Electrolytic hydrogen generation in carbon re-utilizations schemes

Jan Vaes, Technology Director,
Hydrogenics Europe NV
October 18th, Antwerp, I-SUP 2016
Hydrogenics in Brief
Zero-emission Hydrogen Technology Provider

Onsite Generation
Electrolysers
H₂O + electricity $\rightarrow$ H₂ + $\frac{1}{2}$ O₂

Power Systems
Fuel Cell Modules
H₂ + $\frac{1}{2}$ O₂ $\rightarrow$ H₂O + electricity

Industrial Hydrogen | Power-to-X | Stand-by Power | Mobility Power
Global Hydrogen Market

Steam Methane Reforming
- 48%

Crude oil cracking
- 30%

Coal gasification
- 18%

H2 by-product
- 3%

Water electrolysis
- 1%

Hydrogen pipeline infrastructure in the EU
- Air Liquide (NL-BE-FR): 810 km
- Air Liquide (GER): 240 km
- Linde (GER): 150 km

CHEMISTRY & REFINERIES: C, H, O, Amonia
- Fertilizers
- Refineries
- 93%

INDUSTRY: protecting atmosphere (H2/N2), hardening of metals
- 6%

Float glass

Metallurgy

Semi-conductors

AWE medium flow 10-200 Nm³/h

OTHERS: cooling agent, hardening of oil, power generation, mobility
- 1%

Electrical power plants

Food industry

FCEV

Production

Storage / Transport / Distribution

End-use (global market in 2010: +/- 43 Mtons)

NB: 5% is merchant hydrogen (free market), onsite production represents 95%

Main data source: The Hydrogen Economy, M. Ball, 2009
Over 500 Worldwide industrial systems
ranging from 50 kW to 2.5 MW

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

Ukraine: Metallurgy
China: Merchant Gas
Greece: Solar Industry
A selection of H₂ based energy storage 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>Thailand</td>
<td>EGAT</td>
<td>1.2 MW + 500 kW FC</td>
<td>2017</td>
<td>PEM</td>
<td>•</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canada</td>
<td>Enbridge P2G</td>
<td>2 MW</td>
<td>2017</td>
<td>PEM</td>
<td>•</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Germany</td>
<td>MefCO2</td>
<td>1 MW</td>
<td>2017</td>
<td>PEM</td>
<td>•</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Denmark</td>
<td>HyBalance</td>
<td>1.2 MW</td>
<td>2017</td>
<td>PEM</td>
<td>•</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>UK</td>
<td>Levenmouth</td>
<td>370 kW + 100 kW FC</td>
<td>2016</td>
<td>Alkaline + PEM</td>
<td>•</td>
<td>•</td>
<td></td>
<td></td>
<td></td>
</tr>
<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</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>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Germany</td>
<td>WindGas Reitbrook</td>
<td>1.5 MW</td>
<td>2015</td>
<td>PEM</td>
<td>•</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Canada</td>
<td>Raglan Nickel mine</td>
<td>350 kW + 200 kW FC</td>
<td>2015</td>
<td>Alkaline</td>
<td>•</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>Belgium</td>
<td>Don Quichote</td>
<td>150 kW</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 Falkenhagen</td>
<td>2 MW</td>
<td>2014</td>
<td>Alkaline</td>
<td>•</td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
$\text{CO}_2$ pollution is a kinetic problem

Power to X routes demo’s

- CO₂ avoidance – green H₂ replacing hydrocarbons
  - Power-to-H₂ (gas, fuel, refinery,..)

- CO₂ utilization
  - Power to methane
    - Biocat – biological
    - ZSW- Stuttgart – Sabatier
  - Power-to-methanol
    - MefCo2
  - Power-to-polymers
    - MIP – CO2MPASS
Falkenhagen, Germany (2013)

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 $\text{H}_2$ into the high-pressure transmission natural gas pipeline at 55bar (ONTRAS).

SOLUTION
- 6 x HySTAT™ 60 with all peripherals in 20Ft. housings to produce 360Nm$^3$/h $\text{H}_2$.
- A 40 Ft container including 2 compressors to compress the hydrogen to 55barg.
- Power: 2MW

Photo credits: Uniper Energy Storage GmbH
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
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 \( H_2 \).
- installed power: 1.2 MW – maximal capacity of design: 2.5 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)
Power to X routes demo’s

- CO₂ avoidance – user of green H₂
  - Power-to-H2 (gas, fuel, refinery,..)

- CO₂ utilization
  - Power to methane
    - ZSW- Stuttgart – Sabatier
    - Biocat – biological methanation
  - Power-to-methanol
    - MefCo2
  - Power-to-polymers
    - MIP – CO2MPASS
Stuttgart, Germany

Methanation process

OBJECTIVES
- Demonstrate the PtG (Power to Gas) solution using methane.
- Produce $\text{H}_2$ from the surplus of electricity and combine it with $\text{CO}_2$ from a biogas plant to produce methane $\rightarrow 4\text{H}_2 + \text{CO}_2 \rightarrow \text{CH}_4 + \text{H}_2\text{O}$.

SOLUTION:
- HySTAT® 60 Outdoor with all peripherals to produce 60Nm³/h $\text{H}_2$.
- The electrolyser combined with a methanation process produces bio-methane.
- Bio-methane is injected in the gas grid, leading to a carbon neutral process.
Avedøre, Denmark (2016)

**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 (CH₄).
- Feed CH₄ into the gas distribution grid at 3.6 bar.

**SOLUTION**
- 2x HySTAT™ 120 (Alkaline) with all peripherals to produce 240 Nm³/h H₂.
- Power: 1.2 MW

More info: [www.biocat-project.com](http://www.biocat-project.com)
http://biocat-project.com/
Power to X routes demo’s

- CO$_2$ avoidance – user of green H$_2$
  - Power-to-H2 (gas, fuel, refinery,..)

- CO$_2$ utilization
  - Power to methane
    - Biocat – biological methanation
    - ZSW- Stuttgart – Sabatier
  - Power-to-methanol
    - MefCo2
  - Power-to-polymers
    - MIP – CO2MPASS
Lünen, Germany

**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 (admixing in diesel, methanol fuel cells,...)

MefCO₂’s Green methanol compliance with Annex IX of the amended RED directive. MefCO₂ fuels can have a **premium price** over its fossil fuel methanol which significantly improves any business case scenario.
Power to X routes demo’s

- CO₂ avoidance – user of green H₂
  - Power-to-H₂ (gas, fuel, refinery,..)
- CO₂ utilization
  - Power to methane
    - Biocat – biological methanation
    - ZSW- Stuttgart – Sabatier
  - Power-to-methanol
    - MefCo2
  - Power-to-polymers
    - MIP – CO2MPASS
CONVERSION OF CO₂ INTO MONOMERS AND POLYMERS

MIP CO₂MPASS

CO₂MPASS
CO₂-based Monomers and Polymers for Advances in Science and Society

Partners
CONVERSION OF CO$_2$ INTO MONOMERS AND POLYMERS

*MIP CO$_2$MPASS*

O=C=O

Polyhydroxyalkanoates

Lactic acid

Polylactic acid

Prebiotics

3D printing filament

3D printing
What have we learned?
Power-to-gas = Renewable Hydrogen + Grid Balancing Services

Power-to-Gas Solution

Grid Balancing Services

- Renewable Power
- Captive RE
- Grid Services
- Power Grid System Operator

Renewable Hydrogen Options

- H2 Refueling
- Natural Gas System
- Liquid Fuels

H2 or SNG

H2
Grid service capability has been developed
The real time dynamic response makes Power-to-Gas suited for grid balancing service.

Hydrogenics’ Demonstration of Electrolyser in IESO Distributed Loads for Regulation Study

Faster response than AGC Signal

Note: Ontario IESO signal test completed June 2011
Size matters for grid balancing

Hybalance design:
dual stack unit (2.5 MW_p design)

FAT December 2016, Oevel (B)
Presentation to public
Additional value in conventional fuels: Replacing fossil H₂ with green H₂
10 MW building block – cost reduction
A related design factor to the Capex cost is the Stack Efficiency.
Our customers are building Capex cost reductions into future plans for utility-scale Power-to-Gas plants

**Investment cost development power to gas**
Cost estimates for a 40 Mw$_{el}$ installation (subject to change)

Business case for Power-to-Gas developers has six drivers

P2G Economic Drivers

<table>
<thead>
<tr>
<th>Capital</th>
<th>Operating Cost</th>
<th>Multiple Revenue Streams</th>
</tr>
</thead>
<tbody>
<tr>
<td>Equipment Capex</td>
<td>Price of Electricity</td>
<td>H2 Energy Produced</td>
</tr>
<tr>
<td>Capacity Factor</td>
<td></td>
<td>Grid Services</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Renewable Fuel or Gas Premium</td>
</tr>
</tbody>
</table>

size / usage  

efficiency  

application  

size / capabilities  

regulatory / CO₂
## Outlook Power-to-H₂ potential in GW scale

<table>
<thead>
<tr>
<th>Publication</th>
<th>Potential for water electrolysis (P2G)</th>
</tr>
</thead>
<tbody>
<tr>
<td>“Study of the requirement for electricity storage in Germany” Agora Energiewende</td>
<td>GER: 16 GW (2023), 80 GW (2033) and 130 GW (2050)</td>
</tr>
<tr>
<td>“Reduction of CO2 emissions by addition of hydrogen to natural gas” by Haines, Polman and de Laat, in IEA Greenhouse Gas Control Technologies Volume 1</td>
<td>UK: 23.5 GW of electrolysis in 2050</td>
</tr>
<tr>
<td>“Study of hydrogen and methanation as processes for capturing the value of excess electricity” Report by ADEME GRTGaz and GRDF, France</td>
<td>FR: 1.2-1.4 GW of P2G plant in France by 2030 and up to 24 GW by 2050</td>
</tr>
<tr>
<td>“The role of power-to-gas in the future Dutch energy system” ECN and DNVGL for TKI Gas, 2014</td>
<td>HOL: 20 GW of installed P2G capacity if deep CO₂ emission reduction targets in the energy system (-80% to -95% by 2050)</td>
</tr>
<tr>
<td>Effects of large-scale power to gas conversion on the power, gas and carbon sectors and their interactions KULeuven, 2014</td>
<td>BE: 7 GW Power-to-Methane potential a 100% RES scenario</td>
</tr>
<tr>
<td>…</td>
<td>…</td>
</tr>
</tbody>
</table>
Conclusion

- H₂ generation by water electrolysis powered with green electricity
  - Avoids CO₂ emission
    - Direct use of H₂
  - Enables CO₂ re-utilization schemes
    - Synthesize hydrocarbons

- H₂ technology is ready
  - footprint and cost of ownership are decreasing

- Business cases are helped by combining value streams
  - H₂ value (beyond caloric use)
  - Grid services by load management (frequency <-> seasonal)
  - Regulatory schemes where re-use of CO₂ encouraged
Power-to-Gas in Flanders

- **Power-to-Gas Roadmap for Flanders**
  - [www.power-to-gas.be](http://www.power-to-gas.be)

- **Congres Waterstofregio 2.0**
  - 25.10.2016, Antwerpen