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

FCH Heavy-duty 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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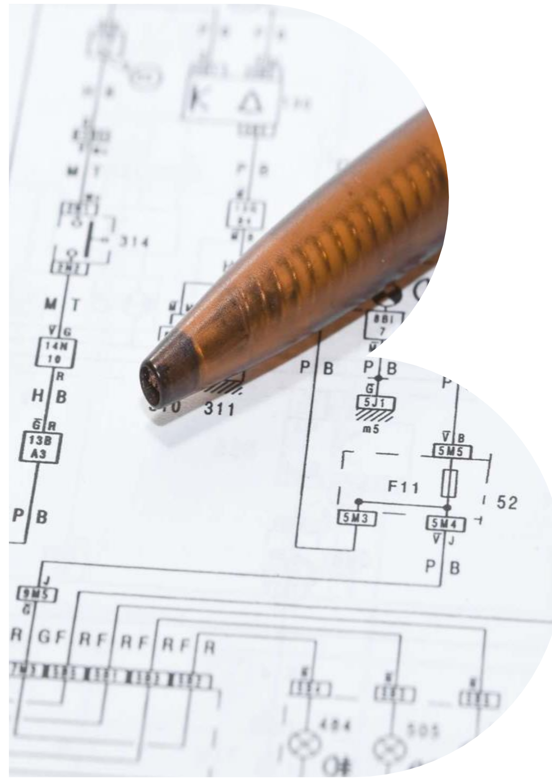
A. Technology Introduction



Fuel cell heavy-duty trucks offer a zero-emission alternative for road-based logistics services, initially likely in a regional context

Fuel cell heavy-duty trucks

Brief description: Fuel cell electric heavy-duty trucks are otherwise-conventional multi-ton trucks using compressed hydrogen gas as a fuel to generate electric power via a PEM fuel cell as energy converter – which in turn fuels an electric engine[1]

Use cases: Cities and regions can use/promote fuel cell electric heavy-duty trucks in the fields of (regional) logistics/shipping/ forwarding operations of specialized operators or logistics-intensive industries (e.g. food and beverage retail), construction and/or O&M services especially for infrastructure assets

Fuel cell heavy-duty trucks[1]	
Key components	Fuel cell stack, system module, hydrogen tank, battery (mostly lithium-ion batteries), electric engine
Output	250-750 kW (~340-1,000 diesel hp)
FC efficiency; consumption; range	~50%; 7.5-15.7 kg H_2/100 km; 320-1,300[2] km
Fuel	Hydrogen (350 bar)
Battery	30-320 kWh
Approximate unit cost	n.a.
OEMs	Esoro, Kenworth, Nikola, Navistar, Toyota, Scania/ASKO
Fuel cell suppliers	PowerCell, Hydrogenics, Ballard, US Hybrid, Toyota, NuCellSys
Typical customers / users	Logistics, forwarding and shipping companies, retailer, large industrial corporates with own road logistics
Competing technologies	Diesel combustion, battery EV, hybrid vehicles

1) Focus on full FCH powertrain trucks, not considering fuel cell APU systems etc.
2) Very limited FCH truck prototypes with indicative numbers referring to respective prototypes (~26t) deployed in regional distribution use cases. 1,300 km is a future prospective of announced prototypes, not yet empirically proven

Several prototypes have been and will be developed – Bottleneck of commercially available vehicles is expected to diminish

Status of fuel cell electric heavy-duty trucks

Overall technological readiness: Generally at advanced prototype-stage; prototypes are being (or will soon be) demonstrated in relevant environments, e.g. Esoro FC truck tailored for retailer COOP or ZECT II program; Nikola One FCH truck officially presented in December 2016; further announcement by Norwegian grocery retailer ASKO in 2017 for FCH truck based on Scania and Hydrogenics systems

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

Demonstration projects / deployment examples (selection)

Project	Country	Start	Scope
H2Share	EU	2018	Production and demo of >12t heavy-duty truck on a DAF chassis and built by VDL. Vehicles to be deployed in DE, FR, BE & NL and used by DHL, Colruyt, Breytner and CURE
ASKO distribution logistics trucks	Norway	2017	Partially gov't-funded demo project to deploy up to 4 FC trucks for regional grocery distribution logistics (~500 km distance); Scania >12t-chassis and Hydrogenics FC
Waterstofregio 2.0/HydrogenRegion 2.0	Netherlands	2016	Interreg Flanders-The Netherlands funded 40t truck based on DAF CF FT 4x2 modular BE truck with FCH range extension up to ~400km range. Built by VDL & Chassis Eindhoven, demo. starting 2018
COOP distribution logistics trucks	Switzerland	2016	Due to a lack of fuel cell trucks in serial production, retailer COOP developed a tailored fuel cell truck with OEM Esoro for its regional distribution logistics

Major prototypes (selection)

Name	OEM	Product features	Country	Since
Project Portal	Toyota Motor North America Inc.	Based on a Kenworth T660 chassis with two Mirai fuel cell stacks and a 12 kWh battery; engine with ~500 kW power output and torque of ~1,800 Nm[1]	Japan	2017
US Hybrid FC drayage truck	US Hybrid	Drayage day cab FCH truck based on Navistar Int'l ProStar for regional haul operations; 320/430 kW operating/max. power (Ballard); ~3,750 Nm max. torque; lithium-ion battery	USA	2017
Esoro FC truck	Esoro	4-wheeled MAN chassis with trailer (total 34 t.); synchronous engine with 250 kW output, stack of 455 fuel cells (PowerCell) with 100 kW output; lithium-ion battery	Switzerland	2016
Nikola One	Nikola Motor Company	Night cab truck with a range of >1,300 km; engine power output ~750 kW, torque of ~2,700 Nm; Lithium-Ion battery (320 kWh); to be comm. available in several years	USA	2016

Source: Roland Berger

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

1) Specifically adjusted to port requirements

A

The deployment of FC trucks is an attractive option for both public authorities and private companies in order to reduce emissions

Fuel cell heavy-duty trucks

3/4

Use case characteristics

Stakeholders involved

> Users (logistics companies, retailers, etc.)
> OEMs and FC manufacturers
> Public authorities (vehicle approval, regulatory framework of pollutants etc.)
> Hydrogen suppliers and infrastructure providers

Demand and user profile

> Typical road-based regional (or even inter-regional) logistics routes (e.g. between hubs/nodes) of several 100 km in different topographies
> Range, performance and refuelling service offerings ideally similar to conventional diesel-fuelled trucks

Deployment requirements

> Hydrogen refuelling stations (incl. sufficient storage) at nodes (as well as along main shipping routes)
> Maintenance centers at key nodes / truck depots
> High safety standards for FCH components, permitting and licensing of commercial operation

Key other aspects

> Tank size typically needs to at least allow for overnight refuelling (~range of 800 km per day), because of highly regulated working times of drivers (not allowed to refuel in their daily break times

Benefit potential for regions and cities

Environmental

> Zero tailpipe emissions from truck operations (pollutants, CO_2, fine dust particles)
> Potentially lower noise pollution
> Depending on the production type of hydrogen, down to zero well-to-wheel emissions

Social

> Lower adverse health effects associated with road-based transport, especially on communities adjacent to major road-based cargo logistics routes, i.e. highways

Economic

> Potentially lower O&M cost (according to COOP project) and long-term savings potential in TCO[1] depending on fuel prices and reduction of product cost
> Development of expertise in FCEV technology as potential driver of future economic growth

Other

> Depending on the production type of hydrogen, reduction of dependency on fossil fuels or energy imports

1) Total Cost of Ownership

Source: Roland Berger

Commercial availability, product cost and hydrogen infrastructure are key challenges for large scale deployment of FCH trucks

Fuel cell heavy-duty trucks

Hot topics / critical issues / key challenges:

- **Commercial availability,** all products now are at prototype stage; most are designed/adapted to service specific use cases
- **Product cost,** capital expenditures expected to be significantly higher as for standard trucks; breakeven point highly dependent on fuel prices
- **Availability of hydrogen refuelling stations (HRS)**, especially challenging for long-distance inter-regional routes (e.g. >500 km); hydrogen storage on the truck or trailer as critical determinant for range – probably in a trade-off with cargo payload space
- **Need for HRS availability** potentially a pointer for initial focus on regional logistics with distances of up to 500 km and relatively fixed routes
- **Environmental sustainability,** well-to-wheel emissions largely depend on hydrogen production

Further recommended reading:

- COOP's world's first fuel cell heavy goods vehicle
- ASKO-Scania FCH truck
- Nicola One by Nicola motor company

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

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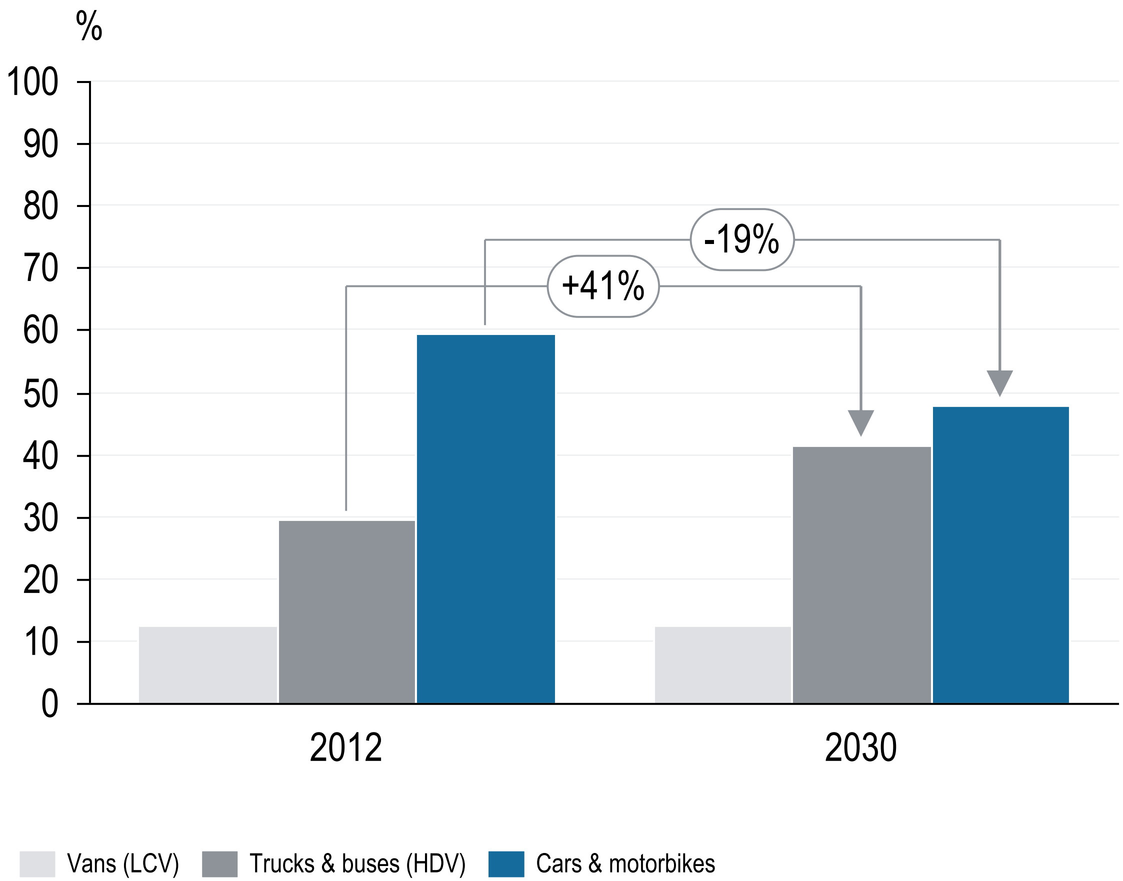
Giving their growing share in road transport GHG emissions, future European regulation will likely also tackle heavy-duty trucks

European road transport greenhouse gas (GHG) emissions [%]

INDICATIVE



> **Emissions from heavy-duty vehicles (HDV), incl. trucks, grew by >35% from 1990 to 2010** and keep increasing. Without additional measures, they are projected to reach as much as 40% of European road transport emissions by 2030

> Current emission regulations in road transport focuses heavily on passenger cars; **it is to be expected that future regulation will tackle trucks as well** – even considering that efficiencies have already been maximised to a great extent, given the highly commercial nature of the sector and the high share of fuel cost in total cost of ownership

> **Several levers for further reducing truck emissions exist** – for example from:
- Alternative powertrains (e.g. fuel cells)
- Alternative fuels (e.g. hydrogen)
- Other levers, e.g. digitization effects such autonomous driving

Source: Transport Environment, EEA, European Commission, Roland Berger

B

First truck prototypes with FCH powertrains are being deployed – Commercial availability of vehicles is expected to improve

Status of fuel cell electric heavy-duty trucks

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Source: Roland Berger *) Technology Readiness Level ≤ 5 6-7 8-9 1) Specifically adjusted to port requirements

B

The truck market is highly heterogeneous with respect to use cases as well as available (and conceivable) low/0-emission technologies

Trucks by category and available low/0-emission technologies

Classification[1]	< 3.5 t	> 3.5 t; < 7.5 t	> 7.5 t; < 12 t	> 12 t	Truck tractor
Description – Use case	Typical "Sprinter" delivery vans, e.g. "last mile" parcel delivery	Delivery in short distance traffic, e.g. around central distribution centre (typically light goods; inner cities)	Delivery in regional transport, transport of bulky goods, e.g. around regional distribution centre	Motor vehicle for drawbar trailer in long-distance hauling, on-site traffic, e.g. for transport companies with standardized freight	Long-distance hauling, e.g. for international transport or transport of goods with special storage requirements
Range [avg. yearly range]	PLEASE SEE WG 2	12,300 – 13,700 km	25,700 – 28,400 km	70,300 – 77,700 km	101,000 – 111,000 km
Emissions[2]		~ 430 g/km	~ 590 g/km	~ 780 g/km	~ 1,000 g/km
Low/0-emission technologies		FCEV, FC hybrid, BEV, CNG/LNG, Diesel[3]	FCEV, FC hybrid, BEV, CNG/LNG, Diesel[3]	FCEV, FC hybrid, BEV, CNG/LNG, Diesel[3]	FCEV, FC hybrid, CNG/LNG, Diesel[3]
Engine output / **Consumption**		Highly dependent on individual use case, for example type of good transported, truck superstructure, etc.; trend towards heavily over motorized fleet			

1) Gross vehicle weight 2) Well-to-Wheel CO_2 emissions for all street categories assuming Euro-IV diesel powertrain and 50% utilization 3) Overhead lines with diesel hybrid trucks

Source: Gnann et al. 2017; DLR, Shell, HWWI 2010; Roland Berger

B

Alternative powertrains still face several challenges, especially regarding the economics of regional and long-distance hauling

Powertrain benchmarking, segment ">12 t" (typ. up to 24-26 t)

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		1 FCH Truck	2 Diesel truck	3 CNG/LNG truck	4 BE truck
CAPEX [EUR]	**Actual 2015**	302,000-334,000	62,000-68,000	95,000-105,000	175,000-193,858
	Estimate 2030	115,000-127,000	78,000-86,000	136,000-150,000	124,000-137,000
Consumption [kWh/km]	**Actual 2015**	1.91-2.11	2.27-2.51	2.53-2.79	1.04-1.14
	Estimate 2030	1.64-1.82	1.80-1.98	2.03-2.25	0.91-1.01
Maintenance [EUR/km]	**Actual 2015**	0.48-0.53	0.15-0.16	0.17-0.19	0.24-0.27
	Estimate 2030	0.11-0.12	0.15-0.16	0.15-0.16	0.11-0.12
Range[1)]		Medium-high range	High range	Medium-high range	Low-medium range[2]
Lifetime		Typical holding periods are ~6 years (e.g. with ~100k km p.a.). Proxy considerations look diesel/FC buses to draw conclusions for FC trucks. Typically, bus demo. projects have shown the two technologies at par.			
Key challenges		Availability of infrastructure; trade-off between size of hydrogen tanks (range) and cargo payload; vehicle cost	CO_2 and NO_x emissions and related regulation	Infrastructure availability/range limitation, higher upfront CAPEX investment	Cost, size and weight of batteries; range limitations; extended recharging times
TRL level		Level 6 - 7	Level 9	Level 8 - 9	Level 6 - 7

1) Expected, still being tested and under constant development
2) BEVs' operational ability to service this segment questionable (different considerations for long-haul logistics vs. depot-based regional distribution use cases)
Source: Gnann et al. 2017, Roland Berger

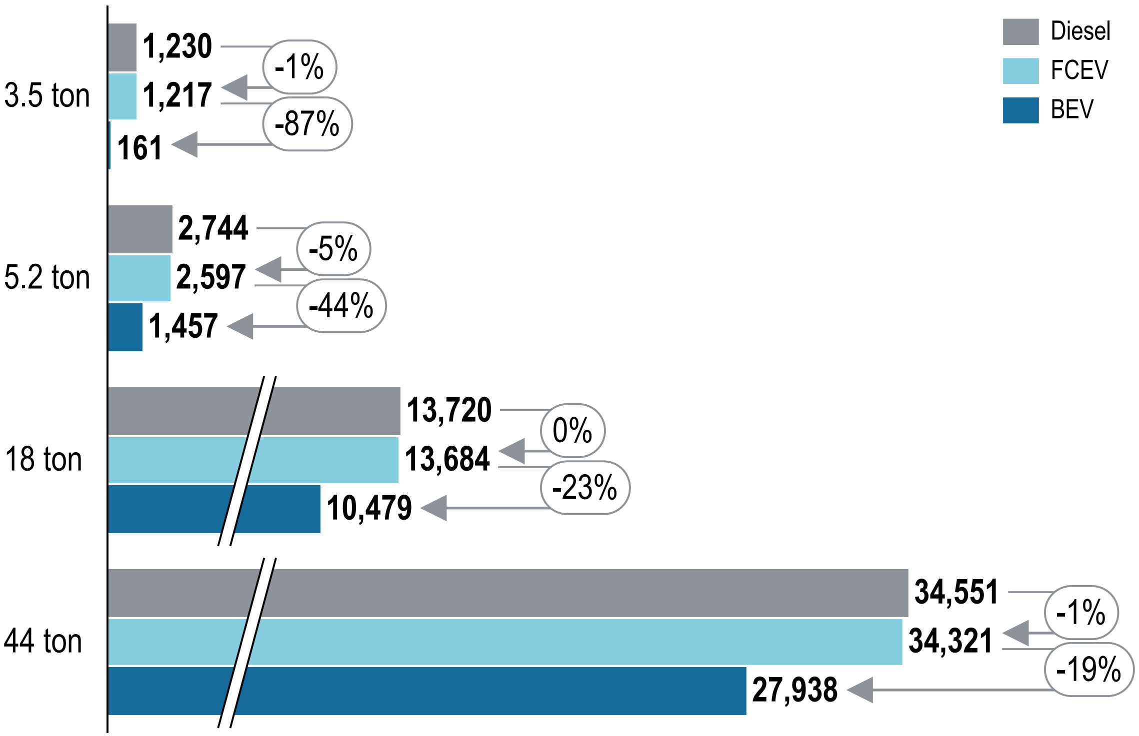
B

In principle, analysts see FCH as a viable option for 0-emission heavy-duty/long-haul trucking – esp. from a payload perspective

Trade-off between alternative powertrains and payload acc. to US DOE

Payload benchmark of alternative powertrains

Available payload for different truck categories and powertrains [kg]



Trade-off considerations

> Assumption: payload considered at **800 km driving range**

> Fuel cell trucks only compromise up to 5% of the payload of the incumbent diesel technology

> BEV trucks offer between 19 and 87% less available cargo payload

> Please note:
 – 800 km driving range is at the upper limit of feasible mileage per day
 – Currently available batteries are economically not fit to match a 800 km driving range. Size and weight of necessary units are show stoppers

Key take-away

FCEV trucks are an attractive option to replace regional and long distance diesel trucks – from an payload point of view

Source: US Department Of Energy - Medium and Heavy Duty Fuel Cell Electric Truck Targets (2016), Roland Berger

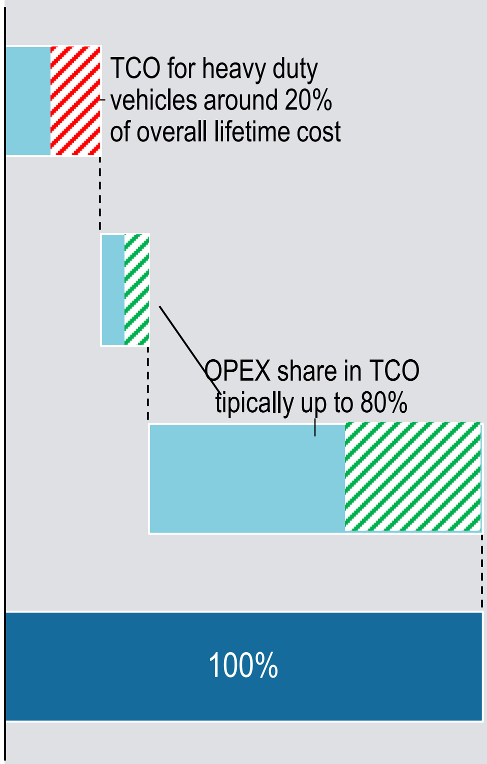
B

FC trucks need significant OPEX savings in order to compete against other low/0-emission competitors

Schematic TCO comparison of different FC trucks – SIMPLIFIED

INDICATIVE

Total Cost of Ownership (TCO)
(e.g. in EUR per km)



	1. Fuel cell	2. Diesel	3. CNG/LNG	4. Battery[1]
Capital cost	> Higher cost/kW > Higher development and permitting cost	> Lower cost/kW > Maturity level reached, low development cost	> Lower cost/kW > Production-at-scale nearly reached	> Higher cost/kW > Higher cost for reaching adequate range (if tech. possible)
Ops. & Maint.	> Less frequent routine, lower cost	> Higher maintenance cost due to engine set-up	> Higher maintenance frequency for safety reasons	> Higher maintenance cost with decr. battery performance
Fuel cost	> Lower fuel prices (with H_2 supply onsite) > High efficiency	> Highly regulated & uncertain prices > Lower efficiencies	> Price-sensitive fuel segment > Lower efficiencies	> Lower fuel prices, but many recharging cycles > High efficiency

Take-away: The upfront investment weights relatively little when considering the intense use and yearly km driven by the trucks; OPEX (esp. fuel cost) become the relevant differentiating factors

Additional **cost** range for alternative powertrains; Range for additional **savings** through alternative powertrains

Source: Roland Berger

1) BEVs' operational ability to service key truck segments questionable (different considerations for long-haul logistics vs. depot-based regional distribution use cases)

B

FC trucks are the "cleanest" option amongst the fully flexible competing technologies; green H_2 bears 0-WTW-emission potential

WTW emissions benchmarking, segment ">12 t" (typ. up to 24-26 t)

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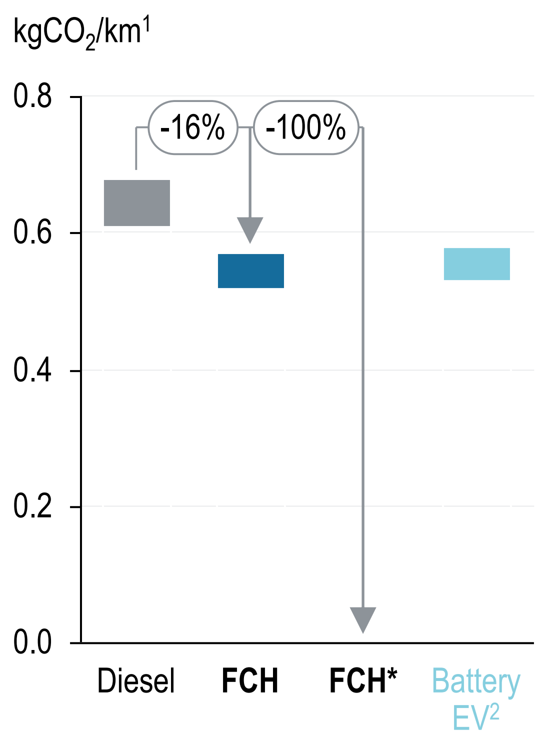
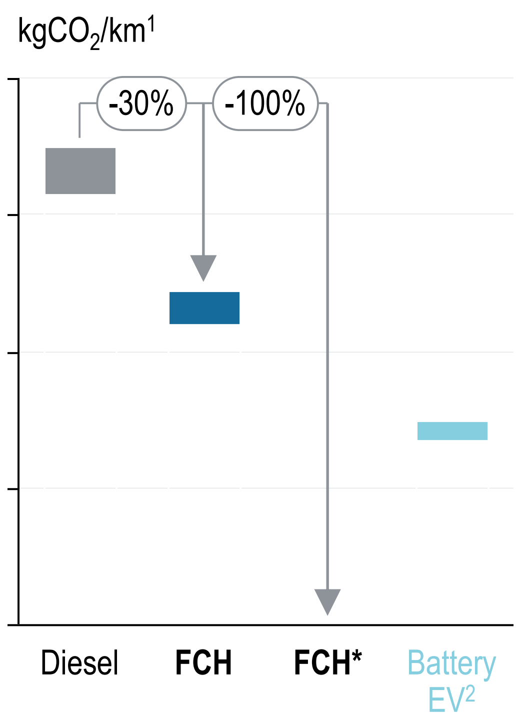
Benchmarking "CURRENT"



Benchmarking "POTENTIAL"



- **Key drivers**:
  - Availability of green hydrogen is decisive in outperforming the benchmark technologies
  - Development of the energy mix highly determines the environmental competitiveness of BE trucks
- **Underlying assumptions**:
  - CO_2 intensity of "grey" hydrogen: 9.00 kg / kg H_2
  - CO_2 intensity of diesel: 2.64 kg/l
  - CO_2 intensity of electricity: 0.51 / 0.30 kg/kWh (BE vehicle's WTW CO_2 emissions depend on development of energy mix in Europe)

*) Green hydrogen
1) Assumed km/a of 80,000
2) BEVs' operational ability to service this segment questionable (different considerations for long-haul logistics vs. depot-based regional distribution use cases)
Source: FCH2 JU, Roland Berger; Gnann et al. 2017; NGVA Europe 2017

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FC trucks can benefit from spillovers from cars and buses; specific challenges include infrastructure and heavy-duty requirements

Potential determinants of FCH truck competitiveness

Spillover effects from FCH sector development

> Technology spillover effects from the development and experience of passenger cars and buses (e.g. fuel cell stack production volumes) are expected to boost the competitiveness of FC trucks

> In particular, FC trucks could benefit from (sector-wide) performance improvements in the following areas:

- Cold start ability
- Lifetime
- Production cost
- Volume of fuel cell production
- Standardization
- Safety requirements
- Consumer acceptance

Specific challenges for FC trucks

Influence of efficiency on TCO	The degree of powertrain efficiency determines much of a truck's TCO because of the high OPEX share (~75-80%[1] OPEX, fuel cost 30-45%); improvements of FCH efficiency thus highly beneficial, as expected efficiency gains for diesel trucks are relatively small
Influence of refuelling infra-structure	HRS are typically considered in the context of passenger cars or depot applications such as buses – long-haul trucks have more specific needs for refuelling determined e.g. by drivers' rest periods and routes (typical refuelling range of 300-350 km along major transport corridors)[2]
Reliability of FC trucks	Econ. value of truck loads puts great pressure on reliability; logistics companies are highly sensitive to downtime issues
Specific challenges for heavy-duty long-haul trucks	> Fuel storage: long-haul transport dependent on large onboard H_2 tanks, 700 bar storage likely necessary; size might compete with commercial truck load (generally solvable issue acc. to industry) > Truck tractors need engine output of up to 300 kW. Current FCH systems (e.g. from buses) need to be scaled up to this level

1) At current diesel prices 2) Assuming an average speed of 70 km/h, also in line with EU regulated rest periods for truck drivers
Source: Gnann et al. 2017; Roland Berger

Regulation will shape technology race for truck use cases; Regions and Cities can stage prototype demonstration projects

Key takeaways, opportunities and immediate implications for Regions & Cities

European, national and regional regulation will shape the future of different truck powertrain technologies; if zero-emission regulation for trucks is put in place (and low-emission alternatives like LNG, CNG, etc. are de-facto excluded from the technology mix), FC trucks could have distinct advantages in long-haul heavy-duty use cases (esp. vs. battery vehicles) due to superior ranges, shorter refuelling times and less adverse impact on payload cargo (same operations – in principle – as diesel trucks[1])

Short-term opportunities and immediate implications for Regions & Cities:

- Map local stakeholder landscape for truck use cases and potentially interested partners and discuss current level of interest in alternative powertrains for truck fleets
- Participate in prototype demonstration projects together with local partners to push technological readiness to the next level
- Closely monitor developments in the various demonstration projects across Europe in alignment with interested regional stakeholders
- Think or re-think hydrogen infrastructure roll-out strategy depending on potential needs of FC trucks in the region

1) Operational equivalence to diesel dependent on H_2 tank size and onboard storage considerations

Source: Roland Berger

Please do not hesitate to get in touch with us

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Source: FCH2 JU, Roland Berger