A (short) focus on Blue hydrogen & LCA

Hydrogen JRP
JOINT RESEARCH PARTNERSHIP

Sustainable fuels (bio -fuels & e-fuels) for CO_2 neutral internal combustion engines

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POLITECNICO MILANO 1863

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The Hydrogen Joint Research partnership (H2 JRP)

Hydrogen JRP – JOINT RESEARCH PARTNERSHIP

La H2 JRP, fondata al Politecnico di Milano ed aperta alle aziende interessate, sviluppa *attività di R&S sull'idrogeno di interesse condiviso tra gli associati* (studi energetici ed ambientali, test e sviluppo di nuovi componenti e materiali innovativi, analisi di nuove tecnologie…)

- *Analysing the role of hydrogen in the transition to NetZero through Integrated Energy System Modeling*
- *LCA of Hydrogen Production Pathways; Hydrogen leakages and GWP impact on LCA;*
- *Innovative experimentation to test hydrogen steel embrittlement;*
- *Conditioning and characterization of polymeric materials in hydrogen atmosphere;*
- *Design and setup of a Liquid Hydrogen Laboratory*
- *New porous framework materials for hydrogen storage (H2-POFs);*
- *Analysis of the state of the art in hydrogen compression technology;*
- *Experimental assessment of electric input-controlled PEM electrolysis;*
- *Novel concepts in energy storage overlapping with hydrogen;*
- *Carriers of Hydrogen (LOHCs) for an Efficient Storage System;*
- *H_2 in internal combustion engines;*
- *Nuclear SMRs + high-temperature electrolysis for H_2 & power;*
- *Large-scale underground hydrogen storage in artificial caverns;*
- *Synthesis and utilization of ammonia as clean hydrogen energy vector;*

(…)

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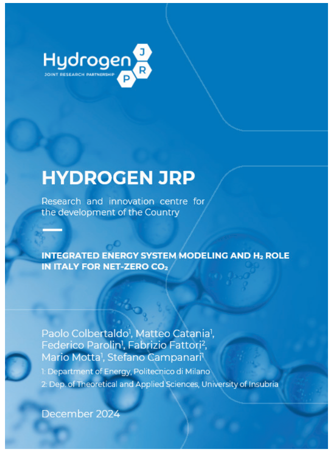

https://www.fondazionepolitecnico.it/progetti/hydrogen-jrp/

Founders

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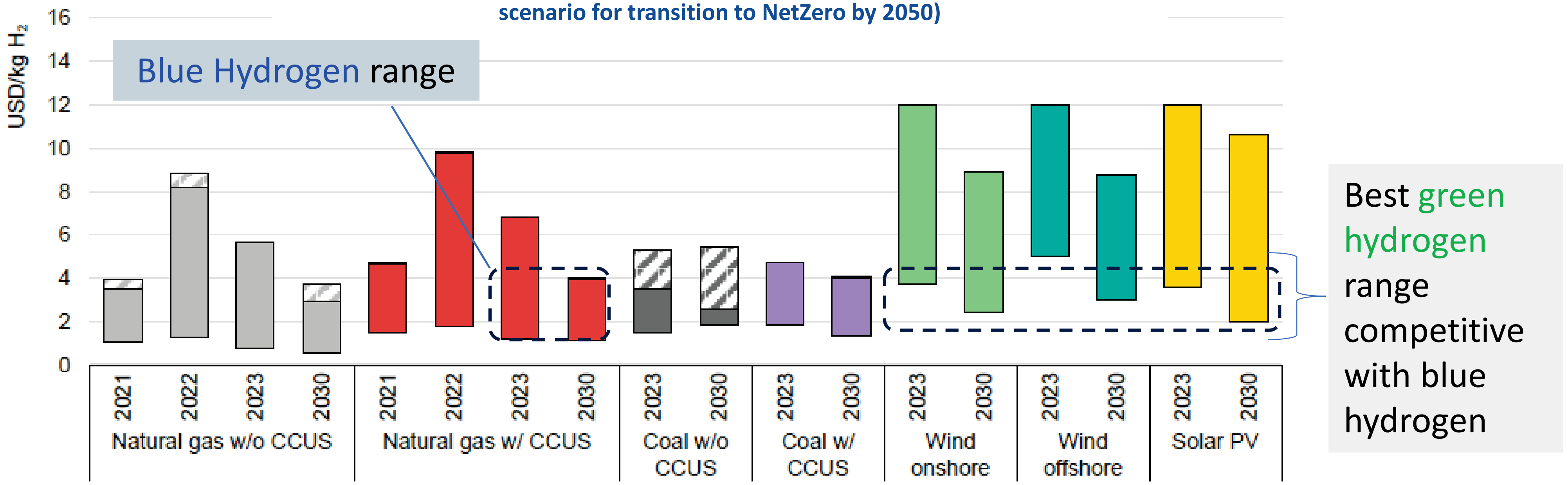
Cost of hydrogen

- Today's cost of clean or low-carbon hydrogen is still high
- Long-term cost projections are favourable (although they depend on many assumptions) and both blue and green hydrogen are competitive

Hydrogen production cost by pathway, 2023 and 2030 (IEA scenario for transition to NetZero by 2050)



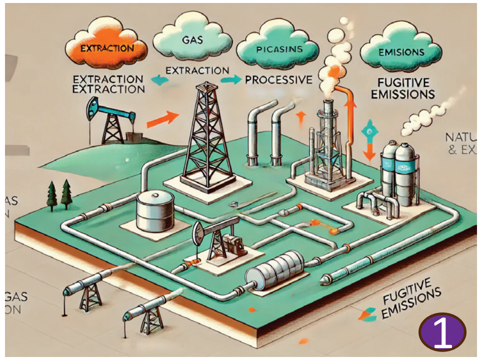
Source: IEA Global Hydrogen Review , 2024

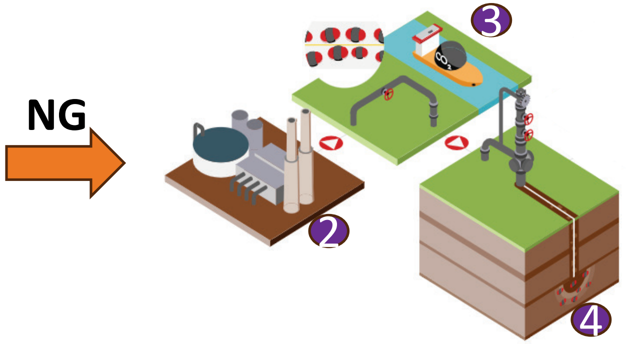
Notes: CCUS = carbon capture, utilisation and storage; w/ = with; w/o = without. Cost ranges reflect regional differences in fossil fuel prices, renewable costs, CO_2 prices, technology CAPEX and OPEX as well as cost of capital. Natural gas price is USD 5-21/MBtu for 2021, USD 6-51/MBtu for 2022, USD 3-35/Mbtu for 2023 and USD 1-15/MBtu for 2030 NZE. Coal price is USD 9-270/t for 2023 and USD 1-120/t for the NZE Scenario in 2030. The levelised production cost of solar PV electricity is USD 20-120/MWh for 2023, USD 14-90/MWh for the NZE Scenario in 2030, with capacity factor of 12-35%. Onshore wind electricity levelised production cost is USD 23-110/MWh for 2023, USD 22-100/MWh for the NZE Scenario in 2030, with a capacity factor of 15-53%. The offshore wind electricity levelised production cost is USD 55-230/MWh for 2023.

USD 36-145/MWh for the NZE in 2030, with a capacity factor of 32-67%. Electrolyser CAPEX is USD 950/kW for the NZE Scenario in 2030 and includes the electrolyser system, its balance of plant and EPC, installation cost and contingencies; electrolyser capacity factor assumed to be the same as the renewable power plant. The cost of capital is 6-20%. The dashed area represents the CO_2 price impact, based on USD 15-140/t CO_2 for the NZE Scenario. Renewable-based hydrogen production costs are capped at USD 12/kg H_2. Water cost is not included. Other techno-economic assumptions are included in the Annex.

Study of LCA for green and blue hydrogen

- **Main parameters for Blue H_2**
  - System overall efficiency
  - System design
  - CCS position and efficiency
  - Methane leakage rate



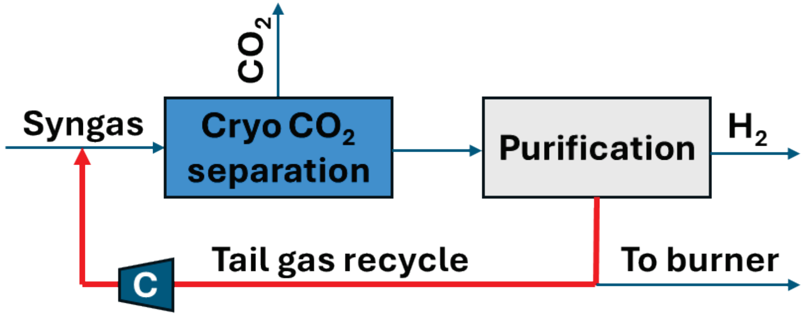


1. NG extraction & processing
2. NG reforming & CO_2 capture
3. CO_2 transportation
4. CO_2 storage

- **CO_2 capture technologies** covered in LCA literature include chemical & physical absorptions, adsorption, membranes, cryogenic processes

The H2 JRP analysis includes:

- Review of natural gas supply chain
- Optimization of cryogenic CO_2 capture with ATR, aiming to reduce the carbon footprint:
  - reduction in NG consumption (partial electrification)
  - analysis of different CCS options (e.g. liquifying or producing solid CO_2)

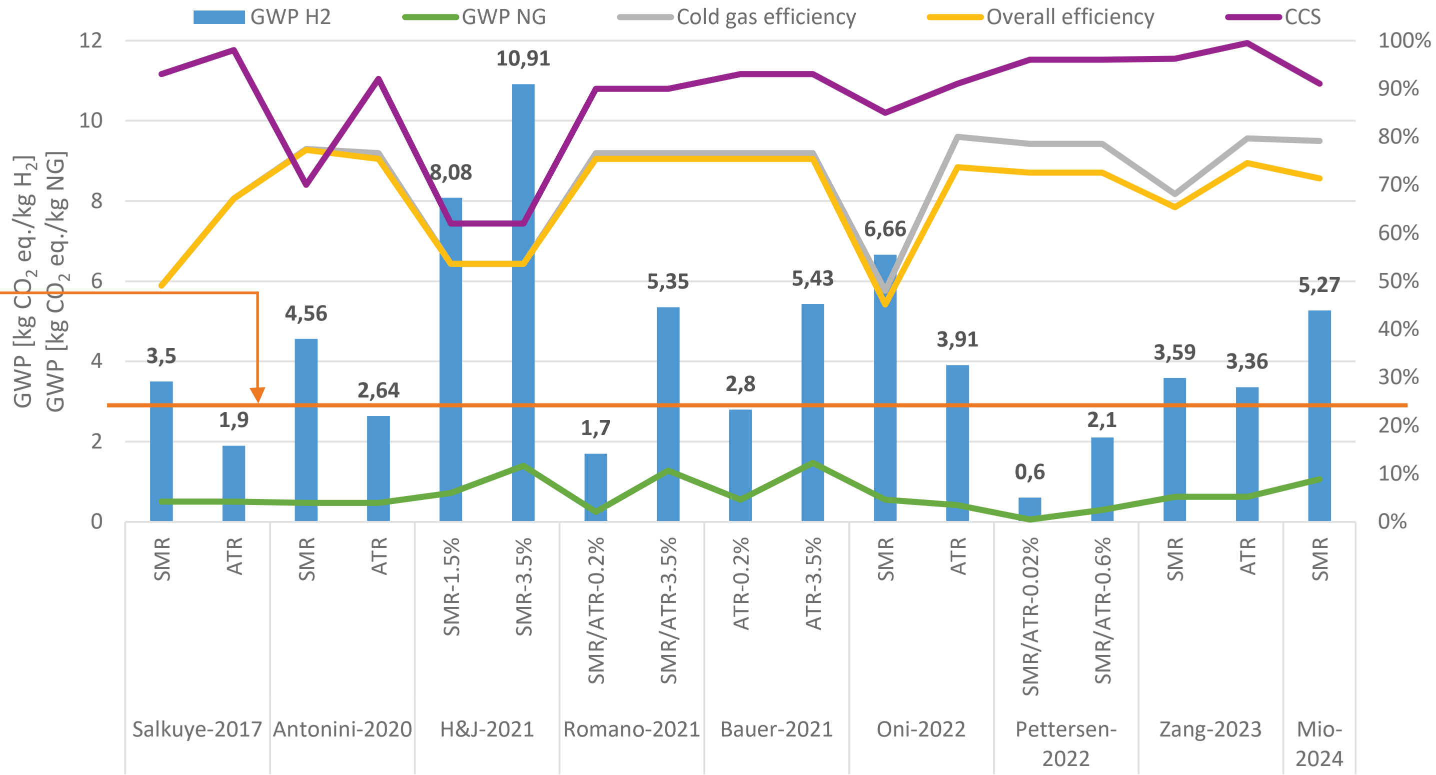


LCA of blue hydrogen in literature

Literature shows great dispersion of results, including ‘polarized’ outcomes

However, it can be concluded that blue H_2 can have equivalent CO_2 emissions below 3 kg_{CO2}/kg_{H2} , depending on methane leakage rates* and with capture >90% , which is the EU threshold for “low carbon hydrogen”

EU taxonomy and low-carbon H_2 threshold ($3\ kg\ CO_2\ eq./kg\ H_2$)



See also:


Comment on “How green is blue hydrogen?”

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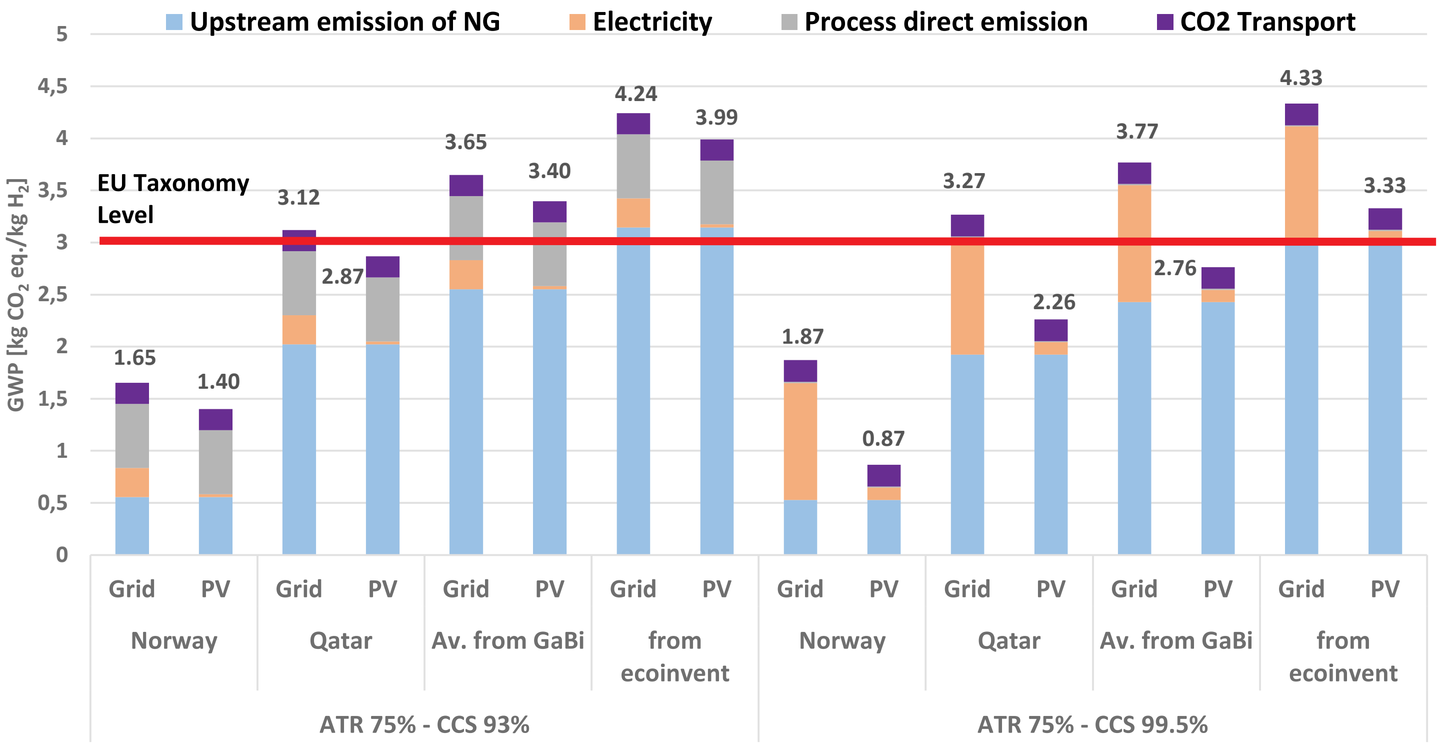
https://doi.org/10.1002/ese3.1126

*Most assessment of current CH_4 leakage are between 0.5% - 3% of the produced methane. The Oil and Gas Climate Initiative (OGCI, industry grouping of nearly 30% global oil & gas production) has shown that upstream emissions of its members are below 0.2% today, with strong reduction targets for 2025.

Our results for LCA of blue hydrogen

- **Assumptions for technology & supply chain**
- State-of-art reforming process with ATR (75% efficient)
- Capture rate 93% or 99.5%
- Natural gas supply (a key factor !) ⚠️
  - NG from Norway
  - LNG from Qatar
  - Average NG reaching Italy (GaBi)
- CO_2 transport via tankers (1300 km)
- Electricity: from grid or from PV



See also: M. K. Tabrizi et al., 2025

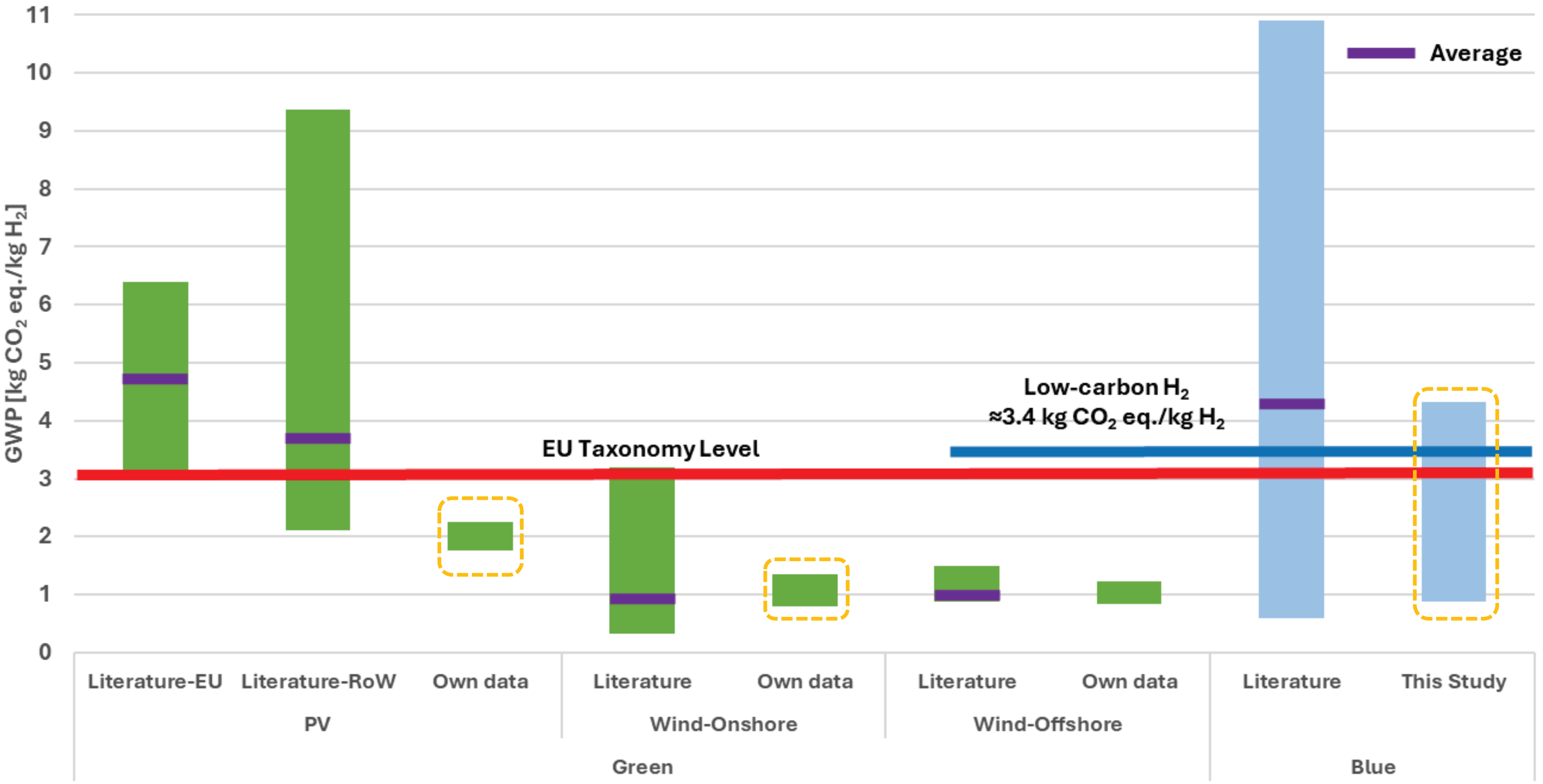
- **Findings**
- Low emission NG (0.3%) → <2 kg CO_2 eq/kg H_2
- Methane leakage (1%)+PV → <3 kg CO_2 eq/kg H_2
- Average scenario may be → <3 kg CO_2 eq/kg H_2

Most of the carbon footprint of blue H_2 (60-95%) is associated with emissions in the natural gas supply chain (energy & emissions in extraction and processing + methane leakages).

Best results achieved introducing renewable electricity & for high CO_2 capture rates (more performant cycles)

Comparison of LCA for green and blue hydrogen in Italy

- The carbon footprint of green hydrogen is lower using wind electricity than using PV
- A properly **blue H_2** — with low emission supply chain, sufficient carbon capture rate, using renewable electricity to power the carbon capture unit — can fully compete with green H_2, achieving carbon footprints below the EU taxonomy or the 'low carbon hydrogen' directive* level -> it **can support effectively the energy transition**



- key role of the NG supply chain
- *suggests a potential also for Italy's domestic production !*

(*) DIRECTIVE (EU) 2024/1788 OF the EU Parliament and of The Council on "Common rules for the internal markets for renewable gas, natural gas and hydrogen"

Grazie dell'attenzione !

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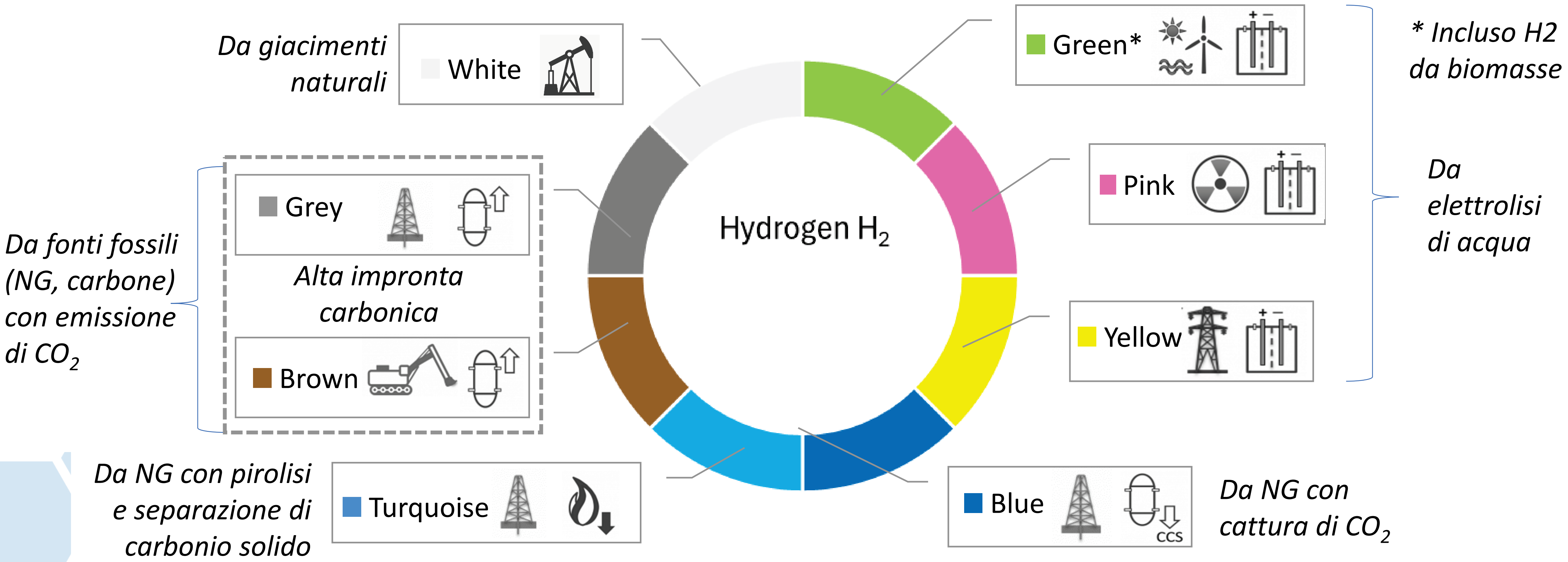
La classificazione ‘a colori’ (non consolidata)

L'idrogeno in sé è incolore, ma i metodi di produzione idrogeno sono spesso etichettati con un colore riassuntivo, seguendo una classificazione informale e non consolidata

- E’ preferibile parlare di idrogeno a bassa o alta impronta ambientale, in particolare in termini di emissioni di CO_2 equivalente (impronta carbonica)
- Tra le alternative a bassa impronta carbonica o ‘low carbon’, le più considerate sono la ‘green’ e ‘blue’, oltre alla ‘rosa’
- L’opzione ‘green‘ o ‘da rinnovabili’ comprende processi basati su elettrolisi da elettricità rinnovabile e sulle biomasse



Esempio di risultati per ruolo H2 in Italia @ Net-Zero target

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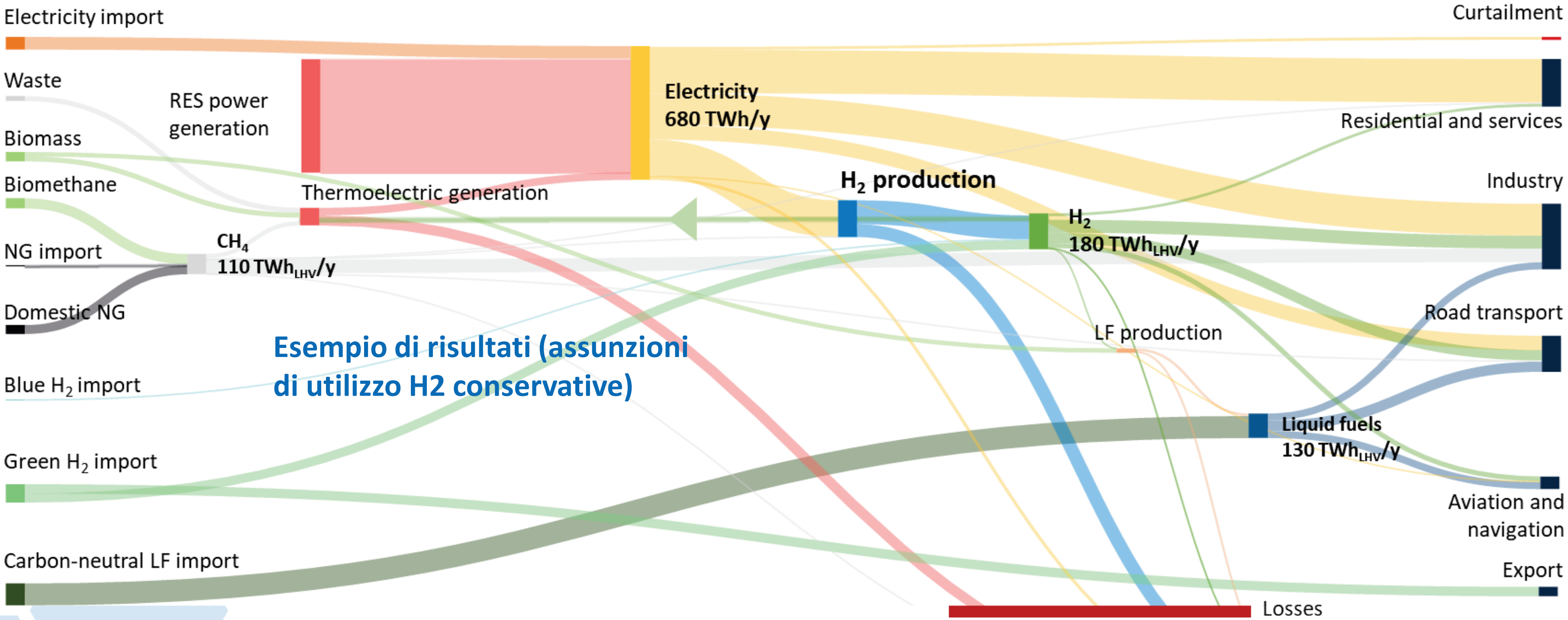
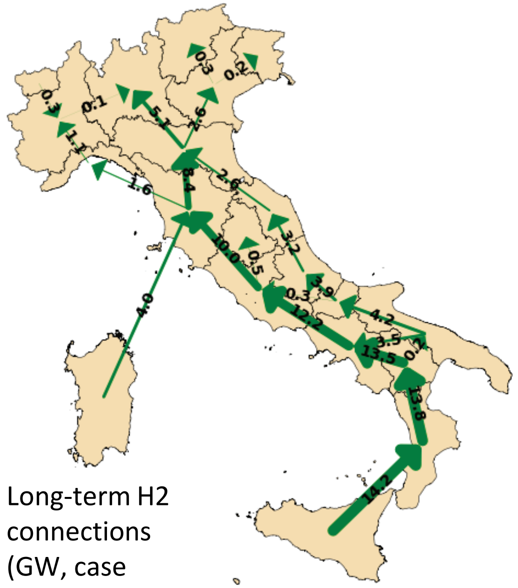
- Ruolo centrale elettrificazione; H2 come «energy hub» che abilita la decarbonizzazione usi hard-to-abate (60-65% H2 a industria, 35-40% a trasporto (tutti i tipi), oltre a usi elettrici e civili più limitati), domanda 6-10 Mt/anno
- Idrogeno come elementi di flessibilità e stoccaggio energia su larga scala; >40 GW elettrolisi dopo il 2040

  - Ruolo cruciale rinnovabili (>10x odierno su FV/eolico) e fonti biogeniche
  - Necessità di importazione H2 green o low carbon e fuel liquidi
  - Cattura CO2 essenziale per le emissioni più difficili da evitare

Corridoi di trasporto Sud-Nord per connettere I punti di import e le zone con produzione low-cost con le aree di consumo





Long-term H2 connections (GW, case without export)

P. Colbertaldo et al. https://doi.org/10.1016/j.enconman.2023.117168, 2023

✓ L'idrogeno consente il 15-25% della riduzione emissioni CO_2 totale necessaria per NetZero (~85 Mt_{CO2}/y vs. 330 oggi)

L'idrogeno nel quadro politico UE ed USA

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EU Hydrogen strategy

European Commission

- 2020: EU Hydrogen Strategy : dove l'elettrificazione è difficile, **promuove l'uso di clean fuels, incluso l'idrogeno rinnovabile e low carbon** per la decarbonizzazione di industria, trasporto, power generation e settore civile;
- 2022: nuovo impulso con i programmi **RepowerEU , Hydrogen Accelerator,** nuovo target per **consumo H2 di 20 Mt/year al 2030**, incluse 10 Mt importate
- 2023: lancio **Hydrogen Bank** per promozione investimenti su H_2
- 2024: supporto addizionale IPCEI (Important Projects of Common EU Interest)

Powering a climate-neutral economy: Commission sets out plans for the energy system of the future and clean hydrogen
Press release | 8 July 2020 | Brussels

Commission proposes new EU framework to decarbonise gas markets, promote hydrogen and reduce methane emissions
Press release | 15 December 2021 | Brussels

REPowerEU Press release | 18 May 2022 | Brussels

Italia

- 2020: prime linee guida per una strategia italiana dell'idrogeno, lancio investimenti PNRR
- 2024: definizione della **Strategia Nazionale dell'Idrogeno (SNI)**
- **2025+: attesa decereto "incentivi OPEX",** evoluzione PNIEC e PNRR

Ministero dell'Ambiente e della Sicurezza Energetica

USA

Il US Department of Energy ha lanciato la 'Hydrogen strategy' ed il 'Hydrogen@Scale' program per obiettivi net-zero @2050

- "Energy Earthshot" : **obiettivo clean hydrogen a 1$/kg entro 10 anni**
- Investimenti in clean energy tech (IRA - Inflaction Reducion Act)

HYDROGEN STRATEGY
Enabling A Low-Carbon Economy
U.S. DEPARTMENT OF ENERGY

- **In tutte le principali politiche energetiche internazionali l'idrogeno è tra i vettori energetici puliti capaci si sostenere la decarbonizzazione, in modo complementare all'elettrificazione**

Alcune motivazioni per la diffusione degli impieghi dell'idrogeno

Insieme a una fortissima elettrificazione, l'idrogeno supporta la decarbonizzazione:

- L'idrogeno 'pulito' può essere prodotto da **diverse fonti primarie** (da rinnovabili o da percorsi low carbon, es. blue hydrogen), similmente all'elettricità
- L'idrogeno permette di decarbonizzare **settori e applicazioni diverse** : in particolare *processi industriali non facili da elettrificare, parte del trasporto terrestre, aereo e marittimo*, del riscaldamento ed impieghi di produzione elettrica, con un ruolo di «Energy Hub»
- Permette il **trasporto di grandi quantità di energia** e **l'accumulo di energia su larga scala**
- Permette di realizzare un'infrastruttura energetica multi-vettore (o 'multi-fuel')
  - **più resiliente** (resistenza a shock economici e ambientali)
  - **più flessibile** (interazione con una società ed economia complessa)

..e può consentire una **riduzione di costi complessivi** (costi di infrastruttura + costi di esercizio) rispetto all'alternativa (non disponibile per tutti i processi...) di sola elettrificazione