REVIEW OF WORLD AND EUROPEAN HYDROGEN INITIATIVES IN TRANSPORT AND ENERGY SECTORS

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Sales Manager EMEA
Hydrogenics Europe NV - OnSiteGeneration

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Agenda

1. Hydrogenics in a nutshell
2. Electrolysers (AWE & PEMWE) and Fuel Cells
3. Project review: Transport, Storage & CO$_2$ usage
Introduction video

https://youtu.be/UJXhX4dLMtA
Hydrogenics, a leading hydrogen technology provider

Onsite Generation | Electrolysers
H₂O + electricity $\rightarrow$ H₂ + ½ O₂

Power Systems | Fuel Cell Modules
H₂ + ½ O₂ $\rightarrow$ H₂O + electricity

Industrial Hydrogen
Hydrogen Fueling

Stand-by Power
Mobility Power
Hydrogenics, a 100% global hydrogen company

**Hydrogenics Corporation**
- **Headquarter**
  - Mississauga, Ontario, Canada
  - Since 1948
  - +/- 70 employees
- Areas of expertise: Fuel cells, PEM electrolysis, Power-to-Gas
- Previously: The Electrolyser Company, Stuart Energy

**Hydrogenics Europe**
- Oevel, Belgium
- Since 1987
- +/- 70 employees
- Areas of expertise: pressurized alkaline electrolysis, hydrogen refueling stations, Power-to-Gas
- Previously: Vandenborre Hydrogen Systems

**Hydrogenics GmbH**
- Gladbeck, Germany
- Since 2002
- +/- 15 employees
- Areas of expertise: Fuel cells, mobility projects, Power-to-Gas

In total: +170 employees
- Incorporated in 2000 [NASDAQ: HYGS; TSX: HYG]
- More than 3,000 products deployed in 100 countries worldwide
- Total revenues (2017): 48.1 Mio $
- Over 65 years of electrolysis leadership

![Diagram showing locations of production facilities and sales offices for Hydrogenics Corporation, Hydrogenics Europe, and Hydrogenics GmbH.](image-url)
Our ‘Renewable Hydrogen’ vision
Agenda

1. Hydrogenics in a nutshell
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But most of the hydrogen produced today is not CO₂-free (from gas, oil, coal)

If produced from renewable power via electrolysis, hydrogen is fully renewable and CO₂-free.

Renewable hydrogen has the potential to decarbonize a large range of applications

Data source: The Hydrogen Economy, M. Ball 2009 & Esprit Associates 2014
HySTAT™ - alkaline electrolyser
Extensive industrial experience with alkaline technology
Our product line | Alkaline & PEM electrolysis

<table>
<thead>
<tr>
<th></th>
<th>HySTAT®-15-10/27</th>
<th>HySTAT®-60-10/27</th>
<th>HySTAT®-100-10/27</th>
<th>HyLYZER®-250-30</th>
<th>HyLYZER®-1000-30</th>
<th>HyLYZER®-3,000-30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output pressure</td>
<td>10 barg – 27 barg</td>
<td></td>
<td></td>
<td>30 barg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of cell stacks</td>
<td>1</td>
<td>4</td>
<td>6</td>
<td>1</td>
<td>2</td>
<td>6</td>
</tr>
<tr>
<td>Nominal Hydrogen Flow</td>
<td>15 Nm³/h</td>
<td>60 Nm³/h</td>
<td>100 Nm³/h</td>
<td>250 Nm³/h</td>
<td>500 Nm³/h</td>
<td>3000 Nm³/h</td>
</tr>
<tr>
<td>Nominal input power</td>
<td>80 kW</td>
<td>300 kW</td>
<td>500 kW</td>
<td>1.25 MW</td>
<td>2.5 MW</td>
<td>15 MW</td>
</tr>
<tr>
<td>AC power consumption</td>
<td>5.0-5.4 kWh/Nm³</td>
<td></td>
<td></td>
<td>5.0-5.4 kWh/Nm³</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrogen flow range</td>
<td>40-100%</td>
<td>10-100%</td>
<td>5-100%</td>
<td>1-100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrogen purity</td>
<td>99.998%</td>
<td></td>
<td></td>
<td>99.998%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Tap water consumption</td>
<td>&lt;1.5 liters / Nm³ H₂</td>
<td></td>
<td></td>
<td></td>
<td>&lt;1.4 liters / Nm³ H₂</td>
<td></td>
</tr>
<tr>
<td>Footprint</td>
<td>20 ft container</td>
<td>40 ft container</td>
<td>40 ft container</td>
<td>40 ft container</td>
<td>2 x 40 ft container</td>
<td>600 m²</td>
</tr>
</tbody>
</table>

Alkaline & PEM (Proton Exchange Membrane)
2018

HyLYZER® -500-30
2.5 MW PEM Electrolyser

- Containerized design & compact footprint: 2 x 40 ft
- Plug&Play modular design based on 2 x 1,25 MW cell stacks
- Fully tested & certified @ Hydrogenics’s factory
New benchmark: 2.5 MW PEM cell stack from Hydrogenics for multi-MW projects

1. Compact MW Scale Electrolyzer Stack
   3.0 MW industry benchmark

2. Reduction of Plant Capital Costs
   Achieved target system cost

3. Stack Efficiency Improvements
   Leading industry performance

4. Fast Response and Dynamic Operation
   Key IPR established

5. Higher pressure
   H2 system delivery at 30 bar

6. Reduced Maintenance
   Limited and optimised

Power Input: 1.25 MW
Hydrogen Output: 260 Nm³/h
Design Pressure: 40 bar

Power Input: 2.5 MW
Hydrogen Output: 520 Nm³/h
Design Pressure: 40 bar
2019

HyLYZER® 1000-30
5MW PEM Electrolyser

- Containerized design & compact footprint: 2 x 40 ft
- Peripherals in a separate container
- Plug&Play modular design based on 2 x 2.5MW cell stacks
Power-to-Mobility
A range of hydrogen fuelled passenger cars are emerging

<table>
<thead>
<tr>
<th>COMMERCIALLY AVAILABLE TODAY</th>
</tr>
</thead>
<tbody>
<tr>
<td>Hyundai ix35 SUV (2014)</td>
</tr>
<tr>
<td>Toyota (2015)</td>
</tr>
<tr>
<td>Symbio F-Cell (2015)</td>
</tr>
<tr>
<td>(range extender on Renault Kangoo)</td>
</tr>
</tbody>
</table>

... Daimler, Honda, BMW, Porsche, Audi, Nissan, VW (2017-2020)

... And buses, trucks, forklifts: Van Hool, VDL, Mercedes-Benz, e-Trucks, Plug Power, Still, Nicola, Hyundai trucks, Toyota buses, ...

Maritime Applications
Fuel cells for mobility applications
Many references
Hydrogen refueling stations
> 50 references with onsite hydrogen production

Shell, Santa Monica, USA
Aberdeen Hydrogen Bus Project, Scotland, UK, 2015
Stockholm, Sweden, 2005
Oslo, Norway, 2012
Vattenfall, Hamburg, Germany, 2012
Barcelona, Spain, 2005
Agenda

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Fueling

A station consists of:

• **Source of Hydrogen**
  - Electrolysis, Delivered, Pipe-line, ...

• **Compression**
  - 350bar (450bar) for buses/Utility Vehicle
  - 700bar (950bar) for cars

• **Storage**
  - Useable storage vs. Total stored volume
  - 3-bank storage system for more efficient use

• **Dispensers**
  - 350bar/700bar dispensers & different nozzles
  - Chillers for pre-cooling (SAEJ filling protocol)
  - Communicated filling (IR)
Hydrogenics References HRS:

- Over 50 Electrolyzers installed in HRS:
  - ACHES – Aberdeen: 130kg/day, 350bar/700bar Station HYGS
  - Colruyt (WaterstofNET) Station– Halle (B): 200kg/day 350bar station HYGS
  - WaterstofNET station – Helmond (NL): Electrolyzers for 350bar/700bar station
  - Projects with LINDE (Bolzano, Stuttgart, Hamburg, Aberdeen (Kitty Brewster), Swindon, Porto, Estonia, ...)
  - Projects with Air Liquide (Oslo, Aarau, Bella Coola, ...)
  - Projects with Shell (Santa Monica, CUTE Amsterdam)
  - Projects with BP (CUTE Barcelona, LAX Airport)
  - Car Manufacturers:
    - Ford USA (Yucca AZ & Detroit)
    - Honda UK (Swindon)
    - Toyota USA (Torrence CA)
Aberdeen Scotland - ACHES

- Hydrogenics:
  - Complete design
  - 1 X HySTAT-60
  - CSD for 350 bar and 700bar fueling station
  - Installation and S&C (02/2017)
Aberdeen Scotland – Kitty Brewster

- Hydrogenics : 3 X HySTAT-60
- BOC : CSD for 350 bar fueling station
Hydrogen can be used to replace gasoline and fuel buses or cars.

Aberdeen Hydrogen Bus Project
Scotland (UK)
Open since 02/2015

1MW Electrolysis – 400kg/day
~ 1,500L gasoline = 15 busses

350bar dispensing
Project with BOC (Linde)
Oslo Norway

- HySTAT-120 350 bar fueling station (Air Liquide)
Bolzano, Italy

- HySTAT-180 indoor

- 350/700 bar fueling station (Linde)
Shell Santa Monica

- HySTAT-15
- 700 bar fueling station
Colruyt (Halle, Belgium)

• Don Quichote (FCH JU project, 9 partners)
  
  • OBJECTIVES
    • Direct use of highly fluctuating RE into the electrolyzers & peripheral equipment.
    • Feasibility study of electrochemical compressor
    • Use H₂ for transport in FC vehicles
  
  • SOLUTION
    • Development of a new 30Nm³/h HyLYZER™ PEM electrolyser.
    • Electrochemical Compressor – higher efficiency, more sustainable and smaller footprint.
    • Connection to existing wind turbines; expansion of the existing Colruyt fueling station
Hydrogen can be used to replace gasoline and fuel busses or cars.

130kg/day = 490L gasoline = 5 busses
350bar dispensing, Norway
Hydrogen can be used to replace gasoline and fuel buses or cars.

780 kg/day = 2'950 L gasoline = 200 cars
350/700 bar dispensing, Germany
• 400kg/day, 350 and 700bar dispensing
• The station is part of the CHIC project and is installed near the Autobrennero highway in Bolzano.
• Five EvoBus busses are driving in the city and can be refueled in the same time as traditional busses.
• The station will have three HySTAT™ 60Nm³/h electrolyzers to produce 180Nm³/h hydrogen and will be operational beginning 2014.
Brügg, Switzerland

- 130kg/day, 350bar dispensing
- The station is part of the CHIC project and is installed at the Postauto bus station near Brügg.

- Five Daimler Citaro H₂ busses are being operated and can be refueled in the same time as traditional busses.

- The station has a HySTAT™ 60Nm³/h electrolyser, two membrane compressors and 5’500Nm³ high pressure storage at 410bar.
Hydrogen can be used to replace gasoline and fuel busses or cars.

- Fueling 65kg/day = 245L gasoline = 15 cars
- 350bar dispensing, Belgium, Halle
Renewable hydrogen
Selection of recent demonstration projects

<table>
<thead>
<tr>
<th>Country</th>
<th>Project</th>
<th>Size</th>
<th>Year</th>
<th>Electrolyser technology</th>
<th>Power</th>
<th>Gas</th>
<th>Industry</th>
<th>Mobility</th>
<th>Fuel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Norway</td>
<td>Haeolus</td>
<td>2 MW + 100 kW FC</td>
<td>2018</td>
<td>PEM</td>
<td>•</td>
<td></td>
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<td></td>
<td>•</td>
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<tr>
<td>Germany</td>
<td>MefCO2</td>
<td>1 MW</td>
<td>2018</td>
<td>PEM</td>
<td>•</td>
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<tr>
<td>Germany</td>
<td>WindGas Brunsbuttel</td>
<td>2.4 MW</td>
<td>2017</td>
<td>PEM</td>
<td>•</td>
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<tr>
<td>Thailand</td>
<td>EGAT</td>
<td>1 MW + 300 kW FC</td>
<td>2017</td>
<td>PEM</td>
<td>•</td>
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<tr>
<td>Canada</td>
<td>Embridge P2G</td>
<td>2.4 MW + 100 kW FC</td>
<td>2017</td>
<td>PEM</td>
<td>•</td>
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<td></td>
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<tr>
<td>Denmark</td>
<td>HyBalance</td>
<td>1.2 MW</td>
<td>2017</td>
<td>PEM</td>
<td>•</td>
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<tr>
<td>Denmark</td>
<td>BioCat</td>
<td>1 MW</td>
<td>2016</td>
<td>Alkaline</td>
<td>•</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Italy</td>
<td>Ingrid</td>
<td>1 MW + 100 kW FC</td>
<td>2016</td>
<td>Alkaline</td>
<td>•</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UK</td>
<td>Aberdeen</td>
<td>1 MW</td>
<td>2016</td>
<td>Alkaline</td>
<td>•</td>
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<tr>
<td>Germany</td>
<td>WindGas Reitbrook</td>
<td>1.5 MW</td>
<td>2015</td>
<td>PEM</td>
<td>•</td>
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<tr>
<td>Belgium</td>
<td>DonQuichote</td>
<td>150 kW + 100 kW FC</td>
<td>2015</td>
<td>Alkaline + PEM</td>
<td>•</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Germany</td>
<td>WindGas Falkenhan</td>
<td>2 MW</td>
<td>2012</td>
<td>Alkaline</td>
<td>•</td>
<td></td>
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</tbody>
</table>

+ CO₂

Main conclusions from these projects:
1. Hydrogen technologies work fine and deliver according to expectations.
2. There is still room for further technical improvement but no technology breakthrough is expected.
3. There is an important potential for further cost reduction: going from project manufacturing to product manufacturing.
4. Energy regulatory framework is no suited for these applications and business operation of these projects remains very challenging.
**BioCat, Avedøre, Denmark (2016)**

Biological methanation and SNG injection in distribution gas grid

[Image of the BioCat project facility]

www.biocat-project.com
MEFCO$_2$, Niederaußem (Germany)
Power-to-Methanol

**OBJECTIVES**

- Produce **green methanol** as energy vector from captured CO$_2$ and hydrogen produced using surplus renewable energy.
- Existing post-combustion pilot CO$_2$ plant at coal power plant of RWE
- Flexible operation (RES driven)

**SOLUTION**

- 1x HyLYZER®-200-30 (PEM, single cell stack design) with all peripherals to produce 200 Nm$^3$/h H$_2$ (power: 1 MW)

**PARTNERS:**

- This project has received funding from the European Union’s Horizon 2020 research and innovation programme under grant agreement (No 637016).

**More information:** [www.mefco2.eu](http://www.mefco2.eu)
- **Budget:** 28M€
- **27 partners, coordinator:** DVGW

**Characteristics of the three demonstration sites**

<table>
<thead>
<tr>
<th>Demonstration site Falkenhausen/Germany</th>
<th>Demonstration site Solothurn/Switzerland</th>
<th>Demonstration site Troia/Italy</th>
</tr>
</thead>
<tbody>
<tr>
<td>Representative region with respect to typical generation of RES</td>
<td>Rural area in the North East of Germany with high wind power production and low overall electricity consumption</td>
<td>Municipal area in the Alps region with considerable RES from PV and hydro production</td>
</tr>
<tr>
<td>Connection to the electricity grid</td>
<td>Transmission grid</td>
<td>Municipal distribution grid</td>
</tr>
<tr>
<td>Connection to the gas grid</td>
<td>Long distance transport grid</td>
<td>Municipal distribution grid</td>
</tr>
<tr>
<td>Plant size (in relation to the el. power input)</td>
<td>1 MW</td>
<td>700 kW</td>
</tr>
<tr>
<td>Methanation technology to be demonstrated</td>
<td>Isothermal catalytic honeycomb/structured wall reactors</td>
<td>Biological methanation</td>
</tr>
<tr>
<td>CO₂ source</td>
<td>Biogas or bioethanol plant</td>
<td>Waste water treatment plant</td>
</tr>
<tr>
<td>Heat integration possibilities</td>
<td>Veneer mill</td>
<td>District heating</td>
</tr>
<tr>
<td>Existing facilities and infrastructure</td>
<td>2 MW alkaline electrolyser, hydrogen injection plant</td>
<td>350 KW PEM electrolyser, hydrogen injection plant, district heating, CHP plant</td>
</tr>
</tbody>
</table>

**Movie on Store & Go – Troia:**
[https://youtu.be/7IEVER8aQdY](https://youtu.be/7IEVER8aQdY)

NB: Hydrogenics is not part of the consortium, but 2 sites will use Hydrogenics’ electrolyzers.
INGRID (Puglia, Italy)

• INGRID (24Mio€ FCH JU project, 7 partners)

• OBJECTIVES
  • Allow increased penetration of highly fluctuating RE into the grid using electrolysis and supply-demand balancing.
  • Improvement of distribution operation through active/reactive power control for optimal voltage regulation and power quality.
  • Use H₂ for transport, industry, grid balancing and injection into the gas network.

• SOLUTION
  • 1MW HySTAT™ electrolyser in a 40Ft. Housing to produce 200Nm³/h H₂.
  • 60kW Fuel Cell backup system.
  • 39 MWh, 1,000kg solid hydrogen storage system.
Summarized

- **Hydrogenics**: manufacturer of Electrolyzers & Fuel Cells
- **Electrolyzers** to produce Renewable Hydrogen from electricity
  - Incl. Services as Grid Balancing & storing curtailment energy – Power to Gas (Storage)
- **Renewable Hydrogen to be used to replace grey hydrogen in industrial processes**
  - Power to Fuel (Refineries) – Production of Synthetic Fuels - Power to Industry
- **Hydrogen can be used as a fuel for FuelCell vehicles**
  - Waste Trucks, Utility vehicles, ...
- **Hydrogen can be used in processes that re-use CO2**
  - CO2 neutral processes: Power to Gas (methane), Power to Fuel (e.g. Methanol), upgrade BioGas, ...
- **Feasibility studies have proven OK – time to access the market**
  - Extra value of greening up has to be monetized to make the proposals economically acceptable
  - Regulatory frameworks needed to help the projects to a positive business case
- **New developments to meet increasing needs – 5MW PEM Elysia blocks**
Thank you for your attention

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