Fuel cell solutions for zero emission rail

June 2019
Ballard by the Numbers

- 700 Employees
- 2,000 Patents & Applications
- Publicly listed Company
  - 24 years Nasdaq
  - 26 years TSX
- 136 (857*) transit buses in service
- 531 (702*) trucks delivering goods
- 4 train projects on track
- 3 ships in development
- 12,000 Forklifts in operation
- $80M automobile stack development program
- Delivered 850MW of fuel cell products
- Produced 5 million MEAs
- >14M km of service for modules operating in buses
- >30,000hrs Operation of fuel cell stack in London BUSES

*Currently in construction or commissioning phase
Content

- Fuel cell technology for rail
- Applications for hydrail
- Ballard’s solution and experience with rail projects
- Hydrogen as a fuel for trains
“FCH trains offer a high technical performance, with similar flexibility and versatility as diesel-powered fleets with similar range.

FCH trains offer a reasonable economic performance and are cost competitive with diesel-powered trains where low-cost hydrogen production is possible providing zero-emission service.

FCH trains reduce greenhouse gas emissions, air contaminants and noise levels.” *(Shift2Rail – FCH-JU Study 2019)*
Fuel cells offer the environmental benefits of electrification without significant infrastructure investment and with the flexibility of diesel.
- No requirement for overhead catenary infrastructure and power substations
- No impact on existing bridges, over-path and level crossings
- Hydrail enables gradual electrification (one train at the time) aligned with budget availability
Fuel cell technology can address several rail applications

- Shunter / yard locomotives
- Regional and commuter trains (Multiple Unit – MU)
- Mainline freight trains
- Trams and light rail
- Underground mining
Rail Market Segmentation

**Multiple Units:**
- Passenger operation in regional transport. Medium-sized operator assumed purchasing and operating a batch of 15 FCH trains.
- Typical daily mileage of **800 km** per train and 8 to 10 hours in operation, refuelling overnight at central depot
- Flat topography with about 8 stops per hour and 10 stops per 100 km
- Average seat load factor of 50%, availability of 97% (incl. planned maintenance)

**Shunters:**
- **Incumbent** assumed purchasing and operating **10 FCH Shunters**
- Typical daily mileage of **120 km** per train and 12 to 16 hours in operation with an average speed of 7-10 km/h, refuelling overnight at central depot
- Flat topography with stops for assembling, disassembling and movement of railroad cars and short distance transfer runs at a shunting yard
- Average load of 500 t and availability of 97% (incl. planned maintenance)

**Mainland Locomotives:**
- Only cargo operations. Large incumbent assumed purchasing and operating **7 FCH mainline locomotives**
- Typical daily mileage of **1,000 km** per train and 5 to 10 hours in operation, refuelling overnight at one of four central depots
- Flat topography with about one stop per hour and one stop per 100 km
- Average load of 1,600 t and availability of 97% (incl. planned maintenance)

Source: Expert interviews, Roland Berger
The market share of fuel cell hydrogen (FCH) trains may reach up to 41% by 2030.

EU Market potential FCH trains – Scenario comparison [standard units]

Low scenario

Base scenario

High scenario

Comments

> The accumulated amount of FCH trains may reach up to 1,753 SU in 2030

> The emission reduction potential is in the range of 229,000 to 305,000 tons of CO₂ annually by 2030 purely due to FCH Multiple Units.
A Market potential in the base scenario is driven by FCH multiple units in the frontrunner markets; by shunters – in other markets

Overview of FCH train markets outlook for 2030 [standard units]

<table>
<thead>
<tr>
<th>Frontrunner</th>
<th>Low</th>
<th>Base</th>
<th>High</th>
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<tbody>
<tr>
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<td>150</td>
<td>273</td>
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<td>951</td>
<td>805</td>
<td>465</td>
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<table>
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<tr>
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<th>High</th>
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<td>21</td>
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<td>17</td>
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<td></td>
<td>497</td>
<td>467</td>
<td>409</td>
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</table>

<table>
<thead>
<tr>
<th>Later Adopter</th>
<th>Low</th>
<th>Base</th>
<th>High</th>
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</thead>
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<td></td>
<td>7</td>
<td>15</td>
<td>30</td>
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<tr>
<td></td>
<td>9</td>
<td>19</td>
<td>37</td>
</tr>
<tr>
<td></td>
<td>4</td>
<td>8</td>
<td>15</td>
</tr>
<tr>
<td></td>
<td>419</td>
<td>398</td>
<td>357</td>
</tr>
</tbody>
</table>

Comments
- The Market potential will depend on the projected diesel purchasing volumes
- Substitution of diesel trains is driven by the Multiple Units in the Frontrunner markets
- On the other hand, Shunters drive the substitution in the Newcomer and Later Adopter markets

Market share of FCH in 2030
Source: Expert interviews, Roland Berger
Under base case assumptions, FCH trains assume a cost premium of up to 14% over a diesel train.

High-level TCO assessment – Base case in 2022 [EUR/km]

- **FCH Multiple Units**: Competitive with a catenary electrified MU and assume a cost premium of EUR 0.5 per km over a diesel.
- **FCH Shunters and Locomotives**: Assume a cost premium of EUR 1.5-1.6 per km.
- **Actual TCO** will differ based on regional differences.

Source: Expert interviews, Roland Berger
Optimistic assumptions suggest competitiveness of the FCH train in all three applications with a TCO advantage up to 10%.
TCO Results – Multiple Units:
Regional multiple units with hydrogen fuel cells are already being developed or put into operation by different system integrators.

Use case – FCH Regional Multiple Unit

Usage profile¹) for TCO model

- Passenger operation in regional transport – Medium-sized operator assumed purchasing and operating a batch of 15 FCH trains
- Typical daily mileage of 800 km per train and 8 h to 10 h in operation – Refuelling overnight at central depot
- Flat topography with about 8 stops per hour and 10 stops per 100 km
- Average seat load factor of 50%, availability of 97% (incl. planned maint.)

<table>
<thead>
<tr>
<th>Power rating</th>
<th>Tractive effort</th>
<th>Max. speed</th>
<th>Hydrogen tank</th>
<th>Max. range</th>
<th>Price</th>
</tr>
</thead>
<tbody>
<tr>
<td>800-1,000 kW</td>
<td>90 kN</td>
<td>140 km/hour</td>
<td>~250 kg</td>
<td>~1,000 km</td>
<td>EUR 4.0-5.5 m</td>
</tr>
</tbody>
</table>

- Typical power rating²) ranges from 800 to 1,600 kW
- Typical seating capacity²) ranges from 100 to 270
- Typical maximum speed²) ranges from 100 to 160 km/hour
- Over longer distances usually higher speed
- Typical tank volume²) for a 2-car MU approx. 1,600 l of diesel
- Typical range²),³) of approximately 1,000 km
- Depends e.g. on passengers on board, stops and topography
- Consumption 0.25-0.3 kg/km

- Lifetime 30 years⁴)

1) Duty cycle data from FINE D3.1 based on EN 50591 considered speed; 0.25 liters of fuel per kilowatt hour
2) For diesel Multiple Units recently purchased in main European markets
3) Based on tank volumes and average
4) Potentially replacement/refurbishment of fuel cells or parts of it necessary after certain period

Source: Expert interviews, Roland Berger
Multiple Units are generally within the range of the TCO of incumbent technology

**Detailed TCO – Multiple Unit in base case [EUR/km]**

<table>
<thead>
<tr>
<th></th>
<th>Diesel</th>
<th>FCH</th>
<th>Catenary-electrified</th>
</tr>
</thead>
<tbody>
<tr>
<td>Financing</td>
<td>0.6</td>
<td>0.8</td>
<td>0.6</td>
</tr>
<tr>
<td>Train maintenance</td>
<td>0.9</td>
<td>0.8</td>
<td>0.4</td>
</tr>
<tr>
<td>Train depreciation</td>
<td>0.7</td>
<td>0.9</td>
<td>0.7</td>
</tr>
<tr>
<td>Downtime</td>
<td>0.0</td>
<td>0.1</td>
<td>0.0</td>
</tr>
<tr>
<td>Infrastructure</td>
<td>0.1</td>
<td>0.7</td>
<td>3.0</td>
</tr>
<tr>
<td>Rail track fee</td>
<td>3.5</td>
<td>3.5</td>
<td>3.5</td>
</tr>
<tr>
<td>Fuel</td>
<td>1.9</td>
<td>1.5</td>
<td>0.4</td>
</tr>
<tr>
<td>Salary</td>
<td>0.5</td>
<td>0.5</td>
<td>0.5</td>
</tr>
<tr>
<td><strong>TCO</strong></td>
<td><strong>8.2</strong></td>
<td><strong>8.7</strong></td>
<td><strong>9.0</strong></td>
</tr>
</tbody>
</table>

Source: Expert interviews, Roland Berger

Comments:
- **Main drivers** for the Multiple Unit TCO difference include:
  - Fuel
  - Infrastructure
  - Maintenance
- **The cost premium** over diesel reaches EUR 0.5 per km
- **Due to high electrification costs**, a FCH train is competitive with a catenary-electrified train given a 100 km route length
“Study concludes that it should be technically feasible to build and operate a Hydrail System for the GO network, and the system’s overall lifetime costs are equivalent to the alternative of a conventional overhead electrification system”

CH2M Hill Canada report for Go Transit (2018)
Adapting fuel cell technologies to rail applications
We have the leading technology.

- World leader in PEM fuel cells
- 2,000 patents & applications
- 850 MW of fuel cell products shipped
- Over 1,200 heavy-duty fuel cell modules shipped to date
Fuel cell system design considerations for rail

- Component choice to reduce noise level and system weight
- Flexible system layout to meet space requirements (roof-top or custom configuration)
- Protection against dust ingress (safety hazard)
- System frame design to meet shock and vibe requirements
FCveloCity® for rail applications

- 100kW building block fuel cell power modules
- Customizable packaging to meet architecture constraints
- Designed and tested to rail-specific standards
- Proven fuel cell stack durability (over 30,000hrs in service)
Ballard scope of supply

Fuel cell power module Composition:

- Control Unit (CAN)
- Pressure Regulation
- Air Humidification
- H₂ Safety Systems
- Stack Hydrogen System
- Coolant Subsystem
- Air Compressor & Motor
- Stack Contactors
- Operational control system
  - Control Management
  - DC/DC Converter
  - Power Management

Fuel Cell Power Module, 100 kW Repeating Unit:

- Fuel Cell Stack
- Tank Control Unit
  - H₂ Tanks & Pressure Relief
  - Hydrogen Storage
- 24V Power Supply
  - Power Supply
- Air/Water Separation
- Product Water Reservoir
- Product Water Drain Valve
- Air Exhaust

Power Management:

- Battery Controller
- HV Battery
- Energy Storage System
- Drive Motor
- Motor Controller
- Traction power converters
- Radiator & Fan
- Drivetrain System

Heat Management:

- Expansion Tank
- Deionized Water Filter
- Radiator & Fan

Option:

Air Inlet Filter
Ballard rail standards and product testing experience

- Experienced with automotive and rail standards (~20 international rail standards)
- Extensive testing capability: vibe & shock, EMC, noise, dust ingress
From bus to rail

- 15 years of experience in designing heavy duty fuel cell engines.
- Integration experience with multiple vehicle platform (bus, truck, train)
- Proven technology with millions of operating hours in revenue service
We have extensive experience in rail applications

- JR East commuter rail in Japan (pic)
- Light rail projects with CRRC in China
- BNSF Railway shunt locomotive in the US
- Shunt locomotive in India
- Electric train retrofit project (UK)
- New train development program with Siemens
Prototype fuel cell powered shunt locomotive

- Moves railroad cars over short distances in yard
- 300-500kW gross power with 60kg hydrogen
- Refueled at hydrogen station within railyard
- Public-private project partnership with Vehicle Projects, BNSF Railway, US Army Corps of Engineers & Ballard
Fuel cell tram demonstration project in Tangshan.

- World’s first hydrogen-powered tram in pilot test phase
- 5 stations – 14 km lines
- 40 km range up to 70km/hour
- Hydrogen refilling in 15 minutes
- 3 cars, 66 seats and 336 passenger capacity
- Powered by 2 x FCveloCity® 150kW modules
Case Study: Fuel cell tram line in Foshan

- Project with CRRC Qingdao Sifang Co, Ltd
- Expected to enter in service in 2019 in Goaming district of Foshan
- Speed up to 70km/h with 125km autonomy – 394 passengers
- 18km line with 20 stops
- 200kW fuel cell module for rail applications
Case Study: Fuel cell tram line in Foshan

Ballard scope of work:

- Develop 200kW fuel cell system for rooftop light rail applications
- Meet rail-specific design standards
- Deliver 1 fuel cell system for engineering testing at Qingdao, China
- Deliver 9 fuel cell systems for revenue service in Foshan, China
Case Study: Fuel cell tram line in Foshan

FCveloCity®-XD:
- Integrated 200kW fuel cell power module
- Robust design: reinforced frame with rigid plumbing
- Built-in fire suppression systems
- Easy service access
- Weight and noise optimized
Hydrogen Refueling Station

- Location: Zhihu Stop (First stop)
- Area: 3,700m²
- Daily Refueling Capacity: 1,000kg
- Refueling Pressure: 35MPa
- Refueling Event: 3-4 times/day (summer), 20kg/time
- Construction Company: Guolian Hydrogen
- Operation Company: Guolian Hydrogen
- Status: Under Construction
- Start of Operation: July 30, 2019 (EST)
Hydroflex project

- Conversion of a classic 'Class 319' electric unit to be supplied by Porterbrook into hydrogen powered train “HydroFlex”

- Development work has commenced and HydroFlex will undertake testing and demonstration runs in summer 2019

- Ballard supplies 100kW FCveloCity®-HD fuel cell power module to be integrated to existing electric drive as “range extender”

- The HydroFlex will retain the ability to operate across existing electric routes (on either 3rd rail or 25kV overhead power) and with the addition of a hydrogen fuel-cell it will also be capable of operating in self-powered mode, without the need for diesel engines

- This demonstrator version focuses on delivering an electric/hydrogen bi-mode to UK gauge and the need to make more effective use of existing electrification with additional emission-free running beyond the wires.

British Class 319 dual-voltage electric multiple unit
Development of a new generation of hydrogen powered EMU with Siemens
Mireo Plus – value added for our customers

- Minimum Energy Consumption
- Minimum Investment
- Minimum Maintenance Cost
- Flexible for different applications
- EMU Performance

The focus of our innovation roadmap is the improvement of life cycle cost
Hydrogen is the energy source for fuel cells

- A clean energy carrier and energy storage
- Commercially available
- Can be produced from natural gas, biogas, and electricity (including renewable sources)
- Hydrogen contributes to energy independence
Hydrogen is a zero-carbon flexible fuel

- Safe and manageable
- High power density and storage capacity
- Supplied as compressed gas or liquid
- Can also be produced on-site
- Existing infrastructure solutions
- Scalable fuelling infrastructure
The Fuel Cell Hydrogen Train Eco-System

Source: Shift2Rail – FCH-JU study 2019
“FCH trains are cost-competitive when designed for long non-electrified lines over 100 km in length;

FCH trains are especially viable for main routes with very low utilization (maximum 10 trains per day) but also for last mile transport;

High hydrogen infrastructure utilization (hydrogen refueling station, electrolyser) and low cost electricity (less than EUR 50/MWh) provide favorable conditions for the FCH technology;

FCH trains are characterized by relatively fast refuelling resulting in less than 20-minute downtimes and can be operated for more than 18 hours without refuelling.”

(Shift2Rail – FCH-JU study 2019)
Further Reading

_shift2rail - FCH-JU study 2019 reports_
STUDY ON THE USE OF FUEL CELLS AND HYDROGEN IN THE RAILWAY ENVIRONMENT

Metrolynx report 2018
Regional Express Rail Program Hydrail Feasibility Study Report

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