Low Carbon Hydrogen

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1. Context

Hydrogen can contribute to mitigate global warming towards "net zero" emissions

35.8 Gt CO_2 — **Total emissions in 2018**[1]

830 Mt CO_2 — **Year emissions due to hydrogen production**

Hydrogen, nowadays, is mainly produced from fossil fuels, emitting 9-11 t CO_2/t H_2.

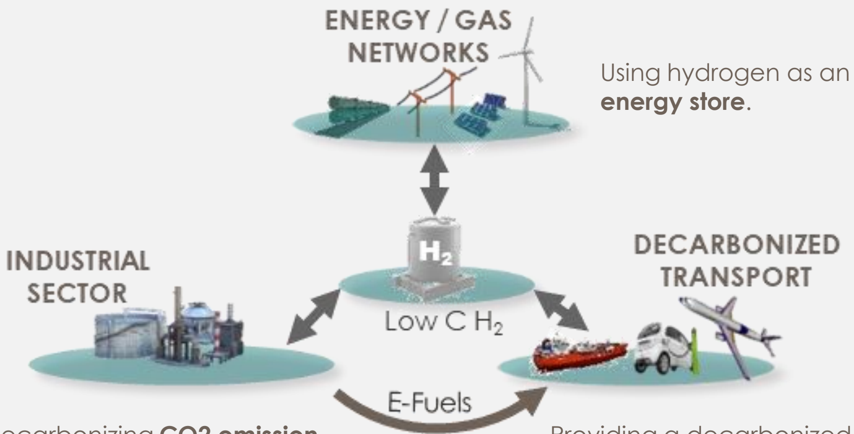
70 Mt H_2 — **Actual demand of hydrogen per year**[2]

Mainly used in petrochemical industry.

200-500 Mt H_2 — **Potential future demand per year**[2 3]

Hydrogen demand could potentially grow driven by decarbonization, if it becomes competitive and **low carbon**.

Low-carbon hydrogen applications



Using hydrogen as an **energy store**.

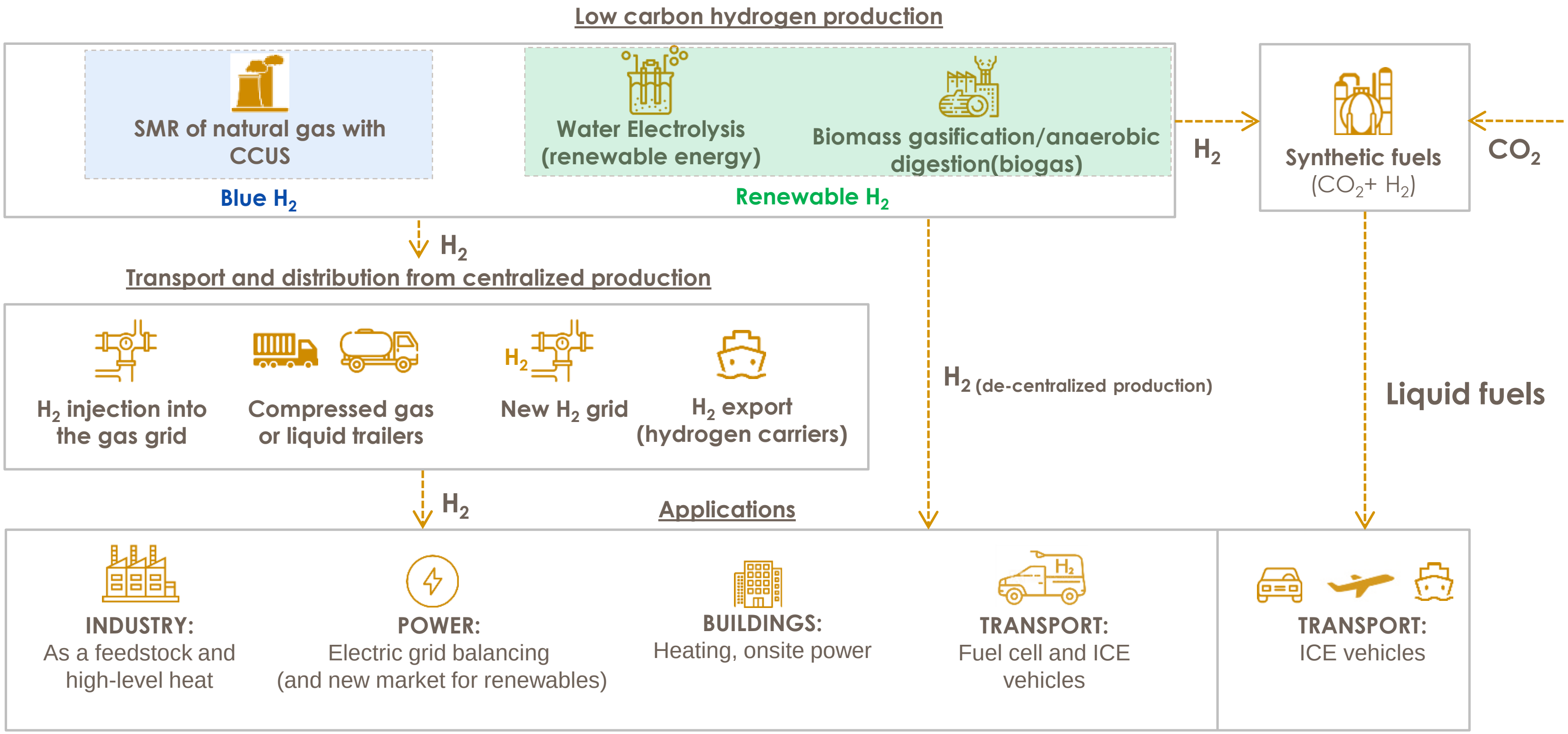
Decarbonizing **CO2 emission intensive industries.**

Providing a decarbonized **fuel for mobility.**

- Fuel cell vehicles.
- Hydrogen combustion engines
- E-fuels

[1] Carbon Dioxide Information Analysis Center (CDIAC)
[2] "Hydrogen from renewable power" – IRENA (September 2018). [3] "The future of hydrogen" – Hydrogen Council (November 2017)

2. Hydrogen value chain



- Hydrogen: **high energy density by mass** but low energy density by volume.
- Challenges: cost, **distribution infrastructure**, safety.

3. Hydrogen production technologies

Technology routes

H_2

Conventional H_2: Conventional H_2, with emissions around 8-10 kg CO_2/kg H_2. Costs (1.5-2 €/kg) are driven mainly by feedstock cost.

H_2

Steam reforming of natural gas with CCUS: H_2 produced from fossil feedstock coupled with carbon capture (CC), reducing emissions by ~85% as compared to grey H_2 and with an extra cost of 50-70 €/t CO_2 associated to CC.[1]

H_2

Renewable H2: Zero emissions H_2 produced from renewable power. Estimated cost of 3.5-5.0 €/kg H_2.[1]

[1] "The future of hydrogen" – IEA (June 2019).

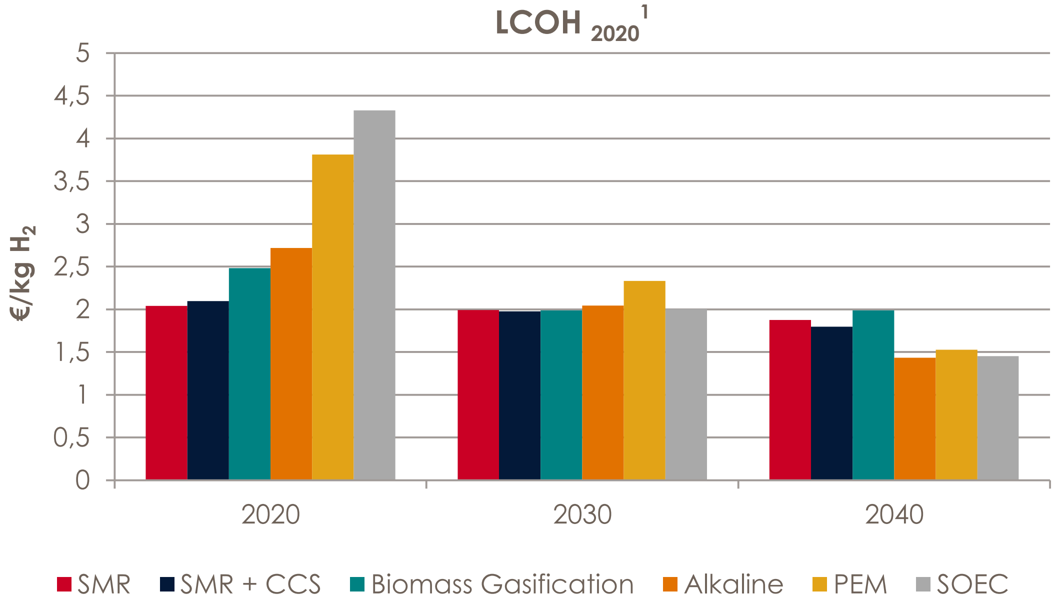
3. Hydrogen production technologies

Low carbon hydrogen production technologies

Feedstock		Technology	TRL	
Renewable electricity and water	Splitting water into hydrogen and oxygen	**Alkaline water electrolysis**	9	Low temperature electrolyser (60-80ºC) with electrodes submerged in a liquid alkaline electrolyte.
		PEM water electrolysis	8	Low temperature electrolyser (60-80ºC) that uses an acidic membrane as electrolyte.
		SOEC water electrolysis	6-7	High temperature electrolyzer (600-700ºC) using a solid oxide electrolyte.
Sun irradiation and water	Splitting water into hydrogen and oxygen w/o electricity	**Water Photoelectrocatalysis**	5	Direct conversion of sun power into chemical energy at ambient pressure and temperature.
Biomass and biogas	Paths to bio-hydrogen	**Biochemical conversion**	8	A bacteria break down, or digest in the absence of oxygen (i.e. anaerobically) the biomass and produce biogas.
		Biomethane SMR	9	Steam reforming biofeedstock.
		Biomass gasification	7-8	Biomass are reacted with steam or partially combusted leading to the production of syngas. CO is transformed into H_2 through the Water Gas Shift
Light hydrocarbons	High temperature catalytic conversion of hydrocarbons or methane splitting	**Steam reforming with CCUS**	8-9	Steam reforming with carbon capture and storage or used.
		Methane pyrolysis	5	Methane is decomposed in a high temperature process generating hydrogen and solid carbon.

3. Hydrogen production technologies

Levelized Cost of Hydrogen (LCOH): actuals and forecasts at reference relevant prices(*)



SMR (Steam Methane Reforming); SMR+CCS (Steam Methane Reforming with CO_2 capture; PEM electrolysis (Polymeric electrocytic membrane); SOEC electrolysis (Solide Oxide Electrolyzer)

KEY INSIGHTS

TECHNOLOGY BREAKTHROUGHS

- Steam reforming with CCS is the most competitive option today as long as there is an option to use or store the CO_2.
- Renewable Hydrogen by electrolysis remains unprofitable under any scenario of electricity prices by 2025.
- Following expected general techno-economic technology developments and with more renewable energy introduced in the electricity grid, it is expected that the profitability of renewable hydrogen by electrolysis could be positive around 2030.

[1] 9,7 tCO_2/ t H_2 for SMR, 8400 working hours, Electrolyzer CAPEX and efficiency from IEA 2019.

	2020	2030	2040
LCOE, €/MWh	51	42	38
Natural gas, €/t	377	450	478
CO_2, €/t	25	46	65
CCS, €/t	66	58	51

4. Hydrogen transportation and distribution

Infrastructure and distribution networks are critical for hydrogen development.

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Challenges

- ✓ Costly transport and storage due to its low volumetric energy density.
- ✓ Energy consumption for compression of hydrogen 3-4 times vs natural gas (lower energy efficiency and higher opex).

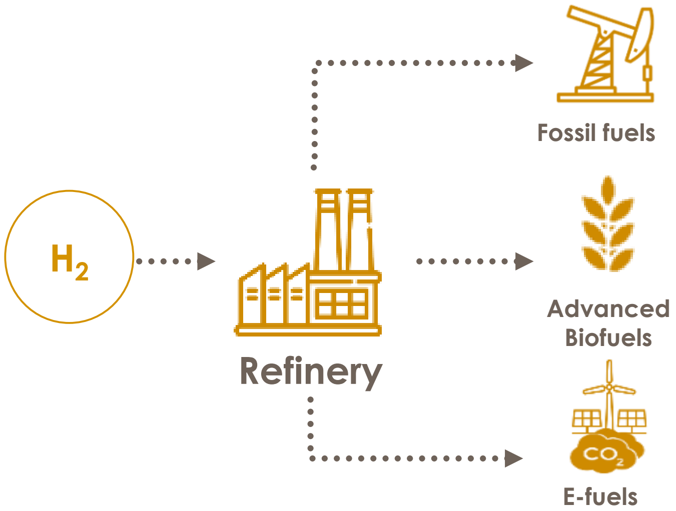
Solutions

H_2 injection into the gas grid	5-20% H_2 max
Compressed gas or liquid trailers	Short-term solution while demand is low
New H_2 grid	High capex, competitive just for high utilization rates.
H_2 exports (hydrogen carriers)	Promising alternatives are cryogenic H_2 or ammonia.

5. Hydrogen applications

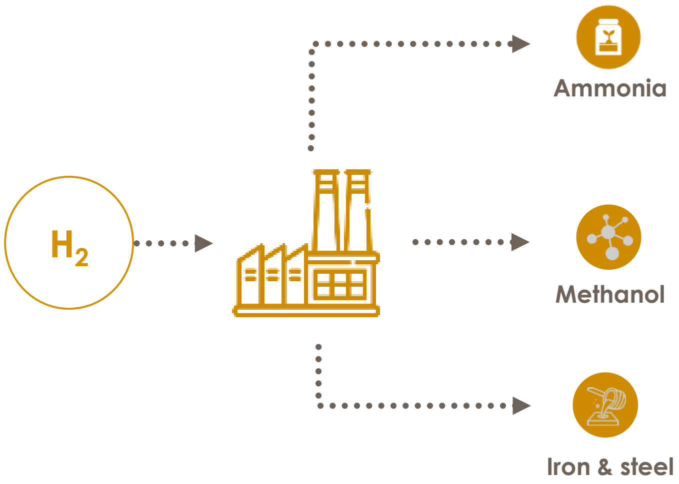
Industry

Feedstock for refineries



Highly-refined fossil fuels and penetration of advanced biofuels and synthetic fuels will lead to an increase in hydrogen demand.

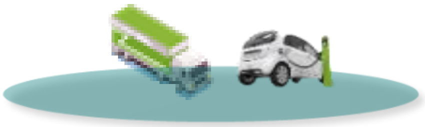
Other industries



No other decarbonization route for basic industries that either use hydrogen as a **feedstock** or need a source of **high-level heat**

5. Hydrogen applications

Transport



Road transport

Opportunities

FCEV vs BEV

Shorter refueling (5-10 minutes)

Longer ranges (500-700 km)

FCEV vs ICE

By 2040 $\mathbf{H_2}$ is expected to be cheaper than e-fuels and biofuels.

Challenges

Infraestructure

CAPEX and OPEX intensive

Markets today

Japan, Korea, California, Germany and UK (government support).

Marine and aviation sector

Alternative routes based on H_2

Marine:

- **H_2** – FC or ICE
- **Ammonia** – FC or ICE
- **Methanol** – ICE

Aviation:

- **Advanced Biofuels**
- **E-fuels**

Challenges

Complex application due to the **low volume energy density** of hydrogen

FC: Fuel cell / ICE: Internal combustion engine

5. Hydrogen applications

Power storage

Opportunities	H_2 as one of the potential solutions

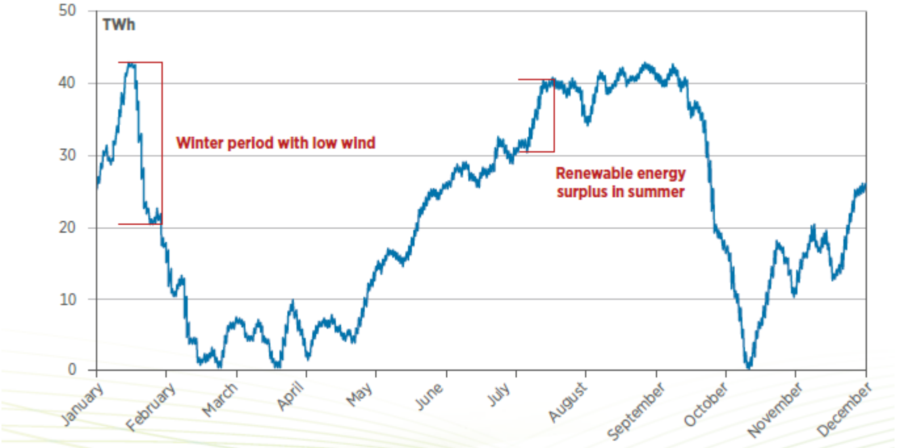
Renewable generation increase

46% in 2030 vs 22% in 2014 [1]

Energy storage is the key enabling to boost renewables growth by **balancing generation and demand.**

Solve renewable energy generation irregularity, dependent on wind and sun.

Hydrogen storage profile in 2050 (2)



Hydrogen used for:

- **Long-term storage** to balance across weeks and seasons.
- **Transfer** of renewable energy to other sectors (industry, mobility, etc.)
- Transfer H_2 as an energy vector to other **regions**

[1] IEA-Energy Technology Perspectives 2017- 2DS Scenario
[2] LBST 2019. Hydrogen Renewable energy perspective. IRENA

5. Hydrogen applications

Heat

Replacing natural gas and other fossil fuels with hydrogen to produce heat.

H_2

Industrial Heat

Combustion in hydrogen-specific burners

Cogeneration plants to generate both heat and power

Economics and opportunities

- Renewable hydrogen remains an expensive alternative to fossil fuels. Bioenergy tends to be more cost-competitive.
- Potential to help decarbonize industrial high-temperature heat demand where direct application of CCUS may prove impractical.

Buildings and commercial Heat

Hydrogen Boilers

- Change to hydrogen would require appliances (or their components) retrofitting.
- Existing gas boilers can run on hydrogen mixtures at low levels.
- **HyDeploy Project in UK: 20% H_2 into the natural gas grid** for use at homes.

Combined heat and power Fuel cells

- Fuel cell CHP systems have high electrical efficiency and low emissions
- **Fuel cells generate both: power and heat**
- Currently **expensive**.
- Existing CHP operate on natural gas, but could switch to hydrogen with little modification.

6. Wrap-up

Low-Zero Carbon Hydrogen

Production of low carbon hydrogen

- Steam reforming of natural gas with CCUS is the most competitive option today.
- Renewable H2 (electrolysis) needs further cost reduction and low electricity prices to be competitive in the 2030's.
- Starting deployment of both technologies makes sense(Blue H_2 at scale and development/demonstration of Renewable H_2).

Transport and distribution of hydrogen

- Transport/distribution infrastructure requirements, together with high production cost, will likely limit hydrogen widespread use to geographical and application niches

Hydrogen for Industry

- Refining: Decarbonization will drive a progressive shift from conventional hydrogen (SMR without CCUS) to CCUS and renewable hydrogen.
- For other industries, CCUS and renewable hydrogen offer an opportunity for "difficult to decarbonize" industrial sectors.

Hydrogen for mobility

- Low carbon hydrogen may be competitive with BEV for certain applications (long-haul heavy road transport, marine).
- E-fuels from low carbon hydrogen and captured CO_2 can be one of the routes for a "zero emissions" internal combustion engine.

Hydrogen for power storage

- Hydrogen is a promising path for weekly and seasonal energy storage.
- Hydrogen could be seen also as a profitable way of monetizing renewable power production in favorable locations (solar/wind resources, hydrogen domestic and export markets).

Hydrogen for heat

- Low carbon hydrogen can replace fossil fuels and natural gas to produce heat.

7. Repsol's Net-Zero Strategy – Hydrogen

Repsol 2050
Net Zero Emissions
Commitment

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Short — Time period — Long

Technology validation

Quick deploy

CCUS and H_2: Studying the integration of CO_2 capture technologies in our natural gas steam reforming hydrogen

Renewable H_2: Replacment of natural gas by biomethane in current SMR. Deploying a 10 MW electrolyzer link to e -fuels project in Bilbao.

Staying ahead of competition

R&D and Innovation

CCUS and H_2: Developing CO_2 capture technology more compact through invested by OGCI, Svante

RenewableH_2: Collaborating in different projects related to PEM and SOEC techs

Photoelectrocatalysis: Development of alternative technologies for the production of renewable hydrogen

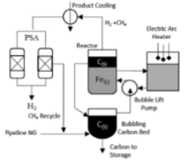
Risk mitigation

Technology watch

Active tracking of status, evolution and potential of technologies for hydrogen production, in order to:

- Improve efficiencies and reduce costs.
- Progress emerging high temperature electrolysis.

Value participation in emerging technologies through Corporate Venturing



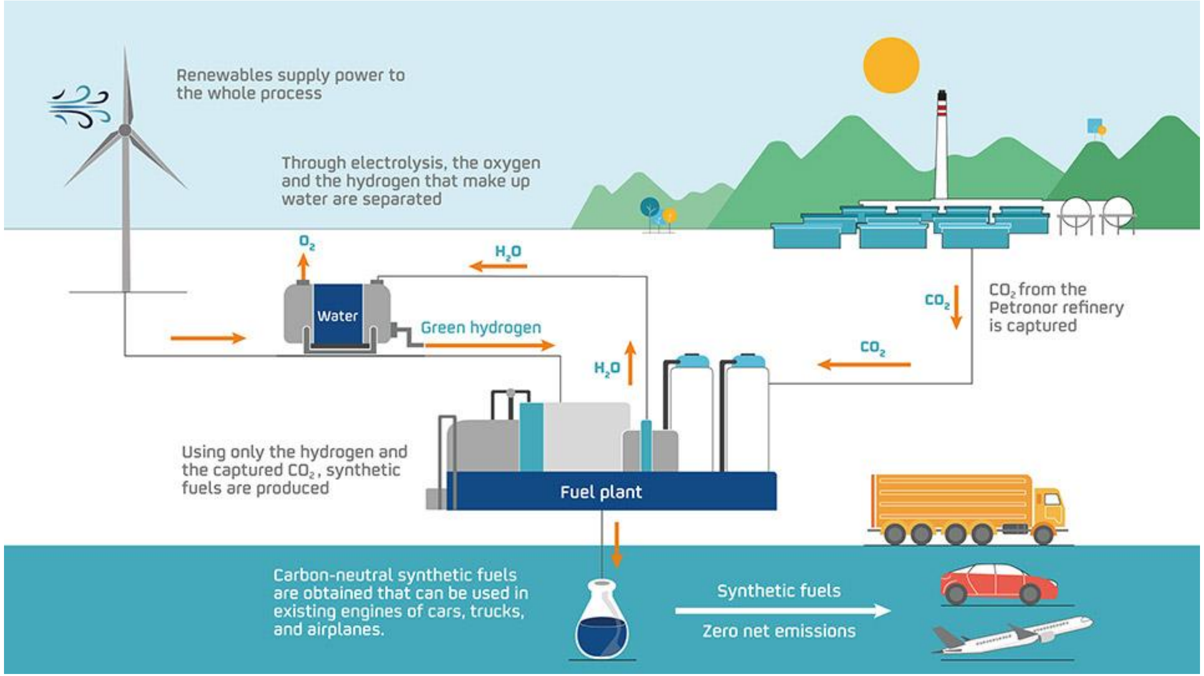
7. Repsol's Net-Zero Strategy – Hydrogen

Bilbao Synthetic Fuel Plant

Repsol 2050
Net Zero Emissions
Commitment

REPSOL

- **Water and CO_2** as only raw materials.
- **Renewable power** for the whole process
- Synthetic fuel produced can be used in combustion engines currently installed.
- Initial phase: 50 barrels per day of synthetic fuel – Scalable.
- **Net zero CO_2 emissions** in the entire production cycle.



7. Repsol's Net-Zero Strategy – Hydrogen

Sun2Hy

Repsol 2050 Net Zero Emissions Commitment

Sun2Hy is a project focused on developing a new photoelectrochemistry technology for **renewable hydrogen** production.

- **>90% CO_2 reduction** vs grey hydrogen.
- Based **on direct utilization of solar energy**.
- **100% renewable**.
- Different public and private entities involved:
    - Technology developed in partnership with Enagás
    - In collaboration with the Group of Applied Electrochemistry and Electrocatalysis of the University of Alicante (LEQA), the Catalonia Institute for Energy Research (IREC), the Aragon Hydrogen Foundation (FHa) and Magrana.

Thank you for your attention

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