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

FCH Material handling equip.

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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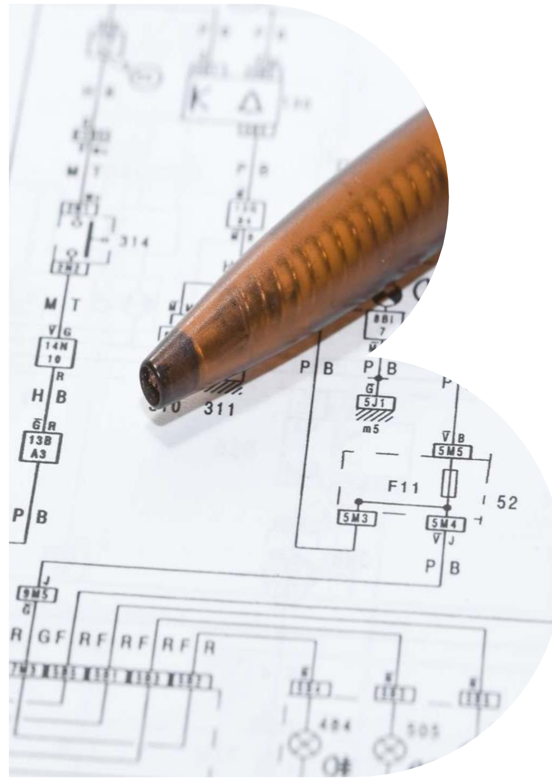


Fuel cell powered material-handling equipment offers multiple, purpose specific deployment options with a variety of benefits

Fuel cell powered material-handling equipment – e.g. forklifts

Brief description: Fuel cell material-handling equipment, e.g. forklift trucks, use compressed hydrogen gas as a fuel to generate electric power via an energy converter (fuel cell); the produced electricity powers an electric motor as well as the forklift

Use cases: multiple uses cases, incl. material handling at warehouses, recycling plants, construction sites, public work sites and municipal utilities; regions and cities can promote zero-emission vehicles through specific tender requirements e.g. forklifts

Fuel cell powered material handling

Key components	Fuel cell stack and system module, hydrogen tank, battery, electric motor
Output[1)]	2.5-4.5 kW
Fuel	Hydrogen (350 bar)
Refuelling interval; charging time[2)]	8 hours; 1-3 minutes
Weight; measurements of FC stack[2)]	270 kg; 624 x 294 x 627 mm
Approximate capital cost[1)]	EUR 12,000-15,000
OEMs & system integrators	Linde, CAT, Hyster-Yale, Still, Fronius
Fuel cell suppliers	Ballard, Nuvera, PlugPower, Fronius
Typical customers	Logistics companies, warehouses, manufacturing facilities
Competing technologies	Battery electric vehicles, diesel engine vehicles or LPG

1) Based on 3 kW PEM Fuel Cell-Powered Pallet Truck according to US D.O.E. 2011
2) PlugPower GenDrive Series 3000
Source: Roland Berger

A

Material-handling equipment is a mature and widespread FCH application – both module-based and all-in-one solutions available

Fuel cell powered material-handling equipment – e.g. forklifts 2/4

Overall technological readiness: Commercial; currently > 10,000 fuel cell-powered forklifts are in operation or in order globally; already proven functionality through thorough long-term usage in real live environments

TRL*: 1 Idea – 2 – 3 Tech. formulation – 4 – 5 – 6 Prototype – 7 – 8 – 9 Fully commercial (indicator at 9)

Demonstration projects / deployment examples (selection)

Project	Country	Start	Scope	Project volume
Carrefour – Distribution center near Vendin-lès-Béthune (project part of HyLIFT-Europe)	EU	2016	150 class-2 & 3 electric lift trucks (STILL) powered with GenDrive (PlugPower) fuel cell stack units for a new distribution center	n.a.
E-LOG Biofleet at DB Schenker cross-docking terminal Hörsching, Austria	Austria	2010 -2016	Test of battery-powered vehicles versus fuel cell-powered vehicles with 10 (+2) Linde T20-24 AP/SP stand-on pallet trucks operating 24/5	n.a.
BMW Manufacturing Co. LLC plant in Spartanburg, South Carolina.	USA	2010	~600,000 m^2 production plant operates more than 350 forklifts to service production and logistic functions; fleet reached > 1,000,000 fills (2015); energy reduction of 4.1 million kW/h p.a.	n.a.

Products / systems available (selection)

Name	OEM	Product features	Country	Since	Cost
T 20 pallet truck	Linde	Provides indoor truck solutions under the use of PlugPowers GenDrive technology	Germany	2010	n.a.
Nuvera	Hyster-Yale	Fuel cell systems for electric lift trucks; PowerTap as supply equipment as well as PowerEdge as replacement for batteries	USA	2009	n.a.
GenDrive Series 1000, 2000 and 3000	PlugPower	24V, 36V and 48V FC modules for a broad range of vehicles like sit-down trucks, man-up order pickers, reach trucks, counterbalanced trucks, rider pallet jacks	USA	2008	n.a.

Source: Roland Berger

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

Benefits include potentially increased utilisation, as well as lower emissions & noise pollution, esp. relevant within warehouses

Fuel cell powered material-handling equipment – e.g. forklifts

3/4

Use case characteristics

Stakeholders involved

- Users (warehouse & logistics operators, municipality-owned & private construction companies)
- OEMs, FC and Power-Box manufacturers
- H_2 suppliers and infrastructure providers

Demand and user profile

- Indoor & outdoor use
- Deployment in low & high temperature environments
- High productivity or throughput requirements
- Continuous operation
- High availability e.g. through fast charging & reliability,

Deployment requirements

- Hydrogen supply and local storage
- On-site hydrogen refuelling station
- Possibility of on-site fuel production from PV or wind

Key other aspects

- Due to technology conversion costs, greenfield deployment projects provide better ROI than fleet conversions within existing deployments, e.g. warehouses

Benefit potential for regions and cities

Environmental

- Reduction of CO_2 emissions and No_x pollutant emissions, improving air quality, esp. within warehouses
- Reduction of noise emissions, also dependent on speed & road quality

Social

- Health benefits for employees due to lower emissions and noise exposures

Economic

- Advantages vs. battery EV: refuelling <3 min vs. 8-10 hrs battery charging, +30% operating range; less space demand (battery charging room, charging docks); longer lifetime
- Potentially lower maintenance and repair cost compared to diesel engines – hence potential TCO[1)]-advantages

Other

- Compact in size, concentrated mass
- No voltage drop as seen in batteries and better performance at low temperatures compared to batteries

1) Total Cost of Ownership

Source: Roland Berger

System costs and tailored solutions drive costs and profitability, while emission reduction is determined by hydrogen production

Fuel cell powered material-handling equipment – e.g. forklifts

Hot topics / critical issues / key challenges:

> **Lack of standardisation**, induced by individual fit-for-purpose modularisation and a large variety of vendors, hindering large scale production and additional economies of scale

> **Strong competitive technologies,** being battery powered material handling equipment as well as diesel-backed systems

> **High CAPEX and system costs,** meaning a full scale deployment of FCH handling equipment requires distribution logistics, local storage, equipment and refuelling stations, among others. This in turn requires large numbers of deployed units in order to be run profitable

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

Further recommended reading:

> U.S. Department of Energy (2014): Early Markets: Fuel Cells for Material Handling Equipment https://www1.eere.energy.gov/hydrogenandfuelcells/pdfs/early_markets_mhe_fact_sheet.pdf

> National Renewable Energy Laboratory publications on material handling: http://www.nrel.gov/hydrogen/publications.html

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

B

We consider the deployment of a sizeable fleet of forklifts for a large warehouse, comparing FCH forklifts to battery-powered forklifts

Use case characteristics and key exogenous assumptions

Use case characteristics

CURRENT / POTENTIAL[1]

> The assumed warehouse operator services 30,000 – 40,000 m^2 warehouse space, deploying ~100 new forklifts (for example ~2/3 pallet forklift trucks, ~1/3 larger forklift trucks, e.g. reach trucks). The forklifts operate approx. 330 days a year in a two-shift system with 7 working hours per shift, resulting in ca. 4,620 operating hours p.a. per forklift.

> Operators typically face technology decision (mainly) between battery-powered and FC-powered forklifts (mainly) for indoor operations

> Refuelling: one hydrogen refuelling station with ~30 m² at central depot for FCH forklifts; ~120 m² depot with charging stations and manned battery-exchange facilities required for counterfactual electric forklift truck deployment

Strongly dependent on reg. circumstances

Key other assumptions

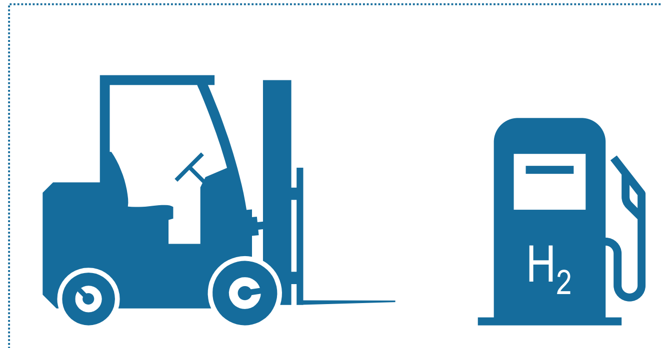
CURRENT / POTENTIAL[1]

> Cost of hydrogen: <u>for example</u> 8.00 / *4.00* EUR/kg H_2

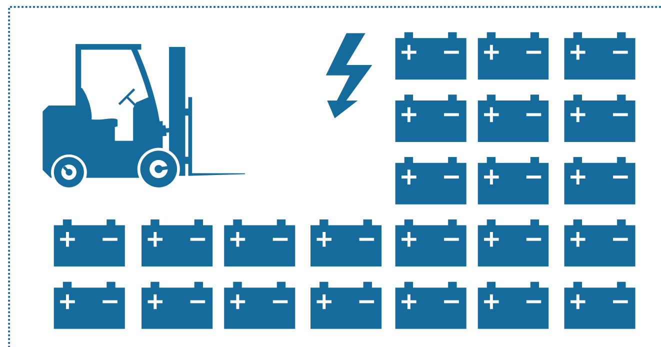
> Cost of electricity: <u>for example</u> 0.14 / *0.18* EUR/kWh

> No policy support (e.g. subsidies) to be considered initially, but possibly well available in practice

Strongly dependent on reg. circumstances



FCH forklift fleets require only one central refuelling station with minimal space occupancy



Battery-powered forklift fleets depend on several charging facilities requiring larger warehouse spaces

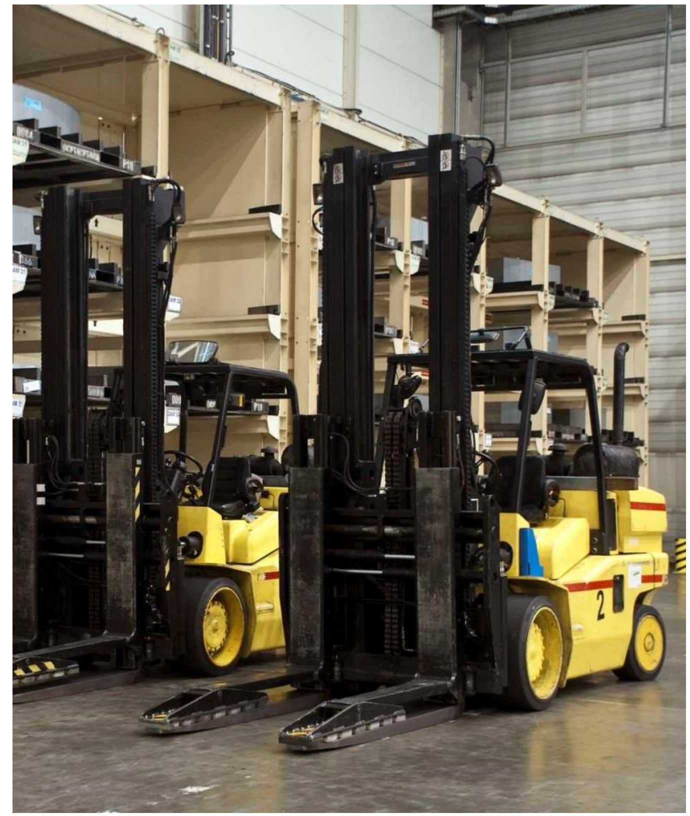
1) One potential future scenario combining alterations of different variables (each considered to be generally achievable by industry experts)

Source: Industry publications, Roland Berger

FCH forklifts typically feature higher availability and vehicle productivity than battery-powered competitors

Application-related assumptions

CURRENT / POTENTIAL[1]	**FCH Forklifts**	**Battery Forklifts**
Key technical specifications	Unit fleet size: 100 Refuelling time: 2.5 min Availability: *slightly higher (incl. refuelling time)*	Unit fleet size: 106 Changing time: 25 min Availability: *slightly lower (incl. refuelling time)*
CAPEX [EUR]		
Average full truck price	~ 35,000 / *~ 30,000*	~ 20,000 (incl. 2 batteries)
Replacements	-	~ 10,000
Refuelling[2]/changing station	~ 1,500,000 / *~ 1,200,000*	~ 950,000
Fuel		
Fuel type	Hydrogen (350 bar)	Electricity
Average fuel consumption (per h)	~ 0.15 kg / *~ 0.10 kg*	~ 3.0-4.0 kW
Maintenance costs [EUR]		
Forklift (per h)	~ 0.30	~ 0.67
Refuelling/changing station (p.a.)	~ 65,000 / *~45,000*	~ 35,000
Add. labour costs [EUR]		
Refuelling personnel p.a.	-	~ 205,000



1) One potential future scenario combining alterations of different variables (each considered generally achievable by industry experts)
2) Assuming a daily refuelling capacity of ~500 kg/d to allow fleet increases in the future, i.e. a larger capacity than for the ~320 kg/d needed for this initial fleet

Source: Industry publications, Roland Berger

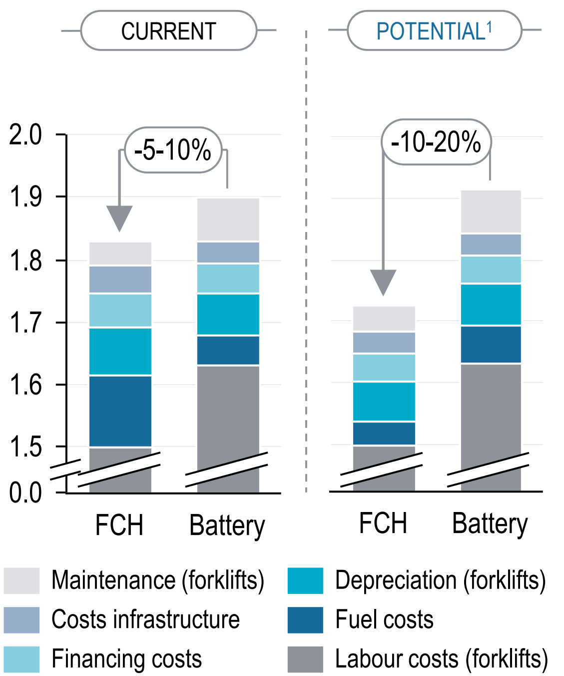
B

Since FCH forklifts display lower total cost of ownership than their battery counterfactuals, they are already fully commercialized

Business case and performance overview – PRELIMINARY/INDICATIVE EXAMPLE

Economic

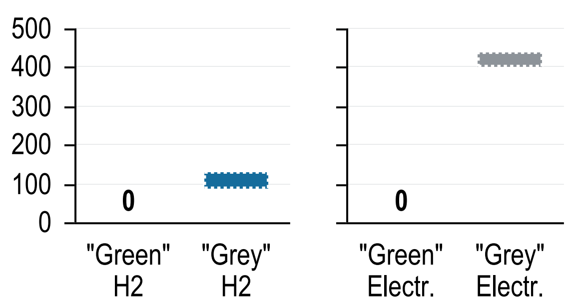
Estimated annualised Total Cost of Ownership (TCO) [kEUR/service hour]



Environmental

> **Zero tailpipe (i.e. tank-to-wheel) emissions** of CO_2, pollutants such as NO_X and fine dust particles for FCH forklifts – key benefit for personnel on site as well as outside environment

> Well-to-wheel CO_2 emissions depend on fuel source, use case characteristics and vehicle efficiency (i.e. fuel consumption) – **potential for zero well-to-wheel emissions for FCH forklifts with "green hydrogen"**



Technical/operational

> **High technical maturity** of fuel cell technology to be used in forklifts – one of the most advanced FCH applications overall

> Hence, FCH forklifts are **already fully commercialized** with >10,000 fuel cell powered forklifts in operation or in order globally

> Functionality proven through long-term usage in real live environments

> Commercial users including multinational companies such as BMW, Daimler, Walmart, Amazon and Carrefour have deployed large fleets already

TRL: 1 Idea, 2, 3 Tech. formulation, 4, 5, 6 Prototype, 7, 8, 9 Fully commercial

1) The "POTENTIAL" scenario requires a number of FCE-related and other factors to fall in place in the medium/long run (please see previous slide)

Source: Roland Berger

B

The impact of TCO drivers varies, creating several levers for further reduction of hydrogen TCO compared to battery TCO

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

Important sensitivities considered…

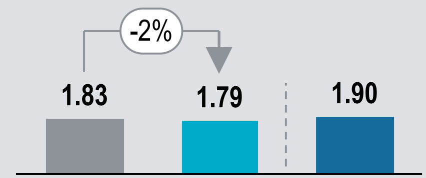
1 **Fuel cell forklift fuel consumption:** reducing the fuel consumption of the FCH forklift to 0.1 kg H_2/h results in an overall reduction of costs per service hour of EUR ~4 ct

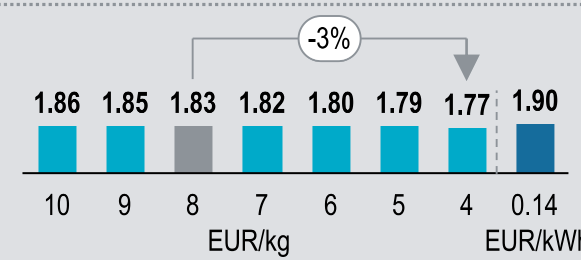
2 **Fuel costs:** a price reduction for hydrogen to EUR 4 per kg H_2 potentially further strengthens the viability of the business case by reducing overall costs per service hour by EUR ~6 ct – **strong regional differences**

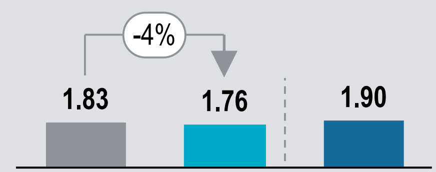
3 **3-shift operating model:** increasing the operating hours per day to a 3-shift model reduces CAPEX costs – this results in a cost reduction per service hour of EUR ~7 ct – **strongly dependent on the effect of maintenance costs and fuel cell stack/battery replacement**

… estimated impact on TCO

['000 EUR / service hour]







FC Forklift TCO, base case | FC Forklift TCO, adjusted variables | BE Forklift TCO, base case

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

Source: Roland Berger

B

When identifying suitable use cases, regions and cities should look for large fleets of FCH forklift trucks operating in several shifts

Key characteristics of promising use cases for FCH forklift trucks

Multi-shift operations: 2 or 3 shifts over 6 to 7 days every week over the course of the year – thus constantly high availability requirements for material handling

Sizeable fleets: several dozens, >50 or even >100 forklift trucks with corresponding infrastructure requirements, e.g. in larger high-throughput food distribution centres, consumer and retail distribution centres, large factories, etc.

Affordable hydrogen supply (esp. relative to electricity supply costs): e.g. hydrogen that is obtainable from low-cost on-site generation in close proximity

High battery changeover costs: hence significant savings from (labour) productivity gains (in environments with comparatively high labour cost

Source: Roland Berger

Please do not hesitate to get in touch with us

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Source: FCH2 JU, Roland Berger