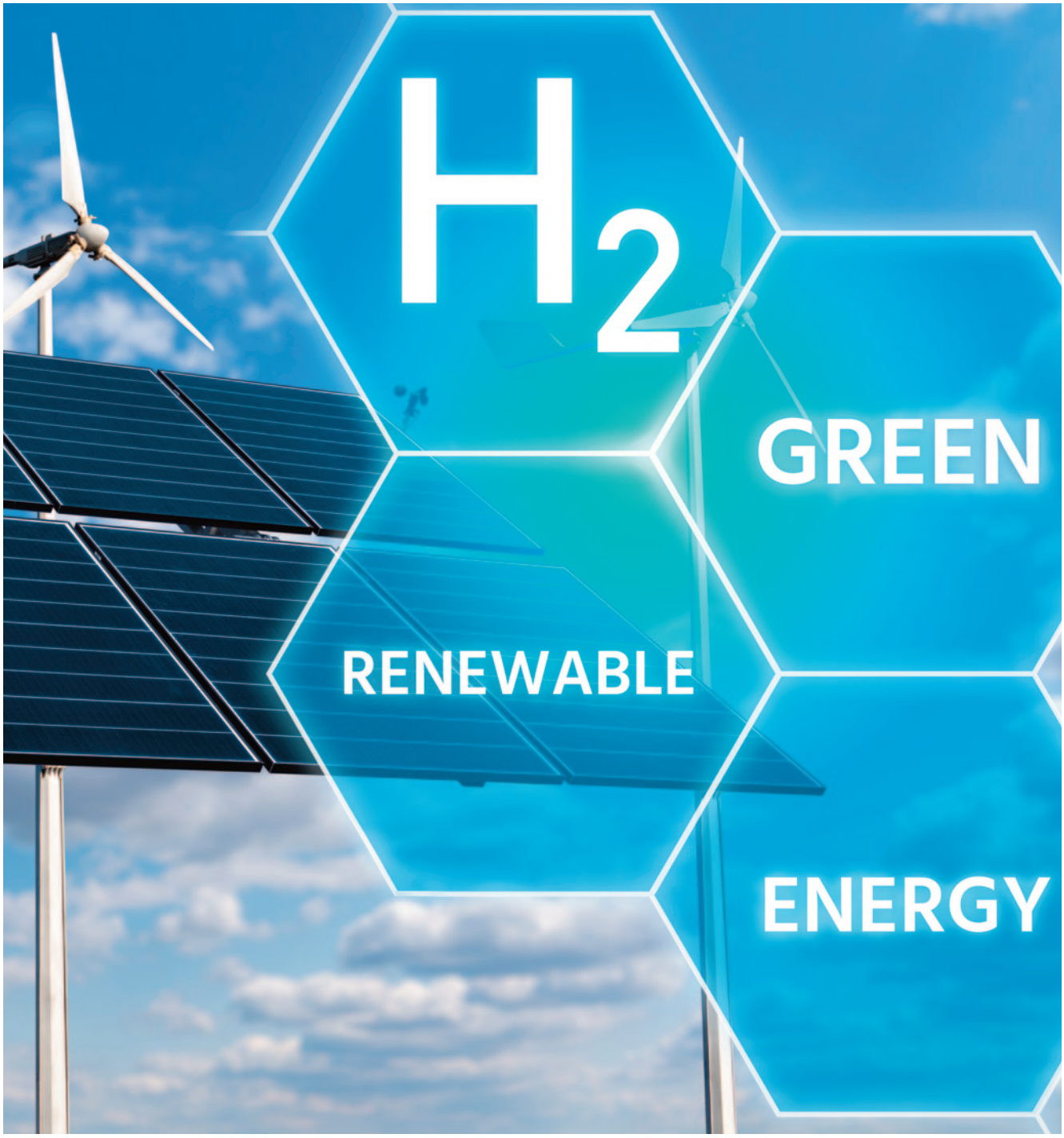
Executive summary

"Science is man's progressive approach to reality"
Max Planck[12]



Hydrogen is the lightest and most abundant chemical element in the universe and is an energy carrier, as it can be used to store and transport energy for later release. It has a high calorific value (although its energy density per volume is much lower than that of other fuels), it is inexhaustible, and it can be combined with other elements to form multiple derivative products.

This gas can be produced from various energy sources and by different methods, giving rise to different designations. These include green hydrogen (produced mainly by electrolysis of water and renewable energy sources), pink hydrogen (obtained by electrolysis with the energy source being nuclear), blue hydrogen (generated from hydrocarbons while capturing and storing the pollutant emissions produced), yellow hydrogen (produced by electrolysis while using non-renewable electricity as a source), turquoise hydrogen (obtained by pyrolysis of natural gas in a molten metal reactor), white hydrogen (present in nature) or black, gray and brown hydrogen (generated from hydrocarbons).

Among them all, green hydrogen is receiving increased attention (including from regulators), as the absence of greenhouse gas emissions during its production, its ability to balance the variability of renewables, the role it can play in the decarbonization of some sectors and its multiple applications make it the main catalyst in the process of energy transition to a carbon-neutral economy. Also, the extraction of white hydrogen from large natural deposits is recently being assessed and studied, which could contribute to the development of the sector and position hydrogen as an energy source in addition to its capabilities as an energy carrier.

The vast majority of the hydrogen consumed is produced from fossil fuels, mainly natural gas, coal and reformed naphtha. These forms of production are responsible for carbon dioxide emissions and contribute to global warming; therefore, there is consensus on the need to generate hydrogen using methods that do not release greenhouse gases in the process, such as electrolysis of water from electricity produced by renewable energies (only 0.1% of hydrogen was produced in this way in 2022).

Once generated, hydrogen must be stored and transported to its final consumption site, which is a challenge in itself. Hydrogen can be transported by ship, truck or pipeline depending on the distance between the producer and the consumer, in a gaseous, liquid or solid state, or in liquid organic carriers. (e.g., methanol, ammonia).

On the demand side, hydrogen has a wide variety of applications, with industrial and metallurgical processes such as oil refining, chemical production or steel reduction being at the forefront (e.g., ammonia or methanol) or steel reduction. In transportation, hydrogen is used in fuel cell vehicles, especially those for commercial purposes and buses, although its application to private cars is expected to grow in the next decade. It is also used for in the production of e-fuels (synthetic fuels). In addition, research is being carried out into applications in other sectors, such as energy and construction, as an alternative to fossil fuels.

Despite the progress and growing interest in green hydrogen, there are significant challenges on the road to its widespread and sustainable adoption. These challenges can be grouped into several areas:

[12] Max Planck, German theoretical physicist, considered the founder of quantum theory. In 1901, Planck published the law of the blackbody spectrum. He was awarded the Nobel Prize in Physics in 1918 for his work in quantum theory.

- **Hydrogen production:** one of the main challenges is to reduce its production cost to make it competitive with other energy sources. The main component of this cost is energy consumption. Therefore, the cost reduction effort will involve improving electrolyzation technology and developing economies of scale, among other measures.

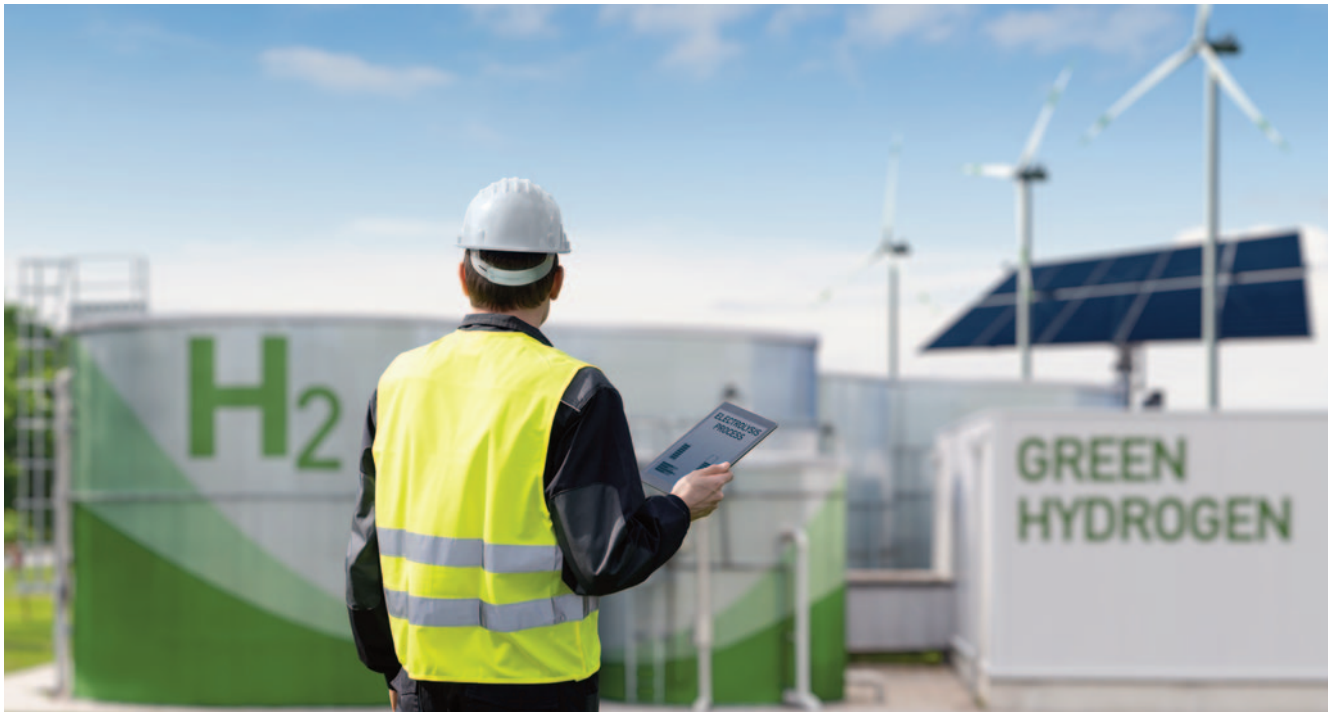
- **Demand creation:** Another challenge is to generate sufficient demand for green hydrogen in different sectors, such as industry, transportation and power generation, to justify investments in production and distribution. This implies the need to improve production and storage technologies.

- **Hydrogen market:** unlike other energy resources, hydrogen is currently predominantly an industrial gas produced and consumed on-site, making it difficult to form a market with benchmark price indexes. However, as the sector develops, the creation of hydrogen markets can be expected, which is essential to encourage investment and competition.

- **Transport infrastructure:** the development of an adequate infrastructure for hydrogen transport, whether by road, pipeline or other means, is crucial for its efficient and safe distribution. This requires addressing technical issues such as the management of hydrogen being misaligned with network or safety requirements.

- **Regulation:** the main challenges at the regulatory level include the creation of specific frameworks for green hydrogen, the technical defining what can be considered green or renewable hydrogen, the development of the necessary financial and non-financial incentives, the creation of guarantee of origin systems, the development of specific regulations that encourage transportation with emission-free vehicles together with the use of hydrogen as a fuel in maritime transportation and the evolution of pipeline gas transportation regulations.

Organizations are facing these challenges by defining strategies, selecting new projects based on an appropriate investment analysis, managing the associated risks (e.g., by carrying out an internal reorganization, if necessary, or transforming their operations to implement new processes), adapting to regulations, and meeting sustainability objectives. Transitioning companies to the hydrogen market requires a holistic approach that spans from strategy to operations, and an understanding not only of its economic viability, but also commitment to sustainability and compliance with evolving regulations. Similarly, investment in advanced technologies and collaboration with partners and suppliers are essential for success in this market.



To solve some of these challenges, it is necessary to rely on specific tools to improve decision-making. An example of this is the application developed by the Chair of Hydrogen Studies at Comillas Pontifical University, of which Management Solutions is a patron, and which relies on Geographic Information Systems (GIS) to identify optimal locations for the construction of renewable hydrogen production projects. The model calculates a hydrogen compatibility index that categorizes the different variables analyzed at each site (land compatibility for the installation of renewables and water availability; existing electricity, gas and road infrastructure; possible off-takers[13]; etc.) and determines the best alternative according to the chosen criteria.

Green or renewable hydrogen is emerging as an essential pillar in the transition to a sustainable economy, but only through collaborative efforts, investment in technology and regulatory support will it be possible to overcome current challenges and unleash its full potential as a transformational energy carrier.

[13] Stakeholders or potential consumers,