New Energies Framework: Hydrogen Ecosystem, Geopolitical and Economic Impacts

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8.1 Introduction

For decades, human society has been looking for sustainable energy production options, whether in the intelligent use of primary resources, in the logistics of storage and distribution or in terms of the cost of implementation. Several energy sources and technologies have been investigated, improved and consolidated in the past 20 years (e.g. biogas, tidal, solar, and wind power plants), and a few more promising ones are on the way to becoming viable from a technical-economic point of view.

It can be seen that hydrogen is an abundant earth's natural element (Lubitz & Tumas, 2007); however, its naturally available form is strongly connected with other atoms of natural elements. Its capture, storage and deployment present challenges in terms of economic feasibility. Besides, the use of the hydrogen as an energy source is not trivial from the point of view of the holistic sustainability approach advocated by international organizations (Bleischwitz et al., 2018; Falcone

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et al., 2021). In order to effectively make hydrogen a significant component of the world energy matrix, international efforts are being made, and increasingly so. These efforts take place from a financial point of view, with extensive funding for research and development like the European initiative (European Commission, 2021), in the social sphere, with the education and awareness of the population about new and clean energy sources (European Commission, 2020; Mazloomi & Gomes, 2012; Schönauer & Glanz, 2022) and in the market sphere (Maggio et al., 2019; Schulte, 2004), encouraging the creation of complete value chains to enable the application of new technological solutions (Lo Faro et al., 2022; Scovell, 2022).

This work aims to consolidate information on important impacts, namely in the technical, geopolitical and economic areas, on the implementation of the use of hydrogen as a primary resource of new technologies of energy production. This article reviews the available literature, and the most recent achievements in the hydrogen economy framework formatted in a logical sequence for a complete contextualization on the topic. This work is structured as follows: Sect. 8.2 presents a review of hydrogen's recent achievements and the consolidating ecosystem. This section still details the technologies, presents geopolitical impacts and goes from business hubs to the general economic aspects. Section 8.3 concludes the work by pointing out the main aspects, challenges and potential benefits that can be achieved.

8.2 Hydrogen Ecosystem

The world energy production based on renewable sources is growing every year according to a report by IRENA (Renewable Energy Agency, 2022), and this growth is not limited to the most socially developed countries. The need to limit carbon emissions and achieve low energy prices in sustainable growth is driving unprecedented changes in the global energy transition. The falling costs of renewable energy and its decentralized nature have increased widespread electrification. Continuous technological advances, well-focused public policy and cost-effective power plant solutions are driving the energy transition accessible to all types of society, even the most socially and economically disadvantaged.

Despite all the advances in electricity production, it is important to note that energy for residential, commercial and industrial use is not limited to just a single secondary energy (i.e. electrical energy). Exclusive dependence on a single secondary energy source is neither a safe nor a reasonable path in technical and economic terms. Other energy sources are needed for the production of heat and movement, which are called end-use energies. At this point, natural gas, methanol, gasoline, diesel and all secondary energy sources play an important role in the energy value chain as a whole. Hydrogen appears as another secondary energy component (Jain, 2009) and can be used basically in the gaseous form (i.e. H_2) or as the main element of hydrogen cells, needing to be combined with other chemical elements (e.g. nickel, platinum, etc.) so that they can produce end-use energy.

All industrial processes for the production of renewabe energy generation solutions, whether for the creation of photovoltaic panels or wind towers, will inevitably have to consume a considerable amount of natural mineral resources and will consume materials based on polymers, that is, based on petroleum. The value chains of these solutions are usually analysed from the moment of their installation until the end of their useful life, discarding the cycles of creation, destruction, recycling or reuse (Jensen, 2019; Tsanakas et al., 2020). The same holistic sustainability analyses and concerns must be made with hydrogen-based solutions, whether they are designed for small-scale or large-scale use.

One of the great advantages of energy production with renewable sources is its ability to use endemic primary energies (e.g. solar, wind, etc.) in a distributed manner on technically possible scales. Regions with high solar intensity may have relatively small areas for the installation of solar panels, which are insufficient to meet their energy demand. However, several endemic sources of primary energies from the same region, being used in a combined and systemic way (e.g. solar, wind and water), could supply this demand. Hydrogen adds great value in this approach to distributed energy production because it is abundant in several natural and industrial substances (e.g. water, methanol and hydrocarbons) that can be endemic or produced in a specific region.

To better understand how complex the hydrogen ecosystem can be, it is important to observe Fig. 8.1 that its use reaches a whole range of applications, such as in industrial and agribusiness resources, through the production of electric energy to the driving energy of large cargo transport equipment.

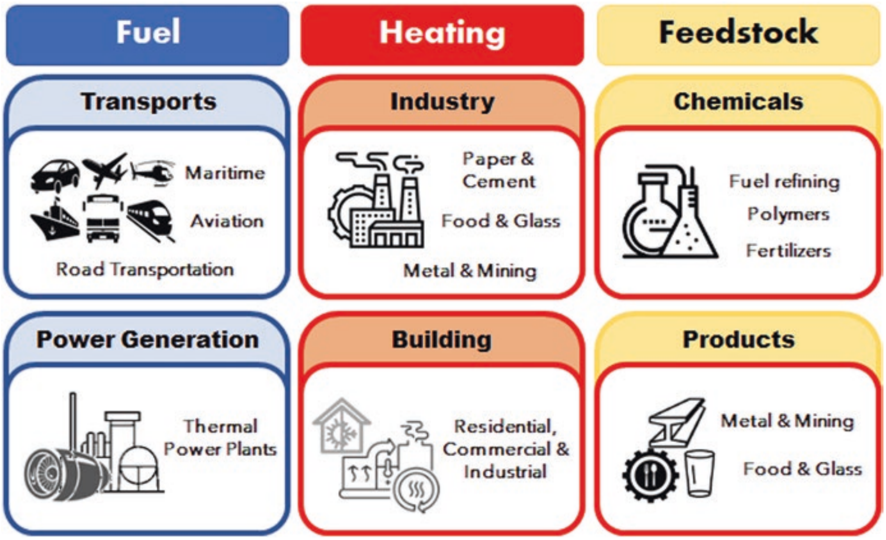

Fig. 8.1 The complex framework of hydrogen usage

8.2.1 Technological Aspects

It is important to emphasize that the use of hydrogen depends primarily on its capture in the molecules of these substances, so that, in its pure and isolated form, it can be used in energy production solutions. Water and fossil substances are the main sources of hydrogen; therefore, a separate analysis of these two types of sources is necessary for a better understanding of the viability of hydrogen in the energy matrix (Fig. 8.2).

8.2.1.1 The Green Hydrogen

Green hydrogen is produced by the electrolysis of water in equipment called electrolyzers. Using electrical energy and water (H_2O) to separate hydrogen (H_2) and oxygen (O_2) molecules, electrolyzers are the key to this process. These equipment are in constant technological evolution in order to optimize their cost-effectiveness (Yue et al., 2021), making them more efficient in terms of energy and monetarily less expensive when using the most abundant catalyst materials on the market. For this hydrogen capture process to be considered fully decarbonized, the electricity used cannot come from fossil sources, such as coal or natural gas, but from renewable sources (e.g. solar, wind or hydro).

It is important to point out that when is it possible the use of renewable energy is directly more efficient than converting it to hydrogen to be used as an energy source.

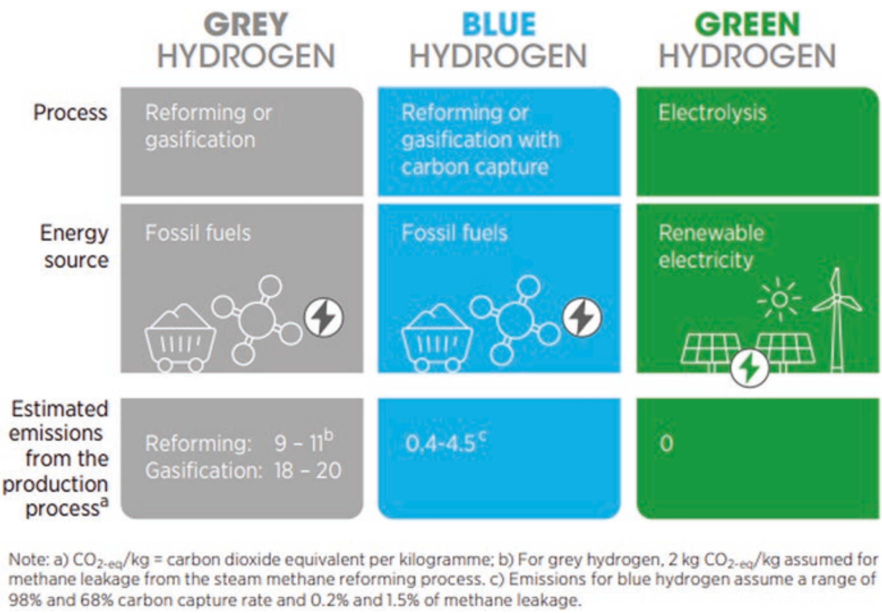

Fig. 8.2 Simplified colour spectrum typology of hydrogen production. (Source: International Energy Agency, 2022)

Using renewable energy to produce hydrogen is about 20–40% less efficient than if renewable energy could be used directly (Energy Transitions Commission, 2021).

8.2.1.2 The Grey Hydrogen

The so-called grey hydrogen is the most used on a world scale for industrial use and is produced from the burning of natural gas, which has increasingly been produced also from coal (so-called brown hydrogen), in a reaction known as steam reforming (SRM). The hydrogen separation process is basically the same for gasoline, naphtha, methanol or even other renewable sources such as ethanol. Regardless of the source, these processes will always emit air pollutants. The process involves the reaction of methane, contained in natural gas and water vapor at high pressure and temperature (around 1000 °C). Steam reform consumes large amount of energy and emits a large amount of carbon dioxide (CO_2) into the atmosphere, which is exactly the main element to be avoided in the new energy transition. An important portion of the world production of grey hydrogen is used to synthesize ammonia and its derivatives (for agriculture) or to carry out oil refining operations.

8.2.1.3 The Blue Hydrogen

Basically, blue hydrogen represents the same capture process as grey hydrogen but with an additional post-processing focused on capturing the CO_2 emitted by the H_2 separation process. This CO_2 capture, called carbon capture and storage (CCS) or CCUS with CO_2 reutilization, can be performed directly in the CO_2 gas outlet or indirectly, capturing CO_2 from the air around the grey hydrogen production plant. The CCS refers to the initiative and its set of technologies (Bui et al., 2018) that aim to prevent the emission of large amounts of CO_2 at the point of origin of its emission pursuing the carbon neutrality for an specific hydrogen plant (Sunny et al., 2020). For this, the CO_2 captured is subjected to a chemical process that produces a relatively pure carbon dioxide stream. This steam is compressed at high pressure to be transported by land and/or sea to its final storage location. This storage is carried out in deep regions, both offshore and onshore (Raza et al., 2019).

The basic technology for the CCS process has been around for many years. However, the high cost of the process and its technical-scientific uncertainties (Koelbl et al., 2014) are the main barriers to the extensive implementation of this technology. In addition, there are studies that consider some risks related to storage techniques in deep geological formations, such as accidental leaks and the occurrence of earthquakes (Zoback & Gorelick, 2012). In a critical analysis, studies show that the methane emission rate from natural gas is reduced at most to about 1.54% (Howarth & Jacobson, 2021), but the greenhouse gas emissions from blue hydrogen are still higher than the combustion of natural gas and between 18% and 25% higher than in the grey hydrogen process.

The composition of the cost of hydrogen production can be understood by taking into account three main factors, namely the price of locally produced electricity, capital expenditure for electrolysis units (CAPEX) and operating costs (OPEX). In cases where hydrogen is not used immediately at your production site, storage,

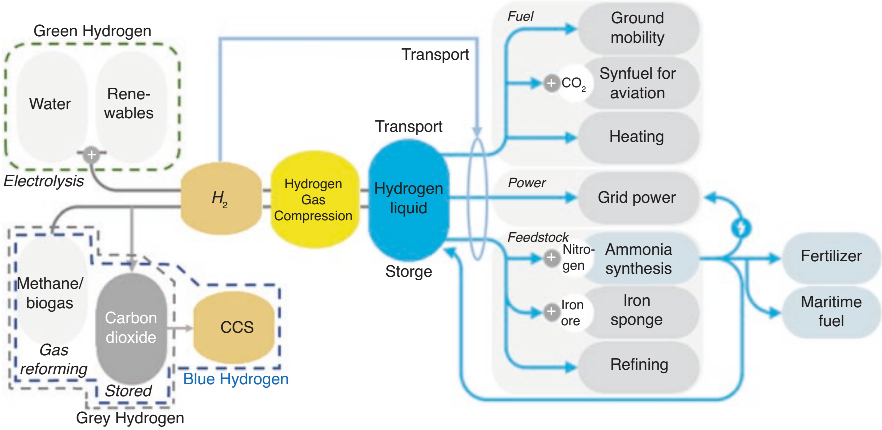

Fig. 8.3 Hydrogen pathways framework

transport and distribution costs would also need to be taken into account, which adds to the complexity of its ecosystem.

Figure 8.3, adapted from (Hydrogen Council and McKinsey & Company, 2021), shows a complete view of the hydrogen pathway since the captation method (e.g. green, grey or blue) of the hydrogen gas (H_2) molecule for use in the final destination, either as a production input or as an energy source. In the process between the capture and the final use of hydrogen, two possible alternatives can be observed. One is the storage and transport of H_2 (gas state) using new gas network infrastructure or using adapted natural gas pipelines already installed, well described in (ACER, 2021; Cerniauskas et al., 2020; Ogden et al., 2018) presenting some technical issues related to the infrastructure adaptation and other challenges. The other alternative is the process of applying low or high compression over the H_2 for its transformation into liquid state. After that, the hydrogen liquid can be transported using long or short distance land or maritime transportation.

8.2.2 The Geopolitical Impacts

The green hydrogen is emerging as an attractive solution for decarbonizing society. This solution allies renewable energy power plants with hydrogen gas production and can help to solve the energy issues that affect the energy-intensive industries that often face challenges in electrification (Balcombe et al., 2018; Espegren et al., 2021). This industry segment is critical to the world economy and comprises long-distance transport (e.g. long-haul aviation and international shipping), heavy industry (e.g. metal mining) and agrochemicals (fertilizers). This analysis is based on the actual technologies and strategies designed or already applied around the world (European Commission, 2019; Marbán & Valdés-Solís, 2007; Neuwirth et al., 2022).

The impact specifically on large maritime freighters and long-distance aviation is a game change in the world demand for fossil fuels, since the great concentration of consumption of these commodities comes from the global logistics chains (Atilhan et al., 2021; Hoelzen et al., 2022). According to the report presented in (Hydrogen Council and McKinsey & Company, 2021), clean hydrogen could reduce cumulative CO_2 emissions by a total of 80 gigatons (GT) by 2050, contributing with 20% of the total abatement forecasted to this period.

All global or local strategies must rank the priorities, especially when the subject, here the hydrogen, is so useful and cappilared into the most important industrial value chains in the world. Figure 8.4 illustrates the maturity level of the hydrogen solutions face to the type of solution, namely centralized or decentralized.

The focus on large impact centralized solution is in line to the technological maturity, which is a consequence of larger investments looking for bigger economical impacts. This strategy is driven by the most important economies in the world (Cuevas et al., 2021) and became an important vector to achieve the challenge of the energy transition (Council, 2017) and the goals for 2030.

Accordingly to the IRENA report (Blanco & Taibi, 2022) shown in Fig. 8.5, the supply and demand of the hydrogen for regions around the world in 2050 will create a new scenario of self-sufficiency. From an optimistic point of view of the technological evolution, the IRENA report shows some emergent countries (e.g. Chile, North Africans countries, etc.) as a potential exporters and some strongly industrialized countries, i.e. Germany, as future importers. Once more in the energy history can be noticed the fragility of the central Europe when natural resources are demanded (e.g. water and petroleum) and the importance of a diverse energy matrix.

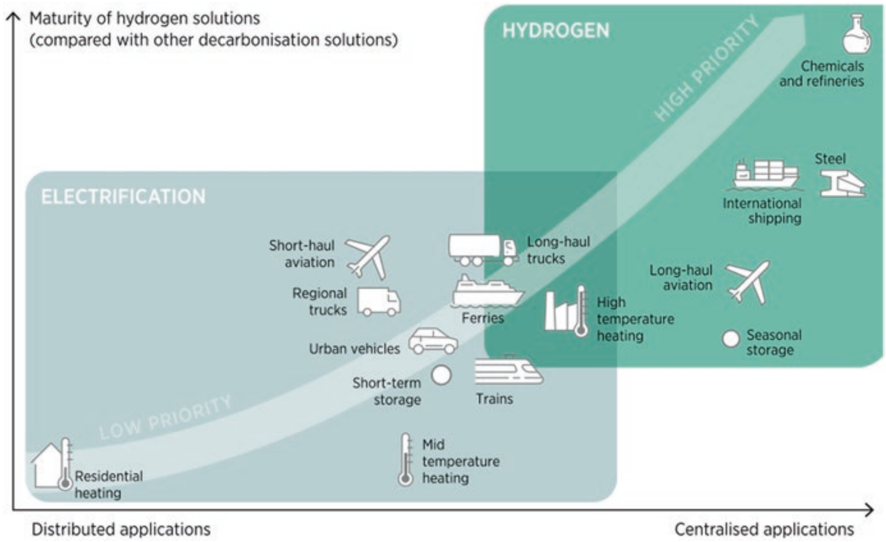

Fig. 8.4 Maturity of hydrogen solutions. (Source: Bianco et al., 2022)

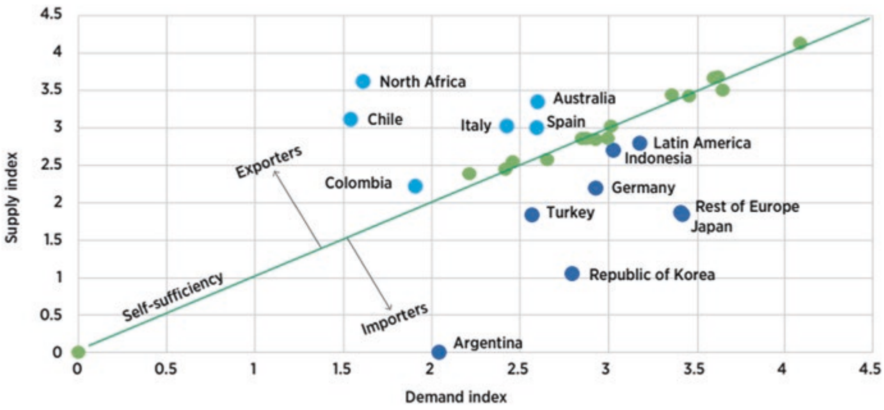

Fig. 8.5 Forecast of hydrogen self-sufficiency. (Source: Blanco & Taibi, 2022)

The Russian invasion of Ukraine in 2022 has pushed the cost of hydrogen from fossil gas to much higher than the cost of hydrogen from renewable sources (i.e. green hydrogen). As fossil fuel prices have risen, so have the costs of grey and blue hydrogen (Fabiola & Pantaleone, 2021). The feasibility of producing green hydrogen from renewable energy sources through electrolysis has become affordable and safe, especially in Europe and countries without natural fossil energy resources.

On 18 May 2022, the European Commission published its "REPowerEU" that is a plan to reinforce the energy independence from Russia as quickly as possible, in principle by 2027 (REPowerEU, 2022). The plan covers three pillars, namely: demand reduction, diversification of fossil fuel suppliers encouraging the construction of new infrastructures and the acceleration of the transition to renewable energy sources. The Russian Federation is one of the largest oil and gas producers in the world, despite this, it has been searching for solutions that prove the viability of hydrogen energy for some years, as explained in (Shulga et al., 2020; Zhiznin et al., 2020).

Focused on the hydrogen, the European Union (EU) is prioritizing energy independency and is developing internal market ecosystems to achieve the optimum level of the green and blue hydrogen. The recent report presented in (Nuñez-Jimenez & De Blasio, 2022) explains the EU strategy for the local and long-distance importation. The future and possible scenarios consider some key strategic variables namely: energy independence, cost (optimization) and energy security, looking for combining long-distance reliable partners (e.g. Australia and the United States) with a inter EU community production.

8.2.3 Hydrogen Hubs

The importance of business hubs in the hydrogen global scenario shows how the use of this natural element are evolving specially as an energy source. The hydrogen energy has emerged from a particular niche of knowledge in the scientific area to a real business ecosystem. The so-called H_2 hubs have been trying to encompass the whole hydrogen usage (i.e. industrial and energetic) in a holistic view of its value chain.

Energy community organizations have emerged and allowed customers to become energy producers and consumers at the same time (i.e. prosumers). These focus on clean energy and uncover opportunities to engage communities, which are milestones in achieving energy goals and carbon footprints. While hydrogen market organizations are gaining momentum and countries are accelerating their adoption through investment policies and cross-border contracts. Likewise, some companies have been consolidating as hydrogen hubs (i.e. H_2 global cluster) and so entire regions (i.e. H_2 sines – Portugal) unlocking the opportunity to accelerate the hydrogen production. Geographic hydrogen hubs are places where hydrogen producers, suppliers and exporters are located. This type of arrangement that combines cross-sector demand and the co-location of the entire hydrogen value chain minimizes the cost of supporting infrastructure, essential for scaling hydrogen production. The H_2 hub companies runs horizontally with actions that engage key resources and shortens the learning curve for stakeholders optimizing the solutions management, decreasing gaps and waste.

The hydrogen hubs must provide the opportunity to develop decarbonization solutions and deploy them at scale. Industrial activity and geological storage capacity in the hub's areas allied to the H_2 hub companies will provide a potential market for producers and consumers of hydrogen and related CCS providers. Figure 8.6, from the American carbon and hydrogen atlas (Abramson et al., 2022), shows a synthetic view of the all roles that can be attributed to the H_2 hubs, not only in United States but also in whole world.

Many aspects of the energy transition are still evolving in the face of challenges and opportunities and some questions often rise such as the position of hydrogen solutions. It could be approaching the peak of inflated expectations (Fig. 8.7) or are still floating over the innovation process? This evaluation is present in many studies such as (Dehghanimadvar et al., 2020) and is important to define the level of trust in the feasibility of this vector in the energy transition agenda.

New global agreements were signed (MECA, 2020), and this trend is growing, as are declarations of interest in intergovernmental cooperation, which have been signed with a focus on practical and objective aspects. The hydrogen hubs initiatives are present in the whole world and are growing towards the industrial and energy supply. Looking at the European H_2 ecosystem, Portugal must accelerate the energy transition and the decarbonization of the economy investing in the production of hydrogen, promoting the substitution of fossil fuels.

The forecasted projects will cover much of the hydrogen value chain, including production, fuel cells, storage, transport and distribution, as well as end-user applications of the mobility sector. Regarding other initiatives, it can be noted the hub "HyDealEspaña" that is the biggest of its kind and focused on green hydrogen. This hub will start in 2025 the H_2 gas supply to the Asturian industrial area to be used as energy source and industrial feedstock. The Netherlands hub called "Heavenn" (H_2 energy applications in valley environments for Northern Netherlands) is a hub

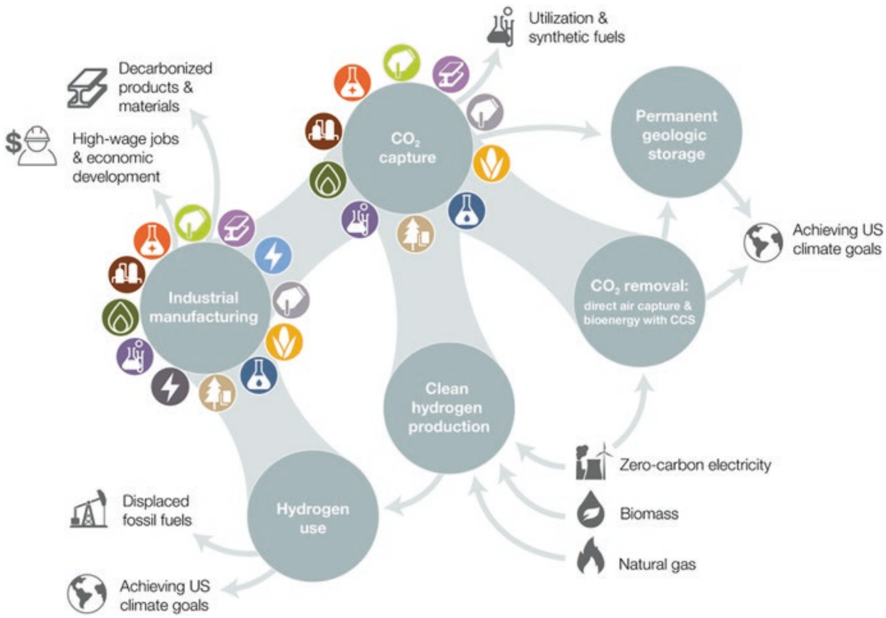

Fig. 8.6 The roles of hydrogen hubs. (Source: Abramson et al., 2022)

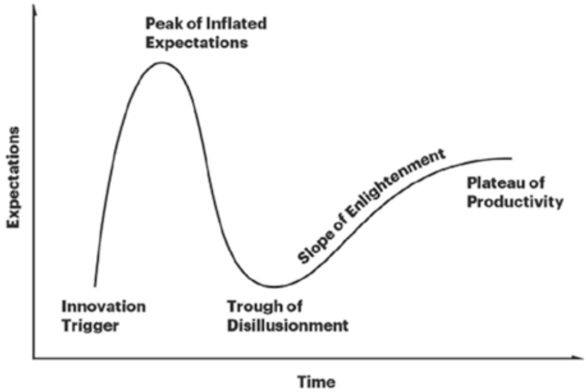

Fig. 8.7 Adapted diagram of a technology and Gartner hype cycle. (Source: Dehghanimadvar et al., 2020)

project that aims the production of green hydrogen through wind energy, decarbonizing the port of Rotterdam and the urban transport, maritime transport and in the countries' infrastructure.

8.2.4 Economical Aspects

Low-carbon hydrogen, amongst its possible varieties, has emerged with the inherent potential to become the driving force towards a more sustainable economy (Fan et al., 2021). For the past decades, it has been considered an essential element by European Union official policies to meet zero emissions target for 2050 and, also, reveals a multiplicity of uses, allowing the implementation of a true circular economy mechanism (Bonciu, 2020) with renewable inputs, reuse of resources and safer outputs.

The current global energy context faces a forced dilemma where the foreseen population growth embracing new cultural standards (technology-based disruption, continually growth-oriented production and digitalized society) is severely increasing energy demand (Saeedmanesh et al., 2018; Sharma et al., 2020) and at the same time the socio-environmental impacts of a linear economy based on hydrocarbons largely compromise the future of the economy itself and the humanity well-being (Lee, 2016). For this reason, the clean energy transition has been reclaimed by most parts of society and widely accepted by policy makers.

In 2016, during the UN Signature Ceremony for the Paris Agreement on Climate Change (COP21), the EU Commissioner for Climate Action and Energy Miguel Arias Cañete, reinforced the mutual commitment between nations as “irreversible and non-negotiable” (European Commission, 2020). Therefore, to achieve this climate challenge, policy makers, scientists, grassroots initiatives and business sectors are creating different pathways to innovate, not just from a technological point of view but also a whole social-economic model, in which energy and feedstock are core functional elements. The European Green Deal, focused on a carbon net-zero economy, has more than 1 trillion Euros budget and highlighted the efficient use of resources by moving to a clean, circular economy (European Commission, 2019). On the other side of the globe is also appearing an inter-state network development towards hydrogen economy, i.e. the Asia-Pacific Hydrogen Valley (Aditiya & Aziz, 2021).

According to the EU – Energy Poverty Observatory Hub, over 34 million people are in an energy poverty situation in the communitarian’s countries. In (Bouzarovski et al., 2021) is presented the understanding of the energy poverty as “a condition in which a household is unable to secure a socially and materially needed level of energy services in the home”. During the COVID-19 pandemic, for example, more than 50 million people and communities are suffering from energy deprivation in the European Union, that is, 1 in 4 households (Guiteras, 2021). Energy poverty is also in intersection with other forms of asymmetries deepening even more social inequality (Brah & Phoenix, 2004).

Therefore, combining the urge for economic decarbonization (Espegren et al., 2021), democratization of energy access (Burke & Stephens, 2017) and social transition requires systemic change in the way we produce, consume and relate with people and the environment, creating a circular hydrogen-centred and sustainable economy.

8.2.4.1 The Hydrogen Nexus

Clean hydrogen (i.e. green, blue or biohydrogen) can take a central role to a long-term sustainable development shifting from a carbon-based system (Aditiya & Aziz, 2021; Dincer & Rosen, 2011; European Commission, 2020; Saeedmanesh et al., 2018). This capacity is not only related to its intrinsic capacity to achieve zero CO_2 emissions in the energy sector (innovating in power and heat production, storage and transport) but also for its possible interrelationship with a variety of other sectors like fertilizers, chemical compounds, food supply chain and other shared benefits like waste management (Fan et al., 2021; Sartbaeva et al., 2008).

This wider nexus involves also a strong structure on a national level that enables the hydrogen economy to evolve, considering a domestic energy competency, economic security, level of advancement in technology (including R&D capacity) and societal influence as well (Aditiya & Aziz, 2021). According to Aditiya and Aziz (Ibidem), social development is closely related to the cultural aspects – its set of norms, values, beliefs and meanings – which is fundamental for social acceptance and, thus, influencing the social impact of a new energy system.

8.2.4.2 Circular Hydrogen Economy

Contrary to a linear process economics (based on extraction, production, consumption and waste), the circular economy contributes beyond recycling to change the way we design products, produce, consume and circulate materials (Bonciu, 2020) to a more regenerative process, based on renewable energy and material, eliminating waste and pollution (Ellen Macarthur Foundation, 2022).

According to (Bibas et al., 2017), in 1950, a total between 60 and 70 Giga tonnes of waste were generated in the world and probably rising to 100 Giga tonnes in 2030. Around 94% of the waste is discarded precariously only in India, and waste generation is growing at an alarming rate of 1.3% per year (Sharma et al., 2020). Hydrogen losses in industrial waste gas streams, estimated as 10 billion Nm^3 per year only in Europe, constitute a potential source for hydrogen recovery (Yáñez et al., 2019). There are many other examples of renewable feedstock to be introduced in the hydrogen economy through circular processes like the waste-to-energy nexus.

In December 2012, through the document "Manifesto for a Resource Efficient Europe" the EU stated that "the EU has no choice but to go for the transition to a resource-efficient and ultimately regenerative circular economy" (European Commission, 2012). Therefore, hydrogen can definitely be well positioned in this direction, using regular waste and lower impact waste as resource that could be reintroduced in the system.

Biohydrogen, for example, generated from poultry, swine, cattle, brewery, dairy and other industrial, agricultural or urban wastewaters can represent an important contribution to the circular "hydrogen" economy (Ferreira et al., 2018). There are many examples of these biohydrogen production around the globe, like in Italy (Pecorini et al., 2017), India (Venkata Mohan et al., 2018), China, Korea and others. According to Lee (2016), there are also multiple examples of cost-efficient bioeconomy models in which biohydrogen is included and is part of a wider and systemic economic process where renewable resources are interlinked with a circular economy fashion.

8.2.4.3 Sustainability

Beyond the economic bias regarding, for example, the distrust in the long-term viability of the current fossil-based industry and a general better cost efficiency ratio, the motivation towards a hydrogen-based economy is intrinsically linked to sustainability, for instance, the awareness of the ecological pressure on resources, necessity to social equity and welfare in energy access and the development of a low-impact economics.

Although, as explained before, to become a truly sustainable and clean fuel, hydrogen should encompass its blue, green or bio versions, nowadays, 95% of the hydrogen produced and consumed in the world market comes from hydrocarbon sources (i.e. grey and brown hydrogen), which reach about 870 million ton/year of CO_2 emissions. In addition, the process takes place at high temperatures, making it more expensive. This type of production consumes 6% of fossil fuels and 2% of coal produced in the world (Song, 2009).

Combining renewable energy, waste reuse and CCUS can be essential to a successful carbon mitigation and energy transition. In fact, there are not only technological and cost-effective challenges to guarantee this "sustainable hydrogen" but also political, institutional and social acceptance. On this matter, many countries are already evolving with national and regional political strategy as demonstrated previously in this paper.

Hydrogen energy systems can also support a more decentralized production to contribute to local economies, allowing flexibility and facilitating local sustainable development interchanging with regional scale strategies. "Hydrogen energy systems often require relatively small-scale equipment, reducing the time from initial design to operation and providing greater adaptability in responding to changes in energy demand" (Dincer & Rosen, 2011).

8.3 Conclusions

The great challenges of humanity have passed through questions of production and supply of food and energy. This last challenge was thought of and prioritized, in financial and geopolitical terms, as the biggest problem today and demands systemic and clear actions with short-term impacts.

Hydrogen, whether green or any other colour of the spectrum presented in this work, appears as another important vector in the world energy matrix, which tirelessly seeks its diversity and reliability.

Despite bringing great technological and logistical challenges, its use can bring more economic stability in production chains and in global logistics as the main source of fuel and energy.

As it is a source of energy that can be generated in a large part of the planet, its capillarity tends to break the large monopolies in the supply of energy sources, mainly in the form of gas, but not only. This resource could promote the development of large regional and global business hubs, as well as developing countries without fossil energy sources, but with abundant water resources, whether maritime, river or underground. Additionally, all essentially agricultural countries with the potential to turn to the production of alcohol subject to hydrogen capture will benefit from this new market. The latter comprise a large group of countries from poor or emerging economies, which will have an impact on the generation of local wealth and, consequently, on an increase in quality of life indices.

The present world economic moment shows that important public, private and coordinated financial support is being increasingly applied even in countries with free market economic bias. The use of hydrogen as a strategic vector in the decarbonization of the economy has also been strengthened by public initiatives to make the applicable laws more flexible and with tax incentives. These processes facilitate the more intense action of private agents and encourage the natural adhesion of the market to the hydrogen economy, which is important for the development of necessary technologies in present and future value chains. This path was successful in the case of incentives for the use of wind and solar energy and tends to work in the case of hydrogen.

Finally, this work showed that paradigm shifts and the introduction of new solutions on a global scale require a period of technological maturation and financial viability. The hydrogen ecosystem has been moving in this direction at an accelerated rate and is should reach a global scale faster than expected.

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