Development of Business Cases for Fuel Cells and Hydrogen Applications for Regions and Cities

FCH Cars

Brussels, Fall 2017
This compilation of application-specific information forms part of the study "Development of Business Cases for Fuel Cells and Hydrogen Applications for European Regions and Cities" commissioned by the Fuel Cells and Hydrogen 2 Joint Undertaking (FCH2 JU), N° FCH/OP/contract 180, Reference Number FCH JU 2017 D4259.

The study aims to support a coalition of currently more than 90 European regions and cities in their assessment of fuel cells and hydrogen applications to support project development. Roland Berger GmbH coordinated the study work of the coalition and provided analytical support.

All information provided within this document is based on publically available sources and reflects the state of knowledge as of August 2017.
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</table>
A. Technology Introduction
Fuel cell electric vehicles offer a viable zero-emission alternative compared to combustion engine cars with similar usability

**Fuel cell electric vehicles – Cars**

**Brief description:** Fuel cell electric vehicles - cars (i.e. passenger cars powered by fuel cells) use compressed hydrogen gas as a fuel to generate electricity via an energy converter (fuel cell) to power an electric motor. FCEV are refuelled at dedicated filling stations.

**Use cases:** Cities and regions can deploy FCH fleets for municipal/community services; additionally, cities & regions can incentivize the adoption of FCEV cars for private or commercial use e.g. through FCEV car-sharing initiatives or local zero-/low-emission zones.

**Fuel cell electric vehicles (FCEV) - Cars**

<table>
<thead>
<tr>
<th>Key components</th>
<th>Fuel cell stack, system module, hydrogen tank, battery, electric motor</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output</td>
<td>70-130 kW</td>
</tr>
<tr>
<td>Top speed; consumption; range</td>
<td>160 km/h; 0.76-1 kg H₂/100 km; 385-700 km</td>
</tr>
<tr>
<td>Fuel</td>
<td>Hydrogen (700 bar)</td>
</tr>
<tr>
<td>Battery</td>
<td>1.6-9 kWh (Toyoty Mirai and Daimler GLC F-cell hybrid)</td>
</tr>
<tr>
<td>Approximate unit cost</td>
<td>EUR 51,000 - EUR 78,600</td>
</tr>
<tr>
<td>Original equipment manufacturers</td>
<td>Audi, BMW, Daimler, Ford, GM, Honda, Toyota, Hyundai</td>
</tr>
<tr>
<td>Fuel cell suppliers</td>
<td>BMW, NuCellSys, Honda, Toyota, Hyundai</td>
</tr>
<tr>
<td>Typical customers</td>
<td>Private consumer, public-sector and commercial fleet operators (e.g. car sharing, taxi, fleets run by enterprises)</td>
</tr>
<tr>
<td>Competing technologies</td>
<td>Gasoline or diesel combustion, battery powered EV¹</td>
</tr>
</tbody>
</table>

¹) Electric Vehicle

Source: FCH2 JU, Roland Berger
Three different models are already commercially available; several European car manufacturers are about to follow.

**Fuel cell electric vehicles – Cars**

**Overall technological readiness**: FCEV technology is commercially ready with leading OEMs offering selected models in serial production; widespread market introduction depending on expansion of hydrogen refueling infrastructure and economies of scale / learning-curve effects to lower the premium on the product cost.

**Demonstration projects / deployment examples (selection)**

<table>
<thead>
<tr>
<th>Project</th>
<th>Country</th>
<th>Start</th>
<th>Scope</th>
<th>Project volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hydrogen Mobility Europe (H2ME)</td>
<td>🇪🇺</td>
<td>2016</td>
<td>H2ME brings together eight European countries in order to improve hydrogen refueling infrastructure and to demonstrate feasibility of over 1,400 cars and vans in real-life operations</td>
<td>EUR 164 m</td>
</tr>
<tr>
<td>Hydrogen for Innovative Vehicles (HyFIVE)</td>
<td>🇪🇺</td>
<td>2014</td>
<td>One of Europe’s largest transnational FCEV projects deploying 185 vehicles and creating clusters of refueling station networks to lead the sectors commercialisation</td>
<td>EUR 39 m</td>
</tr>
</tbody>
</table>

**Products / systems available (selection2)**

<table>
<thead>
<tr>
<th>Name</th>
<th>OEM</th>
<th>Product features</th>
<th>Country</th>
<th>Since</th>
<th>Approx. cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>Clarity Fuel Cell</td>
<td>Honda</td>
<td>Highest driving range of any zero emission car, availability only in California markets outside Japan. Only manufacturer which has its FC technology exclusively located in the engine compartment. Heading towards serial production</td>
<td>🇯🇵</td>
<td>2017</td>
<td>EUR 51,000</td>
</tr>
<tr>
<td>Mirai</td>
<td>Toyota</td>
<td>Availability in Europe limited to BE, DK, DE, F, N, NL, S, UK</td>
<td>🇯🇵</td>
<td>2014</td>
<td>EUR 78,600</td>
</tr>
<tr>
<td>ix35 Fuel Cell</td>
<td>Hyundai</td>
<td>In commercial service by car sharing service BeeZero (Munich, Germany) or world's largest FCEV taxi fleet &quot;HYPE&quot; (Paris, France)</td>
<td>🇰🇷</td>
<td>2013</td>
<td>EUR 65,400</td>
</tr>
</tbody>
</table>

*) Technology Readiness Level: 1 - Idea, 2 - Tech. formulation, 3 - Prototype, 4 - Demonstration, 5 - Field trials, 6 - Fully commercial

Source: FCH2 JU, Roland Berger

2) Selected models commercially available, further market introductions planned by e.g. Daimler (GLC summer 2018), BMW
Zero tailpipe emissions and lower noise pollutions bear significant FCEV-related benefits for European regions and cities

Fuel cell electric vehicles – Cars

<table>
<thead>
<tr>
<th>Use case characteristics</th>
<th>Benefit potential for regions and cities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stakeholders involved</strong></td>
<td>&gt; Zero tailpipe emissions of pollutants (esp. NO\textsubscript{x}) and greenhouse gases (esp. CO\textsubscript{2}), low noise pollution (also depending on model, track conditions etc.)</td>
</tr>
<tr>
<td>&gt; Private/public consumers/drivers, fleet customers such as municipalities, large private companies, taxis, etc.</td>
<td>&gt; Well-to-wheel greenhouse gas emission 25-100% less compared to conv. vehicles, depending on hydrogen supply</td>
</tr>
<tr>
<td>&gt; Hydrogen infrastructure operators</td>
<td>&gt; Overall comfort in driving incl. car range, refuelling process at least comparable to combustion-engine vehicles</td>
</tr>
<tr>
<td>&gt; Commercial (urban) car sharing operators</td>
<td>&gt; Ultimately thanks to low/zero emission footprint: public health benefits and higher standard of living</td>
</tr>
<tr>
<td>&gt; OEMs as well as maintenance/service providers</td>
<td><strong>Environmental</strong></td>
</tr>
<tr>
<td><strong>Demand and user profile</strong></td>
<td><strong>Social</strong></td>
</tr>
<tr>
<td>&gt; Depending on driving patterns and routes, potentially all use cases currently serviced by combustion-engine passenger cars (given similar usability)</td>
<td>&gt; Development of expertise in FCEV technology as potential driver of innovation and future economic growth</td>
</tr>
<tr>
<td>&gt; Range, performance and refuelling process of FCEVs similar to conventional cars</td>
<td>&gt; Additional potential revenue streams for public authorities through licensing of FCEV taxis</td>
</tr>
<tr>
<td><strong>Deployment requirements</strong></td>
<td>&gt; Potentially low TCO in the future (low-cost H\textsubscript{2}, lower CAPEX)</td>
</tr>
<tr>
<td>&gt; Network of hydrogen refuelling stations</td>
<td><strong>Economic</strong></td>
</tr>
<tr>
<td>&gt; Hydrogen supply and distribution network</td>
<td>&gt; Significant reduction of dependency on fossil fuels or energy imports (depending on the type of hydrogen production)</td>
</tr>
<tr>
<td>&gt; Adherence to high safety standards for fuel cell components</td>
<td><strong>Other</strong></td>
</tr>
<tr>
<td>&gt; Permission and licensing of commercial operations</td>
<td></td>
</tr>
<tr>
<td><strong>Key other aspects</strong></td>
<td></td>
</tr>
<tr>
<td>&gt; Lower battery size, superior operability at low temperatures, longer range and shorter refueling time compared to battery powered EV</td>
<td></td>
</tr>
</tbody>
</table>

1) Total Cost of Ownership

Source: FCH2 JU, Roland Berger
High cost and low overall coverage of hydrogen refuelling stations present key challenges for FCEV deployment

Fuel cell electric vehicles – Cars

Hot topics / critical issues / key challenges:

> **Guaranteed basic coverage** of hydrogen refuelling stations ensuring usability for consumers

> **High cost for hydrogen and its distributions/storage** as hurdle for overall commercial attractiveness – need for cost reduction in hydrogen supply, e.g. via a higher utilisation of refuelling stations

> **Currently low willingness-to-pay** for FCEV price premium on the side of end customers – hence need to identify fleet operators as anchor customers / early adopters

> **Large potential for cost reduction** primarily driven by economies of scale (higher manufacturing volumes thus critical) but also further innovation to lower material costs (e.g. decrease amount of platinum in fuel cells)

> **Well-to-wheel emission** largely depending on underlying resources used in hydrogen production

> **Compliance** with EU-level and national safety regulations

Further recommended reading:

> Official website of Hydrogen Mobility Europe: [http://h2me.eu/](http://h2me.eu/)


> Official website of Clean Energy Partnership (CEP): [https://cleanenergypartnership.de/home/](https://cleanenergypartnership.de/home/)

Source: FCH2 JU, Roland Berger
B. Preliminary Business Case
Each customer segment has a distinctive user profile resulting in different priorities with respect to their purchase decision.

FCEV: customer segmentation, share of new vehicles & respective purchasing criteria

**Characteristics**

1. **Private individual customers**
   - Exclusively private use of the vehicle
   - Low mileage (typically less than ~10,000 km p.a.)
   - Holding period ca. 7 years

2. **Company car customers**
   - Private and business-related use of the vehicle
   - Medium mileage (~20,000 km p.a.)
   - Holding period ca. 3 years

3. **Commercial fleet operators**
   - Exclusively commercial use of the vehicle (company fleet)
   - High mileage (up to ~40,000 km p.a.)
   - Holding period ca. 3-4 years

**Share of new vehicles**

- **~40%**
- **~30%**
- **~30%**

**Purchasing criteria**

- **Vehicle cost**
  - Decisively relevant (purchasing price)
  - Partly relevant
  - Partly relevant
  - Partly relevant

- **Technology performance**
  - Partly relevant
  - Not very relevant
  - Partly relevant
  - Very relevant

- **External influences**
  - Partly relevant
  - Partly relevant
  - Not very relevant
  - Very relevant

- **Infrastructure / charging patterns**
  - Partly relevant
  - Not very relevant
  - Very relevant

Source: NPE, FCH2 JU, Roland Berger
As an example, we consider a public procurement of FCEV at the municipal level, with different cost and performance parameters

Key assumptions

<table>
<thead>
<tr>
<th>Application-related assumptions</th>
<th>current/potential</th>
<th>FCEV</th>
<th>BEV</th>
<th>Diesel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical specifications</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Holding period</td>
<td>4 years</td>
<td>4 years</td>
<td>4 years</td>
<td></td>
</tr>
<tr>
<td>CAPEX (1000 EUR)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Purchase price</td>
<td>70 / 35'</td>
<td>35 / 30</td>
<td>31 / 31</td>
<td></td>
</tr>
<tr>
<td>Ref. station</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
</tr>
<tr>
<td>Residual value</td>
<td>50%</td>
<td>50%</td>
<td>40%</td>
<td></td>
</tr>
<tr>
<td>Fuel</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Consumption (per km)</td>
<td>0.008 kg</td>
<td>0.13 kWh</td>
<td>0.043 l</td>
<td></td>
</tr>
<tr>
<td>Maintenance costs (EUR)</td>
<td>0.023</td>
<td>0.018</td>
<td>0.023</td>
<td></td>
</tr>
</tbody>
</table>

Use case and exogenous factors

> A municipal authority has a total vehicle fleet of ~300 medium-sized vehicles, potentially resembling a city with ~500,000 inhabitants. Ca. half of these vehicles are operated by police, emergency services and the fire brigade, each with specific requirements. The other half, e.g. vehicles for social services, are considered in this context.

> Hence, the operator deploys ~30 new vehicles with each vehicle travelling ~100 km a day, five days a week (~220 days of a year) on average, covering a total of ~660,000 km p.a.

> The vehicles hydrogen consumption: ~0.8 kg/d (1 car), ~24 kg/d (fleet)

> Financing costs of operator: 5% p.a.

> Context for refuelling infrastructure: this base case assumes existing availability of public refuelling infrastructure for FCEV, BEV and diesel vehicles

> Source of hydrogen: Steam-Methane Reforming (SMR), truck-in

> Cost of hydrogen: 9 / 5 EUR/kg H₂

> Cost of diesel: 1.2 / 1.4 EUR/l

> Cost of electricity: 0.21 / 0.30 EUR/kWh

> CO₂ emissions from grey hydrogen: 9 / 9 kg / kg H₂

> CO₂ emissions from diesel: 2.64 / 2.4 kg/l

> CO₂ emissions from electricity: 0.51 / 0.3 kg/kWh

1) Assuming production-at-scale scenarios for vehicle OEMs, current price of diesel cars as initial target price for FCH cars (preliminary – to be validated)

Source: FCH2 JU, NOW, Roland Berger
FCH cars might almost reach cost parity with electric and diesel vehicles in the medium run, while reducing CO$_2$ and NO$_x$ emissions.

Business case and performance overview – INDICATIVE EXAMPLE

### Economic

<table>
<thead>
<tr>
<th></th>
<th>CURRENT</th>
<th>POTENTIAL</th>
</tr>
</thead>
<tbody>
<tr>
<td>FCEV</td>
<td>0.6</td>
<td>0.2</td>
</tr>
<tr>
<td>BEV</td>
<td>0.5</td>
<td>0.2</td>
</tr>
<tr>
<td>Diesel</td>
<td>0.4</td>
<td>0.2</td>
</tr>
<tr>
<td>FCE</td>
<td>0.3</td>
<td>0.2</td>
</tr>
<tr>
<td>BE</td>
<td>0.2</td>
<td>0.2</td>
</tr>
<tr>
<td>Diesel</td>
<td>0.1</td>
<td>0.2</td>
</tr>
</tbody>
</table>

- **Maintenance (vehicle)**
- **Financing (vehicle)**
- **Depreciation (vehicle)**

**Estimated annualised Total Cost of Ownership (TCO) [ct/km], 2017 prices**

| Source: FCH2 JU, Roland Berger |

### Environmental

- FCEV have zero tailpipe emissions of CO$_2$, pollutants such as NO$_x$ and fine dust particles, e.g. saving ~115 kg NO$_x$/year compared to diesel fuelled vehicles.
- Well-to-wheel CO$_2$ emissions depend on fuel source, power mix, use case and efficiency (i.e. fuel consumption):
  - kg CO$_2$/km
  - $-40$-$50\%$
  - $-5\%$
  - $-35\%$

### Technical/operational

- FCEV technology is commercially ready with leading OEMs offering selected models in serial production; widespread market introduction depending on expansion of hydrogen refuelling infrastructure and economies of scale / learning-curve effects to lower the premium on the product cost.
- FCEV have a range of approx. 350 – 700 and can reach top speeds of up to 160 km/h.
- Refuelling process & times of FCEV are, with a duration of ~3-4 minutes, comparable to conventional combustion engine vehicles.

**TRL**

<table>
<thead>
<tr>
<th>TRL</th>
<th>1</th>
<th>2</th>
<th>3</th>
<th>4</th>
<th>5</th>
<th>6</th>
<th>7</th>
<th>8</th>
<th>9</th>
</tr>
</thead>
<tbody>
<tr>
<td>idea</td>
<td>Tech. formulation</td>
<td>Prototype</td>
<td>Fully commercial</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
The impact of TCO-drivers varies, creating several levers for further reduction of hydrogen TCO compared to electric and diesel TCO

Key determinants of the business case

Important sensitivities considered …

1 **Infrastructure:** if additional infrastructure investments for fleet operator are included (i.e. in a pure captive fleet case), such as refuelling stations for FCEV (and BEV), this ca. doubles TCO per km

2 **Mileage per day:** varying the mileage of vehicles per day from 50 to 250 km, might result in a potential TCO decrease of ~EUR 0.70 ct – strong use-case dependent differences

3 **Fuel prices:** a price variation from EUR 10 to EUR 3 per kg H₂, potentially reduces overall TCO costs by ~10 ct – prices for H₂ can vary significantly across Europe

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Source: FCH2 JU, Roland Berger

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1) Unless otherwise stated, all statements shall be considered as 2017-based and ceteris paribus, i.e. "all-other-things-equal"
In order to successfully deploy an FCEV fleet, regions & cities can take specific steps

Key considerations for Regions and Cities deploying FCEV

**Use case**
Look for use cases with critical concern for range (>200 or even 300 km per day) as well as refuelling time

**Customers**
Consider especially approaching and incentivizing key fleet customers, e.g. taxis, ride- and carsharing operators, small-vehicle delivery services, social services in order to better distribute CAPEX for e.g. infrastructure

**Emissions**
Look for availability of green H\textsubscript{2} in order to seize full well-to-wheel zero emission potential of FCEV

Source: FCH2 JU, Roland Berger
Please do not hesitate to get in touch with us

Contact information

Carlos Navas
Strategy and Market Development Officer
FCH2 JU
carlos.navas@fch.europa.eu
+32 2 221 81 37

Yvonne Ruf
Partner
Roland Berger
yvonne.ruf@rolandberger.com
+49 69 29924 6334

Dr. Simon Lange
Project Manager
Roland Berger
simon.lange@rolandberger.com
+49 160 7442965

Source: FCH2 JU, Roland Berger