MW-scale PEM electrolysis
Lessons learnt from HyBalance and way forward

HyBalance

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WHo Is CUMMINS?

- Engines
- Power generators
- Electrification
- Hydrogen & Fuel Cells

- 190 Countries
- 61.6K Global Employees
- 1.4M+ Engines built in 2019
- 8K Distributor & dealer locations
- $1B Invested in research & development in 2018

100 YEARS of industry leadership

*2019 figures
CUMMINS IN EUROPE

- 11 Manufacturing Sites
- 18 Distribution Sites
- 300 Dealers
- 7,000 Employees
- €70m R&D in Europe on average per year
- €3.63bn Goods produced each year
**HYDROGEN ACTIVITIES**

- **Key technologies**
  - Alkaline Electrolysis
  - PEM Electrolysis
  - Solid Oxide Fuel Cells
  - PEM Fuel Cells
  - Hydrogen storage tanks

- **FCH manufacturing sites in EU**
  - Belgium: alkaline and PEM electrolysis
  - Germany: PEM Fuel Cells integration & H2 storage tanks

- **Recent acquisitions and partnerships**
  - General Electric (US)
  - Hydrogenics* (Belgium, Germany, Canada)
  - MOU with Hyundai
  - Loop Energy (Canada)
  - JV with NPROXX (Germany)

  *Air Liquide is still owning 19% of Hydrogenics*
PEM WATER ELECTROLYSIS - KEY MILESTONES

1999 - Small Scale PEM Electrolyser

2003 - 1.5 MW Cell Stack

2012 - Test Large Stack

2014 - Field Test 1.5 MW Electrolyzer

2015 - Indoor Design

2017 - HyLYZER®-1000 Architecture (5MW)

2018 - Dual Cell Stack Design

2019 - First 20 MW online

2020 - 20 MW online

The HyBalance project has received funding from the Fuel Cells and Hydrogen 2 Joint Undertaking under grant agreement No 671394. The Joint Undertaking receives support from the European Union’s Horizon 2020 research and innovation program, www.ftu.europa.eu. The HyBalance project has furthermore received funding from the Danish EUDP program, which is administered by the EUDP Board.
HyLYZER PEM Cell Stack - 1500E

250 Nm³/h - ~1.25 MW (max: ~1.5 MW)
HyBALANCE PROJECT: TOP VIEW
PEM ELECTROLYZER DESIGN

- 40 ft container: power racks (rectifiers), dual cell stack + Balance-of-Plant
- 20 ft container: R/O system, control panel, rooftop cooling, compressed air
Air Liquide, HyBalance, Hobro, Denmark

HyLYZER® 230-30 – dual stack
Air Liquide, HyBalance, Hobro, Denmark

HyLYZER® 230-30 – dual stack
LESSONS LEARNT FROM HYBALANCE (1)

- ‘First of its kind’ unit with 2 MW-class PEM cell stacks running in parallel on the same Balance-of-Stack
- A large amount of hardware and software improvements due to pilot design
- High dynamic response capability validated during the testing phase
- Mainly lessons learnt on the dual stack operation and maintenance
- Considering pilot nature of electrolyzer very reliable operation
- Balance-of-Stack assembly in clean room
- Development of in-house testing protocols
LESSONS LEARNT FROM HYBALANCE (2)

- Onsite installation: 1-day lift works (video)
- Controlling and maintaining water quality is crucial to prevent stack contamination (filters, reverse-osmosis maintenance, water polishing system)
- Development of stack swap procedures
- Development of annual testing procedures
- Operating experience to further develop and improve the HyLYZER®-500 platform
LESSONS LEARNT FROM HYBALANCE (3)

- **>120 tons** of hydrogen produced and delivered to end-user
- **>13,937 hours** of operation
- Overall system efficiency (incl. all utilities): **56.5 kWh/kg** (target: 57.5 kWh/kg)
- Cell stacks can be operated asymmetrical
- Fast reaction time for grid balancing services (FCR): **<10 sec** (in real operation), but the system can react in **<2 sec** (in hot conditions)
LEVERAGING THE HyBALANCE EXPERIENCE: DEVELOPMENT OF THE HyLYZER-500 PLATFORM

![HyLYZER-500 - Process container](image)

<table>
<thead>
<tr>
<th>Country</th>
<th>Project</th>
<th>Size</th>
<th>Year</th>
<th>Platform</th>
<th>Power</th>
<th>Gas</th>
<th>Industry</th>
<th>Mobility</th>
<th>Fuel</th>
</tr>
</thead>
<tbody>
<tr>
<td>Denmark</td>
<td>HyBalance</td>
<td>1.2 MW</td>
<td>2017</td>
<td>HyLYZER®-500</td>
<td>•</td>
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<tr>
<td>Canada</td>
<td>Embridge P2G</td>
<td>2.5 MW</td>
<td>2017</td>
<td>HyLYZER®-500</td>
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<tr>
<td>Thailand</td>
<td>EGAT</td>
<td>1 MW + 300 kW FC</td>
<td>2017</td>
<td>HyLYZER®-500</td>
<td>•</td>
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<tr>
<td>Germany</td>
<td>WindGas Brunsbuettel</td>
<td>2.4 MW</td>
<td>2017</td>
<td>HyLYZER®-500</td>
<td>•</td>
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<tr>
<td>Germany</td>
<td>MelCO2</td>
<td>1 MW</td>
<td>2018</td>
<td>HyLYZER®-500</td>
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<tr>
<td>Norway</td>
<td>Haeolus</td>
<td>2 MW + 100 kW FC</td>
<td>2018</td>
<td>HyLYZER®-500</td>
<td>•</td>
<td>•</td>
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<tr>
<td>Belgium</td>
<td>HRS CMB</td>
<td>1 MW</td>
<td>2019</td>
<td>HyLYZER®-500</td>
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<tr>
<td>Germany</td>
<td>HRS Wuppertal</td>
<td>1 MW</td>
<td>2019</td>
<td>HyLYZER®-500</td>
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<tr>
<td>Australia</td>
<td>Jemena</td>
<td>0.5 MW</td>
<td>2019</td>
<td>HyLYZER®-500</td>
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<tr>
<td>New Zealand</td>
<td>Halcyon Power</td>
<td>1.5 MW</td>
<td>2019</td>
<td>HyLYZER®-500</td>
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<td></td>
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<tr>
<td>Canada</td>
<td>AL Becancour</td>
<td>20 MW</td>
<td>2019</td>
<td>HyLYZER®-1000</td>
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<tr>
<td>Poland</td>
<td>Zepak</td>
<td>5 MW</td>
<td>2020</td>
<td>HyLYZER®-1000</td>
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<td>•</td>
<td></td>
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<td></td>
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<tr>
<td>USA</td>
<td>Douglas County</td>
<td>5 MW</td>
<td>2020</td>
<td>HyLYZER®-1000</td>
<td>•</td>
<td>•</td>
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</tbody>
</table>
CURRENT DEVELOPMENT: 2,5 MW PEM CELL STACK

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

<table>
<thead>
<tr>
<th></th>
<th>1500E cell stack (high)</th>
<th>1500E cell stack (small)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Nominal input power (Max)</td>
<td>2,5 MW (3 MW)</td>
<td>1,25 MW (1,5 MW)</td>
</tr>
<tr>
<td>Nominal H2 flow (Max)</td>
<td>500 Nm³/h (620 Nm³/h)</td>
<td>250 Nm³/h (310 Nm³/h)</td>
</tr>
<tr>
<td>Operating pressure</td>
<td>30 barg</td>
<td>30 barg</td>
</tr>
</tbody>
</table>

4. Fast Response and Dynamic Operation
   Key requirement established

5. Very compact
   Lowest footprint on the market

6. Reduced Maintenance
   Limited and optimized

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SCALABLE PRODUCT PLATFORM
8,000 KG/DAY / 20MW / 4x HYLYZER®-1000

HyLYZER®-1000 – Balance-of-Stack
1000 Nm³/h (~5 MW) in total

2x 1500E cell stack (high)

10,000 kgpd PEMWE Hydrogen Plant in 500 m² (598 yard²)
[8,000 kgpd guaranteed]
## WATER ELECTROLYZERS: PRODUCT LINE

### HySTAT®

<table>
<thead>
<tr>
<th>Model</th>
<th>Output Pressure</th>
<th>Design</th>
<th>Number of Cell Stacks</th>
<th>Nominal Hydrogen Flow</th>
<th>Nominal Input Power</th>
<th>AC Power Consumption (incl. Utilities)</th>
<th>DC Power Consumption</th>
<th>Turndown Ratio</th>
<th>Hydrogen Purity</th>
<th>Tap Water Consumption</th>
<th>Footprint (in containers)</th>
<th>Utilities (AC-DC rectifiers, reverse osmosis, cooling, instrument air, H₂ dryer)</th>
<th>Utilities (AC-DC rectifiers, reverse osmosis, cooling, instrument air, H₂ dryer)</th>
</tr>
</thead>
<tbody>
<tr>
<td>HySTAT®-15-10</td>
<td>10 barg (27 barg optional)</td>
<td>Indoor/outdoor</td>
<td>1</td>
<td>15 Nm³/h</td>
<td>80 kW</td>
<td>5.0 to 5.4 kWh/Nm³</td>
<td>≤ 5.1 kWh/Nm³</td>
<td>40-100%</td>
<td>99.998%</td>
<td>&lt;1.4 liters / Nm³ H₂</td>
<td>1 x 20 ft</td>
<td>Incl.</td>
<td>Incl.</td>
</tr>
<tr>
<td>HySTAT®-60-10</td>
<td>60 Nm³/h</td>
<td>Indoor/outdoor</td>
<td>4</td>
<td>60 Nm³/h</td>
<td>300 kW</td>
<td>≤ 5.1 kWh/Nm³</td>
<td></td>
<td>10-100%</td>
<td>99.998%</td>
<td>&lt;1.4 liters / Nm³ H₂</td>
<td>1 x 40 ft</td>
<td>Incl.</td>
<td>Incl.</td>
</tr>
<tr>
<td>HySTAT®-100-10</td>
<td>100 Nm³/h</td>
<td>Indoor/outdoor</td>
<td>6</td>
<td>100 Nm³/h</td>
<td>500 kW</td>
<td>≤ 5.1 kWh/Nm³</td>
<td></td>
<td>5-100%</td>
<td>99.998%</td>
<td>&lt;1.4 liters / Nm³ H₂</td>
<td>1 x 40 ft</td>
<td>Incl.</td>
<td>Incl.</td>
</tr>
<tr>
<td>HyLYZER®-500-30</td>
<td>500 Nm³/h</td>
<td>Indoor/outdoor</td>
<td>2</td>
<td>500 Nm³/h</td>
<td>2.5 MW</td>
<td>≤ 5.1 kWh/Nm³</td>
<td>4.3 kWh/Nm³ ± 0.1</td>
<td>5-100%</td>
<td>99.998%</td>
<td>≤1.4 liters / Nm³ H₂</td>
<td>2 x 40 ft</td>
<td>Incl.</td>
<td>Incl.</td>
</tr>
<tr>
<td>HyLYZER®-1,000-30</td>
<td>1.000 Nm³/h</td>
<td>Indoor</td>
<td>2</td>
<td>1.000 Nm³/h</td>
<td>5 MW</td>
<td>≤ 5.1 kWh/Nm³</td>
<td>4.3 kWh/Nm³ ± 0.1</td>
<td>5-125%</td>
<td>99.998%</td>
<td>≤1.4 liters / Nm³ H₂</td>
<td>2 x 40 ft</td>
<td>Incl.</td>
<td>Incl.</td>
</tr>
<tr>
<td>HyLYZER®-4,000-30</td>
<td>4.000 Nm³/h</td>
<td>Indoor</td>
<td>8</td>
<td>4.000 Nm³/h</td>
<td>20 MW</td>
<td>≤ 5.1 kWh/Nm³</td>
<td>4.3 kWh/Nm³ ± 0.1</td>
<td>5-125%</td>
<td>99.998%</td>
<td>≤1.4 liters / Nm³ H₂</td>
<td>20 x 25 m (500 m²)</td>
<td>Optional</td>
<td>Optional</td>
</tr>
</tbody>
</table>

**Utilities (AC-DC rectifiers, reverse osmosis, cooling, instrument air, H₂ dryer)**

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**Date**: 24.09.2020 | **HyBalance workshop** | **PUBLIC**
CONCLUSIONS

▪ The HyBalance project has allowed Cummins-Hydrogenics to develop and validate its dual PEM cell stack platform in an industrial environment.

▪ There were many learnings during all phases of the HyBalance project and those have been translated in incremental improvements of the HyLYZER®-500 electrolyzer platform (now a commercial product).

▪ The HyBalance unit will continue its operation after the end of the funding period.

▪ Cummins-Hydrogenics is now building the largest 20 MW PEM electrolyser plant based on the HyLYZER®-1000 platform with individual PEM cell stacks of 500 Nm³/h (~2.5 MW each).

▪ Cummins-Hydrogenics is getting prepared for the ‘GW Era’ of hydrogen technologies.

▪ Big THANK YOU to all HyBalance project partners and to the funding authorities: the FCH-JU and the Danish EUDP program.
THANK YOU

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