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# HYDROGEN AS A POTENTIAL ACCELERATOR OF EUROPEAN UNION DECARBONIZATION

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***Abstract:*** *In recent decades, the European Union has elaborated strategies and implemented directives to reduce the impact member states have on the environment and limit the effects of global warming. The actions aimed to reduce the emission of greenhouse gases, increase the presence of renewable energy technologies in the energy generation mix and increase energy efficiency. Throughout the 2000s and 2010s, the focus was on incentivizing the use of renewable energy technologies such as wind turbines, solar panels, and even biofuels. Hydrogen is mainly used to produce chemical products like plastic and fertilizers and implies the production of large amounts of* $CO_2$ *emissions. Renewable hydrogen, however, is obtained through the electrolysis process that splits water into hydrogen and oxygen. The use of this type of hydrogen, combined with sourcing the electricity used in the electrolysis process from renewable energy sources and the fact that hydrogen can be stored can help decarbonize the EU. This paper tries to better understand the types of existing hydrogen, the rationale for which hydrogen is not more present as an energy carrier and highlights the potential benefits and existing downsides of hydrogen from economical, logistical, and environmental points of view.*

***Keywords:*** *hydrogen energy network, decarbonization, green energy transition*

## INTRODUCTION

Today's society is facing multiple challenges caused by recent events that have made governing bodies from around the world reconsider their strategies and policies for the upcoming decade. Starting from the effects of the COVID-19 pandemic from which the world is trying to recover and coming to the recent energy crisis, the beginning of the current decade has forced actors from both the public and private sector to switch their priorities.

The sector that has been affected the most in the past few years, at least on a political level, is the energy sector. Prior to 2020, rising concerns related to environmental changes determined global leaders to take multiple initiatives [1] [2], that had the purpose of lowering greenhouse gas emissions, increase energy efficiency, and increase the penetration of renewable technologies [3].

Adding to the efforts which began in the early 2000s and consisted in increasing the penetration of renewable technologies (predominantly wind turbines and solar photovoltaic panels), and gradually phasing out of polluting technologies, the European Union has begun to focus on hydrogen as another method of decarbonizing the power sector. While more than two decades were dedicated to incentivizing renewable technologies, the same cannot be said about hydrogen, which experienced a "lost decade" [4] due to high investment costs. Considering its wide availability (hydrogen is known to be the most abundant element in the universe) and versatility when it comes to its potential applications (transport, petrochemical, power and buildings sector) [4], hydrogen, nowadays, may complement other technologies in cutting down on greenhouse gas emissions during a period of transition and recovery following the COVID-19 pandemic [5]. At the same time, hydrogen may be facing challenges in many of the fields that it can bring changes due to the rapid development of alternative technologies. In the transport sector, for example, investments in hydrogen vehicles may be facing slowdowns due to the recent development and interest in electric vehicles, batteries and charging infrastructure [6].

## TECHNICAL ASPECTS RELATED TO HYDROGEN PRODUCTION AND CLASSIFICATIONS

Hydrogen is considered by many to be a clean and viable alternative to methane. As an element, it contributes to 75% of the mass of the Universe, thus being known as the most abundantly available chemical element on Earth [7]. However, hydrogen is predominantly found in the molecules of living things, but scarcely found in gaseous form ("less than one part per million by volume") [7]. As a reactant, hydrogen has been predominantly used in chemical and petrochemical processes since the beginnings of the previous century [8].

By the end of 2023, it is expected that hydrogen production capacity will reach 4.5 Mton/year, which marks an increase of 165% compared to the previous year [9].

A major drawback of the use of hydrogen is that, presently, the most widely used methods of obtaining it produce large amounts of $CO_2$ as a biproduct of the chemical reactions that occur in the process. However, in recent years, due to technological advancements and major sustained investments [10], hydrogen production has diversified into several methods that limit or eliminate $CO_2$ emissions. Technological advancements, as well as an increased concern for environmental issues, have also paved the way for applications in previously unexplored industries, such as power generation, transport, and residential and commercial heating [11].

When it comes to the way hydrogen is produced, the first classification comes from the environmental impact that the process has. Thus, based on its source, hydrogen can be fossil based, low carbon and renewable hydrogen.

Another popular classification is based on color coding, and it is also meant to categorize hydrogen depending on its environmental impact:

- **Grey hydrogen** results from natural gas or methane through steam methane reforming. Nowadays, this represents the most widely used method and consists of using high temperature steam to produce hydrogen from natural gas or methane. The steam reforming of light hydrocarbons is also the most efficient and economically viable method used to obtain hydrogen [12].

  This type of hydrogen is fossil based since through the steam methane reforming process greenhouse gases are eliminated into the atmosphere.
- **Blue hydrogen** is produced identically to grey hydrogen; however, carbon capture and storage solutions are used, thus mitigating environmental impact. Based on the previous classification, blue hydrogen can also be referred to as "low carbon" hydrogen.
- **Black and brown hydrogen** are produced using coal and lignite respectively to produce the steam necessary for the methane reforming process and represent the most pollutive technologies. This technology, together with grey hydrogen are responsible for 630 Mt of $CO_2$ emissions [13].
- **Green hydrogen** is produced through the water electrolysis process. During the process, electricity is used to split water into its base molecules, hydrogen, and oxygen. What determines the color coding is the fact that the electricity necessary for this process results from renewable energy sources, thus eliminating any damaging environmental impact. A subset of this classification is known as **yellow hydrogen** and is produced by using energy harnessed by photovoltaic panels. For the electrolysis (the separation of water into oxygen and hydrogen) process to occur, electrolysers are used. Electrolysers are composed out of the stack and the balance of plant (which is split into the power supply, water supply, purificator, compression, electricity and hydrogen buffers and hydrogen processing [14].
- **Pink hydrogen** is also produced in electrolysers, however, the energy necessary for the process is sourced from nuclear power plants. It is important to note that the high temperatures that result from nuclear reactors can also be used in the steam methane reforming process.
- **Turquoise hydrogen** results from a process called methane pyrolysis by using energy from renewable sources. A biproduct of this process is solid carbon, which can classify turquoise as low emission hydrogen. This technology is still being developed and its use has not been implemented at a large-scale level.
- **White hydrogen** can be found in nature, in underground deposits and requires fracking for extraction and harnessing.

Out of the previously presented types of hydrogen, green hydrogen (with the yellow subset in mind as well) stands out as a breakthrough that can aid global efforts in reaching net-zero carbon dioxide emissions. However, compared to the blue counterpart, green hydrogen production is almost three times as expensive [14]. Despite the high costs associated with green hydrogen production, there are several promising technologies, policies, and strategies, which may cut down costs, improve performance and upscale production, thus making green hydrogen cost competitive by 2030 [14].

- As green hydrogen production is still in its early stages, a market must be first established. In its early stages there are few players, with benefit from production scale of mere MW. As the signals of governmental support for hydrogen production are felt by manufacturers, capacities are beginning to scale up. This leads to the discovery of economies of scale [14].

- Manufacturers are beginning to test out new custom designs for electrolysers based on research and development designs. Recently, scientists have managed to use seawater that requires no previous treatment to produce hydrogen [15]. Such advancements do not only represent breakthroughs that will benefit hydrogen production in the future, but also increase competitivity between manufacturers.
- Taking a glance at the evolution of similar technologies (photovoltaic systems) reveals that expanding capacity leads to a decline in costs [14].
- Governmental investments are expected to reduce the costs of electrolysers by 40% until 2030 [14]. The recent energy crisis has only increased the commitment of institutions like the European Union to cutting down on fossil, either by using hydrogen instead if polluting fuels (coal, gas) in end-use applications, or by producing hydrogen from clean energy sources [13].

Despite the many advancements that are taking place regarding hydrogen production, one of the main weaknesses of its mass deployment is the state of the infrastructure required for transportation and storage. Given the technical prerequisites necessary for its production [16], presently, hydrogen is mainly produced close to the consumption site. Given the current rate at which hydrogen demand is growing, the near future will see an increase in hydrogen infrastructure development.

Although hydrogen is transported through pipelines like those which enable gas transportation, the low energy density of hydrogen and its low boiling point [13], make the development of new pipelines difficult. Europe and the US have less than 5000 km of operating pipelines combined, which are connected to large consumers such as refineries and chemical plants.

An alternative to pipelines, where such infrastructure is not feasible, is represented by tube trailers, which are trucks that carry pressurized gaseous hydrogen in tubes that can contain up to 900 kg of hydrogen [17]. Other methods to transport hydrogen which are gaining popularity due to technological advancements are enabled through hydrogen liquefication [18] and solid hydrogen power plants [19].

Although in the short-term future hydrogen production will remain concentrated near the consumption sites, in the long term, as hydrogen becomes more economically viable, the pipeline infrastructure will require to expand, or existing gas pipelines will require repurposing, as gas will slowly be phased out together with coal in favor of renewable energy sources.

European countries currently have multiple planned projects for repurposing natural gas pipelines to facilitate hydrogen transportation:

**Table 1.** European projects for repurposing natural gas infrastructure for hydrogen transport

| **Project name** | **Country** | **Start year** | **Companies** | **Length (km)** |
|---|---|---|---|---|
| **Hydrogen network Netherlands** | **Netherlands** | **2026-2031** | **Gasuine** | **1400** |
| **Get H2 Nukleus** | **Germany** | **2024** | **OGE, RWE, BP, Evonik, Nowega** | **134** |
| **HyPerLink** | **Germany** | **2025-2030** | **Gasuine** | **610** |
| **Green Octopus** | **Belgium, Netherlands, Germany** | **2022-2030** | **WaterstofNet, Gasunie, Fluxys, Ports of Rotterdam, Antwerp and Zeebrugge** | **0** |
| **$H_2$ercules** | **Germany** | **2026-2030** | **OGE, RWE** | **1500** |
| **Project Union** | **UK** | **2030** | **National Grid** | **2000** |
| **Danish-German Hydrogen network** | **Denmark, Germany** | **2030** | **Energinet, Gasunie** | **330-440** |
| **Snam 2030 vision** | **Italy** | **-** | **Snam** | **2700** |
| **Catalina** | **Spain** | **2023** | **Enagás, Naturgy, Fertiberia, Vestas** | **450** |

## APPLICATIONS OF HYDROGEN

Besides its widespread availability, hydrogen represents a decarbonization enabler since it can be used across multiple industries.

In 2021, hydrogen was globally used in refining processes (39.8 Mt of hydrogen), as a component for producing ammonia (33.8 Mt), for methanol (14.6 Mt) and in the iron and steel industry (5.2 Mt) [20]. It is encouraging to note that, although during the COVID-19 pandemic the use of hydrogen diminished slightly (the crude steel output of India drastically decreased in 2020), its demand recovered in 2021 [13].

In the 19th century, hydrogen kicked off city modernization throughout the UK, Europe and USA. Back then, hydrogen was produced using coal, wood and petroleum and was used in the production of "town gas". Town gas was distributed for cooking, heating, and lighting. Later, in the 20th century, hydrogen would be used in the production of ammonia and methanol [12]. Nowadays, demand has increased tenfold compared to 1975, and still rising, as 6% of global gas and 2% of global coal demand is used for hydrogen production [21]. However, in the upcoming years, aside from refining, hydrogen demand in refineries may also be attributed to new processes such as the upgrade of biofuels, or the production of low-emission synthetic hydrocarbon fuels [13].

In recent years, hydrogen, as an energy carrier, could potentially represent a solution for the demand of environmentally friendly fuel [22].

In 2021, the demand for hydrogen in the transport sector (which includes cars, buses, and commercial vehicles) reached 30kt, which represented an increase of more than 60% compared to 2020. Although at first glance this looks encouraging, the share of hydrogen represents only 0.003% of the total transport energy from the market [13].

Recently, in 2022, following a collaboration between France and Germany, the first fuel cell train fleet was deployed on the 100 km Cuxhaven, Bremerhaven, Bremervoerde and Buxtehude route near Hamburg. The technology used for these trains combines the hydrogen on board with the oxygen from the ambient air using a fuel cell present on the train's roof to create electricity. However, the deployment of 14 trains is still a shy beginning for hydrogen deployment in the train sector, given the fact that 20% of Germany's trains run on diesel, and serious investments are required to bring the country's and Europe's infrastructure as a whole to desired levels ahead of its 2030 targets [23].

In the years following 2030, hydrogen may also be used in the maritime and aviation sectors, where technologies are still currently in early stages of development [13]. In [24] it is argued that the main obstacles that hydrogen must overcome in maritime transport are storage, delivery possibilities and the economic viability of hydrogen production.

The sector in which hydrogen applications are the least developed is the buildings sector, since hydrogen technologies are not as efficient as other alternatives, and they require the development of new infrastructure and devices [25]. However, despite these barriers, there may still be some niche applications in old buildings where natural gas infrastructure is in place and decarbonization is hard to implement [13].

Another sector that sees limited use of hydrogen is the power sector, at least for the years leading to 2030. Until then, in Europe, hydrogen power plants will mostly be used in balancing markets for flexibility. This is mostly since the costs associated with the technologies are still high. Furthermore, there have been limited developments when it comes to the adoption of policies in this field [13].

## POLITICAL DIMENSION: HYDROGEN POLICIES AND TARGETS PRIOR TO AND AFTER THE REPOWEREU PLAN

In 2020, the European Commission put forward the "Hydrogen strategy for a climate-neutral Europe" plan [26], to set a clear overview of the state of hydrogen deployment, to offer insights on hydrogen advantages and to present a roadmap of investments into research and innovation in hydrogen technologies in order to boost sustainable growth, decarbonization and new jobs in the context of recovery from the COVID-19 pandemic.

The key takeaways from the report were 20 action points proposed by The Commission to the Parliament, the Council and other EU institutions. A summary of the proposals can be found below:

- The establishment of an investment agenda which could incentivize the roll out of production, usage, and development of necessary infrastructure by the end of 2020.
- Include investments in clean hydrogen in the "*Strategic European Investment Window of InvestEU*" (planned, at the time, for 2021).
- Include hydrogen in the "*Sustainable and Smart Mobility Strategy*" as a fuel alternative in transport.
- Kickoff planning for hydrogen infrastructure which includes fueling stations.
- Remove barriers for efficient infrastructure development.
- Promote research and development through various initiatives.
- Work with strategic partners for the inclusion of hydrogen strategies at an international dimension.

By the first quarter of 2022, all 20 action points were implemented and delivered, however, as it can be noticed, most of the action points dealt with the establishment of strategies and not concrete tangible developments. As a result, in 2022, hydrogen still accounted for less than 2% of Europe's energy consumption, and 96% of the hydrogen which was being used was produced from natural gas, as opposed to renewable energy, which was defined in 2020 as "*the most compatible option with the EU's climate neutrality and zero pollution goal in the long term and the most coherent with an integrated energy system*" [26].

Although there were no notable developments in renewable hydrogen deployment from 2020 to 2022, the energy crisis together with the commitment of the EU to become independent from fossil fuels sourced from unreliable partners, may represent a forced acceleration of renewable hydrogen use in refining.

The "*REPowerEU*" action plan [27] projects that 8 Mt of renewable hydrogen can be used in refining and other processes by 2030, which in turn would result in a decrease of natural gas demand by 27 billion cubic meters. It is projected that 6.6 Mt can be produced domestically, while the rest can be obtained by securing strategic partnerships with countries like Namibia, Egypt, and Kazakhstan.

Overall, the "*REPowerEU*" strategy sets out an ambitious target compared to the "Fit for 55" target. While the previous goal was to reach 5.6 Mt of renewable hydrogen use by 2030, now the target is set to 20 Mt which should replace 50 billion cubic meters of gas which were previously sourced from unreliable partners of the EU. The breakthrough of hydrogen uses by sector can be seen in figure 1.

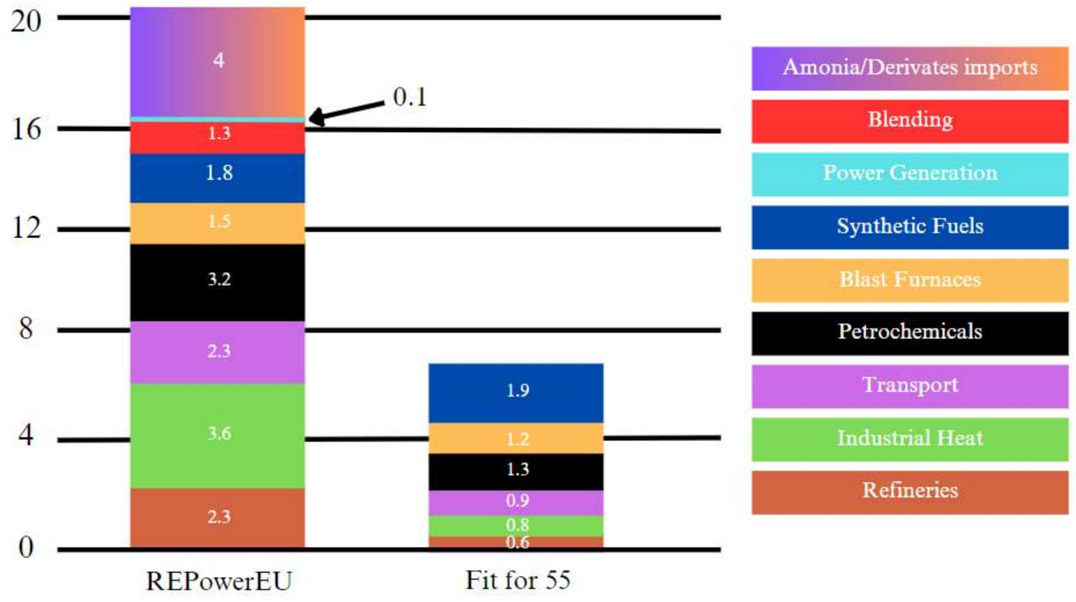

**Figure 1.** Hydrogen applications by sector in 2030; **Source:** Adapted after [28]

The "*REPowerEU*" strategy also pays increased attention to hydrogen derivates like ammonia, methanol, e-kerosene, and e-petrol.

In spite of some voices from the industry [29], which are more than skeptical about the impact that hydrogen can have, given the technological advancement of renewable hydrogen production, transport and storage, the renewed commitment of the European Union to incentivize the acceleration of hydrogen deployment and analyses of economic viability [30], under the correct circumstances, hydrogen might represent to reaching decarbonization and other environmental targets.

However, a more common and measured approach would be to see hydrogen as a second priority when energy efficiency and electrification, which have a significant head start to hydrogen when it comes to climate neutrality and decarbonizing the energy sector [31].

## HYDROGEN DEPLOYMENT IN ROMANIA

In Romania, 0.194 Mt of hydrogen were produced in 2021, according to the draft of the "*National strategy for hydrogen and the action plan for its implementation*" (breakdown of technologies used can be seen in figure 2). According to the information collected from big producers and consumers, the main uses for hydrogen in Romania can be found in refineries, the steel industry, the chemical industry, and fertilizers.

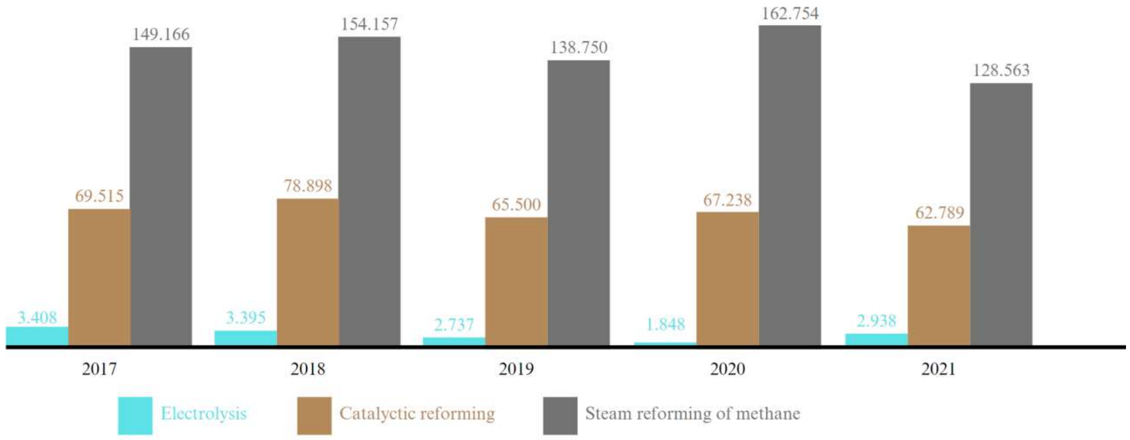

**Figure 2.** Hydrogen production by technology in Romania; **Source:** Adapted after [32]

Compared to western countries, which have defined their strategies for the development of hydrogen extraction and production capabilities several years before, Romania, together with other Eastern European countries are making the first steps towards setting the basis for hydrogen as a means of decarbonization and the establishment of hydrogen as an energy vector in 2023.

Based on the current draft [32], which was released for public debate on the 31st of May 2023, the main goals the use of renewable hydrogen and low emissions hydrogen is analyzed form the perspective of reducing $CO_2$ emissions, developing available technologies, diversifying the current energy mix, and maintaining energy security.

Looking towards 2030, Romania sets out the following objectives in accordance with European plans and legislative packages for the acceleration of hydrogen deployment:

- The development of hydrogen fueling stations once every 200 km in the main TEN-T network (as part of the "Fit-for-55" legislative package), and at least one hydrogen refueling station for every urban hub by the end of 2030
- The gradual replacement of natural gas in the fertilizing industry, refineries, and the steel industry

Given the targets set out by the European Union, Romania must incorporate the following elements in the future hydrogen value chain:

- Prioritizing hydrogen production as follows: renewable hydrogen, low emissions hydrogen from water electrolysis and finally, following 2030, hydrogen resulting from methane gas pyrolysis.
- Hydrogen storage in gaseous or liquid form.
- Hydrogen transport through pipelines or in pressurized tubes (on land by trucks and trains, or on water on the sea or rivers).
- The diversification of the applications of hydrogen (depending on local conditions).

Overall, hydrogen technologies are in a nascent stage in Romania, and the road leading to 2030 is highly reliant on the establishment of a clear strategy and action plan and the collaboration between the public and private sector.

## HYDROGEN AS AN ACCELERATOR FOR DECARBONIZED ECONOMY ANALYSIS

Given the information presented in the previous chapters, an analysis based on the criteria and quadrants of the SWOT analysis framework of the strengths, weaknesses, opportunities, and threats of hydrogen as an accelerator for decarbonized economy is presented to summarize the main takeaways of the research that has been conducted. Given the fact that this analysis does not consider multiple companies, the author acknowledges that it is not a proper SWOT analysis, but rather the concise elements of its framework are used to synthesize the findings of this paper:

- Strengths:
  - Widely available element.
  - Can be used in multiple industries (chemical, steel, transport, buildings, energy sector), both as a low carbon and carbon neutral alternative to polluting fuels.
  - Can be transported through different means (pipelines, road transport) and stored in various states (solid, liquid, gaseous).
  - Can be used in the energy sector to handle fluctuations in demand.

- Weaknesses:
  - Hydrogen has lost a lot of ground to alternatives for decarbonization, such as production of energy from renewable sources, thus leading to technology costs that are still high, relatively untapped potential and an undeveloped legislation in many countries.
  - Lacking or undeveloped infrastructure for transport and storage.
  - The production and, implicitly, use of green hydrogen is impossible in regions where water is unavailable in large quantities.

- Opportunities:
  - Given the renewed commitment of the European Union towards climate neutrality and the gradual phasing out of gas and coal, hydrogen may see an increased attention in the following years and substantive investments.
  - Hydrogen production, transport, storage and uses can lead to the creation of new jobs. This aspect is especially important as the phasing out of coal and gas has left many unemployed.
  - Research in hydrogen technology development can lead to innovation and an increase in industry competition.

- Threats:
  - In many industries, hydrogen competes directly with technologies that are more mature and thus more efficient. For example, while hydrogen-powered vehicles and charging stations are still in the early stages of deployment, electric vehicles have already had several years in which batteries were studied and improved and charging stations were built.
  - Strong opposition from oil companies and economies that rely heavily on fossil fuels.

## CONCLUSIONS

Despite a delayed start caused by high investment costs and strong competition from other technologies, hydrogen faces unprecedented exposure and support at a political level in a time when the focus of many states around the world is building sustainable economies by phasing out fossil fuels.

In Europe, the promise of hydrogen development comes at a time of recovery from the COVID-19 pandemic and during an economic crisis during which most of the European Union states are pledging millions of euros to phase out gas and coal to become independent both from unreliable economic partners and environmental impact.

However, despite political declarations, palpable projects are still far from being implemented, and the evolution of hydrogen demand for multiple sectors is increasing at a slow rate. Many projects are expected to finalize close to 2030, while some applications will see commercial use only after 2030.

Between the strengths that hydrogen has and the potential benefits it can bring to decarbonization, there are many years of research, development, and investment that need to pass, and it is unclear when breakthroughs that would lead to major cost decreases will take place.

Given the fact that in the power sector renewable technologies are going through rapid deployment at a residential level through the rise of prosumers in the context of decentralization, and that in the transport sector electric vehicles are benefiting from increased sales, even after the pandemic, hydrogen may be more suitable to occupying niche markets, such as hydrogen power plants being used for balancing markets and fuel cell trains or commercial vehicles. The same thing cannot be said about when it comes to the industry sector, where hydrogen use is widespread. The following years are expected to see rapid development for low emission hydrogen for ammonia and other industrial processes.

Given the arguments presented throughout this paper, it can be stated that while hydrogen cannot be called a true “accelerator” for decarbonization given the slow pace at which production is expected to ramp up and the lacking infrastructure (transport, refueling and storage), it still represents an option that is worth exploring in the following years.

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