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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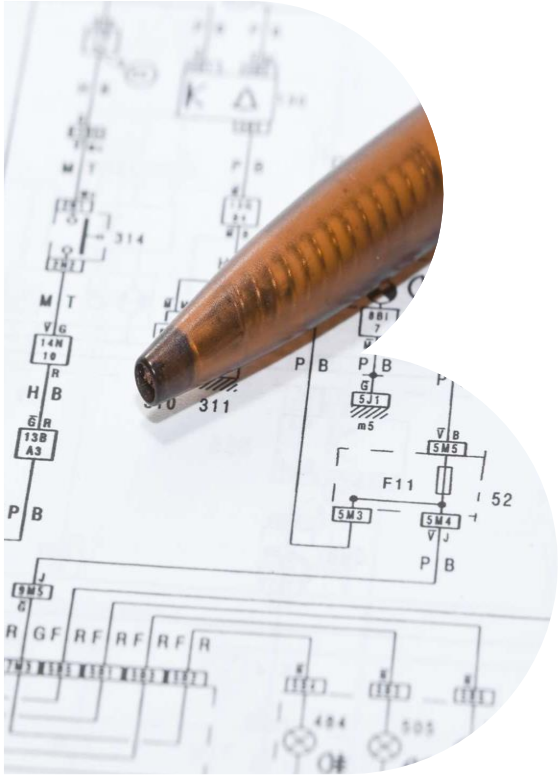
A. Technology Introduction



Fuel cell electric vehicles offer a viable zero-emission alternative compared to combustion engine cars with similar usability

Fuel cell electric vehicles – Cars

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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	
Key components	Fuel cell stack, system module, hydrogen tank, battery, electric motor
Output	70-130 kW
Top speed; consumption; range	160 km/h; 0.76-1 kg H_2/100 km; 385-700 km
Fuel	Hydrogen (700 bar)
Battery	1.6-9 kWh (Toyoty Mirai and Daimler GLC F-cell hybrid)
Approximate unit cost	EUR 51,000 - EUR 78,600
Original equipment manufacturers	Audi, BMW, Daimler, Ford, GM, Honda, Toyota, Hyundai
Fuel cell suppliers	BMW, NuCellSys, Honda, Toyota, Hyundai
Typical customers	Private consumer, public-sector and commercial fleet operators (e.g. car sharing, taxi, fleets run by enterprises)
Competing technologies	Gasoline or diesel combustion, battery powered EV[1]

[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

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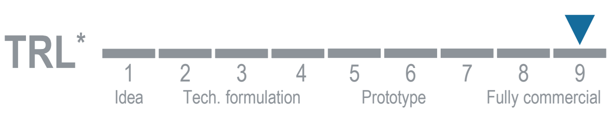
Overall technological readiness: FCEV technology is commercially ready with leading OEMs offering selected models in serial production; widespread market introduction depending on expansion of hydrogen refueling infrastructure and economies of scale / learning-curve effects to lower the premium on the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



Demonstration projects / deployment examples (selection)

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

Products / systems available (selection$^{2)}$)

Name	OEM	Product features	Country	Since	Approx. cost
Clarity Fuel Cell	Honda	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	🇯🇵	2017	EUR 51,000
Mirai	Toyota	Availability in Europe limited to BE, DK, DE, F, N, NL, S, UK	🇯🇵	2014	EUR 78,600
ix35 Fuel Cell	Hyundai	In commercial service by car sharing service BeeZero (Munich, Germany) or world's largest FCEV taxi fleet "HYPE" (Paris, France)	🇰🇷	2013	EUR 65,400

*) Technology Readiness Level ▼ ≤ 5 ▼ 6-7 ▼ 8-9

2) Selected models commercially available, further market introductions planned by e.g. Daimler (GLC summer 2018), BMW

Source: FCH2 JU, Roland Berger

Zero tailpipe emissions and lower noise pollutions bear significant FCEV-related benefits for European regions and cities

Fuel cell electric vehicles – Cars

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Use case characteristics

Stakeholders involved

- Private/public consumers/drivers, fleet customers such as municipalities, large private companies, taxis, etc.
- Hydrogen infrastructure operators
- Commercial (urban) car sharing operators
- OEMs as well as maintenance/service providers

Demand and user profile

- Depending on driving patterns and routes, potentially all use cases currently serviced by combustion-engine passenger cars (given similar usability)
- Range, performance and refuelling process of FCEVs similar to conventional cars

Deployment requirements

- Network of hydrogen refuelling stations
- Hydrogen supply and distribution network
- Adherence to high safety standards for fuel cell components
- Permission and licensing of commercial operations

Key other aspects

- Lower battery size, superior operability at low temperatures, longer range and shorter refueling time compared to battery powered EV

Benefit potential for regions and cities

Environmental

- Zero tailpipe emissions of pollutants (esp. NO_x) and greenhouse gases (esp. CO_2), low noise pollution (also depending on model, track conditions etc.)
- Well-to-wheel greenhouse gas emission 25-100% less compared to conv. vehicles, depending on hydrogen supply

Social

- Overall comfort in driving incl. car range, refuelling process at least comparable to combustion-engine vehicles
- Ultimately thanks to low/zero emission footprint: public health benefits and higher standard of living

Economic

- Development of expertise in FCEV technology as potential driver of innovation and future economic growth
- Additional potential revenue streams for public authorities through licensing of FCEV taxis
- Potentially low TCO in the future (low-cost H_2, lower CAPEX)

Other

- Significant reduction of dependency on fossil fuels or energy imports (depending on the type of hydrogen production)

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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

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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/
- Official website of Hydrogen for Innovative Vehicles: http://www.hyfive.eu/the-hyfive-project/
- Official website of Clean Energy Partnership (CEP): https://cleanenergypartnership.de/home/

Source: FCH2 JU, Roland Berger

B. Preliminary Business Case

B

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

	1 **Private individual customers**	2 **Company car customers**	3 **Commercial fleet operators**
			
Characteristics	> Exclusively private use of the vehicle > Low mileage (typically less than ~10,000 km p.a.) > Holding period ca. 7 years	> Private and business-related use of the vehicle > Medium mileage (~20,000 km p.a.) > Holding period ca. 3 years	> 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)	● Decisively relevant (purchasing price)	● Decisively relevant (TCO)
> Technology performance	◐ Partly relevant	◔ Not very relevant	◐ Partly relevant
> External influences	◐ Partly relevant	◐ Partly relevant	◔ Not very relevant
> Infrastructure / charging patterns	◐ Partly relevant	◕ 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

Application-related assumptions

current/potential	**FCEV**	**BEV**	**Diesel**
Technical specifications	Mid-range car	Mid-range car	Mid-range car
> Holding period:	4 years	4 years	4 years
CAPEX ('000 EUR)			
> Purchase price	70 / 35[1]	35 / 30	31 / 31
> Ref. station	-	-	-
> Residual value	50%	50%	40%
Fuel			
> Fuel	Hydrogen (750 bar)	Electricity	Diesel
> Consumption (per km)	0.008 kg	0.13 kWh	0.043 l
Maintenance costs (EUR)			
> Car per km	0.023	0.018	0.023

Use case and exogenous factors

Strongly dependent on reg. circumstances

- 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

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- Source of hydrogen: Steam-Methane Reforming (SMR), truck-in
- Cost of hydrogen: 9 / 5 EUR/kg H_2
- Cost of diesel : 1.2 / 1.4 EUR/l
- Cost of electricity: 0.21 / 0.30 EUR/kWh
- CO_2 emissions from grey hydrogen: 9 / 9 kg / kg H_2
- CO_2 emissions from diesel: 2.64 / 2.4 kg/l
- CO_2 emissions from electricity: 0.51 / 0.3 kg/kWh

Strongly dependent on reg. circumstances

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[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

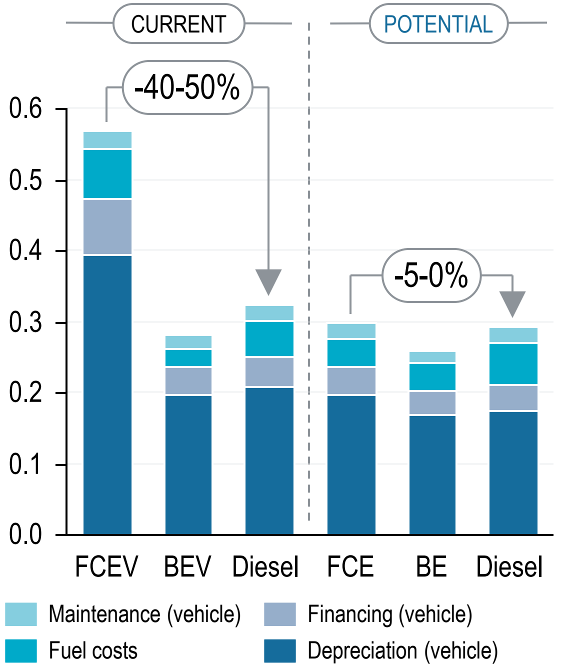
B

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

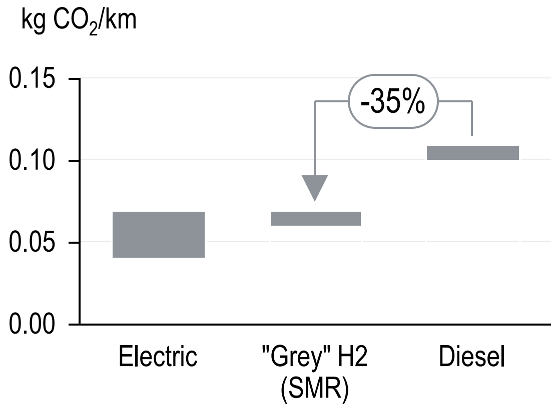
Economic

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



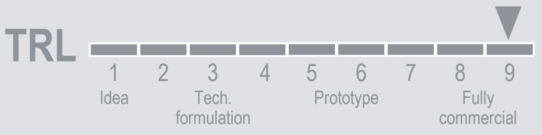
Environmental

- 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):



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



Source: FCH2 JU, Roland Berger

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The impact of TCO-drivers varies, creating several levers for further reduction of hydrogen TCO compared to electric and diesel TCO

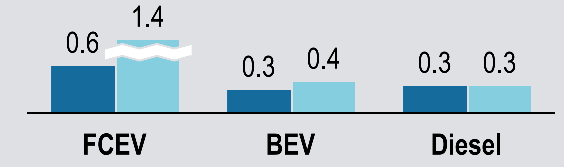
Key determinants of the business case

Important sensitivities considered ...

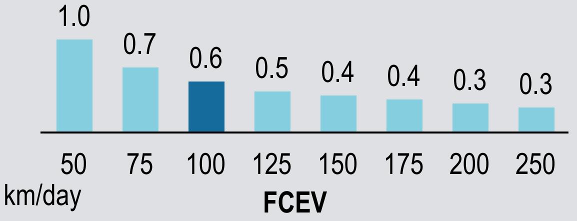
... estimated impact on TCO

[EUR/km]

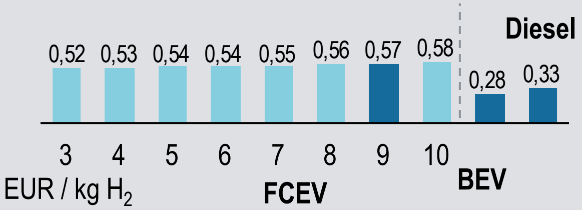
1 **Infrastructure:** if additional infrastructure investments for fleet operator are included (i.e. in a pure captive fleet case), such as refuelling stations for FCEV (and BEV), this ca. doubles TCO per km



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 H_2, potentially reduces overall TCO costs by ~10 ct **– prices for H_2 can vary significantly across Europe**



■ TCO, base case ■ TCO, adjusted variables

1) Unless otherwise stated, all statements shall be considered as 2017-based and ceteris paribus, i.e. "all-other-things-equal"

Source: FCH2 JU, Roland Berger

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_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

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Source: FCH2 JU, Roland Berger