HOW ABB SENSING TECHNOLOGIES ENSURE H_2 PURITY AND SAFETY

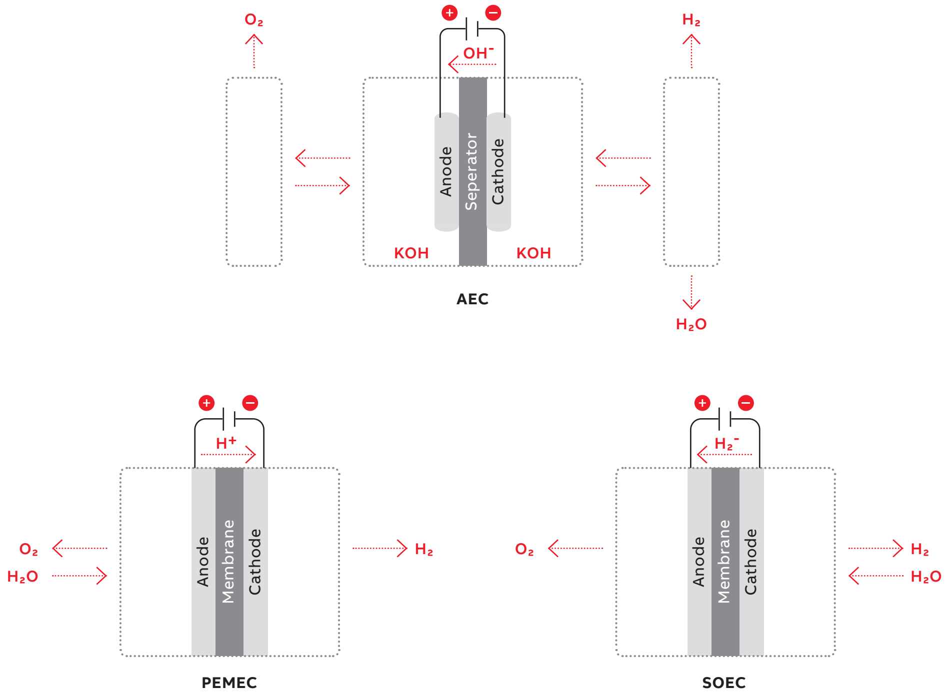
Elusive molecule

The production of hydrogen from green electricity holds the potential to deeply reshape transportation, power, gas, chemicals, and fuel markets. But as the smallest and most elusive molecule in the periodic table, hydrogen presents a number of sensing challenges in terms of production, transportation, storage, and end use. ABB offers a range of instrumentation and analyzer solutions.

Hydrogen is set to play a central role in enabling a decarbonized energy system. It can store energy, provide flexibility, and transport high volumes of energy over long distances via pipelines and ships, making it possible to exploit renewable energy sources (RES) in remote locations.

But hydrogen's contribution extends much further than energy storage because it can be converted into fuels and chemicals. Furthermore, the production of hydrogen from electricity will deeply reshape current power, gas, chemicals, and fuel markets [1]. In short, hydrogen is the best candidate to be the "clean molecule" able to complement "clean electrons."

Although hydrogen use is largely CO_2-free, it is produced using a range of energy sources and technologies each of which has a different impact on greenhouse gas emissions.



01

—
01 Water and gas flows in the main types of commercial electrolyzers.

Ultimately, however, the real game-changer is represented by electrolysis, where hydrogen is produced through an electrochemical process that splits water into hydrogen and oxygen, with zero CO_2 emissions. If electricity can be certified to have come only from renewable energy sources, the resulting product can be defined as green hydrogen – the Holy Grail of the decarbonization effort.

While less than 0.1 percent of global hydrogen production comes from water electrolysis and is mostly used in markets with specific high-purity demand (for example, electronics and polysilicon) [2], green hydrogen is attracting wide attention and unprecedented investments. The European Commission, for instance, has earmarked unprecedented resources to develop a hydrogen strategy aiming at raising the value of its hydrogen sector from the current 2 billion to 140 billion Euros by 2030, with more than 140,000 jobs expected to be created as a result [3]

From a technical perspective, three H_2 production technologies are presently available:
- alkaline electrolyte cells (AEC),
- polymer electrolyte membranes (PEM, or PEMEC), also known as proton exchange membranes, and
- solid oxide electrolyzers (SOE or SOEC) →01.

AEC electrolyzers have a lower CAPEX than the other two technologies. They are also the most mature technology, which means that large scale AEC electrolyzers have a proven track record of reliability that the PEM and SOE processes have not yet had the time to accumulate.

PEM systems offer a quick ramp-up. When operated at pressures of up to 30 bar, which some other electrolyzer technologies can also achieve, they offer a smaller physical footprint

—
The European Commission aims to raise the value of its hydrogen sector from the current 2 billion to 140 billion Euros by 2030.

compared to atmospheric pressure electrolysis systems. This means that subsequent high pressure gas compression costs are minimized if the hydrogen is intended for gas grid injection or high-pressure storage.

Solid oxide electrolysis (SOE) cells are fundamentally the reverse of solid oxide fuel cells. Most SOE equipment operates in the range of 650 to 850 °C using water in the form of steam and deriving a significant percentage of its energy from the heat of the steam. High-temperature electrolysis has significant advantages over low-temperature technologies, including high efficiency and no need for expensive noble metal

Nunzio Bonavita
ABB Process Automation Measurement and Analytics
Genoa, Italy

nunzio.bonavita@it.abb.com

electrocatalysts. This means that approximately one third less electrical power is required, compared to a PEM or AEC electrolyzer, to produce the same amount of hydrogen [4]. However, SOE is still behind in terms of industrial development.

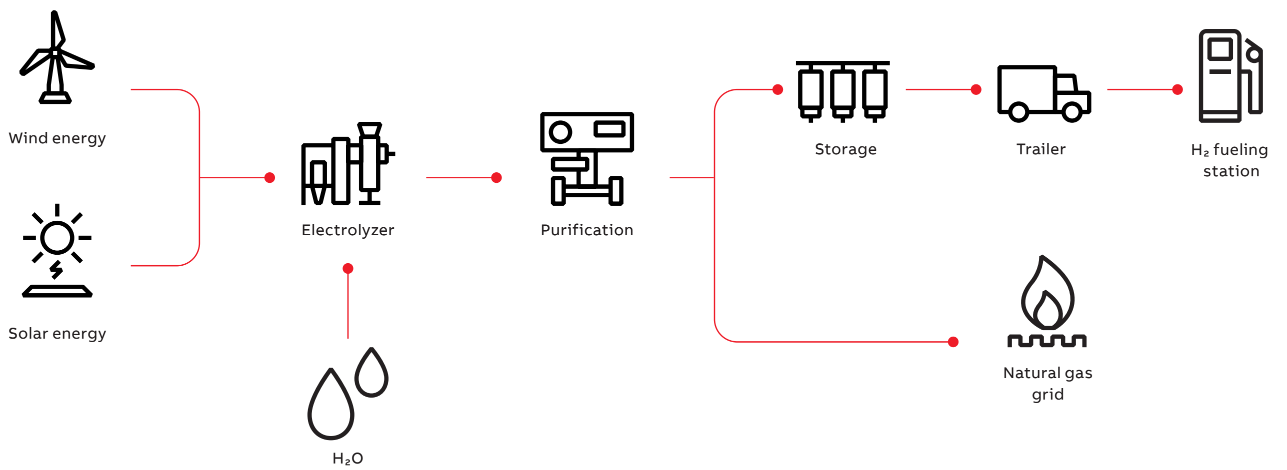
The green hydrogen value chain
Production is just the beginning of the hydrogen economy value chain, which also includes transportation, storage and end-use →02. Most of the business and technical issues associated with H_2 come from the molecule's chemical and physical properties, since it is the smallest and lightest molecule in nature. Thus, hydrogen features a very low boiling point and, under normal conditions, very low density. In order to make it a significant energy vector it must be pressurized and either liquified or converted into some other chemical carrier.

Green hydrogen has a crucial role in reducing CO_2 emissions in hard-to-abate industries, such as steel production.

Typically, H_2 is transported from a production site to end use via pipeline, over roads, in cryogenic liquid tanker trucks or in gaseous tube trailers, by rail or by barge. Pipelines are the most economical means of inland transport in bulk, but for longer distances and overseas shipping, in order to be economical, H_2 must be either liquified or converted into some other carrier such as ammonia or benzyltoluene.

Depending on storage duration requirements, hydrogen may be realized in:
- Gaseous form: This is the cheapest option. In this form it can be stored underground in salt caverns or depleted gas fields, or in pressurized tanks such as in fuel cell vehicles.
- Liquid form: Here, gaseous hydrogen is converted to its pure liquid form to increase its energy density. This mode of storage is more efficient than gaseous storage but more expensive because it requires three steps: a liquefaction stage where gaseous hydrogen is cooled down to below -253 °C and converted to a liquid, liquid storage, and a regasification stage during which it is converted back to a gaseous form.
- Chemical form: In this case, H_2 is bonded to another atom or molecule. Ammonia and liquid organic hydrogen carriers (LOHC) are among the most promising molecules that allow liquid storage.

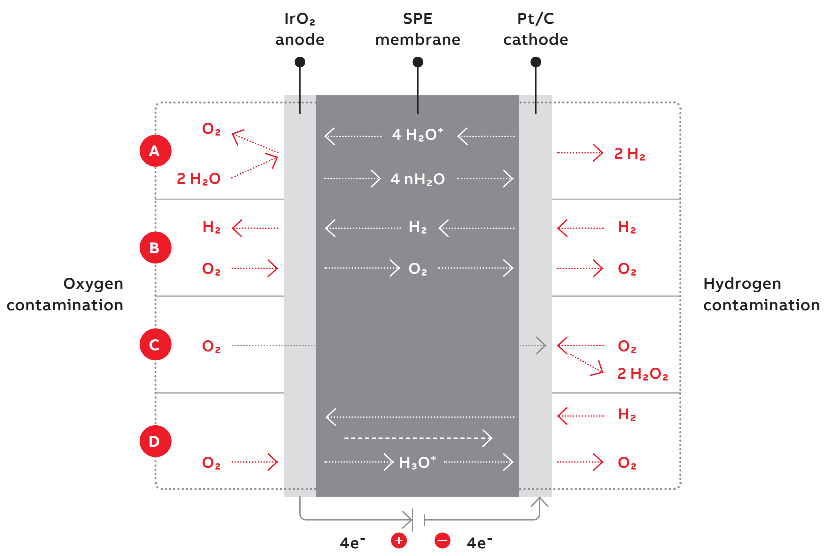
The last step in the green hydrogen value chain is end use. Without entering into details, we can identify three main application areas:
- Mobility: Green hydrogen is being used in transportation by exploiting fuel cell technologies. Fuel cell-powered electric vehicles have a hydrogen tank that feeds a fuel cell, where the electricity that powers the engine is generated. Presently the focus is on public transportation



02

02 How hydrogen is produced and where it is used.

03 Hydrogen reactions and mass transfer mechanisms. SPE: solid polymer electrolyte. Pt/C: particles catalyst.



03

and special purpose vehicles for airports, shopping centers, etc.

- Industrial use: Beyond replacing gray hydrogen in traditional sectors like refining and fertilizers, green hydrogen has a crucial role in reducing CO_2 emission in so-called hard-to-abate industries (ie, where electricity is not applicable or practical), such as steel, glass, and ceramic production.
- Domestic use: Hydrogen blending into natural gas (NG) for domestic households is an effective way to generate heat and power with lower emissions than using NG alone and many gas utilities are investing in this area. Admixing of hydrogen into existing natural gas grids is technically possible and permitted at limited percentages in many countries. At present, several countries have set an upper limit of two percent hydrogen in existing pipeline grids.

Measurement Challenges

As the smallest and most elusive element in the periodic table hydrogen features some peculiar physical-chemical properties that entail a number of measurement problems. To make the hydrogen economy a reality, a number of sensing challenges must be overcome. These are outlined below.

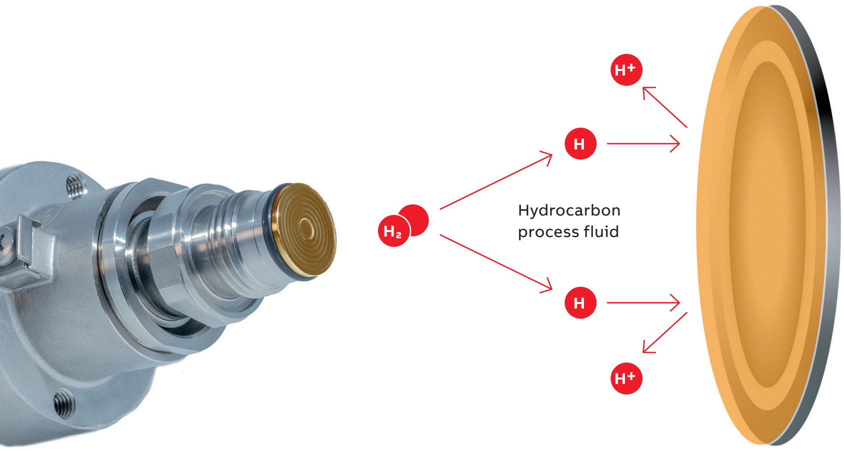
Electrolyzers need sensitive gas analyzers for safe operation. Broadly speaking, they produce oxygen at the anode and hydrogen at the cathode. However, this is a simplification of some very complex electrochemistry. Many reactions that take place in an electrolyzer can cause small concentrations of oxygen to build up in the hydrogen stream and vice-versa. Furthermore, the electrolyzer stack assembly can leak gas from one side of the electrolyzer cell to the other, resulting in significant safety risks →03.

Production

Process control of a hydrogen electrolyzer performs several duties: safe operation, efficient power-to-hydrogen conversion, and hydrogen and oxygen gas purity quality control. ISO22734:2019 explicitly specifies many parameters that must be measured to ensure safe and reliable hydrogen electrolyzer operation [5]

As electrolyzers produce oxygen at the anode and hydrogen at the cathode, they need gas analyzers for safe operation.

While many of the measured parameters are common to all electrolyzers (eg, temperature in the electrolyzer stack to avoid over-heating, gas impurities, etc.), others are specific to the electrolyzer technology seen in the first section of this article. For example, hazardous liquid leak detection is more relevant when handling highly concentrated potassium hydroxide solutions on an AEC electrolyzer than when working with pure water on a PEM system for which water purity is of paramount importance. For its part, SOE technology, when operating at high temperature, is more demanding in terms of steam supply management measurements.



04

Storage and Transportation
Storage and handling of hydrogen involves safety issues that must be understood and mitigated to ensure secure operations. Hydrogen presents some potential hazards because:

- It has a low ignition energy (0.017 mJ against 0.25 mJ for hydrocarbons). Leaks from piping flanges, for example, are particularly hazardous because the simple friction induced by a leak itself can be a source of ignition. Additionally, in case of ignition, hydrogen can burn with an invisible flame and low radiated heat, making it difficult even to spot the flame.
- H_2 is a tiny molecule that dissociates into ions. At high temperatures it can diffuse and permeate metals, leading to embrittlement of equipment and pipelines [6].

Accurate and reliable infrastructure monitoring is therefore mandatory. Furthermore, there are still many unresolved problems regarding, eg, monitoring of long and/or underground pipelines [7]. In addition to rigorous leak detection, storage facilities require preliminary drying in order to remove moisture, thus requiring hydrogen purity analyzers.

End use
Different end uses trigger different problems. With regard to mobility, the main challenges are related to accurate flow metering and to fuel cell protection by measuring H_2 impurities at very low levels (for example total sulphur at 4 nmol/mol) at each refueling station [8]. Probably the lowest-hanging fruit for hydrogen use is its blending in natural gas distribution networks. The main measurement issues here are related to:

- Providing an accurate and effective blend ratio and ensuring H_2 quality measurement.
- Extending and tailoring custody transfer procedures for blending; this is essential since the thermal heating energy value of hydrogen per unit of volume is less than that of natural gas.
- Preventing hydrogen-induced cracking. For some grades of steel, too much hydrogen, particularly at higher temperatures, can cause embrittlement that may lead to cracking and rupture.

ABB Solutions and success stories
ABB has an established range of instrumentation and analyzer solutions for hydrogen applications. Among the products specifically addressing green hydrogen-related challenges is the company's "H-shield" option for pressure, level and flow products, which ensures an extremely high level of resistance against hydrogen permeation →04. Applied using the vapor deposition process, for instance, H-shield forms a protective coating at a uniform thickness across the surface of the diaphragm, while offering sufficient flexibility for the diaphragm to move in response to changing pressure conditions [9].

—

ABB's "H-shield" option for pressure, level and flow products, ensures resistance against hydrogen permeation.

With regard to fuel-cell-powered vehicles, ABB offers Sensyflow FMT700-P, a compact thermal mass flowmeter, which is the latest addition to a product range already proven for measuring engine intake air on test benches. The device is ideally suited to fine-tuning the efficiency of fuel cells. Thanks to its unrivalled response time (25 milliseconds), the device is used by leading automobile manufacturers worldwide to measure intake air in quality assurance, test bench applications, and research and development [10].

ABB contributes to the safe management of electrolyzers through its analyzers, which are able to provide accurate measurement of impurities in the O_2 and H_2 streams in hazardous areas. These measurements can be combined into one device if semi-continuous measurement is acceptable [11].

Finally, as mentioned earlier, hydrogen blending into the NG grid is already a mature option for reducing CO_2 impact. ABB's PGC1000 is ideal for monitoring the gas mixture composition in natural gas distribution and transmission systems. It is a rapid-response process gas chromatograph with a thermal conductivity detector. Established

—
04 Isolation diaphragm with ABB's H-shield coating and pressure.

—
05 An ABB gas chromatograph with a thermal conductivity detector.

05

applications for this type of gas analyzer include monitoring the thermal value of natural gas in burner control systems and ensuring the correct combustion stoichiometry →05.

The track record that ABB has developed with these gas analyzers can be transferred to monitoring natural gas pipelines containing admixed hydrogen. Market acceptance is extremely encouraging. In Italy, where gas transmission and distribution companies are investing in ambitious H_2 blending programs, more than 35 analyzers have been provided in recent months. •

—
ABB's PGC1000 is ideal for monitoring the gas mixture composition in natural gas distribution and transmission systems.

—
References

[1] Hydrogen Council, McKinsey & Company, Nov-2021. "Hydrogen for Net-Zero." Available: https://hydrogencouncil.com/wp-content/uploads/2021/11/Hydrogen-for-Net-Zero.pdf [Accessed August 11, 2022].

[2] McKinsey & Company, Jan-2022. "The net-zero transition: what it would cost, what it would bring." Available: https://www.mckinsey.com/business-functions/sustainability/our-insights/the-net-zero-transition-what-it-would-cost-what-it-could-bring [Accessed August 11, 2022].

[3] "EU aims to make green hydrogen cost-competitive within two years: leaked strategy document," Recharge 19/6/2020 Available: https://www.rechargenews.com/transition/eu-aims-to-make-green-hydrogen-cost-competitive-within-two-years-leaked-strategy-document/2-1-829768 [Accessed August 11, 2022].

[4] ABB White Paper, 2021. "Green Hydrogen, Instrumentation and analyzer solutions for a sustainable future." Available: https://campaign.abb.com/l/501021/2021-09-28/v9lq6p [Accessed August 11, 2022].

[5] ISO22734:2019 September 2019. "Hydrogen generators using water electrolysis – Industrial, commercial, and residential applications." Available: https://www.iso.org/standard/69212.html [Accessed August 11, 2022].

[6] ABB White Paper, 2022. "Hydrogen safety – Hydrogen handling and key process safety steps." Available: https://new.abb.com/process-automation/energy-industries/hydrogen/white-paper-process-safety-and-hydrogen [Accessed August 11, 2022].

[7] S. Elaoud, E. Hadj-Taïeb. "Leak detection of hydrogen-natural gas mixtures in pipes using the characteristics method of specified time intervals." *Journal of Loss Prevention in the Process Industries* September 2010, pp. 637-645.

[8] "Energy transition: Measurement needs within the hydrogen industry." National Physical Laboratory report December 2017. Available: https://www.npl.co.uk/getattachment/bebd3592-e413-43e7-9556-e4dc2c0533d7/energy-transition-measurement-needs.pdf?lang=en-GB&ext=.pdf [Accessed August 11, 2022].

[9] ABB White Paper, 2021. "Tackling the issue of hydrogen permeation in pressure transmitters." Available: https://campaign.abb.com/l/501021/2021-11-05/vpy3nk [Accessed August 11, 2022].

[10] G. Weppner, "Fine tuning hydrogen fuel cell research" *ABB Review* 04/2021, pp. 48-49.

[11] S. Gibbons, "Gas analysis in the circular economy." *Gasworld* June 2021. Available: https://www.gasworld.com/gas-analysis-in-the-circular-economy/2021176.article [Accessed August 11, 2022].