Energy Transition calls for 100% renewable energy systems

with Renewable Hydrogen, without fossil fuels.

Environmental and energy policies focus on 3 objectives:

- Fight climate change
- Decrease dependency on oil, coal and gas suppliers
- Increase air quality

Wind and solar power generation provide evidence that fully decarbonizing the power sector is possible. For transport, heating and industrial sectors however, the issue remains unresolved. Renewable Hydrogen creates the link between renewable power and renewable transport, heating and industry.

- Hydrogen is the most plentiful element in the universe, found mainly in water and organic compounds.
- Hydrogen can be produced via water electrolysis, splitting water molecules (H₂O) into hydrogen (H₂) and oxygen (O₂) with the use of power.
- If produced from renewable sources, hydrogen can be renewable and completely CO₂-free.
- Like electricity, hydrogen can be channeled anywhere it is needed.
- Unlike electricity, hydrogen is suitable for long-term energy storage.
- Renewable hydrogen is a determining factor in fighting climate change, decreasing energy dependency and improving our air quality.

RENEWABLE HYDROGEN: THE GAME-CHANGING vector of a low-carbon energy system
3 PRODUCTION SITES
and 4 sales offices

ON-SITE HYDROGEN GENERATION
Electrolysers
Industrial Hydrogen supply

POWER SYSTEMS
Fuel Cells
Stand-by Power
Mobile Power Modules
MW Power Plants

RENEWABLE HYDROGEN
Energy Storage
Hydrogen Refueling Station
Power-to-X
Grid balancing services

3 BUSINESS SEGMENTS

Your global partner in shifting power to renewable hydrogen
HYDROGEN IS LIFE

- Hydrogen is the most common element around us. It makes up 75% of the mass of the entire universe, in molecular forms such as water and organic compounds.
- Hydrogen is the lightest and simplest element with the chemical symbol H and atomic number 1. It consists of only one electron and one proton.
- Hydrogen is a gas (H₂) at standard temperature and pressure, which can be compressed or liquefied if needed.
- Hydrogen is carbon-free, exceptionally clean, lighter than air, odorless and non-toxic.

HYDROGEN IS WIDELY USED

- Hydrogen is safe to produce, store and transport.
- Hydrogen has been safely used for many decades in a wide range of industrial applications:
  - In chemical plants (ammonia) and refineries
  - In industrial manufacturing (steel, float glass, semi-conductors)
  - In power plants
  - In the food industry for the hydrogenation of oils
- There is growing use of hydrogen in mobility for Fuel Cell Electric Vehicles (FCEV).

Main industries consuming hydrogen

- **93%** Ammonia production and 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
Water electrolysis was discovered in the 18th century and simply uses electricity to decompose or separate water (H₂O) into hydrogen gas (H₂) and oxygen gas (O₂).

WATER + POWER \rightarrow HYDROGEN + OXYGEN

But most of the hydrogen available today is not CO₂-free. When produced for industry from fossil resources (natural gas, oil or coal), approximately 10 tons of CO₂ are generated for each ton of hydrogen produced.

Renewable hydrogen has the potential to decarbonize a large range of industrial applications and also serve as an energy vector in a decarbonized energy system, storing renewable power when needed for use in a variety of applications when required.

A fuel cell is a device that generates electricity by chemically reacting hydrogen (H₂) and oxygen (O₂), generating water vapor (H₂O) and electricity.

Hydrogen + Oxygen \rightarrow Power + Water
Hydrogenics is a renowned and global manufacturer of electrolysers, delivering onsite hydrogen production solutions. Hydrogenics’ electrolysers are ‘plug and play’ units, safely and reliably producing very pure hydrogen in continuous or dynamic operation modes. All systems can be connected to standard power and water connections and are equipped with standard water purification, power conditioning, hydrogen purification and remote servicing. Hydrogenics offers two types of technologies for the cell stack: pressurized alkaline and PEM (proton exchange membrane).

## Alkaline technical specifications

<table>
<thead>
<tr>
<th></th>
<th>HySTAT®-15-10/30</th>
<th>HySTAT®-60-10</th>
<th>HySTAT®-100-10</th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Output pressure</strong></td>
<td>10 barg</td>
<td>27 barg</td>
<td></td>
</tr>
<tr>
<td><strong>Number of cell stacks</strong></td>
<td>1</td>
<td>4</td>
<td>6</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>
</tr>
<tr>
<td><strong>Nominal input power</strong></td>
<td>80 kW</td>
<td>300 kW</td>
<td>500 kW</td>
</tr>
<tr>
<td><strong>AC power consumption</strong></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>
</tr>
<tr>
<td><strong>Hydrogen purity</strong></td>
<td>99.998%</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Tap water consumption</strong></td>
<td>&lt; 1.7 liters / Nm³ H₂</td>
<td></td>
<td></td>
</tr>
<tr>
<td><strong>Footprint</strong></td>
<td>20 ft container</td>
<td>40 ft container</td>
<td>40 ft container</td>
</tr>
</tbody>
</table>

NB: Other configurations (indoor/outdoor) and intermediate hydrogen capacities (10-100 Nm³/h) are possible.
PEM (Proton Exchange Membrane)

PEM is our latest technology, developed under our 10-year R&D program. Our first MW-scale electrolysers were delivered in 2014 and have demonstrated excellent performance. With PEM, water yields H+ ions which cross a membrane to pick up electrons to become H atoms. These atoms then combine to make hydrogen molecules. This technology can operate with a higher current density and higher pressure, making it well-suited for projects where space is limited and where the need for dynamic operation is high, in combination with renewables.

Fast reacting devices

Both alkaline and PEM technologies can modulate their power consumption easily, making them very attractive for stabilizing power grids and delivering grid balancing or ancillary 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>

PEM technical specifications

<table>
<thead>
<tr>
<th></th>
<th>HyLYZER® -300-30</th>
<th>HyLYZER® -1,000-30</th>
<th>HyLYZER® -5,000-30</th>
</tr>
</thead>
<tbody>
<tr>
<td>Output pressure</td>
<td>30 barg</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Number of cell stacks</td>
<td>1</td>
<td>2</td>
<td>10</td>
</tr>
<tr>
<td>Nominal hydrogen flow</td>
<td>300 Nm³/h</td>
<td>1,000 Nm³/h</td>
<td>5,000 Nm³/h</td>
</tr>
<tr>
<td>Nominal input power</td>
<td>1.5 MW</td>
<td>5 MW</td>
<td>25 MW</td>
</tr>
<tr>
<td>AC power consumption</td>
<td>5.0-5.4 kWh/Nm³</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrogen flow range</td>
<td>1-100%</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrogen purity</td>
<td>99.998%</td>
<td>O₂ &lt; 2 ppm, N₂ &lt; 12 ppm (higher purities optional)</td>
<td></td>
</tr>
<tr>
<td>Tap water consumption</td>
<td>&lt;1.4 liters / Nm³ H₂</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Footprint</td>
<td>40 ft container</td>
<td>2 x 40 ft container</td>
<td>10 x 40 ft container</td>
</tr>
<tr>
<td>Footprint utilities</td>
<td>20 ft container</td>
<td>20 ft container</td>
<td>5 x 20 ft container</td>
</tr>
</tbody>
</table>

NB: Other configurations (indoor/outdoor) and intermediate capacities are possible.

PEM technology powers our HyLYZER® electrolysers; it is particularly well suited for large-scale applications in the industrial and energy sector.
Hydrogen solutions for a renewable-based energy system

Hydrogen produced from renewable power via water electrolysis can be used to reduce carbon emissions further in the power, gas, industry, fuel and mobility sectors, for a cleaner and more sustainable future.
Excess renewable energy is converted to hydrogen, stored and then repowered to electricity via a fuel cell system.

To reduce overall emissions from natural gas, renewable hydrogen is injected into the grid, either directly or as synthetic methane using CO₂.

Renewable energy is converted into hydrogen for industries requiring high-quality and low-carbon hydrogen for their processes.

Electrolysis produces a clean alternative to carbon-based hydrogen in oil refining or methanol production, reducing the carbon footprint of fossil-based fuels.

Now more than ever, people are looking for ways to store renewable energy for a flexible, low-carbon power supply. Hydrogen offers a solution. Excess sun, wind or tidal energy can be converted into hydrogen by an electrolyser and stored for later use in a repowering unit such as a fuel cell or hydrogen gas turbine. Typical round trip efficiency is around 35% (±70% conversion efficiency from power to hydrogen and ±50% from hydrogen to power).

Hydrogen technologies are a credible energy storage solution especially when highly reliable long-term energy storage (weeks to months) is needed. Typical applications are to be found in remote locations, off-grid systems or islands with high penetration of renewables.

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
3 HyPMC 120 kW

Excess renewable energy is converted to hydrogen, stored and then repowered to electricity via a fuel cell system.

1 PEM FUEL CELL POWER PLANTS

Hydrogenics is a leading manufacturer of high-quality fuel cells for stationary applications, delivering over 20 years of turnkey fuel cell solutions for back-up power systems (telecom, data centers, and hospitals) and repowering units where hydrogen is converted back to electricity.
One way to use more hydrogen is to add it to the gas grid, expanding energy storage to the TWh range. There are two techniques for this: direct injection and conversion of hydrogen into synthetic methane (methanation). In direct injection, pure hydrogen enters the grid at a 1-10% concentration (depending on applicable regulation). At up to 2% concentration, this technique is generally straightforward, however above this, the grid operator must confirm grid compatibility and client tolerance for variable H₂ concentrations, considering seasonal gas consumption. But even with a 2% limitation, the theoretical storage capacity of our gas grid is immense.

Methanation overcomes direct injection’s limitations, producing methane that is compatible with natural gas and that can be added directly to the grid. Carbon dioxide and hydrogen are converted into synthetic methane, with water as the by-product: 

\[ \text{CO}_2 + \text{H}_2 \rightarrow \text{CH}_4 + \text{H}_2\text{O} \]

The process takes place in either high-temperature conversion over a chemical catalyst or biologically via bacteria.

1 UNIPER’s power-to-gas facility, Falkenhagen, Germany: 2 MW electrolyser
2 BioCat project, Avedøre, Denmark: 1 MW electrolyser
POWER TO MOBILITY

Hydrogenics, a leader in designing and building hydrogen refueling stations

Accessible hydrogen makes fuel cell transport a realistic option. Momentum is building for a hydrogen refueling infrastructure, with clear 2020 and 2030 targets in national and regional policies across several regions of the world including California, Europe and Japan. Over the last 15 years, Hydrogenics has been involved in over 50 hydrogen refueling station (HRS) projects around the world, delivering turnkey solutions to the final customer and main technology components to system integrators.

Hydrogen refueling station - technical specifications

<table>
<thead>
<tr>
<th></th>
<th>HRS 15-700</th>
<th>HRS 100-700</th>
<th>HRS 200-350/700</th>
</tr>
</thead>
<tbody>
<tr>
<td>Electrolyser</td>
<td>HySTAT®-15-10/30</td>
<td>HySTAT®-100-10</td>
<td>HyLYZER®-200-10</td>
</tr>
<tr>
<td>Electrolyser technology</td>
<td>Alkaline</td>
<td>Alkaline</td>
<td>PEM</td>
</tr>
<tr>
<td>Nominal input power</td>
<td>80 kW</td>
<td>500 kW</td>
<td>1 MW</td>
</tr>
<tr>
<td>Daily production capacity</td>
<td>30 kg/day</td>
<td>100 kg/day</td>
<td>200 kg/day</td>
</tr>
<tr>
<td>Refueling pressure</td>
<td>700 bar</td>
<td>700 bar</td>
<td>350 bar and 700 bar</td>
</tr>
<tr>
<td>Compressor</td>
<td>450 bar compressor / 850 bar compressor</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Hydrogen storage</td>
<td>3 banks cascade system sized according to filling requirements</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Dispenser</td>
<td>1 x 700 bar dispenser</td>
<td>1 x 700 bar dispenser</td>
<td>1 x 350 bar dispenser</td>
</tr>
<tr>
<td>Hydrogen Purity</td>
<td>Fuel Cell grade hydrogen at 99.998% according to ISO 14687</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Estimated AC consumption (all included)</td>
<td>68 kWh/kg</td>
<td>65 kWh/kg</td>
<td>65 kWh/kg</td>
</tr>
<tr>
<td>Footprint</td>
<td>1 x 40 ft container</td>
<td>2 x 40 ft container</td>
<td>3 x 40 ft container</td>
</tr>
</tbody>
</table>

Conform to SAE J2601, SAE J2799, SAE J2719 refueling protocols.
NB: Other configurations and intermediate capacities (10-1,000 Nm³/h) are possible.

A car can drive 100 km on 1 kg H₂, while a bus can drive the same distance on 7-8 kg H₂
Both typically travel 400-500 km before they need to refuel.

1 HRS WaterstofNet, Helmond, The Netherlands
HYDROGEN REFUELING STATION (HRS) - KEYS COMPONENTS

HRS design is complex, led by diverse operational parameters that vary for each station. The first is pressure, which depends on the target market: cars refuel at 700 bar, heavy duty (buses, trucks) and light duty (forklifts) vehicles at 350 bar. The HRS design must also meet estimated daily refueling (kg H₂/day) and back-to-back fueling (how many cars will refuel per hour).

Preferences on hydrogen storage tanks, compression and refrigeration units have their impact, and must provide enough cooling capacity for safe, international-standard delivery from high-pressure tanks. The HRS estimates a vehicle’s fuel needs, then delivers this at increasing pressure stages to save compression costs, and at high enough quality to protect fuel cells. In short, extensive expertise and experience go into HRS design!

A fuel cell car usually has a 5 kg tank at 700 bar, while a bus tank holds 35 kg H₂ at 350 bar

Hydrogen production unit: the alkaline or PEM electrolyser
Hydrogen compressors: to increase the pressure from 10/30 bar to 450 bar for buses and to 850 bar for cars
Hydrogen storage banks: comprising of various pressure tanks
Gas control panel: managing the whole system: compression and the storage needs according to the expected hydrogen demand, measuring hydrogen flows, controlling the hydrogen purity
Refrigeration unit: to cool down the hydrogen to -40°C
Dispenser: the interface with the customer. Standard equipment according to pressure (350 bar and/or 700 bar)

FUEL CELL POWER MODULES FOR MOBILITY

Hydrogenics is a leading manufacturer of high-quality fuel cells delivering fuel cell modules for Fuel Cell Electric Vehicles such as material handling vehicles, buses, trucks and trains.
POWER TO INDUSTRY

Hydrogenics, the global reference in electrolysis for onsite industrial hydrogen production!

Companies across the globe benefit from the reliable hydrogen produced by our electrolyser. For over 30 years, we have supplied more than 500 electrolyser to customers active in power plants, steel and metal processing, glass, oil and fat hydrogenation, small refineries and industrial gas supply. Onsite production gives businesses the flexibility to produce as much high-purity hydrogen as they need, wherever they are. It is especially attractive for remote locations far from central large-scale hydrogen production plants, eliminating high hydrogen transport costs.

Our alkaline and PEM electrolyser products have built a strong reputation in our customers’ industries. These demanding sectors expect high quality, reliability, safety and ease of operation and maintenance, all delivered to tight schedules.

1 Steel industry, Kirovgrad, Russia: 4 MW electrolyser
2 Float glass industry, Turkey: 1 MW electrolyser
3 Design of a 40 MW PEM indoor electrolyser

LARGE-SCALE PEM ELECTROLYSER PLANT

To address the needs of large hydrogen customers such as chemical industries and refineries, Hydrogenics has developed new electrolyser designs integrating its latest PEM technology. These MW-scale electrolyser systems are typically indoor with a minimal footprint and integrate a common balance-of-plant. The optimized design ensures high reliability and availability of the electrolyser solution for high-demanding industrial applications.

By using renewable hydrogen, industries can reduce their greenhouse gas emissions!
Transport is an area rich in opportunities to limit air pollution by greenhouse gases and particulates, and is targeted in the Renewable Portfolio Standards (RPS) and the EU’s Renewable Energy Directive (RED) and Fuel Quality Directive (FQD). National measures are increasingly focusing on low-carbon transport and sustainable fuels, and hydrogen has obviously an important role to play here.

Today, more than 43% of global hydrogen production is used in refineries to remove sulfur from fossil fuels. But the hydrogen is usually produced from the reforming of natural gas which generates around 10 tons of CO₂ for each ton of H₂. The ‘Power-to-Refinery’ concept replaces this with hydrogen from renewables, considerably reducing the carbon footprint of the conventional refineries while economies are still relying on fossil fuels until hydrogen mobility becomes a widespread reality.

Renewable hydrogen can also be used to produce bio-methanol (‘Power-to-Methanol’) which can be blended with conventional fuels to reduce carbon emissions. Unlike the more complex story of biofuels, these generate pre-determined carbon savings and benefit from very limited use of land.

Renewable hydrogen has the potential to decarbonize significantly the fuel sector, already consuming large quantities of hydrogen produced from fossil resources.

1.5 MW PEM cell stack developed by Hydrogenics
2. Small refinery in Guatemala: 600 kW electrolyser
Customers rely on our state-of-the-art equipment. They expect the highest standards of hydrogen quality, reliability and safety from electrolyzers that will last.

As with any complex machine, regular maintenance is essential to uphold these standards. We provide a detailed maintenance schedule with each electrolyser, so owners know what to check for each day and how to carry out essential periodic tasks.

Even so, we know that owners sometimes need extra support. A service team of experienced engineers is ready to assist our customers in the day-to-day operation to keep your equipment performing at its best.

Available to clients around the world, our flexible service department helps with:

- Site assessments and check-up
- Start-up and commissioning
- Training
- Maintenance and adjustments
- Remote assistance
- Upgrades
- Spare part recommendations
- Warranties and logistics

Each service agreement can be tailored to the customer so businesses only pay for the services they need, safe in the knowledge that they can count on their hydrogen supply.