Hydrogen Technologies Prospectives

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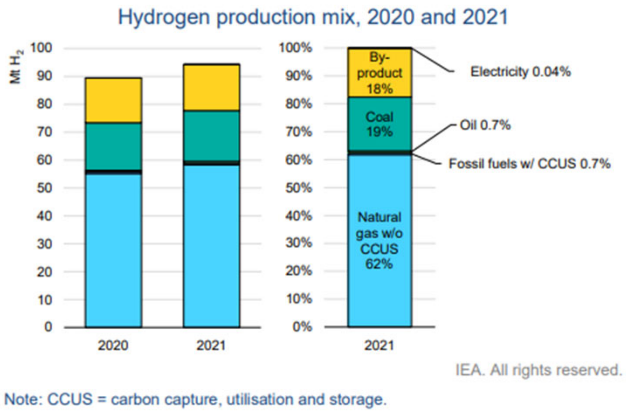
Low-carbon H2 represents only 0.74% of total H2 production



Source: Global Hydrogen Review 2022 (IEA, 2022)

- H2 production is responsible for around 2.5% of global CO_2 emissions.
- According to IEA, H2 production for 2021 reached 94 Mt H2. The energy content in this H2 is approximately equivalent to 2% of global energy consumption.
- Notably, H2 derived from Natural gas comprises 62% of total production, representing 75% of the overall dedicated H2 production.
- H2 production through fossil fuels with carbon capture and utilization (CCUs) surpasses the output from electrolysis-based production of H2. According with IEA , there is operational carbon capture capacity for H2 production of 0.1 MtCO2 in 2022 although it is expected to reach around 60 MtCO2 per year in 2030.
- **Almost all H2 is used as feedstock in industry**. Only 40 000 tonnes are used in new applications such as energy.

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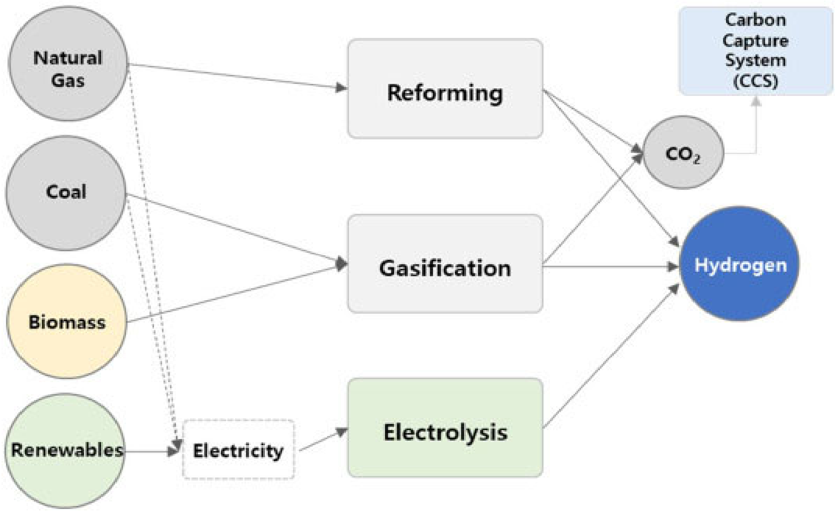
Technologies to produce H2

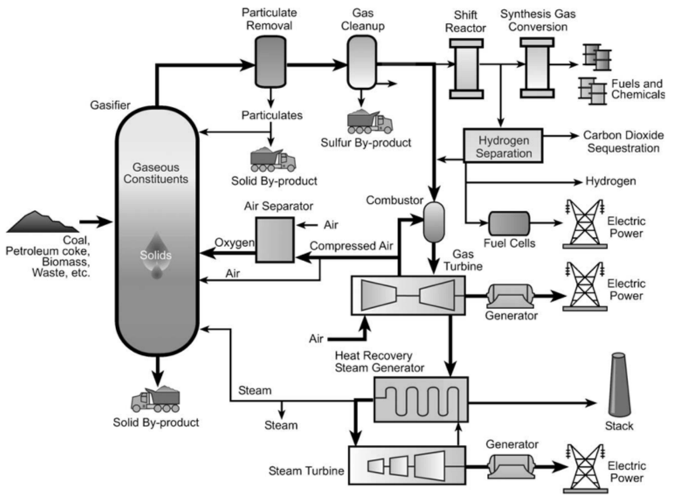


Source: Technology life cycle and commercialization readiness of hydrogen production technology using patent analysis (Chung, Kwon & Kim; 2002)

- The graph does not show all possible technologies for hydrogen production. For example, white hydrogen, a natural occurring H2, has been found. Given the time constraint to reach the environmental goals and the volume of production required, only some technologies seem promising to reach commercialization in few decades.
- Blue hydrogen can be mainly produced through two different paths: steam methane reforming (SMR) and Autothermal Reforming(ATR). Autothermal reforming is more expensive, but it becomes more competitive at bigger H2 production levels and might have advantages in emissions.
- Electrolysis uses three different technology: alkaline , PEM and solid oxide electrolysers. Alkaline and PEM are more mature.

Gasification: H2 from coal or biomass

Coal gasification process



Source: Hydrogen from coal gasification: An economical pathway to a sustainable energy future(Stiegel, Ramezan; 2006)

Coal gasification

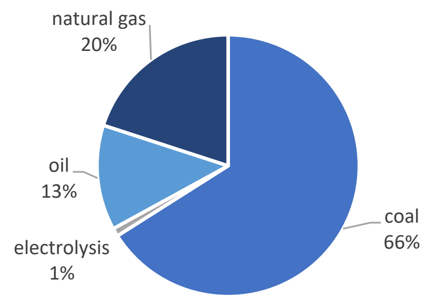
$$C_x + O_2 + H_2O \rightarrow CO + CO_2 + H_2 + \cdots$$

Water-gas shift reaction

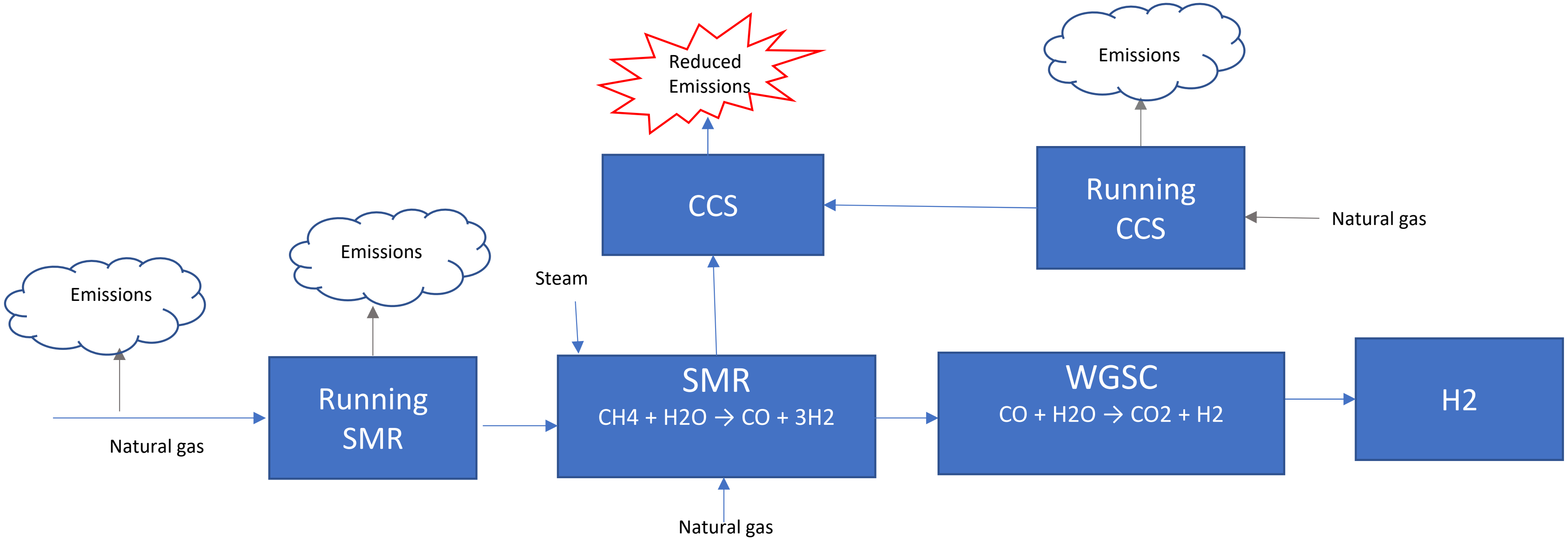
$$CO + H_2O \rightarrow CO_2 + H_2$$

Coal gasification currently stands as the most economical method for H2 production. However, without carbon capture and storage (CCS), this process releases a notable 19 to 23 kg CO2-equivalent per kilogram of hydrogen (kg CO2-eq/kgH2). This emission level is nearly twice that of gray H2 derived from natural gas.

China H2 production mix 2020



Challenges in harnessing H2 from Natural gas



Blue H2 is derived from natural gas an requires the inclusion of carbon capture and storage technologies. However, it's important to note that when discussing carbon capture rates of this facilities, it doesn't necessarily mean a percentage of the entirety of green house emission reduction. The actual carbon intensity will also depend on the natural gas supply system and other operations in the plant.

The viability of blue H2 production closely tied to the economic viability and efficiency of carbon capture and storage (CCS) technologies. There is one running commercial CCS facility in Canada, that is not for H2 production, and few blue H2 pilot plants.

Emissions from H2 derived from Natural Gas

GHG intensity (kg CO2eq/kg H2)

Scenario	Carbon Capture rate	Natural gas production and transport	Plant operation	Electricity	total
Grey H2	0%	1.332	8.436		9.768
Blue Hydrogen					
ATR Average Performance	95%	1.332	0.42	1.044	2.796
SMR, existing (Quest)	48%	1.332	4.392	0.732	6.456
ATR, high performance	95%	0.804	0.42	0.048	1.272
SMR, high performance	90%	0.804	0.84	0.024	1.668

The main difference between SMR and ATR is that the latter combust directly O2 through the following formula

$4\ CH_4 + O_2 + 2\ H_2O \rightarrow 10\ H_2 + 4\ CO$

Considering that the production of blue H2 demands more energy compared to gray H2, the overall efficiency diminishes from 76% to 69% in terms of Lower Heating Value (LHV).

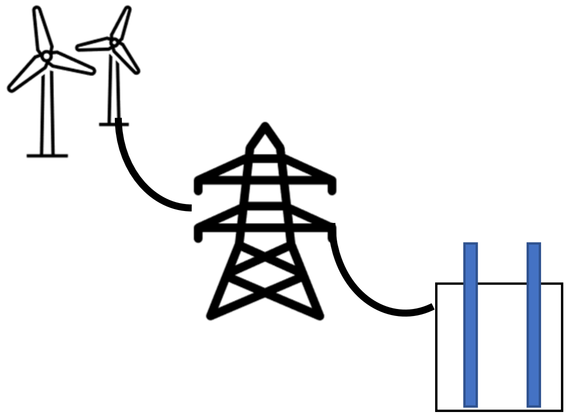
Hydrogen produced through electrolysis

Producing H2 through electrolysis involves a process called water electrolysis through the formula:

$2\ H_2O \rightarrow 2\ H_2 + O_2$

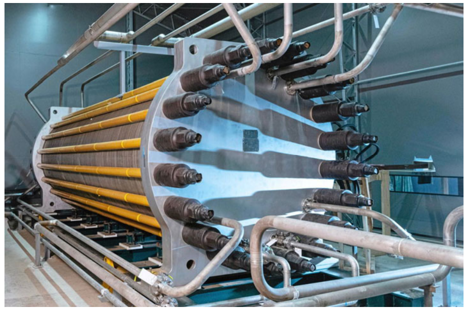
If the electricity comes from renewable sources, the H2 produced by this method is consider green hydrogen.

The typical efficiency of electrolysis generally falls within 65-70% when considering the Lower Heating Value (LHV) of H2. Typical efficiency of fuel cell is around 60% considering only electricity. If heat is recovered, fuel cell efficiency may reach 85%.



Variability of electricity source, temperature, pressure, and other operational factors affect the electrolyser performance.

There are several types of electrolysers that can produce green hydrogen



Source: Hydrogeninsight.com

Alkaline: Simple design, medium H2 purity, but it is not the best suited for variable renewable energy.

Proton membrane exchange: High H2 purity. Used in transport. There are risks because potential bottleneck: it requires platinum and iridium. Faster dynamic responses

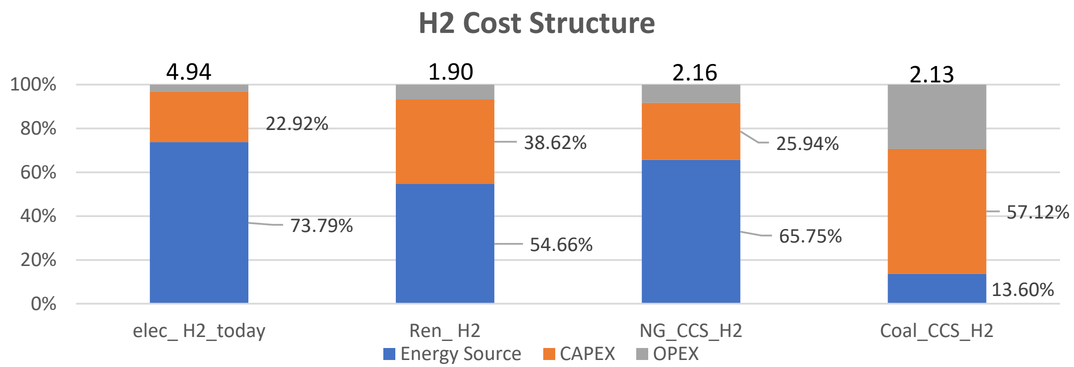
Silyzer 300 – PEM Module Array

Source: siemens-energy.com

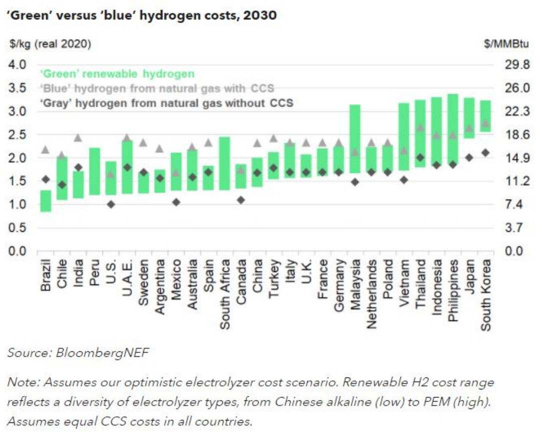
Source: oxeonenergy.com

Solid Oxide Electrolyser:
Demonstration level. It works at higher temperature. It does not work well with ramping up and down.

Cost of H2 production depends heavily on the cost of energy source



Source: Estimations using capital cost from Global Hydrogen Review 2022 (IEA, 2022). Electricity=70 USD/MWH, renewable electricity 23 USD/MWh, Natural gas=7 USD/MMBTU, Coal=30 USD/tonne. Reduction of CAPEX is 50% for electrolysis and 25% in SMR with CCS



Source: 'Green' Hydrogen to Outcompete 'Blue' Everywhere by 2030 (BloombergNF, 2022)

- At present, electricity constitutes approximately 75% of the cost for electrolysis-based hydrogen production (assuming the use of an Alkaline electrolyser).
- In the case of natural gas, fuel expenses account for roughly 65% of the cost.
- This fact carries some implications:
  - The impact of technology cost reduction is less pronounced than that of lowering energy source prices.
  - Should natural gas prices remain high, renewable hydrogen could achieve heightened competitiveness.
  - To drive down the expense of green hydrogen production, it is imperative to decrease the cost of renewable electricity (around 10 USD/MWh) and enhance the capacity factor of electrolysers.

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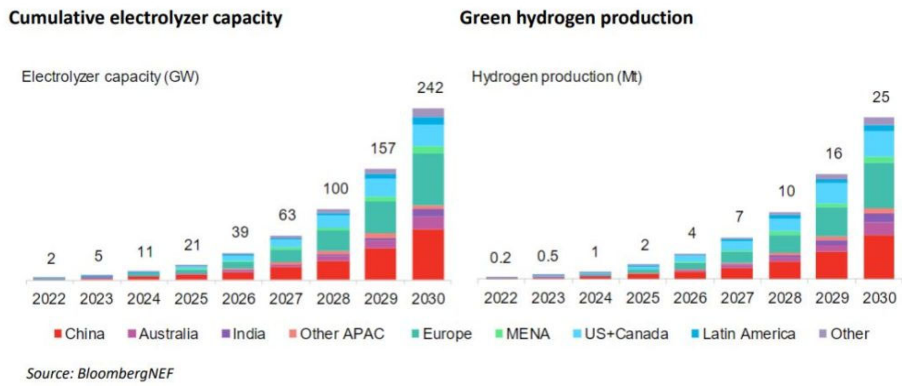
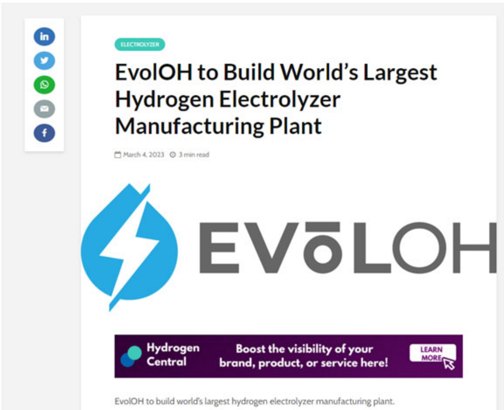
Electrolyser demand requires to increase exponentially the manufacturing capacity



Source: A Breakneck Growth Pivot Nears for Green Hydrogen (BloomberNEF., 2022)



- As of the latest estimates of the IEA, the global manufacturing capacity for electrolysers is projected to reach 8 GW by 2021, with a predominant emphasis on Alkaline technology. According to BloombergNEF, this capacity is expected to escalate to 15 GW by 2022 and a substantial 31 GW by 2023.
- the largest electrolyser manufacturing facility, located in the United States, is poised to achieve an initial capacity of 3.75 GW, slated to expand further to 15 GW by the year 2026. Meanwhile, LONGi, a Chinese company, has announced its ambitious plans to reach a manufacturing capacity of 1.5 GW by 2023 and 5 GW by 2025.
- Some initiatives such as IRA are expected to facilitate investments geared towards augmenting the capacity of electrolyser production.
- Cost of electrolysers is between 1200-1400 USD/KW , and 300- 370 USD/KW in China. The cost is expected to decrease 50% by 2030.

Distribution and Transport (domestic demand)

An important obstacle in the broader adoption of H2 is the distribution infrastructure.

For distances within a short range (less than 350 km) and a demand of less than 0.4 PJ (approximately 10 tons of hydrogen per day), truck transportation emerges as the more competitive option.

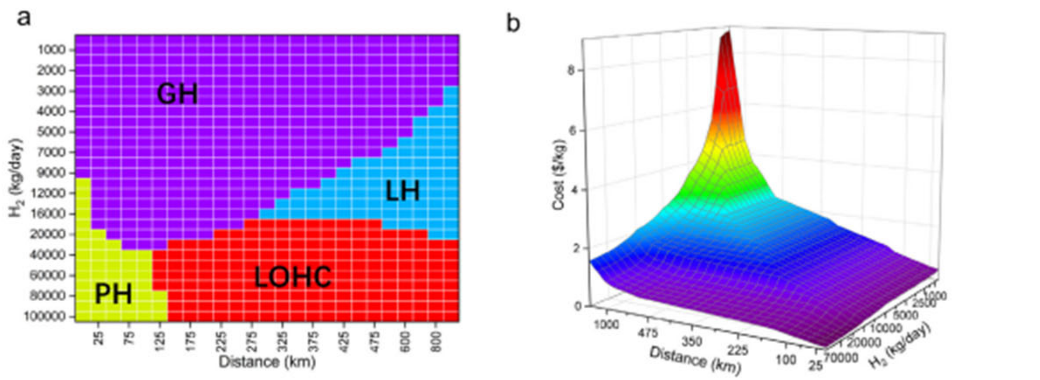


Fig. 3 – (a) Hotspot graph of the lowest unit cost hydrogen storage and transportation mode, (b) The lowest unit cost under different hydrogen demand and transportation distances under the point-to-point hydrogen storage and transportation scenario.

Source: Techno-economic analysis of hydrogen storage and transportation from hydrogen plant to terminal refueling station (Rong et al., n.d.)

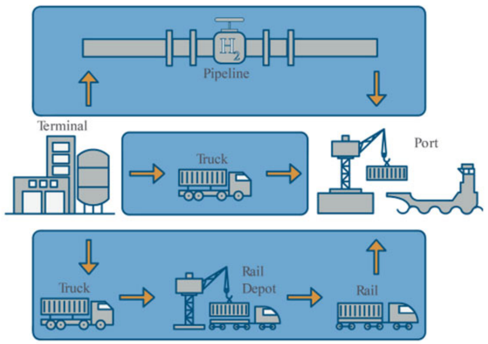


Fig. 4 – The scenario used to evaluate the most effective means of transporting hydrogen to a port for shipping. Not that while the pipeline can only be used for gaseous hydrogen, the remaining methods can transport both liquid and gaseous hydrogen.

Source: Point-to-point transportation: The economics of hydrogen export (Borsboom-Hanson et al., 2022)

The implementation of pipelines encounters challenges, particularly in regions where the existing pipeline network for natural gas is insufficiently developed.

Hydrogen is usually transported in tube trailers. Transportation through hydrogen is limited by some transport regulation. Recently, a new tube trailer model has been announced to carry 1 tonne of hydrogen in USA and 1.3 tonne in Europe.

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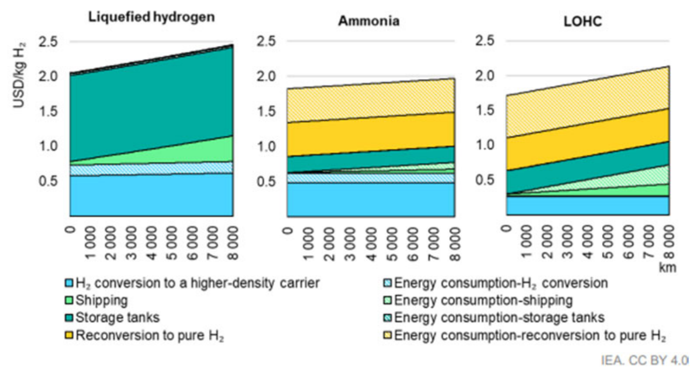
Distribution and Transport (long distance demand)

- For longer distances, exports, transitioning to alternative transportation modes becomes necessary due to the potential lack of competitiveness of compressed and liquefied H2.
- Ammonia (NH3) holds the advantage of direct usability without requiring additional conversion. Nonetheless, it's important to note that ammonia usage comes with the drawback of releasing nitrogen oxides (NOx).

Figure 5.23 Indicative levelised cost of delivering hydrogen, by shipping-option step and distance in the NZE Scenario, 2030



Notes: LOHC = liquid organic hydrogen carrier (methylcyclohexane considered); USD/kg H_2 = USD per kilogramme of hydrogen. The cost per stage includes all capital and operational expenditures except those related to energy, which are illustrated separately with a pattern fill. The discount rate is 5%. It is assumed that import and export terminals handle 20 shipments per year on average.

Properties	Unit	Compressed Hydrogen	Liquid Hydrogen	Methanol	Liquid Ammonia	MCH
Storage Method	-	Compression	Liquefaction	Ambient	Liquefaction	Ambient
Temperature	C	25 (room)	-259.9	25 (room)	25 (room)	25(room)
Storage Pressure	Mpa	69	0.1	0.1	0.99	
Density	kg/m3	39	70.8	792	600	770
Explosive Limit in Air	%Vol	4-75	4-75	6.7-36	15-28	1.2-6.7
Gravimetric Energy Density (LHV)	MJ/kg	120	120	20.1	18.6	43.45
Volumetric Energy Density (LHV)	MJ/L	4.5	8.49	15.8	12.7	33.5
Gravimetric Hydrogen content	wt%	100	100	12.5	17.8	6.16
Volumetric Hydrogen content	kg-H2/m3	42.2	70.8	99	121	47.4
Hydrogen release	-	Pressure release	Evaporation	Catalytic decomposition T > 200 C	Catalytic decomposition T > 400 C	?
Energy to Extract Hydrogen	kJ/mol-H2	-	0.907	16.3	30.6	68.3

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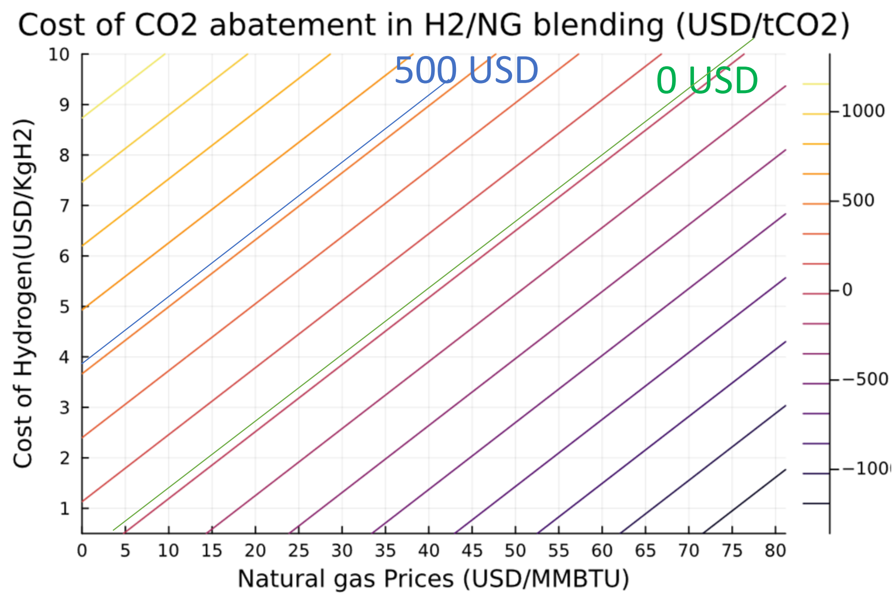
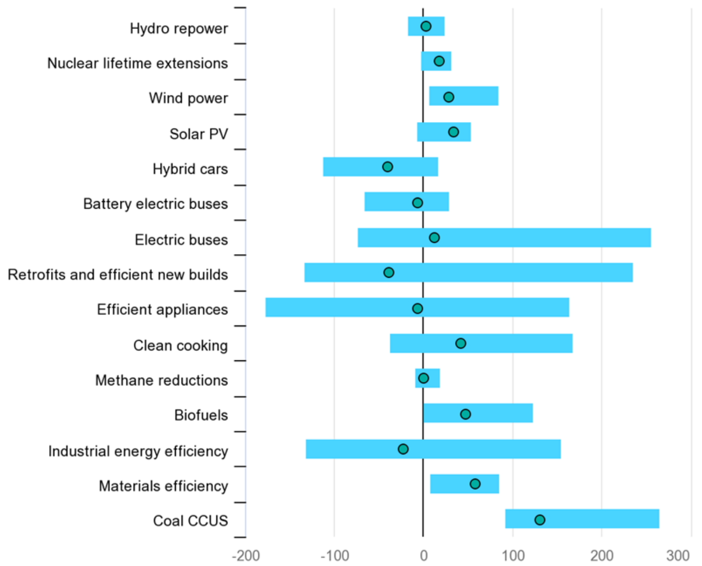
The effects of blending H2 with natural gas supply

- Blending H2 with natural gas has a limit of 20% (V/V) due to technical constraints. A H2 concentration of 20% (V/V) can lead to a reduction of emission by 6.7% emissions per unit of energy.
- Nonetheless, the feasibility of this approach hinges largely on the prevailing high costs of natural gas. In scenarios where natural gas prices are low, achieving CO2 abatement might incur significant expenses, even with the availability of cost-effective hydrogen.
- Another notable drawback of hydrogen blending pertains to the energy-to-volume ratio, which diminishes by approximately 14%. This aspect holds particular significance in the context of residential and commercial consumption, where natural gas is frequently measured in volumetric units.

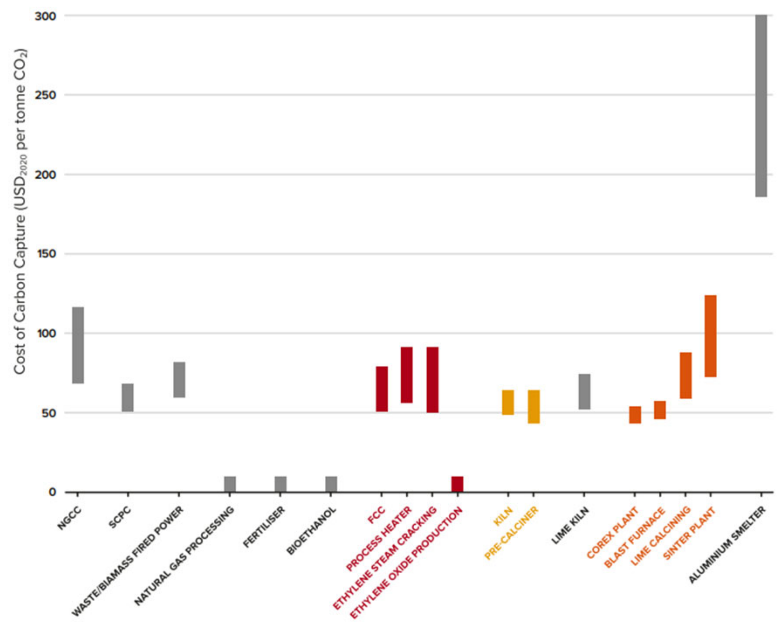


As reference, IEA estimated a prospective cost of capturing CO2 in a Direct Air capture in 125 to 335 USD per tonne of CO2.

Abatement costs using H2 can be very expensive



Source: GHG abatement costs for selected measures of the Sustainable Recovery Plan (IEA, 2022)



Source: Technology readiness and costs of CCS (Global CCS Institute)

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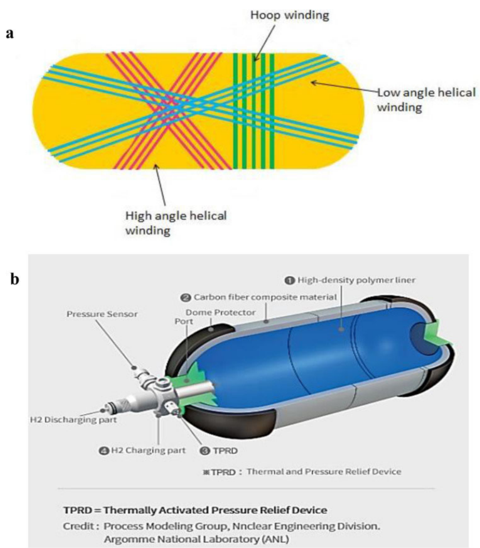
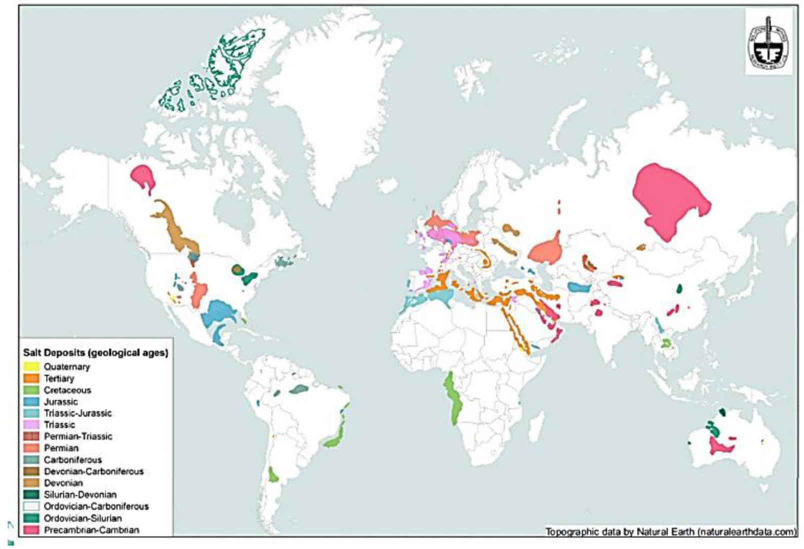
H2 as way to store and transport green energy

- Hydrogen (H2) offers the capacity to store and transport green electricity effectively. In regions where the installation of transmission lines is impractical, hydrogen can act as a conduit for delivering green electricity. In this role, hydrogen competes with established grid infrastructure and locally generated renewable energy.
- Furthermore, hydrogen can serve as a repository for excess renewable energy. However, this purpose faces similar challenges to those encountered by battery storage solutions. The decision to invest in storage capacity is often influenced by the existing rules within electric markets, making it crucial to address these incentives for both hydrogen and battery storage technologies.





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Summary

- H2 technologies have seemingly reached a stage of maturity that allows for commercialization. Nonetheless, there remains a need for continuous improvement to enhance the competitiveness of H2, particularly if it is intended to substitute other conventional fuels. Many of these advancements require developments in renewable energies and carbon capture and storage (CCS) technologies.
- The cost of producing H2 is heavily dependent on the expense of the energy source employed. Notably, higher prices for natural gas or coal can help the competitive edge of green hydrogen, although this can also lead to increased equipment costs for H2 production, as evidenced in recent years.
- Blending H2 with natural gas, while potentially effective in emission reduction, can prove to be a costly measure. It's vital to critically evaluate the hydrogen source while considering the implementation of this measure. In cases where other decarbonization options are not viable, H2 should be regarded as one solution but not as the silver bullet.
- Trucks emerge as competitive transportation options for hydrogen when the demand volume is low and the distance is short. For greater hydrogen demand, pipelines and rail systems tend to offer heightened competitiveness. When it comes to extended distances, hydrogen carriers stand out as the most viable solution, particularly for purposes like exports.
- Ammonia showcases distinct advantages when used directly; however, it's crucial to address the issue of nitrogen oxide (NOx) emissions. Electrofuels (e-fuels) present an alternative pathway worth considering.

Thank you.