



Technology Transfer in Energy Sector



HYDROGEN AND ITS ROLE IN THE ENERGY TRANSITION

- INTRODUCTION
- HYDROGEN AND ITS CHARACTERISTICS
- THE INTEGRATED HYDROGEN CHAIN
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 - Hydrogen for mobility
 - Hydrogen for energy uses
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- CONCLUSIONS

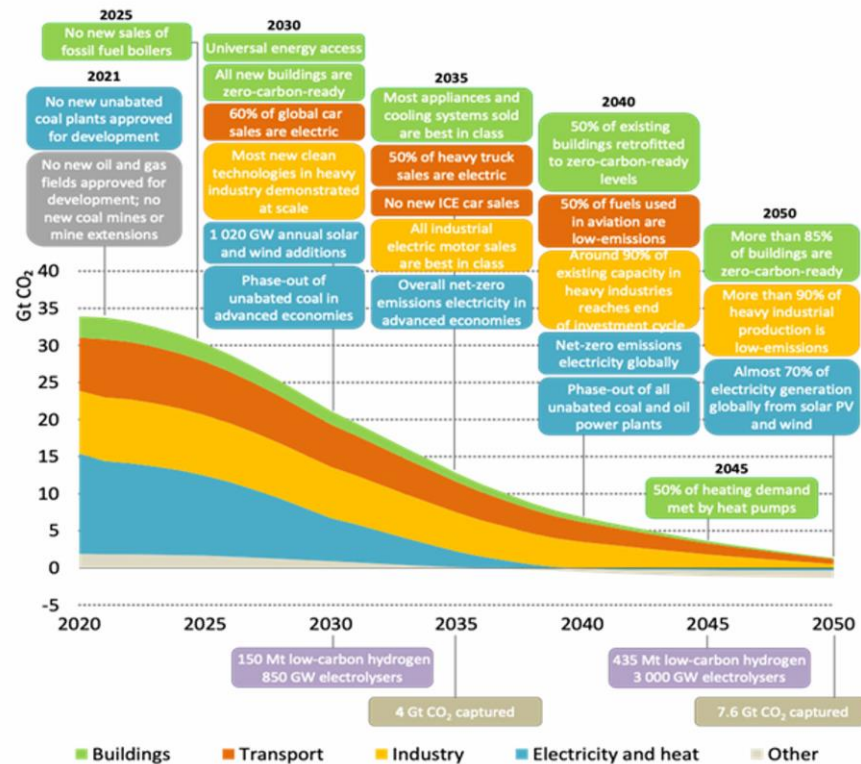
- The "energy transition" represents the transition from an energy production model based on the use of fossil fuels to a model based on renewable energy sources or zero CO₂ emissions.
- The transition process will lead us towards a sustainable economic model and is motivated by:
 - ✓ Need to reduce environmental impact and CO₂ emissions (from fossil sources).
 - ✓ Finite global quantity of fossil resources.



INTRODUCTION



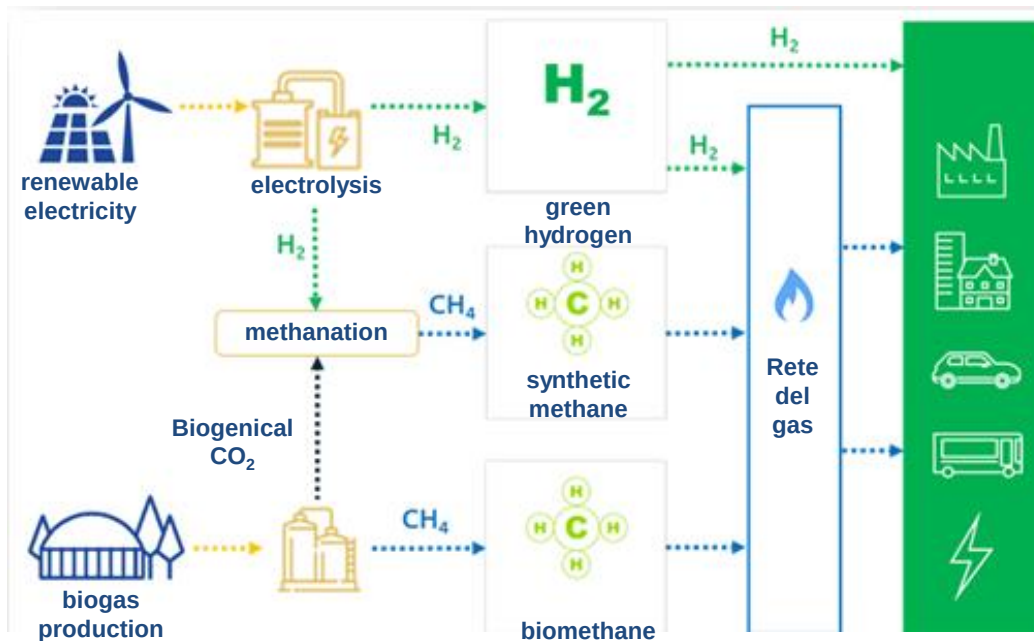
- The European Union has defined a path to transform Europe into the first continent with zero climate impact
 - ✓ «carbon neutrality» by 2050
- The sectors involved are:
 - ✓ construction, transport, industry, electrification and heating



Le The phases of the EU Carbon Neutrality process

INTRODUCTION

- Hydrogen offers a great contribution and multiple advantages to meet energy needs and achieve the 2050 objectives.
- It is added to renewables
 - ✓ contributes to decarbonising the "hard-to-abate sectors" (chemical and steel industries, heavy transport).
 - ✓ It integrates into existing transport networks.



HYDROGEN ADVANTAGE



can decarbonize the so-called "hard to abate" sectors



it can be produced from renewable sources, with significantly decreasing costs of both solar and wind power and electrolyzers

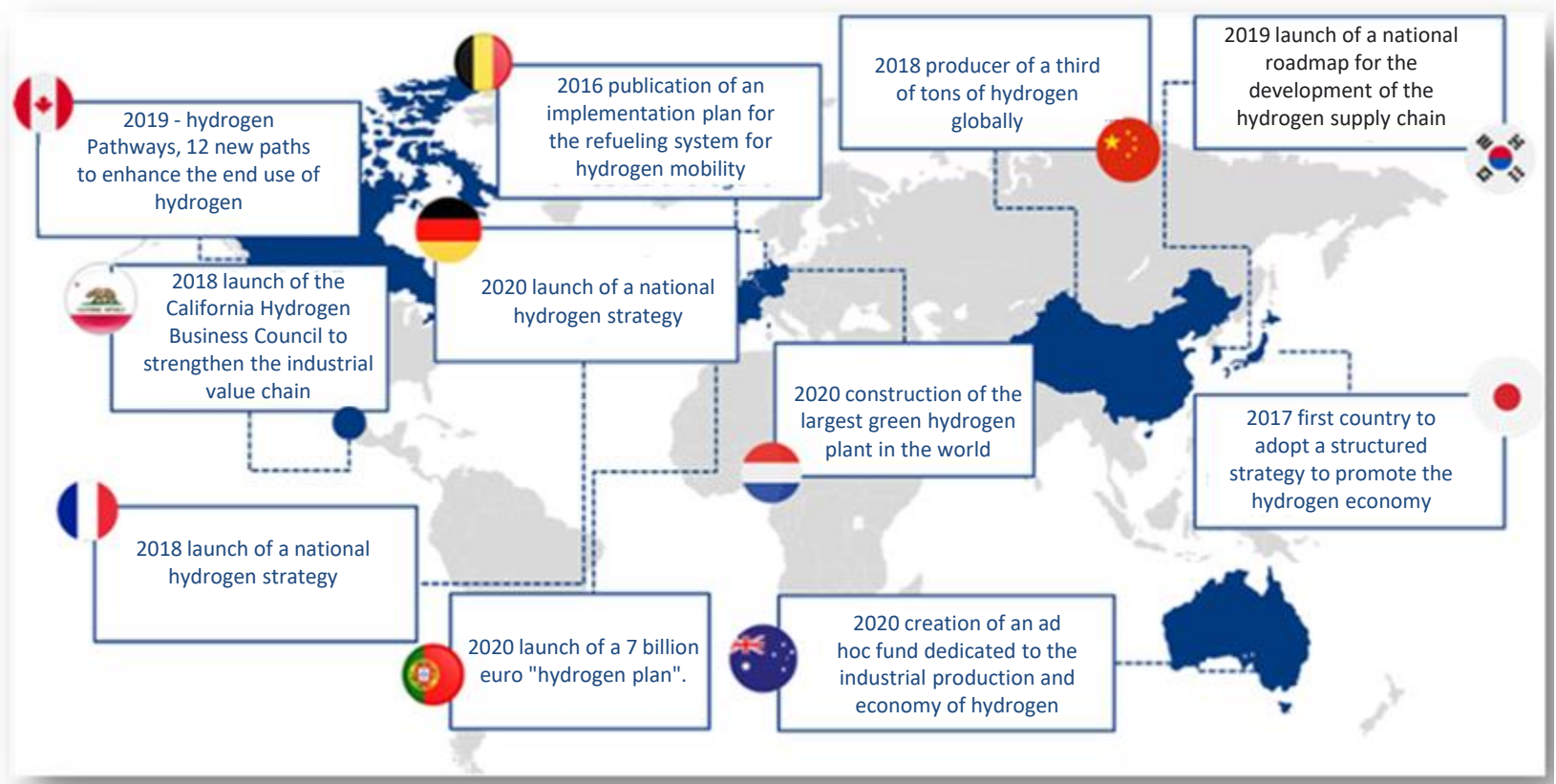


the existing network is already around 70% hydrogen ready



promotes "sector coupling", i.e. the integration between the electricity and gas sectors which allows for greater flexibility and therefore lower costs for the energy system as a whole

- The advantages of hydrogen as a widespread, low-carbon energy carrier are increasingly attracting the attention and interest of governments.

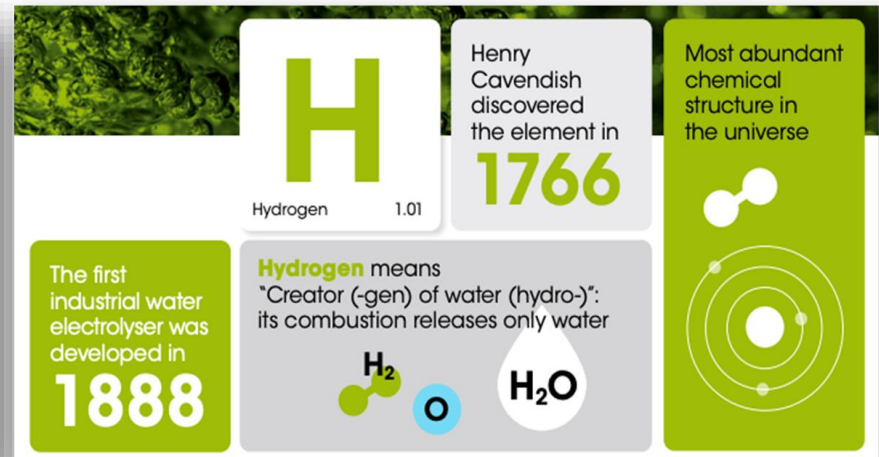


National strategies and related starting year Source: The European House

Ambrosetti elaboration on various sources, 2020

- **Hydrogen**

- ✓ It consists of a simple two-atom molecule (H_2).
- ✓ It is colorless, odorless (at atmospheric pressure and room temperature) and non-toxic.
- ✓ It is flammable (with a blue flame similar to methane in an oxygen-rich atmosphere).
- ✓ It does not produce particulate CO_2 or sulfur emissions.
- ✓ It has less density than air.
- ✓ It has high energy density per unit mass and a low volumetric energy density compared to hydrocarbons



H
Hydrogen 1.01

Henry Cavendish discovered the element in **1766**

Most abundant chemical structure in the universe

The first industrial water electrolyser was developed in **1888**

Hydrogen means "Creator (-gen) of water (hydro-)": its combustion releases only water

H₂ **O** **H₂O**

Property	Hydrogen	Comparison
Density (gaseous)	0.089 kg/m ³ (0°C, 1 bar)	1/10 of natural gas
Density (liquid)	70.79 kg/m ³ (-253°C, 1 bar)	1/6 of natural gas
Boiling point	-252.76°C (1 bar)	90°C below LNG
Energy per unit of mass (LHV)	120.1 MJ/kg	3x that of gasoline
Energy density (ambient cond., LHV)	0.01 MJ/L	1/3 of natural gas
Specific energy (liquefied, LHV)	8.5 MJ/L	1/3 of LNG
Flame velocity	346 cm/s	8x methane
Ignition range	4–77% in air by volume	6x wider than methane
Autoignition temperature	585°C	220°C for gasoline
Ignition energy	0.02 MJ	1/10 of methane

Notes: cm/s = centimetre per second; kg/m³ = kilograms per cubic metre; LHV = lower heating value; MJ = megajoule; MJ/kg = megajoules per kilogram; MJ/L = megajoules per litre.

Comparison table of the characteristics of hydrogen and methane gas

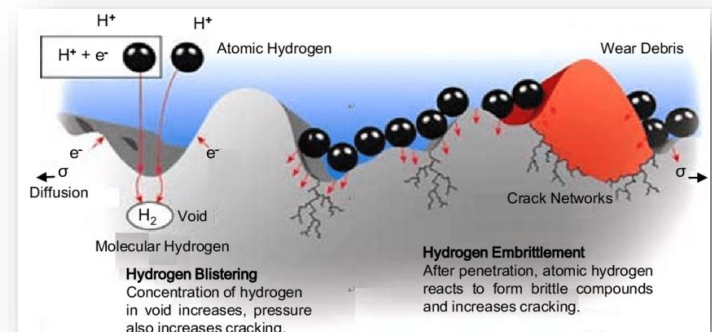
Safety and Health

- The production and use of hydrogen poses primary health and safety issues comparable to those of other energy carriers.
- More specifically, hydrogen requires special equipment and procedures.
- It can spread in some materials (iron, steel).
- It can leak more easily through seals and connectors (compared to natural gas).

Safety and Health

Corrosion Effect

- Some metallic materials (in contact with hydrogen) may be subject to embrittlement and/or stress corrosion.
- **Embrittlement** is the phenomenon due to which normally ductile metallic materials fail through fracture processes in a brittle manner
 - ✓ Caused by the diffusion of atomic hydrogen within the crystalline structure of the metal.
- The factors relevant to this phenomenon are:
 - ✓ temperature, pressure and hydrogen contaminants.
 - ✓ type of metallic material and its structure (discontinuity, porosity, ...).
 - ✓ distribution of stress on the material.



Safety and Health

Corrosion Effect

- **Hydrogen corrosion (acid corrosion) occurs when metal comes into contact with water and there is a lack of oxygen.**
 - ✓ The final product of oxidation-reduction is pure hydrogen which oxidizes the metal.
 - ✓ The metal goes into solution in the form of ions, causing uniform degradation of the metal.
 - ✓ The generated hydrogen diffuses into the steel, occupying the metal lattice of the material.
- **This leads to chemical fatigue of the materials which can cause sudden breakages from the inside out (even at low loads).**



HYDROGEN AND ITS CHARACTERISTICS

Safety and Health Corrosion Effect Material for Hydrogen



Metals for low temperatures and cryogenic applications

Safety and Health

Physiological Effects and Environmental Protection in the presence of hydrogen

- Hydrogen is not toxic/harmful – but if inhaled in high concentrations it can cause asphyxiation.
- Freshly evaporated liquid or gaseous hydrogen can cause cold burns.
- Hydrogen does not cause damage to the environment and if released into the atmosphere it does not damage the ozone layer.

Safety and Health

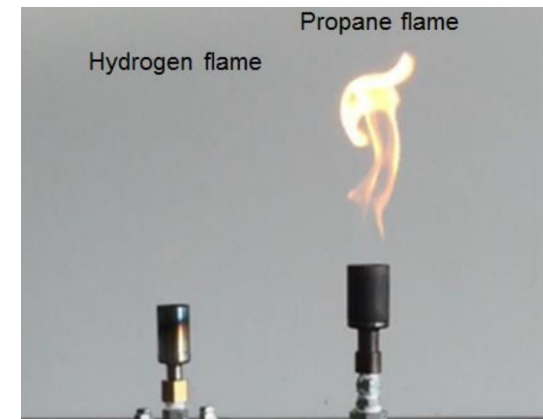
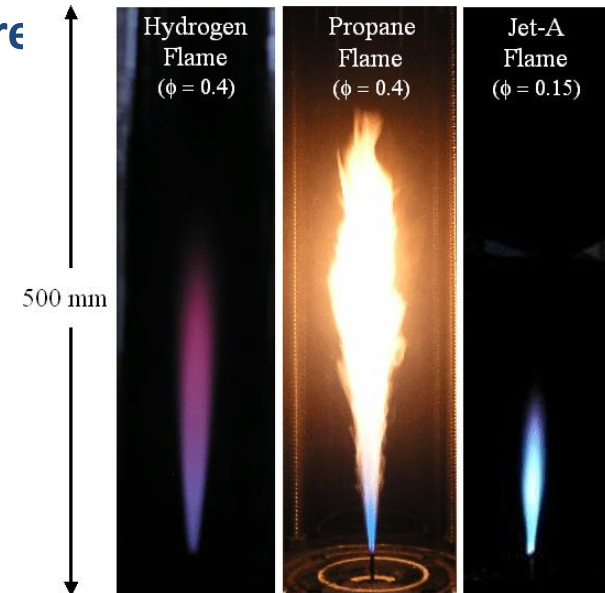
Liquid hydrogen and evaporation

- **Liquid hydrogen can be dangerous due to its low temperature (-253 °C at 1 bar) causing:**
 - ✓ Cold burns.
 - ✓ Embrittlement of materials (e.g. rubber, plastic, carbon steels).
 - ✓ Condensation of air, enrichment of oxygen (nitrogen re-evaporates before oxygen).
 - ✓ Freezing of humidity, blocking of equipment or devices (e.g. safety valves).
 - ✓ Freezing of air, possible creation of explosive atmospheres.

Safety and Health

Fire Risk

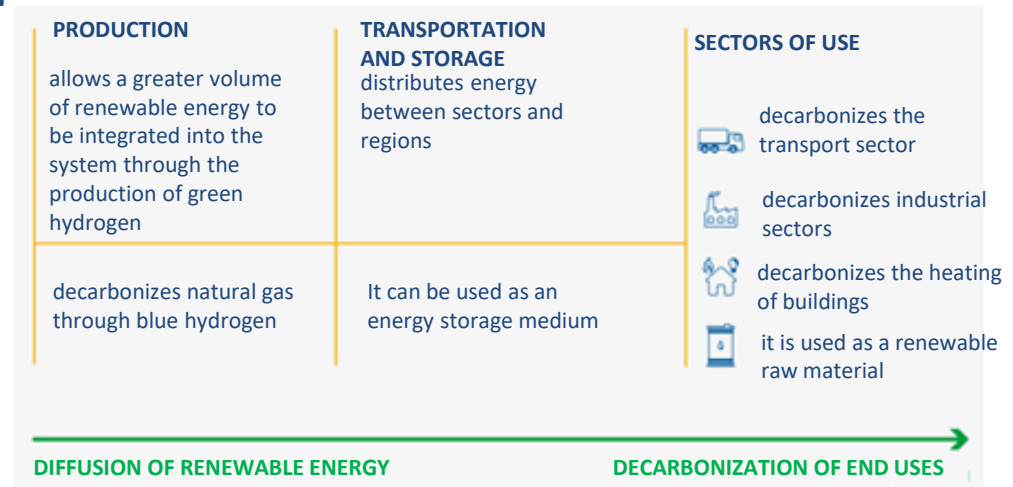
- Hydrogen can form potentially explosive mixture with other oxidizing gases.
- A loss of hydrogen:
 - ✓ can easily trigger
 - ✓ it produces an invisible flame, very narrow and directional, concentrating energy on a small surface



The value of the integrated hydrogen chain



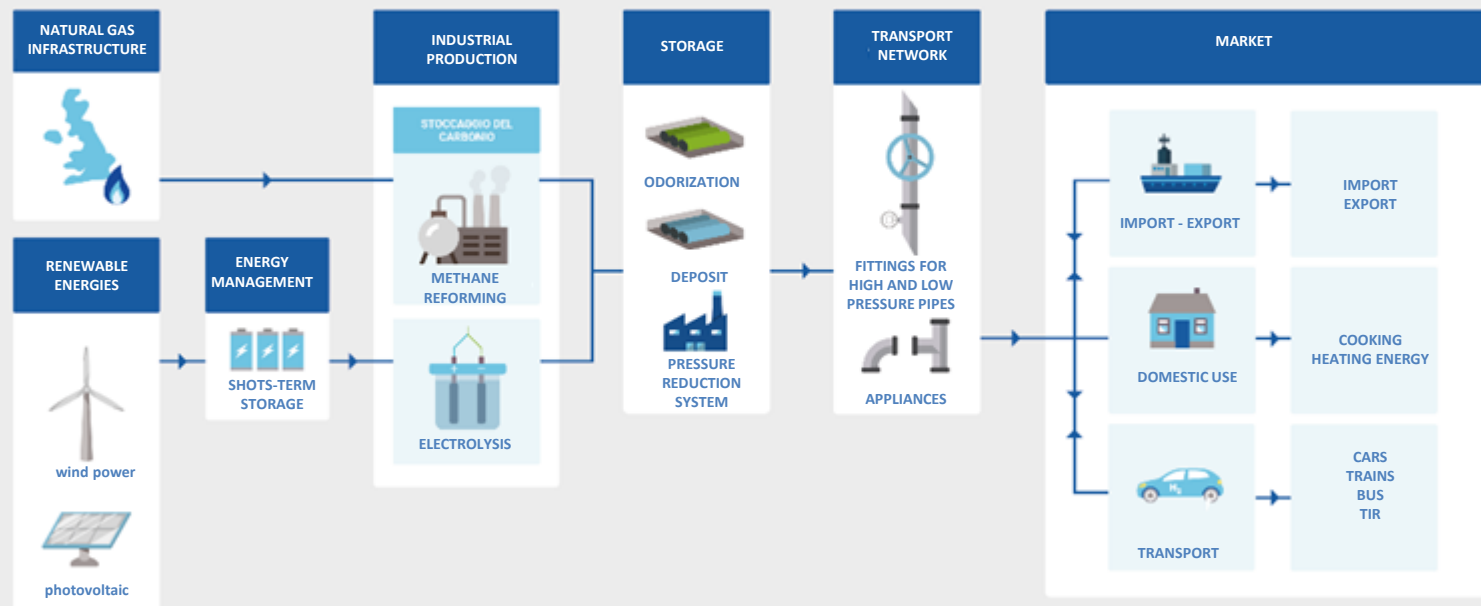
- **Hydrogen can find applications as an energy carrier in various sectors:**
 - ✓ Industry
 - ✓ Transport and Residential
 - ✓ Energy production and storage
- **The integrated supply chain is made up of:**
 - ✓ PRODUCTION
 - ✓ TRANSPORT and DISTRIBUTION
 - ✓ STORAGE and LOGISTICS



La The hydrogen value chain and its impact for the decarbonisation of the different phases

THE INTEGRATED HYDROGEN CHAIN

The value of the integrated hydrogen chain



Hydrogen supply chain

The value of the integrated hydrogen chain

- **Currently, the development of a hydrogen economy must deal with:**
 - ✓ technological gap
 - ✓ high costs
 - ✓ lack of infrastructure, of a mature legislative, regulatory and authorization framework
 - ✓ lack of investments dedicated to research, innovation and development

The color code of hydrogen

- Based on the various production methods and the related CO₂ emissions, hydrogen is classified according to a "color code"

	Colour	Fuel	Process	Products
	Brown/Black	Coal	Steam reforming or gasification	H ₂ + CO ₂ (released)
	White	N/A	Naturally occurring	H ₂
	Grey	Natural Gas	Steam reforming	H ₂ + CO ₂ (released)
	Blue	Natural Gas	Steam reforming	H ₂ + CO ₂ (% captured and stored)
	Turquoise	Natural Gas	Pyrolysis	H ₂ + C (solid)
	Red	Nuclear Power	Catalytic splitting	H ₂ + O ₂
	Purple/Pink	Nuclear Power	Electrolysis	H ₂ + O ₂
	Yellow	Solar Power	Electrolysis	H ₂ + O ₂
	Green	Renewable Electricity	Electrolysis	H ₂ + O ₂

Production processes

- **Hydrogen is produced using several processes:**
 - ✓ ***Thermochemical processes***
 - heat and chemical reactions to obtain hydrogen from water or organic materials
 - ✓ ***Electrolytic processes***
 - Splitting water into its hydrogen (H₂) and oxygen (O) components by applying an electrical voltage to the electrolyzer
 - ✓ ***Biological processes***
 - through microorganisms (bacteria, algae) and related metabolic processes

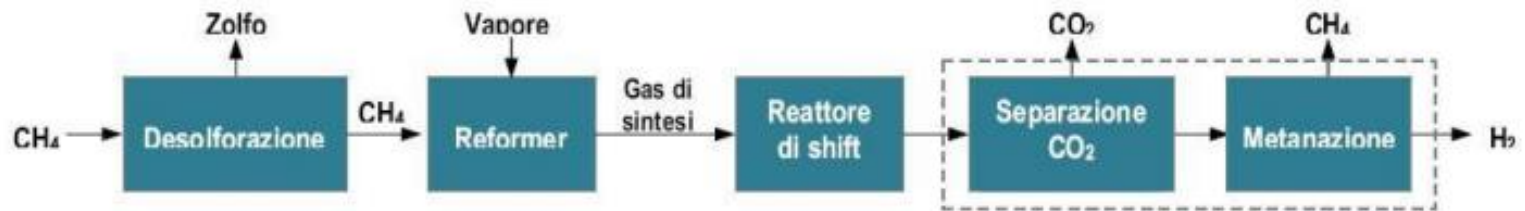
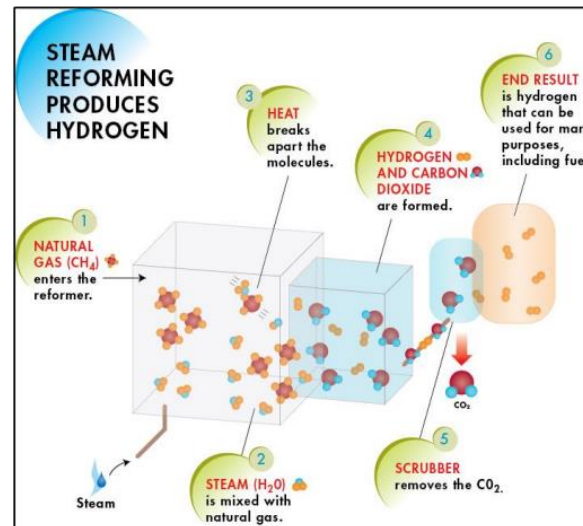
Production processes

Thermochemical Processes for the Production of Hydrogen - Steam Reforming of Methane Gas (SMR)

- **Methane Steam Reforming is a process already developed and marketed and with which the majority of the world's hydrogen is produced**
 - ✓ It involves the reaction of methane and steam in the presence of catalysts.
 - ✓ Requires an operating temperature of approximately 800°C and a pressure of 2.5 MPa.
- **The process in summary:**
 1. In the first phase methane is decomposed into hydrogen and carbon monoxide.
 2. In the second phase (shift reaction), carbon monoxide and water are transformed into carbon dioxide and hydrogen.

Production processes

Thermochemical Processes for the Production of Hydrogen - Steam Reforming of Methane Gas (SMR)

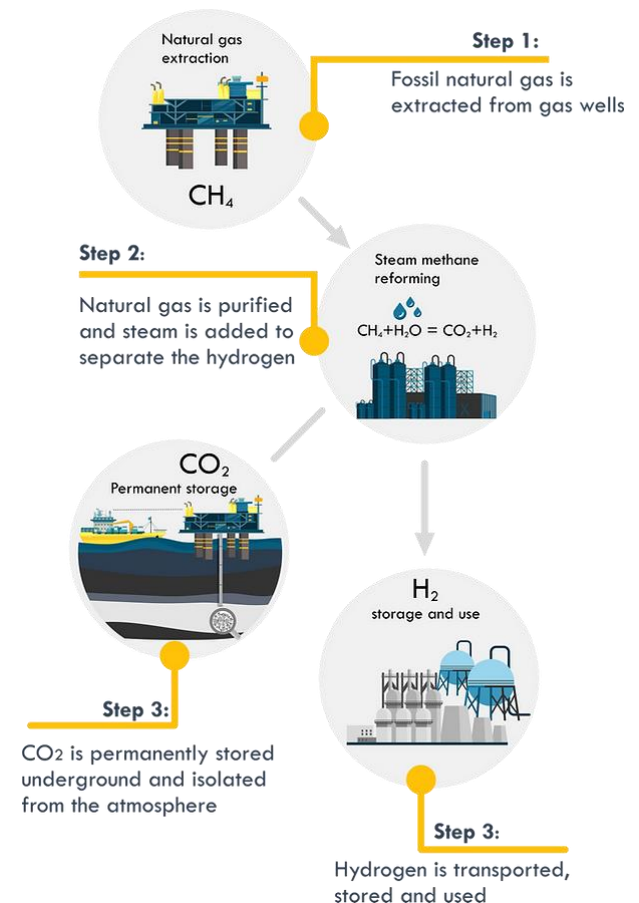


Simplified flow diagram of a plant for the production of hydrogen from methane reforming

Production processes

Thermochemical Processes for the Production of Hydrogen - Steam Reforming of Methane Gas (SMR)

- Hydrogen produced via SRM can only be considered low carbon if:
 - ✓ uses gas with low emissions during the production phases
 - ✓ CO₂ is captured and stored underground

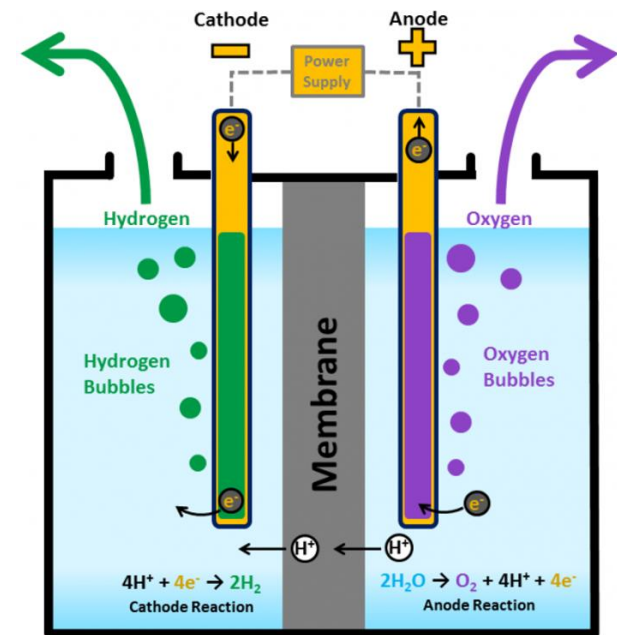


Production process of
hydrogen from gas with CCUS

Production processes

Water Electrolysis

- ***Water electrolysis is the best-known method for producing hydrogen.***
- **An electrolyser contains:**
 - ✓ a cathode, an anode, a membrane
- They are also included
 - ✓ pumps, valves, storage tanks, a power supply, a separator and other components.
- Electricity passes into the anode and cathode through the proton exchange membrane (PEM), causing water to split into its hydrogen and oxygen components.
- Hydrogen molecules are captured and collected.
- The hydrogen obtained does not require purification processes.

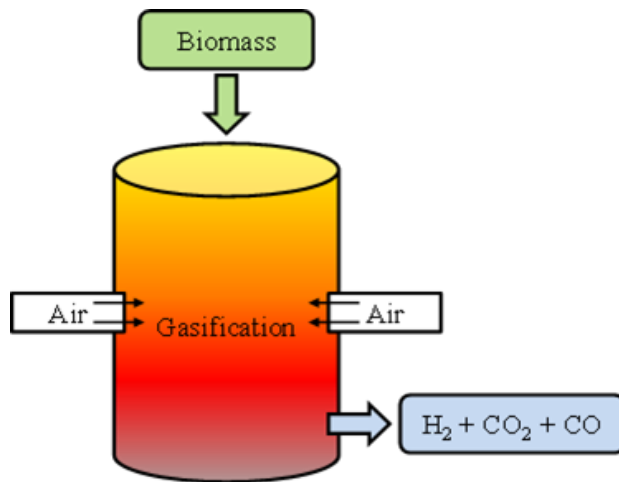


Production processes

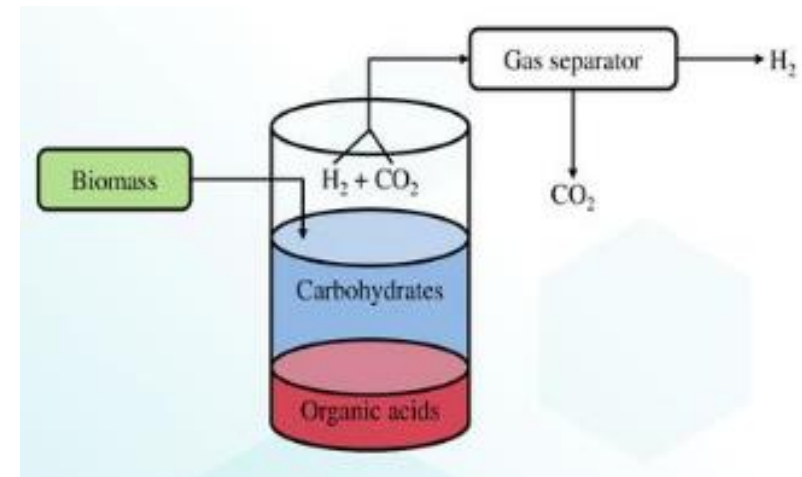
Biological Processes for the Production of Hydrogen

Biomass

- Hydrogen can be obtained by exploiting the products derived from the treatment of biomass
 - ✓ Biomass gasification
 - ✓ Biological reactions (fermentation)



Basic process of biomass gasification



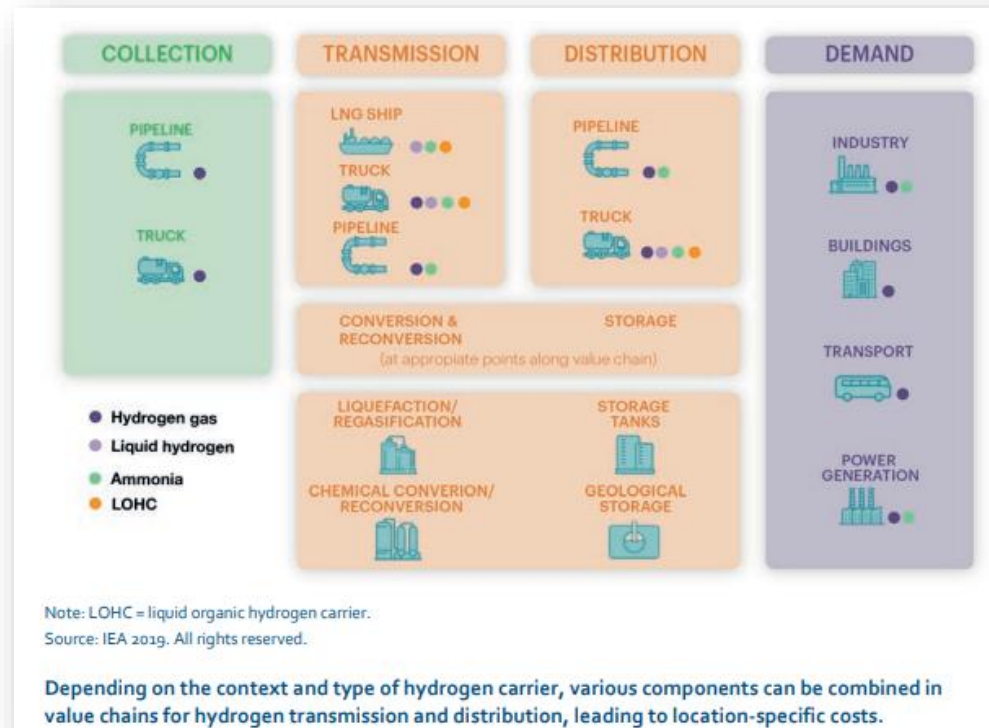
Biomass fermentation process

I Processi di Produzione *Purification of Hydrogen*

- The hydrogen obtained from the various processes can be purified:
 - ✓ ***BEFORE the production process***
 - when using natural oils, coal, natural gas or biomass, using separators for dust removal.
 - ✓ ***DURING the manufacturing process***
 - steam-reforming or pyrolysis.
 - ✓ ***AFTER the production process***
 - by PSA (Pressure Swing Adsorption): raw hydrogen passes through a carbon filter under pressure.

Transport and Storage

- Transportation and storage are complex infrastructure aspects of the hydrogen value chain.
- The efficiency of the chain depends on the availability, capacity and functionality of transport and storage systems.



Transmission, distribution and storage elements of hydrogen value chains

Transport and Storage

- **Hydrogen transport pipelines will be the most cost-effective long-term choice:**
 - ✓ For distances < 1 500 km, pipeline transport is the most economical option.
 - ✓ For distances > 1 500 km, the use of so-called «carriers» (e.g. ammonia) is the most convenient choice.

THE INTEGRATED HYDROGEN CHAIN

Transport and Storage

Injection of Hydrogen Into Natural Gas Pipeline (Blending)

- Hydrogen is mixed with methane and a blend is produced which can also be used in homes for heating or cooking.
- Blending hydrogen into existing pipeline networks would provide support for hydrogen supply
 - ✓ low investment cost
 - ✓ limited development of new dedicated infrastructure
- In this way, hydrogen distribution can be made widespread and gas pipes in the city can be used.
- However, an adaptation and harmonization of the rules that regulate the hydrogen concentration limits within existing pipelines is necessary.

Transport and Storage

Injection of Hydrogen Into Natural Gas Pipeline (Blending)

- In a first phase, short lengths of pipelines can be used to connect green hydrogen production facilities to nearby end users.
- Subsequently, (once a significant reduction in gas demand has been achieved), distribution can be extended to a greater number of users, including domestic ones..

Transport and Storage

H₂ Transport in Gas Pipelines - Distribution Networks

- Technical/practical evaluations are underway for the construction of hydrogen pipelines, both in the context of industrial complexes and in the case of hydrogen production from renewables near consumption centers, at a distributed level.

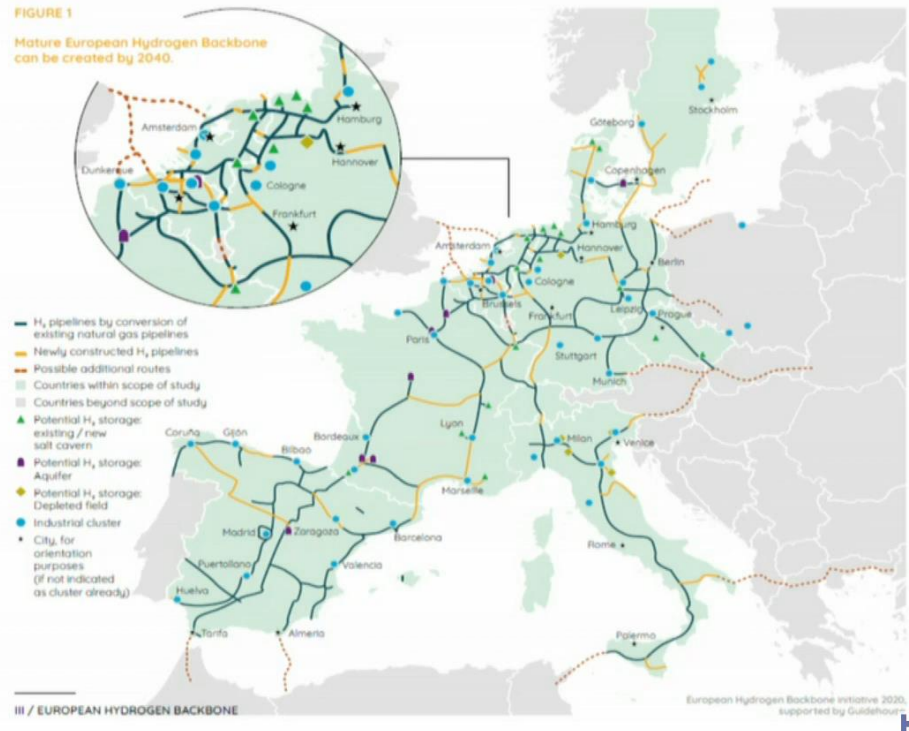


Transport and Storage of Hydrogen

The vision for a European Hydrogen backbone

- First vision endorsed by the European gas transmission operators
- Presented by 11 TSOs from 9 member states

The companies foresee a network gradually emerging from the mid-2020s onwards to an initial 6,800 km pipeline network by 2030, connecting 'hydrogen valleys'. By 2040, a hydrogen network of 23,000 km is foreseen, 75% of which will consist of converted natural gas pipelines, connected by new pipeline stretches (25%).



Transport and Storage

H₂ Transport by Road

- Compressed hydrogen is transported in tankers using high-pressure cylinders.
- Several steel cylinders can contain several kg of hydrogen compressed to a pressure of 20 MPa.
- Tankers can transport hydrogen in liquid form
 - ✓ More convenient from the point of view of energy capacity
 - ✓ Less convenient in relation to maintenance costs and the refrigeration system



Transport and Storage

Storage hydrogen

- **Depending on the phase and quantity of hydrogen to be stored:**
 - ✓ Storage in the gaseous phase in tanks or underground
 - ✓ Storage in liquid phase in tanks
 - ✓ Storage in «carriers»

storage of geological units



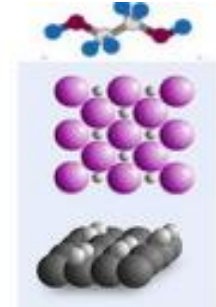
other gaseous phase
storage systems



liquid hydrogen



hydrogen
carrier



Transport and Storage

Hydrogen Storage in Gaseous Phase

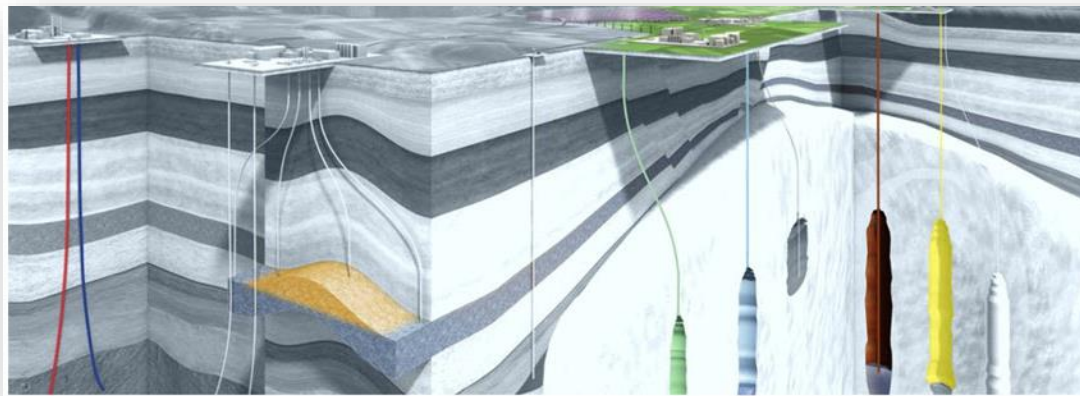
- The storage of hydrogen gas in tanks is the most widespread technology
- The containers are made of different materials
 - ✓ Depending on the quantity and pressure (300-700 bar).
- Modular tanks storage up more than 10 Ton hydrogen are possible



Transport and Storage

Storage in the Gaseous Phase Underground

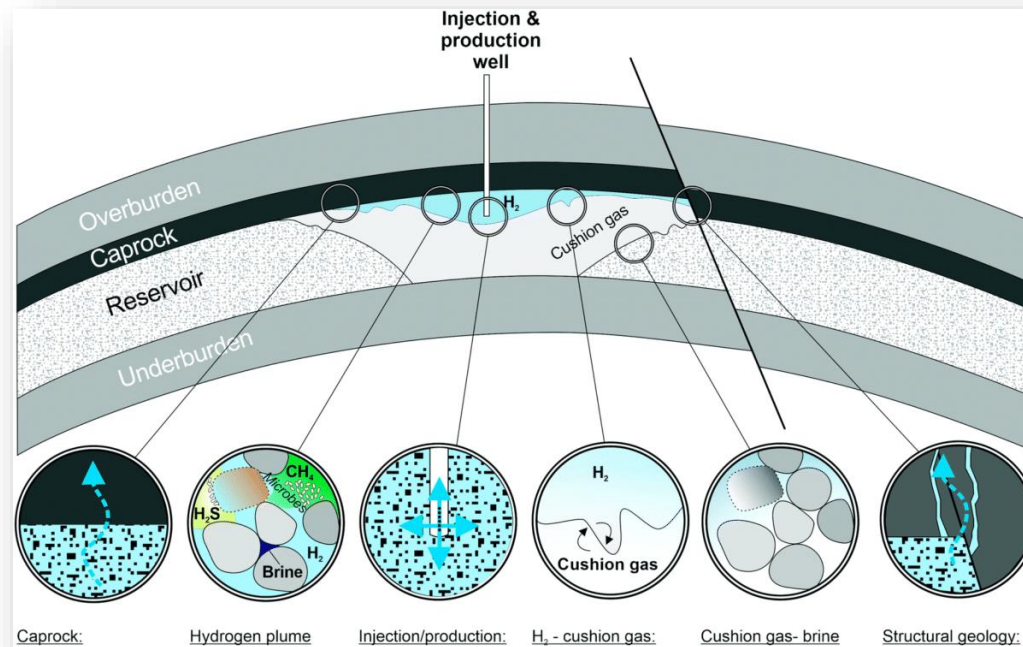
- Subsurface hydrogen storage benefits from experiences of storing CO₂ and natural gas in geological formations
 - ✓ porous rock formations (depleted deposits and aquifers)
 - ✓ artificial cavities in powerful salt formations (salt domes)



Transport and Storage

Storage in the Gaseous Phase Underground

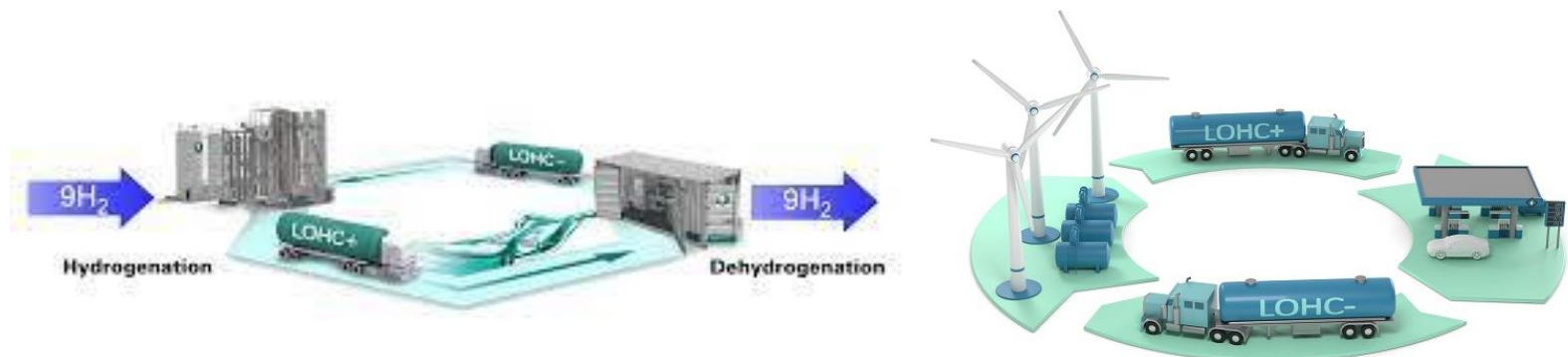
- **Hydrogen storage underground is achieved:**
 - ✓ at pressures lower than those adopted by other types of storage
 - ✓ evaluating the geomechanical characteristics of the geological structure/formation



Transport and Storage

Storage Via Carriers

- The hydrogen is made to interact with a substance (carrier) capable of bonding with it, in order to form a more or less strong reversible interaction.
 - ✓ Storage at low pressures and temperatures
- Different substances (liquid or solid) can act as carriers:
 - ✓ Ammonia and LOHC (Liquid Organic Hydrogen Carrier) are much easier to transport than hydrogen

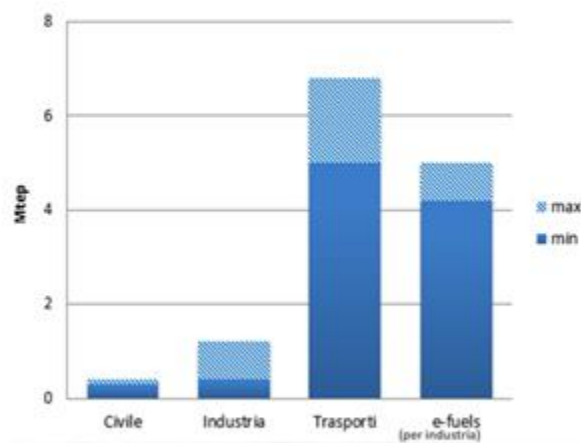


SECTORS OF HYDROGEN USES

- Hydrogen finds application in various sectors:
 - ✓ mobility of goods and people
 - ✓ raw material in industries
 - ✓ fuel in high temperature processes
 - ✓ production of energy and heat (pure or mixed with natural gas)



Hydrogen Penetration Scenarios to 2050



- Renewable electricity** decarbonizes a large portion of consumption (electrification)
- It is not possible to replace fossil fuels with electricity
- the **hydrogen carrier** is first used in sectors with a **high cost of reducing emissions**, such as goods **transport and industries** (steel, glass, chemistry...)
- Growth of renewables** → quantity of **hydrogen produced increases** → **injection into the grid** → use of H₂ quota in **other sectors**, including **civil**

Ricerca sul Sistema Energetico - RSE S.p.A.

Hydrogen for Mobility

- The mobility sector is of particular interest in the field of hydrogen technologies
 - ✓ for the potential impact on decarbonisation strategies of urban environments
 - ✓ due to the proximity to the commercial maturity of many of the technologies currently available
- The construction of a hydrogen refueling infrastructure is essential to make its large-scale deployment possible.

Hydrogen for Mobility

Mobility on Rubber

- Hydrogen for **light and heavy transport**, FCEV (Fuel Cell Electric Vehicle) vehicles
- It provides a transport service comparable to current vehicles in terms of refueling times and autonomy.
- Automakers have integrated Fuel Cell technology into their strategic plans
 - For example, Iveco and Air Liquide have signed a memorandum of understanding to accelerate the development of heavy hydrogen mobility in Europe.
- It constitutes an alternative to replace diesel vehicles for long distances.



Hydrogen for Mobility

Mobility on Rubber

- Hydrogen cars are powered by an electric motor
- Hydrogen vehicles produce their own electricity
 - ✓ The acronym FCEV (Fuel Cell Electric Vehicle) distinguishes them from battery-powered electric cars BEV (Battery Electric Vehicle)
- Hydrogen cars have an efficient power plant of their own on board: the fuel cell in which hydrogen and oxygen generate electricity.
- Depending on needs, this energy is channeled into the electric motor and/or the battery.

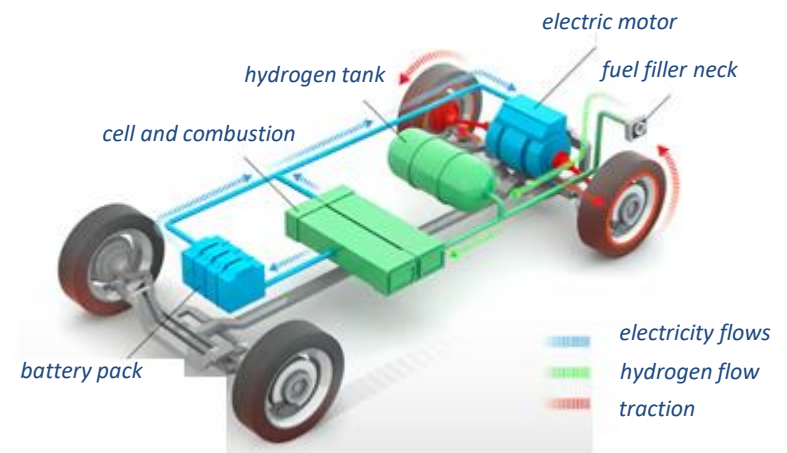


Diagram and components of a hydrogen car (BMW)

Hydrogen for Mobility

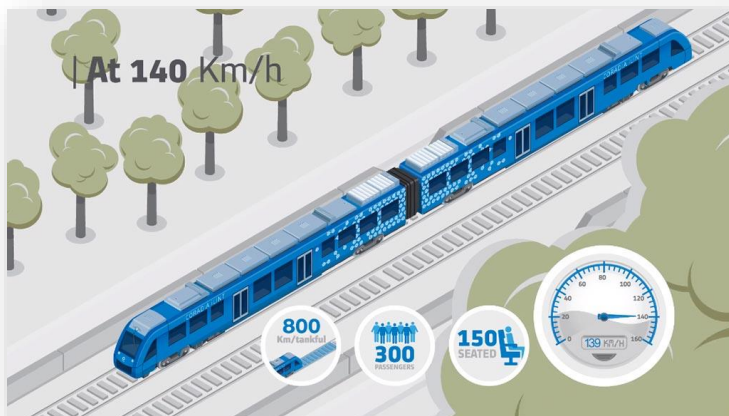
Mobility on Rubber

- Fuel cells are devices that directly convert the chemical energy of a fuel into electrical energy without going through combustion (without emissions)
- Reverse electrolysis takes place in the fuel cell, during which hydrogen reacts with oxygen.
- The hydrogen comes from one or more tanks on the car, while the oxygen comes from the surrounding air.
- This reaction generates only electricity, heat and water, which escapes from the exhaust terminal in the form of water vapour.

Hydrogen for mobility

Mobility by Rail

- In the rail transport sector
 - ✓ Fuel cell trains are a reality in service in some European countries.
- Hydrogen trains are considered a competitive solution for routes currently not electrified and with low service frequency.



Hydrogen for Mobility

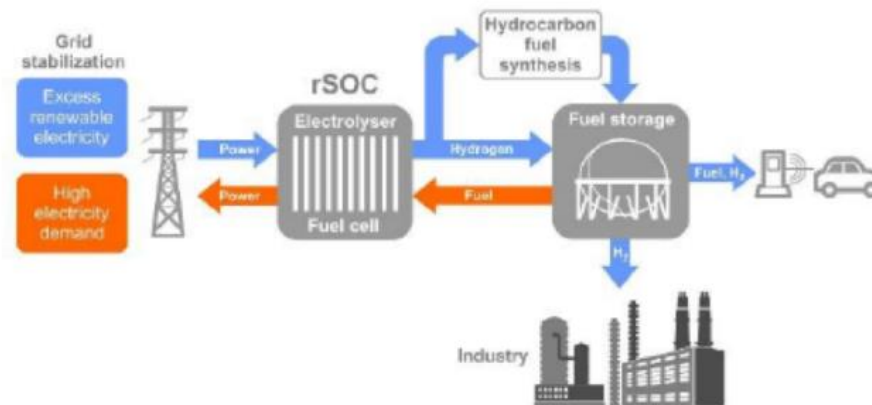
Mobility at Sea

- In the **maritime sector**
 - ✓ Fuel cells show potential in the field of electricity production for both propulsion and APU (Auxiliary Power Units) purposes
- The possibility of success in naval mobility is linked to
 - ✓ availability of a widespread supply network
 - ✓ reliability and cost of the systems compared with traditional electrical storage solutions



Hydrogen for Energy Uses

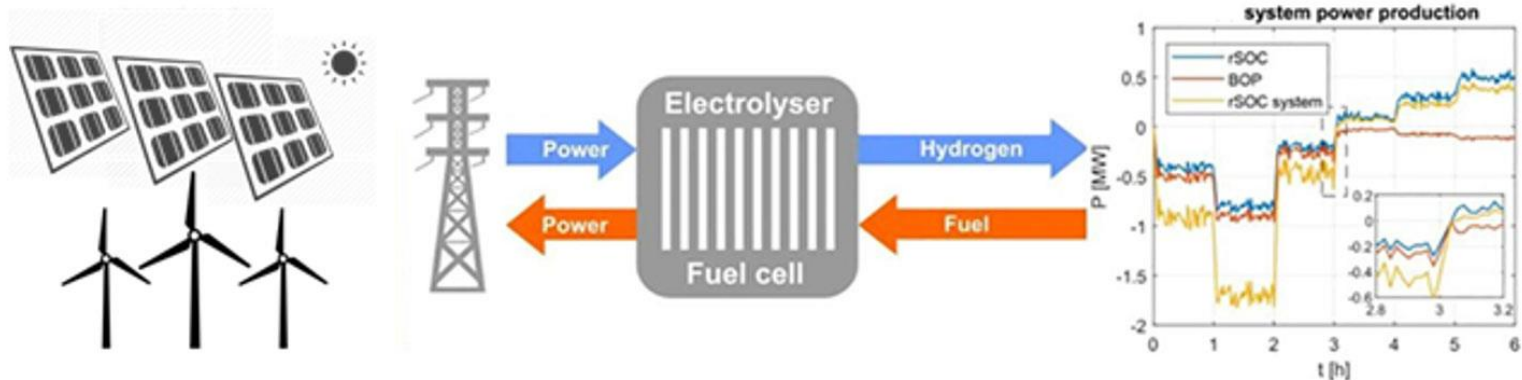
- Hydrogen offers advantageous applications for energy purposes.
- Hydrogen can be stored long-term and used to balance seasonal variations in energy demand.
- Fuel cells and gas turbines are used for power applications.



The integration of intermittent renewable energies within the electricity grid
rSOC: reversible solid oxide cell

Hydrogen for Energy Uses

- **Fuel cells (on-grid generators)** have the possibility of connection to the electricity grid with the possibility of feeding electricity into the grid (integration with non-programmable renewables).
- They can also be used as back up generators as an alternative to diesel generators.



Schematic representation of a fuel cell system for grid balancing

Hydrogen for Energy Uses

- In the context of **hydrogen turbines**, they can be used for electricity generation in simple cycle or combined cycle configurations.
- They are a flexible technology that adapts to play the role of back-up for non-programmable renewable sources.

Hydrogen for Industrial Uses

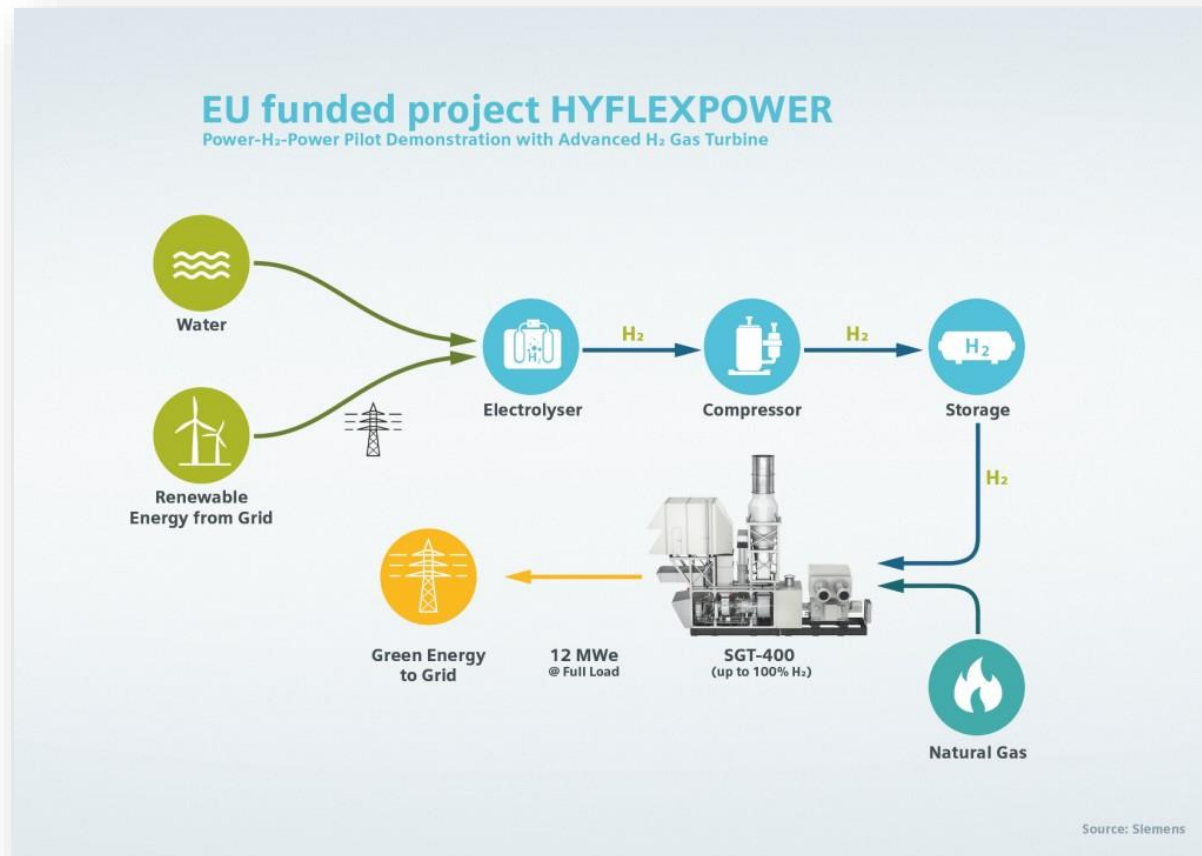
- The applications of hydrogen in the industrial sector are varied
 - ✓ *use of hydrogen for process heat*
 - for high temperatures - glassworks, steelworks, etc.
 - ✓ *use as a reducing chemical reagent*
 - for the synthesis of important chemical intermediates (polymers, and refineries).
 - production of raw materials (ammonia, methanol, etc.).

Hydrogen for Industrial Uses

- Green hydrogen will be used to decarbonize:
 - ✓ Refinery processes.
 - ✓ Industrial processes of steel, glass and construction production.
 - ✓ Production processes of chemical products such as ammonia, methanol, synthetic fuels (gas, liquids).

Hydrogen for Industrial Uses

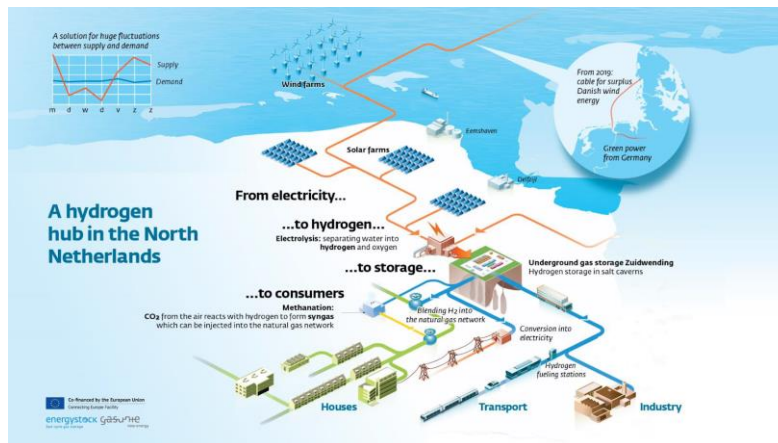
Hydrogen for energy supply to the industrial, commercial and residential sectors



- A hydrogen valley is a geographical area, city, region, island or industrial hub where different hydrogen applications are combined together in an integrated hydrogen-based system.
- A hydrogen valley covers the entire hydrogen value chain: production, storage, distribution and end use.



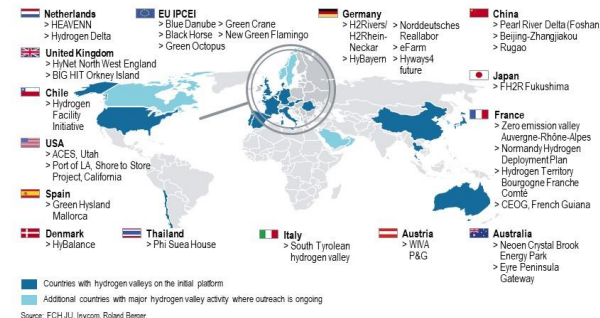
- The hydrogen valley tends to
 - ✓ Facilitate information sharing between hydrogen valleys around the world.
 - ✓ Inform project developers, policy makers and industry representatives.
 - ✓ Promote the development of the hydrogen economy and the energy transition.



The Northern Netherlands region aims to become a "hydrogen valley", a geographical area that hosts an entire hydrogen value chain, from production to distribution, storage and local end-use.

Hydrogen Valleys have become a global phenomenon, with integrated projects emerging all around the world

A fast-growing landscape of globally leading projects ...



... featured on a new platform

- > 30 valleys from 18 countries
- > 3,000 data points
- 10 in-depth best-practice profiles

Hydrogen Valley



Technology Transfer in Oil & Gas Industry

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