Harnessing Renewable Energy Storage and Powering Fleets with Hydrogen Fuel Cell Hybrids in Heavy Mobility

HydRail 2016
July 4th and 5th, Birmingham, United Kingdom

Mark Kammerer
Business Development
Hydrogenics GmbH
## Hydrogenics at a glance

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<th>Power Systems Group</th>
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<td>PEM Fuel Cells</td>
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<td>Hydrogen Fueling</td>
<td>Power-to-X</td>
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<td>HySTAT™ D30</td>
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A significant increase in the capture and utilization of renewable energy is **only possible with matching capacity of Energy Storage**

Falkenhagen Region in Northern Germany

- Increasing excess power
- Huge peak power
- Steep power gradients

Solution: Storage of excess wind power instead of curtailment.

Source: Presentation by Dr. Alexander Vogel, Head of Alternative Energy Systems, E.ON Ruhrgas at Gas to Power Conference, Cologne, Germany – November 2012
The required Energy Storage Capacity while meeting the Emissions targets is only achievable with Hydrogen.
The required Energy Storage Capacity is only achievable with Hydrogen

Hydrogen storage far exceeds the capacity of competing storage technology

This much could be fed into an underground hydrogen reservoir (2 M m3 salt cavern):
600,000 MWh
Renewable H₂ in Electricity, Gas, Transport & Industry
A World Leader in Hydrogen Generation

- **Industrial Hydrogen Generation**
  - Commercialized business with global leading market share in water electrolysis
  - #1 and #2 clients:

- **Electrolysers for Fueling Stations:**
  - Supplied Electrolysers to over 55 stations worldwide, more than any company globally
  - 1 and #2 clients:

- **Electrolysers for Energy Storage:**
  - Leading market share of Power-to-gas projects globally
  - Leading power density PEM Electrolyzer at 1.5MW in a single stack
  - “Lighthouse” projects with:
Over 500 type « IMET » HySTAT-A Electrolyser Units delivered since 1998 Worldwide

Saudi Arabia: Powerplant  
Russia: Float Glass  
Romenia: Float Glass

Ukraine: Metallurgy  
China: Merchant Gas  
Greece: Solar Industry

90% in Industrial Applications
10% in Renewable and Transportation
Electrolyzers in Energy Storage
Electrolysers in Hydrogen Fueling Stations

Stuttgart, Germany  Flanders, Belgium  Bolzano, South Tyrol, Italy

Oslo, Norway  Brugg, Switzerland  Aberdeen, Scotland
Hydrogen Fueling Stations for FC Bus Fleets

11 of 13 electrolyzer FC Bus fueling stations with HySTAT by Hydrogenics

Legend:
Electrolyser HFS
Hydrogenics Electrolyser

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<tr>
<th>CUTE</th>
<th>HYFLEET</th>
<th>CHIC</th>
<th>HiVLOCity</th>
<th>HyTransit</th>
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<tbody>
<tr>
<td>Reykjavik</td>
<td>Reykjavik</td>
<td>Bolzano</td>
<td>Aberdeen</td>
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<td>Amsterdam</td>
<td>Amsterdam</td>
<td>Aargau</td>
<td>San Remo*</td>
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<tr>
<td>Porto</td>
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<td>Hamburg</td>
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<td>Barcelona</td>
<td>Barcelona</td>
<td>Oslo</td>
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<tr>
<td>Hamburg</td>
<td>Hamburg</td>
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<tr>
<td>Stockholm</td>
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</tbody>
</table>

Others:
Malmö (SE), Barth (DE), Stuttgart (DE), Helmond (NL), Swindon (UK)

- Hamburg: 260 kg/d
- Amsterdam: 320 kg/d
- Stuttgart: 130 kg/d
- Stockholm: 130 kg/d
- Others: Malmö (SE), Barth (DE), Stuttgart (DE), Helmond (NL), Swindon (UK)

2001
- 0.3 MW

2017
- 0.3 MW
- 0.6 MW
- 1 MW
Large Scale Power-to-Gas/-Industrial/-Fuel

40 MW = 8 000 Nm3/h = 720 kg/h
17 000 kg/24h (850 FC Buses/day)

60m x 25m footprint

Concurrently Ancillary services, Demand response, Energy storage…
Alstom Transport Regional Commuter Rail

- Nearly 50% of German Rail network is not electrified and currently operated with Diesel propulsion
- Regulations for exhaust emissions are becoming more challenging
- Incumbent solution (electric cables) cost is 1-5 $million per km
- At current investment rate of 230 Million €/year, electrification of the complete network will take 95 years
- Diesel prices in Germany expected to double from 1 €/L in 2010 to 2 €/L in 2025
- Noise regulations intensified 4 times since 2001
FC System Levels and Value Chain:

**PEM Single Cell**
- Proton Exchange Membrane
- MEA - Membrane Electrolyte Assembly
- Bipolar plates
- Gas Diffusion layer
- Gaskets

**Fuel Cell Power Module**

**Hybrid System**
- Fuel management
- Air management
- Water management
- Coolant pump and Control
- Control hardware and software
- Power conditioning
- Hybrid energy storage
- Hybrid control hardware and software
- Cooling rad or heat exchanger (or CHP)
- H₂ storage

**Stack with integral Balance of Plant**
- Multiple cells layered into a stack, including:
  - End plates
  - Tie rods
  - Spring washers
  - Bus bar interfaces
  - Fuel cell voltage monitor

**Integrators, OEMs**

**OEMs, Fleet Owners**

**Hydrogenics Marketed Products**

**Hydrogenics Core Competence**
The 2015 HyPM™ Mobility Portfolio

**HD 200 Series**

<table>
<thead>
<tr>
<th>HyPM™</th>
<th>HD 4-200</th>
<th>HD 5-200</th>
<th>HD 8-200</th>
<th>HD 8-200 aero</th>
<th>HD 10-200</th>
<th>HD 10-200 aero</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous Power [kW]</td>
<td>4.5</td>
<td>5.5</td>
<td>8</td>
<td>8</td>
<td>10</td>
<td>10</td>
</tr>
</tbody>
</table>

**HD 500 Series**

<table>
<thead>
<tr>
<th>HyPM™</th>
<th>HD 8-500</th>
<th>HD 10-500</th>
<th>HD 12-500</th>
<th>HD 15-500</th>
<th>HD 20-500</th>
<th>HD 30-500</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous Power [kW]</td>
<td>8.5</td>
<td>10.5</td>
<td>12.5</td>
<td>15.5</td>
<td>20</td>
<td>33</td>
</tr>
</tbody>
</table>

**Heavy Mobility**

<table>
<thead>
<tr>
<th>HyPM™</th>
<th>HD 60</th>
<th>HD 90</th>
<th>HD 120</th>
<th>HD 180</th>
<th>HD 300</th>
<th>Vehicle Packages</th>
</tr>
</thead>
<tbody>
<tr>
<td>Continuous Power [kW]</td>
<td>66</td>
<td>99</td>
<td>132</td>
<td>198</td>
<td>298</td>
<td>3...MW</td>
</tr>
</tbody>
</table>
HyPM™ HD60 **CELERITY**

- “All-in” design including all HyPM HD features, additionally with…
  - IP rated enclosure
  - Engine bay form factor
  - Voltage range for direct connection to OEM electric drive systems
  - Load contactor
  - Reverse current protection
  - Current pre-charge
  - J1939 communications

- **HyPM™ HD60 Celerity PLUS:**
  - Pre-validated and bundled with SIEMENS ELFA Electric Drive System
1.8 MW (15 @ 120 kW)

Primary side cooling loop with three sets of heat exchangers and cooling pumps, with 15 Fuel Cell Racks (in background), totaling 1800 kW gross power. 5 racks per cooling loop.
Example: Options for 120 kW

<table>
<thead>
<tr>
<th>HyPM™</th>
<th>4 x HD 30</th>
<th>1 x HD 120</th>
<th>2 x HD60</th>
<th>1 x HyPM-R120</th>
</tr>
</thead>
<tbody>
<tr>
<td>Rated Power</td>
<td>kW</td>
<td>120</td>
<td>120</td>
<td>120</td>
</tr>
<tr>
<td>Number of Stacks</td>
<td></td>
<td>4</td>
<td>4</td>
<td>8</td>
</tr>
<tr>
<td>Voltage Range</td>
<td>[V&lt;sub&gt;DC&lt;/sub&gt;]</td>
<td>480…240</td>
<td>480…240</td>
<td>2 @ 640…300</td>
</tr>
</tbody>
</table>

Diagram showing various components and connections, including labels for purge, drain, H2 supply, and coolant.
Example Layout - Public Transit Bus 1
Example Layout - Public Transit Bus 2
Example Layout - Public Transit Bus 3
Wide range of options in form and fit
Trucks: flexible power as needed, easy Integration,
HyPM™ in Urban Transit Bus Applications

Cardiff, Wales

Winnipeg, Canada & Scottsdale, AZ

Aachen, Germany

Honolulu, Hawaii

Volcano National Park, Hawaii

San Francisco, CA USA

Barth, Germany

Los Angeles, CA

Perugia IT
HyPM™ in Heavy Commercial Fleet Applications

- Basel, Switzerland
- Toronto, Canada
- Salzburg, Austria
- Joint Base Hickham-Pearl Harbor
- Joint Base Hickham-Pearl Harbor
- Joint Base Hickham-Pearl Harbor
- Spain
- Los Angeles, CA, USA
- Los Angeles, CA USA
California Energy Commission’s “Medium & Heavy-Duty Vehicle Technology Demonstration” Program

- “Advanced Fuel Cell Vehicle Technology Demonstration for Drayage Truck”
  - Integrators: Hydrogenics and Siemens
  - Fuel Cell: CelerityPlus™
  - Electric Drive: Siemens ELFA system
  - Operator: Total Transportation Services, Inc. (TTSI)
  - Location: Alameda Corridor and the ports of Long Beach and Los Angeles

- “New Flyer Advanced Fuel Cell Vehicle Technology Demonstration for Bus”
  - Integrator: New Flyer
  - Fuel Cell: Hydrogenics’ CelerityPlus™
  - Vehicle: 40-foot Xcelsior transit bus platform
  - Technical Support: Siemens
  - Operator: SunLine Transit
  - Location: Coachella Valley, California.
Commercialization in Transport and Power

- **China** - Bus Commercialization Program
  - Broad supply agreement for fuel cells for over 2000 buses including four bus builders, among them, the world’s largest

- **China** – Development Agreement
  - $13.5M Strategic partnership agreement with SinoHytec for co-development and supply of FC power systems

- **South Korea** – Industrial Prime Power
  - Worlds Largest 24x7 PEM Fuel Cell Plant, a 1 MW pilot with expected expansion into multi-megawatts
Fuel Cell Electric nose gear drive
DLR’s Airbus A320 – Advanced Technology Research Aircraft

30 June 2011

ANTARES-DLR-H2 Gen2

HyFLY Project
First flights planned in 2016

HyPM™ HD10-200

HyPM™ XR12

HyPM™ XR12

Airworthy Technology Development Platform

Multifunctional:
• APU replacement
• Emergency power
• Water production

Flights across Germany, 2013
Regional Train Commercialization in Germany

- **2014-09-24** Alstom to develop a new emission-free passenger trains in Germany
  - LOI to purchase 40 fuel cell-powered regional trains signed by 4 German States
  - Commercial service on non-electrified regional lines in Germany by 2020

- **2014-11-12**: Fuel cell drives to replace diesel railcars – National Innovation Programme hits the rails
  - The Federal Ministry for Transport and Digital Infrastructure (BMVI) supporting the development of a new generation of rail vehicles with fuel cell drives from the company Alstom.

- **2015-05-27**: Hydrogenics and Alstom Transport Sign Agreement to Develop and Commercialize Hydrogen-Powered Commuter Trains in Europe
  - Valued at over €50 million, including the supply of at least 200 engine systems along with service and maintenance support over a 10 year period