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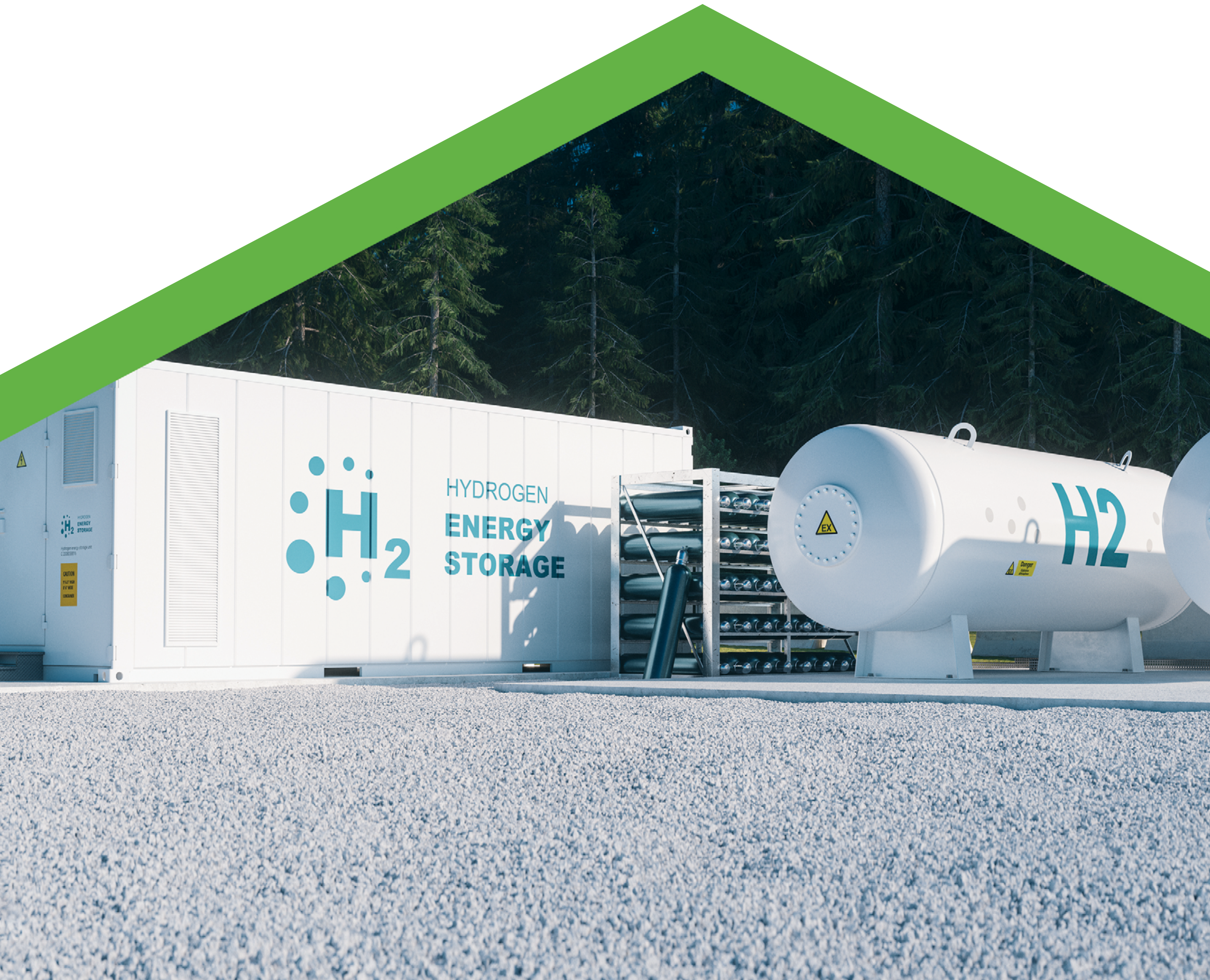
Policy Paper

Hydrogen - Energy Vector in the national and European context



Contents

Executive summary

Hydrogen is not normally found in a gaseous state, so it needs to be obtained by various chemical and industrial processes.

Hydrogen has the ability to balance the variability of energy sources with their volatility. Hydrogen has a high energy content per unit weight, making it **a very efficient fuel for transportation and other applications[1].**

Hydrogen can be used to reduce the carbon footprint of natural gases. Hydrogen is color coded in common industry nomenclature, depending on its source and how it is produced, as follows: green, white, gold, grey, brown, red, turquoise hydrogen.

Hydrogen can be used for two main purposes, either as a reagent to obtain other products or as an energy carrier/ energy vector, according to Institut Polytechnique de Paris. For example, in France today, "hydrogen is currently used specifically in fuel refining (60%), in the production of ammonia mainly for agricultural fertilizers (25%), and in chemistry (10%)"[2].

At the same time, a number of technical challenges remain to be addressed if hydrogen is to become a viable large-scale energy supply option.

According to Institut Polytechnique in Paris, "hydrogen is particularly valuable when used in combination with electricity, which is currently the preferred source for reducing carbon emissions."[3] Hydrogen finds its relevance as a complement to electricity, especially when high charging rates, long ranges and short recharging intervals are important.

While hydrogen-powered bikes and cars are relatively energy inefficient, hydrogen could be particularly beneficial for heavier vehicles such as buses and trucks.

From a legislative framework perspective, provisions need to be established to ensure harmonization of construction permits by streamlining the approval processes for electrolysis projects and hydrogen filling points. At the same time, initiatives to develop hydrogen infrastructure across the entire value chain should be supported through a standardized approach as a basis for handling hydrogen.

1. Introduction

1.1. Definition

Hydrogen is the most common element in the Universe, accounting for 75% of its mass.

Hydrogen is the third most abundant element on Earth, after oxygen and silicon.

Hydrogen is also the element with the lowest density. In molecular form (H_2), it is about 14.4 times lighter than air.

Hydrogen, as a pure gas, rarely occurs in nature, although volcanoes and some oil wells frequently release small amounts of hydrogen gas *(known as gold hydrogen).*

Hydrogen can be found as a component in most products we use. Compounds that rely on the existence of hydrogen include *water, sugar, alcohols, vinegar (acetic acid), sodium hydroxide, medicines, fibers, dyes, plastics, fuels, etc.*

1 Hydrogen's Role in Transportation | Department of Energy.
2 https://www.polytechnique-insights.com/en/columns/energy/hydrogen-in-transport-everything-to-know-in-10-questions/#note-content-6
3 Hydrogen in transport: everything you need to know in 10 questions - Polytechnique Insights (polytechnique-insights.com).

1.2. Categories of hydrogen

Hydrogen is not usually found in gaseous form on the surface of our planet, so it needs to be produced by the various chemical and industrial processes we have at our disposal and cannot be captured directly from the atmosphere.

Hydrogen is color-coded in common industry nomenclature, without formal definitions, according to its source and how it is produced, as follows:

Green hydrogen - refers to hydrogen produced from water and energy from renewable sources. For this process, it should be noted that the production of hydrogen is based on the process of electrolysis, which does not release carbon emissions. However, for green hydrogen to be considered truly net-zero, the electricity used in electrolysis must come from renewable sources - solar, hydro or wind.

The green hydrogen[4] is obtained either by steam reforming, where bio feedstock is available, or by electrolytic water decomposition.

Brown hydrogen - refers to hydrogen produced from brown coal (brown coal - lignite/low-grade coal, high ash and moisture content and less carbon).

Black Hydrogen - refers to hydrogen produced from black coal, which includes anthracite, bituminous, and subbituminous coal-types with a higher carbon content than brown coal.

Gray hydrogen is produced from natural gas, with carbon emissions released into the atmosphere without capture during the production process. Blue hydrogen is generated through the same method; however, in this case, the resulting emissions are captured before being released, preventing pollution. This approach makes **blue hydrogen** a more environmentally sustainable alternative by significantly reducing carbon emissions associated with hydrogen production.

Turquoise hydrogen is produced through methane pyrolysis, resulting in solid carbon as a byproduct. While this technology has not yet been deployed at a commercial scale, the potential for commercializing solid carbon could drive its future development.

Gold hydrogen is formed naturally through temperature-driven reactions between water and iron-rich minerals. It was first discovered accidentally more than a decade ago in Mali. Following these findings, several companies and startups began developing technologies to extract and utilize these significant gas reserves. More recently, France identified a new gold hydrogen deposit, containing a naturally occurring underground variation of hydrogen.

Additionally, **white hydrogen** refers to hydrogen produced as a byproduct of industrial processes.

Yellow Hydrogen - Hydrogen produced by electrolysis, based on energy from the electricity grid, taking into account the energy mix of the country.

Pink/Red/Purple/Purple Hydrogen - Hydrogen produced by the electrolysis of water, based on energy generated from nuclear sources. No emissions are released into the atmosphere in the electricity generation process used to produce hydrogen.

4 Hydrogen value chain, Hydrogen | Linde Gaz Romania (linde-gas.ro).

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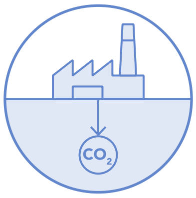
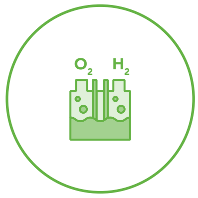
Hydrogen Colours





Grey Hydrogen

- Production from **natural gas or coal in a reformer**
- **Emits CO_2**

Blue Hydrogen

- Production from **natural gas (typically)** in a reformer
- **CO_2 emissions captured** (typically 90%) and stored or used

Green Hydrogen

- Production from **water and green electricity** in an electrolyzer
- **Carbon neutral**

Low Carbon	Zero Carbon	High Carbon	
Blue Hydrogen	**Green Hydrogen**	**Brown Hydrogen**	**Grey Hydrogen**
• Made from CH_2 • CO_2 is captured and stored	• Made from renewable energy • $NOCO_2$ is emitted	• Made from coal • CO_2 is emitted into the atmosphere	• Made from CH_4 • CO_2 is emitted into the atmosphere

Not Low-Carbon	Grey Hydrogen	
Low-Carbon	CertifHy Green Hydrogen	CertifHy Low Carbon Hydrogen
	Renewable Energy	Non Renewable Energy

Green

Hydrogen produced by electrolysis of water, using electricity from renewable sources like hydropower, wind, and solar. Zero carbon emissions are produced.

Turquoise

Hydrogen produced by the thermal splitting of methane (methane pyrolysis). Instead of CO_2, solid carbon is produced.

Pink/Purple/Red

Hydrogen produced by electrolysis using nuclear power.

Black/Grey

Hydrogen extracted from natural gas using steam-methane reforming.

Yellow

Hydrogen produced by electrolysis using grid electricity.

Blue

Grey or brown hydrogen with its CO_2 sequestrered or repurposed.

White

Hydrogen produced as a byproduct of industrial processes.

Brown

Hydrogen extracted from fossil fuels, usually cool, using gausification.

Source: The "Colors" of Hydrogen - Applied Economics Clinic (aeclinic.org)

1.3. Hydrogen production technologies (methods)

a. Water vapor catalytic reforming
b. Water electrolysis
c. Biomass gasification

a. Water vapor catalytic reforming

According to Institut Polytechnique de Paris[5], in 2021, 99.3% of the world's hydrogen production was mainly obtained by steam reforming of methane from fossil gases (62% of production), followed by coal gasification (19% and) or by co-products from oil refining (18%).

In France, by 2021, 95% of hydrogen will be produced from fossil fuels, 5% from the electrolysis of salt water (brine), mainly from chlorine production[6].

Low-carbon production is possible through two main techniques, which account for only a very small fraction of current production. Fossil fuel-based production, which is associated with carbon capture and storage, accounted for 0.7% and water electrolysis for only 0.04% in 2021, according to data from Institut Polytechnique de Paris.

Hydrocarbons, especially methane, are used to obtain hydrogen by catalytic steam reforming.

Steam reforming is the main method currently used to produce hydrogen on an industrial scale.

In the first stage, using steam at a temperature of about 450-500°C and a pressure of 25-30 bar, the more complex hydrocarbons are broken down into methane, hydrogen, carbon monoxide and carbon dioxide.

The second stage involves methane reforming, where methane reacts with water in the presence of a nickel-based catalyst at temperatures of 800-900°C and pressures of 25-30 bar, producing synthesis gas. Since these catalysts are highly sensitive to sulfur-based compounds and halogens, particularly chlorine, a gas purification unit is typically integrated upstream of the reformer to ensure process efficiency and catalyst longevity.

$CH_4 + H_2O \leftrightarrow CO + 3\,H_2$

$CO + H_2O \leftrightarrow CO_2 + H_2$

$CH_4 + 2\,H_2O \leftrightarrow CO_2 + 4\,H_2$

b. Water electrolysis

The production of hydrogen from water was first identified by German chemist Johann Wilhelm Ritter around 1800 and, in the long term, appears to be the most sustainable method, as it generates no CO_2 emissions. A key example is electrolysis, a process often combined with hydroelectric power plants in countries like Norway and Iceland due to its cost efficiency.

During electrolysis, the reaction occurs in a vessel containing an electrolyte - a substance that facilitates electrical conductivity, such as a salt, acid, or base. Two electrodes are submerged in this electrolyte, allowing direct current to pass through and drive the separation of hydrogen and oxygen.

$H_2O \leftrightarrow 1/2O_2 + H_2$

Hydrogen from water electrolysis:

1 Nm^3 H_2 ⇔ ± 5 kWh

1 MW (electrolyzer) ⇔ 200 Nm^3/h H_2 ⇔ ± 18 kg/h H_2

± 55kWh electricity → 1kg H_2 ⇔ 11,1Nm^3 ⇔ ± 10 l H_2O

Electricity generation from hydrogen using fuel cells (→ = ±50%):

1 kg H_2 → 16 kWh

5 https://www.polytechnique-insights.com/en/columns/energy/hydrogen-in-transport-everything-to-know-in-10-questions/#note-2.
6 https://www.polytechnique-insights.com/en/columns/energy/hydrogen-in-transport-everything-to-know-in-10-questions/#note-4.

Hydrogen:

1 kg ⇔ 11,1 Nm^3 ⇔ 33,3 kWh (LHV)

High energy density on mass: 1 kg H_2 = 3,77 l gasoline

Low energy density by volume: 1 Nm^3 H_2 = 0,34 l gasoline

c. Biomass gasification

Biomass gasification is a mature technology that uses a controlled process involving heat, steam and oxygen to convert biomass into hydrogen and other products without combustion.

Since biomass cultivation removes carbon dioxide from the atmosphere, the net carbon emissions of this method can be low, especially if associated with carbon capture, utilization and long-term carbon storage. Gasification plants for biofuels are being built and operated and can offer best practice for hydrogen production.

Gasification is a process that converts organic or fossil carbonaceous materials at high temperatures (>700°C), without combustion, with a controlled amount of oxygen and/or steam into carbon monoxide, hydrogen and carbon dioxide. The carbon monoxide then reacts with water to form carbon dioxide and more hydrogen via a gas-to-water gas shift reaction. Adsorbents or special membranes can separate hydrogen from this gas stream[7].

Simplified example of a reaction: $C_6H_{12}O_6 + O_2 + H_2O \rightarrow CO + CO_2 + H_2$ + other species

Note: The above reaction uses glucose as a substitute for cellulose. Real biomass varies widely in composition and complexity, with cellulose being one of the main components.

Water-gas shift reaction: $CO + H_2O \rightarrow CO_2 + H_2$ (+ a small amount of heat)

Pyrolysis is the gasification of biomass in the absence of oxygen. In general, biomass does not gasify as readily as coal and produces other hydrocarbon compounds in the gas mixture exiting the gasifier; this is especially true when no oxygen is used. Therefore, an additional step of reforming these hydrocarbons with a catalyst is usually necessary to obtain a clean syngas mixture of hydrogen, carbon monoxide and carbon dioxide. Then, as in the gasification process to produce hydrogen, an exchange reaction step (with steam) converts the carbon monoxide to carbon dioxide. The hydrogen produced is then separated and purified.

2. Implementing hydrogen production technologies

2.1. Key advantages

The natural depletion of conventional energy resources, combined with the rising global energy demand driven by improving living standards and the increasing emphasis on climate change mitigation, is driving significant shifts in the energy transition and the energy mix. These transformations necessitate the adoption of energy vectors that not only facilitate the energy transition but also ensure the security and stability of the energy system.

The increased variability of sources and the volatility of consumption require balancing measures radically different from those of the fossil era.

The energy carrier that can contribute to this balance is hydrogen.

Hydrogen, particularly renewable hydrogen, is regarded as a key enabler in reducing greenhouse gas emissions and plays a crucial role in the net-zero energy transition. As part of the decarbonization process, developing a robust renewable energy system allows hydrogen to serve as a substitute for fossil fuels, significantly reducing emissions in industries vital to the Romanian economy, such as manufacturing and transportation, as well as in the energy and heating sectors.

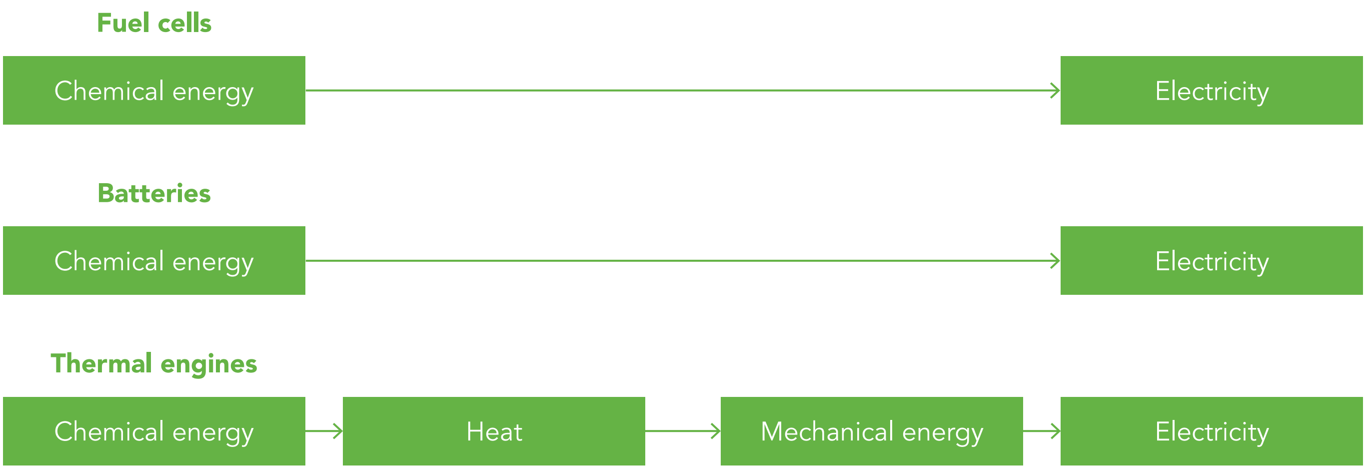
7 Hydrogen Production: Biomass Gasification I Department of Energy.

2.2. How hydrogen technology works

Between 2025 and 2030, hydrogen is expected to become an integral part of an integrated energy system, with a strategic objective of deploying at least 40 GW of renewable hydrogen electrolysers by 2030 and achieving up to 10 million tons of renewable hydrogen production within the EU.

A fuel cell is an electrochemical system that converts chemical energy into electrical energy. In this process, the fuel (energy source) is supplied at the anode, while the oxidizer is introduced at the cathode.

Unlike a battery, which is a closed system, a fuel cell consumes fuel, which can be continuously fed to the anode through electrochemical oxidation to generate low-voltage direct current.



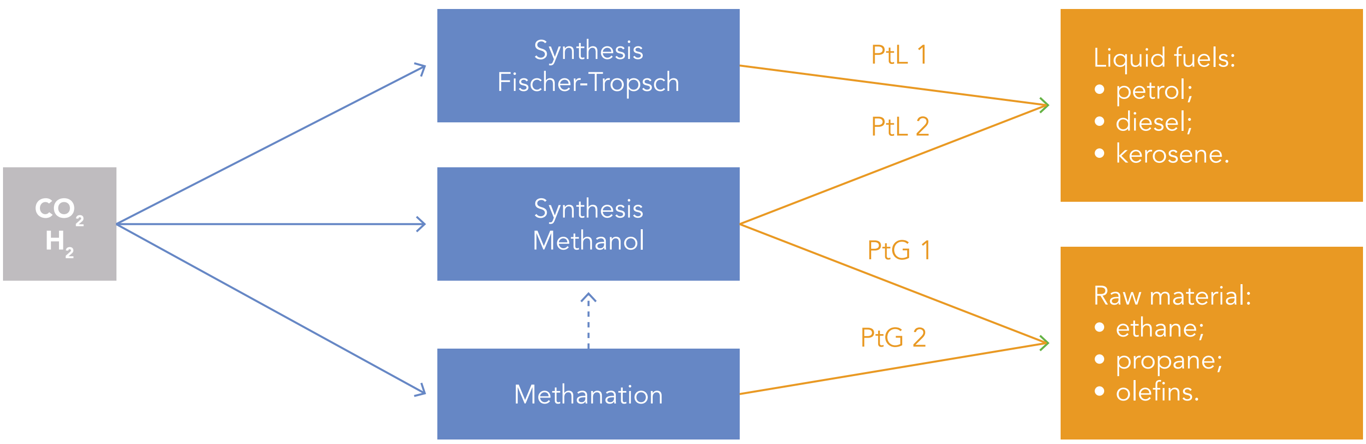
Power-to-gas (PtG or P2G) is a technology that converts electricity into a gaseous fuel. Originally, it was an approach to convert renewable energy into a gas. The concept is sometimes called *"windgas"* when surplus wind electricity is used.

Power-to-gas is the production of an energy-dense gas by electrolyzing water. The first intermediate step is *Power-to-hydrogen (PtH2),* hydrogen which can then be converted to synthetic methane gas in a subsequent methanation process requiring a CO2 feed stream.

Linking the electricity sector with other sectors

It has two meanings:

1. Power-to-X refers to energy transformation, energy storage and conversion pathways that utilize surplus electricity, usually during periods when fluctuating renewable generation exceeds demand.
2. Power-to-X refers to conversion technologies that allow electricity to be decoupled from the power sector for use in other economic sectors (such as transportation or chemical production), possibly with additional investment.



2.3. Using hydrogen in different industries

Hydrogen is widely used today. More than 500 billion cubic meters of hydrogen are consumed worldwide every year for various purposes and in different sectors.

Currently, 95% of existing hydrogen is produced from fossil energy sources, almost exclusively for use in the chemical industry and refining processes[8].

Several future challenges and uses of hydrogen are envisaged for the energy transition. First and foremost is the reduction of carbon emissions from the current use of hydrogen in industry. At the same time, the substitution of those uses with low-carbon hydrogen may be considered, either to reduce carbon emissions in industry or transportation, or to participate in reducing carbon emissions from existing gas networks. Hydrogen could also contribute to electricity storage, providing a flexible solution for balancing electricity grids[9].

Moreover, the production potential of renewable gas and biofuels is significantly constrained by the availability of biomass resources[10]. This limitation underscores the need for a substantial reduction in the consumption of gas and liquid fuels across the economy to effectively lower carbon emissions.

Agro chemistry. In addition to its use in ammonia production, in Romania is also generated as a by-product in chlor-alkali plants.

Refineries. There are various hydrotreating processes[11] in a refinery. These include:

- **Hydroisomerization** – A reaction that converts normal paraffins (n-paraffins) into iso-paraffins, enhancing the fuel's performance characteristics.
- **Dearomatization** – A process in which aromatic compounds are hydrogenated into cycloparaffins[12] or alkanes, improving fuel quality.
- **Hydrocracking** – A method in which long-chain hydrocarbons are broken down into shorter-chain hydrocarbons, typically in the gasoline range, increasing fuel yield and quality.

Metallurgy. Hydrogen plays a crucial role in the iron and steel industry, primarily in the direct reduction of iron (DRI) for the production of metallic materials. It is also used to create reducing atmospheres, which provide chemical protection for metals, as well as in high-temperature processes, cutting, and welding. Hydrogen is particularly important in various welding techniques, where it enhances process efficiency and quality.

Glass industry. Hydrogen is used to make flat glass as well as quartz glass, which is made by melting pure rock crystal, quartz or synthetic silicon oxide in a hydrogen-oxygen flame.

Food industry. In the food industry, hydrogen is used to produce solid fats (margarine) by hydrogenating oils and fats.

Electronics industry. Hydrogen is used to create a reducing protective atmosphere in the manufacture of semiconductors and integrated circuits.

Energy sector. Thanks to its high thermal conductivity and diffusivity, as well as its lack of toxicity, hydrogen is used as a coolant in high-power turbogenerators.

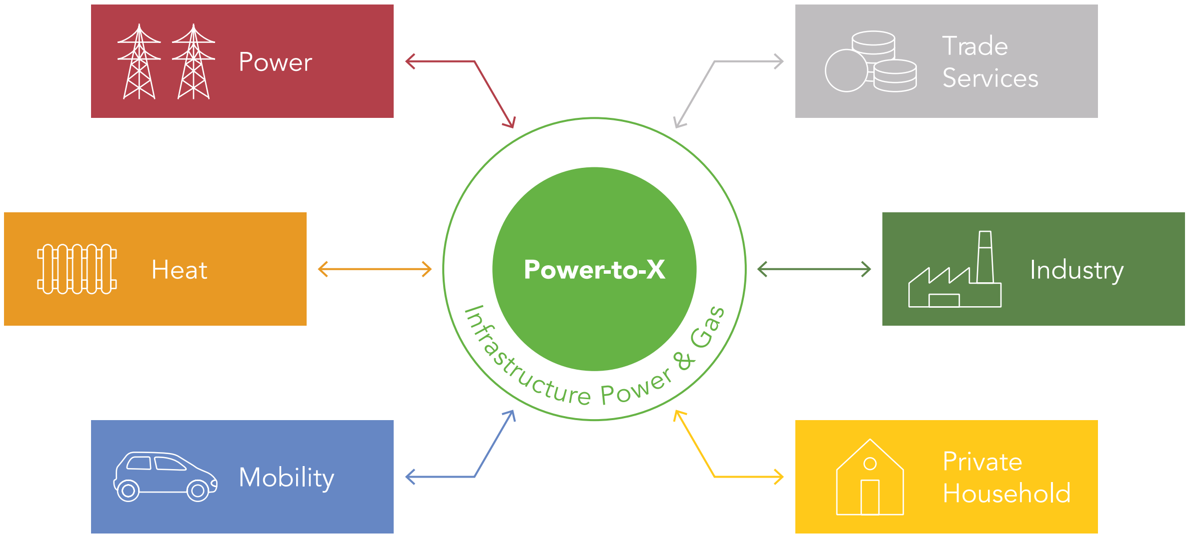
Apart from its use as a reactant, hydrogen has numerous applications in engineering and physics. Liquid H_2 plays an important role in cryogenics research, including superconductivity studies. Hydrogen also has applications in the automotive, aerospace and telecommunications industries.

Hydrogen isotopes, on the other hand, have specific applications. Deuterium in heavy water is used as a moderator in nuclear fission reactions, where it slows down neutrons to sustain the reaction. Additionally, deuterium compounds are utilized in research to study isotope effects in chemical reactions. Tritium, produced in nuclear reactors, is used in the production of hydrogen bombs, in isotope labelling and as an irradiation source for phosphorescent paints.

8 About HIDROGEN | TotalEnergies Romania.
9 https://www.polytechnique-insights.com/en/braincamps/energy/sustainable-hydrogen-still-a-long-way-to-go/
10 https://www.polytechnique-insights.com/en/columns/energy/hydrogen-in-transport-everything-to-know-in-10-questions/#note-15
11 Hydrogen applications in refineries, Linde Gas, Refining | Linde Gas Romania (linde-gas.ro).
12 Hydrogen applications in refineries, Linde Gas, Refining | Linde Gas Romania (linde-gas.ro).

Sectoral coupling refers to the integration of the electricity, heating, mobility, and industrial process sectors along with their respective infrastructures to drive decarbonization. This approach enhances the flexibility of energy use across industry, commerce, residential applications, and transportation, while ensuring cost-effectiveness, sustainability, and security of supply.

Sectoral coupling is crucial for decarbonization and indispensable for the transition to renewable energy.



Source: Hydrogen | Black & Veatch (bv.com)

Hydrogen Valley

The concept emerged in November 2016. "Hydrogen Valleys" have become a global phenomenon, encompassing integrated projects that have emerged around the world. The concept was initiated by the Fuel Cells and Hydrogen Joint Undertaking (FCH JU)[13] of the European Commission, initially referring to the interconnection of ports with industrial areas (parks). The concept is now expanding, leveraging the success and potential benefits of cross-sectoral applications of green hydrogen, further enhancing integration and decarbonization efforts across multiple industries.

Within these industrial clusters, several hydrogen-using applications are interconnected in **an integrated ecosystem** that consumes a significant amount of hydrogen, harnessing the underlying economics.

The concept refers to centers whose different characteristics (based on this asset) indicate a maturing hydrogen market. At this point in time, however, it should be emphasized that developers face common challenges, especially in terms of business plans and regulation.

The aim of Hydrogen Valleys is to create new momentum in the market.

"Hydrogen Valley is a geographical area where several hydrogen applications are combined in an integrated ecosystem covering the entire hydrogen value chain, using hydrogen produced from renewable energy sources (through electrolysis, using renewable electricity).

Ideally, the entire hydrogen value chain should be adressed at this level: production, storage, distribution and end use to ensure a comprehensive and efficient hydrogen ecosystem.

https://www.clean-hydrogen.europa.eu/document/download/3d163fa3-7089-4838-b801-2597c56cba6e_en

2.3.1. Hydrogen Refueling Stations (HRS)

Hydrogen is the most ubiquitous chemical element in nature and hydrogen-powered vehicles have been available for more than a decade. The reasons why large-scale use of hydrogen in transport has not been possible so far are that hydrogen must first be produced by electrolysis, then transported and used in the energy-producing device. These processes can entail losses for market entities, which contribute to the price of electricity production. The technical challenges facing the hydrogen sector remain considerable, in particular for deployment in the transportation sector. As this gas is particularly light and flammable, the risks of spills or accidents need to be controlled to ensure the safety of hydrogen vehicles, storage or transportation[14]. Storage in vehicles also requires compressing hydrogen, an energy-intensive process, as well as the use of tanks that make vehicles very heavy.

At the same time, the low volumetric energy density of hydrogen requires hydrogen production to take place as close as possible to the place of consumption in order to limit the energy and financial costs associated with its transportation. To this end, it is necessary to consider the organization of ecosystems that allow production and use to be spread across several modes of transport or economic sectors in the same place[15].

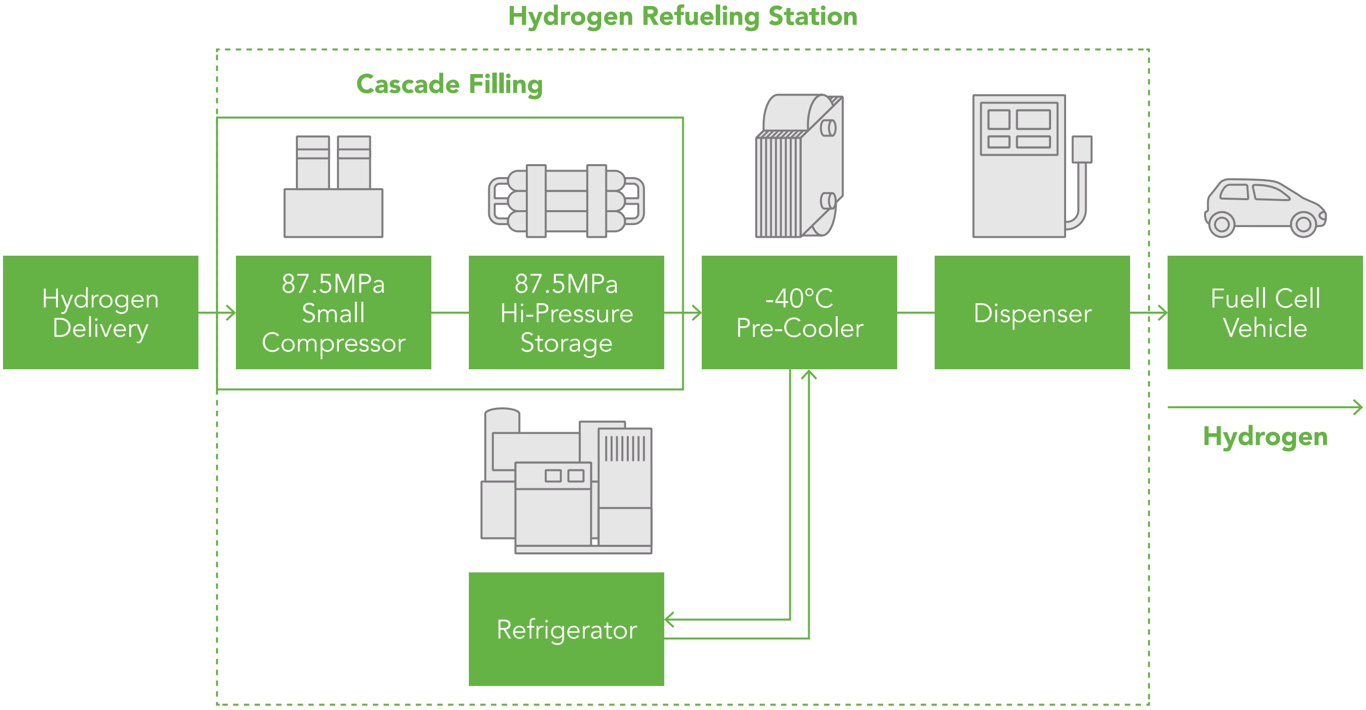
To ensure the coherence of these regional plans, it will also be necessary to provide a network of hydrogen production and distribution infrastructures for heavy road transportation modes.

So, the next step is to use hydrogen from renewable electricity - green hydrogen.

The main advantages of this type of vehicle are that they offer a longer range and less reliance on the battery, and, unlike traditional electric vehicles, refueling times are similar to those of combustion vehicles.

Worldwide, there are 921 hydrogen refueling stations. The main countries are South Korea - 174 stations, Japan - 166 stations, USA - 92 stations. In Europe there are 265 hydrogen refueling stations, the main countries are Germany - 105 stations, France - 51 stations, Netherlands - 22 stations, Switzerland - 17 stations.

The figure below shows a model of a hydrogen filling station:



Source: www.takaishi-ind.co.jp

14 Hydrogen in transport: everything you need to know in 10 questions - Polytechnique Insights (polytechnique-insights.com).
15 Hydrogen in transport: everything you need to know in 10 questions - Polytechnique Insights (polytechnique-insights.com).

Hydrogen is a key alternative for sustainable mobility, but its widespread adoption requires the development of hydrogen refueling infrastructure. Hydrogen filling stations, or hydrogen pumps, are essential to support the refueling needs of hydrogen-powered vehicles and facilitate the transition to a hydrogen-based transport system.

At the same time, all stakeholders in the hydrogen value chain must be supported to:

- Reduce the cost of hydrogen production, making it more competitive with conventional fuels.
- Position green hydrogen, produced via electrolysis using renewable electricity or transported to refueling stations, as a viable alternative to traditional energy sources and a key driver of transport decarbonization and sustainable mobility.

The refueling process at a hydrogen filling station is not very different from that at a conventional gas station, although there are a few details that make the experience a little different. This is because the hydrogen is supplied at high pressure and, being an extremely volatile gas, the connection between the container or connection point of the vehicle and the pump must be airtight.

Hydrogen stored in the vehicle's fuel tank powers the fuel cell, which generates the electricity required to drive the vehicle. The only byproduct of this process is water vapor, which is expelled through the exhaust system, making hydrogen-powered vehicles a zero-emission alternative.

Unlike conventional fuels, hydrogen is sold by the kilogram, not by liter, and the refueling time for a conventional bus - which typically weighs between 30 and 37.5 kg - is no more than 12 minutes. Regarding fuel consumption, it is estimated at about 8 kilograms per 1000 kilometers for trucks and 1 kg/100km for passenger cars, so the range of hydrogen vehicles currently on the market would be around 400 kilometers.

As far as air transport is concerned, the development of synthetic fuels and hydrogen derivatives is still in its infancy, according to the Institut Polytechnique in Paris.

2.4. Combatting climate change

Several studies have assessed the future dynamics of fossil fuel markets. The energy system has been extensively analyzed to assess how fossil fuels will compete with other technologies under a range of scenarios considering factors such as economic growth, the transition to low-carbon energy systems, and fossil fuel availability. In cases where hydrogen is produced by electrolysis using renewable or nuclear electricity, the lifecycle greenhouse gas emissions of a bus sold in 2020 (or a truck sold in 2030) are reduced by 6 times compared to diesel.

Thus, the decarbonization of hydrogen production is an essential prerequisite for securing significant climate benefits from hydrogen development in the transport sector. The impact of emissions from the electricity mix is even stronger for emissions from hydrogen vehicles than for emissions from electric vehicles, due to the lower efficiency of the hydrogen chain and hence the higher amounts of electricity per kilometer travelled. When hydrogen is produced by electrolysis using renewable or nuclear electricity, the lifecycle greenhouse gas emissions of a bus sold in 2020 (or a truck sold in 2030) are reduced by 6 times compared to diesel. This puts hydrogen technology at similar emission levels to electric buses or trucks recharged in France, as well as biogas vehicles.

From an environmental perspective, and in comparison with battery electric vehicles, the primary advantage of hydrogen-powered vehicles is their significantly reduced battery capacity requirement. This reduces pressure on resources and pollution caused by lithium, cobalt or nickel mining. The hydrogen sector also involves the consumption of metals, in particular platinum for fuel cells and electrolysers, the importance of which will depend on the level of development of the sector[16]. Natural gas will play an important role in Europe's energy mix over the next 15 years or more, but here there needs to be a link with Future Gases, which aim to reduce the impact on climate change. Future (Green) Gas is a concept that involves the use of natural gas in a mix with biomethane (produced from household, agricultural, industrial waste, etc.), hydrogen (produced as a result of extra production from renewable resources) and CO_2 reduction (carbon capture, transportation, utilization and storage).

Romania has a historic opportunity to develop the Green Gas concept, much like it did 115 years ago in the natural gas sector. Just as natural gas was discovered by chance over a century ago, Romania now finds itself in a position where its CO_2 emissions per capita are only 10% higher than those of the European country with the lowest emissions.

16 https://www.polytechnique-insights.com/en/columns/energy/hydrogen-in-transport-everything-to-know-in-10-questions/#note-19.

It is worth noting that 100 years ago, the visionary Constantin Ioan Motaș introduced the idea of gasifying Romania in 1919, with the support and promotion of the I.C. Brătianu Government. This initiative positioned Romania as a pioneer in Europe in the use of natural gas.

At that time, investors were entrusted with completing this initiative. Similarly, today, both a committed government and investors are needed to embrace the same vision in promoting and implementing the Green Gas concept.

3. Examples of successful national and international pilot projects

3.1. Projects at national level

To this end, Delgaz Grid launched the 20HyGrid project, the first of its kind in Romania. This pilot project aims to test and validate a nationwide solution for integrating a natural gas-hydrogen mix, with the objective of adapting and developing a safe and efficient distribution infrastructure for consumers. The project's objective was to analyze the compatibility and behavior of the existing natural gas distribution network, as well as the installations and appliances selected for the pilot, in response to a 20% hydrogen blend. Additionally, it aimed to assess the feasibility of converting these systems to operate with a natural gas-hydrogen mixture.

Now successfully completed, the project has demonstrated that, from a technical standpoint, it is both feasible and safe to integrate hydrogen into existing distribution networks and natural gas-powered installations and appliances in Romania[17].

Other companies in the sector are also developing similar projects, though they have not yet disclosed their approach or the results obtained. Meanwhile, Transgaz has supported a study on injecting hydrogen into the gas transmission and distribution network[18].

The EU national gas transmission system operators, including Transgaz, have initiated the European Hydrogen Backbone (EHB) project, which aims to accelerate Europe's decarbonization path by establishing the essential role of hydrogen infrastructure, leveraging both existing and new pipelines. The project seeks to facilitate the development of a competitive, pan-European market for renewable and low-carbon hydrogen.

The EU Directive 2018/2001 (RED II) has been adopted by the key EU institutions, marking an important milestone as it establishes a solid foundation for policies and offers a clear framework for the EU's approach to renewable energy from 2021 to 2030. **RED II provides guidance to EU Member States on the policies required to support the use of renewable energy in the mobility sector.**

A key provision covered by the rules of RED II is the requirement that EU Member States extend existing Guarantees of Origin (GoO) schemes to include **renewable gas.**

This measure supports the use of low carbon or green hydrogen while also promoting market growth and competitiveness. As a result, it will help drive hydrogen prices to a competitive level and facilitate large-scale deployment within a relatively short timeframe.

One of the key aspects is that hydrogen plays a central role in EU policy, strengthening the expectation that support for this emerging fuel will become more consistent and integrated in the long term. This is particularly crucial for the EU to achieve its 2030 climate targets.

The Fuel Quality Directive 98/70/EC requires a 6% reduction in the carbon intensity of fuel from life cycle analysis (LCA) compared to 2010.

17 https://delgaz.ro/despre-noi/20hygrid
18 https://asociatiaenergiainteligenta.ro/hidrogenul-un-nou-capitol-al-tranzitiei-energetice/

The existing natural gas transportation and distribution infrastructure provides the foundation for reconfiguration. A pragmatic approach implies:

1. using existing infrastructure to transport methane and hydrogen mixtures first;
2. understanding the challenges of introducing hydrogen;
3. making operational changes, where appropriate; and
4. progressively increasing the amounts of hydrogen in the mixtures up to 100%.

Replacing fossil fuels with carbon-neutral ones is an important step towards the ultimate goal of climate neutrality. The transition from natural gas-based energy systems to hydrogen must be gradual. The gradual blending of hydrogen with natural gas will ensure a smooth transition and minimize some of the technical shortcomings that may occur in the distribution of energy and heating sources to the population. Academic institutions, industry and governments around the world have supported and continue to support research, development and implementation of projects for the use of hydrogen in natural gas mixtures - examples of projects include HyDeploy, GRHYD, THyGA, HyBlen, etc.

The advantages of hydrogen as a carbon-free energy carrier, however, must be carefully weighed against safety concerns related to the transportation of hydrogen-gas mixtures, particularly regarding overpressure risks and pipeline losses.

Successful conversion, as outlined above, requires a coordinated effort from central (government) and local administrations, along with various institutions and investors.

A target-setting approach to the injection and consumption of renewable and low-carbon gas will provide clear signals to investors, translating into real business opportunities. This will drive action and support efforts to green the gas infrastructure, while expanding the use of hydrogen and other renewable and low-carbon energy sources.

The ultimate objective must be to decarbonize both existing and emerging gas markets, rather than focusing solely on the gas grid. Otherwise, this approach would risk encouraging production solely for injection and grid decarbonization, potentially diverting volumes from higher-value markets where hydrogen and low-carbon gases could have a greater impact.

An EU-wide target, rather than individual national targets, is preferable as it would provide greater flexibility, while acknowledging and respecting the diverse national and geographical characteristics of each Member State.

In light of the EU's long-term climate objectives, the maturity and expansion of the use of renewable and decarbonized gases would be further strengthened by the implementation of specific time-bound targets:

- 2030: at least 7% of the volume of natural gas is replaced by hydrogen.
- 2040: at least 32% of the volume of natural gas is replaced by hydrogen.
- 2050: 100% renewable and decarbonized gas, of which at least 50% is hydrogen.

As such, targets for maximizing the use of renewable and decarbonized gas should be integrated into the strategic plans of each gas portfolio company, in alignment with EU Regulation (EU) 2018/1999.

3.2. Projects at international level

Regarding gold hydrogen, following the discovery by French scientists, Swiss researchers have also conducted their own explorations for hydrogen reserves. Additionally, Spain also planned to start extracting hydrogen gold from the north of the country from 2024, but actual implementation has not yet started.

EU legislation mandates that all new buses must be zero-emission vehicles starting from 2021. Hydrogen fuel cell vehicles can contribute in two key areas: improving air quality and combating climate change.

Public transportation is one of the key applications of hydrogen. Linde is actively involved in numerous projects in this sector and has played a pivotal role in developing many of the technologies used today. One of its first mobility projects was launched in Emeryville, California, in 2011, with the inauguration of a hydrogen fueling station for buses operated by AC Transit.

Schleswig – Holstein (Germania)

Another example is the operationalization of 5,000 **hydrogen-powered trucks in Schleswig - Holstein[19],** Germany. Hydrogen is a viable alternative to electric batteries for large trucks, as hydrogen can be quickly charged in large tanks and converted into electricity.

Electricity will be generated onboard using hydrogen through a fuel cell. Autonomy is expected to exceed 400 kilometers per full tank. To support this expansion, approximately 150 hydrogen refueling stations are required, starting in Schleswig-Holstein. An installed capacity of 2.5 gigawatts will be necessary to supply hydrogen over the next five years. The first trucks hit the roads in the second half of 2023. *"Another 500 in 2024, then another 1,000 every year,"* according to Ove Petersen, CEO of the manufacturing company, GP Joule.

However, the transition to hydrogen trucks comes at a high cost, as hydrogen-powered trucks currently exceed €500,000, compared to just €120,000 for diesel trucks.

Production capacity will be gradually increased at Winsen (Luhe) and Veenendaal in the Netherlands until 2027. At the same time, more skilled workers are needed throughout the Hamburg metropolitan region to meet increasing demand.

"We will create up to 500 new jobs in Winse in the next three to five years and we are desperately looking for qualified staff," says Graszt.

Hydrogen bus fleet, Bolzano (Italy)

In the South Tyrolean capital Bolzano, 17 of the city's 96 buses have been running on hydrogen for several years. According to Linde experts, hydrogen is an *"attractive alternative for local transit"* as it *"provides fast refueling times and long running distances - even in winter when temperatures are low. Hydrogen filling stations also have relatively low energy consumption. In addition, fleets are - by virtue of how they are used - ideal for hydrogen. Buses, trains, and in some cases, trucks are used continuously, but always return to base. So public transportation requires a much smaller infrastructure of refueling stations than cars. As a result, the frequency of refueling at each station is relatively high, thus accelerating the return on infrastructure investment"[20].*

Hydrogen electric buses also contribute to better air quality and overall quality of life by eliminating harmful emissions and noise pollution. In Bolzano, the vehicles travel about 200 km during the day and return to base each evening, where they are refueled within minutes. Several Linde ionic compressors are available at the base for refueling, each compressing H_2 gas to the 350-bar pressure required for buses and 700 bar for cars. This combined bus/car refueling station can serve up to 15 buses and numerous cars. In addition, the carbon footprint of the station is neutral. It generates hydrogen using three electrolysers powered by certifiable renewable energy sources for zero emissions from source to operation.

Asia

Another example comes from outside the EU. **Japan** is far ahead of Europe in developing H_2 infrastructure, being one of the first countries in the world to launch a national hydrogen strategy (in 2017). The country has set ambitious targets, such as building an H_2 supply network by 2030 capable of producing 300,000 tons of hydrogen and expanding H_2 mobility coverage. The plan includes the deployment of 800,000 fuel cell cars and 1,200 fuel cell buses by 2030. Other regions are also investing in H_2 initiatives, developing concrete hydrogen initiatives and working on sustainable infrastructures.

Japan's hydrogen infrastructure is already well-developed as the government has started implementing its hydrogen strategy. In this context, it is worth mentioning the Tokyo Bus Hydrogen Fueling Station, which was inaugurated in January 2020 as part of Japan's commitment to expanding its hydrogen infrastructure. Equipped with a Linde CP90/100 cryogenic pump, the facility can dispense up to 100 kilograms of H_2 per hour at an inlet pressure of just 2 bar, enough for 30 fuel cell buses per day. One of the key elements of this refueling station in Japan is the ability to store H_2 in liquid form, which can then be efficiently converted into gaseous, compressed H_2 using Linde's cryogenic pump technology.

19 First of 5,000 Hydrogen Lorries to Hit Roads in Germany in 2023 - Hamburg - Hydrogen Central (hydrogen-central.com).
20 Supplying buses and trains with H_2 | Linde Gaz Romania (linde-gas.ro).

In the future, refueling stations *"will have to expand and be able to supply more H_2. They will also need to fuel larger vehicles such as trucks. For the market to take off quickly, costs will have to come down in the medium term. In the case of hydrogen filling stations, that means standardization. In other words, the bus, truck and train market need the same standardized, globally valid refueling protocols that already exist for cars. These need to define factors such as the pressure and temperature at which H_2 can be fueled"*[21].

Hydrogen also offers significant opportunities for other transport segments, including commercial vehicles, municipal waste vehicles, road sweepers and other specialized vehicles following scheduled routes. All these vehicle categories can be efficiently supplied from a central hydrogen refueling station.

Hyundai Motor Co and Toyota Motor Corporation manufacture both fuel cell buses and trucks. Linde has built Southeast Asia's first H_2 refueling station **in Malaysia.** The facility serves a fleet of local buses and includes on-site integrated hydrogen production by electrolysis.

At the same time, a refueling station **in Shanghai, China,** has started operating to dispense H_2 for minibuses, trucks and cars.

4. Regulation

4.1. European Hydrogen Strategy

The European Hydrogen Strategy (COM/2020/301) was adopted in 2020, outlining policy measures across five key areas: support for investment; support for production and demand; creation of a hydrogen market and infrastructure; research and international collaboration. Hydrogen is also an important component of **the European strategy for the integration of energy systems** (COM/2020/299).

The EU's priority is to develop green hydrogen, with a target of producing 10 million tons domestically and importing an additional 10 million tons by 2030. Investment support has been provided through the Important Projects of Common European Interest (IPCEIs) for hydrogen. The first such instrument, called IPCEI Hy2Tech[22], which includes 41 projects, aims to develop innovative technologies for the hydrogen value chain to support the decarbonization of industrial processes and the mobility sector.

In September 2022, the Commission approved "IPCEI Hy2Use", which complements IPCEI Hy2Tech and aims to support the development of dedicated hydrogen infrastructure. The Clean Hydrogen Partnership was established in November 2021 to support research and innovation in the hydrogen ecosystem. The regulatory framework was complemented by two delegated acts, formally adopted in June 2023, applicable to sustainable hydrogen under the Renewable Energy Directive. The first one covers green fuels of non-biological origin, while setting criteria for products falling under the category of "sustainable hydrogen".

To facilitate investments in clean hydrogen, **the European Clean Hydrogen Alliance** has prepared a set of more than 840 viable investment projects. These currently cover all components of the value chain, including **hydrogen production, transmission and distribution, and applications in industry, transportation, energy systems and buildings.** Many projects cover hydrogen production and its use in sectors such as chemicals, refineries, steel, cement and transportation, particularly road and maritime transport. The projects are being implemented across Europe, with many expected to be operational by the end of 2025.

21 Supplying buses and trains with H_2 | Linde Gaz Romania (linde-gas.ro).
22 https://ec.europa.eu/commission/presscorner/detail/en/SPEECH_22_4549.

4.1.1. Directive (EU) 2018/2001 and Directive 2023/2413

Directive (EU) 2018/2001 (RED II) has been adopted by the key EU institutions. This is an important milestone as it provides a solid basis for policies and therefore a clear perspective on how the EU will approach renewable energy between 2021-2030. **The RED II Directive provides guidance to EU Member States on the policies they need to implement regarding the use of renewable energy in mobility.**

A key aspect of REDII is the declaration that EU Member States must extend existing Guarantees of Origin (GoO) schemes to include **renewable gases.**

This will support the use of low carbon or green hydrogen. This contributes to increasing the market and competitiveness, thus pushing hydrogen to a competitive price and on a much larger scale in a relatively short time.

Directive 98/70/EC requires a 6% reduction in the carbon intensity of fuel from life cycle analysis (LCA) compared to 2010.

The existence of an infrastructure for the transportation and distribution of natural gas creates the preconditions for reconfiguration. A pragmatic approach involves: (i) using the existing infrastructure to transport mixtures of methane and hydrogen first; (ii) understanding the challenges of introducing hydrogen; (iii) making operational changes where necessary; and (iv) progressively increasing the hydrogen in the mixtures to a 100% share.

Making the transition a success requires a coordinated effort from central government, local government, various institutions, including investors.

Directive 2023/2413 (RED III) imposes stricter rules on alternative fuels. As regards hydrogen, Member States must ensure that the contribution of renewable fuels of non-biological origin (e.g. green hydrogen) used for energy and non-energy end-use purposes should account for at least 42% of hydrogen used in industry by 2030 and 60% by 2035. These targets aim to promote a shift to cleaner energy sources, with the aim of creating a potential for innovation in renewable fuels and hydrogen technologies.

A significant element of RED III is the focus on renewable fuels of non-biological origin, in particular hydrogen.

4.2. National legislative framework

4.2.1. Hydrogen Law

On July 23, 2023, Law No. 237 on the integration of hydrogen from renewable and low-carbon sources in the industry and transport sectors entered into force. According to it, fuel suppliers have the obligation to ensure that the energy value from the amount of non-biological renewable fuels supplied to the market and used in the transport sector for one year is at least equal to 5% of the energy content of all fuels supplied for consumption or use on the market in Romania, starting from 2030.

The law also requires industrial hydrogen consumers to secure non-biological renewable fuels and low-carbon hydrogen from hydrogen suppliers. Industrial hydrogen consumers are obliged to ensure that:

- From 2030 onwards, a minimum of 50% shall be fuel from non-biological renewable sources or low-carbon hydrogen and a minimum of 42% from non-biological renewable sources.
- From 2035 onwards, a minimum of 75% shall be fuel from non-biological renewable sources or low-carbon hydrogen and a minimum of 65% from non-biological renewable resources.

For certificates for the supply of renewable and low-carbon hydrogen, they shall contain at least the following information: the type of fuel placed on the market, the energy source used, the year it was placed on the market and the sector in which it was supplied. Fuel suppliers, hydrogen suppliers and industrial hydrogen consumers shall be entitled to trade in renewable hydrogen supply certificates and low-emission hydrogen supply certificates in accordance with the procedure laid down in Article 14 (1).

The provisions of Law 237/2023 on the integration of renewable and low-carbon hydrogen in the industry and transport sectors should also take into account European regulatory acts, such as those published in the EU Journal on July 15, 2024, Directive 1788/2024 approving common rules for the internal markets in the renewable gas, natural gas and hydrogen sectors & Regulation 1789/2024 internal markets in renewable gas, natural gas and hydrogen).

The overall aim of the updates is to make the regulatory framework fit for purpose for a future gas energy mix that includes less fossil (natural) gas and an increasing share of renewable and low-carbon gases with different origins and properties.

Through these documents it is confirmed that low-carbon hydrogen is considered in the accepted solutions for the energy transition.

The implementation of the law in the form in which it is approved today is ambiguous, as there are still no rules in place to assess how the targets will be achieved. In the absence of implementing rules, the authorities should provide clarity and additional guidance to economic operators and hydrogen suppliers.

On the financing side, for investments in low carbon footprint hydrogen production based on natural gas (catalytic reforming, methane pyrolysis) or other technologies, no call for projects has been opened. Moreover, the national strategic documents have not yet foreseen separate funding lines in the national strategic documents, which would promote the production of hydrogen based on natural gas and motivate the increase of the co-financing percentage for such projects.

4.2.2. National Hydrogen Strategy

In the context of the national strategy, the principle of technology neutrality must be upheld, ensuring that there are no limitations on investment in any technologies that can significantly contribute to reducing carbon emissions.

By using technologies to obtain hydrogen from natural gas, with a reduced CO_2 footprint, the decarbonization of both natural gas is achieved, extending the lifetime of natural gas and the industrial sector (hard-to-abate).

Given that pink hydrogen has zero carbon footprint, it is problematic to fully assimilate the definition of low-carbon-footprint hydrogen with this type of hydrogen.

We suggest maintaining, within the context of this Strategy, the broader definition of clean hydrogen (i.e. low carbon footprint, including zero carbon footprint) to ensure that no type of hydrogen is excluded, provided it meets the 70% threshold for greenhouse gas emission reductions compared to fossil fuels.

"According to EU taxonomy rules, and applicable in the context of this strategy, this category includes any type of hydrogen produced by various technologies, provided that a 70% threshold for greenhouse gas emission reductions relative to fossil fuels is met."

Thus the definition may cover, for example, pink hydrogen, blue hydrogen, turquoise hydrogen or other types of hydrogen, in a broad terminology of low or zero carbon footprint hydrogen.

At the European level, the objective has been set to achieve climate neutrality by 2050 in a way that makes a particularly positive contribution in the economic sphere, with the main goal of reducing greenhouse gas emissions by 55% by 2030.

In the light of Directive of the European Parliament and of the Council amending Directive (EU) 2018/2001 of the European Parliament and of the Council, Regulation (EU) 2018/1999 of the European Parliament and of the Council and Directive 98/70/EC of the European Parliament and of the Council as regards the promotion of energy from renewable sources and repealing Council Directive (EU) 2015/652 ("RED III") - as recently published in the Official Journal, The EU sets, in the perspective of Article 25, **a mandatory minimum share of non-biologically renewable fuels of non-biological origin (RFNBOs) used in transport of 1%** of energy supplied in transport, with the difference up to 5.5% in 2030 being covered by **advanced biofuels.**

On the other hand, through local transposition, **Law 237/2023 ("Hydrogen Law")** imposes a much higher target for the share of RFNBO in the energy supplied in transportation - 0.5% in 2025, rising to 5% in 2030. This target can be reached either directly (through the sale of green Hydrogen at fuel pumps) or indirectly through its use in the production of conventional fuels.

It is important to emphasize that it is crucial for the hydrogen used in the processes related to the production of SAF / HVO - Sustainable Aviation Fuel / Hydrotreated Vegetable Oil - to be properly accounted for. Romania enjoys a favorable position in the European context, having the opportunity to transform its status as an importer into that of a local producer, thanks to all the raw materials that are accessible to it in order to set up a real biofuel production hub.

Another aspect to consider is that the target of **0.5% RFNBO in 2025 cannot be reached objectively.** Currently, the only projects in Romania that focus on the development of green hydrogen production are those that have received funding under the PNRR program, with a completion deadline set for December 2025. In this context, it appears highly unlikely that green hydrogen production will commence by 2025, which raises concerns about the feasibility of meeting the RFNBO target for the transportation sector within the established timeframe.

Other critical points observed refer to the rules outlined in the National Hydrogen Law:

- First, the multipliers currently existing in the Hydrogen Act for use in the calculation of transportation RFNBO allowances need to be corrected, namely: x1.2 for hydrogen used in refineries for the production of fuels supplied in the aviation and maritime modes of transportation, and x1.6 for hydrogen supplied to hydrogen vehicles in public refueling stations. Mirroring this, RED III allows a multiplier of x2 for all RFNBOs, irrespective of the form in which they end up being used in transportation (including renewable hydrogen used to produce conventional fuels). We emphasize that it is crucial to set the multiplier share at a minimum of x2 (ideally, we would like to implement a x4 - here we propose to organize a discussion to understand the importance of updating) in order to reach the 2030 targets.
- Given that the methodology for issuing Green H2 / Low Carbon Footprint H_2 certificates has not yet been adopted, we emphasize the point that the form of the methodology (to be developed) should allow the transfer of issued certificates from one year to another (the system being based on the following model: if 3 certificates were issued in 2028 and only 2 certificates were used, the third one should be able to be used in the following years (2029 or 2030 etc.) depending on the need).

Romania is currently preparing the National Hydrogen Strategy and Action Plan for its implementation.

We would like to bring to your attention several important aspects of the National Hydrogen Strategy that we believe should be revisited before the final version of the document is approved.

As of now, the National Hydrogen Strategy in Romania considers a total share of non-biological renewable fuels used in **the transportation sector of 2.4% - composed of:**

- **the use of hydrogen in the refining processes** of traditional fuels to account for 1% of total energy consumption in transport by 2030; and
- **1.4% RFNBO in Transport from the use of hydrogen as a fuel alternative** by heavy goods vehicles, rail, local public transport, hydrogen-powered personal cars and by maritime transport and aviation through the use of hydrogen-based fuels and sustainable aviation fuels in the production of which green hydrogen is used.

In this sector, it can be stated that **the target set for refineries and transportation is beyond the compliance possibilities in practice** (1% + 1.4% RFNBO in 2030) and not aligned with RED III (minimum 1%):

- Fuel cell vehicles have not yet reached the technological maturity needed to develop mass production and mass adoption. The options for fuel cell vehicles are currently very limited.
- The purchase cost of fuel cell vehicles is a major barrier to their uptake.
- The development of the entire logistics and supply chain for Hydrogen as an alternative fuel requires significant investment projects, which cannot be economically justified in the current context. In addition, the regulatory framework for the construction and operation of hydrogen refueling stations is not yet developed.
- Therefore, the uptake of hydrogen vehicles before 2030 is very unlikely and, by implication, the use of hydrogen 'at the pump' as an alternative fuel is unlikely to occur before 2030.
- With regard to the RFNBO target applicable strictly to refineries, it should be noted that it is imperative that this target is linked to the technical capacity of refineries to use hydrogen in refining processes. There is a technological limitation on the maximum volumes of hydrogen processed in refineries. Furthermore, a significant amount of the hydrogen used in refineries is so-called "white hydrogen", which is a by-product of the crude oil refining process and can never be replaced by another type of hydrogen (renewable or low carbon footprint).
- The only way to increase the volume of hydrogen that can be used in refineries is to expand their production capacity. However, in the context of the transition from fossil fuels to alternative fuels, the production capacity of refineries can only be maintained in the medium to long term through major investments in new products such as sustainable aviation fuels.

Under these circumstances, we would like to note that the target of 1% RFNBO to be used in refineries, both for the production of traditional fuels and sustainable fuels, is at the upper limit of the volumes of hydrogen used in refineries that can be replaced by renewable hydrogen.

In this context, it is crucial to understand the vision of the relevant authorities in relation to when the 1.4% RFNBO from transport target will not be reached (which becomes inevitable in the short/medium term). We reiterate that this should not and cannot be added to the RFNBO target allocated to refineries, as they have a very clearly established technological limitation on the volumes of H_2 they can use. In this framework, a target of 2.4% cannot be achieved from refinery H_2 alone.

We emphasize that for companies in the industry aiming not only to achieve all the targets set at European level, but also to maintain the company's stable positioning in the present/future European context, by developing programs that place not only the Company, but also the Romanian State in a favorable framework, it is imperative that the current regulatory framework **creates the strategies and the environment conducive to promoting a climate and economically sustainable market.**

In order to achieve this, however, **both the Strategy and the Law need to be in line with the RED III rules,** clearly stipulating that the minimum 1% of the RFNBO needed to reach the targets set can be supplemented by accounting for **advanced biofuels** (up to 5.5%).

In addition, it should be made clear that this 1% RFNBO target applicable to refineries (which hypothetically will meet the condition of being used in transport), can also account for renewable hydrogen used in the production of both SAF, HVO and traditional fuels (gasoline, diesel).

This is the only way to achieve the goals set in terms of quantifying green hydrogen, in line with the national priorities aimed at developing the entire hydrogen value chain, through Romania's participation in European initiatives to encourage the development of hydrogen technologies. The aim is to reach the threshold of economic competitiveness and large-scale utilization, with an essential contribution to energy security and support for attracting investment in modern technological solutions that have reached a degree of maturity and have been sufficiently tested to operate under economically efficient conditions.

An additional important point to highlight is that Romania's Hydrogen Strategy explicitly excludes hydrogen derived from natural gas - whether through methane reforming with carbon capture, utilization, and storage (blue hydrogen) or through methane pyrolysis (turquoise hydrogen) - from the category of low carbon footprint hydrogen. Only pink hydrogen is included within this classification. Thus, the principle of technological neutrality is not respected and the appetite for investment in all technologies that can make a significant contribution to reducing carbon emissions in the context of the sustainability targets assumed at European and national level, and which may be compatible with Romania's profile as a European country that will continue to produce natural gas with an important role in the region's energy security, is limited.

Also, since pink hydrogen is produced by water electrolysis (with zero carbon footprint) and nuclear energy (which does not generate carbon emissions), it becomes problematic to fully assimilate the definition of low carbon footprint hydrogen with this type of hydrogen.

Thus, the definition could cover, for example, pink hydrogen, blue hydrogen, as well as turquoise hydrogen, in a broad terminology of low or zero carbon footprint hydrogen, thus respecting the principle of technological neutrality, without imposing limits on the appetite for investment in all types of technologies that can make a significant contribution to reducing carbon emissions.

The use of low CO_2 footprint technologies for hydrogen from natural gas decarbonizes both natural gas, extending its lifetime, and the industrial sector (hard-to-abate).

Given that pink hydrogen has a zero-carbon footprint, it is problematic to fully assimilate the definition of low-carbon hydrogen with this type of hydrogen.

If the aforementioned aspect is not taken into account, we risk failing to fully capitalize on the resources available in Romania.

4.2.3. National Integrated Energy and Climate Change Plan 2021 - 2030

The updated version of the National Integrated Energy and Climate Change Integrated Plan 2021 - 2030 (PNIESC) mentions the introduction of green hydrogen in the energy system among the measures needed for decarbonization.

The PNIESC also refers to Law 237 of July 19, 2023, stating that the priority of this normative act is *"to increase the national energy production capacity and to strengthen Romania's energy security"*.

The plan highlights a number of **key targets and obligations for Member States,** including:

- Install a minimum number of publicly accessible hydrogen refueling stations nationwide by December 31, 2030. Operators of hydrogen refueling stations must offer end-users the possibility to refuel vehicles on an ad-hoc basis at these stations.
- Assess the possibility of developing alternative fuel technologies and propulsion systems, such as hydrogen or battery powered trains and, where appropriate, possible needs for recharging and refueling infrastructure for rail sections that cannot be fully electrified for technical or cost-effective reasons.
- By December 31, 2024, each Member State must prepare and submit to the Commission a draft national policy framework for the market development of alternative fuels in the transport sector and the installation of the relevant infrastructure. By December 31, 2025, Member States must develop their own national policy framework and notify the European Commission of the measures taken.
- By December 31, 2027, and every two years thereafter, each Member State shall submit to the Commission **an individual national progress report** on the implementation of its national policy framework. By March 31, 2025, and every year thereafter until March 31, Member States shall report to the Commission the cumulative total recharging power output, the number of installed publicly accessible recharging points and the number of battery electric vehicles and plug-in hybrid electric vehicles registered in their territory on December 31 of the previous year.
- Member States must designate an identification registration organization that issues and manages unique identification codes to find at least the operators of recharging points and mobility service providers by 14 April 2025.

4.2.4. Missing elements and recommendations for updating existing legislation

Regarding the costs involved in hydrogen production, hydrogen technologies are currently more expensive than electricity, both in terms of transportation and energy costs. However, the additional acquisition costs vary greatly depending on the mode of transportation and the evolution of the vehicle market. Additional energy costs also depend to a large extent on the method of hydrogen production, with electrolysis production currently twice as expensive as steam reforming of fossil gas[23]. Transportation and distribution costs are also significant, especially if there are long distances between production and consumption sites.

In this context, estimates for the different technologies are subject to considerable uncertainty. Therefore, hydrogen competitiveness may vary widely depending on the evolution of technical constraints, available resources or the degree of deployment of different energies. Ultimately, the outcome will depend on the potential levels of support or taxation applied to energy sources or technologies by public authorities.

The technical challenges vary by mode of transportation or vehicle, which also determines the timing of hydrogen diffusion. For example, for air transportation, the low volume density may require a revision of the aircraft shape or at least the shape, weight and size of the tanks, which is one of the major technical challenges in the development of a hydrogen-powered aircraft.

In terms of the regulatory framework, we have five main ideas that we highlight as conclusions:

- It is necessary to align national policies with European ones - specifically for Romania - it is necessary in particular to set realistic targets and to establish the appropriate methodology to quantify the targets (e.g. multiplier x2).
- We need to develop the necessary implementing rules for the uptake of renewable and low carbon footprint hydrogen, both in terms of technical rules and non-discriminatory methodology for the certification of hydrogen, including low carbon footprint hydrogen (including hydrogen from low carbon footprint natural gases such as blue and turquoise - to respect technological neutrality).
- International collaboration needs to be regulated, especially at the European level - trading of renewable / low footprint hydrogen certificates internationally.
- National strategies should focus on diversifying options along the entire hydrogen value chain - from equipment suppliers, materials suppliers to the companies that will trade hydrogen in the market and potential hydrogen consumers in the industrial sector. This should ensure the removal of potential bottlenecks, which can come with a high price tag, during project development and market building around hydrogen.
- Financial support from the Romanian State (through non-reimbursable funds / other potential mechanisms) is imperative to reduce the cost of Renewable / Low Carbon Footprint Hydrogen and encourage the development of the entire value chain, from production to consumption - PNRR is a very good starting point for the development of the renewable hydrogen economy in Romania, but it is far from being enough. Promoting an adjacent idea, we emphasize the need to simplify the application processes for obtaining funds, as well as those related to the implementation of projects, here requiring the revision of HG 907 / 29.10.2016 or the use of other rules / processes for private companies.

Considering all the above, we reiterate the main ideas:

- Romania has the potential to produce and export renewable and low-carbon Hydrogen in the region.
- Romania's targets for the production of renewable and low carbon footprint Hydrogen must be aligned with those at European level, while preserving technological neutrality.
- The way to implement these ambitions of the National Strategy and the Hydrogen Law will need to be clarified as soon as possible in order to ensure an efficient implementation of projects aiming at the production of renewable and/or low carbon Hydrogen.

23 Hydrogen in transport: everything you need to know in 10 questions - Polytechnique Insights (polytechnique-insights.com).

Conclusions

The development of hydrogen infrastructure in Romania should consider the following main directions:

1. New National Energy System Model with the introduction of hydrogen as an energy vector in the power-to-gas sector and Sectoral Coupling.
2. Eliminating the exclusive use of hydrogen as a fuel and developing its role as a renewable energy carrier.
3. Preparing Human Resources for change in the energy sector.
4. Social acceptability for future technologies.
5. Rethinking energy taxation.
6. Developing and implementing public policies to stimulate new technologies.
7. Developing a hydrogen market.
8. Hydrogen critical infrastructure.
9. Legislation, Regulation, Standardization.
10. Full-scale mini pilot projects.