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

FCH Trains

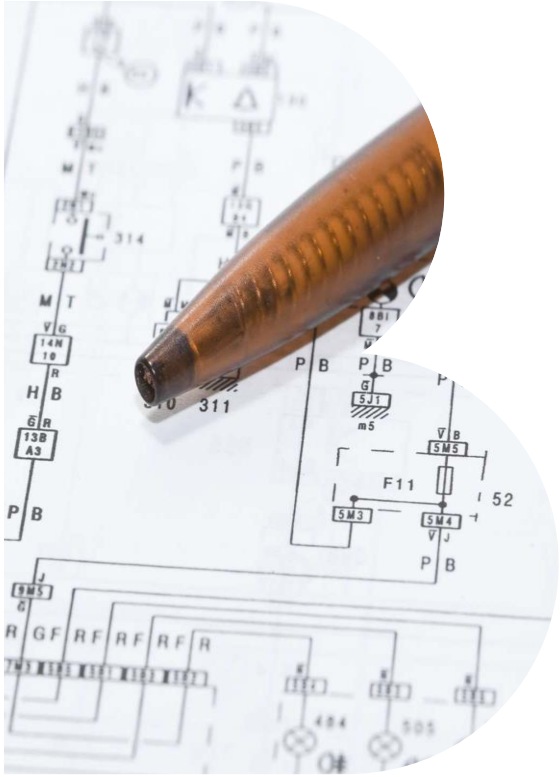
Brussels, Fall 2017

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**.

Table of Contents



A. Technology Introduction

Fuel cell hydrogen trains ("Hydrails") are a future zero-emission alternative for non-electrified regional train connections

Fuel cell electric trains[1]

Brief description: Hydrails are hydrogen-fuelled regional trains, using compressed hydrogen gas as fuel to generate electricity via an energy converter (the fuel cell) to power traction motors or auxiliaries. Hydrails are fuelled with hydrogen at the central train depot, like diesel locomotives

Use cases: Cities and regions can especially deploy hydrails on non-electric tracks for regional train connections to lower overall and eliminate local emissions (pollutants, CO_2, noise); cities and regions can – for example – promote FCH trains through demo projects or specific public tenders

Fuel cell electric trains – Hydrails (based on Alstom prototype)

Key components	Fuel cell stacks, air compressor, hydrogen tank, electronic engine, batteries
Output	400 kW FC, hybridized with batteries
Top speed; consumption; range	140 km/h; 0,25-0,3 kg/km; 600-800 km
Fuel	Hydrogen (350 bar)
Passenger capacity	300 (total) / 150 (seated)
Approximate unit cost	EUR 5.1-5.5 m (excl. H_2 infrastructure)
Original equipment manufacturers	Alstom
Fuel cell suppliers	Hydrogenics
Typical customers	Public transport authorities, regional train operators
Competing technologies	Diesel, diesel-electric hybrid, pure battery trains

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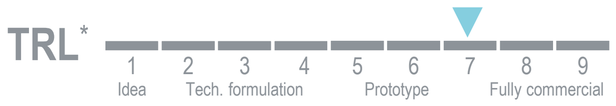
1) Focus on FCH-powered regional trains, not considering FCH trams, shunting locomotives, etc.

Source: FCH2 JU; Roland Berger

Currently, Alstom is testing its Hydrail prototype with two trains in the iLint demonstration project in Germany

Fuel cell electric trains

Overall technological readiness: Overall TRL at ca. seven, i.e. mature prototype; rising technical maturity of larger-scale fuel cell modules to be used in trains or tram cars; small scale roll-out in Germany and China in first major "real-life" demonstration projects to prove technical viability and further refine the technology with the help of all stakeholders involved (train operators, network operators, OEMs, etc.)



Demonstration projects / deployment examples / funding schemes for future projects (selection)

Project	Country	Start	Scope	Project volume
Alstom partnership with Landesnahverkehrsgesellschaft Niedersachsen – iLINT	🇩🇪	2017	Testing of 2 fuel cell powered iLINT trains manufactured by Alstom on the route Cuxhaven-Buxtehude (220 km return) in northern Germany, first operation as part of the regional network to start end 2017 / early 2018 – then for two years	n.a.
Shift2Rail	🇪🇺	2015	EU agencies and bodies supporting research and innovation in railway sector through Horizon 2020 grants for zero-emission technologies – link to Single European Railway Area (SERA), funding scheme for future projects	n.a.
Fuel cell hybrid railcar testing by East Japan Railway Company	🇯🇵	2008	Research and development of fuel cell system within "NE-Train" (two 65 kW PEM fuel cells and 19 kWh lithium ion batteries); tests focusing on performance, environmental impact and hydrogen supply; development refocused in 2009 towards battery driven electric units	n.a.

Products / systems available (selection)

Name	OEM	Product features	Country	Since	Cost
iLint	Alstom	Pre-commercial phase of first fuel cell (Hydrogenics) powered regional train. Matching performance of regular diesel trains, Alstom offers a single-source package including train delivery, maintenance and hydrogen infrastructure	🇫🇷	2017	n.a.
KuMoYa E995-1	Tokyu Car Corporation[1]	Prototype hydrogen fuel cell train; development changed to battery electric unit	🇯🇵	2006 / 2007	n.a.

1) now: Japan Transport Engineering Company

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

Source: FCH2 JU; Roland Berger

A

Hydrails are particularly promising for non-electrified regional tracks where they offer large environmental and social benefits

Fuel cell electric trains

Use case characteristics

Stakeholders involved

- Regional train operators, regional transport authorities
- Rolling stock OEMs as well as operation and maintenance providers, fuel cell suppliers
- Hydrogen suppliers and infrastructure providers
- Permitting and licensing authorities

Demand and user profile

- Typically non-electrified routes (e.g. 40-50% of infra.in Germany) as part of regional networks (i.e. 100-200 km per route, several cycles per day and train with total required range of up to 1,000 km, speed of 140 km/h)
- Differing topographic profiles (e.g. tunnels of 5-10 km each) and large number of stops/stations (15-50)

Deployment requirements

- Supply infrastructure able to supply large quantities of hydrogen per day, e.g. through local production
- Hydrogen storage, regional/ local distribution networks
- Network of hydrogen refuelling stations along relevant train routes, i.e. in train depots

Key other aspects

- Elimination of need for engine idling at train stations due to fuel cell auxiliary power units (contrary to diesel units)

Benefit potential for regions and cities

Environmental

- Zero tailpipe emissions of pollutants (esp. NO_x) and greenhouse gases (esp. CO_2)
- Lower noise pollution (depending on speed and track conditions reduction of overall noise emissions)

Social

- Increased passenger comfort through reduced noise and vibration, fewer adverse impact on neighbouring communities
- Public health benefits (esp. urban areas near tracks/station), reduced social security expenses, higher standard of living

Economic

- Avoiding cost of future electrification of several million EUR investment per km (i.e. power generation, transformers and transmission lines as well as service disruption caused by overhead wire installation)
- Maintenance and other OPEX savings vis-à-vis operations with diesel-locomotive, long-term savings potential in TCO[1]

Other

- Flexibility to move into service areas not covered by electrification (for industry-stakeholders involved)
- Significant innovation and high visibility potential as flagship/lighthouse projects

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[1] Total Cost of Ownership

Source: FCH2 JU; Roland Berger

The single-prototype demonstration and potential regulatory/ permitting challenges need to be addressed in the short-term

Fuel cell electric trains

Hot topics / critical issues / key challenges:

- **Hydrogen infrastructure and supply,** distribution logistics, local storage and refuelling stations, e.g. from an infrastructure-permitting and distribution perspective, but also local availability of large-enough quantities of hydrogen (e.g. from chemical production facilities or large-scale electrolysers)
- **Selection of use cases and suitable routes**, required reassessments of individual train deployment cycle and other necessary performance
- **Technology readiness,** as systems still in advanced prototype phase, e.g. need to extend range from 600-800 km to 1,000 km like diesel trains today
- **General compliance with EU-level and national rolling stock regulations/permitting procedures**, potentially lack or insufficiency of applicable regulatory norms; possibly cumbersome and uncertain rolling-stock approval procedure, need for long-term planning

Further recommended reading:

- Alstom Coradia iLinit product sheet: Alstom Coradia iLinit
- Case Study concerning rail transportation by hydrogen: Rail transportation by hydrogen vs. electrification – Case Study for Ontario, Canada 2: Energy Supply and Distribution

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: FCH2 JU; Roland Berger

B. Preliminary Business Case

B

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 roundtrip-time, target schedule for operations
- Target availability
- Topographic and other ext. conditions
- Fleet size, depot structure
- Energy cost
- Carbon intensities
- …

FCH train / system specifications and performance

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

Hydrogen infrastructure specifications and performance – sharing ratios

1. Capital cost

- Investment / depreciation
- Financing cost

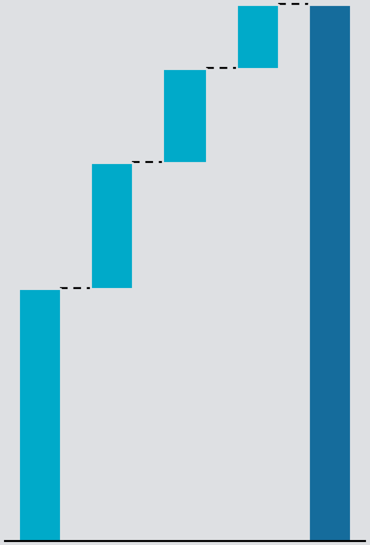
2. Fuel cost – H_2 consumption, H_2 price (dep. on production, distribution, volumes, input prices, etc.)

3. Other O&M cost, e.g. for train 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



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

Source: FCH2 JU, Roland Berger

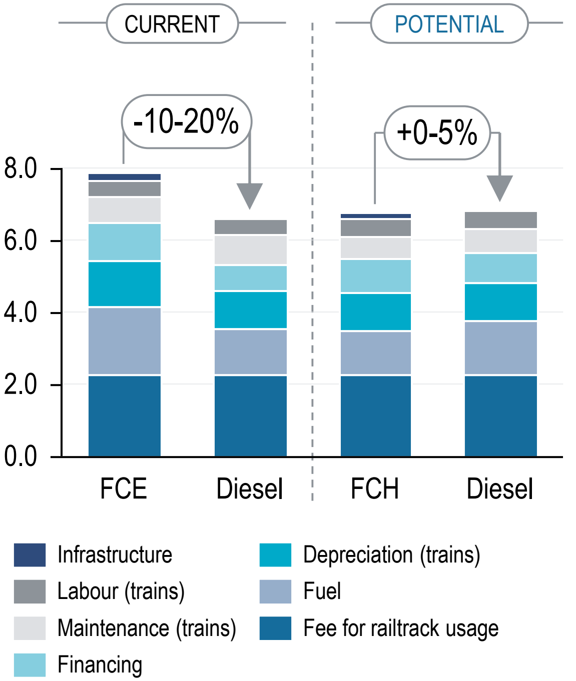
B

Hydrails might almost reach cost parity with diesel trains in the medium run, while reducing CO_2 and putting NO_x emissions to 0

Business case and performance overview – PRELIMINARY / INDICATIVE EXAMPLE

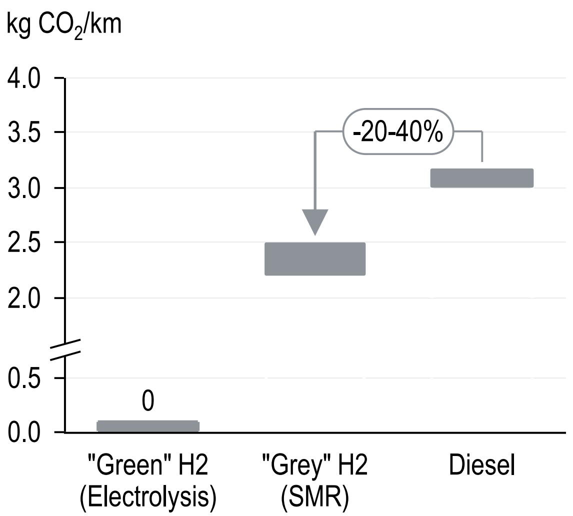
Economic

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



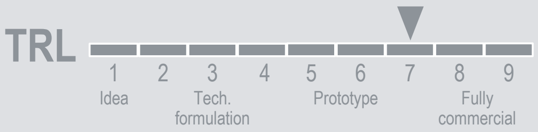
Environmental

- Zero tailpipe emissions of CO_2, pollutants such as NO_X and fine dust particles, e.g. saving ~15-25 t NO_X/year
- Well-to-wheel CO_2 emissions depend on fuel source, use case characteristics and efficiency (i.e. fuel consumption)



Technical/operational

- Rising technical maturity of larger-scale fuel cell modules to be used in trains or tram cars; roll-out in Germany in first major "real-life" projects under way, tech. moving towards commercialisation for trains starting operations over the medium term (tender processes in part already ongoing)
- Once deployed, Hydrail OEMs would (feel compelled to) guarantee same availabilities of conventional diesel trains (e.g. approx. 97%), not withstanding initial deployment challenges
- Range of a fully fuelled Hydrail at 600-800 km, aiming to reach parity with diesel at up to 1,000 km



Source: FCH2 JU; Roland Berger

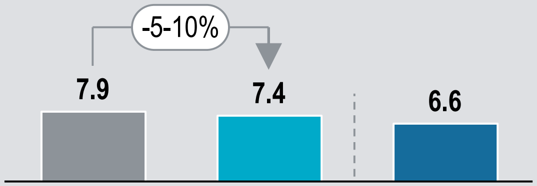
The impact of TCO-drivers varies, creating several levers for further reduction of hydrogen TCO compared to diesel TCO

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

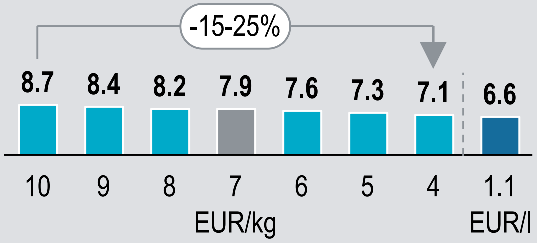
Important sensitivities considered ...

... est. impact on TCO [EUR/km]

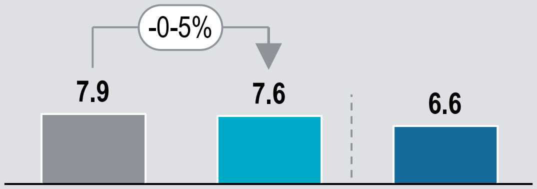
1 **Hydrail purchasing price:** reducing the purchasing price of the FCH train to the price of diesel trains in 2017 potentially results in the overall reduction of costs per km of EUR ~50 ct



2 **Fuel costs:** a price reduction for hydrogen to 4 EUR / kg H_2 potentially results in a reduction of EUR ~80 ct **– strong regional differences**



3 **Infrastructure costs:** omitting the infrastructure expenditures and therefore levelling the infrastructure related CAPEX-costs with the diesel case, potentially results in a cost reduction per km of EUR ~30 ct **– strongly dependent on fleet size and depot structure**



▨ Hydrail TCO, base case ▨ Hydrail TCO, adjusted variables ▨ Diesel train TCO, base case

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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"

Source: FCH2 JU; Roland Berger

As an example, we considered a relatively sizeable fleet deployment of Hydrails, with changing cost and performance parameters

Key assumptions – PRELIMINARY / INDICATIVE EXAMPLE

Application-related assumptions

today / *outlook*	**Hydrail**	**Diesel train**
Technical specifications	150 passenger (seated) Lifetime: 15 years Availability: 95% / *97%*	150 passenger (seated) Lifetime: 15 years Availability: 97% / *97%*
CAPEX		
> Price train [unit]	EUR 5-5.5 m / *4.5[1] m*	EUR 4-4.3 m / *4.5 m*
> Initial HRS[2]	EUR 9 m / *7.2 m*	-
Fuel		
> Fuel type	Hydrogen (350 bar)	Diesel
> Consumption	0.28 / *0.25* kg H_2 / km	*1.2* / *1.4* l diesel / km
Maintenance costs		
> Train per km	EUR 0.72 / *0.65*	EUR 0.79 / *0.71*
> Ref. station p.a.	EUR 180k / *180k*	EUR 10,350 / *10,350*
Labour costs p.a.	EUR 128,000 / *128,000*	EUR 128,000 / *128,000*

Use case and exogenous factors

Strongly dependent on reg. circumstances

- The assumed train operator has several non-electrified routes of ~100 km and ~10 stops each to service. The trains travel at an average speed of ca. 80 km/h. The ambition is to service the route during peak hours hourly, with 10 hours in operation + additional refuelling time per day. The operator deploys ~15 trains with a total expected distance travelled by each train of ~750 km per day (fleet travels ~4 m km per year)
- Hydrogen consumption: ~230-260 kg/d (1 train), ~3,450-4,000 kg/d (fleet)
- Financing costs of train operator: 5% p.a.
- Labour costs: based on 2 shifts and 4 FTE per train, with average Western European wages of EUR 32,000 per person per year
- CAPEX for refuelling stations: one HRS at central depot for FCH trains; for counterfactual diesel train deployment no additional 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: 7 EUR/kg H_2 / *5* EUR/kg H_2
- Cost of diesel : 1.1 EUR/litre / *1.25* 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

Strongly dependent on reg. circumstances

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

2) HRS cost preliminary – to be validated

Source: FCH2 JU, NOW, Roland Berger

Please do not hesitate to get in touch with us

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