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

FCH Trains
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

<table>
<thead>
<tr>
<th>Topic</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>A. Technology Introduction</td>
<td>4</td>
</tr>
<tr>
<td>B. Preliminary Business Case</td>
<td>9</td>
</tr>
</tbody>
</table>
A. Technology Introduction
Fuel cell hydrogen trains ("Hydrails") are a future zero-emission alternative for non-electrified regional train connections

Fuel cell electric trains

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, CO₂, 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)

<table>
<thead>
<tr>
<th>Key components</th>
<th>Fuel cell stacks, air compressor, hydrogen tank, electronic engine, batteries</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output</td>
<td>400 kW FC, hybridized with batteries</td>
</tr>
<tr>
<td>Top speed; consumption; range</td>
<td>140 km/h; 0.25-0.3 kg/km; 600-800 km</td>
</tr>
<tr>
<td>Fuel</td>
<td>Hydrogen (350 bar)</td>
</tr>
<tr>
<td>Passenger capacity</td>
<td>300 (total) / 150 (seated)</td>
</tr>
<tr>
<td>Approximate unit cost</td>
<td>EUR 5.1-5.5 m (excl. H₂ infrastructure)</td>
</tr>
<tr>
<td>Original equipment manufacturers</td>
<td>Alstom</td>
</tr>
<tr>
<td>Fuel cell suppliers</td>
<td>Hydrogenics</td>
</tr>
<tr>
<td>Typical customers</td>
<td>Public transport authorities, regional train operators</td>
</tr>
<tr>
<td>Competing technologies</td>
<td>Diesel, diesel-electric hybrid, pure battery trains</td>
</tr>
</tbody>
</table>

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.)

<table>
<thead>
<tr>
<th>TRL</th>
<th>Idea</th>
<th>Tech. formulation</th>
<th>Prototype</th>
<th>Fully commercial</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
<td>5</td>
</tr>
</tbody>
</table>

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

<table>
<thead>
<tr>
<th>Project</th>
<th>Country</th>
<th>Start</th>
<th>Scope</th>
<th>Project volume</th>
</tr>
</thead>
<tbody>
<tr>
<td>Alstom partnership with Landesnahverkehrs-gesellschaft Niedersachsen – iLINT</td>
<td>Germany</td>
<td>2017</td>
<td>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</td>
<td>n.a.</td>
</tr>
<tr>
<td>Shift2Rail</td>
<td>European Union</td>
<td>2015</td>
<td>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</td>
<td>n.a.</td>
</tr>
<tr>
<td>Fuel cell hybrid railcar testing by East Japan Railway Company</td>
<td>Japan</td>
<td>2008</td>
<td>Research and development of fuel cell system within &quot;NE-Train&quot; (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</td>
<td>n.a.</td>
</tr>
</tbody>
</table>

**Products / systems available** (selection)

<table>
<thead>
<tr>
<th>Name</th>
<th>OEM</th>
<th>Product features</th>
<th>Country</th>
<th>Since</th>
<th>Cost</th>
</tr>
</thead>
<tbody>
<tr>
<td>iLint</td>
<td>Alstom</td>
<td>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</td>
<td>France</td>
<td>2017</td>
<td>n.a.</td>
</tr>
<tr>
<td>KuMoYa E995-1</td>
<td>Tokyu Car Corporation (^1)</td>
<td>Prototype hydrogen fuel cell train; development changed to battery electric unit</td>
<td>Japan</td>
<td>2006 / 2007</td>
<td>n.a.</td>
</tr>
</tbody>
</table>

1) now: Japan Transport Engineering Company

\(^\) Technology Readiness Level \(\leq 5\) \(6-7\) \(8-9\)

Source: FCH2 JU; Roland Berger
Hydrails are particularly promising for non-electrified regional tracks where they offer large environmental and social benefits

**Fuel cell electric trains**

<table>
<thead>
<tr>
<th>Use case characteristics</th>
<th>Benefit potential for regions and cities</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Stakeholders involved</strong></td>
<td><strong>Environmental</strong></td>
</tr>
<tr>
<td>Regional train operators, regional transport authorities</td>
<td>&gt; Zero tailpipe emissions of pollutants (esp. NO\textsubscript{x}) and greenhouse gases (esp. CO\textsubscript{2})</td>
</tr>
<tr>
<td>Rolling stock OEMs as well as operation and maintenance providers, fuel cell suppliers</td>
<td>&gt; Lower noise pollution (depending on speed and track conditions reduction of overall noise emissions)</td>
</tr>
<tr>
<td>Hydrogen suppliers and infrastructure providers</td>
<td>&gt; Increased passenger comfort through reduced noise and vibration, fewer adverse impact on neighbouring communities</td>
</tr>
<tr>
<td>Permitting and licensing authorities</td>
<td>&gt; Public health benefits (esp. urban areas near tracks/station), reduced social security expenses, higher standard of living</td>
</tr>
<tr>
<td><strong>Demand and user profile</strong></td>
<td><strong>Social</strong></td>
</tr>
<tr>
<td>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)</td>
<td>&gt; 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)</td>
</tr>
<tr>
<td>Differing topographic profiles (e.g. tunnels of 5-10 km each) and large number of stops/stations (15-50)</td>
<td>&gt; Maintenance and other OPEX savings vis-à-vis operations with diesel-locomotive, long-term savings potential in TCO\textsuperscript{1}</td>
</tr>
<tr>
<td><strong>Deployment requirements</strong></td>
<td><strong>Economic</strong></td>
</tr>
<tr>
<td>Supply infrastructure able to supply large quantities of hydrogen per day, e.g. through local production</td>
<td>&gt; Flexibility to move into service areas not covered by electrification (for industry-stakeholders involved)</td>
</tr>
<tr>
<td>Hydrogen storage, regional/ local distribution networks</td>
<td>&gt; Significant innovation and high visibility potential as flagship/lighthouse projects</td>
</tr>
<tr>
<td>Network of hydrogen refuelling stations along relevant train routes, i.e. in train depots</td>
<td></td>
</tr>
<tr>
<td><strong>Key other aspects</strong></td>
<td><strong>Other</strong></td>
</tr>
<tr>
<td>Elimination of need for engine idling at train stations due to fuel cell auxiliary power units (contrary to diesel units)</td>
<td></td>
</tr>
</tbody>
</table>

---

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 iLimit product sheet: [Alstom Coradia iLimit](#)

- 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](https://sharefolder.rolandberger.com/project/P005)
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 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
> …

1. Capital cost
   > Investment / depreciation
   > Financing cost

2. Fuel cost – H₂ consumption, H₂ price (dep. on production, distribution, volumes, input prices, etc.)

3. Other O&M cost, e.g. for train maintenance, personnel, utilities, fees/levies, taxes¹

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

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

Hydrogen infrastructure specifications and performance – sharing ratios

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

Source: FCH2 JU, Roland Berger
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

- **CURRENT**
  - FCE
  - Diesel

- **POTENTIAL**
  - FCH
  - Diesel

- ~10-20% reduction in costs
  - +0-5% increase in costs

**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 …**

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

---

\(^1\) 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

<table>
<thead>
<tr>
<th>today / outlook</th>
<th>Hydrail</th>
<th>Diesel train</th>
</tr>
</thead>
<tbody>
<tr>
<td>Technical specifications</td>
<td>150 passenger (seated)</td>
<td>150 passenger (seated)</td>
</tr>
<tr>
<td></td>
<td>Lifetime: 15 years</td>
<td>Lifetime: 15 years</td>
</tr>
<tr>
<td></td>
<td>Availability: 95% / 97%</td>
<td>Availability: 97% / 97%</td>
</tr>
</tbody>
</table>

CAPEX

> Price train [unit] EUR 5.5 m / 4.5 m
> Initial HRS EUR 9 m / 7.2 m

Fuel

> Fuel type Hydrogen (350 bar) Diesel
> Consumption 0.28 / 0.25 kg H₂ / 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 180 k / 180 k EUR 10,350 / 10,350

Labour costs p.a.

EUR 128,000 / 128,000 EUR 128,000 / 128,000

Use case and exogenous factors

> 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 H₂ / 5 EUR/kg H₂
> Cost of diesel : 1.1 EUR/litre / 1.25 EUR/l
> CO₂ emissions from grey hydrogen: 9 kg / kg H₂
> CO₂ emissions from green hydrogen: 0 kg / kg H₂
> CO₂ emissions from diesel: 2.64 kg/l
> NOₓ emissions from diesel: 4 g/l

1) Assuming production-at-scale scenarios for Hyadrail 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

Contact information

Carlos Navas
FCH2 JU
Strategy and Market Development Officer
carlos.navas@fch.europa.eu
+32 2 221 81 37