OMEGA AIR

more than air

H_2

HYDROGEN MARKET

Basics

What is Hydrogen?

The dihydrogen H_2 molecule, made up of two hydrogen atoms, is commonly called “hydrogen” and was discovered in 1766 by the British physicist Cavendish. Under normal conditions of temperature and pressure, hydrogen is a colorless and odorless gas but also the lightest element of the periodic table. It is soluble in water up to 1.6 mg/L at 21 °C.

Fluid group: 1
Boiling point: -252,879 °C
Melting point: -259,2 °C
Density (at STP): 0,08988 g/L

It is the simplest member of the family of chemical elements and the most abundant one in the universe (main element of the Sun and stars). However, it is rarely found alone on and in the Earth, and is very often an integral part of various organic materials and, more importantly, water (H_2O). Depending on its temperature and pressure, it can be found in different states: gaseous, liquid, solid, metallic and triatomic.

The earliest known important chemical property of hydrogen is that it burns with oxygen to form water (H_2O), it was therefore made famous for its usage in the process of nuclear fusion. The value of hydrogen, however, is only fully realised when it is further converted to derivatives. Hydrogen can be combined with carbon from CO_2 to produce hydrocarbons and virtually any molecule. It can be used to produce ammonia, which can be used as feedstock for fertilisers (the majority of current use) or as fuel for new applications such as shipping. It can also be used to produce methanol, synthetic fuels, or even as a reducing agent to replace coal in iron production. Once it is converted to these commodities, the energy density is increased further, making long-distance transport and long-term storage cost-effective. Thus, the conversion to hydrogen derivatives effectively unlocks global renewable energy trade.

List of Industrial, Residential and Mobility applications for H_2:

- Chemical industry (Production of ammonia and other fertilizers (50 % of global consumption))
- Petrochemical industry (Sulfur removal, Creation of gasoline and diesel (hydrocracking), Methanol production (synthesis of amines and alkanes by hydrogenation)
- Food industry (Production of margarine and butter (fat hydrogenation))
- Welding (Atomic Hydrogen Welding (also called Plasma))
- Glass production (As antioxidant or shielding gas when coupled with nitrogen)
- Electronics manufacturing (Production of semiconductors, LEDs, displays, etc)
- Aerospace (Rocket’s engines (liquid form))
- Housing (Lighting, Heating)
- Hydrogen Refueling Stations (HRS) for ‘’Green Mobility’’ (Fuel Cells Electric Vehicles, FCEVs)

Here, we won't talk about Hydrogen as an energy by itself but rather as an energy vector, which is a fundamental aspect to have in mind when thinking about the usage of this gas.

If we take the example of the mobility, the gaseous hydrogen alone won't make the trucks, buses or cars move, as the energy needed and used will still be electricity. Instead, hydrogen's special abilities will be used to store this same energy – which is impossible with electricity alone – to be able to use it at a later stage, in Fuel Cells Electric Vehicles (FCEVs) for instance.

Therefore, hydrogen is now famous for two characteristics that make it a major challenge for the decarbonation of tomorrow's industry:
- Its extremely low density, allowing it to be the perfect energy vector to answer the problematic of electricity storage
- The absence of CO_2, particulates and any other NOx when it is used, making the point of use clean and pure. Byproducts are simply heat and water.

But it was not the subject of so many researches and projects until recently, when a series of crisis and issues put it on the front page. Indeed, successively the COVID-19 crisis and the Ukrainian war provoked unstable political situations all over the globe, which resulted in a new way of looking at international relations, emphasizing more and more states' autonomy rather than their interdependence.
Apart from key components such as semiconductors, the energy sector was the main concern of most of the world's countries, especially after the start of Ukraine's invasion. Pressure around petrol and gas supply increased drastically and gave birth to a simple problematic: how to become more independent as a region or a country when it comes to energy?

In parallel, environmental issues became some of the main concerns for the world's population (especially the younger generations), resulting in increased pressure over the governments to adopt green policies and the private sector to start massive investments.

Those two problematics naturally merged and we saw a rapid and important growth of annual investments in renewable energy: between 2020 and 2022, they grew for more than 50 % worldwide. At the same time, the main aspects of hydrogen started to be harnessed, for it to be used as the perfect complement to the development of green electricity sources.

As an example, we can take the 2030 policies for renewable electricity of some european countries:

	GERMANY	FRANCE	SPAIN	ITALY	NETHERLANDS	UNITED KINGDOM
	GW	GW	GW	GW	GW	GW
Wind turbines						
- Today's installed power	65	19	28	12	8	27
- Goal until 2030	145	40	50	20	20	65
Photovoltaic panels						
- Today's installed power	66	16	17	23	17	15
- Goal until 2030	215	67	50	52	27	40
Hydroelectric plants						
- Today's installed power	6	26	15	23	0-1	5
- Goal until 2030	5	28	15	25	0-1	7
Biomass						
- Today's installed power	8	1	1	?	0-1	1
- Goal until 2030	10	2	2	?	0-1	2
Total installed power today	145	62	61	60	26	48
Total goal by 2030	375	137	117	100	48	114

... and clearly link it with their 2030 policies for Hydrogen, through projects around electrolysis (defined later)

Electrolysis stations' installed power						
- Today	/	/	/	/	/	/
- Goal until 2030	5	6,5	7,5	5	4	10
Europe's electrolysis target by 2030	118					

The advantageous features of hydrogen were used to put it forward as one of the key features that will play a major role in this energy transition, giving birth to a complete industrial ecosystem around this gas.

But how is this ecosystem organized and, first of all, how is hydrogen produced?

The production of hydrogen: opportunities and weaknesses of a new industrial ecosystem

Hydrogen is produced by the separation of chemical elements of which the H atom is a component and by the mobilization of an energy source.

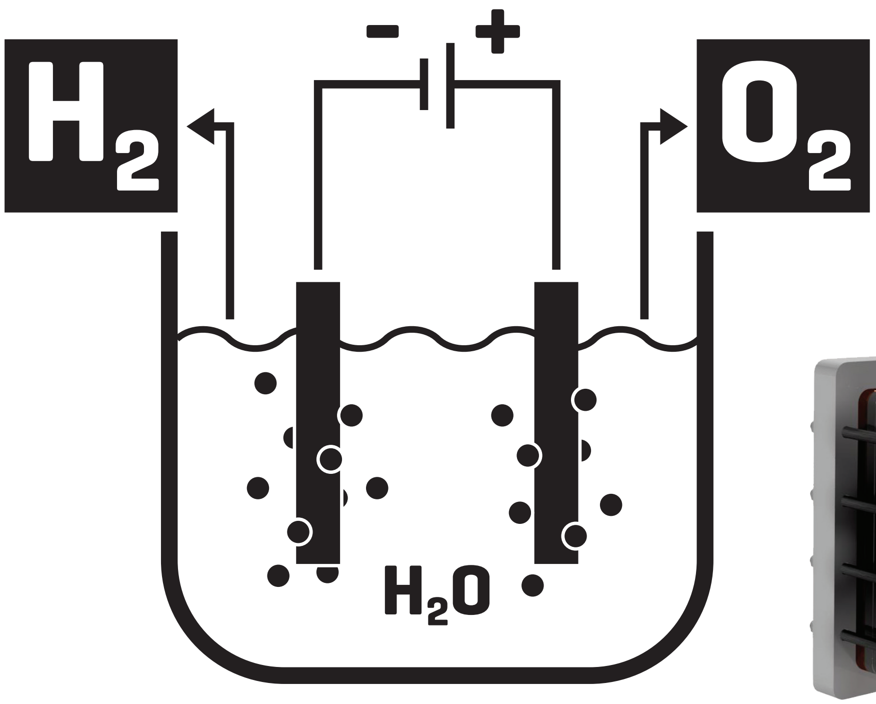
The different ways of producing hydrogen are classified by colors and the International Renewable Energy Agency (IRENA) gives the following list:

- Natural state
- Electrolysis with electricity coming from Renewable Energy Sources (RES)
- Thermal splitting of methane pyrolysis (CO_2 produced is solid and not gaseous)
- Hydrogen produced from different processes including natural gas, with Carbon Capture Utilization and Storage (CCUS) techniques involved
- Electrolysis with electricity from nuclear power plant
- High temperature catalytic splitting of water using nuclear heat
- Chemo-thermal electrolysis through direct nuclear power and heat
- Production from fossil fuels in general (often Steam Methane Reforming - SMR)
- Hydrogen produced from lignite coal. CO_2 released into the atmosphere.
- Hydrogen produced from coal (bituminous or lignite – brown). CO_2 released into the atmosphere.

The production of hydrogen thanks to a renewable or nuclear energy source (or by steam reforming of natural gas if the process is associated with a CCUS system) is called "low-carbon hydrogen" and quickly became an environmental and political priority, as we demonstrated earlier. To achieve Green Hydrogen, we therefore need RES, water and electrolysis.

Amongst all possible Renewable Energy Sources, most of them being in our previous table, the UN retain Solar Energy (PVs), Wind Energy (onshore and offshore wind turbines), Geothermal Energy (using heat from Earth), Hydropower (mainly dams), Ocean Energy (kinetic and thermal energy of seawater) and Bioenergy (electricity produced from biomass, e.g. biogas plants).

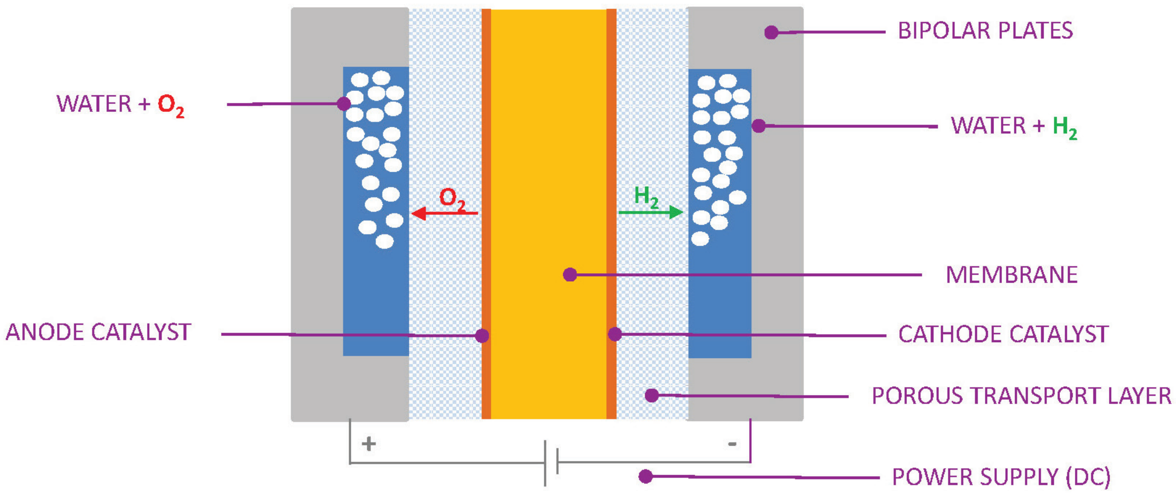
On the other hand, water can be collected from any source (sweet or salty) and be of any type, as long as it is treated to become ultrapure and adapted to the electrolysis' type.



While the two precedents are quite easy to understand, electrolysis process is more complicated and we need to focus on how it works. While there are more and more types of electrolysis being developped, two models are commonly differentiated: alkaline electrolyser and proton exchange membrane (PEM). The creation process of hydrogen (or, more precisely, a mix of hydrogen and oxygen) is slightly different from one type to another but it is commonly accepted that:

- The electrolyzer is composed of a membrane or a diaphragm in the center, surrounded by two electrodes (1x anode on one side, 1x cathode on the other). The ''shell'' is made up of bipolar plates.
- The bipolar plates, in contact with the anode, are supplied with water, H2O. However, the water molecules will be subjected to an electric shock, which will separate the H_2 and O molecules as well as the PROTONS (+) and the ELECTRONS (-). It is OXIDATION.
- Then, the membrane in the middle plays the role of ELECTROLYTE and makes it possible to block the electrons as well as the molecules of oxygen (dioxygen). On the other hand, it allows protons to pass to the cathode as well as hydrogen molecules.
- Here, the protons pick up an electron. This is what is called REDUCTION and what makes it possible to (re)form dihydrogen.
- In summary, the cathode ''produces'' hydrogen and the anode oxygen.

PEM CELL CROSS SECTION



Once the mix of $O_2 + H_2$ leaves the electrolyser, it then needs to be purified (details of this step in next chapters) before it is stored (possibly also compressed at high pressure) and dispatched at point of use. But while green hydrogen produced thanks to electrolysis offers the opportunity to make a valuable step towards carbon neutrality, it is still very much in development phase and there are still a few obstacles on the way. According to its 2021 ''Global Hydrogen Review'', the International Energy Agency (IEA) states that a major part of the hydrogen production is still from natural gas and more generally, approximately 95 % of hydrogen production still comes from fossil fuels (natural gas, oil, coal). As at the end of 2021, almost 47 % of the global hydrogen production is from natural gas, 27 % from coal, 22% from oil (as a by-product) and only around 4 % comes from electrolysis.

Indeed, electricity had a global average renewable share of about 33 % in 2021, which means that only about 1 % of global hydrogen output is produced with renewable energy. Electrolytic hydrogen from dedicated production remained limited to demonstration projects adding up to a total capacity 0,7 GW in 2021. In contrast, the 1,5 °C Scenario would need 4-5 TW by 2050, requiring a faster rate of growth than that experienced by solar photovoltaic (PV) and wind to date.

Hydrogen currently has multiple challenges that may hinder the fulfilment of its potential

High cost and low infrastructure levels
Beyond the difficult comparaison that we can try to make between the production costs of fossil fuels and low -carbon hydrogen through time, other equipments related to low-carbon hydrogen are currently still more expensive than the ones used for fossil fuels. Storage tanks and fuel cells (although more efficient than combustion engines) are for instance more expensive.
But most of the cost increase will come with the mandatory development of the necessary infrastructures that this new industrial ecosystem will need to strive: pipelines, liquefaction plants, dedicated pumps, etc…

Power generation costs (EUR/kWh) in 2021:
- Offshore wind – 0,07 EUR
- Onshore wind – 0,031 EUR
- PV – 0,045 EUR

Lack of normative frame
Despite the work of international research groups such as the Clean Hydrogen Partnership and its CertifHy initiative (EU), the Hydrogen Industry is still lacking its own normative framework, that would help differentiate low carbon hydrogen (green hydrogen especially) from fossil-based hydrogen. This means that, basically, the final consummer has no possibility to verify the source of the used hydrogen and from this, it is impossible to give the priority to the solutions that have the least environmental impact.

Lack of hydrogen market
Hydrogen is not a traded commodity today, which means there is no price index. This translates into higher costs paid by consumers since there is low price transparency and competition. There is little demand for low-carbon hydrogen and projects need to be integrated from supply to infrastructure and end use.

Efficiency
Actual electrolysis technologies (mainly alkaline and PEM) offer an average efficiency of approximately 75 %. Therefore, energy loss will need to be substantially reduced for electrolysis to be appealing for future investments.

Priorities
Most of the investments and policies have been focused on road transport so far. But the priorities need to scale up in terms of end users and start to be directed also towards the industry, which is also a big CO_2 producer.

Hydrogen use as an energy carrier remains limited and is principally limited to road vehicles. By June 2021 more than 40.000 fuel cell electric vehicles were in circulation around the world, with almost 90 % of those in four countries: Korea, the United States, the People's Republic of China and Japan.

By the end of 2020 there were about 6.000 fuel cell electric buses (95 % of those in China) and more than 3.100 fuel cell electric trucks. These totals are of course a very small fraction of the global vehicle fleet.

But beyond those temporary obstacles, we see a lot of opportunities for OMEGA AIR in this growing market, especially in Europe.

Opportunities and potential for OMEGA AIR

OMEGA AIR's opportunities in the H_2 market lie in the facts that it holds very strong arguments to sustain its development of purification units for hydrogen.

First of all and although some efforts still need to be done around customer's education and training, it is becoming clear for most of the actors of the hydrogen industry that purification is much needed in the production process. This conclusion came as much from pre-studies than from experience, as many installations without purification systems have now H_2O content problems and turn to manufacturers like us to give them solutions.

First argument
In favor of the installation of purification solution like ours, evolves around the physical fact that, if a gas is compressed downstream, most of the humidity needs to be previously taken out in order not to have problems of water, condensate or icing in the High Pressure line and at the point of use. In fact, hydrogen produced with electrolysis technology is 100% water saturated, which has an extremely negative impact on several applications and storage systems. This argument is quite straight forward and will need to be used for industrial applications mainly, where the need to separate the oxygen is not present, or at least not regulated like for other applications.

Second argument
Developed by OMEGA AIR is of legal nature: in 2019, the ISO 14687 was edited and gave some precise framework for the Fuel Cells applications.

Minimum performances allowed by ISO 14687:2019 for Fuel Cells applications:

With our complete all-in-one purification unit for hydrogen, composed of filters, deoxo and dryer, we can easily achieve these goals and therefore propose a XD solution that will be adapted to all applications: residential, industrial and mobility.

Third argument
In favor of our OMEGA AIR's solution is more external, as we don't see a lot of competition in this "niche market" which is H_2 purification.

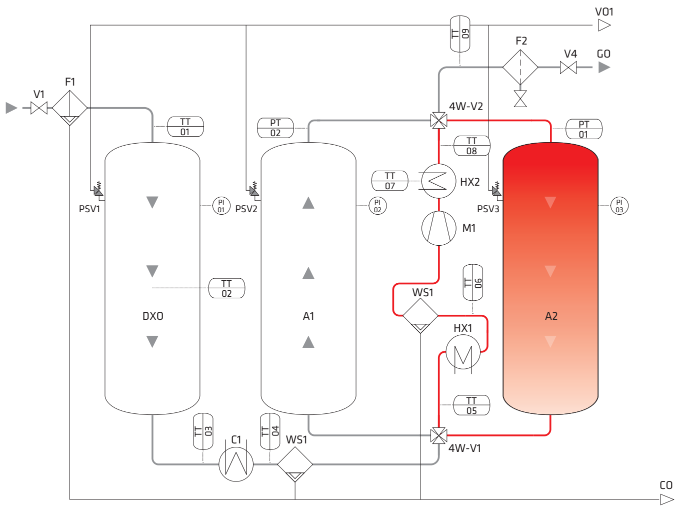
In fact and to our knowledge, only a very few amount of companies are actually developping and manufacturing purification solutions for Hydrogen. Our researches only led us to a couple of actors, that come from the EU, North America and eastern Asia.

Furthermore, we believe that none of those companies have both the capacities and the developped program that we have, which means that we can easily describe ourselves as a world leader manufacturer of hydrogen purification systems. This statement is confirmed by the fact that we have been approached by some of the biggest actors of this business, that could usually propose a solution on their own.

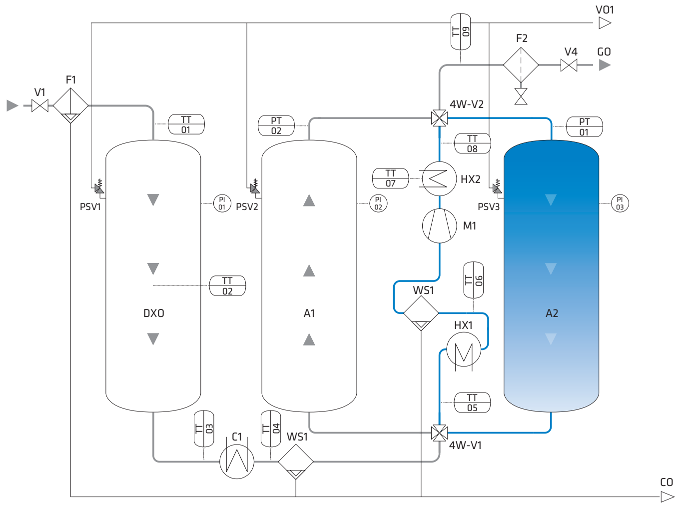
Fourth argument lies in the machines performances themselves and the fact that we are in the position to state that we have a "world's first".

But first, we need to go through the purification unit's operation:
Main steps of H_2 purification refer to:
- removal of solid impurities & aerosols (achieved by filters)
- removal of oxygen - DeOxo (achieved by catalyst)
- removal of water (achieved by adsorption dryers)

First stage of purification is removal of solid particles by filtration. H_2 then flows into column filled with palladium-based catalyst where traces of oxygen react with hydrogen to form water. H_2 then enters one of two drying columns filled with adsorbent which intercept water molecules and dry the gas down to residual water content of <5 ppmv (equals to pressure dew point <40 °C).



While the first column is in drying mode, the second column is being regenerated by circulating hydrogen in a closed loop. An electric blower then circulates the gas in a closed loop while electric heater heats up the H_2 up to temperature allowing to desorb the water from the adsorbent. A hot and humid H_2 leaves the column and enters a water cooled heat exchanger, where intensive condensation occurs as a result of cooling. The condensed water is separated from circulating stream of H_2 in a demister and discharged from the system via liquid level controlled condensate drain. Our special pressure equalisation features maintain constant pressure during heating and cooling without wasting any valuable H_2. When first column is saturated PLC switches between columns and assures continues drying process. Dust filter is installed at the outlet of the system as the final step of purification.

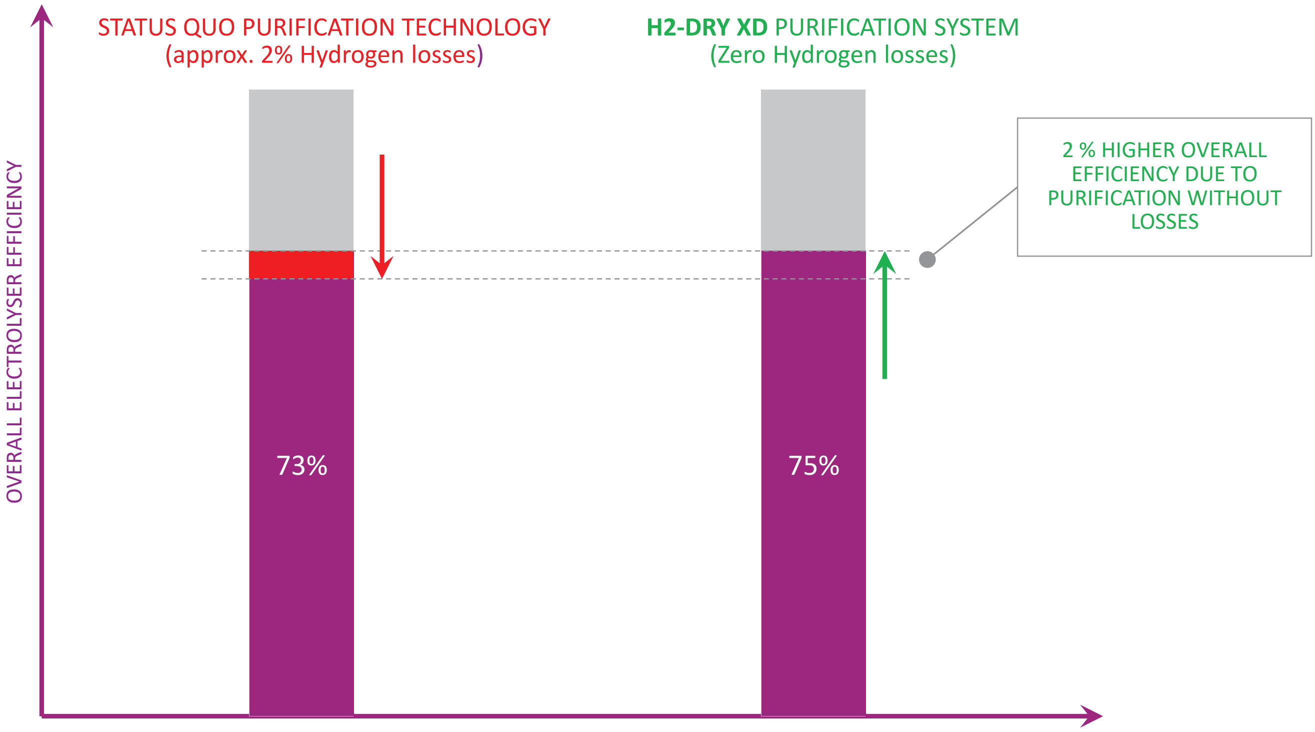


Operation of H2-PURE XD is fully automatic and controlled by PLC controller. Standard version offers communication via Modbus and Profinet while other communication methods are available as an option. **H2-PURE XD is CE certified and suitable to be installed in ATEX zone. ASME and IECEx certifications are optional.**

Core technologies incorporated inside our products are all well known and proven for decades. But what is newer is that we brought a technological improvement that, compared to all existing solutions on the market, is a true innovation of the regeneration circuit: regeneration of adsorbent is now done without wasting any H_2.

We know that the most critical part of purification is drying, especially because commercially available dryers involve certain losses of H_2 for regeneration, where other steps (deoxo, filtration) leave very little space for innovation: inlet oxygen concentration is typically up to 50 ppm which means that catalytic conversion to H_2O will only consume negligible amount of H_2 ; standard SS filters are more than adapted to all H_2 applications.

Indeed, products currently used for drying of H_2 were mainly developed as an upgrade of existing dryers for some other flammable non-aggressive gases (e.g. CH_4) where losses of gas for regeneration are acceptable. And it became the common feature of all commercially available adsorption dryers for hydrogen: certain amount of gas (approx. 2-5 % when operated at 30 barg) is wasted during regeneration process of the adsorbent. Those 2 % does not sound a lot but globally billions of € are being invested to increase overall efficiency of electrolysis technology for the same amount that is wasted during purification.



In OMEGA AIR, we decided to develop a taylor-made purification solution dedicated only to Hydrogen and launched the first 100 % Zero-Loss Hydrogen Purification system with the idea of a complete "all-in-one" solution for purification of hydrogen within electrolyser hydrogen production applications.

According to International Energy Agency (IEA), the amount of green hydrogen produced with electrolyser technology in Europe is estimated to reach 20 Mt in 2030 (total installed electric power of roughly 115 GW). Considering an average electrolyser power of 5 MW, this results in approx. 23.000 electrolyser systems. Our technology increases overall efficiency for approx. 2 % compared to status-quo purification technology and has therefore the potential to become a front-runner in the supply list of many potential customers when it goes about purification systems.

CONCLUSION

- Hydrogen is an abundant gas in the universe, however very rarely found alone. We need to artificially isolate it.
- Thanks to its unique characteristics, H2 is used in many different applications, whether they are domestic, industrial or related to mobility.
- Hydrogen has to be understood as an energy vector only: it is key to answer the problematic of electricity storage for instance, but it won't be directly used as a fuel.
- World's crisis of political and environmental nature made the development of green hydrogen a priority. It can sustain one country's energy independence and both its production and use do not emit any CO2.
- Water electrolysis with electricity coming from Renewable Sources is the ''greenest'' way of isolating H2 so far.
- Hydrogen's ecosystem is facing obstacles of different natures (mainly cost, time, policies and efficiency), that need to be hurdled before its market can fully develop.
- Before the point of use but after the electrolysis, the hydrogen needs to be purified by our H2-PURE units.
- H2-PURE can be fitted in any type of application.
- H2-PURE is one of the rare all-in-one purification solutions in the hydrogen market.
- H2-PURE contains never-before-seen efficiency and technology.

PURIFICATION MODULE IN ELECTROLYSIS PLANT

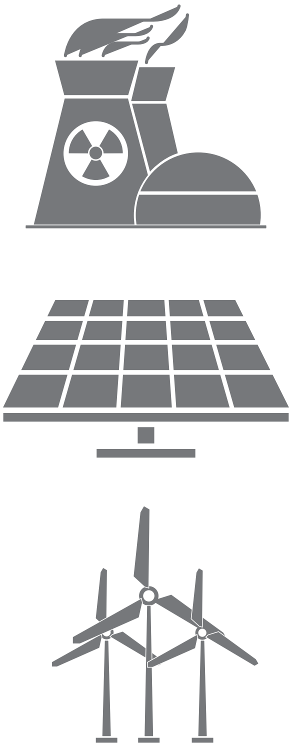
POWER SOURCE
(Electricity)

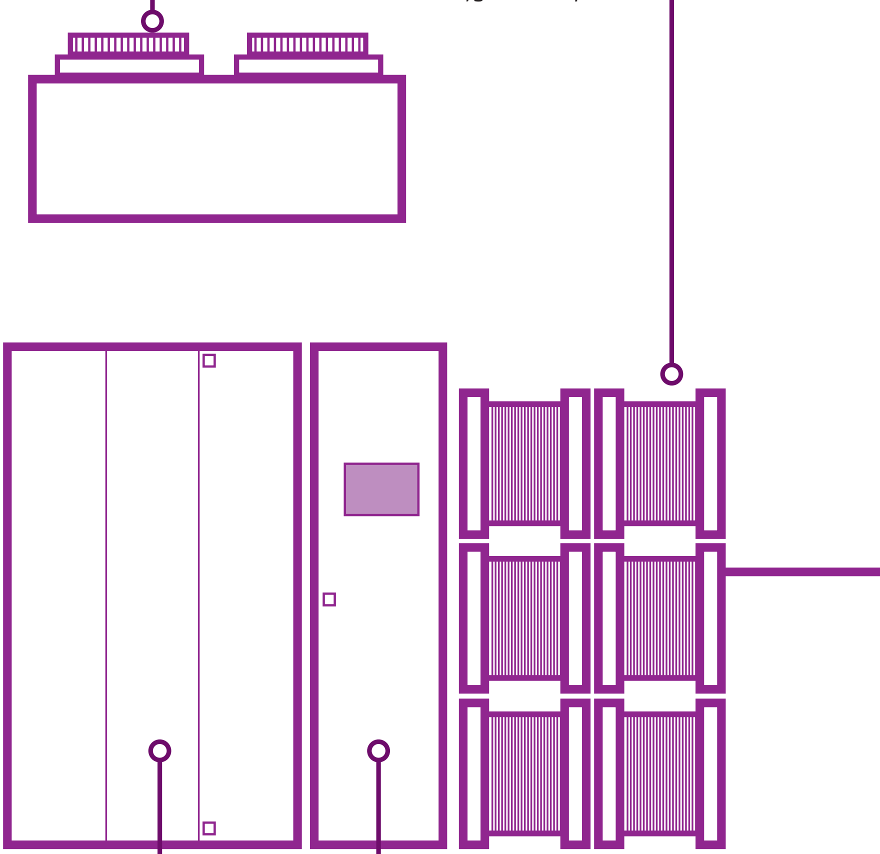
The basis of every electrolysis plant is to have the insurance to receive constant power source (e.g. renewable for green hydrogen) and water supply.

COOLING SYSTEM
(Chiller)

PEM STACK

It then goes into PEM stack where, when it reacts with water, hydrogen and oxygen will be produced.



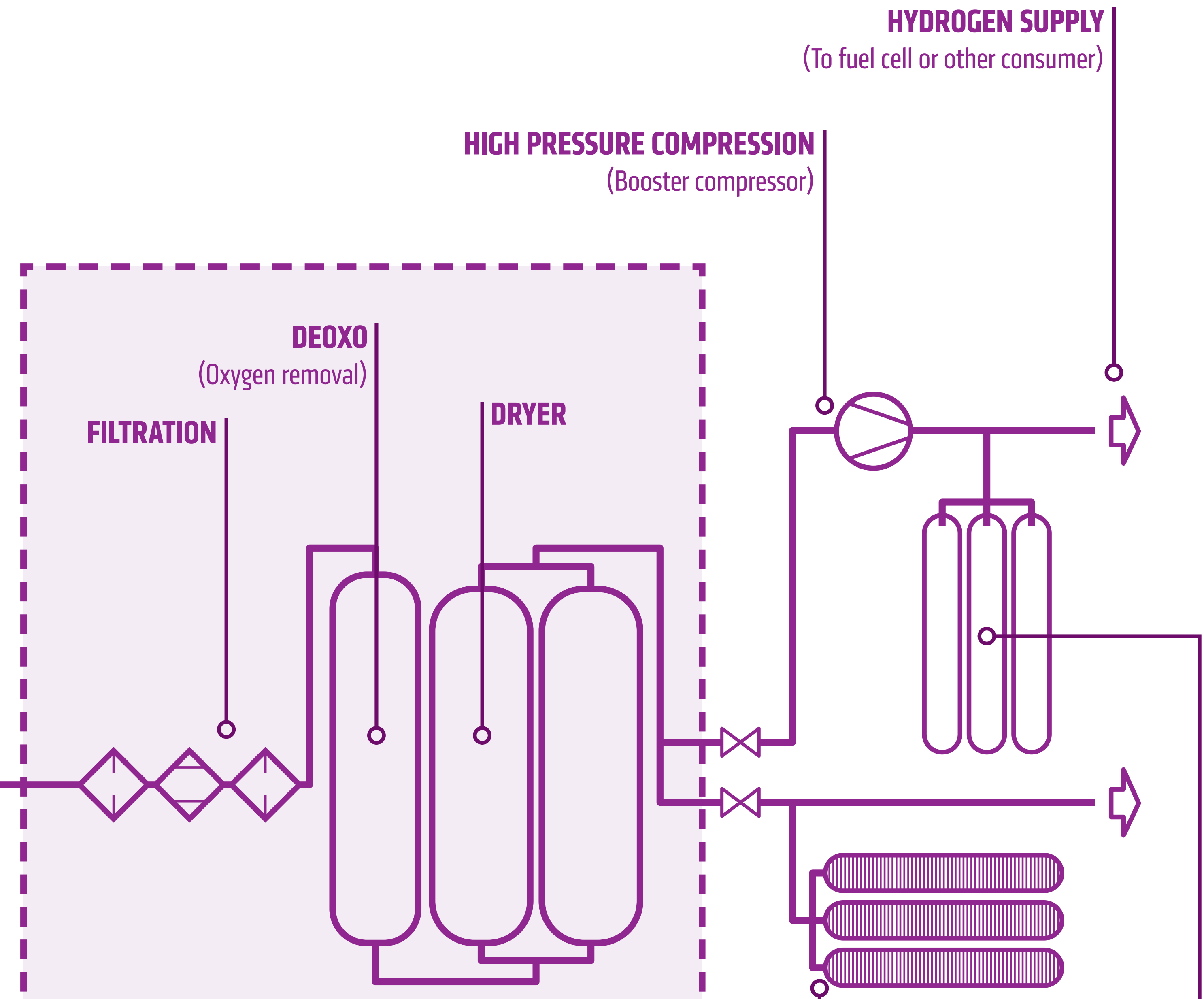


DC POWER SUPPLY

The supplied electricity being usually AC, it needs to go first through a DC power supply before being further processed.

CENTRAL CONTROLLER

This whole system needs to be closely monitored thanks to a CENTRAL CONTROLLER and cooled via a COOLING SYSTEM.



PURIFICATION UNIT

The mix of gas will enter our PURIFICATION UNIT, composed of filtration, DEOXO and dryer units. Thanks to this stage, the exiting gas will be free of any excess of solid particles, oxygen and humidity.

Purification unit main features

- All-in-one unit, built on the most compact SKID.
- Performances according to ISO 14687:2019 for Fuel Cells
  - < 5 ppm of O_2 residual content
  - < 5 ppm of H_2O residual content
  - < 1 um solid particles
- ZERO LOSS of HYDROGEN during the regeneration.

Hydrogen needs to be stored at different pressures depending on the point of use application: low pressure storage or high pressure storage (where a high pressure compressor is needed upstream).

OMEGA AIR

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OMEGA AIR d.o.o. Ljubljana
Cesta Dolomitskega odreda 10
1000 Ljubljana, Slovenia
00 386 1 200 68 00
info@omega-air.si
www.omega-air.fr

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