HYDROG(E)NICS

SHIFT **POWER** | **ENERGIZE** YOUR WORLD

RENEWABLE HYDROGEN SOLUTIONS

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.

RENEWABLE HYDROGEN: THE GAME-CHANGING vector of a low-carbon energy system

- 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 (H_2O) into hydrogen (H_2) and oxygen (O_2) with the use of power.
- If produced from renewable sources, hydrogen can be renewable and completely CO_2-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.

170+
dedicated employees

Our raw materials, water & renewable power are
infinite!

2,000+
fuel cell sites

$48,1M
2017 annual sales

1 single focus:
hydrogen solutions

HYDROG(E)NICS

Publicly traded
NASDAQ (HYGS) and TSX (HYG) since 2000

65+ years
of experience

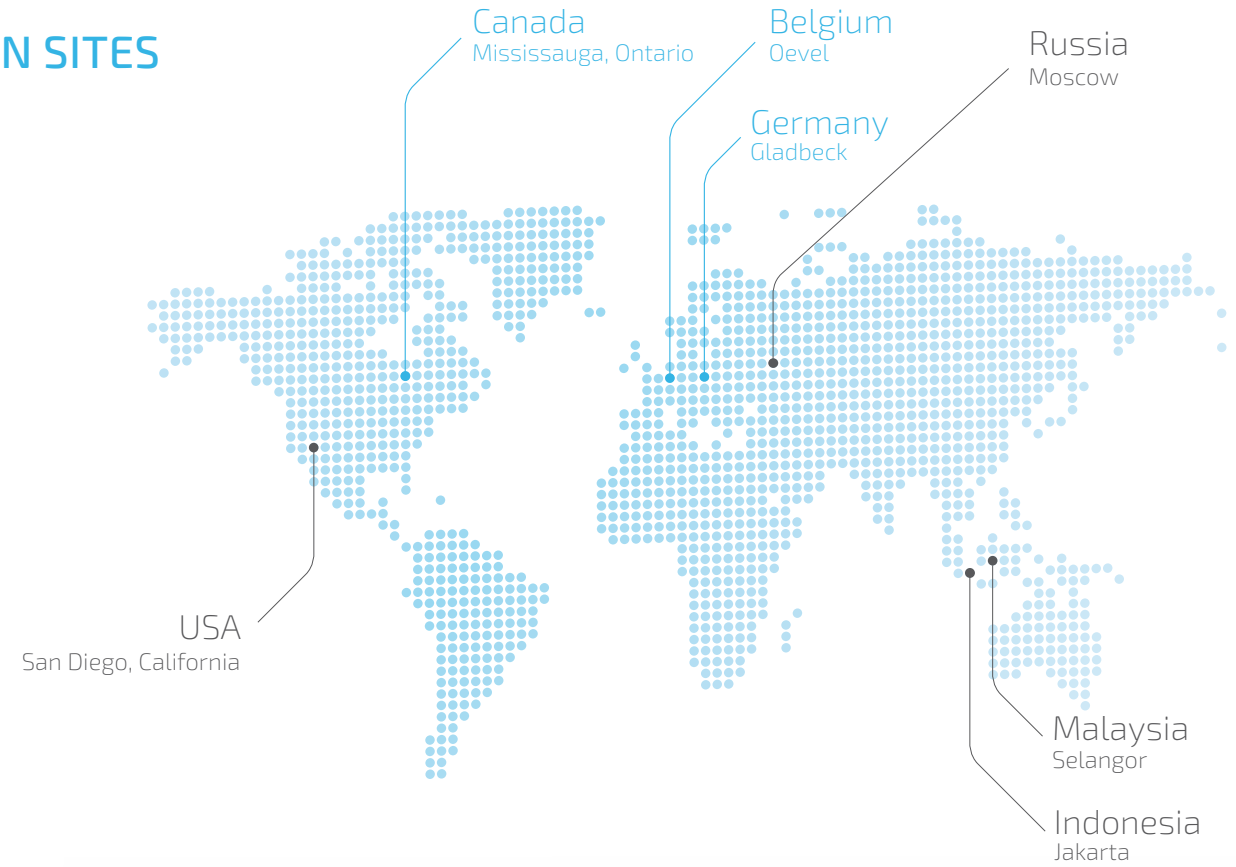
500+
electrolysis plants in operation

Global leader
in 2 main hydrogen technologies: electrolysis and fuel cells

1,500+
electrolysis plants sold since 1948

3 PRODUCTION SITES

and 4 sales offices



Your global partner in shifting power to renewable hydrogen

3 BUSINESS SEGMENTS

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

Key facts on **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 (H_2) 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 H_2)

Data source: The Hydrogen Economy, M. Ball, 2009 & Esprit Associates 2014

BUT MOST OF THE HYDROGEN AVAILABLE TODAY IS NOT CO_2-FREE

When produced for industry from fossil resources (natural gas, oil or coal), approximately 10 tons of CO_2 are generated for each ton of hydrogen produced.

RENEWABLE HYDROGEN

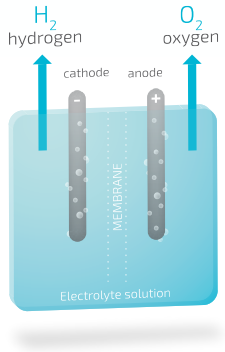
If produced from renewable power via electrolysis, hydrogen is fully renewable and CO_2-free.

RENEWABLE HYDROGEN AS AN ENERGY VECTOR

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.

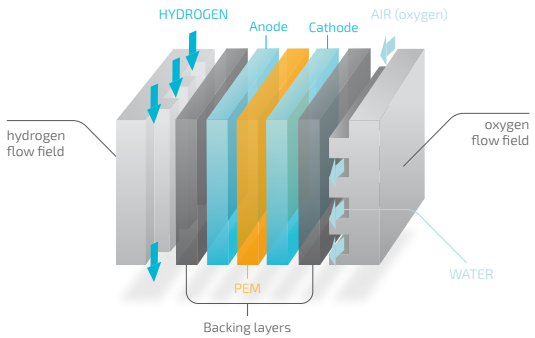
Electrolysis vs. fuel cells?

WATER + **POWER** ➧ **HYDROGEN** + OXYGEN



Water electrolysis was discovered in the 18th century and simply uses electricity to decompose or separate water (H_2O) into hydrogen gas (H_2) and oxygen gas (O_2).

HYDROGEN + OXYGEN ➧ **POWER** + WATER



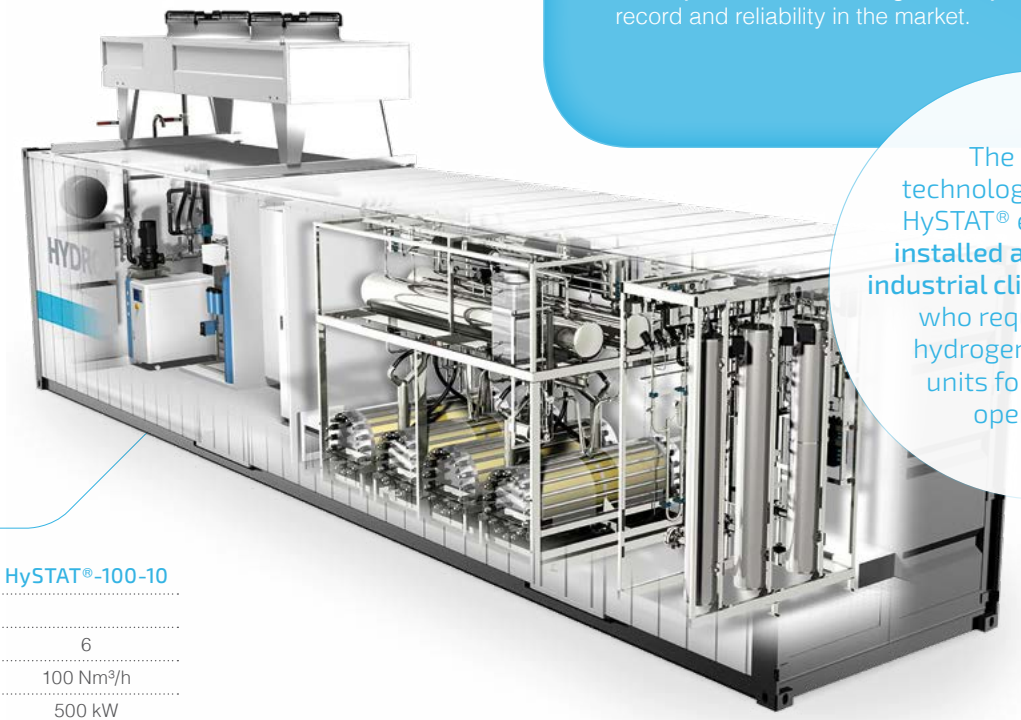
A fuel cell is a device that generates electricity by chemically reacting hydrogen (H_2) and oxygen (O_2), generating water vapor (H_2O) and electricity.

Onsite hydrogen production: Electrolysers

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

Here, an ion-exchange membrane removes OH-ions from an electrolyte-water solution, leaving hydrogen free to be harvested. This long-standing technology is based on our proprietary IMET® membrane, offering best-in-class systems with the strongest safety record and reliability in the market.



The alkaline technology powers our HySTAT® electrolysers, **installed at hundreds of industrial clients worldwide** who require reliable hydrogen production units for their daily operations.

Alkaline technical specifications

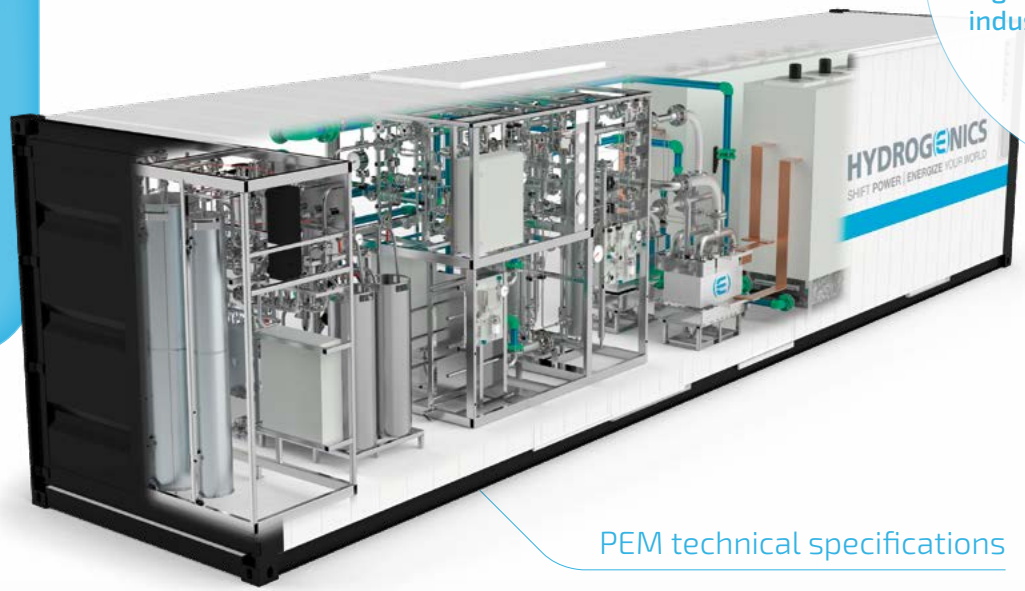
	HySTAT®-15-10/30	HySTAT®-60-10	HySTAT®-100-10
Output pressure	10 barg – 27 barg		
Number of cell stacks	1	4	6
Nominal hydrogen flow	15 Nm^3/h	60 Nm^3/h	100 Nm^3/h
Nominal input power	80 kW	300 kW	500 kW
AC power consumption (utilities included, at nominal capacity)	5.0-5.4 kWh/Nm^3		
Hydrogen flow range	40-100%	10-100%	5-100%
Hydrogen purity	99.998% O_2 < 2 ppm, N_2 < 12 ppm (higher purities optional)		
Tap water consumption	<1.7 liters / Nm^3 H_2		
Footprint	20 ft container	40 ft container	40 ft container

NB: Other configurations (indoor/outdoor) and intermediate hydrogen capacities (10-100 Nm^3/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.

PEM technology powers our HyLYZER® electrolysers; it is particularly **well suited for large-scale applications in the industrial and energy sector.**



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.

	Alkaline	PEM
Response signal (from pressurized stand-by to 100%)	< 3 sec	< 3 sec
Response signal (Operating system = HOT)	<1 sec	<1 sec

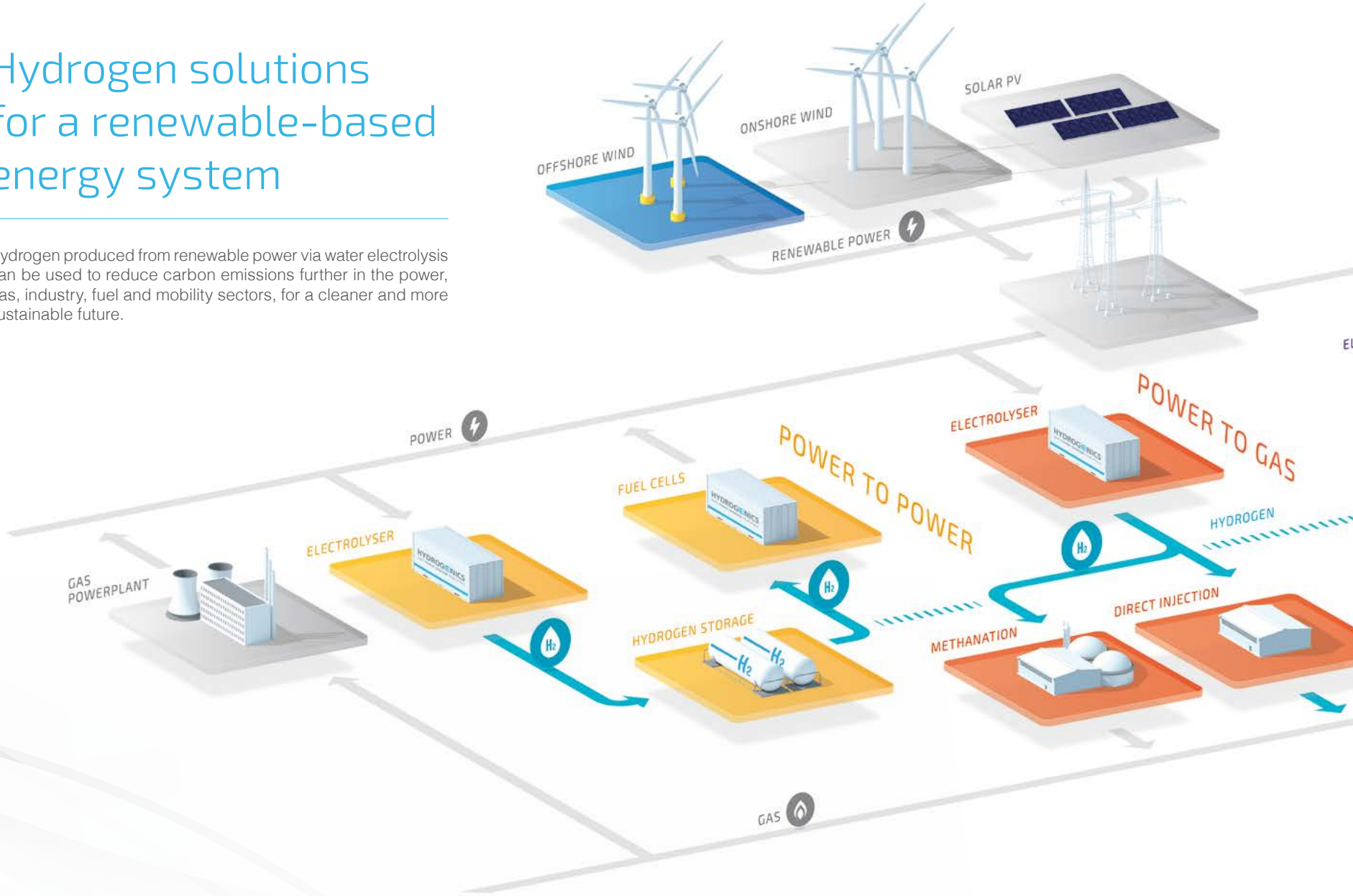
PEM technical specifications

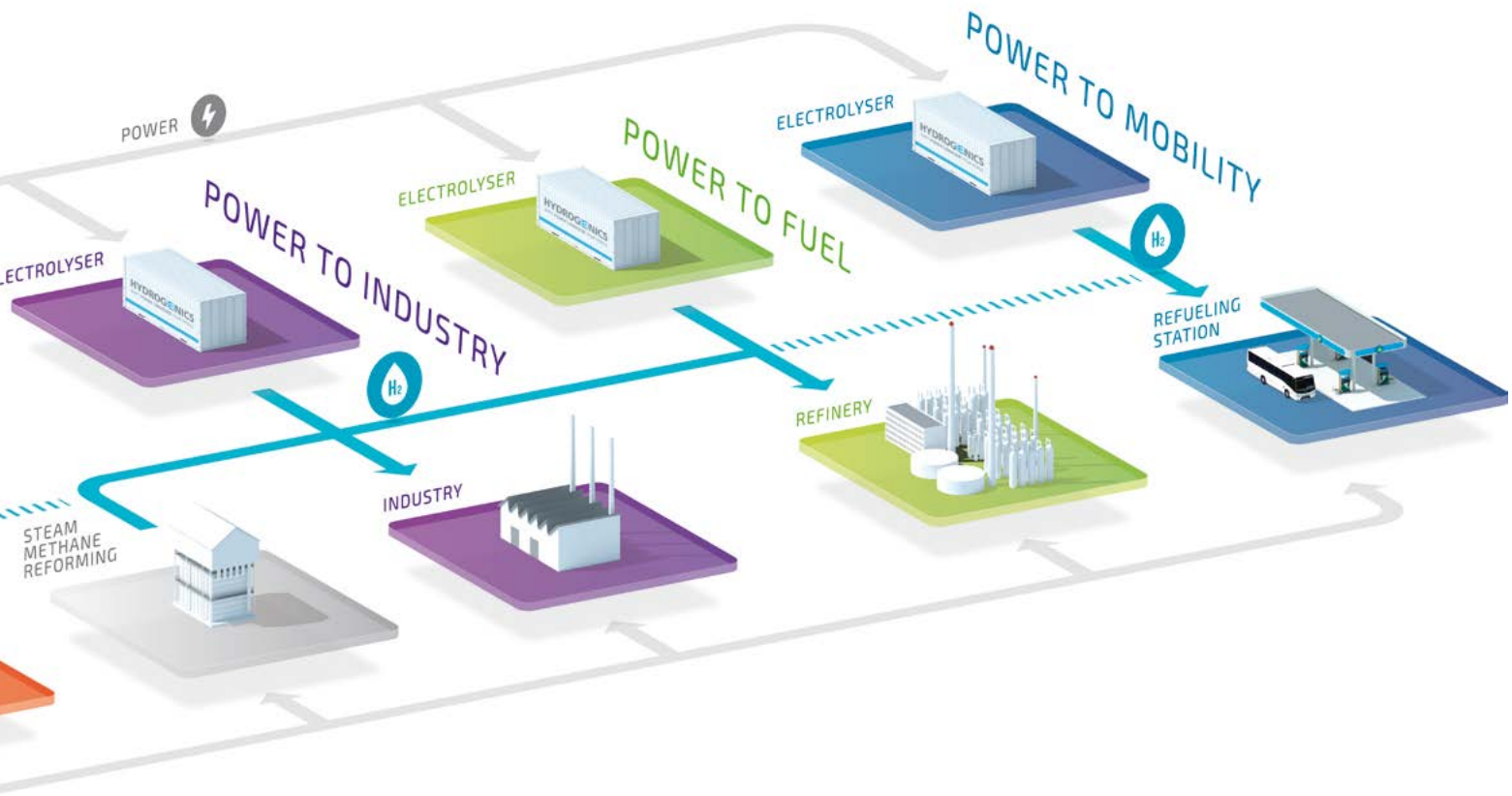
	HyLYZER® -300-30	HyLYZER® -1,000-30	HyLYZER® -5,000-30
Output pressure	30 barg		
Number of cell stacks	1	2	10
Nominal hydrogen flow	300 Nm^3/h	1,000 Nm^3/h	5,000 Nm^3/h
Nominal input power	1,5 MW	5 MW	25 MW
AC power consumption (utilities included, at nominal capacity)	5.0-5.4 kWh/Nm^3		
Hydrogen flow range	1-100%		
Hydrogen purity	99.998% O_2 < 2 ppm, N_2 < 12 ppm (higher purities optional)		
Tap water consumption	<1.4 liters / Nm^3 H_2		
Footprint	40 ft container	2 x 40 ft container	10 x 40 ft container
Footprint utilities	20 ft container	20 ft container	5 x 20 ft container

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

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.





POWER TO POWER p.12

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

POWER TO GAS p.13

To reduce overall emissions from natural gas, renewable hydrogen is injected into the grid, either directly or as synthetic methane using CO_2.

POWER TO INDUSTRY p.16

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

POWER TO FUEL p.17

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

POWER TO MOBILITY p.14

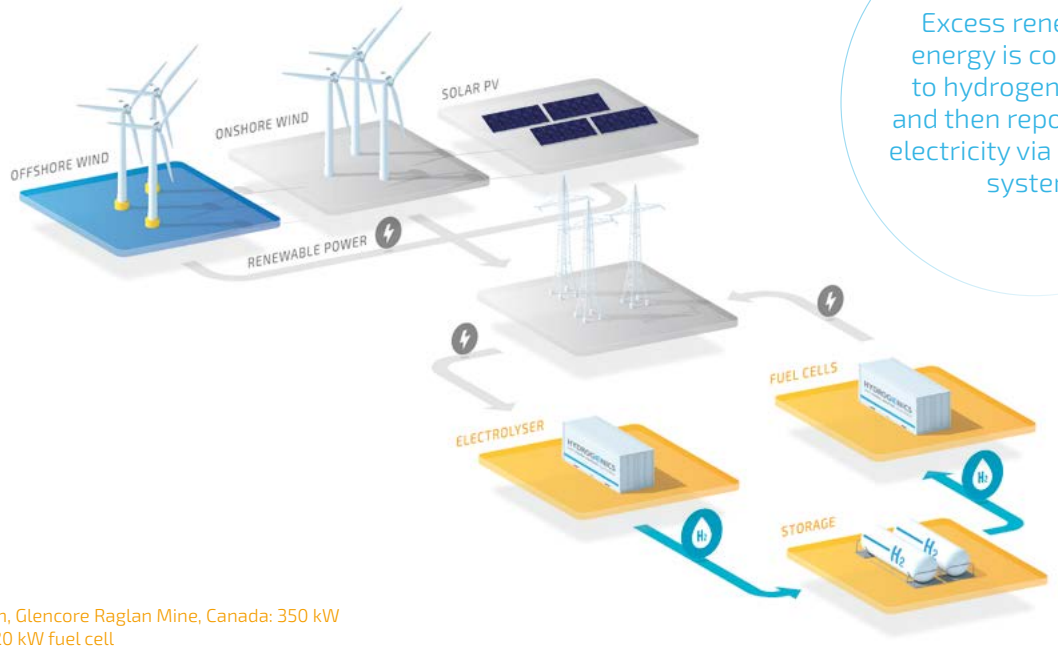
Hydrogen refueling stations dispense renewable hydrogen to Fuel Cell Electric Vehicles (FCEVs), making ultra low-carbon mobility a reality.

POWER TO POWER

Hydrogen, an ideal energy storage solution for isolated energy systems with high penetration of renewable power

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.



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

[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] HyPM© 120 kW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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.

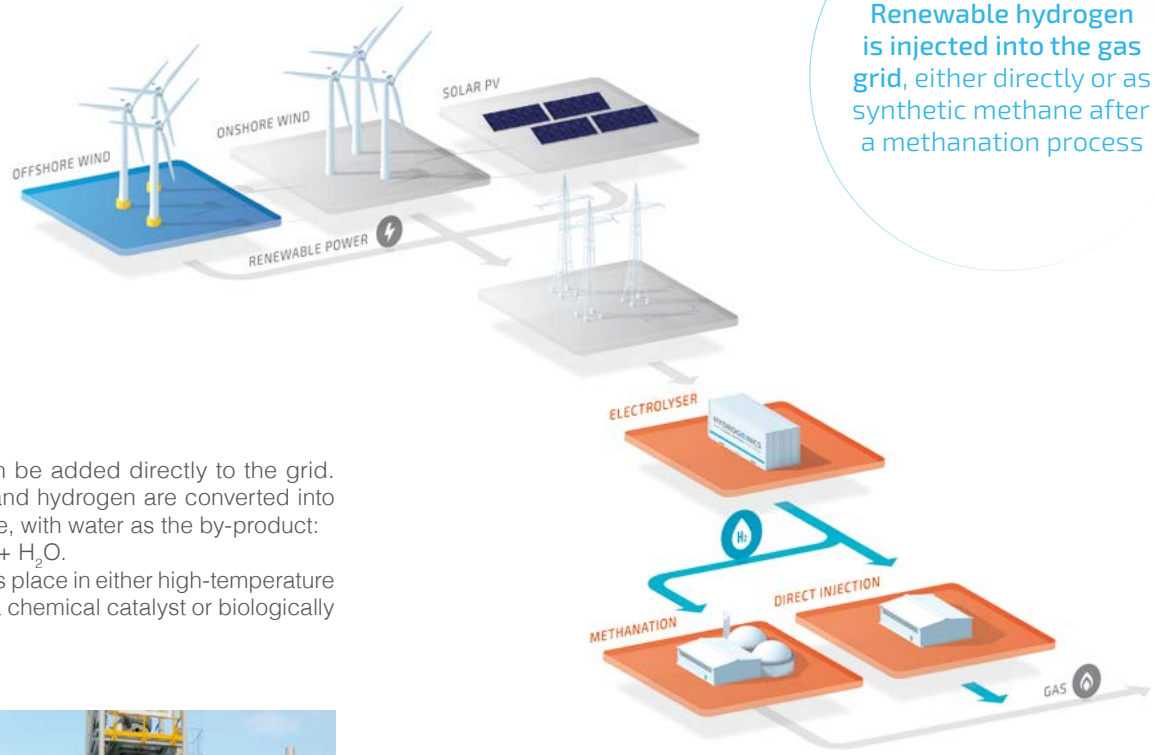

3

POWER TO GAS

Hydrogen or synthetic methane, the TWh energy storage solution!

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 H_2 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:
$CO_2 + H_2 \rightarrow CH_4 + H_2O$.
The process takes place in either high-temperature conversion over a chemical catalyst or biologically via bacteria.



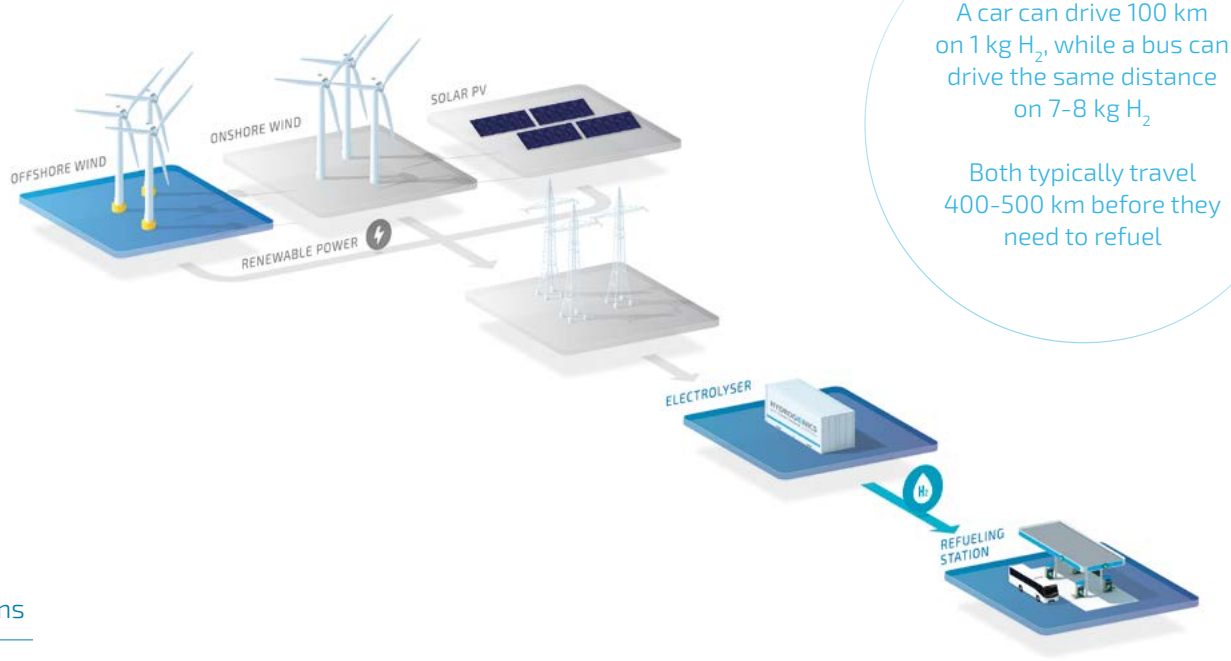
Renewable hydrogen is injected into the gas grid, either directly or as synthetic methane after a methanation process

[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.



A car can drive 100 km on 1 kg H_2, while a bus can drive the same distance on 7-8 kg H_2

Both typically travel 400-500 km before they need to refuel

Hydrogen refueling station - technical specifications

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

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

[1] HRS WaterstofNet, Helmond, The Netherlands

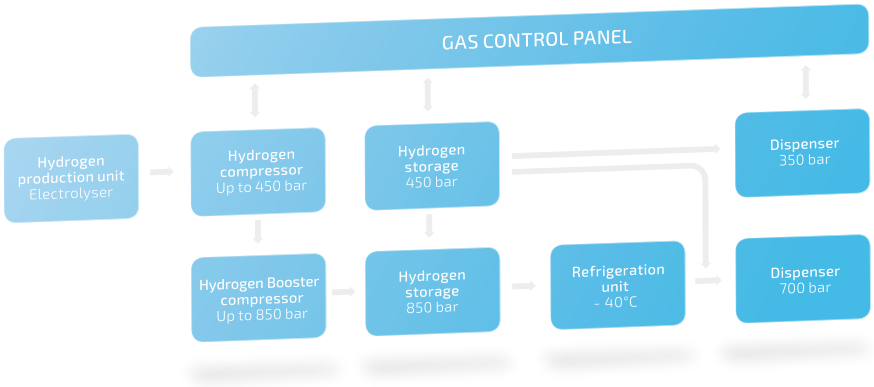
HYDROGEN REFUELING STATION (HRS) - KEYS COMPONENTS

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 H_2 /day) and back-to-back fueling (how many cars will refuel per hour).

A fuel cell car usually has a 5 kg tank at 700 bar, while a bus tank holds 35 kg H_2 at 350 bar

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!

[2] HRS Colruyt, Halle, Belgium



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

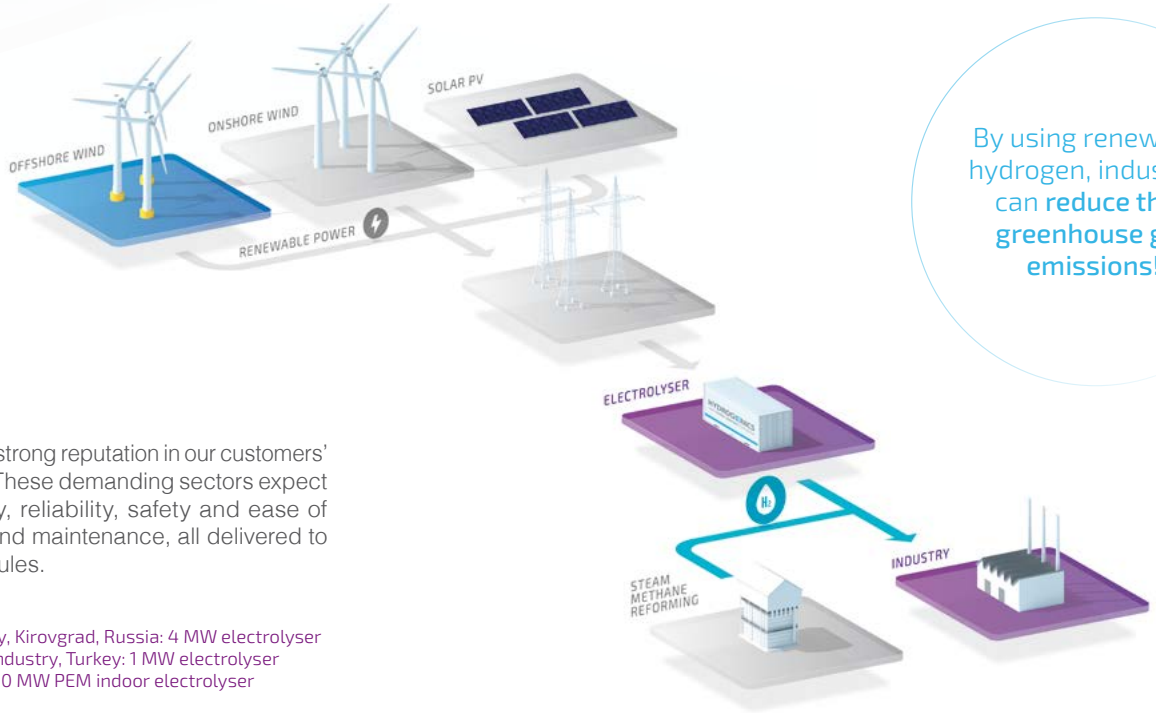
Hydrogenics is a leading manufacturer of high-quality fuel cells delivering fuel cell modules for Fuel Cell Electric Vehicles such as material handling vehicles, buses, trucks and trains.

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 electrolysers. For over 30 years, we have supplied more than 500 electrolysers 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.



By using renewable hydrogen, industries can **reduce their greenhouse gas emissions!**

[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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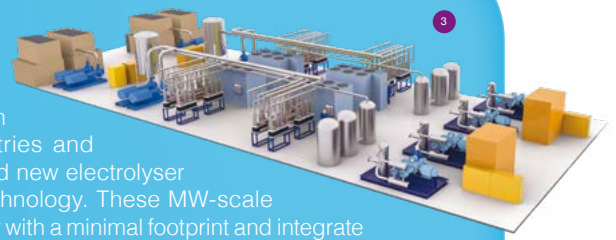
LARGE-SCALE PEM ELECTROLYSER PLANT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To address the needs of large hydrogen customers such as chemical industries and refineries, Hydrogenics has developed new electrolyser designs integrating its latest PEM technology. These MW-scale electrolyser systems 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.

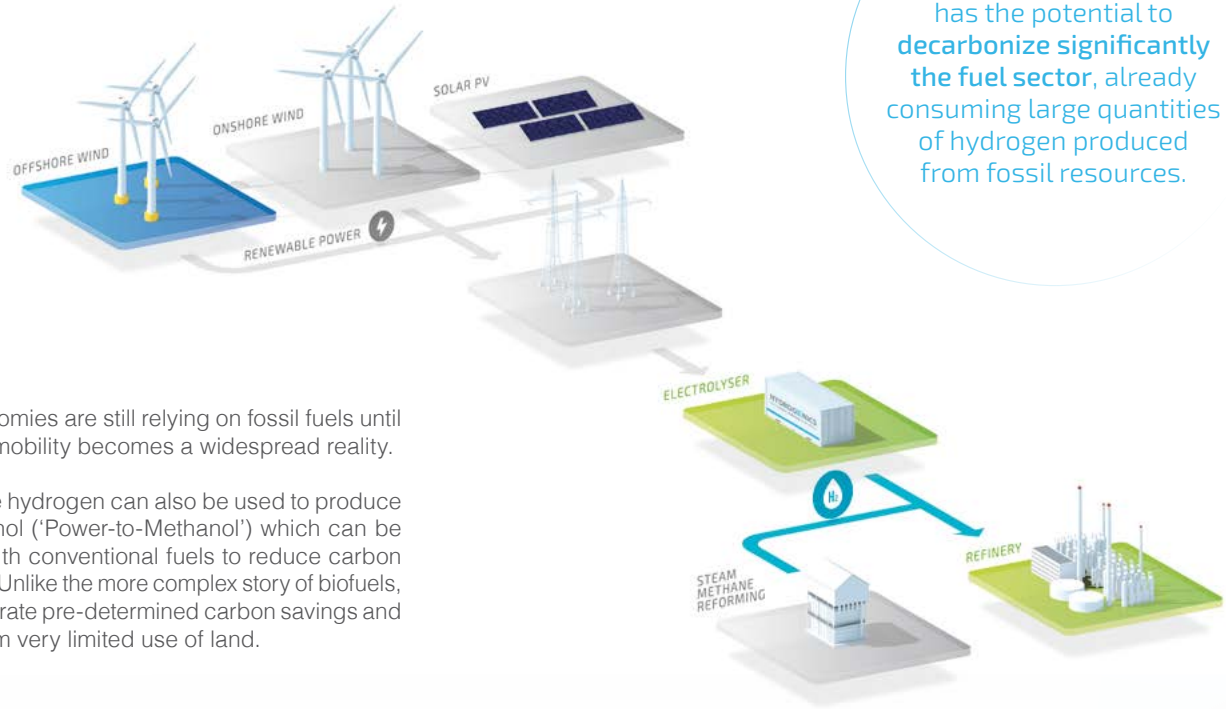
POWER TO FUEL

Hydrogen, a real alternative for creating renewable and sustainable fuels!

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 CO_2 for each ton of H_2. 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] 1.5 MW PEM cell stack developed by Hydrogenics
[2] Small refinery in Guatemala: 600 kW electrolyser

Services

Customers rely on our state-of-the-art equipment. They expect the highest standards of hydrogen quality, reliability and safety from electrolysers 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.

Each service agreement can be tailored to the customer so businesses only pay for the services they need

Our Hydrogenics service team

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.

Hydrogenics **here to help you**

HYDROG(E)NICS

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www.hydrogenics.com

Hydrogenics GmbH
Am Wiesenbusch 2, Halle 5
45966 Gladbeck
Germany
Phone: +49.2043.944.133
Fax: +49.2043.944.146
energystoragesales@hydrogenics.com

Hydrogenics Europe N.V.
Nijverheidsstraat 48 c
2260 Oevel
Belgium
Phone: +32(0)14.462.110
Fax: +32(0)14.462.111
hydrogensales@hydrogenics.com

Hydrogenics Corporation
220 Admiral Boulevard
Mississauga, Ontario
Canada L5T 2N6
Phone: +1.905.361.3660
Fax: +1.905.361.3626
energystoragesales@hydrogenics.com

Hydrogenics Asia
Regus H Tower 18th Floor
Jl. HR. Rasuna Said kav. 20
Jakarta 12940
Indonesia
Phone: +62.821.1089.896
hydrogensales@hydrogenics.com

We're ready.