low CO\textsubscript{2} emissions, with BEVs showing limitations in driving range

CO\textsubscript{2} emissions
\text{gCO\textsubscript{2}/km}

ICE – gasoline\textsuperscript{1}  \hspace{2cm}  ICE – diesel\textsuperscript{1}

PHEV

FCEV

Low emissions and high range

1 ICE range for 2050 based on fuel economy improvement and assuming tank size stays constant. Assuming 6% CO2 reduction due to biofuels by 2020; 24% by 2050

SOURCE: Study analysis
Electric vehicles are more energy efficient than ICEs over a broader range of feedstocks

1 All power-trains have different performance criteria and therefore different driving missions
2 CNG used in gasoline ICE; diesel production from natural gas through Fischer-Tropsch process
3 Gasoline and diesel production from coal-to-liquids transformation through Fischer-Tropsch process

SOURCE: CONCAWE-EUCAR JEC-WTW study; study analysis
After 2025, the TCO of all powertrains converge

TCO ranges\(^1\) of different power-train technologies

EUR/km

- FCEV
- PHEV
- BEV
- ICE

Ranges based on data variance and sensitivities (fossil fuel prices varied by +/- 50%; learning rates varied by +/- 50%)

SOURCE: Study analysis
The cost of a fuel cell system is expected to reduce by 90% by 2020 (80% for BEV-specific parts incl. battery and e-motor)

**EUR per fuel cell system**

<table>
<thead>
<tr>
<th>Component</th>
<th>2010</th>
<th>2015</th>
<th>2020</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>MEA (excl. catalyst, incl. GDLs)</td>
<td>14,274</td>
<td>3,212</td>
<td>7,475</td>
<td>-</td>
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<tr>
<td>Catalyst (incl. platinum)</td>
<td>6,296</td>
<td>2,970</td>
<td>2,970</td>
<td>-</td>
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<tr>
<td>Structure</td>
<td>22,228</td>
<td>9,516</td>
<td>7,475</td>
<td>4,306</td>
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<tr>
<td>Periphery</td>
<td>38,565</td>
<td>3,194</td>
<td>4,306</td>
<td>-</td>
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</tbody>
</table>

**FC stack lifetime**

- '000 km: 115, 180, 247, 290
- Platinum use: 0.93, 0.44, 0.24, 0.11
- Ø Fuel cell stack cost: 500, 110, 43

Min: 221, 42, 16
Max: 781, 252, 98

**Key drivers for cost reduction**

- Innovations in design (e.g., leaving out components)
- Different use of materials (e.g., reduced platinum use)
- Innovations in production technology
- Economies of scale

**SOURCE:** Study analysis
In the long run, FCEVs have a TCO advantage over BEVs and PHEVs in the larger car/long distance segments

EUR/year/car\(^1\), assuming no cost of CO\(_2\)

Lowest CO\(_2\) abatement solution
TCO delta to ICE\(^2\)

1 Constant lifetime, but different total driving distances (90,000 km; 180,000 km; 360,000 km)
2 Calculated as ICE TCO minus lowest FCEV/BEV/PHEV TCO. Negative numbers indicate a TCO advantage over the ICE

SOURCE: Study analysis
Cost of H2 production and supply differ significantly by technology, in the base case a 70% reduction is projected by 2025

**H₂ production methods**

**Examples**

**H₂ production cost**

<table>
<thead>
<tr>
<th>Method</th>
<th>2030</th>
<th>2050</th>
</tr>
</thead>
<tbody>
<tr>
<td>DWE</td>
<td>4.0</td>
<td>2.5</td>
</tr>
<tr>
<td>CWE</td>
<td>5.0</td>
<td>4.0</td>
</tr>
<tr>
<td>DSMR</td>
<td>5.5</td>
<td>4.5</td>
</tr>
<tr>
<td>IGCC + CCS</td>
<td>3.0</td>
<td>2.0</td>
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<tr>
<td>CSMR + CCS</td>
<td>2.5</td>
<td>2.0</td>
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<tr>
<td>CG + CCS</td>
<td>2.0</td>
<td>1.5</td>
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<tr>
<td>IGCC</td>
<td>1.5</td>
<td>1.0</td>
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<tr>
<td>CSMR</td>
<td>1.0</td>
<td>0.5</td>
</tr>
<tr>
<td>CG</td>
<td>0.5</td>
<td>0.0</td>
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</table>

**CO₂ emissions**

<table>
<thead>
<tr>
<th>Year</th>
<th>2010</th>
<th>2015</th>
<th>2020</th>
<th>2025</th>
<th>2030</th>
<th>2035</th>
<th>2040</th>
<th>2045</th>
<th>2050</th>
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<tbody>
<tr>
<td>2010</td>
<td>16.6</td>
<td>9.9</td>
<td>6.6</td>
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<td>2015</td>
<td>16.0</td>
<td>9.0</td>
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<td>4.4</td>
<td>4.4</td>
<td>4.4</td>
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<tr>
<td>2020</td>
<td>15.4</td>
<td>8.4</td>
<td>5.6</td>
<td>5.0</td>
<td>4.7</td>
<td>4.5</td>
<td>4.4</td>
<td>4.4</td>
<td>4.4</td>
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<tr>
<td>2025</td>
<td>14.8</td>
<td>7.8</td>
<td>5.2</td>
<td>5.0</td>
<td>4.7</td>
<td>4.5</td>
<td>4.4</td>
<td>4.4</td>
<td>4.4</td>
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<tr>
<td>2030</td>
<td>14.2</td>
<td>7.2</td>
<td>4.8</td>
<td>5.0</td>
<td>4.7</td>
<td>4.5</td>
<td>4.4</td>
<td>4.4</td>
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<tr>
<td>2035</td>
<td>13.6</td>
<td>6.6</td>
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<td>5.0</td>
<td>4.7</td>
<td>4.5</td>
<td>4.4</td>
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<tr>
<td>2040</td>
<td>13.0</td>
<td>6.0</td>
<td>4.0</td>
<td>5.0</td>
<td>4.7</td>
<td>4.5</td>
<td>4.4</td>
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<td>2045</td>
<td>12.4</td>
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<td>3.6</td>
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<td>4.7</td>
<td>4.5</td>
<td>4.4</td>
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<td>2050</td>
<td>11.8</td>
<td>4.8</td>
<td>3.2</td>
<td>5.0</td>
<td>4.7</td>
<td>4.5</td>
<td>4.4</td>
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**Hydrogen cost in base case (balanced mix)**

EUR per kg, delivered at pump, w/o taxes/excises

Reduction mainly from increasing utilization of hydrogen retail stations

SOURCE: Study analysis
Economic gap and infrastructure buildup require new business and funding models

- Significant economic gap in the early ramp-up phase
- Gap needs to be absorbed by all stakeholders
  - Customer (price premium)
  - OEMs (investment)
  - Infrastructure industry (investment)
  - Public/regulator (taxes, subsidies, incentives)

### Economic gap

<table>
<thead>
<tr>
<th>Year</th>
<th>Economic Gap (EUR billions)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2010</td>
<td>0</td>
</tr>
<tr>
<td>2020</td>
<td>50</td>
</tr>
<tr>
<td>2030</td>
<td>150</td>
</tr>
<tr>
<td>2040</td>
<td>200</td>
</tr>
<tr>
<td>2050</td>
<td>220</td>
</tr>
</tbody>
</table>

### Infrastructure investment

- Significant infrastructure investment required (underutilized in ramp-up)
- Industry groups with different risk profiles
- Synchronization of industry investments required
- Investments need require new integrated business models

1 E.g., selling an FCEV below its cost
**H₂ Mobility** is a second step in evaluating the commercialization of a hydrogen infrastructure and fuel cell electric vehicles

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**Objective**

- **Fact-based evaluation of the market potential of FCEV compared to BEV, PHEV, ICE**
- Development of an integrated perspective across the H₂ value chain based on proprietary industry data
- **Assessment of hydrogen retail infrastructure roll-out in GER**
- Definition of an integrated roll-out scenario for FCEV market penetration with major car OEMs
- **Establishment of a future consortium for the H₂ infrastructure roll-out**
- Implementation of a business case
Main achievements and selected end products for pilot market
Germany - intermediate results

Roll-out scenarios for H₂ station network and FCEVs
- Development of FCEV roll-out scenarios with car OEMs via "clean team" based on assumptions (e.g., incentives, market environment)
- Assessment of H₂ station rollout and network requirements (e.g., density, sizes)

Roll out regions and timing
- Analyses of German regions on traffic density, income per capita, car registrations, etc.
- Definition of "focus regions" and connecting highways

H₂ production and supply road map
- Assessment of H₂ production technologies on cost and CO₂ emissions (water electrolysis, steam methane reforming, etc.)
- Definition of H₂ production and supply mixes focusing on CO₂ abatement, sustainability, and economic efficiency

Holistic roll-out cases
- Description of consistent rollout case for Germany
- Financial assessment of roll-out cases including NPV, investment, payback time
- Evaluation of risks and sensitivities
High momentum of H₂ Mobility-related initiatives in other countries
Overview of selected countries

- Announcement by **13 companies** (3 OEMs and 10 energy and infrastructure providers) and the Ministry of Transport to commercialize FCEV
  - **Mass production of FCEV by 2015**
  - **100 HRS operational** in 4 four metropolitan areas and connecting highways planned, **1,000 HRS** in 2020, and **5,000 HRS** in 2030

- South Korea laid out **"Green Car Roadmap"** including action for EV, PHEV, HEV, FCEV, and bio diesel
- Plans to have **168 HRS** and **100,000 FCEV** deployed by **2020**
- Announced **government support** for **EV** of **up to EUR 20,000** in rebates, tax exemptions, and bonus/malus
- Incentives for **FCEV** will be defined later but are **expected to be comparable** to **EV**

- Hyundai-Kia signed **MOU** with four **Scandinavian countries** (Norway, Sweden, Denmark and Iceland) for the provisional distribution of FCEV
- FCEV will be used to complement the **Scandinavian Hydrogen Highway Partnership (SHHP) fleet** of 26 FCEV and to be increased to 46 in 2011
- SHHP also plans to **increase number of HRS** from 7 to 15 by 2015

**SOURCE:** METI; Government of South Korea; DoE