Main hydrogen challenges

"Virtue is revealed in adversity"
Aristophanes[46]

Although it has great benefits and is set to position itself as an essential energy carrier for decarbonization, green hydrogen development faces numerous challenges along the entire supply chain.

Renewable hydrogen production

The first link in the supply chain is the production of green hydrogen itself, which poses the challenge of being costly compared to conventional alternatives. Today, the levelized cost of green hydrogen (LCOH[47]) is two to three times higher than the production costs of blue hydrogen, which is produced from fossil fuels with CO2 capture (CCUS)[48].

To understand how this cost difference could be reduced, it should first be noted that, typically, between 66% and 75% of the LCOH relates to operating costs, mainly the cost of the renewable electricity required, while capital costs represent between 25% and 33%. Therefore, the main key to lowering the cost of hydrogen production lies in reducing operating costs. These depend mainly on three factors, including the price of electricity, which is the most important, the efficiency of the installation and the degree of load.

The reduction in the price of electricity and the degree of load depend to a large extent on the regulatory framework (applicable tolls and charges, additionality criteria / emissions intensity / temporal and geographical correlation to be set to consider hydrogen and its derivatives as renewable, possibility of injection into the gas grid, etc.), while increasing the performance of the installation, and therefore reducing the amount of electricity needed to produce 1 kg of renewable hydrogen, requires improvements in electrolysis technology and a more optimized design and operation.

With respect to the contribution of CAPEX to LCOH, this may be reduced to the extent that there are falls in production costs favored by a decrease in unit costs due to technological development, changes in the materials used, the effect of economies of scale and the learning curve. There is, therefore, scope for a reduction in electrolysis costs, but in the short to medium term there could be price fluctuations caused by misalignments in the supply chain, due to the growth in demand for electrolyzers outweighing the development of production capacity.

Beyond the cost of producing hydrogen, large-scale renewable hydrogen production also faces challenges associated with the main inputs to electrolysis: water and renewable electricity.

- To produce 1 kg of hydrogen, 9-10 liters of distilled water must be supplied to the electrolyzers. If the use of water for cooling the plant and the reject water (the volume of water, rich in dissolved salts, obtained as a by-product of water purification) is also taken into account, the volume required can amount to between 20 and 27 liters per kg of hydrogen.

  This means that projects have to properly plan the water abstraction to be used. Although the volume of water required, compared to other current water uses, is very small, this is an increasingly sensitive aspect due to periods of drought and water stress, which have occurred more frequently as a result of climate change. On the other hand, projects must also obtain authorization to discharge the aforementioned reject water, which is mainly clean water with a higher concentration of salts resulting from the osmosis process.

[46] Aristophanes, Ancient Greek playwright. Born around 446 BC, he is considered one of the greatest representatives of the comic genre in classical literature.
[47] The LCOH (Levelized Cost of Hydrogen) is a variable that indicates how much it costs on average to produce 1 kg of hydrogen considering all the costs, both capital and operating, involved in its production over the lifetime of the facility.
[48] IRENA. "Green Hydrogen Overview". (2021).

- The other major challenge of large-scale hydrogen production is likely to be obtaining all the renewable electricity needed. As an indication, with current technologies, 50-60 kWh of electricity is needed to produce 1 kWh of hydrogen. If the use of hydrogen and its derivatives is also expanded into new industrial sectors and heavy transport, a lot of electricity would be needed. This requires installing a large wind and solar power capacity, in addition to that needed for the direct electrification of other sectors such as light mobility or air conditioning, with the consequent challenges of grid connection, land use, etc.

Hydrogen transportation infrastructure

At present, hydrogen is mainly transported by road, in trucks loaded with hydrogen cylinders at different pressures, or by pipeline. It is important to highlight the challenges related to the latter mode of hydrogen transport, either by injection into the existing gas network (blending) or in a network dedicated exclusively to hydrogen transport.

Existing natural gas pipelines cannot be used directly to transport hydrogen at high concentrations due to the embrittlement of the steel that this gas produces in direct contact with the pipeline. As seen previously, blending hydrogen with natural gas is considered as an option to deliver hydrogen from production facilities. However, this is always considered at very low concentrations, currently varying between 3% and 5% by volume[49], and even at these concentrations, pipeline life can be significantly affected.

Likewise, due to the operation of the gas network and fluid mechanics, it is not easy to ensure that the maximum admissible volumetric concentrations are not exceeded in sections of the network, since the real concentration of hydrogen in the gas circulating through a part of the network depends on the flows at any given time, the number and location of injection points, etc. In addition, injection points must be carefully designed and located to avoid high concentrations around them.

On the other hand, it is important to keep in mind that different types of users are connected to the same gas network, and, once hydrogen is injected into the network, it is not possible to know how much hydrogen is leaving the network at each point. Where the gas is used as a fuel, low concentrations of hydrogen are unlikely to have a significant effect beyond variations in the calorific value of the gas (since the mixing ratio is volumetric and the energy intensity of hydrogen by volume is much lower than methane, so the higher the mixing ratio, the lower the calorific value per unit volume of the resulting gas). On the other hand, those industries that use methane as an input, mainly in the petrochemical sector, may see their processes affected by the lower purity of natural gas.

An alternative (or evolution) to blending is the creation of networks dedicated exclusively to transporting hydrogen. In this sense, repurposing, or conversion of the existing gas network to transport hydrogen, allows significant cost and time savings (permitting, expropriation, etc.). However, the transition from one to the other vector poses new challenges: when should natural gas transport be stopped and the infrastructure be adapted to hydrogen?

One possibility is to start on sections that have two parallel pipelines by first transforming one of them. The limitation is that this is probably only possible in a small part of the network.

[49] Energy Sci Eng: Howarth RW, Jacobson MZ. "How green is blue hydrogen?". (2021).

Moreover, it will depend on whether production and consumption are located in the right volumes in precisely these areas. Another possibility would be not to repurpose existing pipelines, but to build greenfield hydroproducts parallel to the existing network by taking advantage of available land and rights-of-way. In this case, one of the main problems to be solved is where to build the new hydrogen compressor stations, as there is a high probability of not having enough space.

In Spain, Enagás has announced the start of the non-binding "Call For Interest" process for the first essential components of the Spanish Hydrogen Backbone Network. This process aims to assess the level of interest from key players in the energy sector in the creation of the necessary infrastructure for the transport of renewable hydrogen.

Hydrogen utilization

Another key factor for renewable hydrogen to be an effective lever in global decarbonization is that it is necessary not only to produce it, but also to transform end uses and create the demand needed to justify investment in its production and distribution. This implies the need to invest in supply infrastructure, production and storage technologies, and to create the right policies to encourage and ensure adoption.

As discussed throughout this document, most of the end uses of hydrogen are currently focused on industrial applications, such as the production of ammonia or methanol, or other uses such as oil refining. However, renewable hydrogen also needs to be used in other sectors, such as transportation and power generation.

- In the transportation sector, renewable hydrogen can be used in fuel cell vehicles to provide a clean, emission-free fuel alternative. However, to achieve mass adoption of these vehicles, it is necessary to develop a hydrogen supply infrastructure that meets the needs of users in different regions. This implies significant investment in building hydrogen stations and retrofitting existing fossil fuel stations.

- In terms of electric power generation, renewable hydrogen can be used to balance the variability of renewable sources such as wind and solar energy. However, for this to be viable, large-scale hydrogen production and storage technologies need to be developed. In addition, appropriate incentives and regulations are also needed to encourage investment in hydrogen storage projects.

- Another important factor in the transformation of hydrogen end uses is the need for a just and equitable transition. The transformation of vehicle manufacturing industries that rely on fossil fuels to use renewable hydrogen can have a major impact on the workers and communities that depend on these industries. Therefore, policies and programs are needed to ensure that they have access to employment and training opportunities for new skills in the renewable hydrogen economy.

Hydrogen market

Hydrogen is currently an industrial gas generally produced in the same facilities where it will be consumed. Therefore, there is not yet a mature market for it. This implies that there is no reference price index established in the market, which translates into higher costs paid by consumers, as there is little price transparency and competition. On top of this, there is low demand for low-carbon hydrogen at present, indicating that projects must be integrated from production to infrastructure and end use.

However, as the hydrogen sector develops, markets can be expected to develop. Although it is possible to draw certain parallels between the development of these markets and that of natural gas (based on LNG), there are some particularities:

- While fossil fuels are extracted from geological deposits located in very specific geographic areas, hydrogen can be produced almost anywhere, as long as there is water and electricity. This favors the creation of supply and dilutes the market power of producers.

- The costs of transporting hydrogen by ship (measured in amount of energy per kilometer) are much higher than in the case of LNG due to its lower energy density by volume and its very low boiling point. Additionally, if it is transported in another form (methanol, ammonia, LOHC, etc.), the corresponding conversion losses (especially relevant if it is not used directly in the same form as it is transported) must also be added. This also means that the cost of transporting pressurized hydrogen by pipeline is much lower than by ship, and therefore, the location factor is more relevant in price formation than in the case of LNG.

- Because of this, competitiveness in the markets will be strongly marked by the aggregate cost of both producing and transporting the hydrogen to the final demand or reference site (not solely or primarily by the cost of production).

Finally, it is necessary to stress that the product should not be hydrogen itself, but green/low-emission hydrogen. Therefore, there needs to be a relative standard and credible definition and certification system. Without this, it is not possible to know whether the hydrogen generated meets similar criteria, and you are not paying for dirty, or not so clean, hydrogen at the price of green.

In addition, a major challenge in establishing the hydrogen market is to meet the requirements for access to financing. In the European Union, the Innovation Fund auctions exist to support the production of non-biological renewable hydrogen in Europe. These auctions represent a key initiative to accelerate the transition to cleaner and more sustainable energy sources, but they also require a sound financial structure and careful planning to ensure that hydrogen projects can access the funding necessary for their long-term development and success. In addition, the Green Pact Industrial Plan announced the launch of the first auction for renewable hydrogen production in autumn 2023, with an Innovation Fund budget of 800 million euros intended to be paid as a fixed premium to renewable hydrogen producers. Also of note is the EU Hydrogen Bank, a European auction that will award up to 800 million euros to renewable hydrogen producers.

Finally, there are levers that could accelerate and encourage the decarbonization of industry by introducing hydrogen into these markets. One policy instrument that could help in this context is carbon contracts for difference (CCfDs) – long-term contracts to pay the difference between the current carbon price and the actual cost of CO2 reduction. At the EU level, the Commission plans to launch CCfDs as part of its REPowerEU scheme to support the shift of current hydrogen production in industrial processes from natural gas to renewables.

Regulation

Regulation plays a key role in the development and implementation of green hydrogen. Some of the main regulatory challenges are the following[50]:

- Creation of specific regulatory frameworks for green hydrogen, preventing it from being treated in the same way as other common industrial gases, for example, by limiting its production to industrial areas.

[50]HyLaw: "EU policy paper" (2019).

- Definition of what is considered green or renewable hydrogen, where the conditions and maximum greenhouse gas emissions allowed in the production process are limited, the perimeter of which must be specified.

- Development of the necessary financial and non-financial incentives to encourage investment in renewable hydrogen production facilities.

- Creation of guarantee of origin systems for renewable or low-emission hydrogen to facilitate the emergence of a hydrogen market.

- Development of specific regulations to promote transportation with zero-emission vehicles, ensuring a space for those powered by hydrogen fuel cells.

- Creation of specific frameworks for maritime transport with gas-powered ships, including green hydrogen.

- Evolution of pipeline gas transportation regulations to determine hydrogen producers' conditions for hydrogen connection / injection into the network (blending, connection and injection, equipment, maximum percentages, applicable tolls, safety considerations, etc.).

Summary of regulatory activity by continent and country.

	Europe		North America		South America		Asia + Oceanía	
	European Union	**United Kingdom**	**USA**	**Canada**	**Colombia**	**Chile**	**China**	**Australia**
National hydrogen strategy	EU Hydrogen Strategy REPowerEU	UK Hydrogen Strategy	National Clean Hydrogen Strategy and Roadmap	Hydrogen strategy for Canada	Hydrogen roadmap in Colombia	National Green Hydrogen Strategy	"Medium and long-term plan for the development of hydrogen energy industry (2021-2035)"	Australia's National Hydrogen Strategy
Installed capacity target for 2030	44 GW (Fit-for-55) 65 GW (REPowerEU)	10 GW	-	-	1-3 GW	5 GW	"Medium and long-term plan for the development of hydrogen energy industry (2021-2035)"	Australia's National Hydrogen Strategy
Legal and regulatory framework	Fit-for-55 Renewable Energy Directive (2009/28/EC) 2 actos delegados	Low Carbon Hydrogen Standard (LCHS) Industrial Carbon Capture Business Model (ICC BM) UK Emissions Trading Scheme (ETS)	Bipartisan Infrastructure Law (BIL) Inflation Reduction Act (IRA)	Clean Hydrogen Investment Tax Credit-	Decree 1476 of 2022	Energy Efficiency Law 21,305	14th Five-Year Plan for National Economic and Social Development and the Outline of Long-Term Goals for 2035	Commonwealth Hydrogen Regulation Guarantee of Origin scheme
Support for investment and innovation	NextGenerationEU IPCEI Hy2Tech IPCEI Hy2Use European Hydrogen Bank European Clean Hydrogen Alliance	Hydrogen Investment Roadmap Powering Up Britain: Net Zero Growth Plan	Clean Hydrogen Electrolysis Program	Net Zero Accelerator (NZA) Clean Fuels Fund	Law 2099 of 2021	CORFO	National Key R&D Programs (NKPs)	Hydrogen Headstart Program
Regulation of hydrogen in the gas network	EU Directive on Gas and Hydrogen Networks CertifyHy	Ten Point Plan for a Green Industrial Revolution	HyBlend	G-25—Policy on the use of gas meters in hydrogen-blending activities in the natural gas network	-	-	-	National Gas Law (NGL) National Energy Retail Law (NERL)
Regulations for adapting H2 to transport	'Sustainable and Smart Mobility Strategy' together with an Action Plan CertifyHy	Targeting net zero - next steps for the Renewable Transport Fuels Obligation: Hydrogen and renewable fuels of non biological origin	Alternative Fuel Excise Tax Credit Alternative Fuel Infrastructure Tax Credit Carbon Reduction Program (CRP)	Emissions Reduction Plan 2030	-	Energy Efficiency Law 21,305	-	Commonwealth regulation relevant to hydrogen mobility and transport

Detail of the regulatory framework in different geographical areas.

European Union

- **Hydrogen strategy published.** The EU strategy on the use of hydrogen was adopted in 2020 and is focused on enabling the production and use of renewable hydrogen to help decarbonize the EU economy in a cost-effective way, in line with the European Green Deal, and to contribute to economic recovery following the COVID-19 crisis. Today, the foundations set out when this strategy was adopted in July 2020 are already beingfulfilled, as the first 20 action points in the strategywere achieved within the first quarter of 2022.

  In addition, with the publication of the REPowerEU plan in the second quarter of 2022, the European Commission completed the strategy proposed in 2020, thereby strengtheningits ambitions for renewable hydrogen as a key energy carrier in the transition away from fossil fuel imports from Russia.

- **Legal and regulatory framework.** In terms of regulation, in 2021 the EU approved the "Fit for 55" package, which includes a series of legislative proposals to promote the reduction of net greenhouse gas emissions. In addition, in February 2023, the European Commission took a further step to define the regulatory framework for hydrogen and its relationship with other existing standards by specifying the definition of renewable hydrogenin two delegated acts. The first act sets out the requirements for considering hydrogen-based fuels as renewable fuels[1]. The second defines how emission reductions must be calculated when using this type of fuel[2].

  In addition, the REPowerEU set a target to produce 10 million tons of RFNBOs by 2030, equivalent to 500 TWh of renewable electricity (14% of the EU´s total electricity consumption)[3].

- Support for investment and innovation. In recent years the EU has been promoting various initiatives to encourage investment and innovation in the hydrogen market. The COVID-19 post-crisis recovery program, "NextGenerationEU" involved large investments in green transition and digitalization projects. Later in 2020, hydrogen was included into the Major Projects of Common European Interest (IPCEI Hy2Tech and IPCEI Hy2Use). Finally, in recent months, the "European Hydrogen Bank" has been consolidating a proposal that seeks to create a financial entity specializing in hydrogen projects in the European Union. Its aim is to mobilize private and public investment to accelerate the development of green hydrogen projects and contribute to the energy transition.

- **Regulation of hydrogen in the gas grid.** In 2021, the European Commission proposed to reform the 2009 EU Gas Directive as part of the proposed hydrogen and decarbonized gas markets package. The reform seeks to create a legal framework for hydrogen networks similar to that existing for gas and electricity, extending consumer rights and regulating the integration of hydrogen into EU energy networks. This proposal advanced in the EU Parliament and Council during 2022 and 2023 as part of an ongoing legislative process.

  In addition, initiatives are being promoted to build a robust system of guarantees of origin for renewable hydrogen, an example of which is CertifHy, which provided the basis for the world's first non-governmental Guarantee of Origin scheme for hydrogen.

- **Regulations to adapt hydrogen to transport.** The development of hydrogen transport in Europe is supported by the European Commission's Sustainable and Intelligent Mobility Strategy published in 2021[4], which sets out a series of milestones for achieving intelligent and sustainable transport in Europe. These milestones include at least 30 million zero-emission vehicles on Europe's roads and a doubling of high-speed rail traffic by 2030.. In addition, it is envisaged that short-distance scheduled collective transport will be carbon neutral. Hydrogen will play an important role in achieving these goals, especially

United Kingdom

- **Hydrogen strategy published.** In August 2021, the United Kingdom published its national hydrogen strategy, UK Hydrogen Strategy[5]. The document outlines the objectives and the route to follow to achieve the "Net Zero by 2050" target. Subsequently, in August 2023, the Department of Business, Energy and Industrial Strategy published an update to the strategy, increasing the installed capacity target for 2030 to 10 GW.

- **Legal and regulatory framework.** The Low Carbon Hydrogen Standard (LCHS) sets out the necessary requirements for hydrogen produced to be considered low carbon. The standard addresses both the emissions at the point of production and the methodology for calculating them. In addition, studies have been carried out to assess the impact of existing policies on the development of hydrogen production. These include the Industrial Carbon Capture Business Model (ICC BM)[6] and the UK Emissions Trading Scheme (ETS)[7].

- **Support for investment and innovation.** In 2023, the "Hydrogen Investor Roadmap"[8] was updated to provide details of hydrogen project funding, supporting up to £11 billion of private investment by 2030. In addition, in April 2023, the "Powering Up Britain: Net Zero Growth"[9] plan was published, detailing the latest developments in the delivery of financial support to encourage the first large-scale deployment of electrolytic and CCUS-enabled hydrogen production facilities.

- **Regulation of hydrogen in the gas network.** In accordance with the Gas Safety (Management) Regulations 1996, the current hydrogen content in gas networks is limited to 0.1% by volume. However, as part of the "ten-point plan"[10], the necessary tests for the blending of up to 20% hydrogen in the gas distribution network by the end of 2023 are being promoted?.

- **Regulations to adapt hydrogen to transport.** Since 2008, the Renewable Transport Fuel Obligation (RTFO)[11] has required companies to demonstrate that a certain percentage of the fuel they distribute is from renewable sources. In addition, in July 2022, the Department for Transport published the "Targeting net zero - next steps for the Renewable Transport Fuels Obligation: Hydrogen and renewable fuels of non biological origin"[12].

USA

- **Hydrogen strategy published.** In September 2022, the US Department of Energy (DOE) published a draft National Clean Hydrogen Strategy and Roadmap, laying the strategic foundation for clean hydrogen development in the United States.

[1]EU Commission, "Delegated regulation on Union methodology for RFNBOs" (2023)
[2]EU Commission, "Delegated regulation for a minimum threshold for GHG savings of recycled carbon fuels" (2023)
[3]EU Commission, "Commission sets out rules for renewable hydrogen". (2023).
[4]European Commission – "Sustainable and Smart Mobility Strategy". (2021)
[5]HM Government, "UK Hydrogen Strategy" (2023)
[6]Department for Business, Energy & Industrial Strategy, "Carbon Capture, Usage and Storage" (2022).
[7]HM Government, "Developing the UK Emissions Trading Scheme (UK ETS)" (2022).
[8]Department for Business, Energy & Industrial Strategy, "Hydrogen Investment Roadmap" (2023).
[9]Department for Business, Energy & Industrial Strategy, "Powering Up Britain: Net Zero Growth Plan" (2023).
[10]HM Government, "The Ten Point Plan for a Green Industrial Revolution" (2020)
[11]Department for Transport, "Renewable Transport Fuel Obligation: Compliance Guidance" (2022).
[12]Department for Transport, "Targeting Net Zero" (2022).

- **Legal and regulatory framework.** In November 2021, the U.S. Congress signed the Bipartisan Infrastructure Law (BIL)[13]. This landmark legislation authorizes and appropriates $62 billion for the U.S. Department of Energy (DOE), including $9.5 billion for clean hydrogen.

  In addition, in August 2022, the President signed into law the Inflation Reduction Act (IRA) that enables additional incentives for hydrogen, including a production tax credit that will further boost the U.S. market for clean hydrogen.

- **Support for investment and innovation.** To support investment and innovation, programs such as the "Clean Hydrogen Electrolysis Program" have been established to improve the economics and profitability of electrolysis technologies. In addition, $8 billion has been allocated to regional clean hydrogen centersto enable the development of networks of clean hydrogen producers and the infrastructure to connect them.

- Hydrogen on the gas grid regulation. In addition, regulation of hydrogen on the gas grid is being addressed through the HyBlend initiative, which focuses on overcoming technical barriers to blending hydrogen in natural gas pipelines. including research on the compatibility of materials, as well as technical-economic and life-cycle analysis.

- **Regulations to adapt hydrogen to transportation.** The U.S. Department of Energy has been passing certain laws and tax incentives to promote and adapt hydrogen for transportation. These include the Alternative Fuel Tax Credit, which offers a $0.50 per gallon tax credit for certain alternative fuels such as liquefied hydrogen, and the Alternative Fuel Tax Exemption, a tax incentive that applies to fuel equipment including liquefied hydrogen. It has also approved the "Carbon Reduction Program (CRP)" which includes state funding for the deployment of alternative fuel vehicles.

Canada

- **Hydrogen strategy published.** In December 2020, the Canadian government published its hydrogen strategy, setting ambitious targets in terms of production and use.

- **Legal and regulatory framework.** The Government of Canada has recently introduced three tax credits aimed at encouraging the transition to a net-zero emissions economy in its 2023 budget. Of most relevance to hydrogen is the Clean Hydrogen Investment Tax Credit, a refundable tax credit that incentivizes the production of clean hydrogen, with credits ranging from 15% to 40%, depending on the carbon intensity of the hydrogen.

- **Support for investment and innovation.** In terms of initiatives aimed at fostering innovation and propelling investment, several programs have been developed including: (1) Net Zero Accelerator (NZA), an $8 billion program that supports projects enabling large emitter decarbonization, clean technology and industrial transformation; and (2) Clean Fuels Fund, a $1.5 billion fund established in 2021 to reduce the capital investment risk required to build new or expand existing clean fuels production facilities, including facility conversions.

- **Hydrogen on the gas network regulation.** The bulletin "G-25-Policy on the use of gas meters in hydrogen-blending activities in the natural gas network" establishes the time requirements and conditions to allow injecting concentrations of 5 to 25% hydrogen into the natural gas network.

- **Regulations to adapt hydrogen to transportation.** Finally, an emissions reduction plan "Emissions Reduction Plan 2030" has been published, aiming for 35% of the country's total sales of medium and heavy-duty vehicles to come from zero-emission vehicles by 2030. This would create a significant strategic opportunity for hydrogen fuel cell vehicle manufacturers.

Colombia

- **Hydrogen strategy published.** In early 2021, the Colombian government, in collaboration with multilateral organizations and research institutes, began to develop a roadmap to establish the basis for the hydrogen market in the country. The so-called Hydrogen Roadmap[14] establishes the basis for:

  - Reaching a production capacity of between 1 GW and 3 GW of green hydrogen production and 50 kt of blue hydrogen by 2030.
  - Setting a target price for green hydrogen generation at 1.7 USD/kg.
  - Achieving40% green hydrogen consumption out of the total H2 currently consumed in the industrial sector.

- **Legal and regulatory framework.** Regarding the current regulatory status, Law 2099 of 2021, through articles 21 and 23, gives the National Government general powers to define the mechanisms for promoting innovation, research, production, storage, distribution and use of hydrogen.

- **Support for investment and innovation.** In addition, Decree 1476 of 2022 establishes provisions to define mechanisms, conditions and incentives to promote innovation, research, production, storage, distribution and use of hydrogen for public electricity services, energy storage and decarbonization of sectors such as transportation, gas, hydrocarbons and mining.

Chile

- **Hydrogen strategy published.** In October 2020,he Chilean government presented a set of policies aimed at creating a green hydrogen industry, the National Green Hydrogen Strategy. This is divided into 3 phases, each with a different objective:

  - First (2020 - 2025): the aim is to accelerate the use of green H2 in refineries, ammonia production and transport vehicles, and to encourage the adoption of blending up to 20% of hydrogen into gas networks.
  - Second (2025 - 2030): the experience gained would allow a strong entry into the international markets by exporting up to 5 GW of H2 ,produced by electrolysis, by that date.
  - Third (2030 onwards): the goal would be to position Chile as a global leader in the export of clean fuels, achieving 25 GW of electrolysis-based hydrogen production, as well as a green hydrogen price below 1.5 USD/kg.

- **Legal and regulatory framework.** In terms of regulations, Law 21,305 on Energy Efficiency, published in February 2021, defines hydrogen as a fuel, allowing the Ministry of Energy to regulate its use, review and update the electricity market regulations to allow for the participation of hydrogen in the sector, update the natural gas regulation to introduce green hydrogen quotas and facilitate the processing of permits for projects involving it.

- **Support for investment and innovation.** Within the framework of the sustainable economic reactivation and the national hydrogen strategy, CORFO (Corporación de Fomento de la Producción) promotes access to financing for hydrogen projects, accelerates the implementation of initiatives aimed at producing Green Hydrogen and facilitates the creation of industrial and commercial alliances along its value chain.

[13]BIL: Bipartisan Infrastructure Law signed by President Biden on November 15, 2021.
[14]Ministry of Energy, Government of Colombia, "Roadmap for hydrogen in Colombia" (2021).

- Regulations to adapt H2 to transport. The Energy Efficiency Law 21.305 includes tax benefits for "zero emission" cars, among which Hydrogen cars are included.

China

- Hydrogen strategy published. In 2022, the National Development and Reform Commission and the National Energy Administration jointly published the Medium- and Long-term Plan for the Development of the Hydrogen Energy Industry (2021-2035. This is the first medium- to long-term plan to implement hydrogen use in China by 2035. Years earlier, in 2018, The National Alliance of Hydrogen and Fuel Cell (NAHFC) was established. On the other hand, the Chinese government has declared the goal of achieving carbon neutrality by 2060,with emissions expected to peak in 2030.
- Legal and regulatory framework. China does not have a defined overall legislative framework for hydrogen, so some provinces have decided to include their own strategy in the 14th Five-Year Plan for National Economic and Social Development and the Outline of Long-Term Goals for 2035. The documents compile progress on local hydrogen industry development, plant construction and operation. For example, the NEV industry action plan released by Shanxi Province in 2019 outlined plans on the use of hydrogen fuel cells in vehicles, and Guangdong Province also conducted a similar exercise through the "Implementation Plan for Accelerating the Development of Hydrogen Fuel Cell Vehicle Industry" released in 2020.
- Support for investment and innovation. The largest source of investment comes from the "National Key R&D Programs (NKPs)," applied research funds, which are an important source of public funding for research and developement. Since 2016, more than 60 NKP projects focused on hydrogen technologies have been announced. These projects promote research in electrolyzer technologies and seek to improve renewable hydrogen production.
- Regulation of hydrogen in the gas network. Projects are underway to transport hydrogen through the gas grid by blending it with natural gas. The China National Petroleum Corporation has transported hydrogen in the city of Yinchuan in Northwest China. The hydrogen was successfully transported by blending it into a natural gas pipeline.
- Regulation to adapt hydrogen to transportation. Since the publication of the 13th Five-Year Plan (2016), there has been a push for the development of hydrogen-powered vehicles have been stimulated, reaching 7700 FCEVs by the end of 2020.

Australia

- • Hydrogen strategy published. Australia has developed a national hydrogen strategy that sets out a framework for the development, production and export of green hydrogen.
- Legal and regulatory framework. Today, there is a Commonwealth Hydrogen Regulation that provides regulatory guidance on understanding what federal laws apply to hydrogen projects. In addition, in the 2023-24 budget, $38.2 million was allocated for the creation of a Guarantees of Origin scheme that will certify renewable energy and track and verify emissions of clean energy products. This scheme is essential for international hydrogen trade, as it will provide a measure of reliability and sustainability for hydrogen produced in Australia. It will also help new projects secure funding and improve the effectiveness of the government's efforts to scale up renewable energy and the hydrogen industry.
- Support for investment and innovation. Australia has established the $2 billion Hydrogen Headstart program to accelerate the production and use of green hydrogen as a clean and sustainable energy source in the country, while stimulating investment in large-scale hydrogen-related projects.
- Hydrogen on the gas network regulation. In 2022, the Ministry of Energy reformed the National Gas Law and Regulations. The reforms will ensure that existing regulatory provisions and consumer protections work as intended when hydrogen and renewable gases are incorporated into the gas grid. Previously, the National Gas Law (NGL) and the National Energy Retail Law (NERL) referred only to "natural gas". With projects underway to introduce hydrogen and biomethane into the gas grid, this terminology has been updated to provide regulatory certainty for the emerging industry.
- Regulations to adapt H2 to transportation. Within the "Commonwealth regulations", there is a section solely on federal regulations governing hydrogen powered vehicles, hydrogen or ammonia powered vessels, and the transportation of hydrogen or ammonia as cargo.

Many countries are already addressing these challenges by publishing hydrogen strategies, defining concrete measures and targets to promote green hydrogen, creating a legal and regulatory framework with specific regulations for the treatment of hydrogen along the value chain and specific definitions for green hydrogen, supporting investment and innovation, promoting guarantee of origin mechanisms, promoting zero-emission vehicle transport, and so on.

- Global interest in promoting a "hydrogen economy" has grown in recent years. Although some countries have shown greater commitment than others, the regulatory and strategic vision is the same: to achieve decarbonisation through the use of hydrogen. In order to get an overview of the positioning of some countries, various ongoing actions or future proposals related to renewable hydrogen have been compiled. Among these, the following stand out:

- The Publication of National Hydrogen Strategies defines measures and objectives designed by each country to promote the production, distribution and use of hydrogen as a clean and sustainable fuel. Within these strategies, national hydrogen installed capacity targets are defined for the 2030 horizon.

- Creation of a legal and regulatory framework that includes legal measures to facilitate the production and distribution of hydrogen, as well as the establishment of safety and quality standards.

- Investment and innovation support to encourage the development of innovative and more sustainable technologies aimed at promoting hydrogen projects throughout the value chain.

- Regulation defining the technical and safety requirements for blending hydrogen with natural gas in gas distribution networks.

- Adaptation of hydrogen as a transport fuel, establishing regulations for the installation of supply points and the necessary infrastructure for transporting green hydrogen.

Finally, it should be noted that, in this new energy landscape, companies are also facing significant challenges in terms of their strategy, their operations and their commitment to sustainability.

- **Strategy definition:** organisations will need to define their strategic positioning with respect to hydrogen, understand existing projects, keep abreast of regulatory developments, analyse the potential market and potential customers or off-takers, evaluate possible commercial alliances to strengthen their position, etc.

- **Strategy implementation:** Strategy implementation will involve the development of new projects whose investment decisions will need to be accompanied by appropriate technical-economic analyses, such as assessing the optimal location for renewable hydrogen production or analysing and applying for potential financial support.

- **Project Execution:** Project portfolio management must include identifying, assessing and managing potential risks using specific management methodologies.

- **Governance and reorganization:** Implementing the defined strategy may require internal reorganization and recruitment of skilled talent. The impact on information governance and the quality of hydrogen-related data will also need to be considered.

- **Operating and managing the business:** at the operational level, it will be necessary to adapt processes and systems to control the quality, safety and profitability of projects, to develop adapted commercial strategies, to evaluate hydrogen contracts, to model prices, to evaluate the execution of hedges, etc.

- **Link to sustainability goals:** Hydrogen development is also an opportunity for companies to meet their sustainability goals through monitoring of their commitments and key indicators.

Timeline of the European hydrogen regulatory and legislative framework

En la Unión Europea se han abordado distintas acciones para adoptar un marco regulatorio sobre el hidrógeno:

- In December 2015, the Paris Agreement[51], a global climate changed agreement aiming to reduce global greenhouse gas emissions, was reached.d

- In December 2018, the European Renewable Energy Directive (RED)[52] was revised to include a new overall EU renewable energy consumption target of 32% by 2030, including a section for transport.

- In December 2019, the European Commission proposed the European Green Pact[53], a package of policy initiatives aimed at positioning the EU as the first climate neutral region by 2050. It identifies hydrogen as a means to combat climate change.

- In July 2020, the European Hydrogen Roadmap[54] was published, placing this energy source at the heart of EU plans to decarbonize the economy.

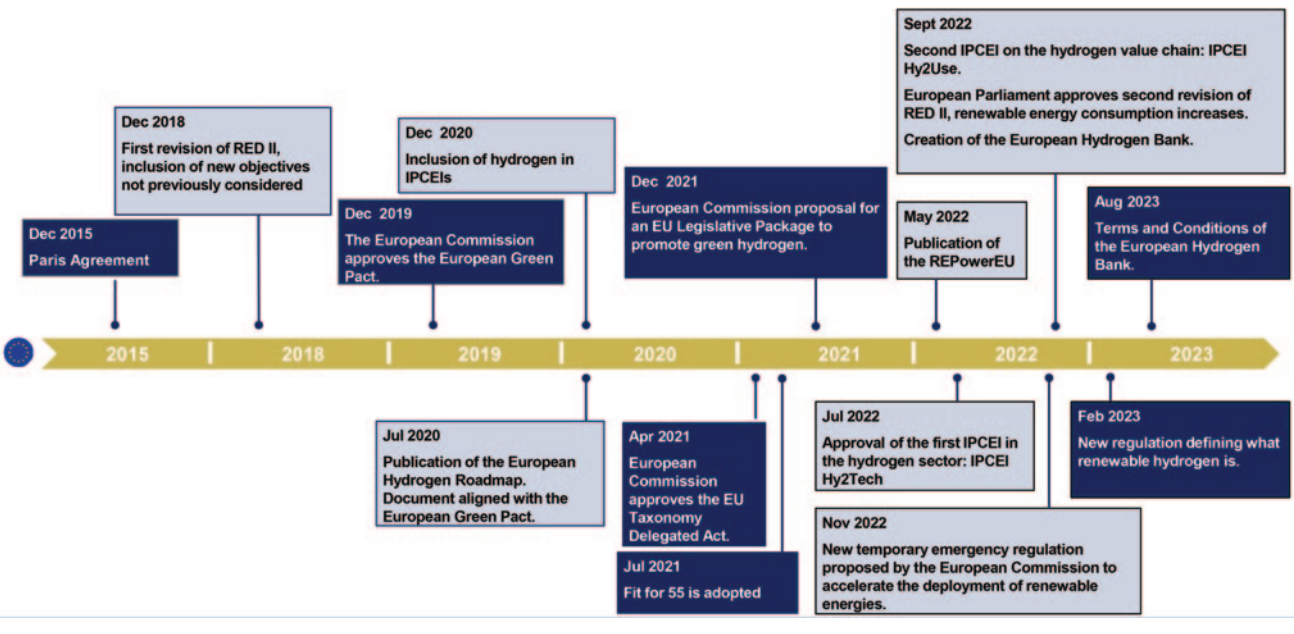
- In December 2020, hydrogen was integrated into the Important Projects of Common European Interest (IPCEI)[55] .

- In April 2021, the European Commission adopted the EU Taxonomy Delegated Act[56], encouraging renewable hydrogen production but also allowing high-efficiency blue hydrogen plants to meet European classification standards.

- In July 2021, the "Fit for 55" package[57] was adopted, a set of legislative proposals and amendments to existing EU legislation that will help the EU reduce its net greenhouse gas emissions and achieve climate neutrality.

[51] United Nations, "The Paris Agreement" (2015).
[52] RED: "Renewable Energy Directive". Approved in 2016, it is a legislative document that defines the objectives of the European Community's energy policy in the field of renewable energies and the legal framework for their development.
[53] EU Commission, "A European Green Deal" (2019).
[54] EU Commission, "Hydrogen" (2020).
[55] EU Commission, "IPCEIs on Hydrogen" (2020).
[56] EU Commission, "Acto Delegado de Taxonomía de la UE". (2021)
[57] EU Commission, "Fit for 55". (2021)

Figure 22. EU regulatory timeline



- In December 2021, the European Commission proposed an EU Legislative Package on the decarbonization of gas and the promotion of green hydrogen[58], with the aim of creating a hydrogen market and developing a dedicated infrastructure. It also provided for the creation of a European Network of Hydrogen Network Operators (ENHR) to ensure the development and management of the hydrogen network.

- In addition, in 2021, the first project for green guarantees of origin in the EU, "CertifHy", was approved.

- In May 2022, REPowerEU[59] was published, setting a target of 10 million tons of domestic green hydrogen production by 2030 and increasing the targets set by the Hydrogen Roadmap.

- In July 2022, the IPCEI Hy2Tech[60], was approved, with 41 innovation projects to develop hydrogen technologies. In September 2022, the IPCEI Hy2Use was also approved, complementing the IPCEI Hy2tech for the development of hydrogen infrastructure.

- In September 2022, the European Parliament approved the revision of the RED II[61] to increase the share of renewable energy in the EU's final energy consumption by 45% in 2030 (compared to the 32% originally proposed).

- In November 2022, the European Commission proposed new temporary emergency regulations to accelerate the deployment of renewable energy sources[62].

- In February 2023, the definition of renewable hydrogen was set out in two delegated acts. The first act sets out the requirements for hydrogen-based fuels to qualify as renewable fuels[63]. The second defines how emissions reductions from the use of this type of fuel should be calculated[64].

- In August 2023, the terms and conditions of the European Hydrogen Bank were published, which aims to encourage and support investment in renewable hydrogen production.

[58] EU Commission, "Questions and answers on the hydrogen and decarbonized gas package" (2021).
[59] EU Commission, "REPowerEU: A plan to rapidly reduce dependence on Russian fossil fuels and fast forward the green transition" (2022).
[60] EU Commission, "Remarks by Executive Vice-President Vestager on IPCEI in the hydrogen technology value chain". (2022).
[61] Balkan Green Energy News, "European parliment votes to raise renewables 2030 target to 45 %". (2022).
[62] EU Commission, "REPowerEU: Commission steps up green transition away from Russian gas by accelerating renewables permitting (2022).
[63] EU Commission, "Delegated regulation on Union methodology for RFNBOs" (2023).
[64] EU Commission, "Delegated regulation for a minimum threshold for GHG savings of recycled carbon fuels" (2023).