Alkaline vs PEM electrolysers: lessons learnt from Falkenhagen and WindGas Hamburg

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Renewable Hydrogen – EU Regulatory Affairs and Business Development Manager

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Agenda

1. Hydrogenics in a nutshell

2. Falkenhagen : Alkaline electrolysis technology

3. Hamburg Reitbrook: PEM electrolysis technology

4. Review of other ongoing demo projects

5. Conclusions
Hydrogenics in Brief
Zero-emission Hydrogen Technology Provider

**Onsite Generation**
Electrolysers
H₂O + electricity → H₂ + ½ O₂

**Power Systems**
Fuel Cell Modules
H₂ + ½ O₂ → H₂O + electricity

- Industrial Hydrogen
- Hydrogen Fueling
- Stationary Power
- Mobility Power

**Energy Storage**

**Power-to-Gas**
Hydrogenics in Brief
International structure

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: +/- 155 employees
- Incorporated in 1995 [NASDAQ: HYGS; TSX: HYG]
- More than 2,000 products deployed in 100 countries worldwide
- Total revenues (2014): 45.5 Mio $
- Over 70 years of electrolysis leadership
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Industry “Workhorse” for Onsite Electrolysis
Hydrogenics HySTAT™ Alkaline Stack

“We have strategically positioned ourselves with the highest quality products that combine innovation, customer-centric features with industrial design and robustness.”
Over 500 World-wide Industrial Systems
50 kW > 4 MW

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

Ukraine: Metallurgy
China: Merchant Gas
Greece: Solar Industry
# Hydrogenics HySTAT™ Alkaline - Technical specifications

<table>
<thead>
<tr>
<th>MODEL</th>
<th>HySTAT™-10-10</th>
<th>HySTAT™-15-10</th>
<th>HySTAT™-30-10</th>
<th>HySTAT™-45-10</th>
<th>HySTAT™-60-10</th>
</tr>
</thead>
<tbody>
<tr>
<td>Operating Pressure</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Nominal hydrogen flow</td>
<td>10 Nm³/h</td>
<td>15 Nm³/h</td>
<td>30 Nm³/h</td>
<td>45 Nm³/h</td>
<td>60 Nm³/h</td>
</tr>
<tr>
<td>Nr. of cell stacks</td>
<td>1</td>
<td>1</td>
<td>2</td>
<td>3</td>
<td>4</td>
</tr>
<tr>
<td>Hydrogen flow range</td>
<td>40 - 100% (25 - 100% as an option)</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Hydrogen Purity (before HPS)</td>
<td>99.9% H₂O saturated, O₂ &lt; 1,000 ppm</td>
<td></td>
<td></td>
<td></td>
<td>Falkenhagen</td>
</tr>
<tr>
<td>Hydrogen Purity (after HPS)</td>
<td>99.998% (99.999% as an option); O₂ &lt; 2 ppm; N₂ &lt; 12 ppm; Atm. Dew point: -60°C or -76°F (-75°C or -103°F as an option)</td>
<td></td>
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</tr>
<tr>
<td>Estimated AC power consumption (kWh/Nm³)</td>
<td>5.4 kWh/Nm³ at full capacity</td>
<td>5.2 kWh/Nm³ at full capacity</td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Voltage</td>
<td>3 x 400 VAC ± 3% (3 x 480 or 575 VAC ± 3% as an option)</td>
<td></td>
<td></td>
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<td></td>
</tr>
<tr>
<td>Frequency</td>
<td>50 Hz ± 3% / 60 Hz ± 3% (option)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Installed power</td>
<td>100 + 35KVA</td>
<td>120 + 35KVA</td>
<td>240 + 35KVA</td>
<td>120 + 240 + 35KVA</td>
<td>2 x 240 + 35KVA</td>
</tr>
<tr>
<td>Max. cooling water temperature (electrolyte)</td>
<td>Design flow cooling water (electrolyte)</td>
<td>Closed loop cooling circuit installed</td>
<td>Chiller gas cooling circuit installed</td>
<td>Feed water purification system installed</td>
<td></td>
</tr>
<tr>
<td>Max. cooling water temperature (gas cooling)</td>
<td>Design flow cooling water (gas cooling)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Demineralized water consumption</td>
<td></td>
<td></td>
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<td></td>
<td></td>
</tr>
<tr>
<td>Tap water consumption</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td>Electrolyte</td>
<td>1,5 - 2 liters/Nm³ H₂</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Electrolyte Quantity</td>
<td>220 L</td>
<td>240 L</td>
<td>360 L</td>
<td>480 L</td>
<td>610 L</td>
</tr>
<tr>
<td>Installation area</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>Falkenhagen</td>
</tr>
<tr>
<td>Ambient Temperature Range</td>
<td>-20°C to +40°C (-40°C or +50°C as an option)</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Power at full capacity (+/-)</td>
<td>54 kW</td>
<td>81 kW</td>
<td>156 kW</td>
<td>234 kW</td>
<td>312 kW</td>
</tr>
</tbody>
</table>
Greening of Gas

OBJECTIVES
• Demonstration of the Power-to-Gas process chain.
• Optimize operational concept (fluctuating power from wind vs. changing gas feed).
• Gain experience in technology and cost.
• Feed H₂ into the high-pressure transmission natural gas pipeline at 55bar (ONTRAS).

SOLUTION
• 6 x HySTAT™ 60 with all peripherals in 20Ft. housings to produce 360Nm³/h H₂.
• A 40 Ft container including 2 compressors to compress the hydrogen to 55barg.
• Power: 2MW
Learnings from the Falkenhagen project

Power-to-Gas project: it works!

- Start of Construction: August 2012
- Start of Operation: August 2013
- Quoted from UNIPER:
  - 2 years of operation very successful
  - >2 Mill. kWh Hydrogen (“WindGas”) have been produced from renewable electrical power and have been injected in the natural gas grid up to July 2014.
  - More than 7,000 operating hours with more than 500 starts and stops
  - The efficiency is better than expected.
  - The technology is ready for the market and has further potential in performance and costs reduction.
  - No PtG-specific showdowns of the plant have been detected during operation. Degradation was not detectable.
  - Using Pressure Electrolysers have a cost reducing potential if compressors can be avoided.
  - The technology fulfilled the requirements of the German secondary balancing market.
Dynamic cycling of the alkaline electrolyser
…from pressure control to power set-point control
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The New Benchmark in Electrolysis: PEM
Proton Exchange Membrane

1.5 MW, MODEL 1500E

- Electrical Power Input: 1.5 MW
- Hydrogen Output: 285 Nm3/h
- Max. Operating Pressure: 40 bar (g)
- Dimensions: L800xW550x1000mm
- Certifications: PED (97/23/EC)

1. 1.5MW industry benchmark
2. Achieved target system cost
3. Leading industry performance
4. Key IPR established
WindGas Hamburg Reitbrook, Germany (2015)

1.5 MW Power to Gas

OBJECTIVES
- Demonstration of the Power-to-Gas process chain.
- Development of 1.5 MW PEM Electrolysis Stack and System
- Optimize operational concept (fluctuating power from wind vs. changing gas feed).
- Gain experience in technology and cost.
- Feed H₂ into the medium-pressure distribution natural gas pipeline at 30 bar.

SOLUTION
- 1x 1.5 MW PEM Electrolyser with all peripherals in 40Ft. housings for max 285 Nm³/h H₂.
- Power: 1.5 MW

• This 1.5 MW building block is now the foundation for multi MW P2G plants

More info: www.windgas-hamburg.com
WindGas Hamburg Reitbrook, Germany (2015)

**1,5 MW Power to Gas**

**OBJECTIVES**

- Demonstration of the Power-to-Gas process chain.
- Development of 1.5 MW PEM Electrolysis Stack and System
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More info: [www.windgas-hamburg.com](http://www.windgas-hamburg.com)
Learnings from the Hamburg Reitbrook project

MW PEM upscaling was successful!

- Start of operation: 15/10/2015

- Quoted from UNIPER:
  - The upscaling of PEM-Technology to the MW-Class was successful
  - The new PEM-Technology is very compact and efficient
  - Depending on higher pressure (25 bar) no compressor is necessary for injection of the hydrogen into the natural gas grid
  - The performance of the 1.5 MW PEM-stack is 50% better than originally planned
1,5 MW PEM: **efficiency** and **dynamic behaviour achievements (prel.)**

- Graph showing changes in power output and efficiency over time.
  - **Leistung** (Power) and **Wirkungsgrad Stack** (Stack Efficiency) are plotted.
  - The graph displays fluctuations that could indicate dynamic behavior.
  - A timeline of approximately 8 minutes is highlighted.

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**HYDROG(EN)ICS**
SHIFT POWER | ENERGIZE YOUR WORLD
1.5 MW PEM: temperature and pressure achievements (prel.)
Hamburg Reitbrook : short project movie
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Renewable hydrogen usage in power, gas, transportation and industry sectors
Puglia, Italy (2016, in construction)

**INGRID (FP7 project)**

**OBJECTIVES**
- Allow increased integration of RES into the grid using electrolysis and supply-demand balancing
- Improvement of distribution operations through active/reactive power control for optimal voltage regulation and power quality
- Hydrogen used for transport, industry, grid balancing and injection into the gas grid

**SOLUTION**
- 1 MW HySTAT™ electrolyser 40 ft, outdoor solution to produce 200 Nm³/h of hydrogen
- 120 kW fuel cell back-up system
- 39 MWh, 1.000 kg solid hydrogen storage system

More info: www.ingridproject.eu
BioCatProject

OBJECTIVES
- Design, engineer, and construct a commercial-scale power-to-gas facility
- Demonstrate capabilities to provide energy storage services to the Danish energy system.
- Demonstrate capability and economic viability of oxygen and heat recycling in the on-site wastewater operations
- Biological methanation system to produce pipeline-grade renewable gas (CH$_4$)
- Feed CH$_4$ into the gas distribution grid at 3.6 bar

SOLUTION
- 2x HySTAT™ 100 (Alkaline) with all peripherals to produce 200Nm$^3$/h H$_2$.
- Power: 1MW

More info: www.biocat-project.com
BioCatProject

OBJECTIVES

- Design, engineer, and construct a commercial-scale power-to-gas facility
- Demonstrate capabilities to provide energy storage services to the Danish energy system.
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- Power: 1MW

More info: www.biocat-project.com
Hobro, Denmark (construction in 2017)

**HyBalance Project**

**OBJECTIVES**
- Validate the highly dynamic PEM electrolysis technology in a real industrial environment
- Provide grid balancing services on the Danish power market
- Validate innovative hydrogen delivery processes for fueling stations at high pressure
- Hydrogen is used by industrial customers and for clean transportation (refueling stations)

**SOLUTION**
- 1x HyLYSER™ 230 (PEM, dual cell stack design) with all peripherals to produce 230 Nm³/h H₂
- Power: 1.2 MW

This project receives financial support FCH-JU (GA No 671384) and ForskEL program, administered by Energinet.dk.

More info: [www.hybalance.eu](http://www.hybalance.eu)
Colruyt, Halle (Brussels, Belgium)

65 kg/day, 350 bar dispensing

- Located at one of the warehouse of Colruyt, one of the biggest Belgian retail company
- Hydrogen is used to fill fork lift trucks, additionally it can refuel other vehicles
- The station has a 30 Nm³/h alkaline electrolyser, 50 kg storage and -20° chiller the customer’s SAEJ 2601 refueling sequence.
- Funded by InterReg project (Waterstofregio Vlaanderen Zuid-Nederland)

- + 30 Nm³/h PEM electrolyser
- Electrochemical compressor HYET
- + 100 kW Fuel Cell
- Smart grid operation
MefCO2 project (Methanol Fuel from CO2)

OBJECTIVES
- Increase efficiency and reduce emissions of STEAG’s coal fired power plant
- Leverage existing carbon capture pilot plant (= CO₂ source) owned by UDE

SOLUTION
- 1 MW PEM electrolyser for 200 Nm³/h of Hydrogen
- EU Horizon 2020 research and innovation programme funding (SPIRE)
- Flexible methanol synthesis.
- Power: 1MW

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Large Scale Power-to-Hydrogen Plant (40 MW)

- **60m x 25m footprint**
- **40 MW = 8 000 Nm³/h = 720 kg/h**
- **17 t H₂/day**

**Components:**
- Cooling units
- Rectifier banks
- H₂O Feed pumps
- Gas/water separators
- H₂ Compressors
- Controls and electrical

H₂ Compressors:
- >1.25 MW per stack
- 4 stacks = 5 MW
- 8 stacks = 10 MW
Grid Fees and Levies
~50%

Wholesale Price Electricity
~30%

Capex
~20%

Opex ~2%

Investor Bonus

Renewable Credit:
Technology Push & Market Pull measures
~xx%

Service Income (balancing)
~xx%

Feedstock Income (H₂, O₂, Heat)
~xx%

Business Case Drivers

Hydrogen Cost

~30% ~50%
Hydrogen provides the means to significantly increase the use of renewable energy across the entire energy system.

**Final energy consumption by fuel (EU-27, 2012)**

Data source: European Environment Agency, Final energy consumption by sector and fuel (CSI 027/ENER 016)
Assessment published Jan 2015
Key conclusions

- Alkaline water electrolysis is a **mature** and **proven technology**, but there is still **room for further improvement** (footprint, dynamic operation, pressure, materials, costs).

- **PEM electrolysis technology** developments are **very promising** (efficiency, costs, flexibility, MW scale), especially for **large scale applications**. The technology has been **tested in a relevant environment**. It needs now to be tested over **many operating hours** (cost is a problem !) and **pre-qualified for commercial applications**. There is still **room for further improvement** (cost, efficiency), especially for very large scale projects (> 10 MW).

- Renewable Hydrogen offers **many synergies with other sectors** (power, gas, mobility, chemistry, water) and with CO$_2$.

- There is a **need for demonstration** projects (at large scale).

- **Most of the cost decrease for both technologies is expected from mass production** (project manufacturing → product manufacturing, optimization of supply chain).

- There is a **need for an appropriate regulation** at EU and national level to allow market uptake !

- **Industry focus should shift progressively from technology improvement to market creation activities.**
Thank you for your attention!

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Email: dthomas@hydrogenics.com