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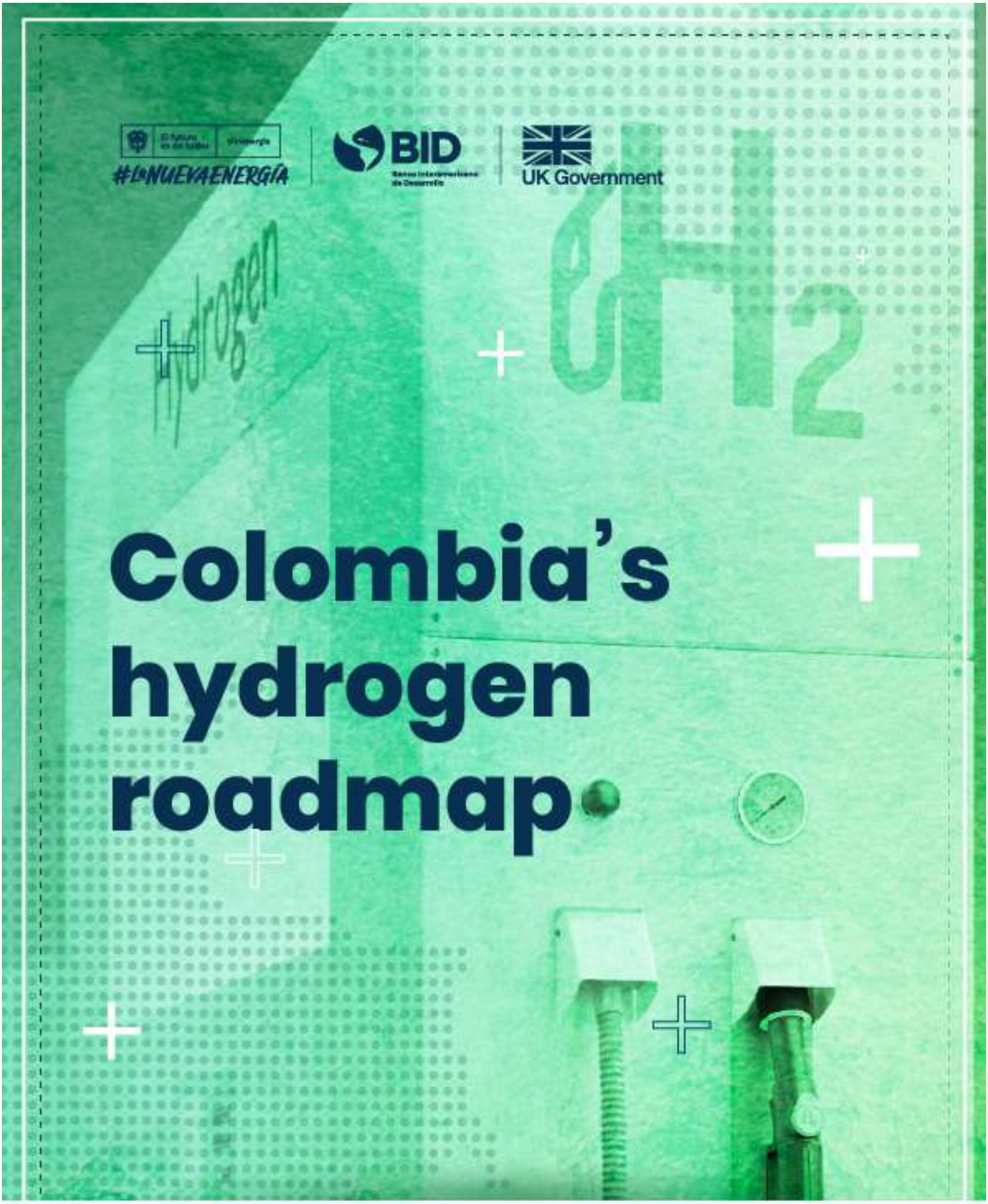

Colombia's hydrogen roadmap

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Prologue

The purpose of the Hydrogen Roadmap is to contribute towards the development and implementation of low-emission carbon hydrogen in Colombia, thus reinforcing the Government's commitment to the reduction of emissions according to the objectives set forth in the 2015 Paris Agreement. In order to develop this Roadmap, the Colombian Government has the support of the Inter-American Development Bank (IDB) through its Energy Division and its Climate Change and Sustainability Division.

As its starting point, the Roadmap uses the analysis of hydrogen production capacity, expected demand, associated emissions reductions, the country's export potential and the regulatory measures needed to implement a hydrogen deployment plan in Colombia.

Hydrogen is drawing a great deal of interest as a key element in the energy transition process. It is the simplest and lightest element in the periodic table and its versatility as an industrial feedstock, fuel and energy vector for storing and transporting energy allows for a large number of applications, some of which have not yet been fully developed. Furthermore, hydrogen does not emit any greenhouse (GHG) or pollutant gases during its use/consumption. Because of its reactivity, hydrogen cannot be found in nature in its pure elemental state and must be extracted from water, hydrocarbons or biomass. Depending on the hydrogen production process and the energy source used, its associated CO_2 emissions will vary. The use of renewable energies or implementation of CO_2 capture when fossil fuels are used in its production make hydrogen a viable option for the decarbonization of multiple end uses, with the process becoming progressively interesting as the electrification of these final applications becomes more complex.

Low-carbon hydrogen will contribute towards accelerating the achievement of the objectives established in Colombia's decarbonization strategy. As an energy vector, hydrogen will accelerate the deployment of Non-Conventional Renewable Energy Sources (FNCER for its Spanish acronym), such as solar and wind energy, through seasonal energy storage and transport to demand centers. Colombia has a highly decarbonized energy matrix and renewable resources for the production of green hydrogen at competitive costs. In addition, Colombia is rich in gas and coal resources that, combined with CO_2 capture and storage or utilization, diversify the options for low-carbon hydrogen supply, thus ensuring self-sufficiency.

In the industrial sector, hydrogen will progressively replace the use of fossil fuels and feedstocks in industries for which few low-carbon alternatives exist today. Hydrogen also provides an alternative for those modes of transport that are difficult to electrify. Currently, low-carbon hydrogen initially faces a cost gap with gray hydrogen and conventional fuels. However, low-carbon hydrogen would allow it to maintain current energy self-sufficiency and avoid, in the future, dependence on imported energy sources, facilitating in the long-term industrial development based on the creation of new value chains for low-carbon products.

Colombia meets the necessary conditions to exploit the hydrogen opportunity and become a regional leader in energy transition thanks to its privileged geographic location and a stable regulatory and political framework capable of attracting long-term investments. The development of hydrogen production and the adaptation of economic sectors to its use will require large investments in technology development and infrastructure creation. Colombia, like other leading global economies, has created investment plans and incentives to build up complete value chains around low-carbon hydrogen. These plans are combined with a series of regulatory changes, a research and development (R&D) policy aligned with an industrial course of action, and the creation of markets that would stimulate the use of hydrogen. Colombia will accelerate the development of national capabilities and position itself globally in this emerging market through cooperation agreements to access new technologies, project financing and the opening of export routes for hydrogen and its derivatives.

1. Hydrogen, an opportunity for Colombia

1.1. Hydrogen as part of the global decarbonization framework

The fight against global warming caused by Greenhouse Gas (GHG) emissions has become an international priority. The 2015 Paris Agreement includes the need to hold the increase in the planet's average temperature below 2°C, along with the recommendation to prioritize working towards a temperature increase of no more than 1.5°C. In this regard, Colombia has committed to a 51% reduction in emissions by 2030 compared to the baseline scenario in the Nationally Determined Contribution, with the goal of achieving carbon neutrality by the middle of the century.

In this context, hydrogen is a tool for achieving these objectives, and its role will be key in the long-term decarbonization of certain sectors that are difficult to electrify. Other economies preset a similar situation, and consequently low-carbon hydrogen will give rise to a global market in which Colombia will play a prominent role.

The worldwide considerable interest towards hydrogen is due to its great versatility. Hydrogen is the simplest element in the periodic table and is highly reactive; it is not normally found freely in nature, but rather combined with other molecules. This makes hydrogen not a source of energy but an energy vector, as energy must be used for its production[1].

Currently, there are several ways to produce hydrogen which are characterized by the inputs used and the technologies employed. Hydrogen can be classified according to the sustainability of the energy vector, which depends largely on the production technology and the energy source. The classification is made according to the emissions associated therewith. This classification has been adopted by the European Commission as part of its hydrogen strategy[2]:

- **Hydrogen produced from fossil fuels**, produced by processes that use a fossil fuel as feedstock, such as natural gas reforming or coal gasification, with emission factors of 9.5 $kgCO_2/kgH_2$[3] for natural gas and 20 $kgCO_2eq/kgH_2$ for coal.
- **Hydrogen produced from fossil fuels with CCUS**, a subcategory of the previous category, which uses carbon capture, storage and in some cases utilization (CCUS[4]), with emission factors that can range from 1 to 2 $kgCO_2/kgH_2$[5] .
- **Hydrogen from power generation**, produced by electrolysis, regardless of the origin of the power generation. Consequently, the sustainability of this hydrogen depends on the structure of the power generation mix. If in Europe the average emission factor would be 14 $kgCO_2/kgH_2$, globally this value would rise to 26 $kgCO_2$/kgH2,[1] while in Australia it could reach 54 $kgCO_2/kgH_2$.[6] It should be noted that these values are higher than the steam methane reforming (SMR) emission factor of 9.5 $kgCO_2/kgH_2$. However, Colombia achieves a lower emission factor due to the high presence of hydropower in its energy mix. In the case of Colombia, hydrogen production from the grid would emit 8.2 $kgCO_2/kgH_2$.[7]
- **Renewable hydrogen (or clean hydrogen)**, produced from renewable sources and therefore considered to generate virtually zero emissions.[8] This category includes hydrogen produced

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[1] *Energy vector: in this case, a substance that stores energy in such a way that it can be released later in a controlled manner and at the required time. In contrast to primary energy sources, these are manufactured products, in which a greater amount of energy has been invested in their production than the amount stored.*
[2] *European Commission (2020): A Hydrogen Strategy for a Climate-Neutral Europe*
[3] *IRENA (2019): Hydrogen: A Renewable Energy Perspective*
[4] *Corresponds to Carbon Capture, Utilization and Storage*
[5] *European Commission, (2020): A Hydrogen Strategy for a Climate-Neutral Europe.*
[6] *Barnes, A., Yafimava, K., (2020): EU Hydrogen Vision*
[7] *XM (2019): Emission factor of the power grid in Colombia 164,38 gCO_2/kWh; IEA (2019), The Future of Hydrogen: efficiency in the production of H_2 of 50 kWh/kgH_2*
[8] *Only emissions due to the production and use of hydrogen are considered.*

by electrolysis, provided the power generation originates from renewable technologies, and biohydrogen, obtained from biomass.

- **Low-carbon hydrogen** can include both hydrogen from fossil fuels with CCUS and hydrogen from power generation and other sources, provided that their emission factors are substantially lower than those of the current production methods.[9]

In recent years, a color code has been developed which simplifies the classification of hydrogen according to the energy source used to produce it and sometimes also to the production process used. This last classification will be used throughout this document to differentiate between the different hydrogen production pathways in Colombia. The types of hydrogen mentioned include:

- **Gray hydrogen** produced from fossil fuels, mainly natural gas and coal, without subsequent carbon capture and storage.
- **Blue hydrogen** defined as hydrogen produced from fossil fuels that incorporate CO_2 capture and storage. The Energy Transition Law defines blue hydrogen as hydrogen produced from fossil fuels, especially from the decomposition of methane (CH_4), and which includes a carbon capture, utilization and storage (CCUS) system as part of its production process. Blue hydrogen is included in Non-Conventional Energy Sources (FNCE for its Spanish acronym).
- **Green hydrogen** corresponds to renewable hydrogen. According to Article 5 of Colombia's Energy Transition Law (Law 2099 of 2021), green hydrogen is defined as hydrogen produced from Non-Conventional Renewable Energy Sources (FNCER), such as biomass, small hydropower, wind, geothermal heat, solar, and tidal, among others.

The role of low-carbon hydrogen and its derivatives in the decarbonization of multiple sectors has sparked the interest of the world's largest economies and has led to the development of projects, initiatives and public strategies that aim to promote hydrogen deployment, among which this Roadmap is framed. Each country's natural resources and the decarbonization goals set will normally define the type of low-carbon hydrogen to be promoted.

Currently 30 countries have developed their own hydrogen roadmaps or energy plans in which hydrogen plays a key role in their emission reduction strategies. The European Commission's strategy is particularly ambitious and envisages mobilizing between 180 and 470 billion euros of public-private financing ranging from research and development of technologies to incentives for the installation of green hydrogen generation plants. Low-carbon fossil-fuel hydrogen pathways will be allocated a smaller budget of between 3 and 18 billion euros. In addition, the different member states will also provide their own incentives, of which Germany's public support program of 9 billion euros (2 billion euros will be earmarked for international agreements) and France's 9 billion euros program are worth highlighting. Other large economies such as Japan or South Korea will also allocate 19 and 2.4 billion dollars respectively for the financing of hydrogen economy projects.

Interest in the development of renewable hydrogen projects in the private sector has also accelerated significantly. As of February 2021, 228 hydrogen-related projects had been announced worldwide across the entire value chain, of which 17 correspond to production projects with a scale of more than one gigawatt (more than 1 GW of renewable power or 200,000 tons/year of low-carbon hydrogen production). Europe accounted for 55% of projects, followed by Australia, Japan and South Korea.[10] The renewed interest in hydrogen is mainly explained by the need to accelerate the global decarbonization process, the rapid reductions in the cost of renewable energy, the evolution of key technologies in the hydrogen value chain and the public support for the energy transition that has increased as part of the economic recovery strategy following the COVID-19 pandemic.

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[9] *The international measurement system and maximum emission thresholds are in the process of being defined. In this document, blue and green hydrogen are considered low-carbon hydrogen.*
[10] *Source. Hydrogen Council (2021): Hydrogen Insights*

Therefore, current global demand for pure hydrogen is expected to rapidly increase from 75 Mt in 2019,[11] primarily in gray hydrogen, to more than 800 Mt in 2050 in the most optimistic scenarios, thanks to the development of low-carbon production alternatives.[12]

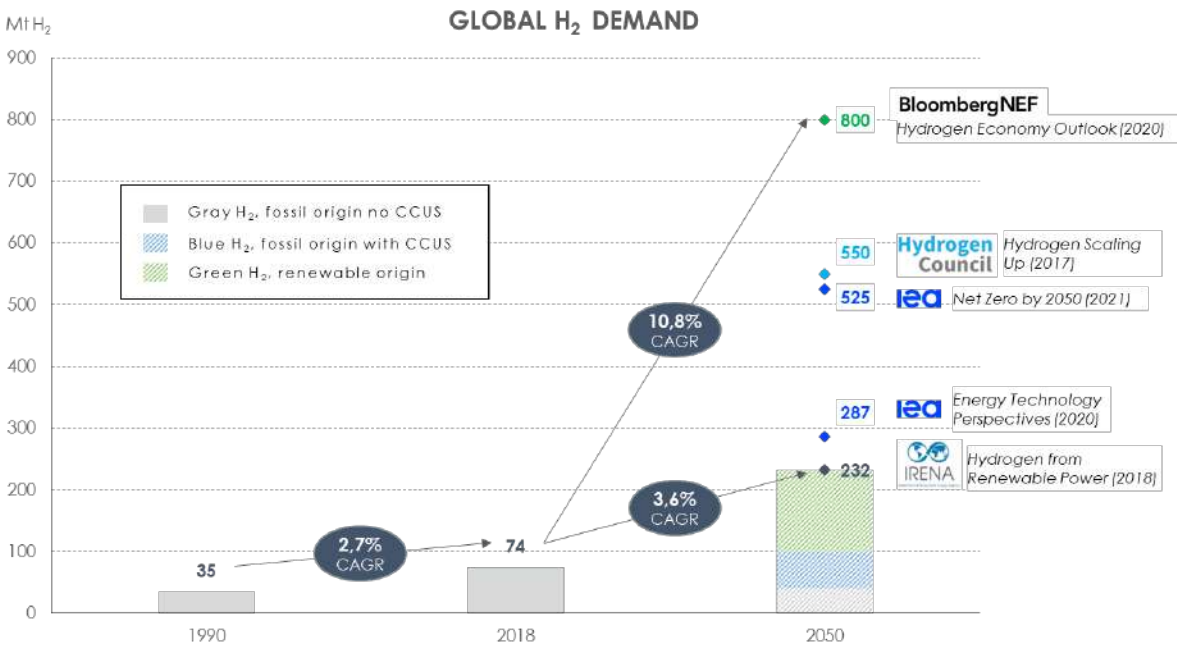

Figure 1: Global Hydrogen Demand[13]

New global demand will be driven mainly by hydrogen's potential new uses. In the transportation sector, hydrogen emerges as an alternative to replace fossil fuels, providing significant advantages in terms of range and filling times compared to electric battery-operated vehicles. Similarly, in order to reduce industrial CO_2 footprints, low-carbon hydrogen will replace fossil fuels in the provision of high-temperature industrial heat and as feedstock in some processes, such as refining, steel production and other minor industrial uses (chemical industry, glass production, grease and oil processing, explosives manufacturing for mining, etc.). In the electricity sector, hydrogen will facilitate better integration of non-conventional renewable energies and enable the requisite seasonal energy storage, thus reducing the impact of variability in power generation with non-manageable renewable sources. Finally, hydrogen can replace fossil fuels used to provide heating and hot water in both residential and commercial buildings. Across all these applications, hydrogen will be a low-carbon alternative if produced with a reduced CO_2 footprint, thus contributing to achieving several of the UN Sustainable Development Goals (SDGs): 7 – Affordable and clean energy, 8 – Decent work and economic growth, 9 – Industry, innovation and infrastructure, 11 – Sustainable cities and communities, 12 – Responsible consumption and production, 13 – Climate action, and 17 – Partnerships for the goals).

Hydrogen can be transformed into other substances that can have direct applications in industry and mobility, or be considered as alternative energy carriers, including ammonia, methanol and other derivatives, such as synthetic fuels or Liquid Organic Hydrogen Carriers (LOHCs), which are easier to store and transport and are compatible with the existing infrastructure.

Currently, ammonia accounts for 27% of hydrogen consumption[14], with the most important applications being the production of fertilizers and its use in the chemical industry. An annual growth

[11] *Energy Technology Perspectives, IEA (2020).*
[12] *NEO Scenario of New Energy Outlook Scenario, BloombergNEF (2020): Hydrogen Economy Outlook*
[13] *CAGR: Compound Annual Growth Rate*
[14] *IEA (2019): The Future of Hydrogen. Taking into account both pure and blended hydrogen, i.e. 110Mt of total demand.*

of 1.5% is expected up to 2030 as a result of the growing demand for fertilizers driven by population growth, although new additional uses are projected for low-carbon ammonia as a maritime fuel or in power generation.

Alternatively, methanol production consumes 11% of the world's hydrogen[15]. Methanol is used in the manufacture of chemical products and as a transportation fuel. The annual expected growth rate for methanol demand is 3.6% until 2030.

Like other countries, Colombia believes that low-carbon hydrogen and its derivatives will play a key role in meeting its decarbonization goals and serve as a new economic engine for the country. The achievement of these goals will be leveraged on Colombia's differential capabilities, which range from the sustainable use of its natural resources to the existence of a stable regulatory and normative framework committed to decarbonization.

1.2. Colombia's strengths in hydrogen

1.2.1. Abundant natural resources for the production of low-carbon H_2

Colombia enjoys a privileged position in terms of the diversity and availability of natural resources required to meet its current energy needs, laying thus the groundwork for future low-carbon hydrogen production.

First, Colombia has significant oil, natural gas and coal reserves that place it close to fuel self-sufficiency and which could be used for the production of blue hydrogen by capturing, storing and/or utilizing the CO_2 emissions generated.

Natural gas reserves are estimated at around 2,949 Gpc (7.7 years)[16] with the main production fields located in the Llanos Orientales, the Lower Magdalena Valley and La Guajira. In addition, Colombia can import natural gas through the port of Cartagena, with a second plant that will soon begin operations in the port of Buenaventura, thus ensuring the country's long-term supply. With respect to coal, Colombia is the largest producer in Latin America and one of the main exporters worldwide. Proven coal reserves exceed 4,500 Mt,[17] enough to supply the country for more than 50 years. These reserves are located mainly in the departments of La Guajira, Cesar, and some areas in the center of the country. Considering the annual production of both energy sources, Colombia could comfortably supply the national demand for low-carbon hydrogen both in the medium and long term, where CO_2 capture and storage technologies are the key features to be developed in the coming years, in order to exploit these existing resources. In addition, the possibility of developing natural hydrogen reservoirs is being evaluated, although determining their location and potential is still at a very early stage.

Second, Colombia has renewable generation resources comparable to those found in the best locations worldwide. On the one hand, its water supply is six times the world average and three times that of Latin America's. Its orography and precipitation regime present optimal conditions for hydroelectric generation in a large part of the national territory, accounting for 70% of the country's electricity generation.

On the other hand, the vast wind potential in the north of the country and an attractive solar potential in a large part of the territory, together with the significant decrease in the costs of non-conventional renewable technologies, will allow for a rapid deployment of Non-Conventional Renewable Energy Sources (FNCER). The share of Non-Conventional Renewable Energy Sources in the Colombian electricity matrix, which was less than 1% in 2018, will increase to more than 12% by 2022, reaching an installed capacity of 2,800 MW. In particular, some coastal areas in the north of

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[15] *IEA (2019): The Future of Hydrogen*
[16] *Ministry of Mines and Energy (2021)*
[17] *National Mining Agency (2021)*

the country such as La Guajira, Magdalena, or Atlántico possess a combination of renewable resource that ensures a competitive production of green hydrogen. Primarily, wind resources on the coast are comparable in intensity and constancy to those obtainable in offshore conditions with plant capacity factors exceeding 60%. Solar resources are also abundant in these regions where solar photovoltaic technology installations achieve plant capacity factors in excess of 19-20%. These conditions will enable green hydrogen production costs similar to those obtained from fossil sources as of the end of the present decade, and will be competitive on a global scale.

1.2.2. Strategic geographic location and infrastructure

Colombia is located in a strategic geographical enclave. Colombia is the gateway between Central and South America and is linked through transport, distribution and trade networks with five other countries. Its electrical grid is interconnected with neighboring countries and will be extended in the next decade with an additional interconnection with Ecuador and a new line with Panama. Colombia also has a natural gas pipeline network of more than 7,500 km in length and a distribution network that supplies a national demand of 911 MPCD. This network could be reconditioned if necessary for the transport and distribution of hydrogen in the sections connecting production and demand centers.

In addition, Colombia is located between two oceans, a position that situates it as a maritime trade and export node. Colombia has 10 port zones, with Cartagena in the Caribbean and Buenaventura in the Pacific being the most important ports. Most ports have developed infrastructure for the import/export of crude oil and gas that can be reconditioned for the transport and storage of hydrogen and derivatives.

As a result, Colombia could become a hydrogen logistics hub, supplying nearby countries both by sea and land. In addition, the expected competitive costs for low-carbon hydrogen in Colombia will favor exports, which in turn will stimulate trade in other products throughout the hydrogen value chain.

1.2.3. A solid and innovative business ecosystem

Colombia has a dynamic and entrepreneurial business network with extensive experience in the mining industry, oil and gas production, fuel refining, power generation, and the management and transportation of gases. This knowledge and the use of the existing industrial infrastructure are an excellent starting point to accelerate the development of hydrogen production. However, the Colombian industry is much broader and diversified, making it a key player along the entire value chain. In the future, the Colombian business network aims to maximize value capture by extending and diversifying its activities through the production of key equipment and technologies in the hydrogen value chain, as well as by participating in the development and operation of projects. In addition, it will encourage the use of hydrogen to obtain low-carbon products through the transformation industry.

To this end, the Colombian Hydrogen Association has been formed, which brings together business partners interested in fostering the development of the domestic hydrogen industry. The growth and consolidation of this type of associations will generate synergies between companies with the purpose of developing projects that combine production and demand, and will give way to new business and innovation opportunities.

Colombia’s innovative ecosystem will also rely on academia and universities for research activities in new technologies and for training professionals.

1.2.4. Stable political-regulatory climate conducive to hydrogen project development

The National Government is fully committed to the decarbonization of the economy. First, in November 2020, the Office of the President of Colombia and the Ministry of Environment and

Sustainable Development announced the goal of reducing 51% of the country's greenhouse gas emissions by 2030. This commitment is reflected in Colombia's 2050 Strategy, in the update of the Comprehensive Climate Change Management Plan for the mining and energy sector and in the process of updating Colombia's Nationally Determined Contribution, known as NDC, which establishes ambitious actions to address the effects of climate change over the next 10 years.[18] In this regard, in addition to the current carbon tax and the offset system, the implementation of different mechanisms is being evaluated, such as a system of tradable emission quotas, to encourage the use of more sustainable energy sources. The system is expected to incorporate adequate economic signals for the transition from the current demand for hydrogen to different forms of low-carbon production and will open the door to the substitution of fossil fuels for hydrogen in new applications, underpinning new demand.

Colombia's excellent natural resources will allow it to compete in the future with other countries in the low-carbon hydrogen market. However, in order to position itself in this market, Colombia will need to attract domestic and international funding to develop the first commercial projects at both production and local demand levels. In line with the results obtained with the promotion of non-conventional renewable energy projects, the Colombian government has included low-carbon hydrogen, which includes both green and blue hydrogen, in its Energy Transition Law (Law 2099 of 2021), as it is considered a key element in the decarbonization strategy.

Therefore, a further boost to the development of renewable generation projects for the production of green hydrogen is expected, following the trend initiated in 2014 by the approval of Law 1715 and the organization of non-conventional renewable energy auctions, which have accelerated the participation of FNCER in the Colombian energy matrix.

Moreover, the National Government's support for low-carbon hydrogen will also include domestic mining and gas activities through the exploration and exploitation of critical resources in the low-carbon hydrogen value chain. A fair transition will be encouraged through the reconversion of mining and hydrocarbon projects for the generation of low-carbon hydrogen, including the capture, storage and potential valorization of CO_2.

The implementation of the low-carbon hydrogen Roadmap in Colombia will require a substantial effort in public-private investments for the development of low-carbon hydrogen production, transportation and end-use infrastructure, and therefore a framework of attractive, stable and predictable support mechanisms has been established to provide adequate guarantees for investors.

In order to encourage the development of competitive hydrogen projects and facilitate the search for international agreements capable of attracting the necessary investment and technological capabilities, the Energy Transition Law (Law 2099 of July 10, 2021) establishes a favorable fiscal framework for investment in Non-Conventional Energy Sources, thus contributing to the recovery of the economy. Green and blue hydrogen both play a central role therein, as they are considered as FNCERs and FNCEs respectively and the benefits of Law 1715 of 2014 will be applied to both for a period of 30 years. The exemption from payment of customs duties, VAT exclusion, accelerated depreciation and income tax deduction of 50% of the investment, are powerful instruments that help support the competitiveness of low-carbon hydrogen projects and provide security to investors.

At the direct investment level, Law 2099 extends the scope of the Non-Conventional Energy and Efficient Energy Management Fund (FENOGE for its Spanish acronym) to the financing and/or execution of viable projects in the low-carbon hydrogen value chain, regardless of the point in the chain. Such investments will be prioritized according to their impact on emissions reduction in line with the goals set and the creation of wealth and jobs.

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[18] *Ministry of the Environment and Sustainable Development (2020)*

The benefits, incentives and investments provided for in Law 2099 represent a powerful gesture of support and commitment by Colombia to the deployment of low-carbon hydrogen, positioning it as a benchmark country in terms of this new energy vector's future markets.

2. Competitiveness of domestic hydrogen

The Government of Colombia is clearly committed to the decarbonization of its energy matrix while simultaneously encouraging the long-term sustainability and competitiveness of the country's productive capacities. In this sense, low-carbon hydrogen is a lever for a gradual and fair transition towards a carbon neutral economy: first, it allows for the progressive replacement of fossil fuels in those sectors where their substitution by other low-carbon energy sources is particularly complex. Furthermore, it fosters the development of a new value chain that includes the development of knowledge, the industrial deployment of renewable technologies and CCUS as well as the implementation of hydrogen use in various activities.

The first step in the deployment of low-carbon hydrogen is to enhance its competitive production by taking advantage of the country's diverse and abundant natural resources, both in the case of blue and green hydrogen.

2.1. Production of blue hydrogen

Hydrogen produced from the reforming/gasification of hydrocarbons, usually gas and coal, is called gray hydrogen. When CO_2 capture is applied to these processes, together with its utilization or storage, this hydrogen is called blue hydrogen. Colombia has ample reserves of fossil resources, especially abundant coal, which can be used for the production of blue hydrogen.

The expected evolution in Colombia of the levelized cost of blue and gray hydrogen (LCOH[19]) for the next decades is shown in Figure 2, considering the incentives of Law 2099 of 2021. It shows that the costs of blue hydrogen remain practically constant because the cost reduction of CO_2 capture technologies is offset by the increase in gas and coal prices. The LCOH of gray hydrogen, on the other hand, increases progressively due to the impact of the rising costs of CO_2 emissions.

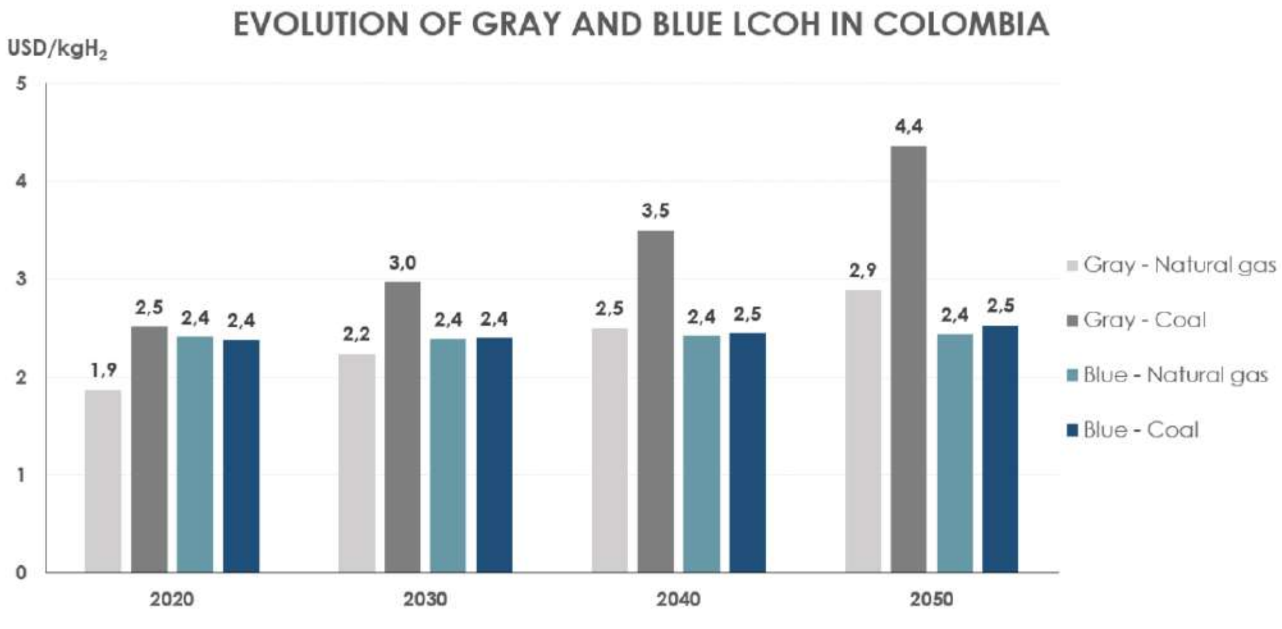

Figure 2: Gray and blue LCOH from natural gas and coal[20]

To offset the additional cost of CO_2 capture and storage, mechanisms are needed to create market signals to stimulate the use of blue hydrogen over gray hydrogen, i.e., moderate or high CO_2 prices

[19] *Corresponds to Levelized Cost of Hydrogen*

[20] *CO_2 emissions generated during the 20-year life span of the project are considered. The model considers a cost of 20 USD/tCO_2, (average international floor price) as of 2023, with a CAGR of 5%.*

are required. In fact, if the cost of CO_2 in Colombia was only 10 USD/ton in 2023 with an annual growth of 5%, the competitiveness of blue hydrogen versus gray hydrogen would not occur until after 2045.

Under current conditions, the value of the carbon tax is expected to reach a range between 6.2 and 11.2 USD/ton CO_2 by 2030, which would restrict the opportunity for traditional sectors such as mining and hydrocarbons to invest in CCUS technologies and thus contribute to the goals set in Colombia's 2020 NDCs. To this end, the government will work on designing additional mechanisms to those currently in place to level conditions in the carbon market, either through the internalization of emissions costs or by providing benefits and incentives to industries that invest in CO_2 capture.

A first option would be the aforementioned implementation of an emissions trading system with moderate or high prices. However, other schemes are also possible and therefore the Government of Colombia will evaluate and analyze the following mechanisms: (i) setting emission quotas for blue and green hydrogen, which can be included in the Colombian tradable quota system defined in Law 1931 of 2018 and the 2020 NDC targets; (ii) identifying and adopting incentives in the tradable quota market for CCUS technologies or other mechanism that encourage compliance with the 2020 NDC; iii) enabling CCUS technologies as an activity to achieve carbon neutrality (regulation under Law 2099 of 2021), which in turn allows the non-causation of the carbon tax; and iv) evaluating a modification of the carbon tax, considering that the price reaches the value of 1 Tax Value Unit (UVT for its Spanish acronym).

Moreover, from a technical standpoint, locations prepared for CO_2 storage must be identified, in addition to ensuring that the technologies and infrastructure required for its capture and transport are available, with the latter being a priority for this Roadmap.

The cost model shown in Figure 2 considers only new construction projects. It is important to highlight that taking advantage of existing infrastructure in the mining, oil and gas industries could lead to even more competitive blue LCOH values that would shorten the lead time required to reach the break-even point between blue and gray LCOH in some industries.

Consequently, blue hydrogen would enable early decarbonization of certain industrial applications, such as in the refining sector. In addition, blue hydrogen production can be implemented in all regions of Colombia where fossil resources are available, supplying local demand and guaranteeing long-term hydrogen supply. In this manner, blue hydrogen is a low-carbon alternative for the progressive transition of the country's mining and gas sectors, while taking advantage of the large reserves of gas and coal and the expert know-how of the Colombian industry. Blue hydrogen will serve as the basis for initiating the expansion of the hydrogen value chain in Colombia, and lead to the large-scale competitive development of green hydrogen.

2.2. Production of green hydrogen

Green hydrogen is the hydrogen obtained from renewable energies. Colombia, taking advantage of its potential for FNCERs, will encourage the production of green hydrogen through electrolysis with renewable electricity as an essential tool in the reduction of emissions.

In addition to having a favorable incentive system for the development of hydrogen projects, Colombia will benefit from the cost reductions of electrolysis and renewable generation technologies, especially solar photovoltaic energy.

To estimate the costs of renewable production, solar and wind resources have been evaluated throughout the Colombian geography, establishing 8 climatic areas.

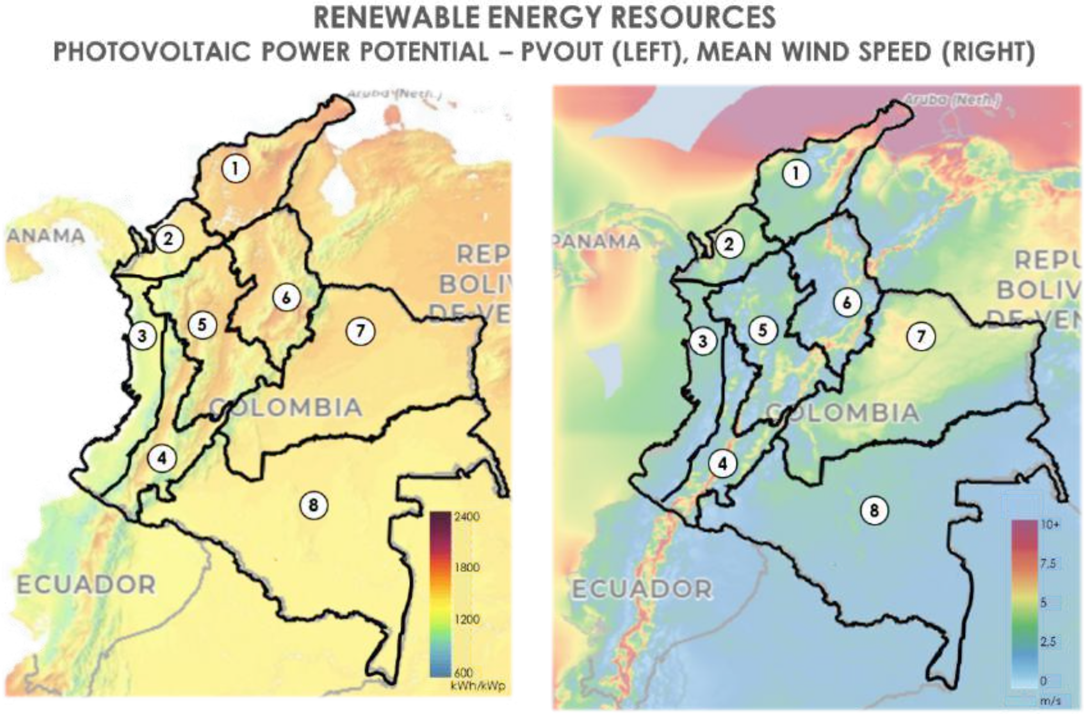

Figure 3: Regions in Colombia divided by renewable energy source[21]

Each region is comprised of several departments or parts thereof:

1. Northern Caribbean Region: La Guajira, Magdalena, Atlántico, Sucre, northern Cesar, northern Bolívar
2. Southern Caribbean Region: Córdoba, northerner Antioquia, northern Chocó
3. Pacific Region: southern Chocó, western Valle del Cauca, western Cauca, western Nariño
4. Southern Andes Region: Huila, eastern Valle del Cauca, eastern Cauca, eastern Nariño , Quindío
5. Central Andes Region: Tolima, Cundinamarca, southern Antioquia, Risaralda, Caldas, D.C.
6. Northern Andes Region: Boyacá, Santander, Norte de Santander, southern Cesar, southern Bolívar
7. Orinoco Region: Vichada, Meta, Casanare, Arauca
8. Amazon Region: Guainía, Guaviare, Vaupés, Caquetá, Putumayo, Amazonas

Figure 4 shows the evolution of LCOH between 2020 and 2050 in different regions of the country, considering the incentives introduced by Law 2099 of 2021. It illustrates that, from 2030 onwards, it will be possible to produce green hydrogen in some regions at a cost comparable to that of blue hydrogen, thus resulting in a robust, reliable and competitive production mix.

The results presented correspond to the renewable capacity factor mode values[22], i.e. those most frequently encountered in each climate region. However, specific areas have been identified where LCOH values may be even more competitive.

[21] *Separation by climate zones based on the analysis of the competitiveness of low-carbon hydrogen developed for the Colombia Roadmap. Image background obtained from the Global Solar Atlas and Global Wind Atlas.*

[22] *Mode: statistical term to define the value that appears most often in a data set.*

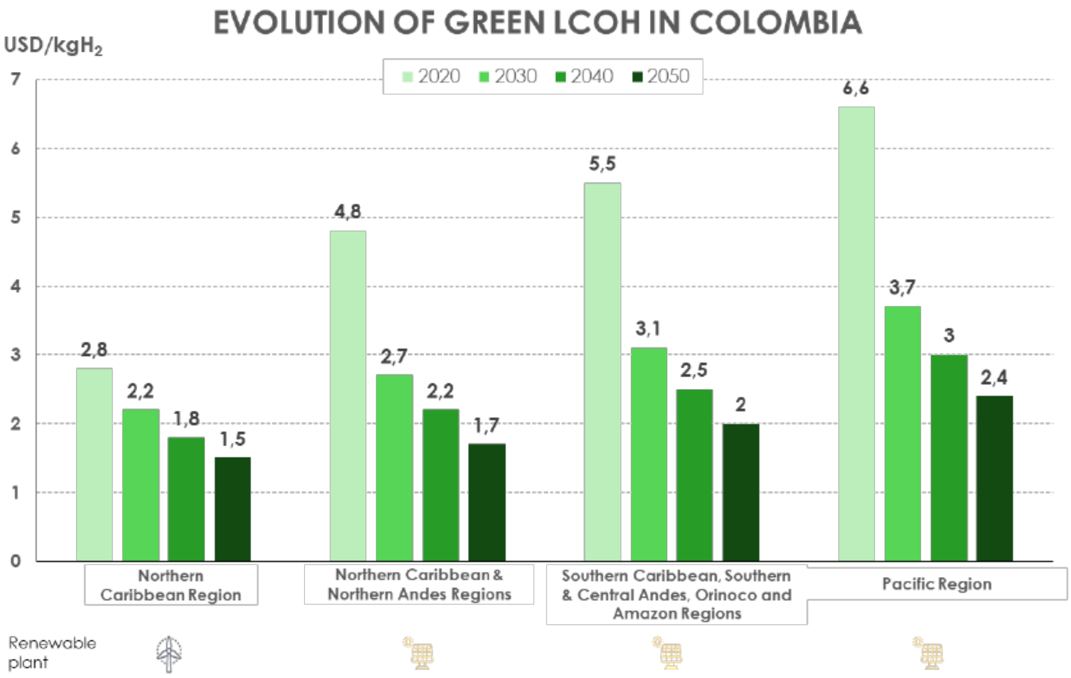

Figure 4: Green LCOH with renewable mode capacity factor by region

In fact, there are significant wind resources in certain areas of the Northern Caribbean region, reaching plant factors of up to 63% in the department of La Guajira, which are comparable to those found in the best areas of the world. Additionally, very competitive solar energy production costs can be achieved, reaching plant factors of 21% in the Northern Caribbean and Northern Andes regions.

Therefore, the selection of areas with high plant factors will be key in the short term to reduce costs by up to 25% in the development of renewable projects dedicated to the production of green hydrogen, as shown in Figure 5.

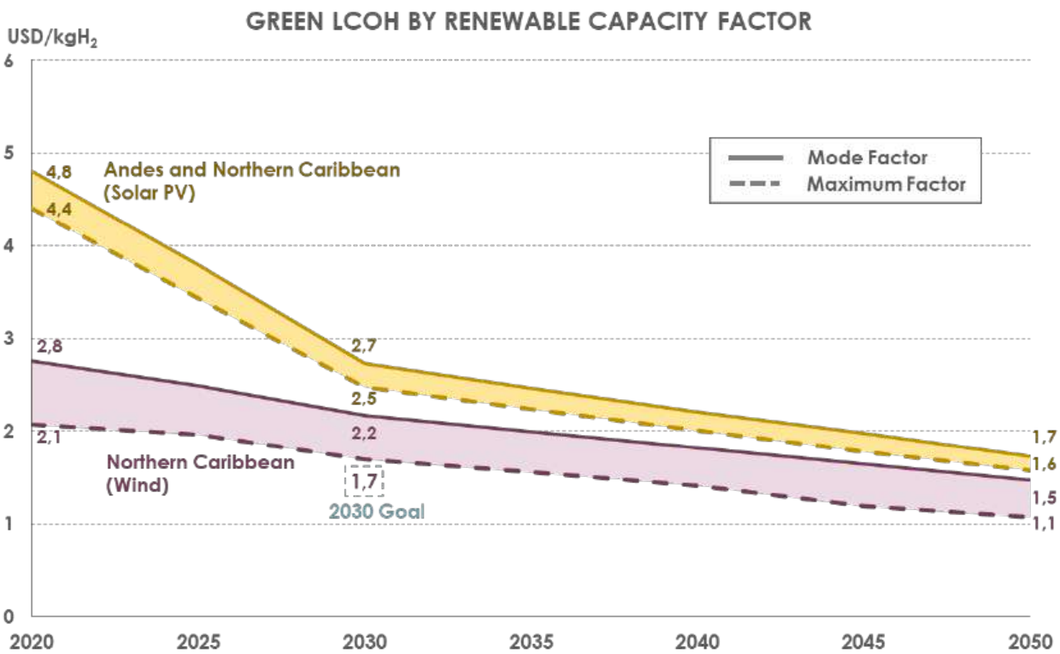

Figure 5: Green LCOH according to renewable mode and maximum capacity factors

The more competitive costs achieved through the use of wind energy in the Northern Caribbean are comparable to those of other reference countries. Thus, for example, the LCOH value obtained in 2030 of 1.7 USD/kg is very similar to the goals established in the strategies of relevant countries in terms of hydrogen, such as Australia and Chile, thus positioning Colombia as a significant actor in the global hydrogen market of the future.

The country's solar resources can also be harnessed in many regions in order to supply domestic demand, especially after 2030, when a significant reduction in costs for solar photovoltaic technology is expected.

Until such time, power production from plants dedicated to the generation of hydrogen can be complemented by grid power in all connected regions, exploiting the country's significant water resources and allowing further decentralization of projects in the first phase of hydrogen deployment. In fact, the analyses carried out show that grid hydrogen could contribute to the reduction of LCOH values, although this result is obtained only in the areas with the lowest renewable resource and only during the next decade. Therefore, the use of grid energy is expected mainly in the first pilot projects with the aim of encouraging an initial deployment of new demand that, due to its characteristics, can be covered with decentralized production plants. In addition, detailed studies will be carried out on the use of large hydroelectric power plants, evaluating the potential of this conventional renewable energy source in the production of green hydrogen.

Finally, renewable solar and wind power plants dedicated to the production of green hydrogen can be combined with other Non-Conventional Renewable Energy Sources such as geothermal or biomass to make the most of synergies in regions where these resources are available.

2.3. Evolution of the competitiveness of low-carbon H_2 in Colombia

Considering the different cost evolution perspectives of low-carbon technologies and Colombia's natural resources, low-carbon hydrogen is expected to progressively prevail in different applications. The comparative evolution of both blue and green LCOH is shown in Figure 6.

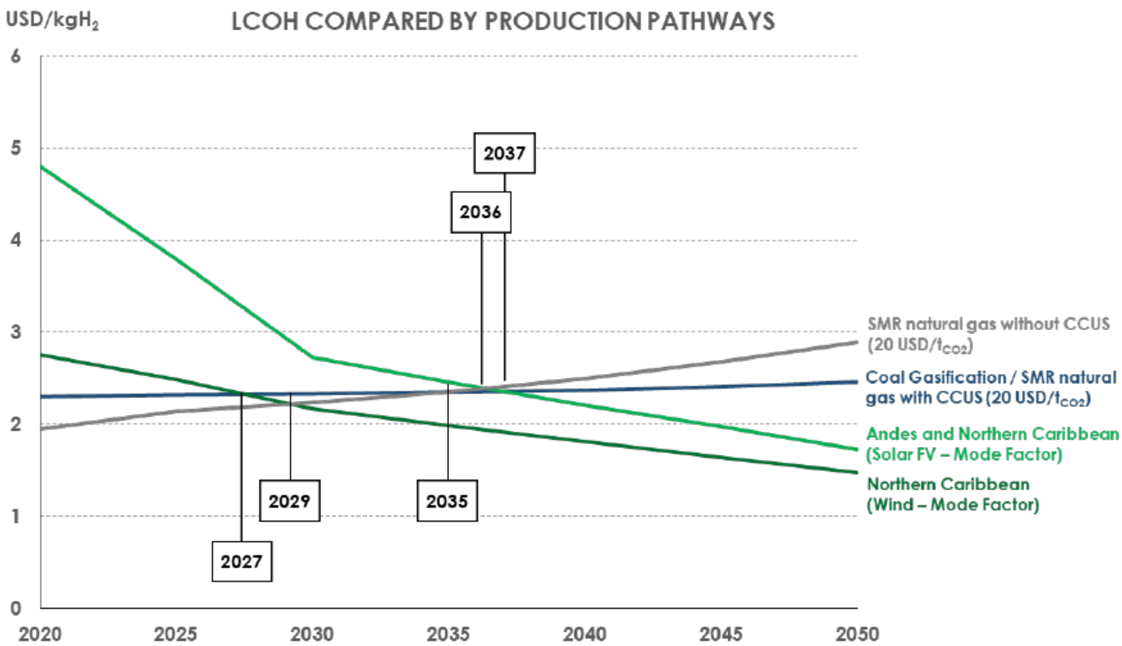

Figure 6: LCOH compared by production pathways[23,24]

[23]*Only the curve of blue H_2 from natural gas is shown, since the curve obtained from coal is similar.*
[24] *Green LCOH shown with the renewable mode capacity factor in the two most competitive regions*

For comparison purposes, the renewable mode capacity factor of the Northern Caribbean and Northern Andes have been considered as a reference for green hydrogen and a scenario of average CO_2 prices to show the evolution of blue hydrogen. The results obtained indicate three main phases of low-carbon hydrogen deployment between 2020 and 2050:

- In the short-term, blue hydrogen is the most favorable low-carbon option, especially if existing industrial infrastructures are exploited. However, as early as 2030, green hydrogen production in the areas with the best wind resources in the country (Northern Caribbean) becomes the most competitive alternative.
- Between 2030 and 2040, the coexistence of blue and green hydrogen is expected according to the natural resource available for production in each region of Colombia. In fact, from 2035 onwards, blue H_2 (from coal gasification or NG reforming) would be more competitive even than gray H_2 due to the increase in CO_2 prices and the decrease in the cost of capture technologies.
- From 2040 onwards, green H_2 will be the most competitive alternative nationwide.

The three phases of deployment can be seen in Figure 7, which also shows the most competitive low-carbon LCOH (USD/kgH_2) by region.

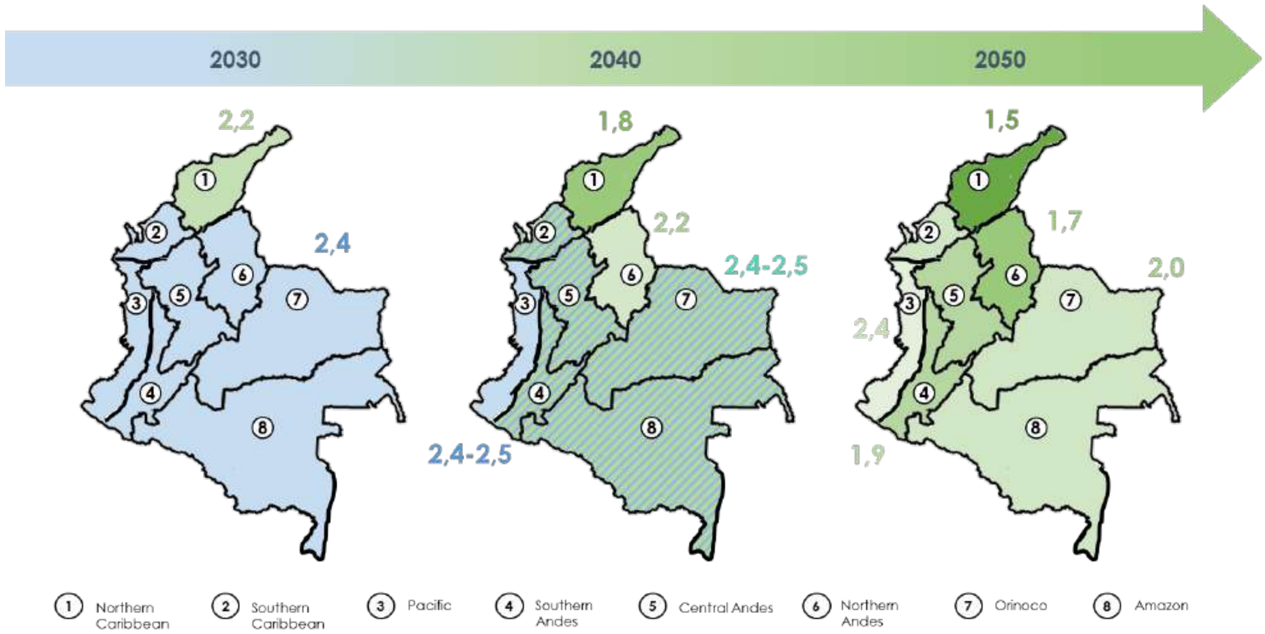

Figure 7: Competitiveness of low-carbon hydrogen in Colombia by region

Blue hydrogen has a limited window of opportunity in the short/medium term, although its use can contribute towards the decarbonization of important industrial sectors. In addition, early production of blue hydrogen could also facilitate the overall deployment of hydrogen as an energy vector in the country through the development of transport, distribution and storage technologies, as well as solve technical challenges associated with CO_2 capture, transport and sequestration in Colombia.

Green hydrogen will be the benchmark production pathway to supply the demand for low-carbon hydrogen in the long-term. Likewise, the international competitiveness of the costs obtained in the Caribbean coasts will enable the creation of a new export market that will transform the domestic trade balance towards lower-emission energy sources.

3. Domestic demand and export of hydrogen and derivatives

Hydrogen is currently consumed globally as feedstock in various industrial activities including refining, the chemical industry and the iron and steel industry. In fact, in Colombia, the annual demand for hydrogen, estimated at 150 kt, is produced by reforming natural gas (gray hydrogen) and is primarily consumed in refineries. The remaining demand is distributed between the production of fertilizers and other minor industrial uses, such as the production of float glass or the processing of fats and oils for food, where electrolytic hydrogen produced using electricity from the grid is also used.

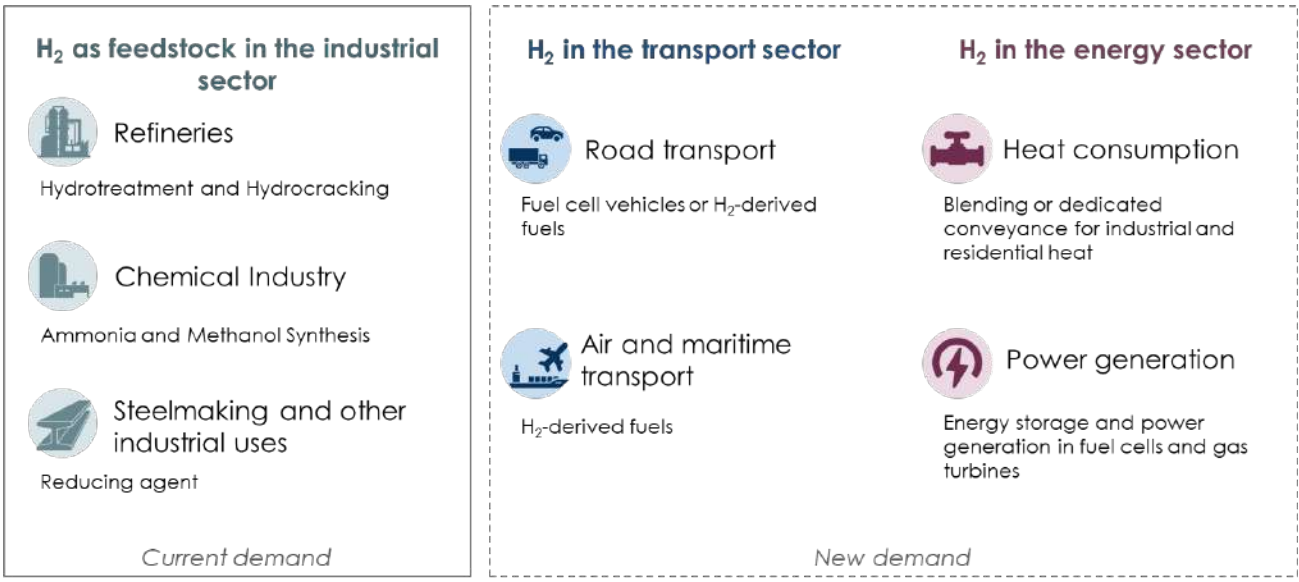

Figure 8: Main current and future applications of hydrogen

However, low-carbon hydrogen is considered a new key energy vector in the transformation and decarbonization of the Colombian economy. First, hydrogen and its derivatives offer opportunities for the modernization and development of multiple industrial applications, in addition to replacing fossil fuels in other sectors such as transportation or power generation.

Internationally, Colombia will be part of a new energy market that encompasses both nearby Latin American countries and the great centers of demand for low-carbon hydrogen in other continents, thus contributing to its global exposure.

3.1. Expected demand for low-carbon hydrogen and derivatives

In the future, new uses of hydrogen and its derivatives will lead to an exponential increase in the total demand for low-carbon hydrogen in Colombia between 2020 and 2050. The main sources of demand will be the transport and industry sectors, although the relative share of each sector varies over time as shown in Figure 9.

In the short term, moderate growth in new low-carbon hydrogen demand is expected to reach 120 kt by 2030, including both a partial replacement of the 150 kt of gray hydrogen consumed today and some new uses. Industrial demand will be the first to develop, motivated by the decarbonization of processes that currently consume hydrogen in Colombia: fuel refining and the production of fertilizers. Additionally, the demand from the transportation sector is estimated to start in 2026, primarily in heavy-duty road transport (buses and trucks).

By 2040, the transport sector will experience strong growth, with demand matching that of the industrial sector. During this decade, the first projects related to the use of low-carbon hydrogen in other industries and in power generation are also expected to appear.

Between 2040 and 2050, new uses of low-carbon hydrogen will be consolidated in Colombia, with domestic demand estimated at approximately 1,850 kt by 2050. The transport sector will account for 64% of total demand, i.e. 1,180 kt of hydrogen. This considerable increase will be due both to the emergence of low-carbon hydrogen in air and maritime transport and to the increased demand by road transport. In the industrial sector, new uses of low-carbon hydrogen are evenly distributed between the fertilizer, mining and steel sectors, while refining remains the subsector with the highest demand. Finally, demand in the electricity sector continues to represent a relatively small percentage (around 2% of total hydrogen demand) equivalent to 37 kt by 2050.

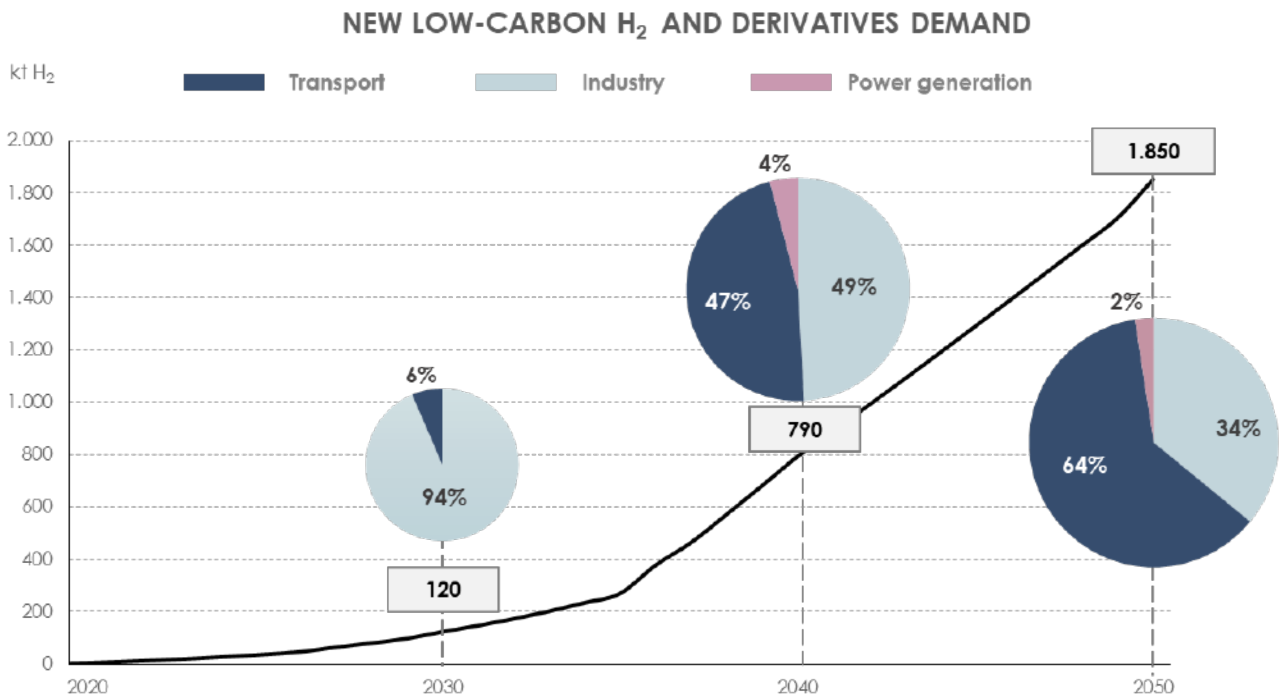

Figure 9: Expected evolution of new low-carbon hydrogen and derivatives demand in Colombia

The demand for low-carbon hydrogen contemplates both the demand related to the direct use of hydrogen and the production of hydrogen derivatives, which allow the decarbonization of some applications where pure hydrogen is not as competitive or presents difficulties in its transportation and distribution.

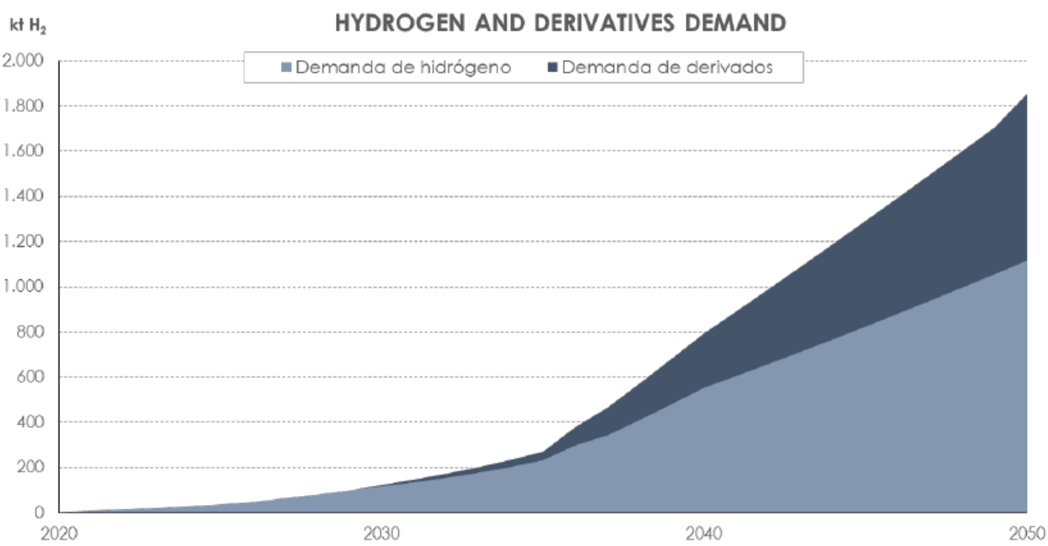

Figure 10: New low-carbon hydrogen and derivatives total demand in Colombia

According to the results obtained, 40% of the total hydrogen demand in 2050, i.e. 740 kt of hydrogen, will be used to supply the production of low-carbon derivatives, mainly in the form of ammonia and synthetic fuels (Figure 10). The ammonia will initially be used in the production of fertilizers, thus reducing Colombia's imports in this area and boosting the local industry. In addition, low-carbon ammonia will transform the demand for fuels in maritime transportation by substituting fossil fuels. Similarly, in air transportation, the lack of alternatives to mitigate emissions will force the use of synthetic fuels.

The expected penetration of hydrogen in each subsector mentioned is summarized in Figure 11**Error! Reference source not found.**. Two factors have been considered in determining the starting year for the use of low-carbon hydrogen for each application: first, the year in which break-even is expected to occur has been calculated, i.e., the year in which the use of hydrogen is competitive with the conventional fossil alternative. Furthermore, not only is cost competitiveness taken into account, but also the development of knowledge and maturity in the implementation of hydrogen technologies for each application, driven by pilot projects and demonstrations conducted by Colombian companies.

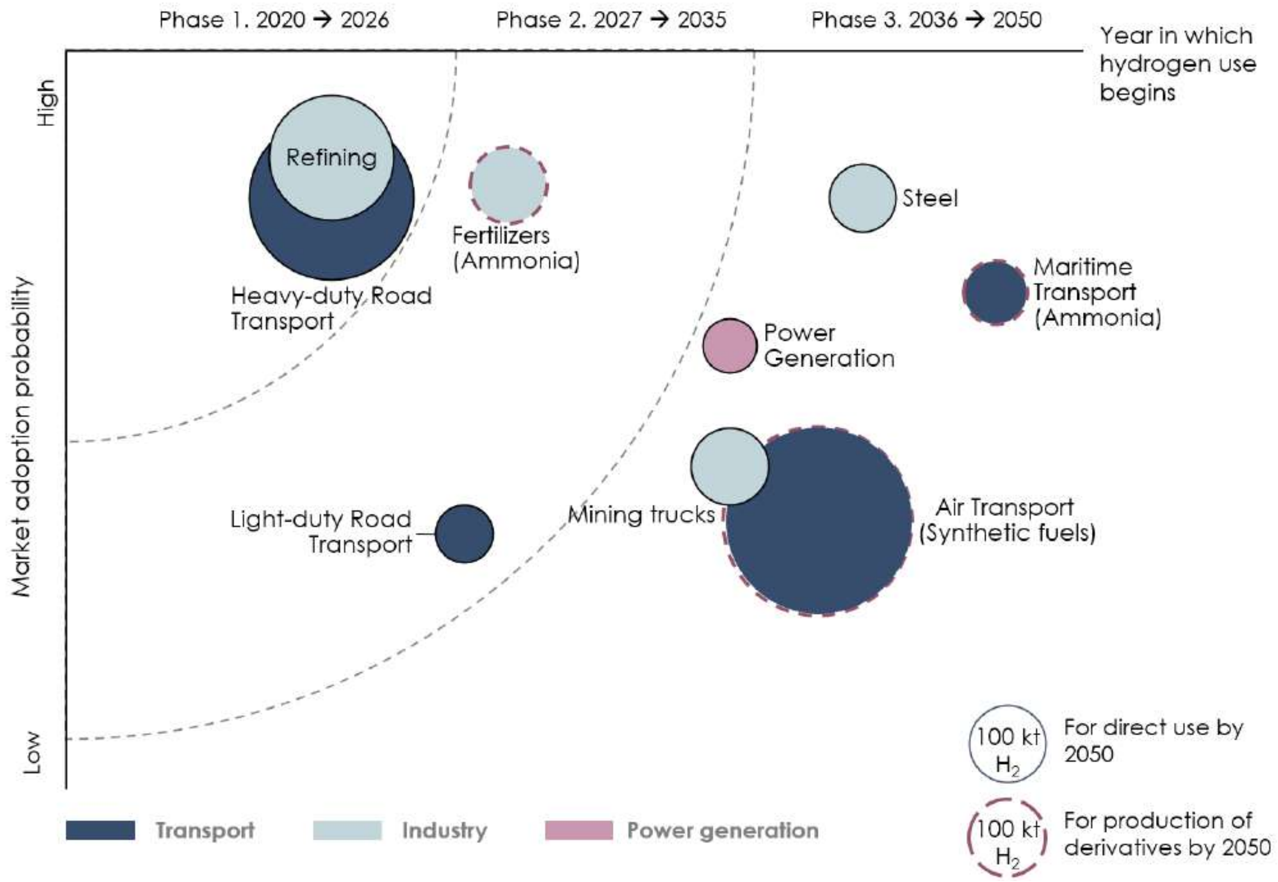

Figure 11: Development of low-carbon hydrogen applications in Colombia

The vertical axis shows the probability of adoption, which depends on technological maturity, the difficulty of developing the value chain and the existence of more competitive alternatives than hydrogen to decarbonize the application. The diameter of the circles represents the expected hydrogen demand in 2050 for each use.

Hydrogen penetration by application will occur in three distinct phases based on the probability of the hydrogen market adopting each end-use:

- **Phase 1. Existing applications (2020 → 2026):** Low-carbon hydrogen will begin to be consumed in refineries as a replacement for gray hydrogen. Some of this hydrogen will be blue hydrogen derived from the implementation of CO_2 capture and storage in existing natural gas steam reforming plants. This phase will also see the penetration of hydrogen in the heavy-duty road transport sector (trucks and buses) which currently has a relatively small demand (0.4 kt in 2026), yet will begin to gain traction through pilot projects and specific cases of use (e.g. decarbonization of public transport).

- **Phase 2. Emerging applications (2027 → 2035):** Hydrogen will begin to be competitive and used in new sectors. This phase will see the entry of applications with the capacity to foster Colombian industry: the production of low-carbon nitrogen fertilizers that will reduce current imports. In addition, the decrease in costs of green hydrogen will lead to the entry of light-duty transport vehicles starting in 2029.
- **Phase 3. Disruptive applications (2036 → 2050):** This last phase will see a major deployment of hydrogen in the above applications, as the use of green hydrogen will become more competitive than fossil alternatives. In parallel, new opportunities will open up for hydrogen, which will begin to be in demand for applications that are currently technologically immature. These new applications will make it possible to decarbonize new sectors such as maritime and air transport through the use of derivatives. Hydrogen is also expected to enter the power generation sector as a flexible seasonal storage method in the face of a major deployment of FNCERs and their subsequent use in combined cycle plants powered by hydrogen or fuel cells. In the industrial sector, in this third phase, hydrogen would be used in the production of primary steel by direct reduction (DRI), or in the mining industry through the use of fuel cell mining trucks.

In conclusion, refining and heavy-duty road transport are the applications that will first reach cost parity with their fossil alternative (before 2030). Therefore, these applications will be a priority when it comes to deploying new hydrogen projects, as they will help drive new demand and contribute to decarbonization in the short term.

3.2. Emission abatement associated with hydrogen use

The introduction of low-carbon hydrogen in processes in which it replaces fossil fuels or feedstocks will contribute to the reduction of domestic CO_2 emissions. In the case of Colombia, the introduction of low-carbon hydrogen can reduce more than 13 Mt of CO_2 by 2050, which would represent about 14% of all emissions from energy uses and industrial processes in 2019 (99 Mt of CO_2).

Aligned with the distribution of hydrogen demand, most of the emission reductions correspond to the transport and industry sectors.

By 2030, the abated emissions will be primarily due to the penetration of hydrogen in the industrial sector, while the transport sector will play a secondary role. However, this distribution changes over time, with transport accounting for 70% of the abatement in domestic emissions as a result of hydrogen use by 2050 (Figure 12).

In fact, in the long term, air transport will become the subsector that accounts for the greatest abatement in emissions (5050 kt of CO_2 reduced by 2050) due to its high carbon intensity and the few alternatives that exist to decarbonize it. Secondly, road transport, mainly heavy-duty transport (trucks and buses), can achieve an abatement of up to 4100 kt of CO_2 by 2050.

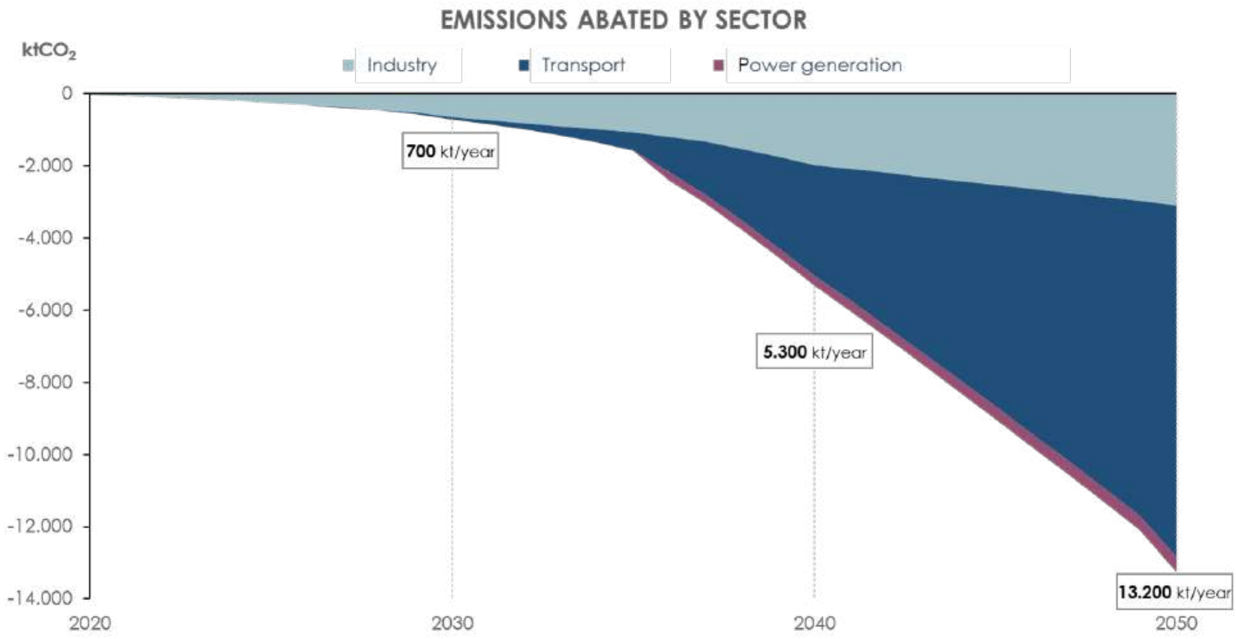

Figure 12: Emission abatement in Colombia as a result of H_2 consumption by sector

In the industrial sector, the refining sector is positioned as the third sector with the greatest reduction in emissions, and could reach 1,700 kt of CO_2 by 2050. These three sectors are clearly the dominant players in terms of emission reductions and should therefore be the prioritized sectors.

3.3. Potential for export

Colombia aspires to become a benchmark in the global hydrogen economy primarily because of its exceptional renewable resources and the government's determination to foster their deployment. Therefore, Colombia will begin to compete in the international low-carbon hydrogen markets, reaching an export potential comparable in revenue to its current coal exports (more than 5 billion dollars) in the long-term.

Three major regions have been identified where hydrogen demand will be concentrated and which are expected to import part of this demand (Figure 13). Asia will be the main focus of hydrogen demand, with a total demand of more than 190 Mt by 2050 and with relevant import needs both in absolute terms (China) and in terms relative to its total demand (Japan, Korea and India). In particular, Japan is currently developing projects to validate the hydrogen supply chain from other regions and expects to import both green and blue hydrogen.

The European Union will generate a demand for approximately 60 Mt of hydrogen by 2050, which will be satisfied through local production and exports from nearby countries (Morocco, Norway, etc.) and eventually by other exporting countries such as Colombia.

Finally, hydrogen demand in the United States could also reach 60 Mt of hydrogen by 2050. However, good renewable resources can be found in many regions of this country, it has abundant and competitive fossil resources and its constant commitment to energy independence suggest that, if there is a demand for hydrogen imports in the United States, it will be small in relative terms to its total expected demand by 2050.

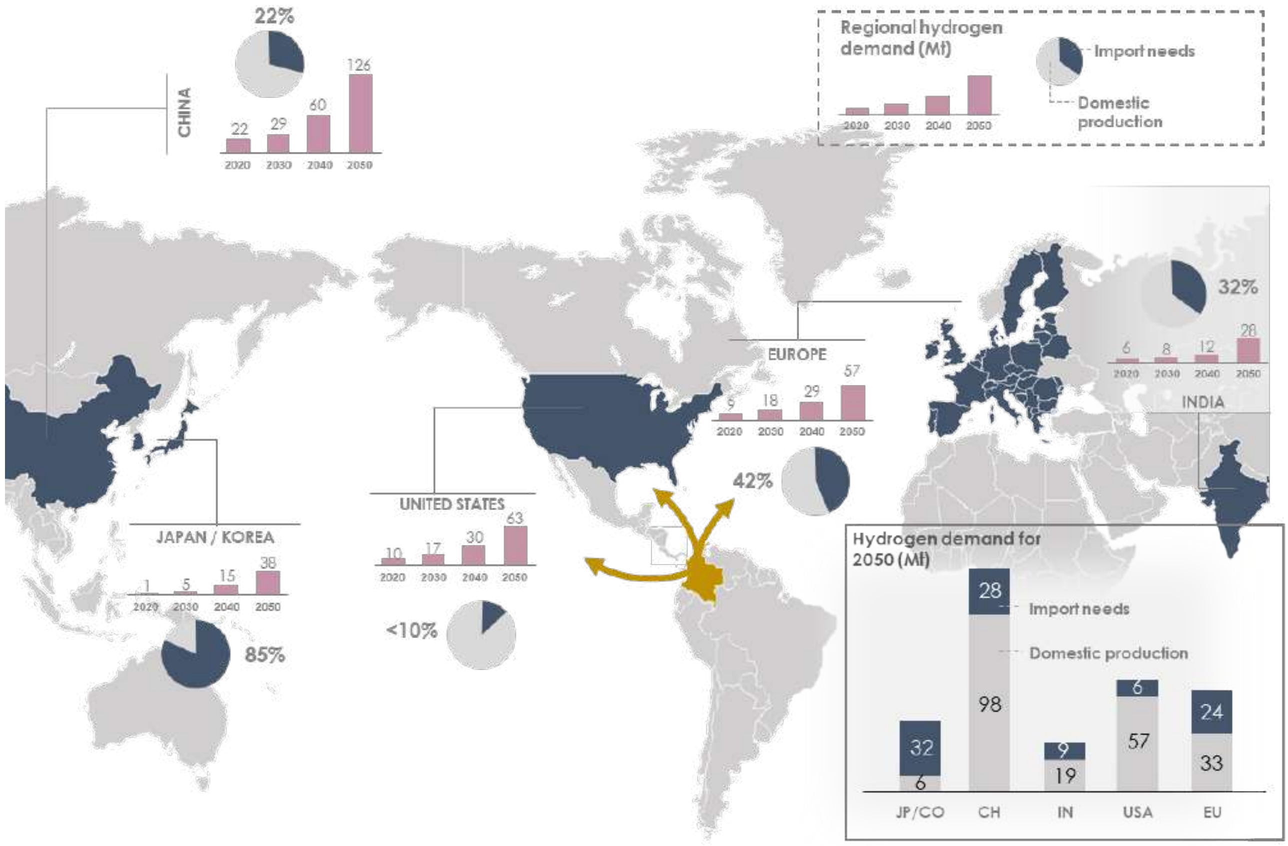

Figure 13: Main centers for global hydrogen demand [25]

While Colombia can take advantage of its abundant fossil reserves, hydro and FNCER resources to satisfy domestic hydrogen demand, in the north of the country there is an ambitious plan to create a logistical export hub, taking advantage of the region's outstanding wind and solar potential, especially the very high-quality wind resource on the La Guajira peninsula. The Caribbean hydrogen export hub will be able to serve hydrogen demand in both Atlantic and Pacific markets. This hub is strategically located close to North America, it has direct access to European markets through the Caribbean and access to Asian markets, either through the Panama Canal or from Colombian Pacific ports via pipeline. Colombia is also ideally positioned to serve the hydrogen demands that may develop in Central American countries.

Colombia will expand existing port infrastructure and seek bilateral agreements with importing countries to position Colombia as a strong player in the world markets for low-carbon hydrogen and its derivatives.

[25] *Map prepared by i-deals through the analysis of the hydrogen strategies published by the different countries and regions.*

4. Horizon 2030 and 2050

4.1. Pillars of Colombia's Hydrogen Roadmap

The strategy is based on five pillars that pursue the social, environmental and economic development of Colombia, and are the result of collaborative work by multiple public and private players.

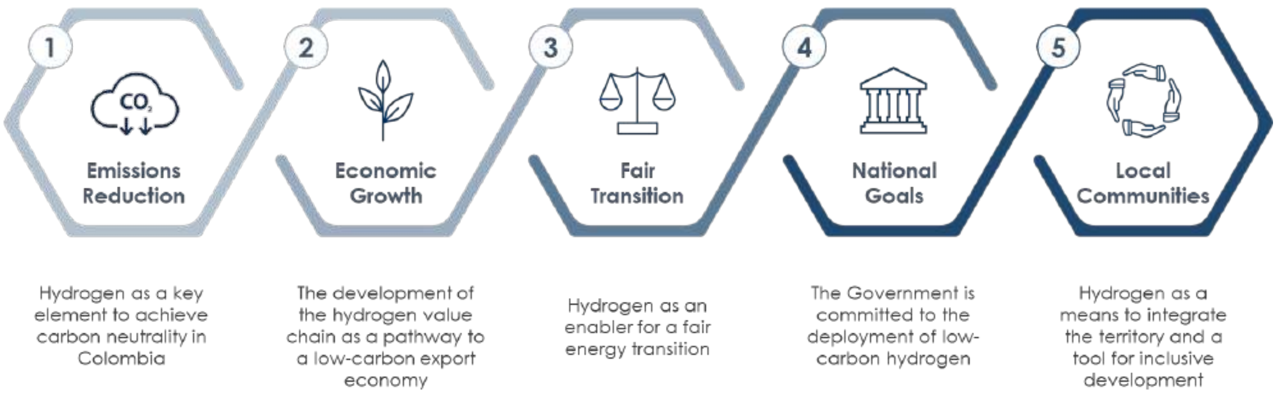

Figure 14: Pillars of Colombia's Hydrogen Roadmap

1. Hydrogen as a key element in achieving carbon neutrality in Colombia

Colombia has committed to an ambitious goal of achieving carbon neutrality by 2050 and will begin this process during the next decade. Low-carbon hydrogen and its derivatives will be an important tool available for the decarbonization of the economy and its deployment will be based on cost-benefit considerations. Hydrogen will have a place in applications where electrification is not feasible or where there are no other suitable energy sources from a cost, environmental or technical point of view. Applications such as long-distance heavy-duty transport, air and sea transport, as well as various industrial sectors will benefit from these fuels.

Green hydrogen will also facilitate the deployment and integration of greater FNCER generation capacity, favoring a sustainable economy, facilitating system management and enabling energy transportation and storage.

2. The development of the hydrogen value chain as a pathway to a low-carbon export economy

Colombia boasts locations were natural resources for renewable energy production comparable to the best in the world are readily available, as well as a very strategic geographic position between two oceans and maritime routes to all continents. This will allow Colombia to compete in a global market in which large industrial economies will import low-carbon hydrogen to meet their decarbonization goals. This will require cooperation with these countries in order to gain access to technology, training and investment that will position Colombia in an incipient market.

The export of fossil fuels is one of the pillars of Colombia's trade balance. However, the global transition to a low-carbon economy will lead to a progressive reduction in the export of fossil fuels to major international customers as well as in their local use. The production and export of hydrogen, by taking advantage of Colombian natural resources, will progressively compensate for the decrease in the weight of traditional energy sources in our economy.

Hydrogen will attract investments and generate new jobs so that decarbonization will boost the Colombian economy. The Government and the authorities will take advantage of hydrogen not only for export, but also for the development of new domestic industrial capacity.

Colombia can attract opportunities within technological value chains by manufacturing equipment for hydrogen production, transportation, storage and transformation through international cooperation. In addition, the use of hydrogen produced at low cost in Colombia opens the door to the development of low-carbon industries that use hydrogen in their processes.

Fostering innovation and research, supporting local industry and attracting investment will be key to maximizing wealth and job creation by extending the hydrogen value chain and creating industrial clusters.

3. Hydrogen as an enabler for a fair energy transition

Low-carbon hydrogen provides an opportunity to ensure a fair transition, designed to maintain jobs in sectors impacted by decarbonization and involve the territories, communities, cities, academia and companies in the process, while opening new doors for the creation of new industrial structures that will benefit from the competitiveness of hydrogen produced in Colombia.

The deployment of the low-carbon hydrogen industry in mining and oil regions will benefit from the use of existing infrastructures and professional capacities, allowing for a fair and balanced transition. Similarly, green hydrogen opens up opportunities for local development in new regions with high potential for renewable energy production, contributing to a balanced and cohesive economic development between territories.

4. The Government is committed to the deployment of low-carbon hydrogen

The Government is committed to the deployment of low-carbon hydrogen as a driver for economic, social and environmental development. We are in the early stages of creating this industry at a global level and a regulatory and incentive framework must be defined to encourage the implementation of the first pilots.

The Government will develop a transparent and stable regulatory and normative framework in the short-term, together with an incentive strategy. In addition, integrated infrastructure planning will be undertaken to enable the first deployments. These initiatives will involve the private sector, academia and civil society as key players in launching the industry in Colombia.

5. Hydrogen as a means to integrate the territory and a tool for inclusive development

The development of the hydrogen economy will place communities at its heart from the outset, taking into account their current situation, needs, aspirations and capabilities. The Government and local authorities will implement a socialization plan that communicates the potential of hydrogen as a means of economically transforming communities through balanced generation of wealth and employment while training personnel and protecting natural resources, people and the environment.

Communities will be involved in the discussion surrounding the opportunities presented by FNCERs in general, and hydrogen in particular, placing them at the center of territorial and economic planning. The discussion will also involve the sponsors to define the best practices for local economic development favoring the shared creation of value.

4.2. 2030 Goals

The Colombian Government has set ambitious national goals for 2030 for both production and demand, the achievement of which will make it possible to develop the technical and industrial capabilities and the necessary experience to harness the full future potential of hydrogen. The main instruments for achieving the goals set for 2030 are the measures described in the action lines detailed in the following chapter.

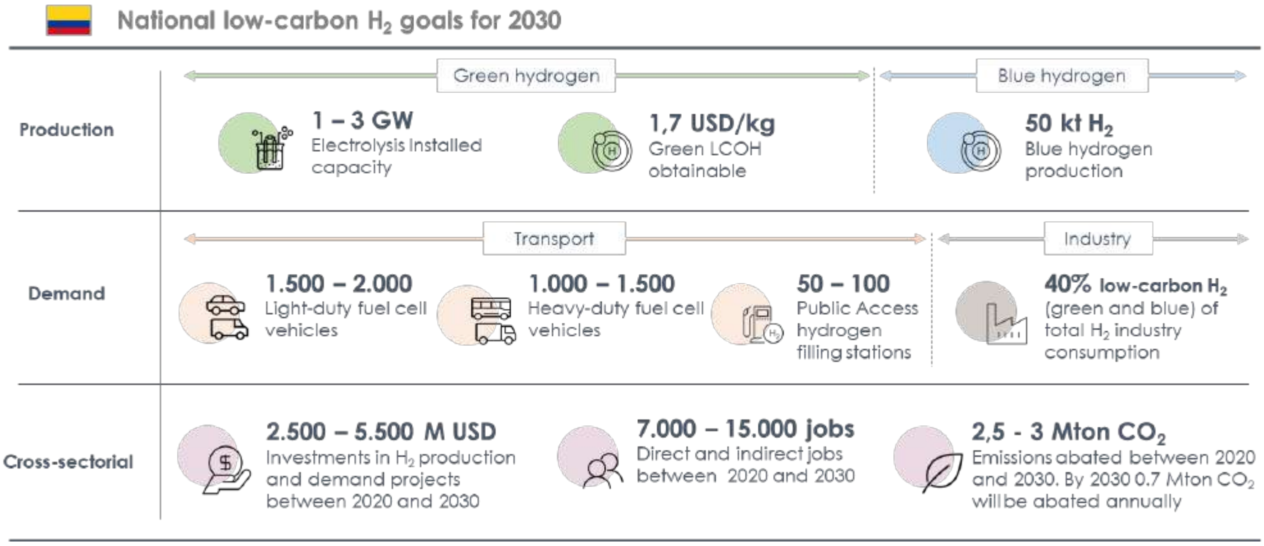

Figure 15: National Hydrogen Goals for 2030

In terms of the **production of low-carbon hydrogen**, expectations for 2030 include the following:

- Develop between **1 and 3 GW of electrolysis capacity** in regions with high renewable resources such as La Guajira, as well as in places close to where consumption takes place in order to minimize transportation costs, thereby implying the installation of at least 1.5 - 4 GW of FNCER throughout the country. Reaching this installed electrolysis capacity will also allow Colombia to position itself as a hydrogen exporting country.
- Achieve competitive **green hydrogen** production, realizing costs of 1.7 USD/kg when produced in optimal renewable resource areas (see Figure 5).
- Produce at least **50 kt of blue hydrogen** by capturing CO_2 in existing SMR plants or new plants (SMR or gasification) for storage or use.

Regarding **hydrogen demand**, substantial penetration is expected in industrial sectors, mainly in refining, and chemical and fertilizer industries, as well as initial demand in the road transport sector. By 2030 these sectors are expected to reach:

- A fleet of at least **1,500 - 2,000 light-duty fuel cell vehicles** for passenger and cargo transportation. The development of hydrogen filling stationsl in large population centers is considered essential, encouraging the acquisition of hydrogen vehicles for long-haul applications such as cabs or delivery vans.[26]
- A fleet of at least **1,000 - 1,500 heavy-duty fuel cell vehicles** for passenger and freight transport. Focus will be placed on the deployment of hydrogen filling stations on high traffic routes connecting cities in the country, encouraging the adoption of this technology by freight and passenger transport companies. In addition, as a result of the National Electric Mobility Strategy,[27] a significant participation of hydrogen in the country's fleet of inter-municipal buses is foreseen.
- A network of at least **50 - 100 public access hydrogen** fueling stations for the above vehicles. These stations will be concentrated in large population centers and commercial routes, guaranteeing a high demand for hydrogen and its economic viability.
- Consumption of **40% of low-carbon hydrogen in the industrial sector** within the total hydrogen currently consumed by this sector, considering hydrogen consumption as feedstock and its use as an energy source.

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[26] *This goal is complementary to the goals already established for the entry of battery electric vehicles.*
[27] *By 2035, 100% of public vehicles purchased for mass transportation will be electric or zero-emission.*

The aforementioned goals will enable three cross-sectional objectives:

- Mobilize between **2.5 and 5.5 billion dollars in investments** during the 2020/30 period, with the lower range corresponding to the 1 GW goal for 2030 and the higher range to the 3 GW goal. These investments will originate primarily from the private sector, although public support will be provided where needed.
- The above investment will generate a multiplier effect throughout the hydrogen value chain in terms of wealth and job creation. In particular, **between 7,000 and 15,000 direct and indirect jobs are expected to be created** during the 2020/30 decade thanks to the development of hydrogen production, demand and transport projects.
- Contribute to the decarbonization of Colombia with the **reduction of 2.5 - 3 million tons of CO_2** during the 2020/30 period thanks to the use of low-carbon hydrogen for transportation and industry. In addition, it is estimated that approximately 0.7 million tons of CO_2 emissions will be avoided annually by 2030.

4.3. 2050 Ambition

Colombia's long-tern national strategy is divided into two main periods:

- **2020-2030 period**: Low-carbon hydrogen penetrates only the most competitive applications. This period is highlighted by close public-private collaboration that will enable and encourage market development.

- **2030-2050 period**: Hydrogen is competitive in many applications, triggering a large increase in demand both domestically and internationally. During this period export to other geographies begins and applications with a current lower technological maturity will be enabled.

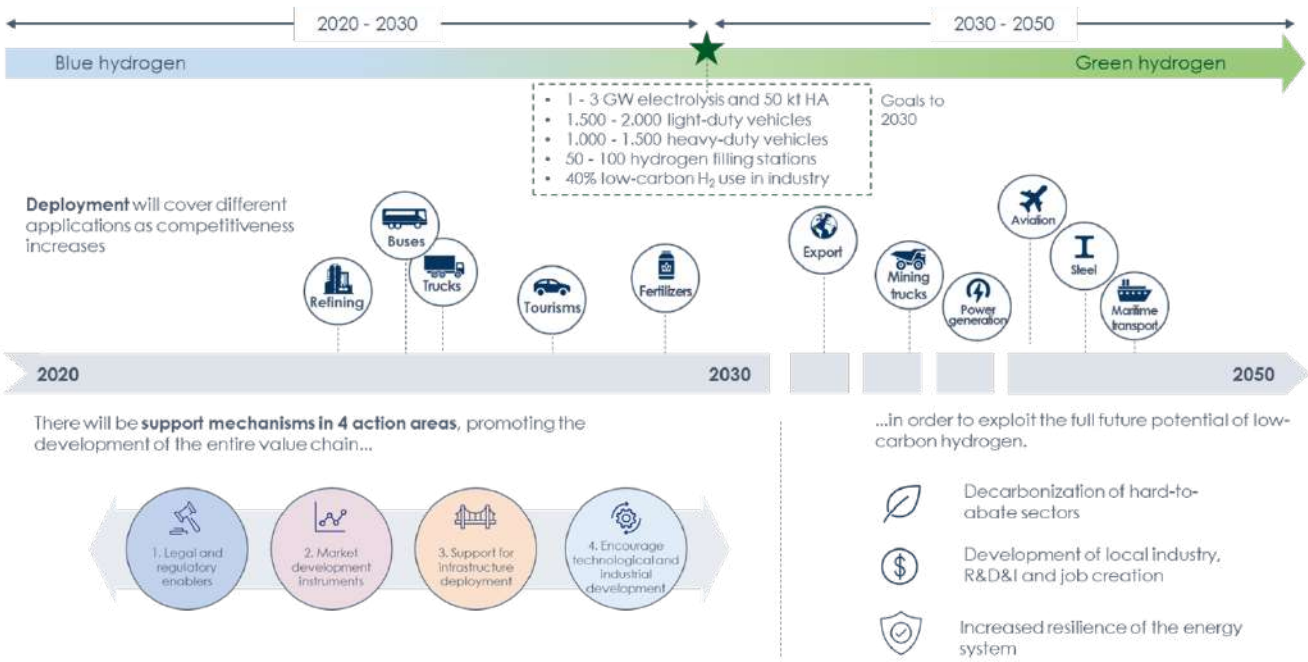

Figure 16: National low-carbon hydrogen strategy for 2050

5. Our commitment framed within four axes

The National Government has established 4 main axes on which a series of measures and instruments have been defined in order to guarantee the correct development of the low-carbon hydrogen market. It will be the responsibility of the relevant ministries to ensure that the defined measures are implemented and financed on the basis of existing budget allocations and financial plans.

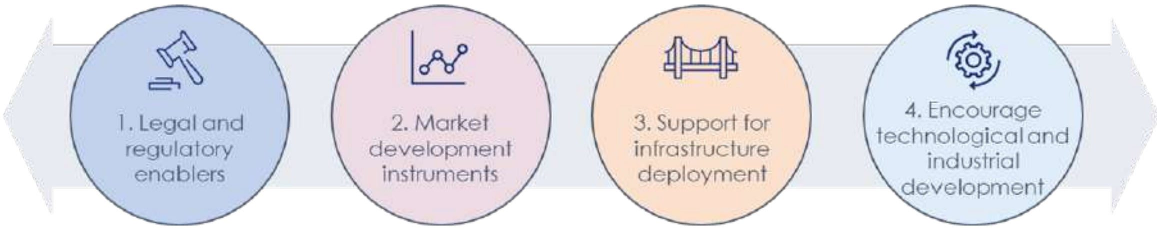

Figure 17: Action axes on which Colombia's Hydrogen Roadmap is based

1. **Legal and regulatory enablers**: Measures aimed at establishing a clear, consistent and fair regulatory framework. First, the applicable legislation must be precise and stable in order to provide certainty, thus encouraging private investment and project development. In addition, an adequate regulatory and oversight regime allows for fair competition between energy sectors and companies, safeguards the interests of all parties involved, including end users, investors, operators and the general public, protects the environment and aligns with the climate strategies of each of the sectors through Comprehensive Sectorial Climate Change Management Plans.
2. **Market development instruments**: Mechanisms and tools aimed at encouraging the transition from conventional solutions based on fossil fuels to clean hydrogen technologies, promoting both the production and consumption of low-carbon hydrogen, including the national system of tradable quotas for CO_2 emissions trading.
3. **Support for infrastructure deployment**: Actions aimed at facilitating the effective and coordinated deployment of hydrogen transport and distribution infrastructures, thus solving what is considered one of the main barriers to the use of hydrogen at present. These actions will take into account the interaction with the power generation and natural gas transportation infrastructure, as well as the existing fueling stations in Colombia in order to maximize synergies and minimize deployment costs.
4. **Encourage technological and industrial development**: Measures aimed at guaranteeing the development of the industry in a sustainable manner and with socio-economic value for the country. These instruments will leverage existing technical and industrial resources, promoting research, technological development, national innovation, and the development of technical regulations to ensure the safety of everyone.

5.1. Action Map

For each of the aforementioned axes, several action lines have been defined at a secondary level that makes it possible to understand the action areas in hydrogen matters on which the different national and regional management bodies will work during the next decade.

Three phases are defined in which the action lines will be addressed:

- **Phase 1. Lay the foundations for hydrogen**: Actions to be carried out in the short-term (less than 2 years), including the definition of laws or the preparation of technical studies and training plans in order to establish a solid foundation for the correct development of the market.

- **Phase 2. Enable and promote market development**: Tasks aimed at promoting the use of low-carbon hydrogen. These measures will be carried out in the short/medium-term (period of less than 5 years). Early measures focus on stimulating and mitigating the risk of early participants, while later measures will seek to scale up hydrogen along the entire value chain.

- **Phase 3. Monitor and enable new uses**: Actions to be carried out in the medium/long-term in order to follow up and guarantee the correct implementation of the measures taken in the previous periods, as well as to enable the entry of hydrogen in those applications with lower maturity levels. This monitoring phase is envisaged in the medium/long-term as oversight activities to be carried out periodically.

Below is the map of action lines, some of which affect different action axes due to the transversal nature of hydrogen. Specific measures within each line are presented in the following sections.

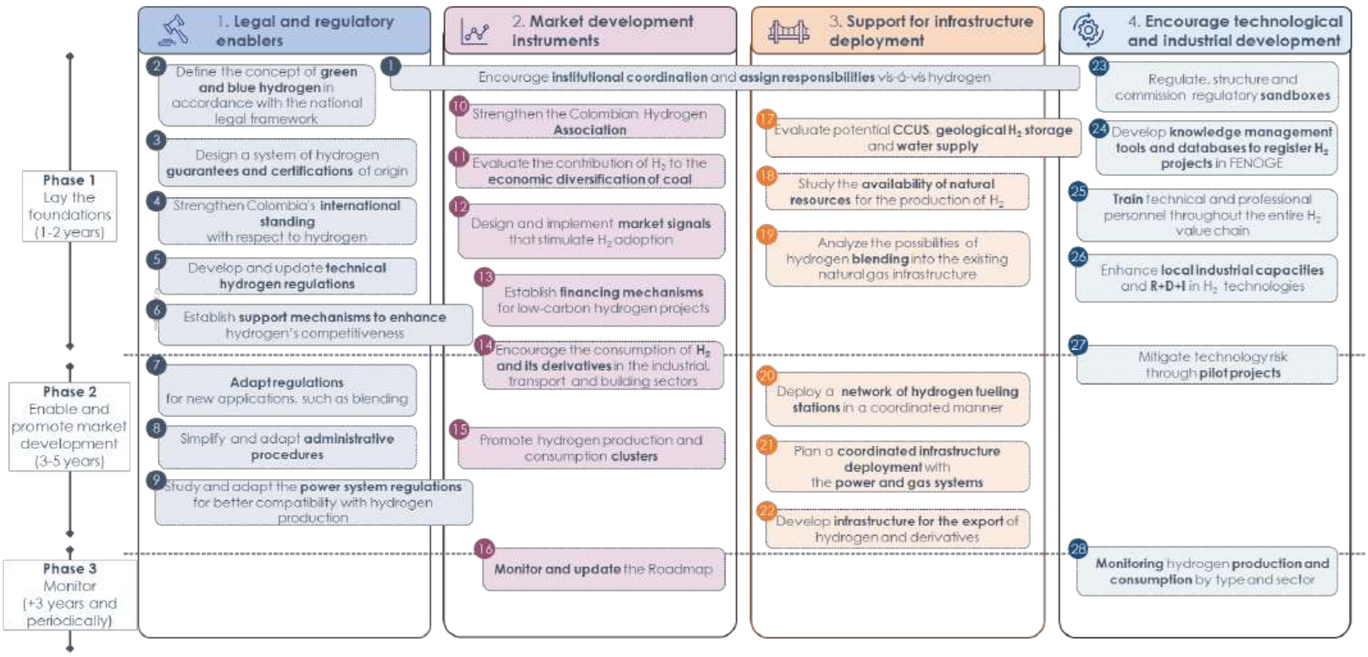

Figure 18: Action lines for the development of hydrogen

5.2. Legal and regulatory enablers

Phase 1. Lay the foundations for hydrogen

1. Encourage institutional coordination and assign responsibilities vis-à-vis hydrogen

- Establish work groups/task forces to identify and assign institutional responsibilities among the various ministries

On the matter of institutional organization, the development of the hydrogen industry generates new regulatory requirements and necessitates the assignment of new responsibilities among administrative entities.

Given the cross-sectional nature and broad spectrum of hydrogen applications, this coordination must consider all the relevant ministries, such as the Ministry of Mines and Energy, the Ministry of Environment and Sustainable Development, the Ministry of Finance and Public Credit, the Ministry of Transportation, the Ministry of Commerce, Industry and Tourism, the Ministry of Science, Technology and Innovation, and the Ministry of Finance, among others.

The Colombian energy sector enjoys a robust institutional framework in which the Government, through its Ministries, defines the strategic objectives and regulatory guidelines for each sector. The Mining and Energy Planning Unit (UPME for its Spanish acronym) frames collective long-term planning, and the Energy and Gas Regulatory Commission (CREG for its Spanish acronym) regulates the public utility services including power generation, fuel gas, and liquid fuels.

The recent Law 2099 of 2021, through a general clause in articles 21 and 23, unlocks the competence of the National Government to define mechanisms to stimulate hydrogen innovation, research, production, storage, distribution, and use. This enables a multi-stakeholder scenario, where various national entities will play an active role in the regulation and planning of hydrogen's contribution in their respective sectors.

In this context, work groups will be established with the different agents involved to assess whether the current organization that exists for the energy field is relevant for the low-carbon hydrogen sector. The newest element is the integration of energy systems that hydrogen will bring about. For this reason, each institution's activities and the exchanges between them should take into account the coupling between the electricity and gas sectors, bearing in mind that regulatory changes in one sector may have repercussions on the other.

- Coordinate the Hydrogen Roadmap with the instruments to implement the national climate change policy, especially in the sectorial and territorial Comprehensive Climate Change Management Plans (PIGCCs for its Spanish acronym)

According to Law 1931 of 2018: "It is the responsibility of the Ministries that are part of the SISCLIMA (National Climate Change System), within the scope of their powers, to issue the guidelines and adopt the necessary actions to ensure compliance with the objective of reducing greenhouse gases agreed in the CICC (Intersectorial Commission on Climate Change)." Accordingly, the approval of the inclusion of hydrogen in the different PIGCCs must be submitted for consideration by the CICC, in order to synchronize the Roadmap with the carbon neutrality strategies and those for decarbonizing the economy.

2. Define the concept of green and blue hydrogen according to the national legal framework

- Establish the definitions and taxonomy of green and blue hydrogen, considering the related CO_2 emissions

Law 2099 of 2021 approved in July of 2021 updates current energy regulations to achieve an effective energy transition and invigorate the energy market. One of the key measures adopted was the amendment of Law 1715 of 2014, which represents the most important norm in Colombia in terms of promoting Non-Conventional Energy Sources (FNCE) and Non-Conventional Renewable Energy Sources (FNCER), which includes incentives and tax benefits for investments in these sources. The new Law includes green and blue hydrogen as FNCER and FNCE, respectively.

This addition allows the application of tax benefits and incentives to green and blue hydrogen projects and provides clarity and certainty regarding the support given by Colombian public administrations for the development of low-carbon hydrogen.

According to the definitions of Law 2099 exclusively, green hydrogen is considered an FNCER and can be produced from sources such as biomass, small hydroelectric plants, wind, geothermal, solar, or tidal. Blue hydrogen is considered an FNCE and is produced from fossil fuels adding CO_2 capture, utilization, and storage system (CCUS).

However, a more precise definition is still required to delimit the hydrogen category produced by other renewable energy sources such as hydropower with a capacity greater than 10 MW. According to international recommendations, it is to be determined whether energy source certifications of origin might be enablers for hydrogen production systems having these accreditations (e.g. projects with bilateral hydropower contracts accessing the benefits of Law 2099).

Finally, the CO_2 emission thresholds considering hydrogen as low-carbon will be established. These points are addressed in the following action line.

3. Design a system of hydrogen guarantees and certifications of origin

- Involve Colombia in international task forces

In order to learn from international experiences, increase Colombia's involvement in international task forces that include participants from multiple countries. In the case of platforms that restrict participation to specific countries, an attempt will be made to include Colombia with observer status.

This involvement allows the adoption of the international best practices, as well as the development of a national guarantee and certification system aligned with potential export markets.

- Design a system of guarantees of origin through workshops with industry and other stakeholders

Law 2099 of 2021 brings with it the definition of green and blue hydrogen as FNCER and FNCE, respectively. This is a first step towards defining and clarifying the national vision around this new energy vector. However, it is essential to design a system of guarantees of origin or serialization which, in addition to considering the production pathway, takes into account maximum emissions or additional environmental factors for commercializing hydrogen as green or blue.

Guarantees and certifications of origin are some of the most relevant features in the nascent regulation for the hydrogen sector, as it is essential to develop a mechanism that makes it possible to trace the origin with certainty and achieving the emission reduction of this vector offers. It is necessary to define the procedure, the requirements, and the responsible body for the issuance of the guarantees of origin. This system will provide the appropriate price signals to the end-consumers and will be the basis for establishing future support mechanisms.

At this time, there is no established international standard, with Europe currently being the most advanced. Therefore, headway will be made in this phase at the national level to assign responsibilities and define the most appropriate certification mechanisms, as well as the actors involved, the governance framework, and the manner in which the system could be validated at the local and international levels. This definition will be carried out in tandem with the industry and other relevant agents through specific workgroups.

- Develop a monitoring tool for the guarantees and certifications of origin system

In addition to establishing a hydrogen certification and guarantee of origin system, a scheme must be developed that guarantees the correct monitoring, reporting, and verification thereof. This system must be aligned with the existing Monitoring, Reporting, and Verification systems to evaluate the reduction of CO_2 emissions.

4. Strengthen Colombia's standing and international cooperation with respect to hydrogen

- Explore international hydrogen collaboration agreements

It is considered indispensable to establish international agreements with other countries, both bilateral and multilateral, with the aim of creating collaborative partnerships regarding hydrogen. In the initial stage, the agreements will focus on the exchange of knowledge, technology, and experiences, and later move to explore the joint development and joint investment in projects for local consumption and the export of hydrogen or derivatives.

Relying on the Ministry of Foreign Affairs and the Colombian Presidential Agency of International Cooperation, Colombia's current network of trade agreements will be used to explore synergies and collaboration opportunities. Dialogue with neighboring countries will be fostered in order to promote regional cooperation and the standing of Latin America in the hydrogen field.

- Further participation in international hydrogen forums and committees

The involvement of Colombia in roundtables with international institutions will continue to be encouraged, such as those already carried out with the International Energy Association (IEA), the Latin American Energy Organization (OLADE for its Spanish acronym), the Inter-American

Development Bank (IDB), the World Energy Council (WEC) and the International Renewable Energy Agency (IRENA).

The country's inclusion in international platforms that seek to accelerate innovation, promote policies, and share experiences vis-à-vis hydrogen will be a priority to foster the national adoption of best practices.

The participation of public institutions and private companies in the main international hydrogen task forces will be encouraged.

In addition to promoting participation in forums, the inclusion of Colombian companies in technical committees for the development of international regulations and hydrogen standards will be pursued.

- Develop outreach campaigns regarding Colombia's renewable resources and the potential of local green hydrogen

Colombia's high renewable potential will be conveyed abroad to attract foreign companies and capital to develop hydrogen projects in the country. Regions such as La Guajira have outstanding conditions for generating renewable hydrogen.[28]

5. Develop and update technical hydrogen regulations

- Review in workgroups the current national standards and identify applications where new technical standards are required

The current technical standards are not designed to be applied to hydrogen as an energy vector. Hydrogen is currently regulated as a dangerous substance and consequently said standards are inadequate and technologically outdated for new hydrogen applications.

It is crucial to review and adapt existing standards to allow the safe deployment of new applications. To this end, the creation of workgroups will be recommended to analyze the current status of hydrogen standards, and prepare proposals for general provisions or standards considered necessary to strengthen its implementation. This analysis will cover all links of the hydrogen value chain, from its production to its consumption.

The workgroups will be comprised of expert members, such as representatives from the Colombian Institute for Technical Standards and Certification (ICONTEC for its Spanish acronym), from the private sector, universities, private companies, and the Colombian Society of Engineers (SCI for its Spanish acronym).

- Adopt international standards in Colombia's hydrogen technical standards

Concurrent with the previous measure, the international standards set by institutions such as the National Fire Protection Association (NFPA), the American Society of Mechanical Engineers (ASME), the International Organization for Standardization (ISO), the American National Standards Institute (ANSI), the European Industrial Gases Association and the Society of Automotive Engineers (SAE) will be analyzed and adopted. These institutions have developed codes and standards for hydrogen applications whose adoption simplifies the development of national standards, and therefore the accreditation of conformity certifications already granted in other countries will be advocated.

In addition, participation by national companies in international forums and technical committees responsible for developing new standards will be encouraged, such as specific standards for the use of hydrogen in the mining industry.

6. Establish support mechanisms to enhance hydrogen's competitiveness

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[28] *La Guajira has an onshore wind capacity potential of at least 25 GW and 45 GW solar, with an average wind speed of 9 m/s at a height of 80m (double the world average) and a constant solar radiation throughout the year of 6 kW/m^2 (60% higher than the world average). Source: UPME, IDEAM*

- Implement measures to support low-carbon hydrogen and derivatives production

The current production cost is one of the main barriers to the development of low-carbon hydrogen projects. For this reason, it is necessary to identify incentives that provide security to investors and encourage the first pilot-scale projects as a preliminary step to develop industrial-scale projects.

Law 2099 of 2021 encourages investment in the entire green and blue hydrogen value chain, as it extends the provisions of Chapter III of Law 1715 of 2014 to these types of hydrogen and improves the incentives applicable to FNCEs. Hence, investments, equipment, and machinery for production, storage, conditioning, and distribution will enjoy income tax deduction, VAT exemptions, duty exemptions, and accelerated depreciation. It should be highlighted that encouraging hydrogen production also fosters the production of derivatives such as ammonia or methanol.

As the market develops, the Government will evaluate if the incentives established are sufficient, or if greater motivation is required. If deemed necessary, Law 2099, specifically its articles 21 and 23, confers power for defining other incentives to encourage further development of the hydrogen industry. The measures will be aimed at promoting green or blue hydrogen as opposed to fossil hydrogen, or hydrogen of untraceable origin.

- Implement measures to support the national demand for hydrogen

The lack of new demand constitutes another clear barrier to the development of hydrogen projects, both for production as well as infrastructure, given that there must be end-uses with viable business cases in order for the projects to be economically feasible. The measures aimed at encouraging demand provide a more technology-neutral focus, which may prove to be more resilient to supply innovations and allow the early development of this new industry.

The abovementioned production incentives of Law 2099 also apply to the end uses. The Government will assess whether greater incentives are required for the transition from fossil fuel-based technologies to low-carbon hydrogen technologies, as has already been legally recognized in the mobility sector through Law 1964 of 2019. Likewise, the cooperation of regions is critical to stimulate demand.

At the direct investment level, Law 2099 extends the scope of action of the Non-Conventional Energy and Efficient Energy Management Fund (FENOGE) to the financing and/or execution of viable projects within any link in the hydrogen value chain.

- Define the hydrogen goods, equipment, and machinery that can be certified to access the benefits of Law 2099 of 2021

The Mining and Energy Planning Unit (UPME) must certify FNCE projects so that those who invest in them have access to the tax and tariff incentives of Law 2099.

With the inclusion of green and blue hydrogen as FNCEs, investments, goods, equipment, and machinery destined to green and blue hydrogen will enjoy the benefits of income tax deductions, VAT exclusion, duty exemptions, and accelerated depreciation, when certified by the UPME.

To fulfill this new role, the UPME will need to establish a list of goods, equipment, and machinery for the production, storage, conditioning, distribution, re-electrification, research, and end-use of green or blue hydrogen, as well as technologies for the capture, utilization, and storage of CO_2.

- Update the practical guidelines to apply the tax incentives of Law 2099

The UPME will be responsible for updating the practical guidelines developed for the application of the tax incentives of Law 1715 of 2014[29] to include the new incentives established by the new Law 2099 of 2021, which includes green and blue hydrogen.

<u>Phase 2. Enable and promote market development</u>

[29] UPME (2016): Practical Guidelines for the Application of the Tax Incentives of Law 1715 of 2014

7. Adapt regulation for new applications, such as blending

- Review and update the RUT to allow for blending

The transport of natural gas in Colombia is regulated by the Unified Transport Registry for Natural Gas (RUT for its Spanish acronym), which, although it doesn't explicitly prohibit hydrogen injection, sets minimum gas quality parameters that would be impossible to meet if hydrogen is blended in the network.

Therefore, if blended hydrogen will be allowed in the gas network, it will be necessary to modify the RUT. This amendment process could be initiated by the National Council for Natural Gas Operation (CNO Gas for its Spanish acronym) or by the CREG, which may propose the amendment after reviewing the national and international experience, taking into account the observations provided by all the stakeholders involved.

8. Simplify and adapt administrative procedures

- Review the permits and procedures for the execution of hydrogen projects, including environmental and land use aspects

Currently, the production and handling of hydrogen are considered an industrial activity since hydrogen is classified as a dangerous good or substance. This implies that hydrogen-related activities are subject to rigorous environmental impact assessments regardless of the source of production.

In this context, and considering the positive environmental impact of low-carbon hydrogen, a review of the permits and procedures necessary for the start-up and operation of projects will be carried out in order to facilitate their development. Regarding environmental matters, at this point, it is important to mention that the special regime established in Law 1715 applies to green and blue hydrogen, classified as FNCER and FNCE respectively, whereby the National Environmental Authority (ANLA for its Spanish acronym) and Regional Autonomous Corporations (CAR for its Spanish acronym) are called in to establish a rapid evaluation cycle for FNCE projects. It is recommended that these environmental authorities carry out studies to quantify the environmental impacts of these projects, analyze the environmental procedures they will require, and eliminate unnecessary procedures to expedite the procurement of environmental permits and licenses. To achieve the streamlining and the effective implementation of the procedures, the technical capabilities of officials from the environmental authorities will be strengthened through training practices.

Likewise, it is recommended that municipalities include within their Territorial Organization Arrangements the locations within their territory where hydrogen projects can be established. Bear in mind that Law 1715 of 2014 declares the FNCE production and utilization activities to be of public and social interest, and therefore take precedence with regard to territorial ordering. Said assertion, through Law 2099 of 2021, is extendable to green and blue hydrogen projects. It is recommended that the territorial entities analyze the basic building standards and land uses in a way that favors the development of green and blue hydrogen projects within their territory.

- Reduce administrative procedures for low-carbon hydrogen projects

Regulatory measures that streamline and facilitate the development of blue or green hydrogen projects will be furthered. These measures include combined project approvals and the streamlining of procedures for the construction of hydrogen pipelines or the conditioning of existing gas pipelines.

For the particular case of green hydrogen wherein, it is necessary to address the development of joint FNCER projects for electricity generation (e.g. wind and/or solar) and electrolysis for hydrogen production, a combined approach will be encouraged regarding their processing. This new approach may reduce delays in administrative procedures, which represents a barrier to investment and the deployment of the FNCERs.

These revisions require that regulations be modified at the sectorial level, which will be carried out while avoiding placing at risk the financial sustainability of the current power generation and gas system.

9. Adapt the electrical system regulations for better compatibility with hydrogen production

- Analyze the participation of electrolyzers in network flexibility services

The regulation of the power generation system will be reviewed based on an analysis that evaluates the costs and benefits of the provision of flexibility services (AGC service or participation in the reliability charge) by the electrolyzers, as long as the technology meets the obligatory technical requirements.

Electrolyzers can contribute towards increasing the resilience of the electrical system in a scenario with a high penetration of unmanageable (high volatility) FNCERs, while simultaneously lowering the final cost of hydrogen production by collecting additional income.

- Analyze electricity cost reductions in hydrogen production

For hydrogen production systems through electrolysis having certifications of origin that substantiate a low CO_2 footprint, the possibility of exonerating the payment of certain electrical system costs will be assessed to increase its competitiveness.

5.3. Market development instruments

Phase 1. Lay the foundations for hydrogen

10. Consolidate the Colombian Hydrogen Association and other hydrogen-related organizations

- Strengthen the industrial fabric through collaboration with relevant stakeholders

Consolidating industry associations such as the Colombian Hydrogen Association is necessary to promote and stimulate the development and growth of hydrogen technologies domestically, as well as to provide worth and fortify the country's industrial fabric.

Through the participation of partners from the entire value chain (academia, renewable energy project sponsors, engineering companies, equipment manufacturers, transport companies, industries, etc.), a favorable environment can be constructed and a strong national industry with an international vision will be achieved.

The associations will serve as a point of convergence for companies, institutions, technology centers, and universities involved in hydrogen-related activities. One of the main objectives will be to share best practices and endorse laws and standards for regulating hydrogen. In addition, common ground will be sought with associations from other areas that offer synergies, and workgroups will be formed up to detect and solve gaps that hamper the development of the market.

11. Evaluate the contribution of hydrogen to the economic diversification of coal

- Evaluate the feasibility of transitioning coal plants towards blue hydrogen production

The restructuring of the global demand for coal as a result of decarbonization objectives implies a decrease in its consumption in some markets (mainly in Europe and North America) and will negatively impact the demand and prices of Colombian exports.

In this context, feasibility studies will be undertaken to evaluate the commercial viability of hydrogen production through the gasification of national coal. Blue hydrogen from coal offers a possible alternative for transforming mining companies towards a more sustainable exploitation of the country's mining resources.

- Construct a human capital transformation plan to accelerate hydrogen deployment

The decarbonization of the economy entails the creation of new positions that require specific knowledge and skills. Taking advantage of the existing human capital in sectors affected by the energy transition process and updating their knowledge and skills is an objective for the National Government, social agents, companies, and academia that will enable an equitable transition.

The role of hydrogen as a transformation tool will be evaluated, allowing the relocation of workers into the renewable energy or hydrogen sectors. This will require collaborating with the private sector to detect personnel needs in these new sectors and train professionals in new technologies like solar, wind, electrolysis, or the capture and storage of CO_2.

12. Design and implement market signals that stimulate hydrogen adoption

- Design a pricing system for emission and implement the National Program of Tradable Emission Quotas

A key element for generating a domestic demand for low-carbon hydrogen is setting a CO_2 price that reflects the externalities of fossil fuel use. Emissions trading, provided in the form of tradable emission quotas, is already being drawn up under the competence of the Ministry of Environment and Sustainable Development.

Technical work tables will be created which include technical representatives of the Ministry and other public and private stakeholders to discuss fair tariffs on emissions. It will also consider the experiences in other geographies as well as international recommendations provided by institutions on effective carbon rates, including the International Monetary Fund (IMF) or the Organization for Economic Co-operation and Development (OECD).

The system of emissions trading and the monitoring of guarantees and certifications of origin will be synchronized with the MRV System(monitoring, reporting, and verification of the Intersectorial Commission on Climate Change, which is the instrument responsible for identifying investments and projects addressing national climate change targets.

- Evaluate other mechanisms to levelize the carbon market's conditions

Additional mechanisms will be evaluated that allow levelizing the carbon market's conditions, such as identifying and adopting market incentives for tradable CCUS technology quotas or another mechanism that encourages compliance with the NDC 2020, the enabling of CCUS technologies as an activity to achieve carbon neutrality and the evaluation of modifications to the carbon tax.

13. Establish financing mechanisms for low-carbon hydrogen projects

- Design new public-private financing instruments

Low-carbon hydrogen production of both green and blue hydrogen requires high initial investments. Although CO_2 capture technologies, renewable generation, and electrolyzers can be considered overall to be in an advanced stage of development, they are not yet fully mature in terms of costs, with reductions expected in the coming years. For this reason, it is considered essential to develop new financing mechanisms to accelerate the deployment of these technologies which will be continually adjusted to reflect the progress which is expected to occur both globally and locally in the coming years with regard to hydrogen at the technical, social, economic and environmental levels, among others.

In addition to the FENOGE funds and current tax incentives, other instruments such as low-interest loans, issuance of green bonds by national companies, or exclusive public financing rounds for low-carbon hydrogen projects will be evaluated. This financing will seek to support national and international companies and consortiums in the development of projects in the country.

In addition to the existing mechanisms, Law 2099 authorizes the National Government to finance, with contributions from the Nation's General Budget and the General System of Royalties, the participation of territorial entities in the projects for the generation, distribution, and commercialization of FNCERs, including among these green hydrogen.

- Attract international funding

International cooperation is considered an essential tool for encouraging investment in Colombian hydrogen projects. Hence, the creation of consortia comprised of national and foreign companies will be fostered.

Opportunities provided by multilateral and international institutions and programs will be exploited. It is considered crucial to leverage these institutions and initiatives in order to be able to develop the hydrogen studies and pilot projects required at the national level.

International cooperation will be supported by national institutions such as the Ministry of Foreign Affairs, the Colombian Presidential Agency of International. Cooperation, and ProColombia, which will play a central role in enhancing Colombia's network of trade agreements and establishing collaborations with foreign embassies and governments.

Phase 2. Enable and promote market development

14. Encourage the consumption of low-carbon hydrogen and its derivatives in the industrial, transport, and building sectors

- Promote the consumption of low-carbon hydrogen and its derivatives through the implementation of industry penetration plans

Currently, the use of hydrogen in Colombia is concentrated in industrial sectors such as refining, fertilizers, and chemicals. Due to the compatibility of their infrastructure, which minimizes the investment required for the adoption of low-carbon hydrogen, these sectors are considered to be the most inclined towards the use of low-carbon hydrogen and its derivatives in the short/medium term. However, hydrogen and its derivatives have potential use in many other industries, where they can be employed as a raw material or for heat production.

It is expected that the hydrogen market will mainly be concentrated in those areas where no other decarbonization alternatives exist. Focusing on these sectors, technical roundtables will be held with associations, private sector representatives, and officials of national ministries - particularly the Ministry of Commerce, Industry and Tourism, and the Ministry of Transport - in order to evaluate the definition of low-carbon hydrogen penetration targets for certain industrial sectors. These targets for the use of low-carbon hydrogen will be accompanied by support mechanisms that facilitate private investment while protecting at all times the country's industrial competitiveness.

Finally, studies by subsector will be urged in order to better understand and design long-term decarbonization and carbon neutrality strategies. For example, while the residential sector has some certified equipment for the use of hydrogen and methane blends, the industrial sector stands out for having a large number of applications that have not been fully evaluated. Thus, it is expected that some processes using natural gas may need to be adjusted if hydrogen were to be injected into the gas network.

- Prepare plans for the penetration of low-carbon hydrogen and its derivatives in the land, water, and air transport sector

Gradual acceleration in the introduction of hydrogen and its derivatives in transport is foreseen, driven by growth in energy requirements and the increasingly demanding decarbonization targets. Low-carbon hydrogen can be used in the form of gas, or it can also be transformed into liquid fuels such as ammonia, methanol, and synthetic fuels that can be used to achieve carbon neutrality in the different transport modes.

As regards to land transport, hydrogen will contribute to Colombia's National Sustainable Mobility Strategy, helping to improve air quality and avoid carbon dioxide, nitrogen oxides, particulates, and unburned hydrocarbons emissions. A significant contribution is expected in public transport systems, heavy-duty freight transport, and in light-duty intensive-use vehicles such as taxis.

This process requires the participation of local governments that, through the renewal of the public transport fleet, can drive the adoption of hydrogen and the deployment of the necessary fueling infrastructure. In addition, the inclusion of additional incentives to increase the demand for hydrogen in transport will be assessed, such as a decrease in the tax rates or subsidies for the acquisition of hydrogen vehicles.

To implement a decarbonization plan for the national air, river, and maritime transport sectors, coordination with international entities and regulators such as the International Maritime Organization (IMO) or the International Air Transport Association (IATA) is proposed. Concerning shipping, the IMO has committed to reducing 50% of emissions by 2050 versus 2008 levels, while in air travel the IATA establishes an emissions reduction of 50% in versus 2005 levels.

- Identify barriers for hydrogen consumption in the residential and tertiary sectors

The buildings sector, both residential and tertiary, are potential hydrogen consumers, either by using small-scale fuel cells for micro-cogeneration or through hydrogen combustion in equipment connected to the natural gas network for heat production. While the former case is considered unlikely given its high costs, injecting hydrogen into the gas network is perceived as a transient option that encourages low-carbon hydrogen consumption, especially in large urban areas where a rapid escalation in demand is expected.

However, a stimulus in these sectors requires prior studies to assess the technical, safety, and availability considerations of the equipment adapted to operate with the hydrogen blends.

- Develop an open socialization program regarding hydrogen to present these technologies to the communities

Hydrogen is a gas that is difficult to handle and whose current range of applications is limited to a few industries. However, cost reductions and technological developments will allow its adoption in new sectors and make it a pillar of the energy transition.

However, there is currently a high degree of ignorance with respect to hydrogen, both socially and professionally, regarding its application possibilities and associated advantages, which makes difficult its acceptance as a sustainable and safe alternative.

Communication strategies and campaigns targeting citizens and potential consumer industries and companies will be encouraged in order to divulge the potential and benefits of hydrogen to the entire Colombian society, decreasing the perceived risk and expounding on the opportunities it offers for decarbonization and industrialization.

There will be an early and close dialogue with stakeholders to understand the potential and benefits in the different regions, while concurrently identifying the risks and possible action measures to be implemented. Particularly, open dialogues will be held with communities to resolve issues such as local employment, compatibility with property, environmental and social factors.

15. Promote hydrogen production and consumption clusters

- Identify areas that gather potential hydrogen consumers and producers

Workshops and roundtables will be held with departmental public administrators, Regional Autonomous Corporations (CAR), prospective hydrogen consuming companies, and project sponsors in order to identify the regions that have the potential to become hydrogen clusters.

Clusters are areas of the country that, due to their industrial development or their proximity to ports or other relevant infrastructure in the hydrogen supply chain, would demand large volumes of hydrogen through aggregate consumption.

Among the regions to consider are: Barranquilla and Cartagena (with the Mamonal industrial complex), Bogotá, Medellín, Bucaramanga and areas of Manizales, Pereira, Armenia, Ibagué and Barrancabermeja, among others. However, all territories of Colombia may be considered if the local administrations and companies allow grouping a sufficient level of demand. In addition, the possibility of stimulating the creation of these clusters in areas that are being negatively affected by the energy transition process will be assessed, such as mining regions.

- Encourage regional cooperation between companies and public agents to obtain economies of scale

Once the regions and stakeholders interested in hydrogen are identified, the development of relevant-sized projects will be promoted, understood as those that can benefit from economies of scale and facilitate a low-carbon hydrogen supply with competitive costs.

However, it should be noted that many essential technologies for the hydrogen economy still need to be developed, and there are significant risks to their implementation. For this reason, the public-private collaboration will be encouraged to facilitate the mobilization of the private investments needed for its initial deployment.

Phase 3. Monitor progress and enable new use cases

16. Monitor and update the Hydrogen Roadmap

- Review the technological advancement and achievement of the country's objectives

Given that the low-carbon hydrogen industry is in a state of nascent development, it is to be expected that relevant changes will take place in the future at the level of technologies and markets, needing in turn to adopt the energy policy.

Periodic reviews of the Roadmap, in sufficiently short cycles, will be required. This review will be carried out with at minimum a 3-year frequency, reaching an annual review if considered necessary due to changes and market trends. These reviews will be leveraged on specialized technical studies and will make it possible to determine the degree of implementation of the measures, the quantification of their impact and the fulfillment of the established goals.

5.4. Support for infrastructure deployment

Phase 1. Lay the foundations for hydrogen

17. Evaluate potential CCUS, geological hydrogen storage and water availability

- Conduct studies to determine potential CO_2 geological storage capacity

In accordance with Law 2099 of 2021, the National Government will develop the necessary regulations to promote and develop technologies for the capture, utilization, and storage of CO_2 (CCUS). In this context, it is considered indispensable to study and validate the geographical areas and the most suitable technologies to drive the development of blue hydrogen. Therefore, studies are necessary to analyze, on the one hand, the potential CO_2 geological storage capacity in depleted fossil reservoirs, aquifers, salt caverns, or other natural containers and, on the other hand, the most efficient technologies for its capture and injection. In addition, CO_2 valorization in industrial processes will be examined as an option to increase the competitiveness of low-carbon hydrogen. Along with capacity studies, training of future professionals in this area, in collaboration with universities and the Ministry of Science, will also be required.

The capture and storage of CO_2 are critical for the development of blue hydrogen, as delays in this area could negatively impact the deployment timeline of blue hydrogen as a bridge towards green hydrogen. Blue hydrogen could be directly substituted for green if the latter's development is delayed, as green hydrogen is potentially more competitive in the long term.

- Conduct studies to determine the potential geological storage capacity of H_2

In line with the previous measure, the same studies carried out for the geological storage capacity of CO_2 will allow evaluating the potentially most suitable locations for the geological storage of hydrogen. This large-scale storage would make it possible to have large seasonal renewable energy reserves, which will help mitigate the impact of weather-related events such as El Niño or La Niña.

- Assess water stress in Colombia and the development and implementation of desalination technologies

In collaboration with universities, laboratories, and public entities, regional studies will be carried out on water stress that could constrain the production of green hydrogen on a large scale.

Research already initiated by universities and research groups throughout the country that encourage the use and development of desalination technologies will be further encouraged. These technologies will facilitate, on the one hand, ending the scarcity of water for consumption by local communities and, on the other, to have the water required for the production of hydrogen through electrolysis.

18. Study the availability of natural resources for the production of low-carbon hydrogen in Colombia

- Quantify the potential of solar and wind technologies (onshore and offshore) in the different departments of Colombia

The development of tools for decision-making in the field of renewable solar and wind resources will be stimulated, such as climate atlases and radiation and wind maps produced by the IDEAM (Institute of Hydrology, Meteorology and Environmental Studies for its Spanish acronym). These studies will assist in identifying optimal renewable resource zones and will be made available to companies to facilitate the development of projects.

Regarding renewable potential, possible current capacity is known for the region of La Guajira, where onshore wind potential surpasses 20 GW and solar 40 GW.[30] Although La Guajira is the region that presents the best renewable resourced and, consequently, the most competitively levelized hydrogen cost, analyzing and developing the potential of other regions will ensure a long-term supply for the national and export markets, in addition to reducing transport costs when hydrogen is produced closer to its consumption areas.

Within this framework, studies will be encouraged to quantify the renewable potential of other regions, also taking into account new technologies such as offshore wind, to determine total potential green hydrogen production capacity. This would allow appropriate decision-making regarding the balance between power generation and hydrogen production for domestic consumption and export purposes.

- Quantify the feasibility of other non-conventional renewable technologies

The national feasibility of other FNCER technologies for the production of green hydrogen will be studied. For this, subsoil surveys will be carried out to pinpoint areas with geothermal potential and the availability of biomass in the different regions. The use of these technologies in the production of green hydrogen as a complement to solar and wind technologies will depend on available resources and the financial and operational viability of each project.

- Evaluate the potential of hydroelectric plants to produce renewable hydrogen

[30] Ministry of Mines and Energy (2018), Public Policy for the Electricity Sector

Colombia has one of the best hydric resources in Latin America, with a hydropower projects potential of 56 GW without reservoirs.[31] For this reason, the feasibility of allocating part of the hydroelectric energy for the production of renewable hydrogen will be analyzed to take full advantage of the country's water potential. It will be necessary to constantly evaluate the electricity needs and the reliability of the supply, considering both the existing infrastructure and the new hydroelectric plant projects planned for the next decade.

- Appraise the impact of blue hydrogen on Colombia's natural gas supply

Blue hydrogen provides a transitory tool for early decarbonization, but its production requires the consumption of fossil fuels, either coal or natural gas.

While Colombia is a country with large coal reserves (of over 4,500 Mt[32]), its natural gas reserves are smaller (3,000 G cu ft).[33] For this reason, the feasibility of developing a local natural gas supply that can be dedicated to the production of blue hydrogen must be assessed, as long as this new demand for natural gas will not compromise the supply for other uses.

19. Analyze the possibility of blending hydrogen into the existing natural gas pipeline network

- Determine the adequate percentage of hydrogen blending into the gas network

International experience shows blending to be a viable tool to encourage hydrogen production, enhance the existing gas infrastructure and reduce transportation costs. In order to evaluate the country's blending options, regional assessments will be carried out, in cooperation with gas companies, to determine the maximum admissible volumes of hydrogen by the Colombian network.

The adaptation requirements of the gas network will be analyzed (additional compression capacity, the internal lining of the pipes, adapting the measurement stations, etc.) to allow blending without compromising the quality of the supply and the reliability of the infrastructure. This may lead to the eventual modification of the RUT, CREG Resolution 071 of 1999, as indicated in aforementioned action line 7 on eliminating regulatory barriers.

The assessment will be grounded on international experiences and best practices, which show that the existing network can potentially tolerate hydrogen blends of 5-10% without significant modifications, and cooperation will be sought with other countries that are further along in this process to streamline the pilots that will be implemented, save costs and shorten timelines. In addition, an inventory must be made of the different elements in the existing networks that may be affected by the presence of hydrogen in order to define a plan for their updating.

Phase 2. Enable and promote market development

20. Deploy a network of hydrogen fueling stations in a coordinated manner

- Develop specific legislation for hydrogen fueling stations

Recently, the Ministry of Mines and Energy issued Resolution 40223 of July 9, 2021, which establishes the minimum conditions and market standardization for implementing the charging station infrastructure for electric vehicles. However, this resolution refers solely to wholly electric vehicles. Regarding vehicles will fuel cells, the Ministry must issue technical regulations that consider the specific characteristics of the hydrogen dispensing infrastructure.

The Ministry will issue regulations according to its competence under article 9 of Law 1964 of 2019 and article 6 of Law 1715 of 2014. The necessary administrative requirements and permissions will be established for their construction and handling. To this end, the existing international standards on

[31] UPME (2015), Atlas of Colombia's Hydropower Potential
[32] National Mining Agency (2021)
[33] Ministry of Mines and Energy (2021)

hydrogen fueling will be used as a reference, such as ISO 13984, ISO 17268, ISO 19880-1, SAE J2601, or SAE J2799.

- Plan and monitor the development of hydrogen fueling infrastructure

The lack of hydrogen fueling infrastructure is a barrier to initiating the deployment of zero-emission mobility using hydrogen. Alternatively, the lack of hydrogen-powered vehicles discourages investment in fueling stations due to their limited profitability.

For this reason, it is considered indispensable to support the deployment of hydrogen fueling infrastructure for its use as a fuel and to do so in a manner that is in sync with the expected deployment of the fleets, as well as with the deployment of electric charging infrastructure to avoid incurring in duplicities and cost overruns.

A network of at least 20 publicly accessible hydrogen fueling stations will be planned for every 1000 fuel cell vehicles. The objective is to take advantage of the existing network of service stations, mainly those with easily accessible locations, seeking that they are distributed throughout areas with the highest vehicular traffic, maintaining the maximum possible distance between each fueling station. For the above, the Ministry of Mines and Energy, in accordance with the competence established in article 9 of Law 1964 of 2019, may regulate the conditions necessary for the service stations to expand their service offer and include hydrogen dispensing infrastructure.

The first hydrogen fueling stations will be located in strategic locations that guarantee demand, such as highly populated cities with a large fleet of taxis or inter-municipal buses; or on land trade routes with a high heavy-duty cargo and passenger vehicle traffic where so-called hydrogen corridors will be promoted.

21. Plan a coordinated infrastructure deployment with the power generation and gas systems

- Analyze the adequacy of the existing electricity infrastructure with regard to the production of green hydrogen

Most of Colombia's renewable potential is located in areas where the electricity grid is in the expansion phase, such as La Guajira. Although it has been decided in these areas to favor a direct connection between renewable power generation plants and electrolyzers, there must also be an available power generation infrastructure that makes it possible to take advantage of excess discharges from renewable plants, as well as to supply the demand in hours with low renewable energy production.

Alternatively, if electrolyzers are installed in regions with fewer renewable resources but with access to the power grid, then their impact on the grid stability must be assed contigent on their efficiency in converting power from the grid into hydrogen.

- Analyze the possible reconditioning of gas pipelines for hydrogen transport

Colombia currently has a gas pipeline network of over 7,500 km destined for the transport of natural gas. This network can be reconditioned for the transport of hydrogen in those sections that connect large production centers with the main demand centers. In fact, retrofitting existing natural gas infrastructure is the most competitive way to transport large volumes of hydrogen, costing up to 50% less versus installing new hydrogen pipelines.

Consequently, it is necessary to identify where are the sections of the gas network that could competitively be used for hydrogen transport, especially if these are currently in disuse, and to outline a plan to adapt this infrastructure.

- Evaluate the potential advantages of sector coupling

Sector coupling, understood as integrating gas and electricity-producing infrastructures with the consuming sectors, is considered one of the key tools to achieve decarbonization thanks to the lower cost of transporting gas versus electricity and to the joint infrastructure planning.

Hydrogen can increase the degree of coupling between the gas and electricity sectors, wherein - although they have long been connected - transport currently only happens in one direction: gas consumption for electricity production. However, electrolysis allows coupling in the other direction as well, by allowing electrical energy to be transformed into the form of hydrogen gas that can be stored and transported exploiting the gas infrastructure.

However, the benefits obtained by the coupling between systems entail greater planning effort. For this reason, incorporating the role of hydrogen within the plans for the expansion of the electricity and gas systems prepared by the UPME will be promoted.

UPME carries out centralized infrastructure planning, encouraging the efficient development of power generation and gas infrastructure but without yet taking into account the role of hydrogen as a coupling element between both sectors. Therefore, public policy will be developed to include studies on sector coupling within a regulatory and policy framework that will allocate this task to the UPME.

22. Develop infrastructure for the export of hydrogen and derivatives

- Prepare a port and export infrastructure deployment plan according to expected international demand and export ambition

Colombia can become a relevant player in hydrogen production and export due to favorable weather conditions, the large surface area available for the installation of renewable plants and electrolyzers, and its geostrategic position with access to two oceans.

In order to fully take advantage of the country's potential, studies and development plans for port infrastructures will be promoted. The assessments will be used to qualify and adapt the country's ports for exporting hydrogen. Cartagena, Buenaventura, Coveñas, and Tumaco are among the most important ports in Colombia for the export and import of fuels. In addition, the country has ports located in areas of high renewable resource potential, such as Puerto Brisa in La Guajira. In the selected ports, the development of conditioning and storage infrastructure will be considered.

Hydrogen transport by ship will be in the form of liquid hydrogen or by carriers such as ammonia, methanol, and liquid organic carriers. Among these, ammonia stands out because it is a compound commonly used in numerous processes, is produced on an industrial scale with mature technologies, and has consolidated technical regulations and standards. The port of Cartagena already has infrastructure for handling ammonia exports and imports.

- Promote the role of Colombia as a prospective logistics hub in the Caribbean

Colombia is close to large maritime traffic routes such as the Panama Canal. From this perspective, the possibility of turning the north of the country into a Caribbean hydrogen distribution hub will be analyzed. In addition, hydrogen could be converted into derivatives such as ammonia or methanol that can be used as marine fuel for national and international transport.

To evaluate the viability of this plan, the collaboration will be endorsed with fellow Caribbean countries that are also interested in exploring and exploiting this opportunity.

5.5. Encouraging technological development

Phase 1. Lay the foundations for hydrogen

23. Structure and create regulatory sandboxes

- Enable sandboxes for innovation projects outside the current legal framework

Regulatory sandboxes are instruments that allow supporting innovative projects through a temporary and limited lifting of regulations for certain activities that have a restrictive effect on their development.

These enablers will be encouraged, considering as well that generating knowledge on hydrogen is also necessary at the regulatory level. Therefore, for the development of innovative projects that are not permitted according to current regulations but are considered of strategic interest, a flexible regulatory framework will be applied that encourages regulatory learning and allows for the most efficient regulatory approach to be studied. The learning will be based on international experience gained by other countries, thus simplifying the pilots that will be undertaken and reducing costs.

A clear example of this application are projects for the injection of small volumes of hydrogen blends into the natural gas network. These projects are necessary to understand possible variations in the quality of gas, potential operating problems that may occur, and the maximum limits admissible in the local gas network.

In Colombia, the possibility of a regulatory sandbox has been legally introduced as a mechanism to promote entrepreneurship in the country through article 5 of Law 2069 of 2020, requiring a specific regulation for its application in the hydrogen field.

24. Develop knowledge management tools in Colombia's hydrogen ecosystem

- Create a database to register hydrogen projects and companies

Create a centralized registry of projects and companies that own production, conditioning, transport, distribution, storage, or marketing facilities of hydrogen and derivatives, in order to identify the typology and number of companies interested in participating in hydrogen projects, determine potential project types, detect synergies and share best practices among companies.

According to the third paragraph of article 7 of Law 2099 of 2021, the FENOGE can create, manage and administer a platform and/or database for centralizing information on FNCE and efficient energy management projects.

25. Train technical and professional personnel throughout the entire hydrogen value chain

- Include hydrogen in existing training plans

In cooperation with national educational institutions, encourage the inclusion of hydrogen technologies in educational plans and existing qualifications, both vocational and technical, which are related to hydrogen. To this end, the development of technology and knowledge transfer plans with universities and companies will be encouraged, as well as financing programs for professional training.

- Train and certify local personnel on hydrogen and its enabling technologies

Hydrogen is a gas difficult to handle and store due to its low density and high flammability. Therefore, the penetration of hydrogen in new applications requires professional profiles with suitable technical skills. Similarly, it is necessary to create competencies in low-carbon hydrogen enabling technologies such as the capture, utilization, and storage of CO_2.

For the deployment of hydrogen and these technologies to take place safely without rejection by the general population, it is essential to provide training and create certifications to accredit technical professionals. Consequently, specific training plans for each sector will be drafted, adapted to professionals such as workshop technicians, emergency personnel, or road assistants for the safe handling of hydrogen.

The Ministry of Labor, together with the Ministry of Education, Mines and Energy, and the National Apprenticeship Service (SENA) will work towards the development of training programs for the personnel required to configure the hydrogen industry.

To maximize Colombia's hydrogen potential, a training plan will be drawn up and executed for public officials of the ministries whose action fields are related to hydrogen. This will allow better decision-making regarding this new energy vector, will encourage the emergence of hydrogen decarbonization projects and opportunities and will serve as a point of reference to later extend the training to other areas.

26. Enhance local industrial capacities in hydrogen technologies

- Evaluate the strengths of local industry in the hydrogen value chain

The new hydrogen industry requires the development of technology throughout the entire value chain. Additionally, it requires manifold companies such as manufacturers, assemblers, engineering companies, and component and equipment recyclers.

The completion of a socio-economic impact study of hydrogen technologies in Colombia will be promoted. Furthermore, in order to leverage on the opportunity for furthering socio-economic growth and recovery after the Covid-19crisis, the creation of workgroups with public institutions (most notably the Ministry of Science, Technology and Innovation), business associations, and private sector representatives will be encouraged to promote the participation of local companies in the development, manufacturing, assembly, installation and/or equipment recycling. This collaboration will allow the creation of favorable conditions for generating wealth and creating qualified jobs in Colombia and even include evaluating the possibility of exporting equipment/technology.

- Support national Research, Development, and Innovation (R+D+I) through the financing and progress of existing workgroups

Nevertheless, the development of hydrogen still requires great technological progress and is therefore considered that, beyond supporting the deployment of production and demand, Colombia should also encourage technological innovation, particularly when this allows the creation and strengthening of local companies and initiatives. For this reason, research and innovation programs will be encouraged to improve national technological and industrial capabilities.

The Government must play a central role in assisting R+D+I by promoting research programs and encouraging the uptake of private capital through public-private cooperation schemes. There are currently various funds in Colombia created by law that would be called upon to finance low-carbon hydrogen projects: the Science, Technology, and Innovation Fund (FCTeI for its Spanish acronym), which aims to increase scientific, technological, innovation, and regional competitiveness; the National Financing Fund for Science, Technology, and Innovation, which allows the Ministry of Sciences to develop flexible mechanism to finance science, technology and innovation activities by incorporating public, private, international resources along with donations.

Alternatively, existing hydrogen-related workgroups in Colombia will be encouraged in the different national universities and business associations, responsible for facilitating the transfer of technology from research to the national and international market. Later on, once the aforementioned initiatives in place have been fostered, the suitability of creating a National Hydrogen Center will be assessed that would serve as a showcase for pilot projects and the development of future applications, allowing Colombia not only to position itself in the production of this new energy vector but also to contribute towards the improvement of its technology. In accordance with the new developments carried out, an evaluation will be conducted to define which technologies could be industrialized and exported from Colombia.

Phase 2. Enable and promote market development

27. Mitigate technology risk through pilot projects

- Drive early pilot development throughout the entire value chain

To mitigate technological and business risk, the development of pilot projects will be fostered to determine the viability of low-carbon hydrogen, both technical and financial, from its production to its end-use. The stimulus will be carried out through economic incentives and administrative facilities that reduce the cost difference between the applications of low-carbon technologies compared to conventional solutions.

Pilots will be promoted in multiple areas, highlighting the following: electrolysis, CO_2 capture and storage technologies, hydrogen distribution infrastructure at the national level, and the transport of hydrogen and its derivatives to other countries.

In order to stimulate private investment and best practices adoption, the creation of an operations team will be endorsed to assist in the processing of permits and the development of the first pilots. This will reduce uncertainty, generate learning, resolve coordination shortcomings, and enable the safe introduction of new technologies. Additionally, these pilots could become the first demand and production nuclei, encouraging market development that will later benefit the other players.

Phase 3. Monitor progress and enable new use cases

28. Monitoring hydrogen production and consumption by type and sector

- Develop a monitoring system for the production and consumption of hydrogen

To guarantee the correct development of the low-carbon hydrogen market, the development of a national platform that records the production, consumption, and prices of hydrogen on an industrial scale in Colombia will be promoted, differentiating by types of hydrogen, such as gray, blue, or green, and by consumer sectors.

This system, which will be integrated with the national hydrogen projects and companies registry (first measure of action line 24), will facilitate decision-making regarding the deployment of infrastructure and will allow evaluating the degree of compliance with the established measures and objectives. It will be aligned with the national system of guarantees or certification of origin for low-carbon hydrogen.

The monitoring system will also track other social and economic criteria such as job creation and the level of investments to determine the impact of hydrogen technologies on the Colombian economy.

Annex I. Socialization plan

In parallel to the preparation of this Roadmap, a socialization plan has been executed in which the preliminary results of the evaluations carried out have been shared and experiences and best practices have been exchanged with relevant entities for the development of hydrogen in Colombia. In said socialization plan, contributions from various entities have been collected, including:

- Public entities
- Associations and business groups
- Power generators
- Natural gas carriers and distributors
- Hydrogen producers and consumers
- Carbon companies
- Mobility services companies
- Engineering firms
- Equipment manufacturers
- Universities and research centers
- Multilateral organizations

The objective of the socialization plan is to align the ambitions and objectives of the Ministry with those of the different stakeholders that will develop hydrogen projects and that will contribute towards the decarbonization of the Colombian economy.

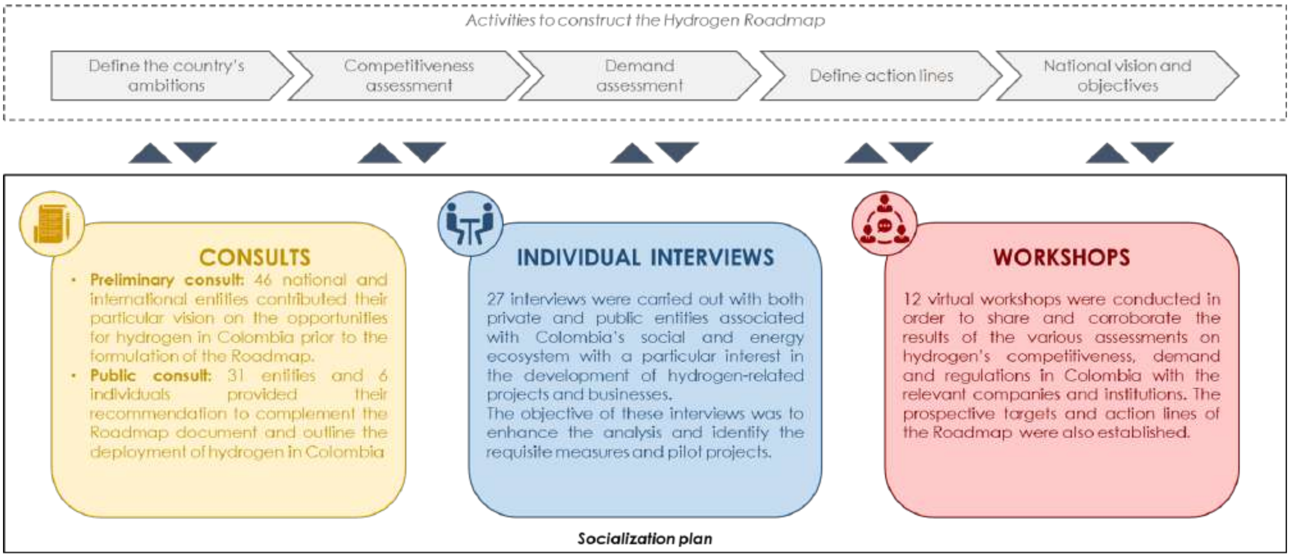

Figure 19: Hydrogen Roadmap Socialization Plan

Initially, a preliminary consultation has been launched, consisting of a survey with questions related to initial assessment analysis activities preceding the preparation of the Roadmap. In this consultation, 46 national and international organizations participated by contributing their particular vision regarding the opportunities and barriers to the development of the low-carbon hydrogen economy in Colombia.

In parallel to the aforementioned activities, 27 in-depth interviews were carried out with various actors in the Colombian economic and social ecosystem (private companies, associations, universities, and multilateral agencies). These interviews touched on experiences and best practices to be implemented in Colombia, thus complementing the Ministry's assessments.

The key results and conclusions of the assessment phase preceding the preparation of the Roadmap have been validated through 12 workshops wherein various ministries have taken part (Ministry of Mines and Energy, Ministry of Environment and Sustainable Development, Ministry of Science, Technology and Innovation, and Ministry of Transport) and other entities not directly related to the public sector. In these workshops, attendees have been able to comment on and assess the results and conclusions shown in this Roadmap.

Finally, the draft of this Roadmap has been submitted for public consultation. The comments and recommendations have helped to outline the final version, incorporating therein the perspectives of the different sectors.

Annex II. Governance

To ensure the correct deployment, monitoring, and evaluation of this Roadmap, it is considered necessary to create a governance structure that monitors the progress of low-carbon hydrogen in Colombia.

Governance model

The Hydrogen Roadmap's oversight will be headed by a Monitoring Committee, which will be responsible for ensuring the correct implementation and development of the measures set out in the action lines. The Committee will be comprised of members of the Ministry and representatives of other organizations, both public and private, as shown in Figure 20.

The Committee will have the task of coordinating with the different stakeholders, both public and private, the execution of the measures specified in the action lines. For this, the creation of a PMO (Project Management Office) will be evaluated to assist in managing the committee's activities, as well as to ensure compliance and execution of the measures indicated in the action lines.

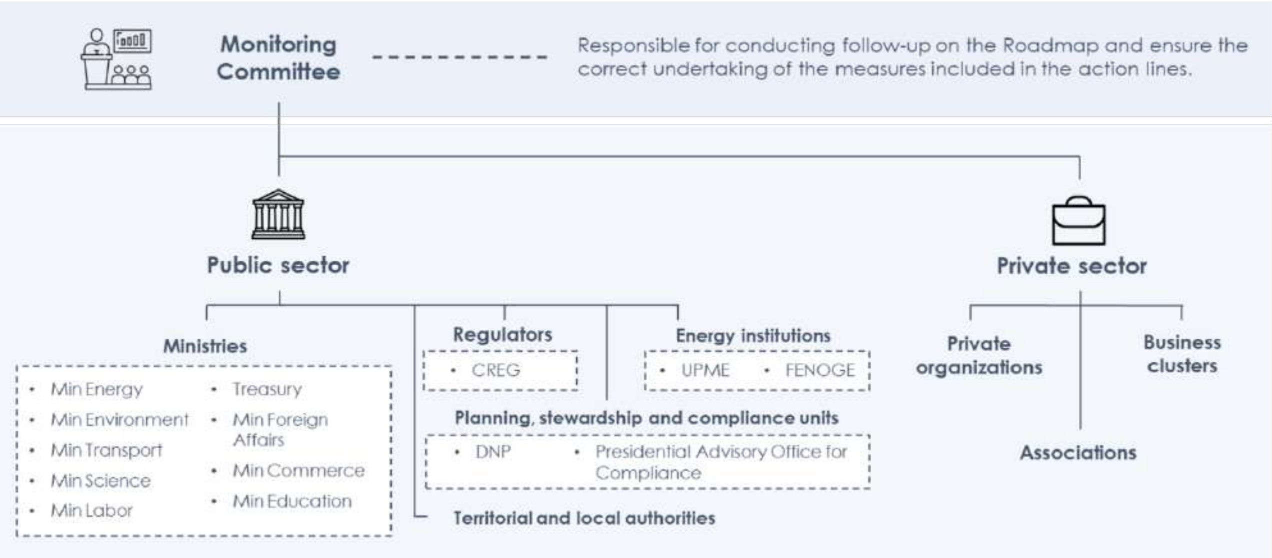

Figure 20: Hydrogen Roadmap Governance Model

Duties of the Monitoring Committee

The duties to be carried out by this public-private body are:

- Provide a global vision of the Roadmap, in terms of its implementation, monitoring, and evaluation.
- Develop general recommendations to exploit the opportunities hydrogen offers.
- Coordinate stakeholders and develop technical hydrogen-related roundtables.
- Actively assist the various ministries in implementing the Roadmap´s measures.
- Promote the establishment of consortia and agreements, national and international, to attract investment and facilitate the financing of projects.
- Identify new areas and strategic initiatives, as well as intervene in their development.

For the performance of the aforestated duties, the Monitoring Committee will meet annually, without limiting the possibility to call extraordinary meetings when deemed necessary. The members of the Committee may request the specific participation of sector experts to debate and decide on any specific issue.

Monitoring indicators

Progress monitoring and assessment will be carried out based on a series of indicators. These indicators will be analyzed at minimum every 3 years and will provide a comprehensive assessment of the strategy, determine the degree of implementation of the measures and evaluate the fulfillment of the objectives.

This review will be the main tool to achieve any necessary modifications to the Roadmap, ensuring that it remains consistent with developments regarding new market technologies and trends.

The indicators have been framed within two areas - production and demand - as follows:

Low-carbon hydrogen **production** indicators:

- **Number of projects developed.** Based on the registry of hydrogen projects that will be carried out (first measure of action line 24), the number of projects, the companies involved, the hydrogen production capacity, the technology used, and the location chosen will be quantified.
- **Electrolysis capacity (installed GW).** Electrolysis projects will be extricated from the above list to record the cumulative installed capacity in Colombia.
- **Production volume (tons of hydrogen).** The total hydrogen production volume in Colombia will be recorded, distinguishing by type of hydrogen (gray, blue, or green) and technology used.

Low-carbon hydrogen **demand** indicators:

- **Volume of consumption (tons of hydrogen).** To develop a national platform to monitor the production and consumption of hydrogen (first measure of action line 28), hydrogen producers will be asked to specify the contracts with consumer companies (national or international) or, in its absence, if the hydrogen is for its own consumption. This record will make it possible to evaluate the penetration of low-carbon hydrogen in the different sectors and subsectors, as well as its contribution to decarbonization.
- **Number of vehicles.** In collaboration with the Ministry of Transport, and based on the Unified Transport Registry (RUT), the number of fuel cell vehicles will be totaled specifying their typology (distinguishing between light-duty passenger vehicles, light-duty cargo, heavy-duty passenger vehicles, and heavy-duty cargo), and the penetration of these vehicles within the national automotive fleet.
- **Number of hydrogen fueling stations.** In line with the previous indicator, the number of publicly accessible hydrogen fueling stations available in the country will be recorded to guarantee a coordinated deployment of fleet and fueling infrastructure.