“INDUSTRIËLE WATERSTOFGENERATOREN, VIA ELECTROLYSE NAAR GROENE WATERSTOF”

Filip SMEETS, Hydrogenics Europe N.V.
Managing Director

December 2018
Agenda

1. Hydrogenics
2. Water electrolysis
3. Renewable Hydrogen
4. Conclusions
Leading Hydrogen TECHNOLOGY PROVIDER

Onsite Generation | Electrolysers

$\text{H}_2\text{O} + \text{electricity} \rightarrow \text{H}_2 + \frac{1}{2} \text{O}_2$

Power Systems | Fuel Cell Modules

$\text{H}_2 + \frac{1}{2} \text{O}_2 \rightarrow \text{H}_2\text{O} + \text{electricity}$

Industrial Hydrogen

Hydrogen Fueling

Stationary Power

Mobility Power
Hydrogenics, a 100% global hydrogen company

Hydrogenics Corporation
- Headquarters
- Mississauga, Ontario
- Incorporation: 1996 [NASDAQ: HYGS; TSX: HYG]
- 175 employees worldwide
- Fuel Cells, PEM electrolyser stacks, Power-to-Gas, H₂ refueling and mobility products/projects

Hydrogenics Europe
- Oevel, Belgium
- Since 1987
- Power-to-X, and industrial onsite hydrogen production

Hydrogenics GmbH
- Gladbeck, Germany
- Since 2002
- Fuel Cell power module integration

Hydrogenics USA
- Carlsbad, California
- Since 2018
- Fuel Cell power module integration

Productions Facility
Sales Office
Our History: Over 60 Years of Experience

1948
The Electrolyser Corporation, a manufacturer of Atmospheric Alkaline Electrolyzers is incorporated in Toronto, Canada

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195
Hydrogenics is founded

1987
Vandenborre Hydrogen Systems, a manufacturer of Pressurized Alkaline Electrolyzers is founded in Belgium

2000
Hydrogenics goes public

2000
Hydrogenics goes public

2003
Stuart Energy acquires Vandenborre

2003
Stuart Energy acquires Vandenborre

2002
Hydrogenics acquires ENKAT GmbH and begins operations in Germany

2005
Hydrogenics acquires Stuart Energy to become the only fuel cell and electrolyzer company in the industry

2018
Hydrogenics is the global leader in fuel cell and hydrogen technology solutions
Selection of our key references

**Electrolysis**
- 700 bar Hydrogen Refueling Station
  Aberdeen, Scotland (UK)

**Fuel cells**
- 1 MW stationary Fuel cell (H₂ repowering)
  Kolon, South-Korea
- 1,5 MW PEM P2G (direct injection), Hamburg, Germany
- 1 MW alkaline P2G (methanation)
  BIOCAT, Copenhagen, Denmark

- Fuel cell for mobility (H₂ trains)
  Alstom Coradia iLint, Germany
- Fuel cell for mobility (H₂ buses), China
Agenda

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Water electrolysis
H₂O + electricity → H₂ + ½ O₂
HySTAT® ALKALINE SYSTEMS TODAY

10 Nm³/h  ...  100 Nm³/h
HySTAT® ALKALINE SYSTEMS TODAY

10 Nm³/h ... 100 Nm³/h
Extensive experience with alkaline technology
PEM water electrolysis – ‘only circulating water’
HyLYZER® - PEM: key milestones @ Hydrogenics

- **R&D**
  - Small scale PEM electrolyser
- **1999**
  - 1,5 MW cell stack
- **2004**
  - Test large stack
- **2012**
  - Field test 1.5 MW electrolyser
- **2014**
  - 2.5/3 MW cell stack
- **2015**
  - Dual cell stack design
- **2017**
  - Multi MW design
- **2018**
  - +15 MW
PEM, 2012: LET’S GO FOR IT

92E

450E

1500E
PEM electrolyser
Membrane-Electrode-Assembly (MEA) technology

- High purity
- >30 bar operational pressure
- 150 µm thick
- 2.3 A/cm²
2014
First commercial large stack
2015

First 1.5 MW delivered

Uniper, WindGas Reitbrook, Hamburg, Germany
Relationship between cost and efficiency
First “MW” PEM Stack Measured Efficiency

Example: 1.5 MW PEM Electrolyser, WindGas Reitbrook, Hamburg

Increase efficiency $\rightarrow$ Reduction of operational cost (€/kg)

Increase current density $\rightarrow$ Reduction of capital cost (€/MW)
Electrolysers | Fast reacting devices

- A matter of power electronics
- ‘Power’ operated rather than ‘Pressure’ operated
- Idea to balance renewables (wind and solar) and provide Grid Balancing Services

<table>
<thead>
<tr>
<th></th>
<th>Alkaline</th>
<th>PEM</th>
</tr>
</thead>
<tbody>
<tr>
<td>Response signal (from pressurized stand-by to 100%)</td>
<td>&lt; 3 sec</td>
<td>&lt; 3 sec</td>
</tr>
<tr>
<td>Response signal (Operating system = HOT)</td>
<td>&lt;1 sec</td>
<td>&lt;1 sec</td>
</tr>
</tbody>
</table>

Example: 1.5 MW PEM Electrolyser, WindGas Reitbrook, Hamburg
New benchmark in PEM electrolysis HyLYZER®-600
3 MW cell stack from Hydrogenics for multi-MW projects

1. **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. **Very compact**
   - Lowest footprint on the market

6. **Reduced Maintenance**
   - Limited and optimised

Power Input: 3.0 MW
- Hydrogen Output: 620 Nm³/h
- Design Pressure: 40 bar

Power Input: 1.5 MW
- Hydrogen Output: 310 Nm³/h
- Design Pressure: 40 bar
## Alkaline & PEM electrolysis | Product’s line

<table>
<thead>
<tr>
<th></th>
<th>HySTAT®-15-10</th>
<th>HySTAT®-60-10</th>
<th>HySTAT®-100-10</th>
<th>HyLYZER® -300-30</th>
<th>HyLYZER® -1.000-30</th>
<th>HyLYZER® -5.000-30</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Output pressure</strong></td>
<td>10 barg</td>
<td>10 barg</td>
<td>10 barg</td>
<td>30 barg</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>(27 barg optional)</td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Number of cell stacks</strong></td>
<td>1</td>
<td>4</td>
<td>6</td>
<td>1</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td><strong>Nominal Hydrogen Flow</strong></td>
<td>15 Nm³/h</td>
<td>60 Nm³/h</td>
<td>100 Nm³/h</td>
<td>300 Nm³/h</td>
<td>1.000 Nm³/h</td>
<td>5.000 Nm³/h</td>
</tr>
<tr>
<td><strong>Nominal input power</strong></td>
<td>80 kW</td>
<td>300 kW</td>
<td>500 kW</td>
<td>1.5 MW</td>
<td>5 MW</td>
<td>25 MW</td>
</tr>
<tr>
<td><strong>AC power consumption</strong> (utilities included, at nominal capacity)</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><strong>Hydrogen flow range</strong></td>
<td>40-100%</td>
<td>10-100%</td>
<td>5-100%</td>
<td>1-100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Hydrogen purity</strong></td>
<td>99.998%</td>
<td>99.998%</td>
<td>99.998%</td>
<td>99.998%</td>
<td></td>
<td></td>
</tr>
<tr>
<td></td>
<td>O₂ &lt; 2 ppm, N₂ &lt; 12 ppm (higher purities optional)</td>
<td>O₂ &lt; 2 ppm, N₂ &lt; 12 ppm (higher purities optional)</td>
<td></td>
<td></td>
<td></td>
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</tr>
<tr>
<td><strong>Tap water consumption</strong></td>
<td>&lt;1.7 liters / Nm³ H₂</td>
<td></td>
<td></td>
<td>&lt;1.4 liters / Nm³ H₂</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Footprint (in containers)</strong></td>
<td>1 x 20 ft</td>
<td>1 x 40 ft</td>
<td>1 x 40 ft</td>
<td>1 x 40 ft</td>
<td>2 x 40 ft</td>
<td>10 x 40 ft</td>
</tr>
<tr>
<td><strong>Footprint utilities (optional)</strong></td>
<td>Incl.</td>
<td>Incl.</td>
<td>Incl.</td>
<td>Incl.</td>
<td>1 x 20 ft</td>
<td>1 x 20 ft</td>
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<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td>5 x 20 ft</td>
<td></td>
</tr>
</tbody>
</table>
Renewable Hydrogen
Power-to-Power | For Electrical Energy Storage

- Conversion of excess power in hydrogen via an electrolyser
- **Storage of hydrogen** in gas bottles, tanks or underground
- Repowering of the hydrogen through a **fuel cell**
- Ideal for long-term energy storage (remote locations, telecom, off-grid systems)

1. Wind-Hydrogen, Glencore Raglan Mine, Canada: 350 kW electrolyser + 120 kW fuel cell
2. WIND-projekt, Mecklenburg-Vorpommern, Germany: 1 MW electrolyser + 150 kW hydrogen combustion engine
EGAT Lam Takhong Wind Hydrogen Hybrid Project
Thailand (2017)

• OBJECTIVES
  – Use of curtailed energy from 24 MW wind farm with limited injection capacity
  – Repowering of the hydrogen through a 300 kW fuel cell to power the new energy center of EGAT

• SOLUTION
  – 1 MW PEM electrolyser (HyLYZER®-500-30)
  – 300 kW PEM fuel cell
  – 3 MWh (10 hours) of compressed hydrogen storage (250 bar)

• PARTNERS:
  – EGAT

• More information: www.egat.co.th/en/
Hychico, Patagonia, Argentina (2008)
Wind-to-Hydrogen, direct injection in depleted gas field & repowering

• **OBJECTIVES**
  – Demonstrate variable hydrogen production with direct connection to wind park
  – Store hydrogen in a depleted gas field
  – Re-electrification of the hydrogen blended with natural gas through a gas genset

• **SOLUTION**
  – 2 x HySTAT®-60-10 with all peripherals in 40Ft. housings to produce 120 Nm³/h hydrogen (power: 0,6 MW)

• **PARTNERS:**
  – Hychico

• **More information:** [www.hychico.com.ar](http://www.hychico.com.ar)

Photo credits: Hychico
**Power-to-Gas**

- Direct injection of hydrogen in gas grid (2%-10%\textsubscript{vol})

- Injection of Synthetic Natural Gas (SNG) after a methanation step:
  \[ \text{H}_2 + \text{CO}_2 \rightarrow \text{CH}_4 + \text{H}_2\text{O} \]

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1. UNIPER’s power-to-gas facility, Falkenhagen, Germany: 2 MW electrolyser
2. BioCat project, Avedøre, Denmark: 1 MW electrolyser
WindGas Falkenhagen, Germany (2013)
Direct injection of hydrogen in natural gas grid (transportation)

• OBJECTIVES
  – 1st demo project worldwide to inject hydrogen in the high-pressure transmission natural gas pipeline at 55bar (ONTRAS) with a max concentration of 2%vol
  – Optimize operational concept (fluctuating power from wind vs. changing gas feed).
  – Gain experience in technology, cost and business aspects.

• SOLUTION
  – 6 x HySTAT®-60-10 with all peripherals in 20Ft. housings to produce 360 Nm³/h hydrogen (power: 2 MW)
  – A 40 Ft container including 2 compressors to compress the hydrogen to 55barg.

• PARTNERS:
  – UNIPER Energy Storage GmbH (ex-EON)

• More information: www.uniper.energy
WindGas Reitbrook (Hamburg), Germany (2015)
Direct injection of hydrogen in natural gas grid (distribution)

• OBJECTIVES
  – Development of 1,5 MW PEM Electrolysis Stack and System
  – Validate PEM technology in operational environment
  – Gain experience in technology and cost.
  – Feed hydrogen into the medium-pressure distribution natural gas pipeline at 30 bar without compression.

• SOLUTION
  – 1x HyLYZER®-285-30 PEM electrolyser with all peripherals in 40ft. housings for max 285 Nm³/h H₂ at 30 bar (Power: 1.5 MW)

• PARTNERS:

• More information: www.windgas-hamburg.com

Photo credits: Uniper Energy Storage GmbH
• **OBJECTIVES**
  - Biological methanation system to produce pipeline-grade renewable gas (CH$_4$) and feed into the gas distribution grid at 3.6 bar
  - Demonstrate capability and economic viability of oxygen and heat recycling in the on-site wastewater operations

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

• **PARTNERS**

• **MORE INFORMATION:** [www.biocat-project.com](http://www.biocat-project.com)
OBJECTIVES

- Development of innovative 1 MW alkaline electrolyser
- Alkaline cell stack up-scaling to 2500 cm²
- 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
- 39 MWh, 1.000 kg solid hydrogen storage system (McPhy)

SOLUTION

- 1 MW HySTAT™ electrolyser 40 ft, outdoor solution to produce 200 Nm³/h of hydrogen
- 120 kW fuel cell back-up system

More information: http://www.ingridproject.eu
**Power-to-Gas**

- **Budget**: 28M€
- **Partners**: 27 partners, coordinator: DVGW
- **Duration**: 48 months (03/2016-02/2019)
- **Website**: [www.storeandgo.info](http://www.storeandgo.info)

### Characteristics of the three demonstration sites

<table>
<thead>
<tr>
<th>Demonstration site Falkenhagen/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>Regional 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>

**NB**: Hydrogenics is not part of the consortium, but 2 sites will use Hydrogenics’ electrolyzers.
Wind-to-Gas Südermarsch (Brunsbtuttel), Germany (2018)
Direct injection of hydrogen in high-pressure natural gas grid

• **OBJECTIVES**
  – Development of 2,4 MW PEM Electrolysis System
  – Dual stack design of 1,2 MW each
  – Feed hydrogen into the medium-pressure distribution natural gas pipeline at 40-70 bar without compression
  – Optional connection to future hydrogen refueling station

• **SOLUTION**
  – 1 x HyLYZER®-400-30 PEM electrolyser with all peripherals
  – Max 400 Nm³/h H₂ at 30 bar (Power: 2 MW)
  – 2x 40 ft. ISO containers

• **PARTNER:**

• **More information:** [www.w2g-energy.de](http://www.w2g-energy.de)

Photo credits: Wind to Gas Energy GmbH
Markham Energy Storage Project (Markham), Canada (2018)
Secondary Frequency Control for the IESO

- **FEATURES**
  - Plant has been designed for 5MW (currently installed 2.5MW)
  - High purity H2 is produced by the PEMWE stacks at 30 barg
  - Plant provides +/- 1.05 MW of regulation service for the IESO
  - 2 second response time, 2 MW/sec ramp rate
  - 100 kW fuel cell with 8 MWh of onsite hydrogen storage

- **SOLUTION**
  - 1 x HyLYZER®-500-30 PEM electrolyser with all peripherals
  - Max 500 Nm³/h H₂ at 30 bar (Power: 2,5 MW)
  - Indoor design

- **PARTNER:**

- More information: www.enbridge.com
Markham Energy Storage Project (Markham), Canada (2018)
Secondary Frequency Control for the IESO

+/- 1.05 MW of regulation service for the IESO
Power-to-Mobility

- Hydrogen refueling stations with onsite hydrogen production
- **For cars (700 bar)**, a refueling takes 3-5 min for a driving range of 400-500 km
- **For buses (350 bar)**, a refueling takes 10 min for a driving range of 350 km

Example: Toyota MIRAI

ACHES 350/700 bar hydrogen refueling station, Aberdeen (UK)
**Don Quichote**, Halle, Belgium (2015-2018)
Hydrogen from wind to power fuel cell forklifts

- **OBJECTIVES**
  - Located at one of the warehouse of Colruyt, one of the biggest Belgian retail company
  - Hydrogen is used to fill forklift trucks

- **SOLUTION**
  - 30 Nm³/h alkaline + 30 Nm³/h PEM electrolysers
  - 50 kg 350 bar storage + dispenser
  - 100 kW Fuel Cell

- **SUPPORT**
  - 1st part funded by InterReg project (Waterstofregio Vlaanderen Zuid-Nederland)
  - 2nd part funded FCH-JU

- **More information:** [www.don-quichote.eu](http://www.don-quichote.eu)
Power-to-Industry

- Hydrogen is used massively in the industry: ammonia (fertilizers), refineries, steel, float glass, semi-conductors, oil and fat, power plants.
- 1 ton of renewable hydrogen avoids the emission of +/- 10 tons of CO₂

Main industries consuming hydrogen
- 50%: chemical industry (ammonia, methanol)
- 43%: oil refineries
- 6%: float glass, steel and semi-conductors
- 1%: power plants, oil hydrogenation and mobility

Total consumption 2014 = 571 bcm H₂

Data source: The Hydrogen Economy, M. Ball 2009 & Esprit Associates 2014
HyBalance, Hobro, Denmark (construction in 2017)
Industrial hydrogen and delivery to hydrogen refueling stations

• **OBJECTIVES**
  – Validate the highly dynamic PEM electrolysis technology in a real industrial environment and provide grid balancing services on the Danish power market
  – Validate innovative hydrogen delivery processes for fueling stations at high pressure

• **SOLUTION**
  – 1x HyLYZER®-230-30 (PEM, dual cell stack design) with all peripherals to produce 230 Nm³/h H₂ (power: 1,2 MW)

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

• **More information:** [www.hybalance.eu](http://www.hybalance.eu)
Huge decarbonisation potential via Renewable H₂ in EU industry: chemistry, refineries, steel....

Power-to-Fuel

- Renewable hydrogen for refineries (substituting hydrogen produced from natural gas)
- Synthesis of renewable methanol: \( \text{H}_2 + \text{CO}_2 \rightarrow \text{CH}_3\text{OH} + \text{H}_2\text{O} \)
- Introduced in Renewable Energy Directive (RED II, 2021-2030)
MEFCO₂, Niederaußem (Germany)
Power-to-Methanol

- **OBJECTIVES**
  - Produce green methanol as energy vector from captured CO₂ and hydrogen produced using surplus renewable energy.
  - Existing post-combustion pilot CO₂ 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 Nm³/h H₂ (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)
Power-to-Refinery
What about renewable hydrogen in refineries?

Source: Uniper
Concluding messages

• **Power-to-Gas** has been successfully demonstrated and is **ready for commercial operations**

• **Massive cost reduction is expected** for electrolysers: from project to product manufacturing & product up scaling

• **A favorable regulatory framework is being prepared** (EU and national) and this is **NOW THE TIME TO ACT** with
  1. Quantified objectives (2030-2050)
  2. Green hydrogen (gas) certification mechanism
  3. Premium value for end product / application (cf. green gas tariffs)
  4. Access to renewable electricity at low cost
  5. Grid connection to deliver balancing services
How to unlock the potential of renewable hydrogen

- Find sites with suitable conditions “connecting all the dots”
- Integrate the renewable power production in the economics and promote RES→H₂ as a way to lock-in future-proof fuel or feedstock prices
- Create market conditions for renewable hydrogen via regulation
- Reducing the cost of the hydrogen technology by going very large scale.

NB: Only the industry can provide a sufficient market to absorb large quantities of hydrogen.
We’re Ready for large scale Power-to-Gas projects

Filip SMEETS | Managing Director Hydrogenics Europe NV
+32 477 445 839
Email: fsmeets@hydrogenics.com