Overview of hydrogen

"We recognize that low-carbon and renewable hydrogen [...] should be developed and deployed where it can have an impact as an effective emissions reduction tool to drive decarbonization across all sectors and industries"

Declaración G7 2023[19]

What is H2?

Hydrogen (H2) is the lightest chemical element and the most abundant substance in the universe (75% is H_2)[20]. It has the properties of an energy vector, i.e. it can be used to store and transport energy for later release. Moreover, in the case of hydrogen, this energy release is carried out without emitting greenhouse gases into the atmosphere, unlike fossil fuels. This property, together with the fact that its use can be extended to a multitude of industrial and commercial applications, makes it an essential player in the energy transition to a more sustainable ecosystem.

The most outstanding properties that would allow hydrogen to spearhead the transformation of the current energy model are the following:

- **High calorific value and low energy density per volume.** Hydrogen has a high calorific value (the energy of 1 kilogram of hydrogen gas is approximately the same as that of 2.8 kilograms of gasoline), but because it is a light gas and occupies a large volume in its natural form, it has a much lower energy density per volume than other fuels (see LH_2 and CH_2 in Figure 4). This means that, depending on the application, it is not necessarily the most energy-efficient option[21]. Although an electric motor powered by a hydrogen fuel cell is two to three times more efficient than a gasoline internal combustion engine[22], when considering the upstream transformations necessary to produce the hydrogen (e.g. electrolysis process with an efficiency of around 60%) or compared to electric mobility, which has efficiencies of around 90% for cars with batteries, its efficiency is not a decisive factor.

- **Inexhaustible.** Since it is stored in water, hydrocarbons, and other organic matter, a priori hydrogen can be considered inexhaustible.

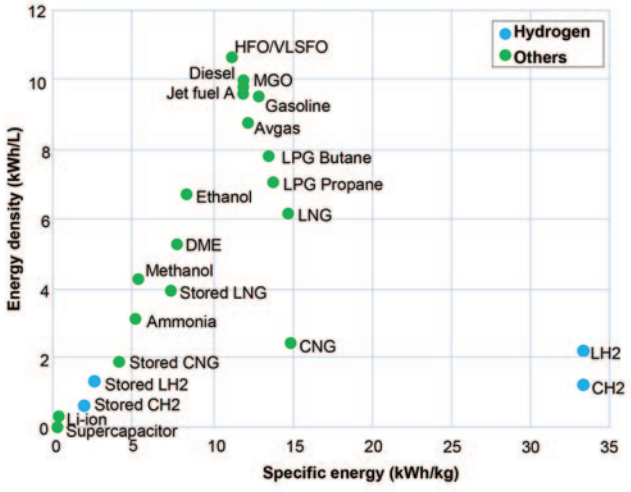
- **Storable.** Unlike other forms of energy, it can be stored and transported in multiple ways (transport by hydroproduct, sea, land, etc.).

- **Production flexibility.** It can be produced from different sources and in different parts of the world depending on the availability of renewable energy in each region.

- **Versatility of conversion to derivatives.** It can be combined with other elements to form multiple derivative products (such as hydrocarbons, ammonia, methanol and synthetic fuels, etc.), with higher density per unit volume than gas and greater efficiency for transportation purposes.

[19] G7 Ministers meeting on Climate, Energy and Environment in Sapporo, Japan April 15, 2023.
[20] IPNA - CSIC: "The origin of the first chemical elements".
[21] National Renewable Energy Laboratory. "National Renewable Energy Laboratory (2020).
[22] US Department of Energy, "Hydrogen Basics" (2022).
[23] IRENA: International Renewable Energy Agency

Figure 4. Energy density and specific energy of various fuels and energy storage systems.



Notes: Avgas = aviation gasolina; CH2 = hydrogen compressed at 70 Mpa; CNG = natural gas compressed at 25 Mpa; DME = dimethyl ether; HFO/VLSFO = heavy fuel oil/very low sulphur fuel oil; LH2 = liquefied hydrogen; Li-ion= lithium-ion Battery; LNG = liquefied natural gal; LPG = liquefied petroleum gas; Stored CNG = Type IV tank at 250 bar; Stored CH2 = best available CH2 tanks at 70 Mpa; Stored H2 = current small-scale LH2 on-board tanks; Stored LNG = small-scale Storage at cryogenic conditions; MGO = maritime gasoil. Numbers are exptessed on a lower heating value (LHV) basis. Weight of the storage equipment is included.

Source: IRENA[23]. "Hydrogen Overview" (2022).

In addition to the above properties, if hydrogen is produced without emitting greenhouse gases, it is considered a clean fuel. This occurs, for example, in the case of water electrolysis production from renewable sources, with oxygen being emitted as a by-product of the process followed by water vapor during combustion. It should be noted that hydrogen produced from other non-renewable energy sources is also considered clean hydrogen but only if the emission of CO2 in the production process is controlled and does not exceed established limits, which will depend on the country and its legislation.

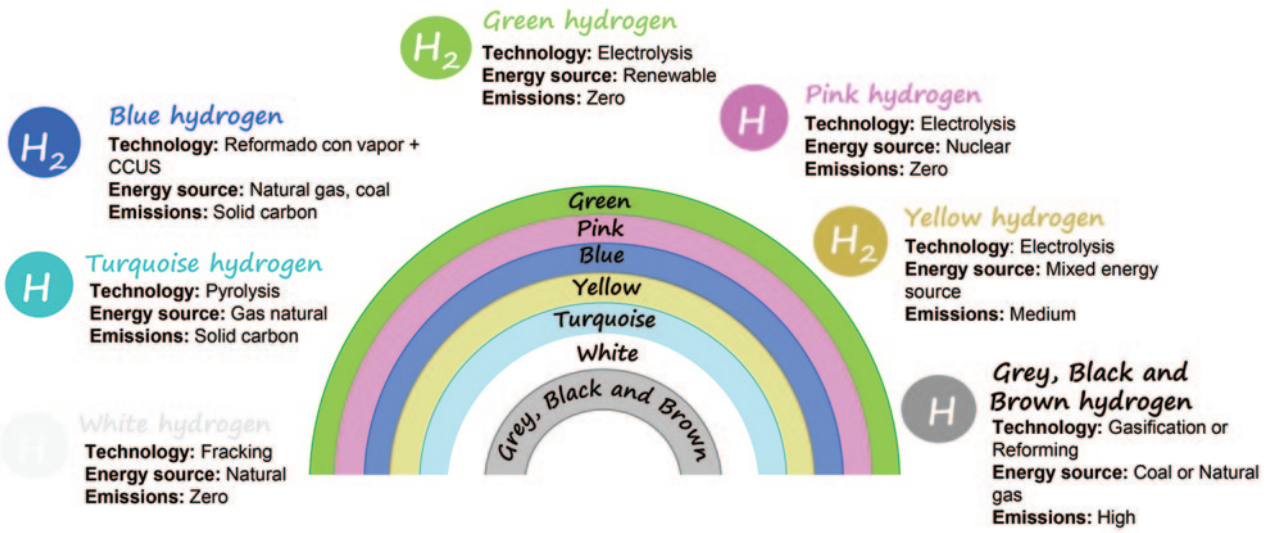
What types of H2 are there?

On the planet, hydrogen is found combined with other elements, such as carbon in the formation of organic compounds, or oxygen in the formation of water molecules. To separate hydrogen from the element that accompanies it, it is necessary to subject the compounds to specific processes. Depending on the process and the energy used in the process, hydrogen is called by different names (see Figure 5):

- **Green.** This is hydrogen generated by water electrolysis which uses electricity from renewable sources. Other examples of green sources of hydrogen include those produced through natural gas reforming which is the process by which hydrogen is replaced with biomethane or through photocatalysis and photoelectrocatalysis, whereby the energy source is renewable and no CO2 is emitted.
- **Pink.** Hydrogen is called pink when it is obtained by electrolysis, but the energy source used to produce electricity is nuclear energy. It is considered clean due to the low carbon emissions in its production.
- **Blue.** This hydrogen is also obtained from hydrocarbons, but in this case the polluting emissions are captured and stored using CCUS technologies[24]. This makes it possible to produce low-carbon hydrogen that is considered clean hydrogen.
- **Yellow. I**n this case, the hydrogen production method is also electrolysis, but the electricity source used is mixed (not completely renewable).
- **Turquoise.** Hydrogen is generated through the pyrolysis of a molten metal by passing natural gas through it, releasing hydrogen and carbon in a solid state.
- **White.** Hydrogen found in nature, usually in subway deposits, is called white[25].
- **Black, gray and brown.** This is obtained from hydrocarbons by steam reforming, partial oxidation and autothermal reforming techniques or gasification of the fossil fuel which separates the carbon and hydrogen bond.

[24]Carbon capture, utilization and storage (CCUS).
[25]Earth-Science Reviews, "The occurrence and geoscience of natural hydrogen: A comprehensive review." (2020)

Figure 5. Types of hydrogen by production method, energy source and emissions.



Source: Técnicas Reunidas "Present and future of hydrogen".

Among all forms of hydrogen production, it is green hydrogen that is receiving the greatest regulatory impetus, as the absence of greenhouse gas emissions during its production makes it the main catalyst in the process of energy transition to a carbon-neutral economy.

When is hydrogen considered renewable?

In order to boost the role of hydrogen, the different regulatory bodies are defining the premises under which hydrogen can be considered as green or renewable[1]. By way of example, the European Union considers hydrogen renewable if it meets the following characteristics:

- Liquid and gaseous fuels of non-biological origin that are produced from electricity are considered renewable only when the electricity used in their generation comes from renewable sources.
- This renewable electricity can be supplied in two ways: (i) direct connection to a renewable production plant (wind, photovoltaic, etc.), or (ii) electricity taken from the grid as fully renewable.

  (i.a) "The renewable electricity generating facilities must have been in operation for a period of less than 36 months prior to the start-up of the plant for the generation of liquid and gaseous fuels of non-biological origin".

  (i.b) "If the installation producing renewable electricity is connected to the grid, apart from the plant generating liquid and gaseous fuels of non-biological origin, it must be demonstrated that no electricity from the grid is used by means of a smart metering system".

  (ii.a) "Electricity shall be considered as fully renewable if the facility producing the liquid and gaseous fuel of non-biological origin is located in an auction area where the average production of renewable electricity is above 90% in the previous calendar year and the production of liquid and gaseous fuel of non-biological origin does not exceed a maximum number of hours in relation to the production of renewable electricity in the auction area".

  (ii.b) "In auction zones where the average production of renewable electricity represents the dominant percentage, but less than 90%, the electricity used shall be considered as fully renewable as long as the hours of production of liquid and gaseous fuel of non-biological origin do not exceed the share of renewable electricity generated in the auction zone".

  (ii.c) "If the above conditions are not met, the electricity shall be considered as fully renewable if it originates from an auction area where the emission intensity is less than 18 g CO_2 eq./MJ provided that the following condition is met:

  There are one or more renewable power purchase agreements justified by a PPA (Power Purchase Agreement)[2] in one or more renewable generation facilities for an amount of electricity equivalent to that declared as fully renewable in the production of liquid and gaseous fuel of non-biological origin".

In addition, the European Commission's hydrogen strategy defines renewable hydrogen as hydrogen produced by electrolysis of water driven by electricity from renewable sources or also through biogas reforming or biochemical conversion of biomass. In EU legislation, renewable hydrogen and hydrogen-derived fuels produced without the use of biomass are referred to as renewable fuels of non-biological origin (RFNBO).

[1]European Commission. "Delegated regulation on Union methodology for RFNBOs" (2023).

[2]PPA: long-term clean energy purchase and sale agreement from a specific asset and at a pre-fixed price between a renewable developer and a consumer.