Hydrail: Moving Passengers Today and Freight Tomorrow

Rob Harvey
Director, Energy Infrastructure

H2@Rail Workshop
Lansing, MI
March 27, 2019
On a clear day you can see the future
Alstom’s Coradia iLint—world’s first hydrogen train now in service
China Railway Rolling Stock Corp (CRRC) Hydrail Trams
Commuter Hydrail Retrofit in the UK

United Kingdom
Breeze Converted Class 321 Trains

© Alstom
The Business Case for Zero-Emission Passenger Hydrail based on the combined Rolling Stock and Energy Infrastructure TCO

- **Diesel MU**
  - Diesel Fueling Infrastructure
    - Mature Energy Supply Chain
    - Operator Storage and Dispensing

- **Electric MU**
  - Overhead Catenary System
    - Operator builds entire system—catenary wires, traction power system and grid interconnection

- **Hydrogen MU**
  - Hydrogen Fueling Infrastructure
    - Build-out H2 Prod’n and Distribution
    - Operator Onsite Hydrogen Storage and Dispensing
Passenger Hydrail vs. OCS Electric

- Lower upfront Capex and lower TCO over time
- Avoids roadwork disruptions and utility relocates for faster implementation and revenue capture
- Greater operational flexibility by providing service on both diesel and electrified lines
- Scalable solution as capacity can be added to meet ridership growth over time
- Avoids negative aesthetics and visual impact of overhead wires in urban areas
- Hydrail rolling stock costs and fueling infrastructure will decrease dramatically over next decade
Global Leader in Hydrogen Technology

70 years of experience in delivering top-tier hydrogen solutions

Over 2,000 fuel cell and 500 electrolyzer installations around the world

Supplied equipment for 55+ fueling stations

Serving customers in 100+ countries around the world

Publicly traded: NASDAQ (HYGS) and TSX (HYG)

Over 145 patents

Segments:
Hydrogen Generation
Fuel Cell Power Systems

Leading PEM stack and system technology, including unmatched power density in a single stack (3MW)
**Fuel cells** use hydrogen to create electricity for **mobility** and **critical power applications**

1. **Fully Integrated Systems**
   - Integrated software and mechanical control
2. **Differentiated Technology**
   - Self-humidified, low-pressure stack
3. **High Reliability**
   - Unlimited start/stop, sub-zero operation
4. **Flexible Architecture**
   - Scalable stack for mobility and stationary applications
Safety & Predictive Maintenance

• Design based on FMEA (Failure Mode and Effects Analysis)
• Multi-function stack end plate
• Integrated manifold
• Hardware safety
  – Temperature, Pressure connect to the H2 inlet solenoid
• Predictive maintenance and improved system availability
• Advanced onboard controls and diagnostics
  – Self-check can give a stack health report after each run
• Shock & vibration system tolerance

Multi-function stack end plate
Fuel delivery assembly
Cell voltage graph
Fuel Cell Power Modules for Mobility Applications

30 kW
- PEM FC Power Module
- Fundamental Building Block
- Freeze-protected
- Integral Balance of Plant
- Ease of Integration

60 kW
- CELERITY designed for heavy duty; ready connection with Siemens ELFA electric drive
- Full feature set, including Pre-charge, Load contactor, reverse current protection, IP rated enclosure

120+ kW
- Multiple HD30 FC modules plus:
  - Frame and enclosure
  - Manifolding
  - Single interface set
  - 120/150/180/240kW+ variants
Powering Planes, Trains, and Buses and Trucks

Germany

Germany

USA

China

USA

Switzerland
## Coradia iLint HyPM™ Design and Delivery Schedule

<table>
<thead>
<tr>
<th>Date</th>
<th>Design and Delivery Schedule:</th>
</tr>
</thead>
<tbody>
<tr>
<td>2014-09</td>
<td>LOI signed by 4 German States</td>
</tr>
<tr>
<td>2015-09</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; Prototype FC System delivered</td>
</tr>
<tr>
<td>2016-09</td>
<td>Unveiling at Innotrans Exhibition, Berlin</td>
</tr>
<tr>
<td>2017-03</td>
<td>1&lt;sup&gt;st&lt;/sup&gt; two Pre-Series trains on track testing</td>
</tr>
<tr>
<td>2018-1H</td>
<td>Completion of Type Approval testing</td>
</tr>
<tr>
<td>2018-2H</td>
<td>Pre-series validation in revenue service</td>
</tr>
</tbody>
</table>
HyBalance Facility, Denmark
Producing hydrogen for refueling stations and industrial customers.

- Electrolyser
- Compression
- High pressure storage
- Refilling station

Dual PEM Stack
Markham Energy Storage Facility, Ontario
Grid Balancing Services for IESO
What’s Holding Us Back for Commuter Hydrail?

❖ Industry is ready for commercial deployments for hydrogen rolling stock
  ▪ Fuel Cell companies have been working directly with the rolling stock suppliers to develop the design and integration for several years now
  ▪ Demonstration trials underway have validated design and performance characteristics

❖ Scaling of hydrogen fueling infrastructure capacity
  ▪ Hydrogen production and distribution scale exists for refineries today
  ▪ Electrolysis is established technology, but larger scale plants required for Hydrail
  ▪ Required fueling dispensing volumetric and transfer rates are achievable with today’s engineering capabilities

❖ Volume production
  ▪ No technology limiting barriers, but component supply chain is immature today
  ▪ Volume production needed to accelerate cost reductions over next decade

❖ Project financing and structures
  ▪ Railway operators accustomed to 30+ year asset planning horizon and life
  ▪ New hydrogen technology has higher risk than century old Overhead Catenary System
What about Hydrail Freight Trains?

<table>
<thead>
<tr>
<th>Commuter Hydrail</th>
<th>Freight Hydrail</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rolling Stock</td>
<td></td>
</tr>
<tr>
<td>Shorter Operating Range</td>
<td>No technical issue for FC electric power on Class I Locomotive</td>
</tr>
<tr>
<td>On-board Gaseous Fuel Storage</td>
<td>Long haul freight routes</td>
</tr>
<tr>
<td>Overnight Fleet Stabling</td>
<td>Gaseous hydrogen not feasible</td>
</tr>
<tr>
<td>Centralized Depot Refueling</td>
<td>North America wide operator logistics</td>
</tr>
<tr>
<td></td>
<td>Massive investment for hydrogen fueling infrastructure network required</td>
</tr>
</tbody>
</table>
Freight Hydrail Research Needs

❖ Operating range and hydrogen fueling infrastructure are constraints today

❖ On-board liquid hydrogen is feasible option as it would provide sufficient energy density for long-haul freight trains, but massive fueling infrastructure investment to support North American network

❖ Other fuel options are on-board liquid at ambient
  ▪ Methanol
  ▪ LOHC
  ▪ Ammonia

❖ Let’s not lose sight of the H2@Scale end goal
Rob Harvey
Director, Energy Infrastructure
rharvey@hydrogenics.com
905-361-4587