Foundation Redexis

HYDROGEN, THE KEY TO A SUSTAINABLE ENERGY MODEL

CONTENTS

INTRODUCTION

The Redexis Foundation was born with the motivation of being a fundamental active agent in energy transition and, as a result of that effort, has elaborated its first publication, focused on hydrogen.

The Redexis Foundation has elaborated this publication with the goal of raising awareness about hydrogen's current situation, the related projects that are being carried out and those that will be developed in the future, the existing regulations in Spain and the stance that the different countries of the world are taking.

Through promotion of technological innovation, social and welfare actions and the educational and cultural fields, the Redexis Foundation develops its commitment to the United Nations Sustainable Development Goals. And it is within this framework of economic, social and environmental responsibility that this publication is presented.

Hydrogen is set to be the energy vector that will play a relevant role, due to it being clean, safe, and affordable for the future. It has been several times in the last 40 years that hydrogen has been presented as a potential energy source, but it is only now that its potential has become a reality.

By using hydrogen as an energy vector, the European Commission goal for emission reduction can be made feasible and Europe can be the first climate-neutral continent by 2050.

Foreword by the President of the **REDEXIS FOUNDATION**

Sustainable energy to promote economic recovery

The gas infrastructures are ready to transfer the benefits of renewable gases, hydrogen among them, to society as a whole, by developing clean energy models that also generate professional opportunities.

The situation we have experienced in recent months is unprecedented. The health crisis generated by the COVID-19 pandemic, whose economic impact is yet to be defined, has hit society as a whole and has marked a turning point in our understanding of numerous habits and routines. Carrying on with our work in spite of all the added difficulties created by the lockdown, social distancing and the paralysis of the economy was a challenge that, as a society, we had to face since the outbreak of the health crisis. In the case of Redexis, whose activity was considered essential since the Government decreed a state of alarm, the commitment to remain fully operational during this period has been inescapable, ensuring a seamless supply of natural gas to each and every one of our customers, including numerous hospitals and health centres.

However, as we get normalcy back in all those areas of our day to day life that had been altered, we also recover the need to resume all the work that we had already invested in developing natural and renewable gases as a means of developing a socially and environmentally sustainable economy, a challenge that now includes the economic recovery.

> “Renewable hydrogen is an energy vector with a great future prospect. Its use in Spain is still incipient, but its potential is very relevant”

The challenge of sustainable economy, whose development entails the energy sector reducing its emissions, is a commitment that Redexis is promoting through natural gas; the cleanest, most efficient, and environmentally friendly traditional source of energy.

This low-emission energy, whose industrial and vehicular applications allow for the emission of particles and other polluting gases to be reduced, supports the entry of renewable energies in the electricity sector, favours industrial competitiveness and guarantees supply's security. It is a reliable and economical energy that is essential to displace an increasing volume of petroleum products.

Redexis owns modern, efficient and technologically cutting-edge gas transmission and distribution networks in the industry. We are also pioneers in the use of artificial intelligence in networks giving priority to criteria such as digitization, innovation and automation throughout our supply chain. Therefore, our networks are also prepared to exploit the potential of renewable gases, mainly hydrogen and biomethane, which the Company is promoting as energy solutions for the future.

Renewable hydrogen is an energy vector with a great future prospect. Its use in Spain is still incipient, but its potential is very relevant: it can be generated from renewable energy sources and involves zero pollutant emissions in any of its uses, being also injectable in the current natural gas transmission and distribution networks. It represents a clear and innovative opportunity to develop a stable energy source with virtually no environmental impact.

In the last year, Redexis has made a strong and determined commitment to promote the development of hydrogen in Spain by committing to invest more than 60 million euros in renewable gas projects for the 2025 horizon. Being already part of the Balearic Government's 'Power to Green Hydrogen Majorca' project, which will allow a green hydrogen production plant to be available in 2021. In addition, Redexis is currently undertaking a project to integrate a hydrogen fuel cell to generate electricity and heat in a Control and Measurement Station (CMS). A pioneer project in Spain regarding the implementation of a technology that may be key to the development of carbon-free energy consumption. Redexis is also a part or the HIGGS project, led by the Aragon Hydrogen Foundation. This project's goal is to measure the impact on the gas infrastructure its components and management of different hydrogen percentages.

Biomethane, is also a perfect exponent of the circular energy economy development. From reusing residues from livestock, the agri-food industry and human activity, a biogas is generated which is refined through an upgrading process that gives us biomethane, a fuel that is similar to natural gas in all its properties and advantages. Redexis is in constant search for new opportunities to exploit waste reuse capacity for energy generation, in line with the recent approval of the Spanish Strategy for Circular Economy (EEEC), to which we can make a significant contribution from the gas industry through renewable gases.

> “Redexis has made a firm commitment to promote hydrogen's development in Spain by undertaking large investments”

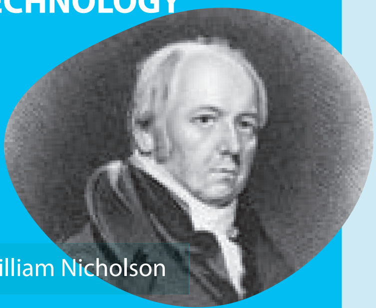
Our gas infrastructures, to which we must add all the efforts we are investing in the construction of new filling stations of Vehicular Natural Gas (VNG) as an alternative for sustainable mobility and low emissions over these years, which are prepared to transfer the benefits of renewable gases to society as a whole, developing new sustainable energy models that also generate new professional opportunities and result in a quality of life improvement for everybody.

Fernando Bergasa
REDEXIS FOUNDATION PRESIDENT

HISTORICAL OVERVIEW

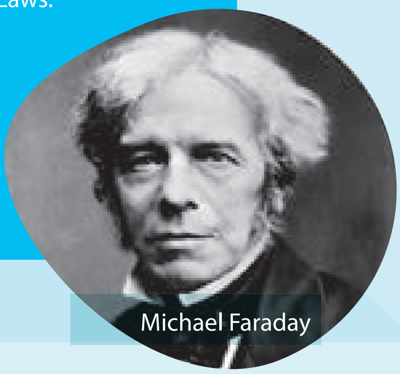
“Hydrogen production through simple and known chemical reactions has been taking place for over 200 years”

MATURE TECHNOLOGY



William Nicholson

- Electrolysis has been known for more than 200 years.
- In 1800, the chemist William Nicholson performed water electrolysis achieving the separation of hydrogen and oxygen by applying an electrical current.
- In 1834, Michael Faraday published his results on electrolysis research, resulting in Faraday's electrolysis First and Second Laws.



Michael Faraday

1787

- The name “hydrogen” was formulated in **1787** by the French chemist Antonie Laurent de Lavoisier, who already related this element to water by using the Greek word hydro (water). It had previously been called “flammable air” by the English chemist Henry Cavendish and, today, its German name “wasserstoff” (water substance) which reveals its properties.
- Hydrogen and energy have a long history together. The first demonstrations of electrolysis and fuel cells began to occupy the engineers' imagination in the **19th century**.

60's **70's** **90's**

- Hydrogen was used to fill balloons and aircraft and, in the **60s** demonstrations began to use it as space rockets fuel, taking men to the moon in **1969**. In these years, the first passenger vehicle with a fuel cell was made.
- During the **70s**, due to the high cost of fuel cells, the concept of a hydrogen economy linked to solar energy began to develop. Subsequently, in the **90s**, hydrogen and fuel cell technologies evolved, with great technical progress being made in this regard, especially aimed at the mobility sector.

"Replacing energy used in industries with hydrogen of renewable origin is today one of the main challenges at global level"

21st century

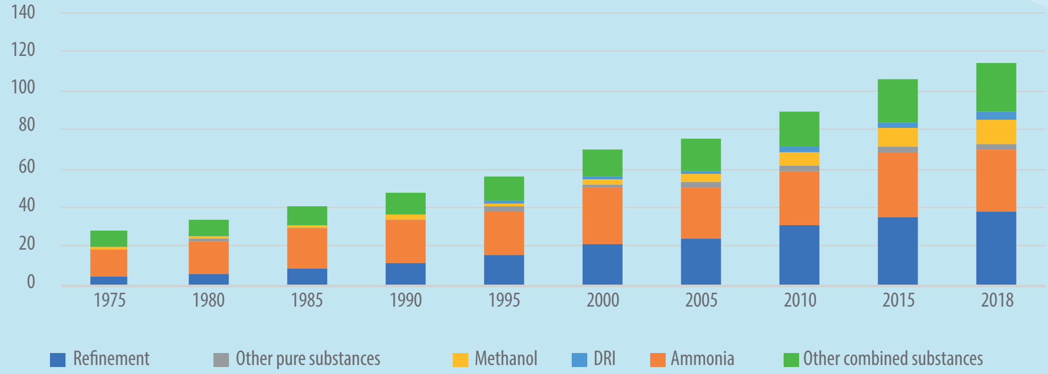
- With the advent of the **21st century,** issues such as sustainability and the growing importance and development of renewable energies brought the idea of a hydrogen-based economy back into the table.

Today

- Today, the concept of hydrogen is linked to that of energy transition at both, national and global levels, since its leading this transition to become one of the energy vectors of the future. Considered the cleanest way to store energy and due to its ease of transmission, hydrogen obtained through electrolysis will play a major role in the future.

- Hydrogen demand has multiplied three times since **1975** and it continues to increase, at about **70** million tons per year. Today, the growing interest in hydrogen production from renewable energies is based on:
  - Hydrogen does not produce pollutant emissions or greenhouse gases.
  - It can be obtained from renewable energy sources.
  - Electricity can be stored in the form of hydrogen.

Annual global demand for hydrogen since 1975:



1 Quantities in millions of tons of hydrogen
2 DRI: Direct Reduction Iron
3 Refinery, ammonia and "other pure substances" represent the demand for specific cases where hydrogen combined with small amounts of other substances is needed. Methanol, DRI and "other combined substances" represent the demand for solutions that mix hydrogen with other gases, such as for fuels.
4 Source: International Energy Agency `The future of Hydrogen`

Hydrogen's current status
PRODUCTION, STORAGE AND TRANSMISSION

More than 100 elements are known in chemistry and, out of them, more than 90 are produced naturally. Hydrogen is the smallest and lightest of all chemical elements. It is the first of the periodic table and also the simplest. It consists of a positive charge (proton) and a negative electron. Is the lowest atomic weight element (1,008 g/mol): 12 times lighter than coal, 14 times lighter than nitrogen and 16 times lighter than oxygen.

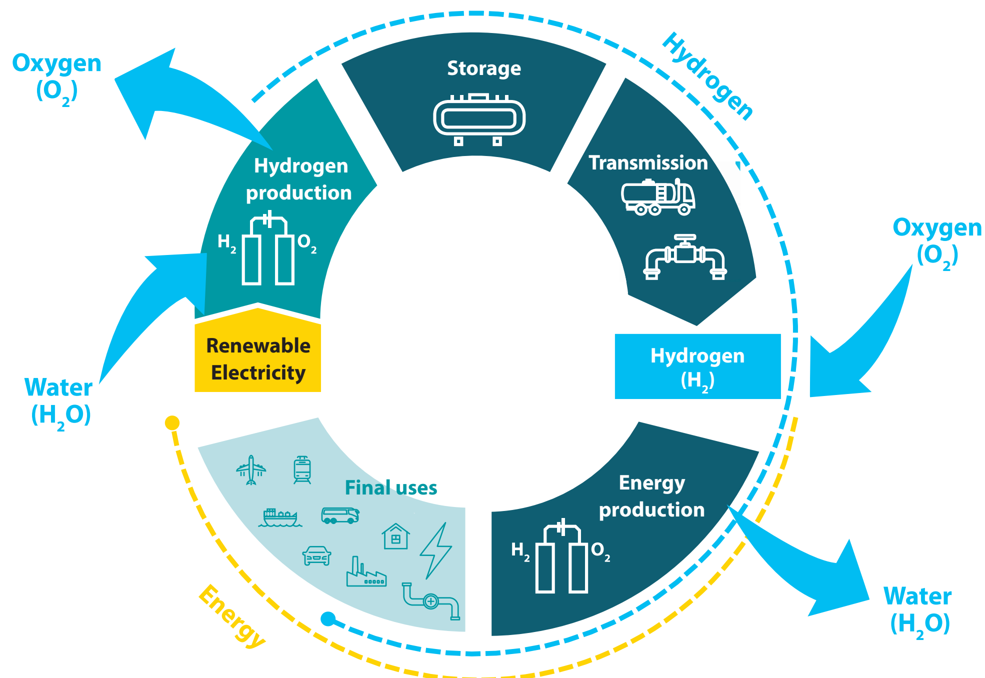
Two hydrogen atoms bind to form a hydrogen molecule (H_2), which is stable and chemically inert at room temperature. Temperatures above 6,000ºC would be required for the hydrogen molecule to separate into hydrogen atoms.

Hydrogen is one of the most abundant elements on Earth and it is possible to generate a large capacity of energy from its combustion. However, it is difficult to find it in its pure form and is usually combined with other elements such as oxygen in the form of water (H_2O), for which it needs to be extracted. Additionally, it is also possible to find it along with fossil energy sources such as natural gas.

Hydrogen has a high calorific value (39.41 kWh/kg) and one of its main advantages for its application in energy uses is its high energy density per unit mass, represented by a HCV (Higher Calorific Value) of 39.41 kWh per kilogram of hydrogen.

Despite this high energy content, hydrogen in gas phase presents the disadvantage of its low density, which means that 11.12 cubic meters of space are required to store a kilogram of hydrogen in gas phase under conditions of 1 bar of pressure and a temperature of 15°C. In this way the energy contained in 1 kg of hydrogen allows to shift an equivalent amount of energy of between 2.54 and 3.14 kilograms of natural gas (depending on the composition of the natural gas). However, at a pressure of 1 bar and 15ºC of temperature, the volume occupied by 1 kg of hydrogen is 8.2 greater than that of 1 kg of natural gas.

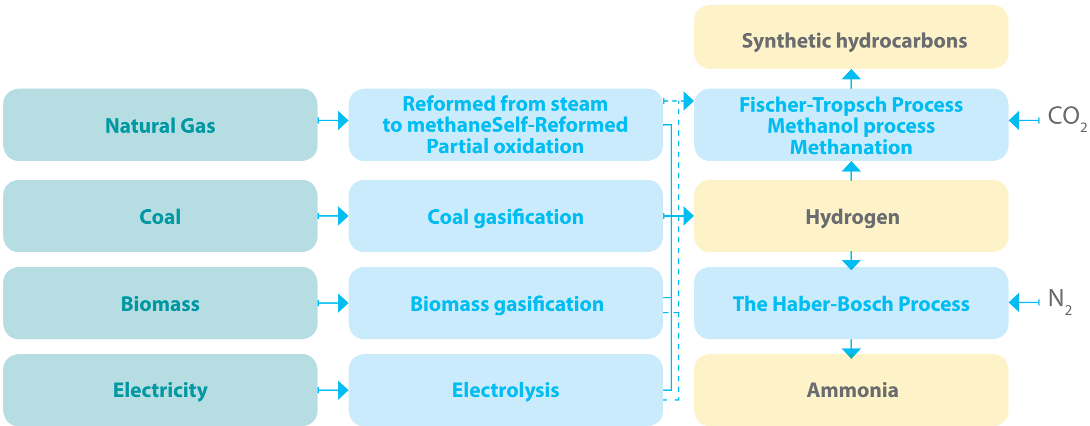
Renewable hydrogen as **a decarbonized energy vector**

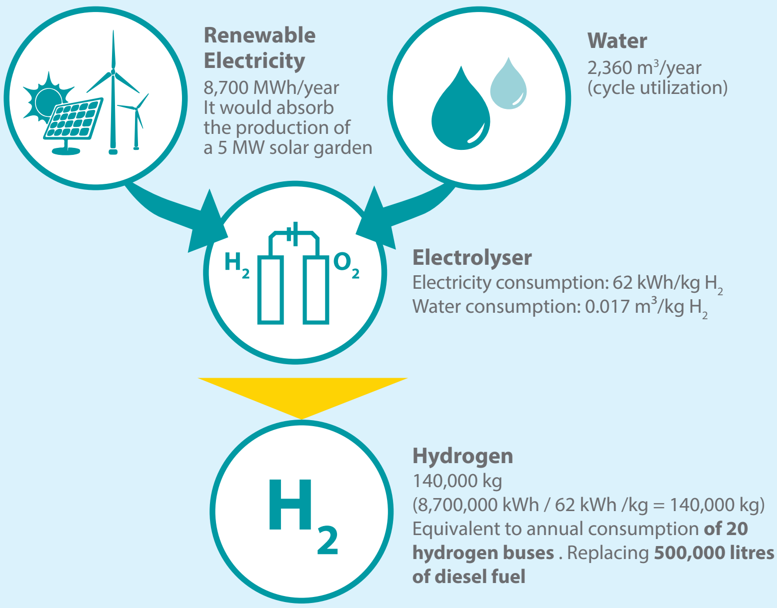


PRODUCTION

Hydrogen can be extracted from fossil fuels and biomass, or from water, or from a mixture of both.

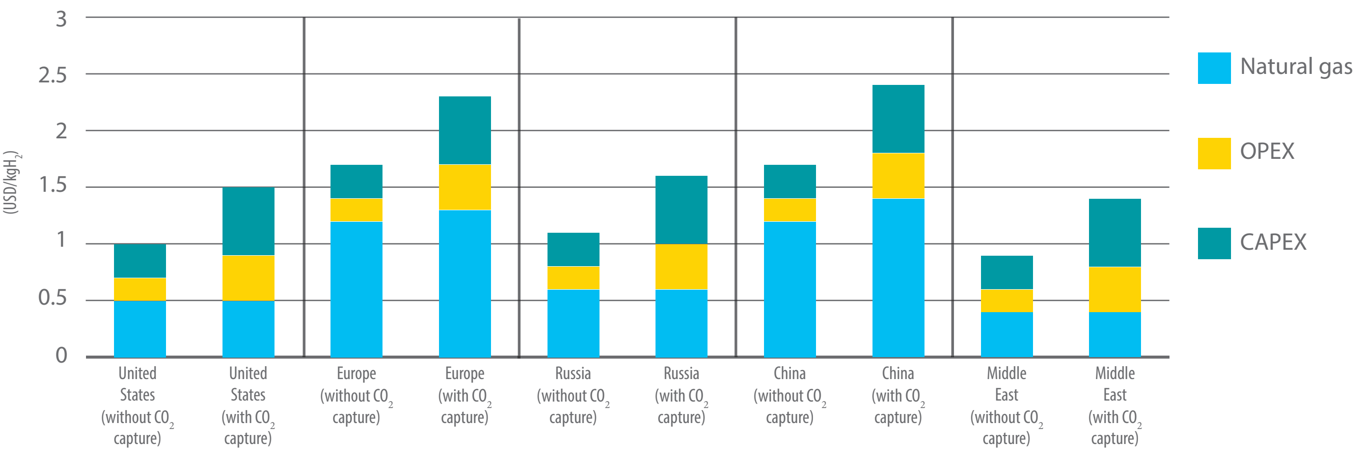
Potential **hydrogen and hydrogen-based products production pathways:**





Hydrogen production from water electrolysis has historically been very low, mainly due to the high capital cost of electrolysers and the associated electricity supply cost. However, the decline in the cost of generating electricity and the increase in surplus renewable generation resulting from the increase in solar and wind production capacity, pose a new scenario in which the production of green hydrogen in larger plants facilitates a significant reduction in hydrogen cost.

Costs of hydrogen production
using natural gas in different regions (2018)



Notes
kgH_2 = Kilograms of Hydrogen
OPEX: Operating Expenses
CAPEX in 2018: SMR without CO_2 capture=500-900\$/kWH_2, SMR with CO_2capture=900-1600 \$/kWH_2, with variations by region. Gas price=3-11\$/MBtu, varying by region.
More information at www.iea.org/hydrogen2019
Source: IEA 2019

According to their production method, **there are three types of hydrogen:**

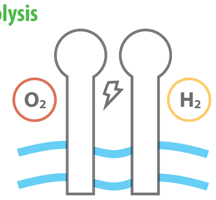
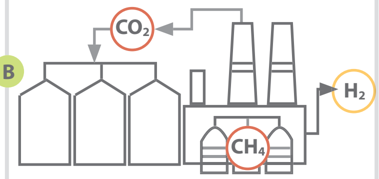
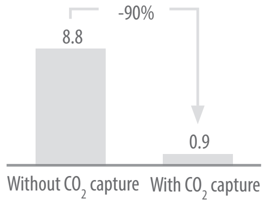
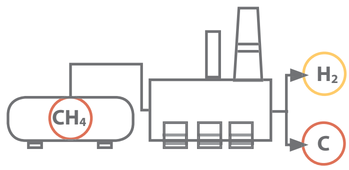
BROWN HYDROGEN:
from natural gas steam reforming without CO_2 capture.

BLUE HYDROGEN:
from natural gas steam reforming capturing CO_2.

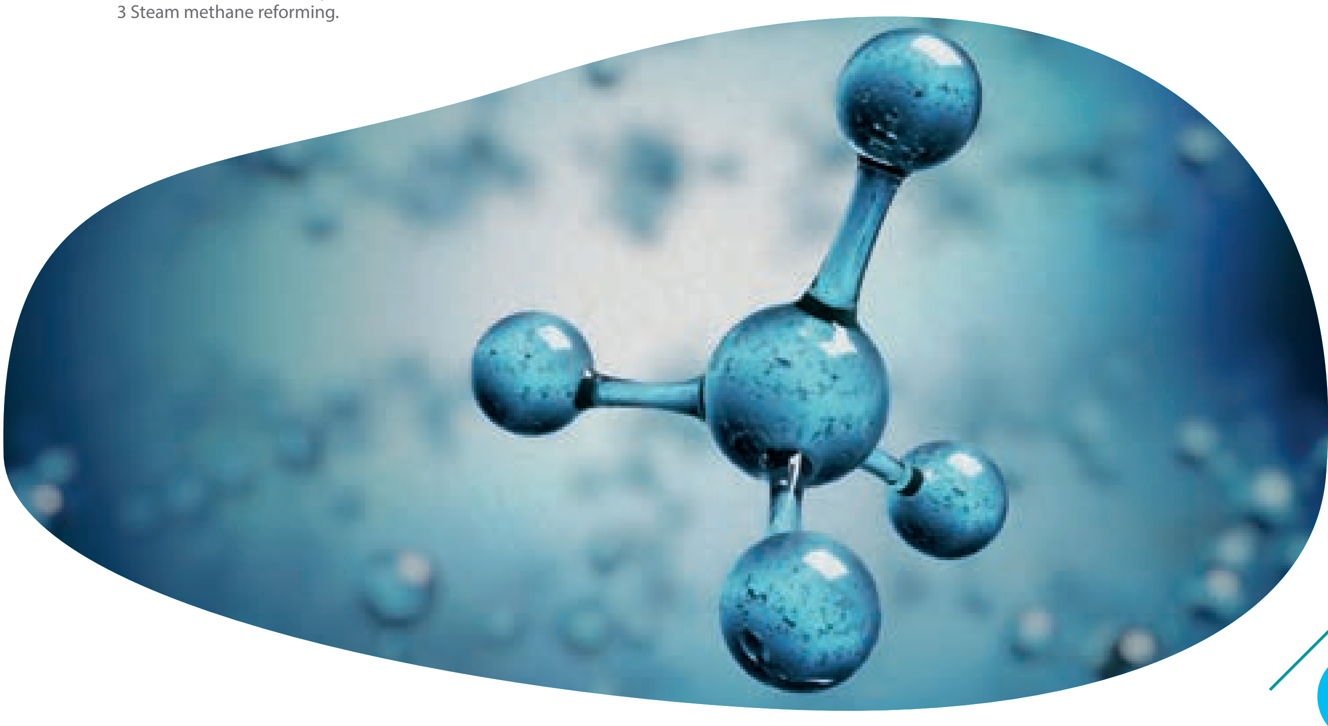
GREEN HYDROGEN:
by water electrolysis from renewable sources electricity.

> Extracting hydrogen from water using an electrolysis process through renewable sources would result in a green hydrogen 100% renewable, with zero emissions

Hydrogen Production Technologies and Processes:

	Technique	Process	Emissions ($kgCO_2/kgH_2$)
Renewable energies (without emissions)	**A** **Electrolysis** 	• **Separation** of water into hydrogen and oxygen through electricity flow. • There are different techniques: **alkaline, PEM[1], SOEC[2].**	Zero CO_2
Natural Gas	**B** **SMR[3] reactor and CO^2 capture** 	• **Separation** of natural gas into hydrogen and carbon dioxide (capturing and storing CO_2). • This process without capturing CO_2 is the most commonly used.	
	C **Pyrolysis** 	• **High temperature separation** of natural gas into hydrogen and solid carbon. • This technique is still being developed to achieve a large hydrogen economy.	Zero CO_2

1 Proton exchange membrane.
2 Solid state oxide electrolyser.
3 Steam methane reforming.



STORAGE

One of the major advantages of hydrogen is that, unlike electricity, it can be stored for long periods of time, one of the reasons why it is destined to play a major role in the energy transition.

The most common storage methods, which have been tested for long periods of time, are physically based on compression and cooling.

> “Hydrogen can be stored for long periods of time”

Physical storage methods:

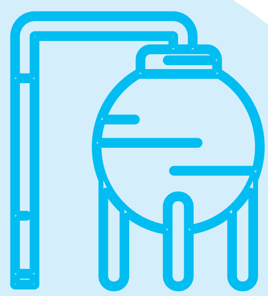
- These are the most commonly used and with a more developed technology.

- Compressed hydrogen in gaseous state (350. 700 bar)
- Hydrogen in liquid state LH_2
- Pressurized cylinders
- Liquefied hydrogen
- Geological storage

Material storage methods:

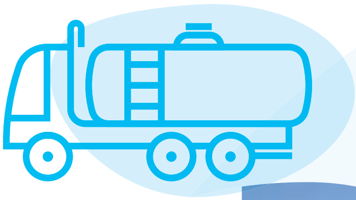
- These storage methods, which can be in a solid or liquid state, are still in development due to the costs and times spent during the different processes.

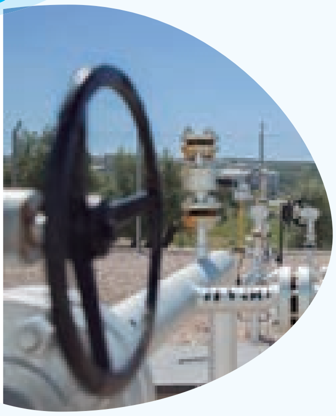
- Hydrides
- Absorbent materials



TRANSMISSION

Today, hydrogen is transported in gaseous form through transmission networks or in both liquid and gaseous form by trucks.

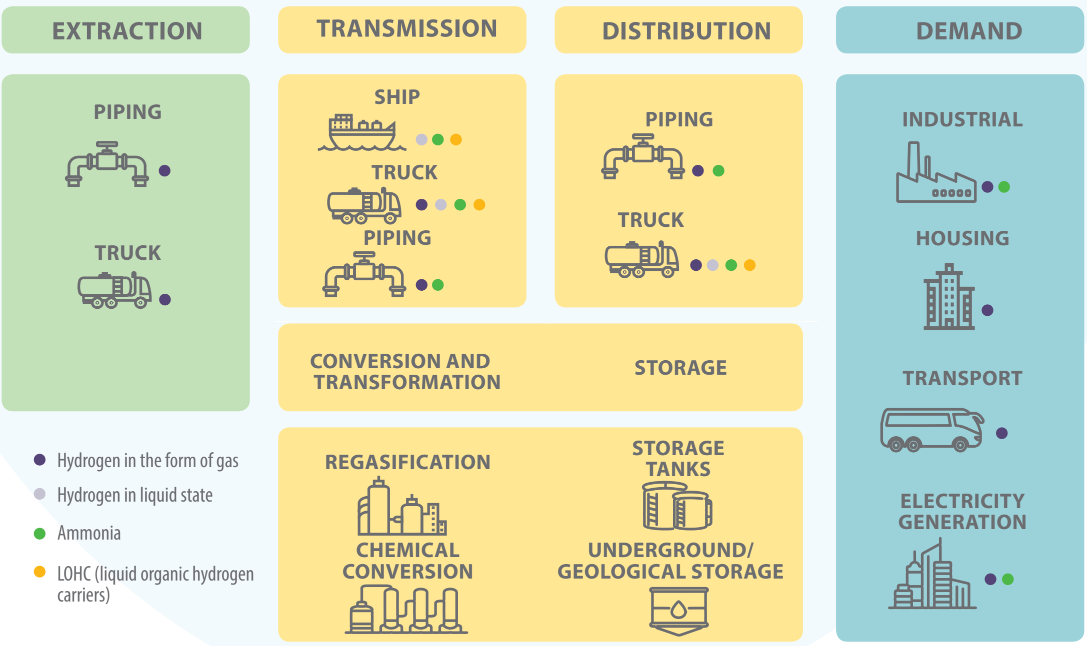




- The **networks** through which hydrogen can be transported are the best choice for long distances and on a large scale. In this case, there is the possibility of building hydrogen pipelines, with the resulting high initial investment. There are already more than 4,500 kilometres of hydrogen pipelines in the world, with the United States leading the list, followed by Belgium and Germany. The second option is gas pipelines, transporting hydrogen mixed with natural gas, which is already being done. The big advantage of this process is that most of the infrastructure is already available and only small investments would be needed to transport hydrogen through the networks.

- **Trucks:** hydrogen can be transported in compressed gas containers by heavy vehicles such as trucks. The volume of available containers is small and each truck can carry approximately 500 kilograms of hydrogen, making this system more suitable for moving small amounts. It is also possible to transport it in liquid form obtaining higher volumes of hydrogen and making this, the more effective option for large volumes and distances.

Hydrogen value chain transmission, distribution and storage elements:



Source: IEA 2019

Hydrogen in the world

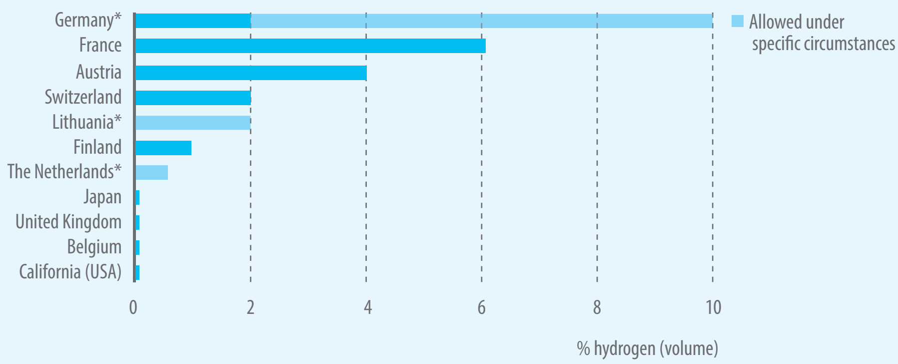
In the **2015 Paris Agreement**, **195** countries **agreed** to increase their efforts to **reduce their emissions** to **zero** in all sectors over the course of this century.

In **2018**, at the **Intergovernmental Panel on Climate Change**, it was agreed that emissions had to reach **zero** by **2050.**

By mid **2019**, the total number of political leaders **who encouraged** this vector was around **50**.

Within the G20 and the **European Union**, **11 countries** had **policies for** hydrogen and **9** had **road maps** for its transmission.

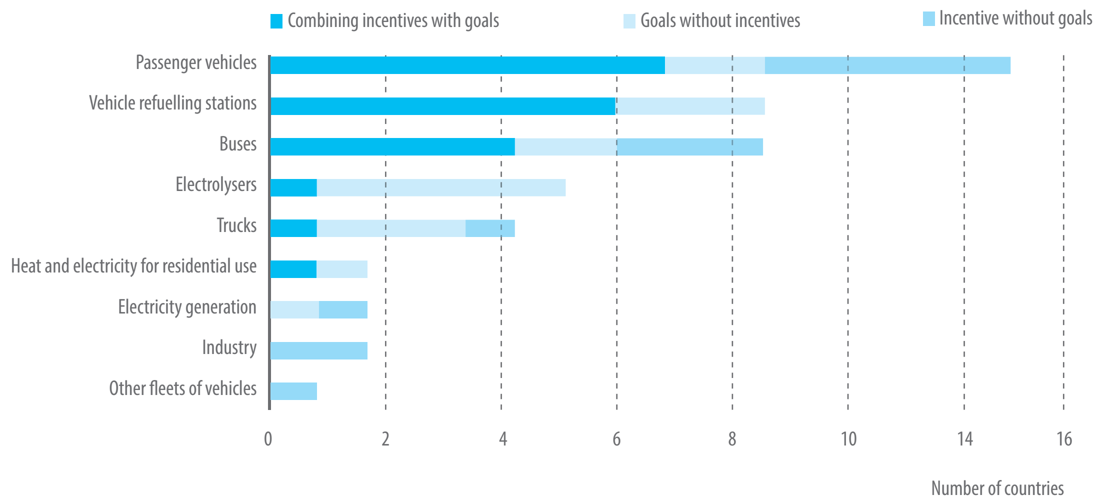
Current limits of hydrogen injected into natural gas networks



* In Germany, higher limits are allowed if there are no CNG refuelling stations nearby; in the Netherlands higher levels are allowed according to high gas calorific levels; in Lithuania higher levels are allowed when the network pressure is greater than 16 bar.
Source: Dolci et al (2019)

> "The number of countries with policies that directly support hydrogen investments is increasing"

Policies that directly support the deployment of hydrogen based on its final application:



Notes:
Based on data available in May 2019
Source: IEA analysis and surveys from governments collaborating with IEA Hydrogen Technology Collaboration Programme, IPHE (2019)

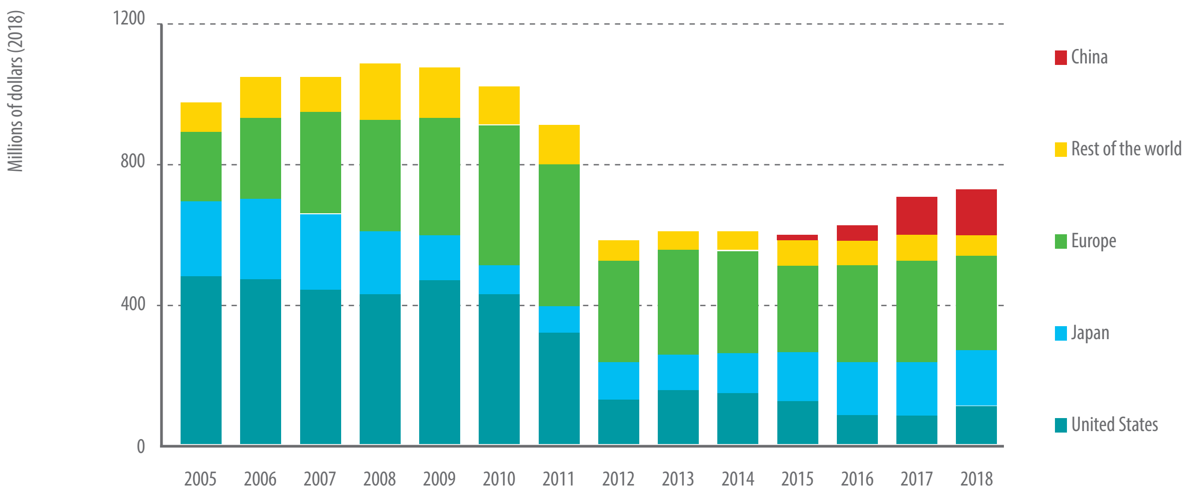
> "International cooperation is vital to accelerating the growth of a worldwide clean and versatile hydrogen"

'Hydrogen Council' is a global initiative made up of **81 energy, transport and industry companies** that seeks to develop a long-term hydrogen economy.

The goal is that by **2050**, **18%** of the world's energy demand will be satisfied by **hydrogen.**

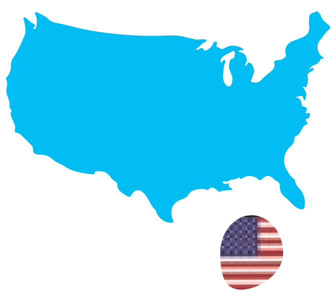
The number of countries that are setting targets to reduce greenhouse gas emissions is increasing, and with it, the number of sectors that are beginning to consider the use of green hydrogen. In 2017, the Hydrogen Council was established to bring together key private sector actors.

Government R&D budget for hydrogen and fuel cells:

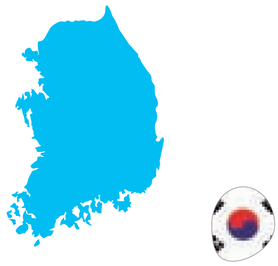


Notes:
Government expenditure includes European Commission funds, but does not include sub-national funds, which may be significant in certain countries
Source: IEA (2018)

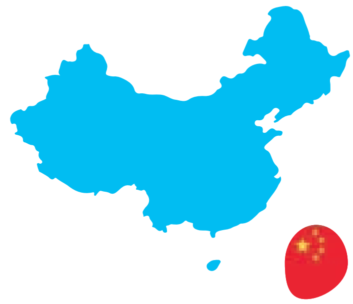
The **world's leader** in **hydrogen production** is **Japan,** which is driving this energy vector and sees it as a protagonist in the future. By **2030**, it aims to have **5.3 million** fuel cell installations and a production of **300,000 t.**



In **California**, **in the United States**, a commitment was made to invest **$20 million** per year between **2014** and the following seven years to construct refuelling stations for hydrogen vehicles.
The target is to have **94** by **2023**, **200** by **2025** and **1,000** by **2030.**
Recently, California has built **the world's largest green hydrogen production plant**, which will gasify recycled paper waste to economically produce green hydrogen.



South Korea is promoting renewable energies and plans to have, by **2022**, **310 refuelling stations** for hydrogen vehicles; and up to **1,200** by **2040.** By that year, its goal is to have more than **6 million hydrogen-powered light vehicles**, **60,000 buses** and **1,200 heavy vehicles.**



In turn, **China** is making major efforts in the **research** of fuel cells and hydrogen technologies, with the goal of having in **2030** **1 million** electric fuel cell vehicles (using hydrogen) and **1,000** refuelling stations.

Hydrogen in Europe

The European Commission, following the trend to reduce greenhouse gas emissions by 50% by 2030 and aiming to be the first climatically neutral continent by 2050, considers the development of hydrogen essential within the energy transition. With this "Green Deal", the aim is to transform the European Union's economy into a sustainable model and to make a fair transition to a circular economy, with an efficient use of resources, reducing emissions and protecting biodiversity.

The 'Hydrogen Europe', which brings together a total of 160 companies, 78 research organizations and 21 associations from different countries, has joined the 'Fuel Cells and Hydrogen Joint Undertaking' (FCH JU), a public-private initiative to support research, development and fuel cells projects and technologies linked to the use of hydrogen in Europe, demonstrating their potential and ability to achieve a clean energy system.

In addition, 'Hydrogen Europe' has promoted the '2x40 GW Green Hydrogen' initiative, with the aim of increasing electrolysers' production within the European Union to support hydrogen production. 20 billion euros will be allocated over the next 5-10 years and half of the materials and plants will be assigned to the European Union countries, the other half to Ukraine and North Africa, both of which are well located for renewable energy production. The resulting energy would then be imported to Europe.

> "The "Green Deal" aims to transform the economic model of the European Union"

Hydrogen Strategy

#EUGreenDeal

New EU roadmap

"The European Commission has drawn up, within the European Green Deal framework, a Communication with its Hydrogen Strategy for a Climate-Neutral Europe in 2050. The EU's hydrogen strategy addresses how to make the potential for hydrogen decarbonisation a really through investment, regulation, market creation and research and innovation.

The Commission therefore conveys the following **messages** in its strategy:

- Hydrogen is attracting a great deal of attention to the fact that it can **be used as raw material, stored and an energy vector**, and all of it without emitting CO_2 or affecting air quality.
- The fast reduction of renewable energy costs, technological developments and the urgency of drastically reducing greenhouse gases are opening up new possibilities in the **green hydrogen** development.
- Hydrogen can support industry's decarbonisation, transport, electricity generation and buildings in Europe.
- Hydrogen **can provide storage** to balance variations in renewable energy flows.
- The priority is **to develop renewable hydrogen**, produced mainly using wind and solar energy. However, in the short and medium term, other forms of low-carbon hydrogen are needed to rapidly reduce emissions and support the development of a viable market.
- A progressive incorporation of hydrogen solutions can lead to **a repurposing of existing gas infrastructures**.
- A rapid, large-scale deployment of green hydrogen is key for the Union to achieve its goals, as it can reduce greenhouse gases by 50% to 55% while being economically sustainable.
- **A hydrogen value chain** can provide work for up **to one million people in direct and indirect employment**.
- Analysts estimate **that green hydrogen can meet 24% of global energy demand** by 2050.

This whole process will have to be carried out by a gradual transition in a **phases** approach:

- **From 2020 to 2024**, the Union will support the installation of at least six gigawatts of renewable hydrogen electrolysers in the European Union and the production of up to one million tons of renewable hydrogen.
- **From 2025 to 2030**, hydrogen must become an intrinsic part of the Union's integrated energy system, with at least forty gigawatts of renewable hydrogen electrolysers and the production of up to ten million tons of renewable hydrogen in the Union.
- **From 2030 a 2050**, renewable hydrogen technologies are expected to reach maturity and be deployed on a large scale in all sectors of difficult decarbonisation.

To this end, the Commission proposes, among others, the following **measures**:

- A **coordinated action between the public and private sectors of the EU** is necessary, and the Commission has therefore launched an European Clean Hydrogen Alliance with industry and civil society leaders, national and regional ministers and the European Investment Bank. The Alliance will create a portfolio of investment projects to expand production and support demand for clean hydrogen in the EU.
- **Measures to promote the use of hydrogen in transport** will be proposed in the future Sustainable Mobility Strategy.
- **Further support measures** will be explored, including demand-oriented policies and end-use sectors under the Directive on Renewable Energy.
- **Hydrogen production facilities that take into account their total life cycle performance will be promoted** in terms of reducing GHG emissions.
- **Pilot projects to promote carbon by difference (CCfD) contracts** will be developed to encourage green hydrogen production over ordinary production by covering the cost difference.
- Begin **a plan for hydrogen infrastructures**, including Trans-European networks, and also taking into account the need to develop a hydrogen refuelling stations network.
- **Eliminating barriers that may hinder the development of a hydrogen infrastructure**, including the use of the existing gas network.
- Ensuring producers and customers' **access to a liquid hydrogen market.**
- **Promoting new technological developments in R&D**, including a Collaborative Framework on Clean Hydrogen focusing on the best and most modern technologies being ready to use, both in terms of renewable hydrogen production, transmission and distribution and in end-use key components.
- All this will also be supported by the relevant international collaborations that broaden the development horizon.

GERMANY

Germany, the European leader in the production and use of hydrogen, is firmly committed by this vector to transform its energy matrix and to contribute to the decarbonisation objectives of the territory, having a national strategy that advocates becoming the world's leading country in hydrogen uses and technologies, and that foresees an investment of 300 million euros by 2023 to support the research and development of green hydrogen projects.

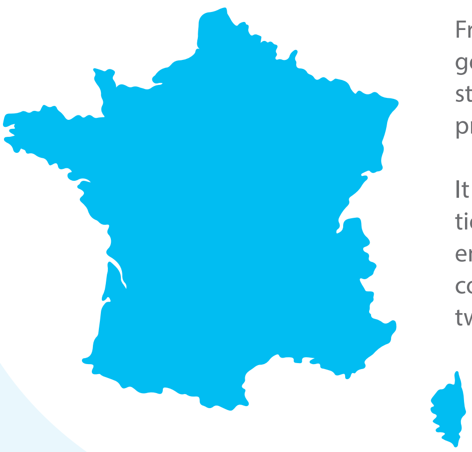
By 2025, it plans to have more than 400 hydrogen vehicle fuelling stations throughout the country and more than 500,000 vehicles that use this kind of fuel. In addition, it intends to have more than 500,000 fuel cell cogeneration facilities that produce at least 1,000 MW for that year.

The targets for hydrogen production from renewable sources in Germany for 2025 are 1,500 MW.

BELGIUM

Belgium places great value on the generation of renewable energy, especially through wind turbines, but the amount of energy generated is often lost because there is insufficient demand. To cope with this, it wants to develop a hydrogen economy in the country that allows for the storage of surpluses and to reduce emissions.

For 2025, it will have a green hydrogen production plant in the port area of Ostende.



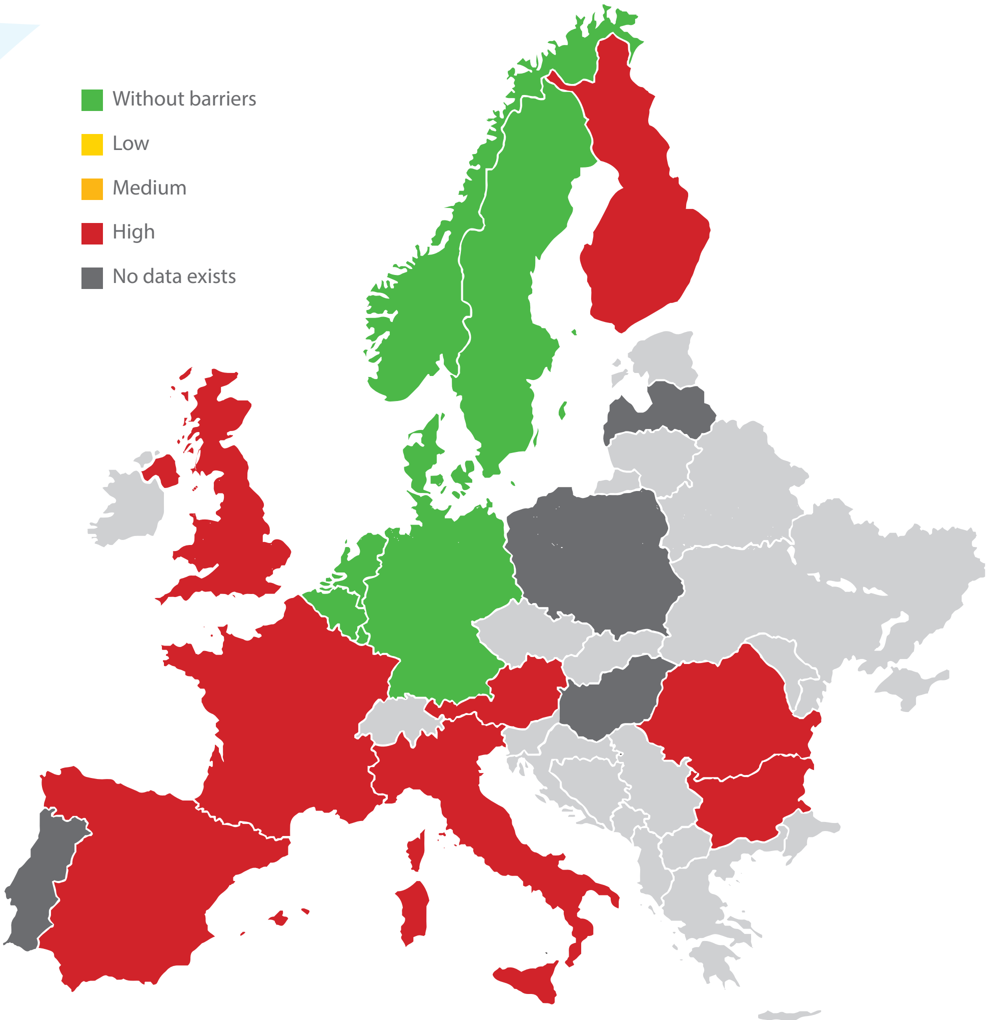
FRANCE

France, in turn, promotes hydrogen and relies on this vector as a storage solution for its renewable production.

It plans to have 400 fuelling stations and 200,000 hydrogen-driven vehicles in 2028, as well as a cogeneration with fuel cells of between 800 and 1,000 MW.

In addition, a European consortium funded by the European Commission is carrying out a project to build a hydrogen facility in France. With this project, hydrogen will be obtained by electrolysis and stored for later use in conjunction with natural gas. This would reduce 65,000 tons of CO_2 emissions.

The Hylaw project for the development of hydrogen technologies analysed the different legal barriers and their rigidity in the 23 countries that are part of it.
The map shows the specific barriers within the costs, payments and incentives allocation framework that covers hydrogen injection and distribution facilities



Note: 'HyLaw Project': promoted by the Foundation for the Development of New Hydrogen Technologies in Aragon, designed to promote the market absorption of hydrogen and fuel cell technologies, providing a clear view of applicable regulations, at the same time that seeks to promote the elimination of existing legal barriers.

A European hydrogen strategy is currently being developed, with the aim of turning this vector into an indispensable source of energy for certain sectors such as mobility. The European Commission considers that renewable hydrogen will play a leading role in Europe's energy future and, through its use, reduce emissions from fossil fuels, positioning itself as a safe and clean alternative. Through this strategy, not only will new hydrogen technologies be developed, but it is intended that trade and competitiveness policies common to the entire continent be formulated.

Hydrogen in Spain

Spain presents some additional regulatory barrier to hydrogen development to those present in other European countries, for example, the regulation that allows hydrogen to be injected into the natural gas network is not yet developed. However, in line with the European Union's decarbonisation goals for 2050 and the importance that hydrogen is reaching as a clean energy vector, a roadmap for green hydrogen is being developed.

The National Integrated Energy and Climate Plan 2021–2030, within the Strategic Energy and Climate Framework, identifies renewable gases as essential in generating electricity and meeting the energy demand of certain industries. In this regard, the development of a road map for green hydrogen, where Spanish competitiveness would be compared and improved with respect to that of Europe and the rest of the world with the objective of achieving climate neutrality is considered indispensable.

Our country sets a target for the year 2030, when it intends to have 400 hydrogen fuelling and service stations and a minimum of 200,000 vehicles that require this energy vector.

In addition, fuel cell cogeneration will be 1,000 MW and hydrogen production from renewable sources will be 300,000 t and more than 1,500 MW.

> “It is necessary to give a regulatory boost to hydrogen treatment in Spain, in order to extract its potential in the energy transition”

CURRENT MAIN BARRIERS TO THE DEPLOYMENT OF RENEWABLE HYDROGEN IN SPAIN

Of a legal nature

- Since there are no binding targets for hydrogen content in natural gas marketing or regulated incentives associated with these objectives, green hydrogen does not receive economic value; and hydrogen produced and injected into the network in current pilot projects loses its value, becoming a mere technological experience without an economic viability implicit in the project itself.

  In addition, there is no system that certifies the renewable origin of green hydrogen which allows its national and international sales to contribute to the viability of pilot projects.

- Because there is insufficient liquidity in the purchase, no liberalized and individual initiatives have emerged to make the hydrogen sector take off at national level. Nor is it a sufficiently mature market to establish a third-party access regime to the specific network for the transmission, distribution and marketing of hydrogen.

- The natural gas sector does not include in its regulatory and economic framework the transmission, distribution and marketing of pure hydrogen, although hydrogen is the logical evolution of natural gas, as in its day natural gas was the evolution of manufactured gases.

> “There is no system that certifies the renewable origin of green hydrogen”

Of an economic nature

- Hydrogen production activity from mainly renewable electricity sources does not have a specific regulation that gives it an economic framework to make investments viable.

  The production activity is, within the life cycle of hydrogen, the one that is less competitive at market prices since, in addition to having to bear the price of electricity, it is the only one that requires scale-up investments from zero to develop the renewable hydrogen generation associated projects.

- The voluntary market for CO_2 emissions for diffuse sectors does not present sufficient liquidity.

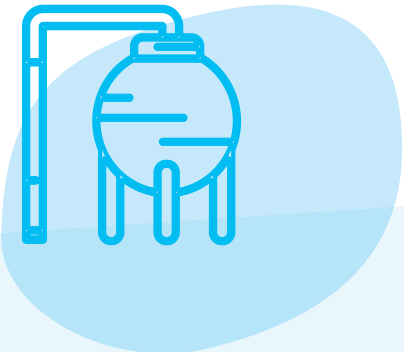
> “Production activity is the least competitive at market prices”

Of a technical nature

- **There is no standardization in natural gas end-use equipment** that requires the admission of certain proportions of hydrogen, or even that forces the equipment to be prepared for future internal adaptation that allows it to move from consuming natural gas to consuming pure hydrogen. For example, at present, when an LPG consumer equipment is transformed to consume natural gas, the equipment is still valid and only a small adaptation of the equipment is necessary.

In a similar sense, there is no standardized, specific documentation supported by the Administration (which is necessary for the conclusions of these documents to have sufficient effect) on the modifications necessary in the adaptation of the gas infrastructures (gas pipelines, regasification plants, storages, control and measurement stations, compression stations, etc.) to transport increasing proportions of hydrogen or even pure hydrogen. This is also applicable to users' receiving installations.

> "There is no standardized documentation on the necessary modifications of gas infrastructures"



Among the **PROPOSALS** submitted by the sector to the Ministry are:

Promotion of hydrogen blending in natural gas networks

It is the necessary previous step to creating technical expertise in the distribution and transmission of hydrogen as well as in end-uses, helping to develop production activity as well. To this end, it is proposed to:

1. Establish mandatory quotas or targets for the composition of hydrogen in natural gas that marketers sell to end customers.

2. Define technical standards for the design and making of equipment and networks that allow the incorporation of increasing proportions of hydrogen.

3. Create a system of guarantees of origin that, giving traceability to the hydrogen produced and consumed, allows to establish a value for the same.

4. Call for auctions of green hydrogen production projects that give investors adequate profitability and long-term visibility.

5. Improve competitiveness of electricity prices for green hydrogen production through tax and legal incentives.

Development of green hydrogen production centres close to end consumers

Promoting this type of centres in which transmission and distribution infrastructures of pure hydrogen are developed will contribute to the social diffusion of this energy vector and its end uses.

These centres would be integrated into the natural gas regulatory framework as subsystems that, while not initially interconnected with the natural gas transmission and distribution network, will be able to be so in the future as their integration evolves.

Development of service stations for green hydrogen supply

The use of hydrogen as fuel in vehicles is an application of the present moment, and the development of service stations for the supply of green hydrogen, produced from renewable energies, is the ideal showcase for the diffusion of the benefits of this kind of real zero-emission mobility, since neither emissions are generated in its production nor in its use.

Valuing the storage service of surplus renewable energy in the form of hydrogen

While one of the main lines of hydrogen development is its use as a stored energy vector for a deferred use to its production, it is necessary that this storage service adopts an economic value that encourages its development on a general basis. This will also contribute to progress on the proposed pathways for hydrogen storage in natural gas infrastructures.

SPAIN'S ROLE AS A TECHNOLOGICAL LEADER IN THE GLOBAL AND EUROPEAN DEVELOPMENT OF THE POTENTIAL OF RENEWABLE HYDROGEN

As this is a cross-sectional vector to the main energy sources of the current mix, and given that Spain has an abundant solar and wind resource, it could become a major renewable hydrogen producer.

Thanks to the gas infrastructures, it could store and transmit, not only at national level but also to other countries, the production of renewable hydrogen, facilitating the decarbonisation of industrial sectors, and being an ideal complement to the greater penetration of renewable energy by facilitating seasonal storage, securing support for such energies to a greater extent than other types of storage such as batteries.

By replicating the positive aspects of the experience that Spain has accumulated in the development of renewable energy, and taking advantage of the existing industrial fabric, Spain can develop an economic activity sector of high added value and with export orientation, linked to the design and manufacture of electrolysis equipment, and to the integral supply of renewable hydrogen production plants under the "EPC" scheme (Engineering, Procurement and Construction).

Spain can also achieve technological leadership in each of

THE STAGES OF THE HYDROGEN VALUE CHAIN:

In the integration of the renewable resource into the electrolysis process:
The high intermittency of solar and wind resources in Spain pose a major technological challenge for their integration as a source of electricity in the process of water electrolysis. Spain can take advantage of the experience gained in coupling renewable production in its electrical system over the last decade, to apply it on a small scale in hydrolysis systems.

In the storage of hydrogen in gas infrastructures:
Gas hydrogen injection and transmission by taking advantage of the storage capacity of gas transmission and distribution infrastructures is the most economical alternative to the development of an integral hydrogen chain. Spain can thus take advantage of its modern and high-quality gas network.

In the transmission and distribution of hydrogen by conduction:
In particular, with regard to ensuring that the injection into the existing transmission and distribution pipeline network is carried out under adequate safety and quality conditions, in its efficient management, and in the construction of new pipelines that carry only renewable hydrogen, making it possible for hydrogen to reach industry and households for different uses.

In short, Spain can become one of the leading European producers of renewable hydrogen at low cost (due to the abundance of renewable resources), establishing itself as an energy supplier that guarantees the rest of the European Union's countries their supply security within the legal framework of the Union, carrying out transmission on a scale that will be very efficient by taking advantage of the existing gas infrastructure.

OPPORTUNITIES FOR APPROVAL AND STANDARDIZATION OF TECHNOLOGIES OR INDUSTRIAL PRODUCTS IN SPAIN

- Development of specific regulations for the certification and standardisation of **electrolysers, plant and systems balances**, which facilitate the implementation and, also, enable new improvements and actions to be achieved.
- Development of specific regulations and national certifying bodies of **hydrogen tanks** and other storage systems elements.
- Development of requirements, specifications and standardization in the field of **equipment, safety and product quality.**
- Specific development **of regulations for hydrogen production installations** at national level for use as feedstock and as an energy storage.

OPPORTUNITIES FOR RENEWABLE HYDROGEN DEVELOPMENT IN SPAIN

Access to a renewable energy source that achieves the environmental objective of producing zero emissions would be widespread.

- **Conduction-transmission of hydrogen** allows end-use power generation to be performed in a delocalised manner, with less traffic losses than transmission through power grids (the domestic electricity final consumer sees an additional 15% invoice increase in transmission losses), so in terms of energy efficiency this is a great opportunity.
- **Green hydrogen links** the electricity and gas grids by taking advantage of the resources invested in the natural gas network that allows the large-scale storage of surplus renewable generation and obviously allow its consumption in final applications.
- **It would represent a real alternative** to the decarbonisation of industry energy consumption and mobility in all its fields, and in particular heavy mobility.
- **Spain is already a pioneer** in the uses of industrial hydrogen on a small geographical scale, so it has a head start to extend its development to green hydrogen and can constitute an R&D&i core.
- **Production of green hydrogen** for national consumption will also reduce external energy dependence.
- **In addition, the use of green hydrogen** will be a real and efficient alternative to the use of energy storage batteries which, if positioned as the only alternative in an electrification process, could lead to intense external dependence.

This decoupling occurs mainly in photovoltaic solar power plants and wind farms, since at given periods of time the electricity demand is lower than the generation. This phenomenon can be solved by storing energy in the form of renewable hydrogen and could also help optimize investments in new electrical infrastructures such as substations or transmission and distribution lines.

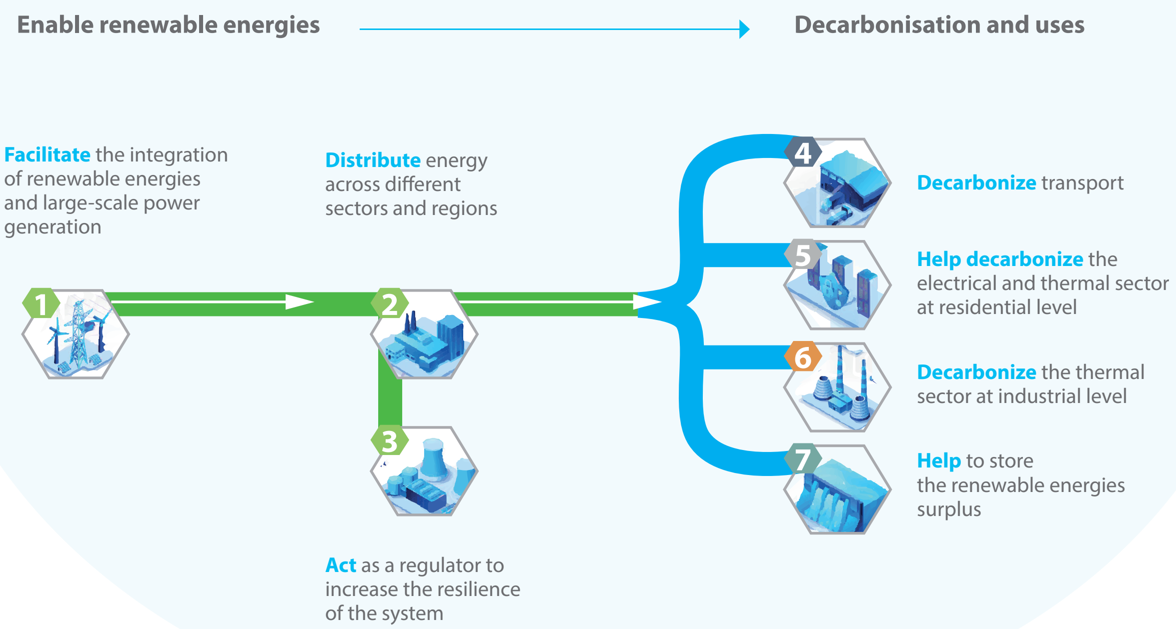
> “Surplus electric power generation could be used both for generating electric power (fuel cells) as using hydrogen directly in industrial processes or in mobility”

The role of renewable hydrogen: **KEY TO ENERGY TRANSITION**

Hydrogen is a key energy vector for achieving a renewable energy system and reducing emissions of gases and particles, thus achieving a decarbonisation of the economy in line with the 2030 UN Agenda and the EU's zero-emission objective for 2050.

> “Hydrogen is a crucial energy vector for achieving a renewable energy system and reducing emissions of gases and particles”

Hydrogen as a facilitator of Europe's energy transition:



Source: Hydrogen Roadmap Report, FCH JU.

- **Unlimited availability:** Hydrogen is the most abundant element and on Earth it is found in matter of organic origin and, mainly, in water.

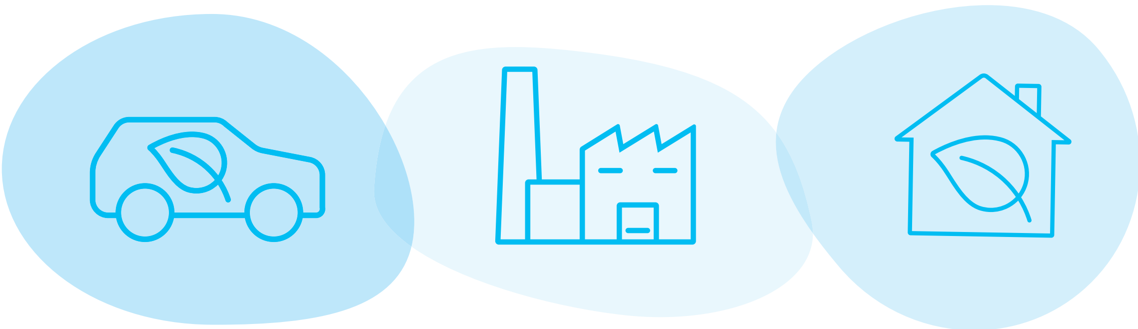
- **Storable:** Hydrogen can be stored and transported with already available technologies.

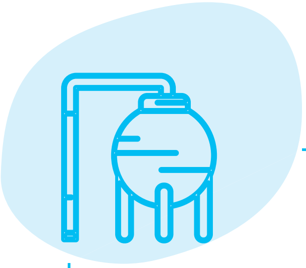
- **Zero emissions:** Hydrogen can produce heat and electricity without emitting carbon dioxide by combustion, like any fuel, or by electrochemical combination with oxygen.

- **Hydrogen is versatile:** Today's technologies can produce hydrogen, store it, move it, and use it in different ways. Various types of energy are capable of producing hydrogen such as renewable or nuclear energies, natural gas or coal. It can be transported by gas pipelines or ships and then transformed into electricity and methane to power homes, industries or as fuel for transport.

> "Hydrogen is an unlimited resource to be obtained from water and be part of a zero carbon renewable cycle"

Using hydrogen for end-uses would allow the decarbonisation of entire sectors with a CO_2 reduction of 100%, given its versatility to supply energy for households, industry, mobility and energy storage.

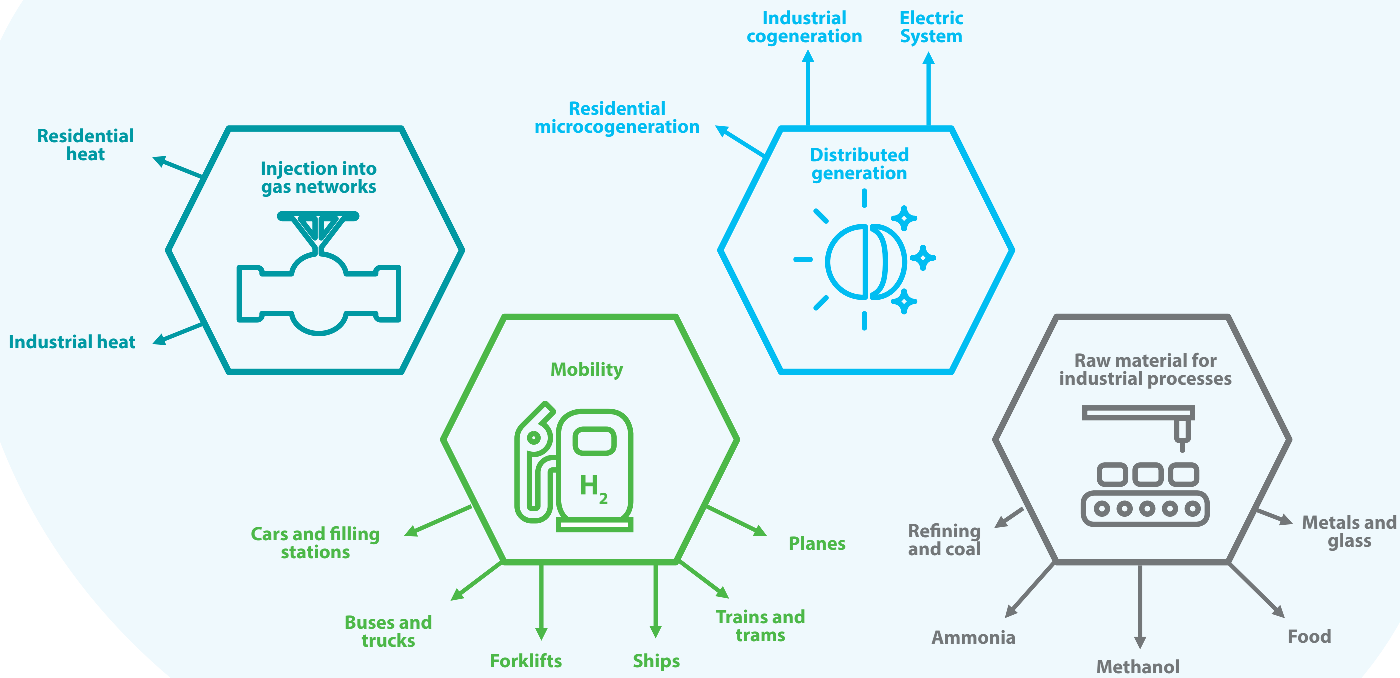




- **Transport:** Hydrogen is the most effective technology to eliminate emissions in transport.
- **Industry:** Hydrogen can replace fossil fuels in processes where high temperatures are required and electrification is difficult.
- **Residential and tertiary segment:** hydrogen can be a less expensive alternative to electrification for heat generation.

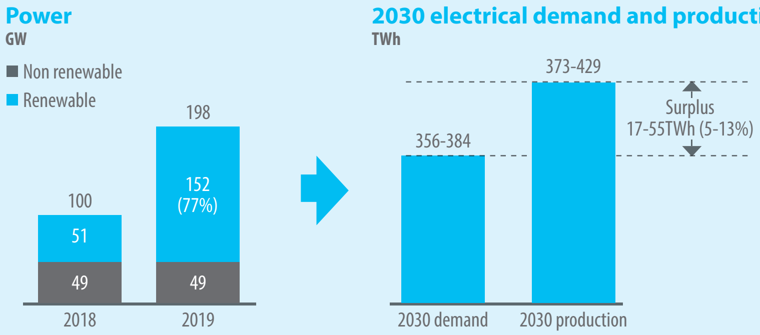
HYDROGEN IS THE OPTIMAL WAY TO STORE THE FULL POTENTIAL OF RENEWABLE GENERATION

Universal vector to decarbonise the economy as a whole:



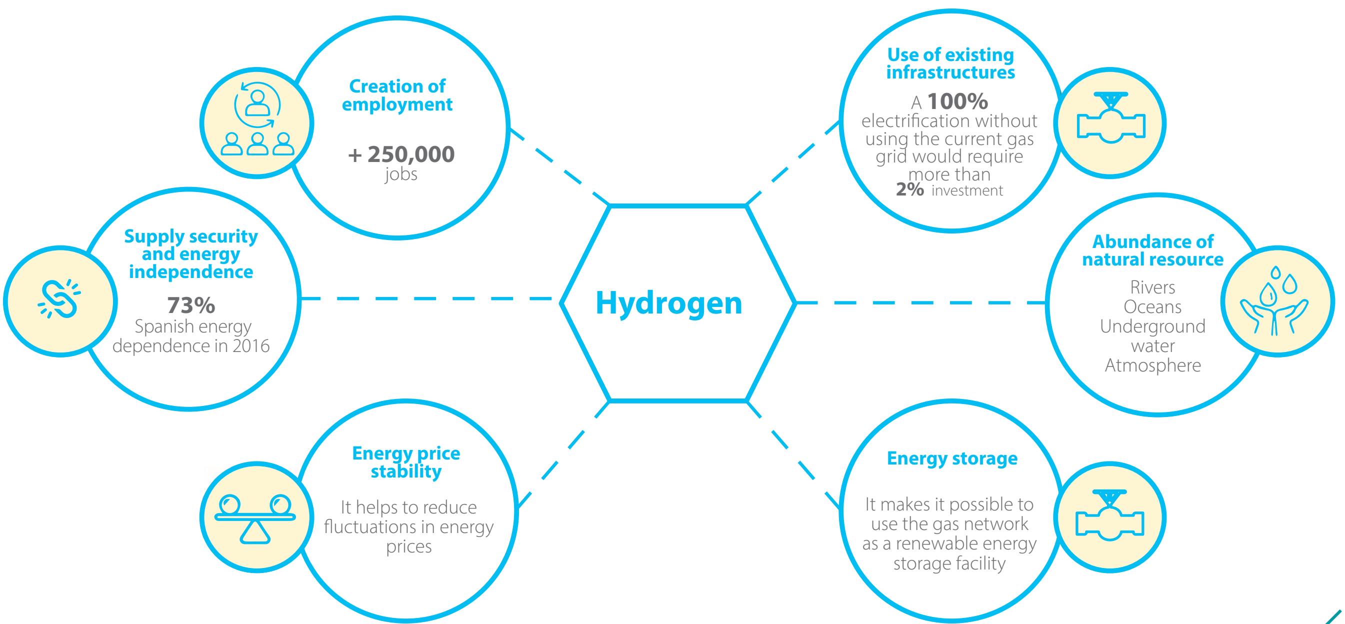
Generation of renewable energies is seasonal, depending on external factors such as the weather situation, having a random character according to seasonal cycles. The volume and timing of generation do not often match the volume of demand, so much of the energy produced is lost since there is no optimal storage solution. Hydrogen bridges this gap and allows storage of large volumes of electricity, with storage capacity similar to those of pumping allowing seasonal storage with zero environmental impact.

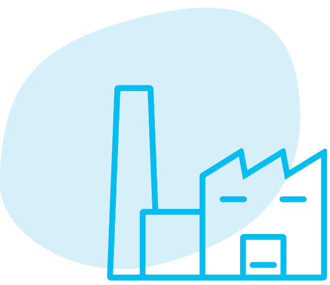
Electricity demand and production from renewable energies by 2030



> “Deploying hydrogen and renewable gas could avoid 6 to 12 million t of CO_2”

Additionally, the deployment of hydrogen would have the following **benefits**:





Each ton produced of **brown hydrogen** emits **10** tons of CO_2. In contrast, a **1 GW** electrolyser is capable of producing between **40,000** and **100,000** tons **of green hydrogen** per year.

This would mean avoiding between **400,000** and **1,000,000** tons of CO_2.

How does renewable hydrogen contribute to achieve the Fair Transition Strategy objectives?

- **Elimination and/or substantial reduction** of pollutant emissions and GHG emissions.
- **Circular economy:** use of indigenous renewable energy sources for the production of renewable hydrogen for different uses.
- **Technological leadership** at international level.
- **Creation of new business areas** and employment in the equipment production field at all levels (fuel cell manufacturing, storage and user supply systems, associated electrical apparatus, hydrogen generation equipment manufacturing, etc.)
- **Empowerment of new hydrogen production energy centres** which, being delocalised, will help to avoid rural depopulation and achieve demographic challenge objectives.

Integration of renewable hydrogen INTO EXISTING INFRASTRUCTURES

Renewable hydrogen is obtained from water and, through it, electricity can be stored allowing the use of all the existing generation capacity and avoiding energy loss. Through its storage in the gas network, this vector allows the integration of the gas and electrical systems.

One of the main problems that the renewable energy generation faces today is the inability to store the generated surplus, which leads to significant energy loss. Hydrogen injection into existing gas networks allows the energy use of potential renewable generation surplus.

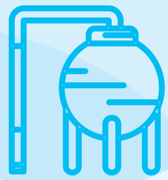
Technical studies point to the possibility of diluting between 5% and 15% (in volume) of hydrogen in today's natural gas networks; and technological developments could cause this percentage to increase.

The combustion resulting from the mixture of hydrogen and natural gas allows the reduction of the end consumers' emissions, that enjoy energy with the same capacity as natural gas without any difference in the appliances' performance.

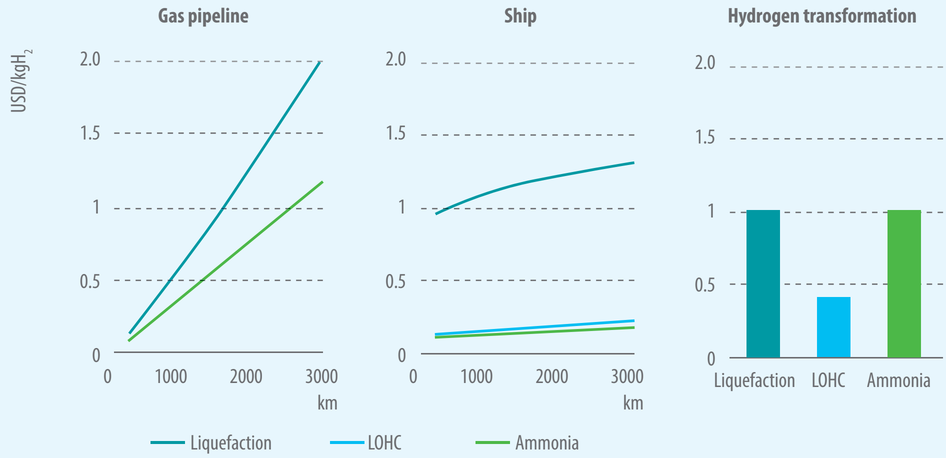
> “Energy infrastructures: key to a transition to a hydrogen economy”

BENEFITS of hydrogen transmission through existing gas infrastructures:

- **Infrastructure is already available** and only small investments would be needed to adapt it.
- **Hydrogen transmission by pipeline is more competitive than** by road.
- **It would increase the domestic industry's competitiveness** by decoupling it from international energy prices.



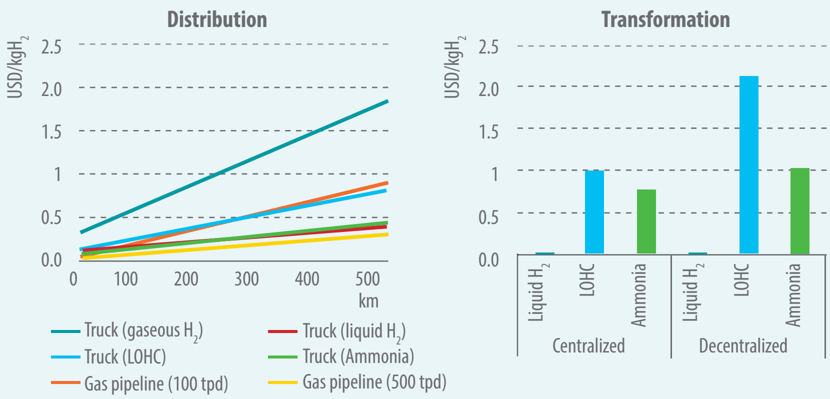
Cost of storage and hydrogen transmission by pipeline and by ship, and cost of hydrogen liquefaction and transformation:



Notes:
The hydrogen transported by pipeline is in a gaseous state while transported by ship is in a liquid state. Costs include transmission and storage costs if required, distribution and transformation costs are not included.
More information at www.iea.org/hydrogen2019
Source: IEA 2019

> “The cheapest option to transport hydrogen depends on shape and distance. Additional processing costs must be weighed against transport savings”

Cost of distributing hydrogen to a central facility and regasification costs:



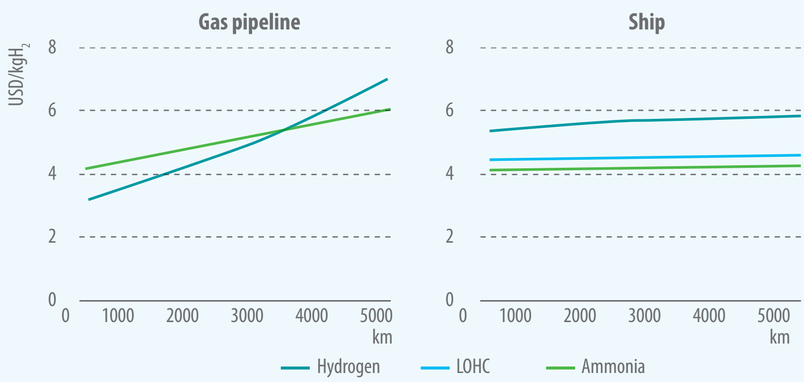
Notes:
More information available at www.iea.org/hydrogen2019
Source: IEA 2019

> “It is highly likely that the new pipelines become the cheapest option for distributing large volumes of hydrogen. Extracting pure hydrogen from ammonia or LOHC is expensive”

Renewable hydrogen can be successfully implemented as an additional energy alternative in all sectors (domestic, tertiary, industrial, and also in light and heavy mobility).

In any case, there is chance it will have a greater initial success in the decarbonisation of the industrial sector, since electrification of this sector is not possible, and also in heavy mobility, by allowing the development of an electric mobility, that by its autonomy and power requirements, cannot be supported by batteries, which means real zero emissions as electricity is generated in a delocalised and completely clean manner.

Total hydrogen distribution costs for the industrial sector by pipeline and by ship in 2030, according to distance:



Notes:
Hydrogen production costs: 3 $/kgH_2$, considering that distribution is by a 100 tpd pipeline to a final destination located 50 km away.
More information available at www.iea.org/hydrogen2019
Source: IEA 2019

Uses of **HYDROGEN**

MOBILITY OPPORTUNITIES

The competitiveness of hydrogen use in transport depends on the costs of fuel cells and refuelling stations. The priority for the mobility sector is to reduce the costs of these batteries and on-board storage systems. If this costs were lowered, these types of vehicles could be highly competitive with an autonomy of 400-500 km, which would make them potentially attractive to consumers.

> “The use of hydrogen and mobile fuel cells is key to complete decarbonisation of transport”

	TODAY	DEMAND OUTLOOK	FUTURE DEPLOYMENT	
			OPPORTUNITIES	**CHALLENGES**
Cars and vans (light vehicles)	**11,200** vehicles in circulation, mostly in California, Europe and Japan.	Increased fleet of vehicles, so hydrogen could capture part of this fleet.	Short charging time, less weight per energy storage and zero emissions. Fuel cells may have a smaller material footprint than lithium batteries.	The small number of filling stations makes it expensive, with less power and with storage costs. High electricity consumption and very high production costs.
Trucks and buses (heavy vehicles)	• **25,000** lifting machines. • **500** buses. • **400** trucks. • **100** vans.	Strong sector growth.		
Marine	Limited demonstrations of small ship projects and on-board power supplies on large ships.	Marine loads are expected to increase by 45% by 2030 and air pollution targets must be met by 2050, which could promote hydrogen.	Hydrogen and ammonia are the most viable options for sea decarbonisation and emission reduction.	The cost of hydrogen storage is higher than other fuels and has lower density.
Rail	Two trains moving with hydrogen in Germany.	The train is the main mean of transport in many countries.	Hydrogen freight trains can be more competitive.	Rail is the most electrified transport.
Aviation	Small limited demonstrations of projects and studies.	The fastest means of transport. Aircraft would need to be redesigned and changed to use pure hydrogen.	Hydrogen along with batteries could replace the on board energy of airports during taxying.	It is 4-6 times more expensive than kerosene.

As for countries, United States has the largest fleet of such vehicles followed by Japan, Germany, France and South Korea.

PUBLIC AND PRIVATE INITIATIVES FOR HYDROGEN VEHICLES

Several vehicle manufacturing companies have ambitious plans for the future in this regard and expect to produce a large number of fuel cell cars that will be available between 2020 and 2030.

As for heavy vehicles, thousands of fuel-cell buses are in production phase and are expected to arrive in the market in the next five years, mostly in China. Government support for such projects is increasing, most coming from Europe and the United States. In South Korea, a public-private sponsor intends to develop 1,000 buses of this kind by 2022, in line with the country's purpose for 40,000 by 2040.

EUROPEAN PROJECTS

A number of ambitious projects are under way and a new mobility model is being introduced with fuel cell trucks. A 2MW electrolysis plant for heavy vehicles in Europe has been built at the Gösgen hydroelectric plant in Switzerland.

In addition, the H2Haul project plans to deploy 16 fuel cell trucks in four European locations: Belgium, Germany, France and Switzerland. This project will make a significant contribution for the European market preparation and the development of this technology, in line with the 2030 CO_2 reduction target. This demonstration is intended to show how hydrogen fuelling stations operate and how they can directly replace vehicles currently on the market, offering the same load capacity and efficiency when travelling long distances, but with zero CO_2 emissions. The project will start in four years and the 16 heavy vehicles will be deployed for a minimum of two years.

On the other hand, the H2Bus project will involve the deployment of one thousand fuel cell buses in Europe by 2023. The first 600 buses will be funded by CEF (Connecting Europe Facility), which will reduce the selling price of hydrogen to 5-7 euros/kilo with a maintenance fee of 30 cents per kilometre and zero emissions.

> "The use of hydrogen in heavy transport is encouraged in Europe"

OPPORTUNITIES FOR THE INDUSTRY

> "Hydrogen is the main option for decarbonisation of industrial processes with high thermal requirements"

Blast furnaces for iron manufacturing are a good example: the coke used in these furnaces not only creates the heat needed to melt the iron, but also allows the chemical reaction between the carbon electrodes in the coke and the oxygen of the iron ore that is needed to produce iron. While it is possible to increase the heat of the blast furnace with other fuels such as hydrogen, it is not possible to replace the blast furnace with an electric one.

Renewable hydrogen is an alternative to carbon capture and storage. In addition, hydrogen cogeneration also enable greater energy efficiencies to be achieved with a low carbon footprint.

> "Renewable hydrogen is the sustainable solution to decarbonise the sectors with most emissions"

Today, a large number of industrial sectors such as refineries, chemical or of fertilizers, use hydrogen in their industrial processes, but it is brown hydrogen. Replacing this hydrogen with green hydrogen would significantly reduce CO_2 emissions.

OPPORTUNITIES FOR THE HOUSING SECTOR

Hydrogen can easily be transported and distributed by existing infrastructures, this being one of its main advantages, since it does not need a large investment for the deployment of new networks, so it could be destined for domestic and commercial consumption.

In addition, renewable energy surplus could be stored in the form of hydrogen with adequate infrastructures, which would result in cost savings and a significant reduction in emissions.

Homes with their own renewable energy generators such as solar panels would find that hydrogen can be a strong ally to store the surplus produced, which would result in both energy and cost savings.

Redexis: GREEN HYDROGEN PROMOTER

- **Redexis is a partner of the Foundation for the Development of New Hydrogen Technologies in Aragon**, whose goal is to develop projects linked to hydrogen and fuel cell technologies.
- **Redexis is a partner of the Spanish Hydrogen Association**, in order to promote the use of this energy vector in industrial and commercial applications, promoting its development.
- **Redexis is the coordinator of Gasnam's Hydrogen Work Group**.

> "Redexis plans to allocate 60 million euros to hydrogen and renewable gas projects in the 2025 horizon"

POWER TO GREEN HYDROGEN MAJORCA PROJECT

This project brings together all the central elements of the hydrogen value chain, i.e. the production, distribution infrastructure and end-use of green hydrogen through mobility, heat and energy, and it will enable the deployment of renewable hydrogen supply infrastructures on the island, with the objective of providing 100% renewable and sustainable energy to transport, industries and hotels. Redexis is actively involved with Enagas, Acciona and Cemex.

Power to Green Hydrogen Majorca's overall approach is based on the integration of six deployment sites on the island of Majorca, which include 7.5 MW of electrolysis capacity connected to local photovoltaic plants and six buses and cars, two commercial cogeneration applications in buildings, electricity supply at the port and injection of hydrogen into the local gas network.

> "The Power to Green Hydrogen Majorca project addresses the deployment of a fully integrated and functioning renewable hydrogen ecosystem on the island of Majorca"

The intention is to expand the impact beyond the technology demonstrations delivered by the project, laying the groundwork for the first scale renewable hydrogen project in southern Europe. This will provide Europe with a plan for the decarbonization of the island economies, and an operational example of hydrogen's contribution to the energy transition and the 2050 zero-emission objectives.

The project has already been declared a Strategic Project by the Balearic regional government and has the support of the national government through IDAE.

HIGGS PROJECT

Redexis participates in the HIGGS project, a European co-operation initiative that will study the possibility of injecting hydrogen into existing natural gas infrastructures as a means of reducing CO_2 emissions.

This project has a European funding of two million euros from the Fuel Cells and Hydrogen 2 Undertaking, the main public-private grouping supported in Europe with the endorsement of the European Commission. A study will be carried out to see how different degrees of natural gas mixture with hydrogen behave in gas networks, developing a testing platform.

FUEL CELL INTEGRATION INTO GAS PIPELINES

Redexis has integrated a fuel cell into a control and measurement station (CMS) in one of its Zaragoza's gas pipelines to supply electricity and heat, being this the first integration of this type to be carried out in Spain.

The objective of this project is to test this technology and its application for domestic or tertiary uses, generate high efficiency and study its feasibility to be generally implemented in gas transmission and distribution networks, in order to reduce the environmental impact and carbon footprint.

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