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

FCH Garbage trucks

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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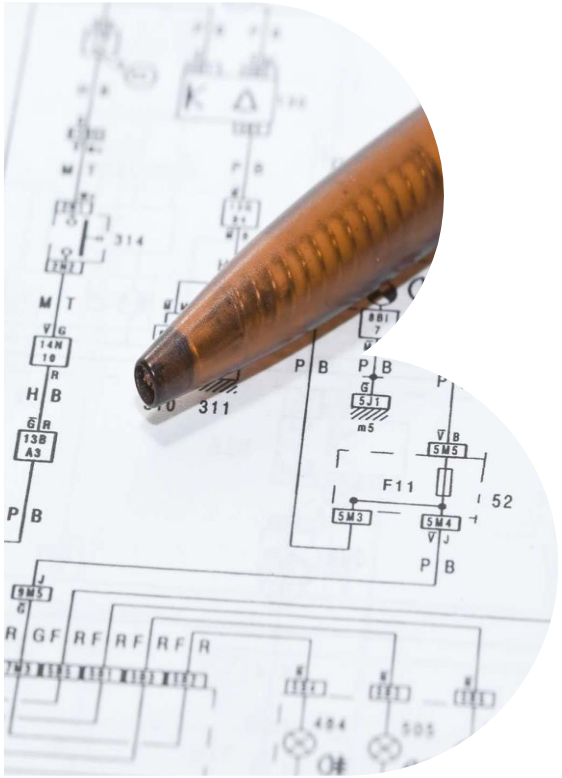
A. Technology Introduction



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FCH on garbage trucks today typically power loaders, compactors & range extension systems on diesel or EV[1] undercarriages

Fuel cell garbage trucks

Brief description: Fuel cell garbage trucks use compressed hydrogen and fuel cells to power the electric engine that empties garbage bins and compresses waste. Currently, only fuel cell range extended electric trucks or diesel trucks with power-box exist

Use cases: Cities and regions can use/promote fuel cell electric garbage trucks for waste collection; cities and regions can stipulate zero-emission vehicles through tender requirements

Fuel cell garbage trucks	FCH range extender	FCH power-box
Key components	Fuel cell stack and system module, hydrogen tank, battery, electric engine	"Power-box" for loader and compactor (truck power-train typically conventional diesel combustion)
Output	40 kW (extender)	32-68 kW (power box)
Range (full truck)	360 km (45-50kg H_2 tank)	200 km
Fuel	Electricity, hydrogen	Diesel, hydrogen
Consumption	6-9 kg H_2/100 km	*tbc*
OEMs & vehicle integrators	E-Trucks Europe, FAUN Kirchhoff, ULEMCo, Navistar, Heliocentrics	
Fuel cell suppliers	Hydrogenics, Symbio Fcell, Nedstack	
Typical customers	Offices of municipal sanitation, city cleaning companies	
Competing technologies	Battery electric, diesel combustion	

1) Electric Vehicle

Source: Roland Berger

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Currently, battery-FCH range-extended prototypes and diesel-hydrogen hybrid prototypes are part of demonstration projects

Fuel cell garbage trucks

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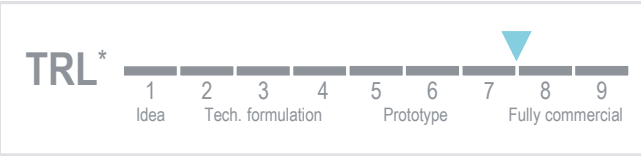
Overall technological readiness: So far, only electric trucks with hydrogen fuel cell range extender or conventional diesel combustion powertrain with hydrogen fuel cell power-box for loader and compactor as prototype demonstration; no technology concept for entire fuel cell garbage truck publicly disclosed



Demonstration projects / deployment examples (selection)

Project	Country	Start	Scope	Project volume
Levenmouth Community Energy Project Hydrogen Dual-Fuel garbage trucks[1)]		2016	2 prototypes based on Heil Farid trucks in cooperation with ULEMCo converted to run on diesel power trains and hydrogen power box; project partners: Bright Green Hydrogen and Toshiba	n.a.
LIFE'N GRAB HY! (managed by European Commission (DB Environment and DG Climate Action))		2016	Phase 1: demonstration of two 26t hydrogen-electric hybrid garbage trucks by Cure Afvalbeheer (Eindhoven) and Baetsen Groep (Veldhoven) Phase 2: large-scale demonstration on 10 locations in Europe, planned for Sept. 2017	EUR 2.7 m
Nationales Innovationsprogramm Wasserstoff- und Brennstoffzellentechnologie (NIP)		2011 - 2013	2-year test of world's first garbage truck with hydrogen fuel cell at Berliner Stadtreinigung (BSR). A diesel motor moves the vehicle and is turned off when it is loaded; the fuel cell powers the loader and compactor. Prototype built by FAUN Group, fuel cell from Heliocentris Energiesysteme GmbH	n.a.

1) Out of up to 25 vehicles of the project only 2 are garbage trucks

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

Source: Roland Berger

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Fuel cell garbage trucks have strong local FCH potential, especially regarding noise and NO_x / CO_2 emission reduction

Fuel cell garbage trucks

Use case characteristics

Stakeholders involved

> Users (municipality-owned & private waste management companies)
> Public authorities (vehicle approval, regulatory framework of pollutants etc.)
> OEMs, FC and Power-Box manufacturers
> H_2 suppliers and infrastructure providers

Demand and user profile

> High vehicle uptime enabling a continuous utilisation of vehicles, including low refuelling times
> Short but multiple driving distances due to inner-city traffic and decentralised waste collection
> Fast and powerful onboard waste management systems

Deployment requirements

> Network of refuelling stations along relevant routes or at least at key depots
> High safety standards for fuel cell components

Key other aspects

> Engine only produces low excess heat, additional heating of the driver's cabin necessary

Benefit potential for regions and cities

Environmental

> Reduction of CO_2 emissions and No_x pollutant emissions, improving air quality
> Reduction of noise emissions (still, some noise emissions at breaking, emptying and compressing)

Social

> Public health benefits (esp. urban areas near deployment route), reduced social security expenses, higher standard of living
> Lower adverse impact on residents adjacent to major inner-city routes

Economic

> Reduction of fuel consumption during waste collection of up to 30% (as stated by the Berlin waste management company, BSR)
> Energy savings and extension of brake durability through storage of breaking energy

Other

> Fast and smooth acceleration
> Potentially very visible FCH application for public demo purposes

Source: Roland Berger

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Fuel cells already form part of demonstrational garbage truck fleets, with additional technological & commercial developments required

Fuel cell garbage trucks

Hot topics / critical issues / key challenges:

> **Current lack of availability of fully-fledged FCH applications**, only hybrid systems presented so far

> **Niche application**, due to low number of garbage trucks required by regions and cities there is no imminent economies of scale for regions and cities fit-for-purpose modularisation

> **Hydrogen infrastructure deployment**, i.e. expensive distribution logistics, local storage, refuelling stations and respective costs

> **Well-to-wheel emissions**, uncertain reduction potential largely depends on resources used for hydrogen production

> **Long-term procurement and services contracts**, e.g. concessions with private waste companies, limiting the scope of direct action for local public authorities

Further recommended reading:

> Life 'N Grab H4 project, technical explanation: http://www.lifeandgrabhy.eu/garbage-trucks-hydrogen

> Hydrogen Region for Flanders and the southern Netherlands: http://www.waterstofnet.eu/en/hydrogen-waste-collection-vehicle

Key contacts in the coalition:

Please refer to working group clustering in stakeholder list on the share folder

https://sharefolder.rolandberger.com/project/P005

Source: Roland Berger

B. Preliminary Business Case

Use case and applications determine capital, fuel, O&M and infrastructure cost that in turn make up the operator's TCO

Key elements of FCH transport applications' TCO – SCHEMATIC, SIMPLIFIED

Operator's perspective …

The task / scenario at hand: use case, deployment context, target operating model, e.g.

- > Route definition and length, required stops/stations
- > Target capacity
- > Target shift schedule for operations
- > Target availability
- > Topographic and other ext. conditions
- > Fleet size, depot structure
- > Energy cost
- > Carbon intensities
- > …

FCH truck / system specifications and performance

- > Size, volume, weight, other physical configurations
- > Maximum / average speed
- > Powertrain design, i.e. fuel cell + battery / other hybridisation + engine
- > Fuel cell technology
- > Efficiency / fuel consumption
- > Hydrogen storage system
- > Lifetime
- > Availability
- > …

Hydrogen infrastructure specifications and performance – sharing ratios

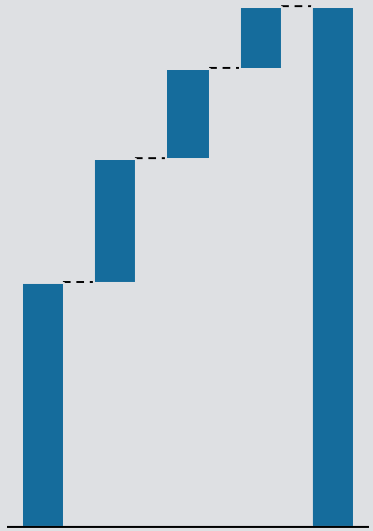
1. Capital cost
- > Investment / depreciation,
- > Financing cost

2. Fuel cost – H_2 consumption, H_2 price (dep. on production, distribution, volumes, input prices, etc.)

3. Other O&M cost, e.g. for truck maintenance, personnel, utilities, fees/levies, taxes[1]

4. Infrastructure cost
- > Investment / depreciation
- > O&M cost

Total Cost of Ownership (TCO) in EUR p.a. or EUR/km



1) Largely excluded for preliminary business case analysis, more detailed consideration in Project Phase 2

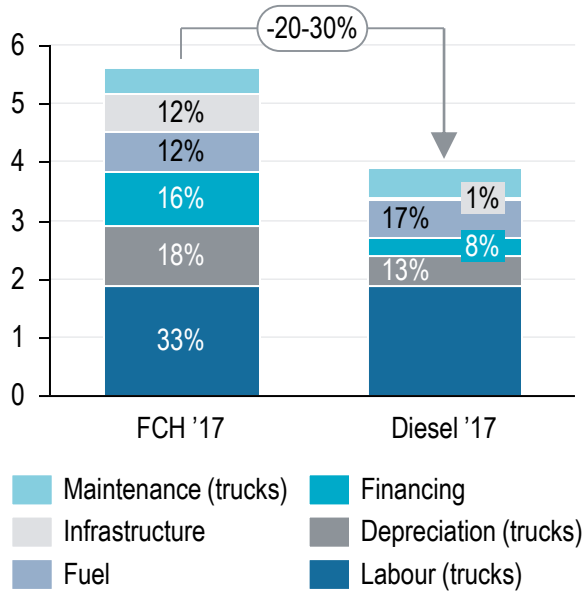
Source: FCH2 JU, Roland Berger

There is a cost premium for FCH trucks for each km travelled and a significant CO_2 emission reduction potential of ~25-35%

Business case and performance overview – PRELIMINARY / INDICATIVE EXAMPLE

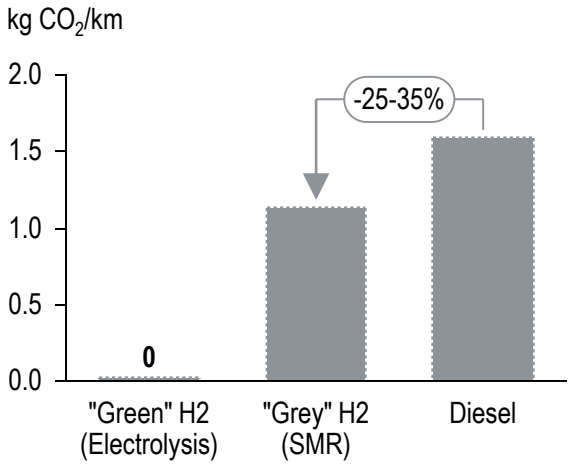
Economic

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



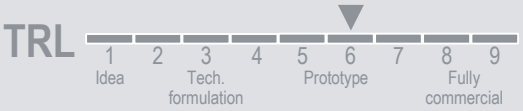
Environmental

- Zero tailpipe emissions of CO_2, pollutants such as fine dust particles and NO_X, saving ~80-100 kg NO_X/year
- Well-to-wheel CO_2 emissions depend on fuel source, use case characteristics and efficiency (i.e. fuel consumption)



Technical/operational

- So far, only electric trucks with hydrogen fuel cell range extender (e.g. in Eindhoven) or conventional diesel combustion powertrain with hydrogen fuel cell power-box for loader and compactor (e.g. in Berlin) as prototype demonstration; only conceptual studies for entire fuel cell garbage truck publicly disclosed (e.g. in Honolulu, HI, U.S.)
- FC powered garbage trucks currently have an availability of ~85% due to higher down times, with reliability expected to reach 95% eventually
- Range[2] of FC electric garbage trucks likely up to ~360 km, similar to diesel



1) Analysis is based on a hydrogen vehicle with both, hydrogen propulsion as well as hydrogen "power-box", consisting of the loader and compactor
2) Specification based on the DAF CF FA freight truck with hydrogen as a range extender, deployed within the project *Hydrogen Region for Flanders and the southern Netherlands*

Source: Life `N Grab H4, U.S. DoE, Roland Berger

The impact of drivers on vehicle economics varies, creating several levers for further reduction of hydrogen TCO compared to diesel

Key determinants of the business case[1] – PRELIMINARY / INDICATIVE EXAMPLE

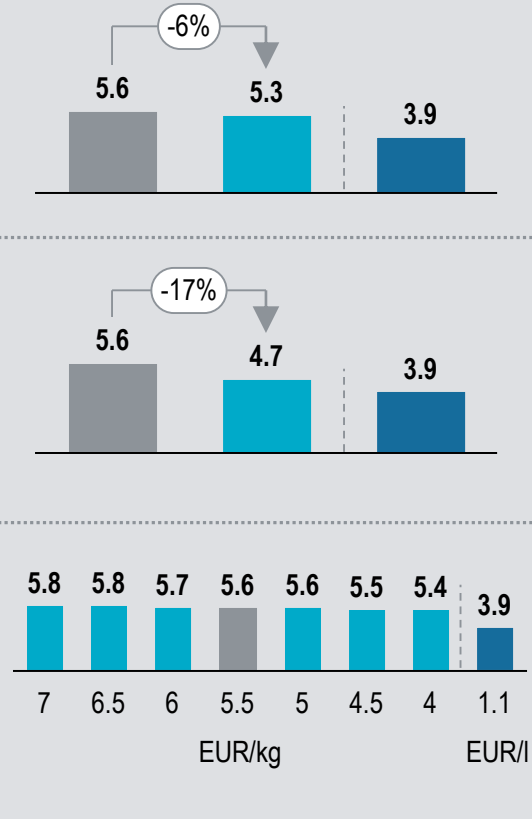
Sensitivities considered …

1 **Garbage truck purchasing price:** reducing the hydrogen garbage truck purchasing price by 20% might lead to EUR 30 ct reduction of TCO per km

2 **Infrastructure costs:** excluding infrastructure costs in the hydrogen case, i.e. levelling of infrastructure expenditure in both cases to EUR 0, could result in a decrease of the TCO per km of EUR 90 ct **– infrastructure costs strongly dependent on fleet size and depot structure**

3 **Fuel costs:** reducing the fuel costs for hydrogen supply from EUR 7 per kg H_2 to 4, results in a potential reduction of total costs per km of EUR ~40 ct **– strong regional differences for H_2 prices**

… est. impact on TCO [EUR/km]



FCH truck TCO, base case | FCH truck TCO, adjusted variables | Diesel truck TCO, base case

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

Source: Life `N Grab H4, U.S. DoE, Roland Berger

Similarities regarding lifetime, costs of labour and maintenance for FCH trucks likely, differences in CAPEX investment for HRS

Key assumptions – PRELIMINARY / INDICATIVE EXAMPLE

Application-related assumptions[1]

	FCH side-loader	Diesel side-loader
Technical specifications	Full FCH vehicle Weight: ~24 t Lifetime: 12 years Availability: 85%	Full diesel vehicle Weight: ~20 t Lifetime: 12 years Availability: 95%
CAPEX		
> Purchase price	~ EUR 400-450k	~ EUR 200-220k
> Initial HRS	~ EUR 2.4 m	-
Fuel		
> Fuel type	Hydrogen (350 bar)	Diesel
> Consumption (/km)	~0.120-130 kg	0.6 litre
> Consumption (/day)	~20-25 kg	110 litre
Maintenance costs		
> Trucks	0.40-0.50 EUR/km	0.5 EUR/km
> Ref. station p.a.	EUR 70-75k	EUR 10,350
Labour costs p.a.	EUR 64,000	EUR 64,000

Use case and exogenous factors

Strongly dependent on reg. circumstances

> Municipal waste management company with need to renew (part of) its 150 garbage truck fleet. First tranche of ~12 vehicles to be purchased. Overall coverage of ~400,000 km per year, with a daily distance covered by a single truck of ~180 km within a 5-day week at an average speed of ~15 km/h

> Financing costs of waste management company : 5% p.a.

> Labour costs: based on 2 FTE per truck with averaged Western European wages of EUR 32,000 per year

> CAPEX for refuelling stations: one HRS considered at depot for FCH buses; for counterfactual diesel truck deployment not add. investment considered due to wide-spread availability of diesel refuelling infrastructure today

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

> Cost of hydrogen for operator: ~5.5 EUR/kg H_2

> Cost of diesel : 1.1 EUR/l

> CO_2 emissions from grey hydrogen: 9 kg/kg H_2

> CO_2 emissions from green hydrogen: 0 kg/kg H_2

> CO_2 emissions from diesel: 2.64 kg/l

> No_x emissions from diesel: 4 g/l

1) Tech. spec. based on fully hydrogen powered garbage truck deployment as simulated in the *Fuel Cell –Electric Refuse Truck for Waste Transportation* study (DoE, 2015)

Source: FCH2 JU, Life `N Grab H4, U.S. DoE, Roland Berger

Please do not hesitate to get in touch with us

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Source: FCH2 JU, Roland Berger