ENVIRONMENTAL IMPACT OF e-FUELs

Davide Bonalumi

POLITECNICO MILANO 1863 | DIPARTIMENTO DI ENERGIA

Group of Energy COnversion Systems

Hydrogen JOINT RESEARCH PLATFORM

Outline

- Intro
- EU-targets
- e-fuels production
- Carbon footprint for the Green hydrogen
- Carbon footprint of E-fuels
- Application in the car sector
- Conclusions

The Hydrogen Joint Research partnership (H2 JRP)

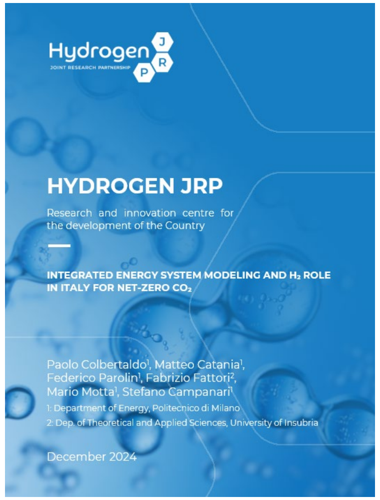
Fondazione Politecnico di Milano

The H2 JRP, founded at Politecnico with the support of leading energy companies, develops research activities on hydrogen which are *of shared interest for all the associates*; the topics include energy and enviromental studies, development of innovative components, experimentation on materials..

- *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 options of ammonia as clean hydrogen energy vector;*

(…)

Hydrogen JOINT RESEARCH PARTNERSHIP


Hydrogen JRP JOINT RESEARCH PARTNERSHIP

HYDROGEN JRP

Research and innovation centre for the development of the Country

INTEGRATED ENERGY SYSTEM MODELING AND H_2 ROLE IN ITALY FOR NET-ZERO CO_2

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

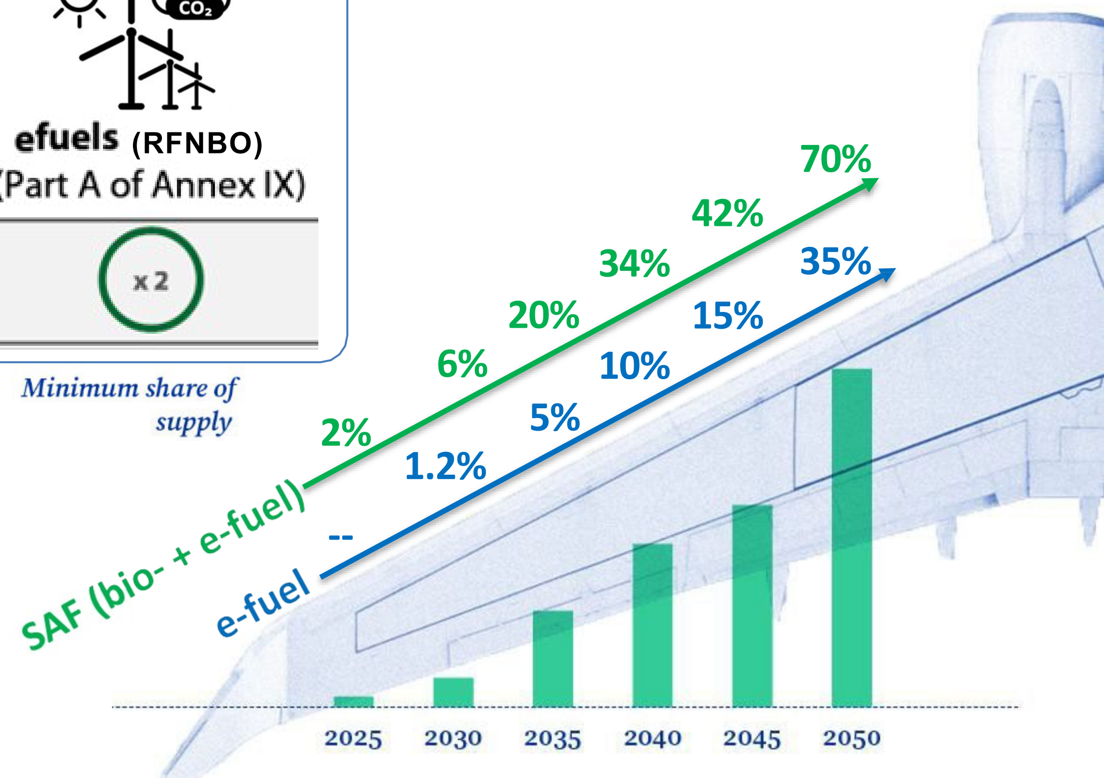
A specific activity is dedicated to evaluating the **role of hydrogen in Italy's energy system** for future net-zero CO_2 targets and to **evaluating the environmental balances of hydrogen production** routes

Current EU targets (and constraints) for 2030

REDIII →29% RES-T (or -14.5% GHG wrt 2010); Adv. bio-fuels + RFNBO > 5.5% (of which RFNBO > 1%)

	Food and feed crops	Advanced biofuels (Part A of Annex IX)	Mature biofuels (Part B of Annex IX)	efuels (RFNBO) (Part A of Annex IX)
2030-target	7 % max.; no high-ILUC crops	x 2	1.7 % max.; x 2	x 2

- **7 % max.** – value capped at 2020 level, but not more than 7 % of final consumption of energy in transport
- **x 2** – value counted twice of its energy content
- no high-ILUC crops counted for target
- **1.7 % max.** – value capped at the level of 1.7 % of final consumption of energy in transport

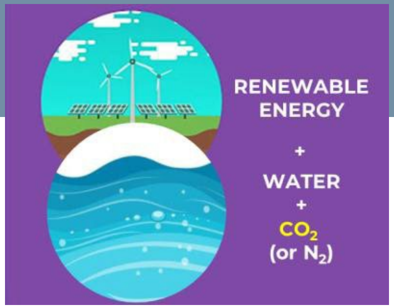


ReFuelEU Aviation → Adv. bio-fuels + RFNBO > 6% (of which RFNBO > 1.2%)

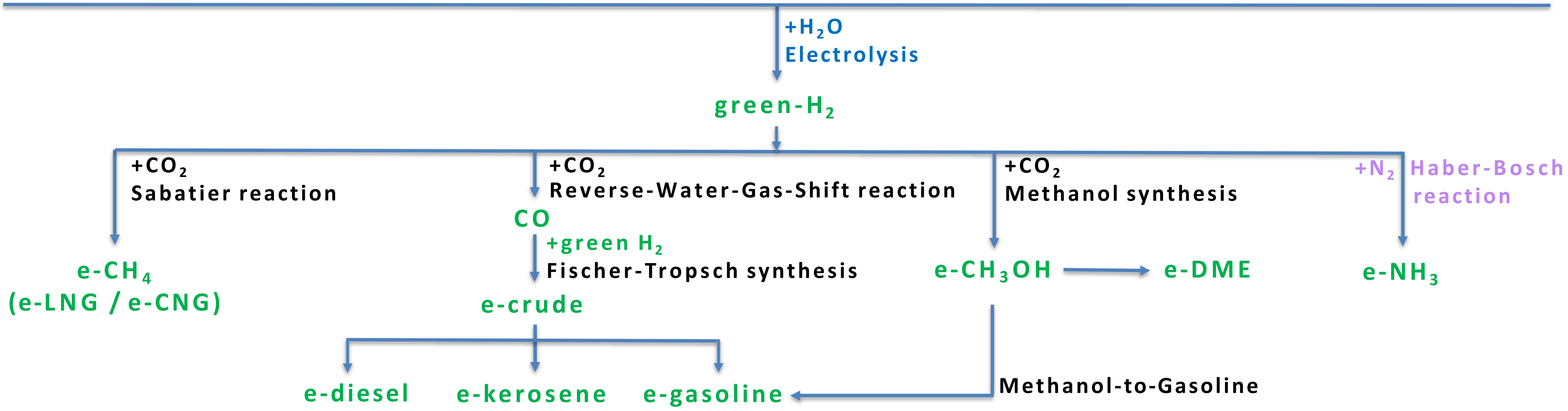
FuelEU Maritime → -6% GHG wrt 2020 baseline; RFNBO 1% by 2031 or 2% by 2034

2015: Indirect Land Use Change (ILUC) Directive – 2x on biofuels listed in Annex IX; 7% cap on the contribution of energy from crop-based biofuels in transport.
2018: Revised RED(Directive EU/2018/2001) – REDII – 14% ren. target for transport, 3.5% adv. biofuels by 2030; 7% cap on food and feed; 1.7% cap on adv. Part-B, Annex IX.

e-FUELS: definition and main synthesis routes



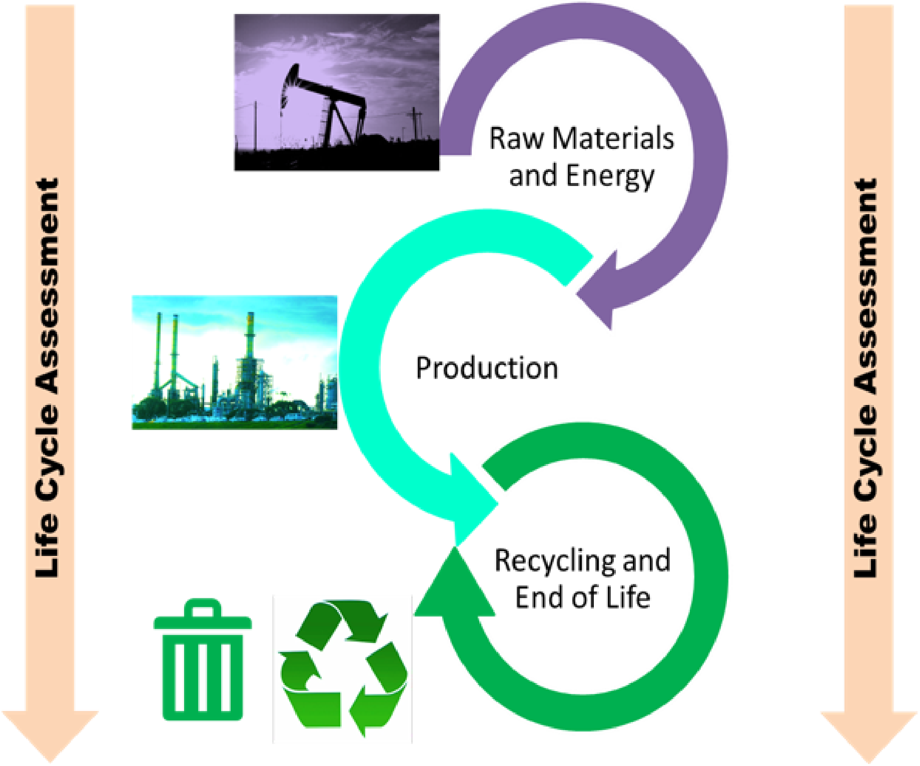
Electrofuels (e-fuels) or Renewable Fuels of Non Biological Origin (**RFNBO**), are **drop-in SFs** synthesized through PTX (Power-to-X) processes from green-H_2 and CO_2 (or N_2) exploiting appropriate catalysts.

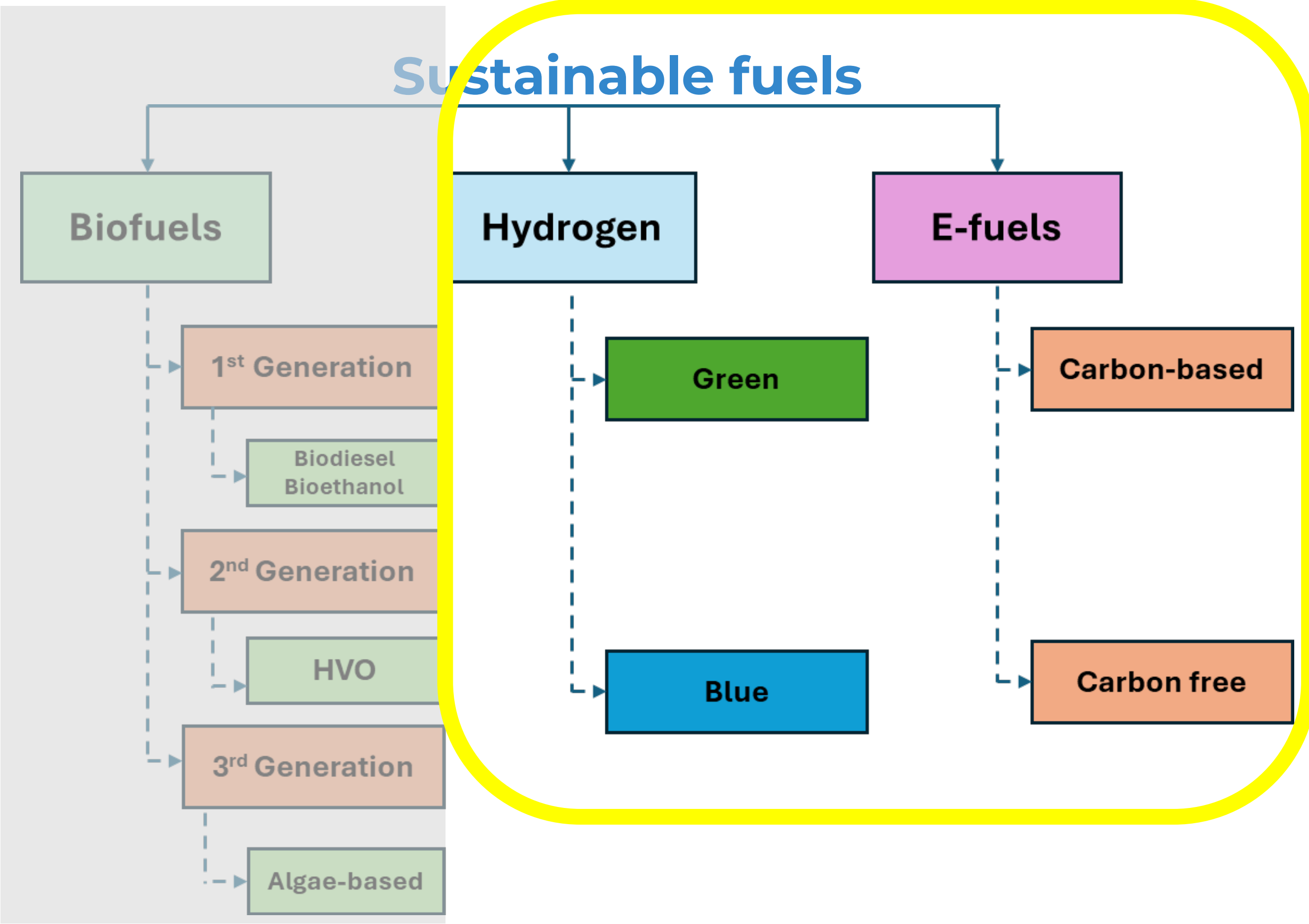


The carbon footprint of the sustainable fuels

- The emission intensity are evaluated based on **Life Cycle Assessment** (LCA) methods
- LCA is a method used to evaluate the **environmental impact** of a product throughout its entire life cycle - from the acquisition of **raw materials** through the **production process** to **its use** and finally to its **disposal**

Sustainable fuels are the goal

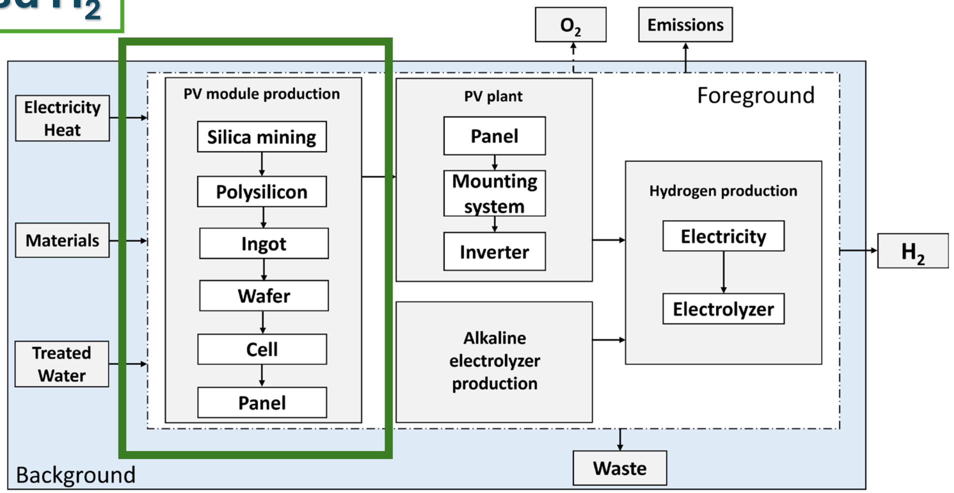




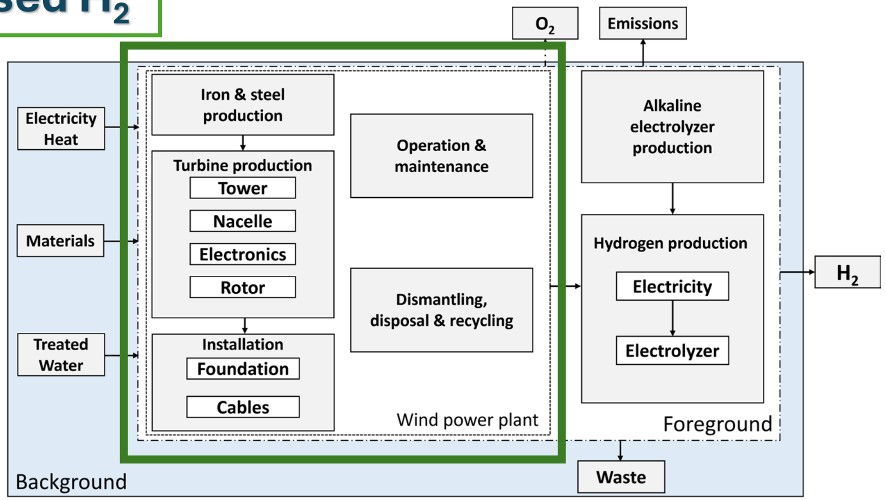
GREEN H_2- Research aim

- **A significant portion of the literature relies on outdated commercial databases, resulting in a wide range of varied outcomes.**
- ✓ **We updated the renewable electricity supply chain that affects the carbon footprint of H_2 production**
  - Development of updated supply chains with market-based models
    - State-of-the-art PV panels and wind turbines
    - Considering specific supply chains (like European turbines Vs Chinese turbines)
- ✓ Integrated with the analysis of the electrolysis and compression supply chain

PV-based H_2



Wind-based H_2



Updated PV and European wind turbine supply chain

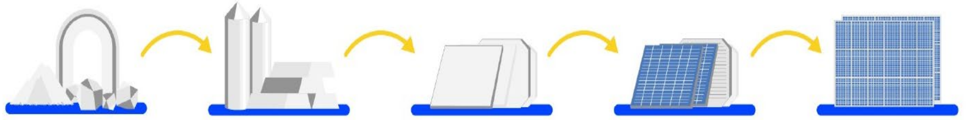
➢ Photovoltaics

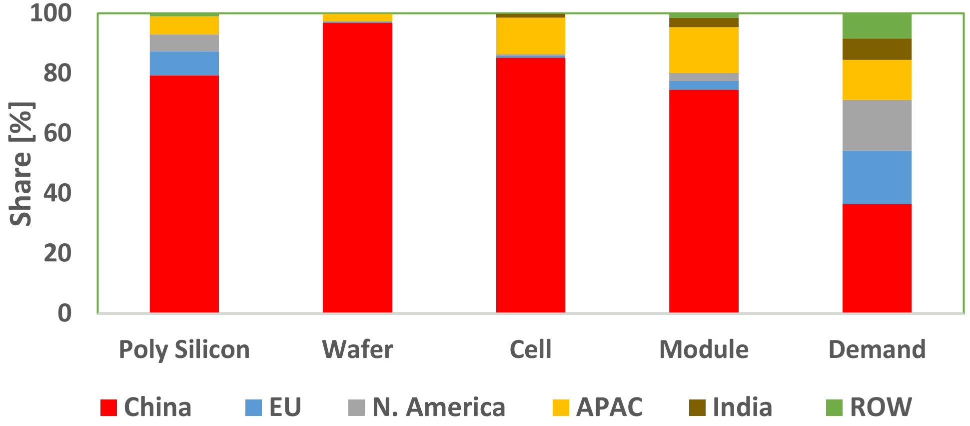
➢Actual supply chain is considered- **Market data** (2021)

➢Increase the share of Chinese products w.r.t ecoinvent

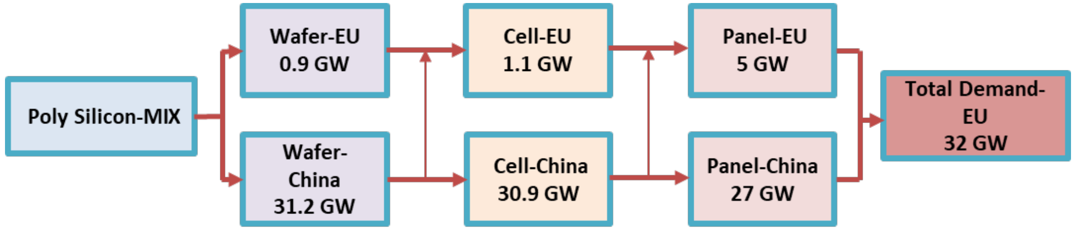
➢Conservative assumptions (APAC* neglected)

➢Advancement in PV industry is included





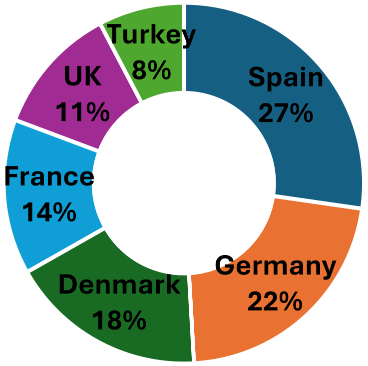
*Asia-Pacific region countries



➢ Turbine

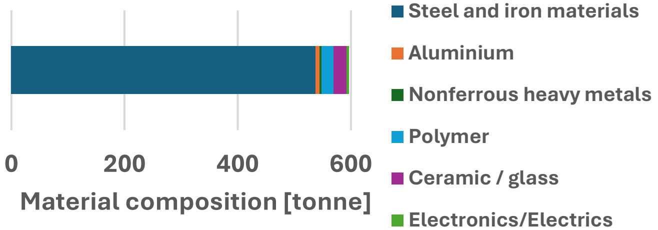
- Average of tower, blade & nacelle production capacity in Europe (2022)- assigning the electricity for manufacturing

Calculating the contribution of countries involved in turbine production



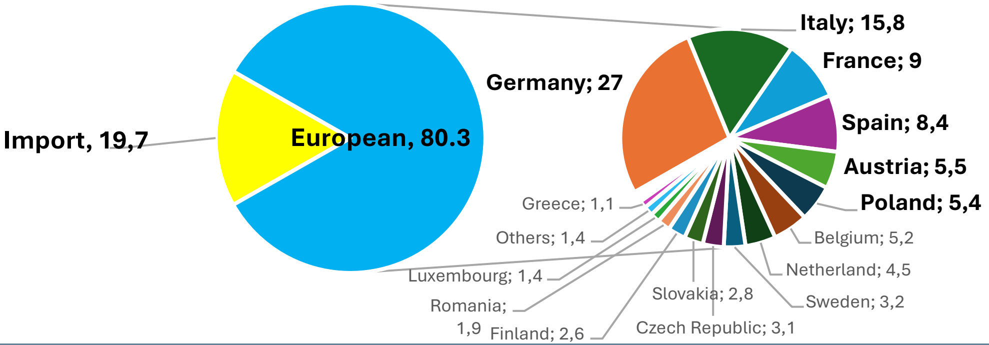
- Turbine material breakdown (3.45MW Vestas)

90% Steel & Iron



➢ Steel

- The most used material
- EU 27 (2022) steel market is adopted

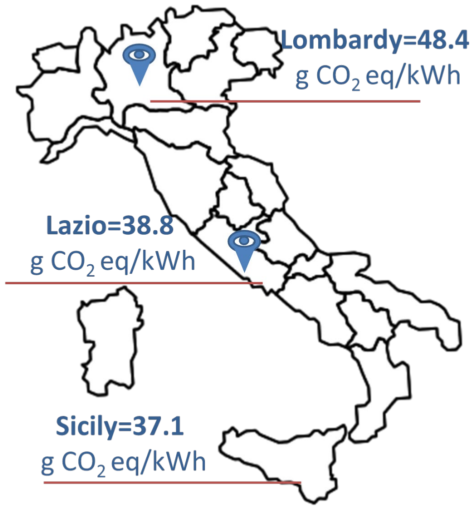


Source: *1. IEA (2022), Solar PV Global Supply Chains, IEA, Paris https://www.iea.org/reports/solar-pv-global-supply-chains, License: CC BY 4.0 2. IEA (2020),* Life Cycle Inventories and Life Cycle Assessments of Photovoltaic Systems 3. Rystad Energy – The State of the European Wind Energy Supply Chain – April 2023, https://windeurope.org/intelligence-platform/product/the-state-of-the-european-wind-energy-supply-chain/ 4. The European Steel Association | EUROFER AISBL, European steel in figures 2023, https://www.eurofer.eu/publications/brochures-booklets-and-factsheets/european-steel-in-figures-2023/

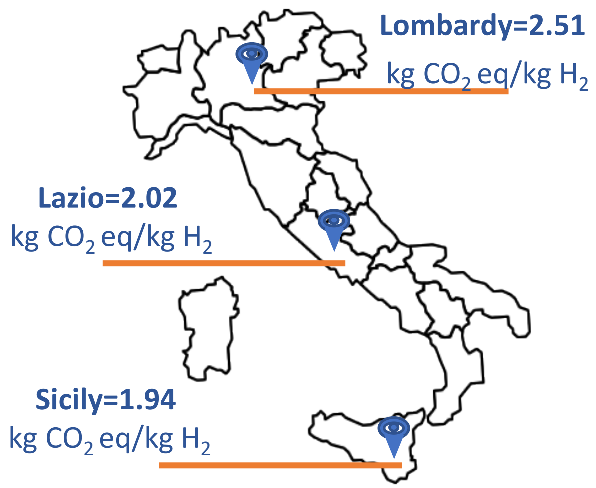
Results of LCA for H_2 production: the case PV or wind + electrolysis

- PV case: around 2-2.5 $kgCO_2eq/kg\ H_2$, the largest weight in emissions (90%) ⚠️ comes from the consumption of green electricity from photovoltaics (linked to the life cycle of solar panels, which depends on their origin), the rest from the life cycle of electrolysis and compression
- Similar considerations but with lower values (0.7-1.5 $kgCO_2eq/kg\ H_2$ depending on the region and turbine type) for H_2 from wind power

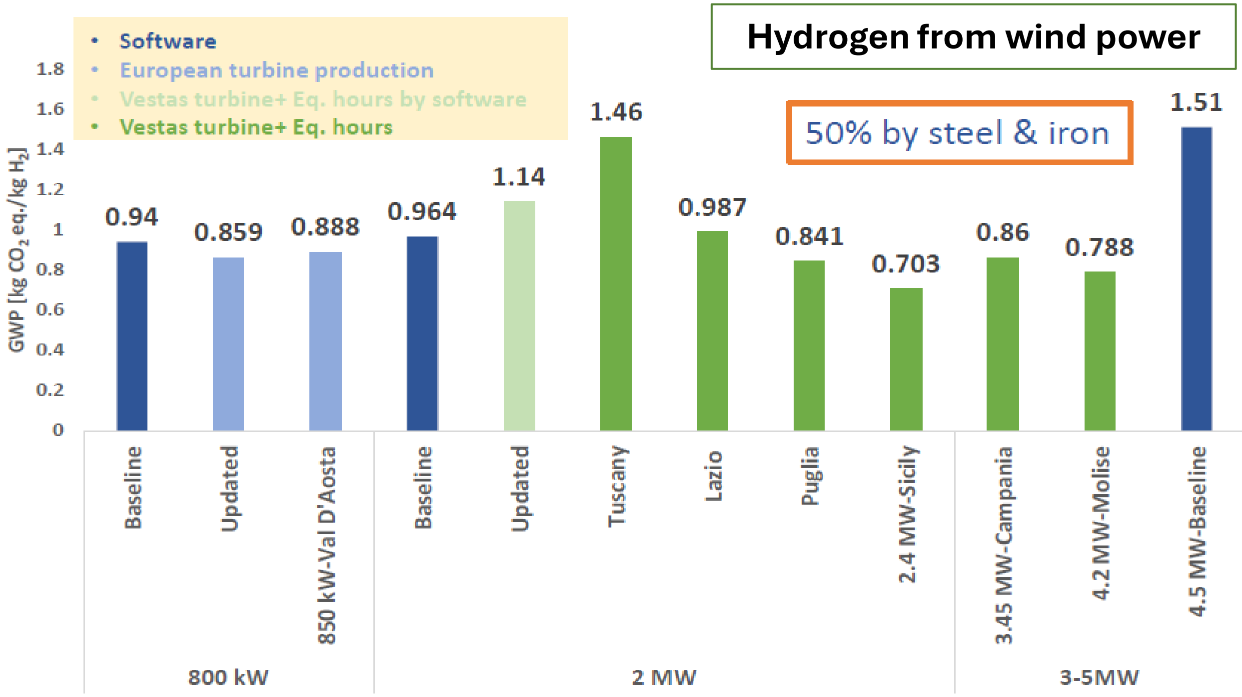
Electrical energy



Hydrogen from PV



Hydrogen from wind power



M.K. Tabrizi, J. Famiglietti, D. Bonalumi, S. Campanari «*The carbon footprint of hydrogen produced with state-of-the-art photovoltaic electricity using life-cycle-assessment methodology*», Energies,2023 https://doi.org/10.3390/en16135190

M.K. Tabrizi, J. Famiglietti, D. Bonalumi, S. Campanari «How the boundaries of the supply chain affect climate profile: The case of renewable electricity and green hydrogen for Italy and the UK», IJHE,2025 https://doi.org/10.1016/j.ijhydene.2025.01.372

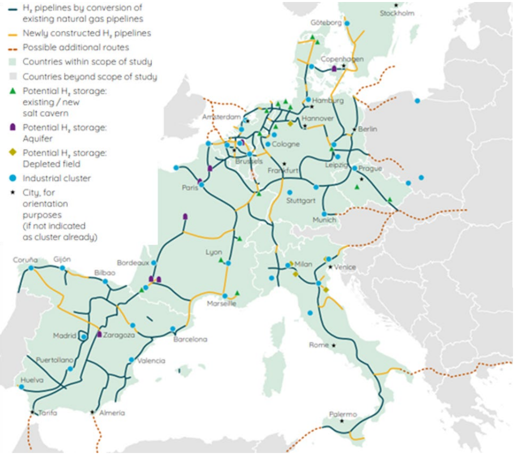
Categories of sustainable fuels and their availability

➢ **Biofuels**

- Compatible with existing units but limited (availability of feedstock)
- Reaching sustainable supply limit by 2030
- 350-500 billion liters/y (IPCC AR6)
- ≈10% of current demand (4000 BL/y)

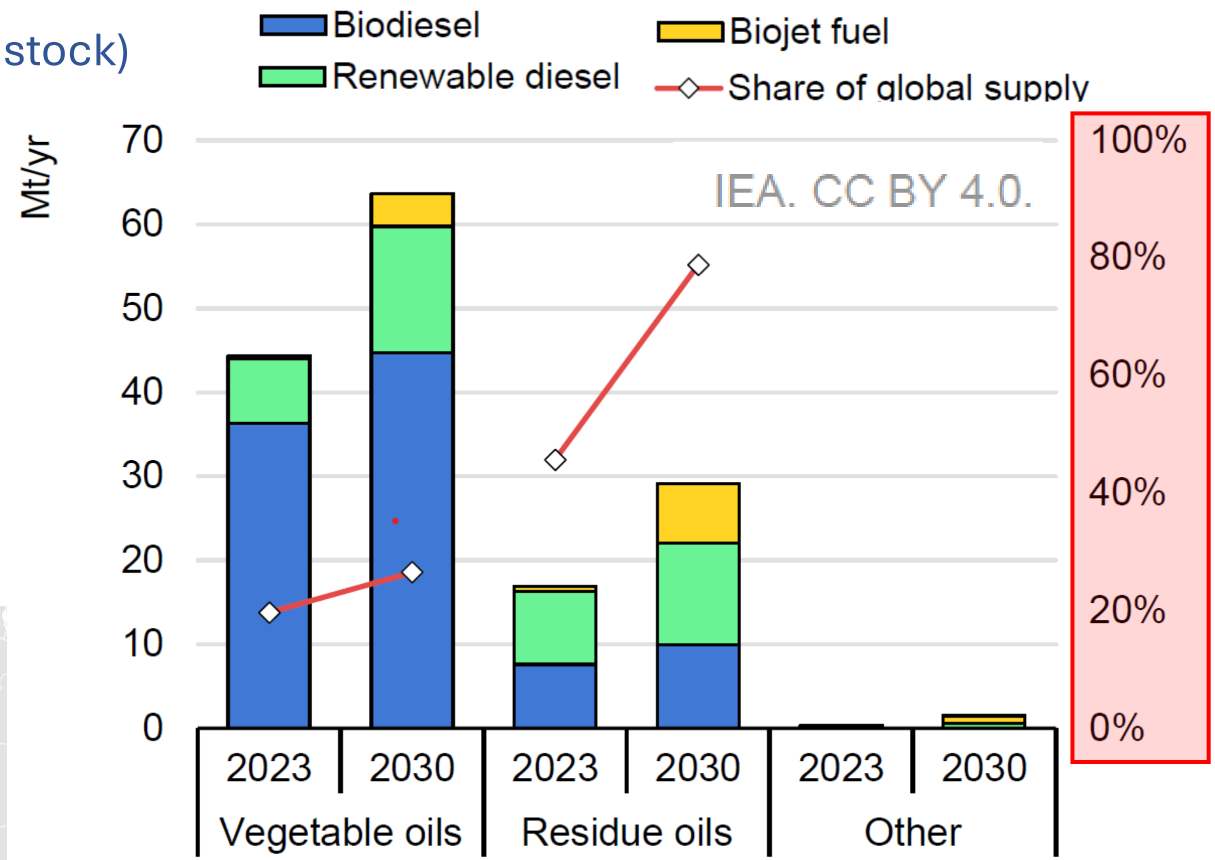
➢ **Green H_2 and e-fuels**

- Not limited quantity-wise
- Facilitating the transport of renewable electricity



Source: EU Hydrogen Backbone (EHB) initiative https://ehb.eu/

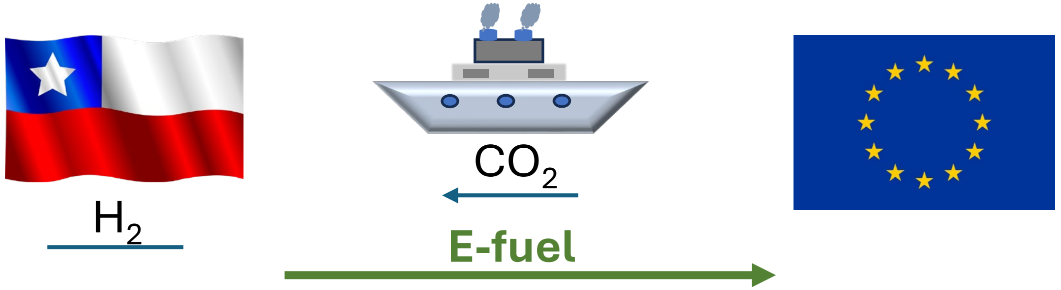
➢ A single ∅1.0-1.2 m pipeline can transport an amount of energy similar to 6-8 large high voltage powerlines (at ~3 GW each)

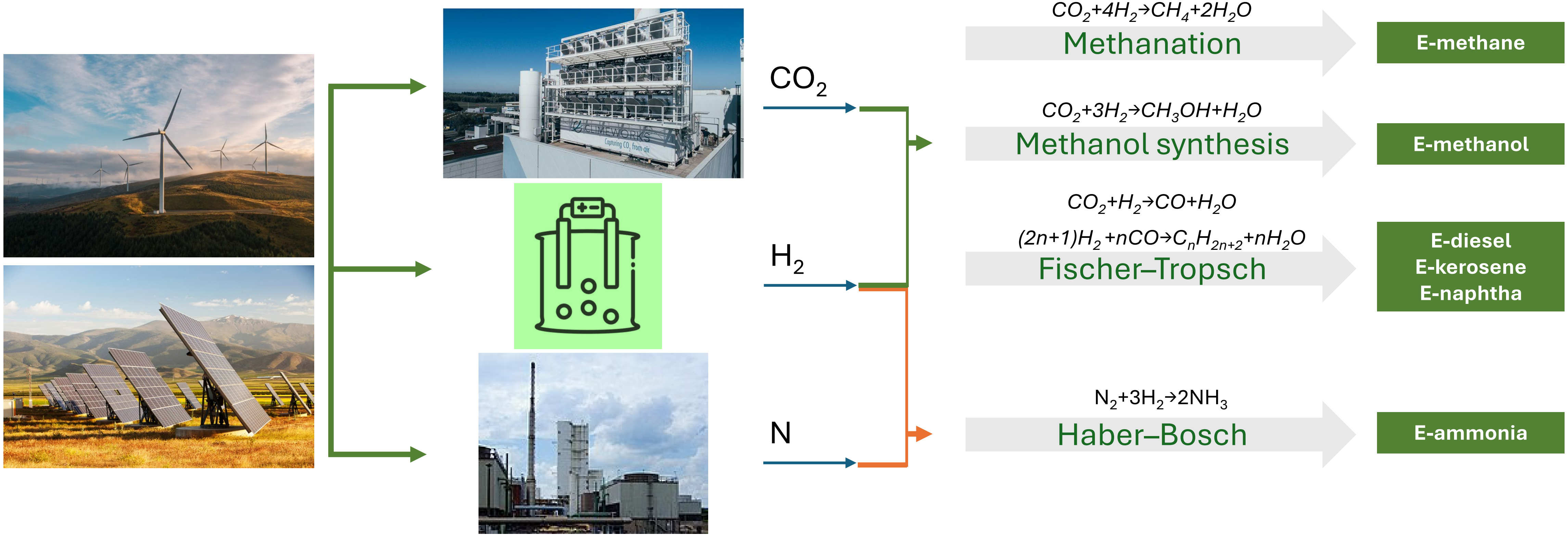


E-Fuels

➢ **A wide range of products**

- Based on green H_2
- CO_2 from DAC (Why not biogenic CO_2 form biogas upgrading?)
- E-methane, e-methanol, e-diesel, and SAF
- N instead of CO_2 ➞ e-ammonia





LCA of fuels

➢ **Main influencing factor**

- Location of plants
- Assumptions on consumption and efficiency of the process
- Database used for analysis

✓ **H_2**

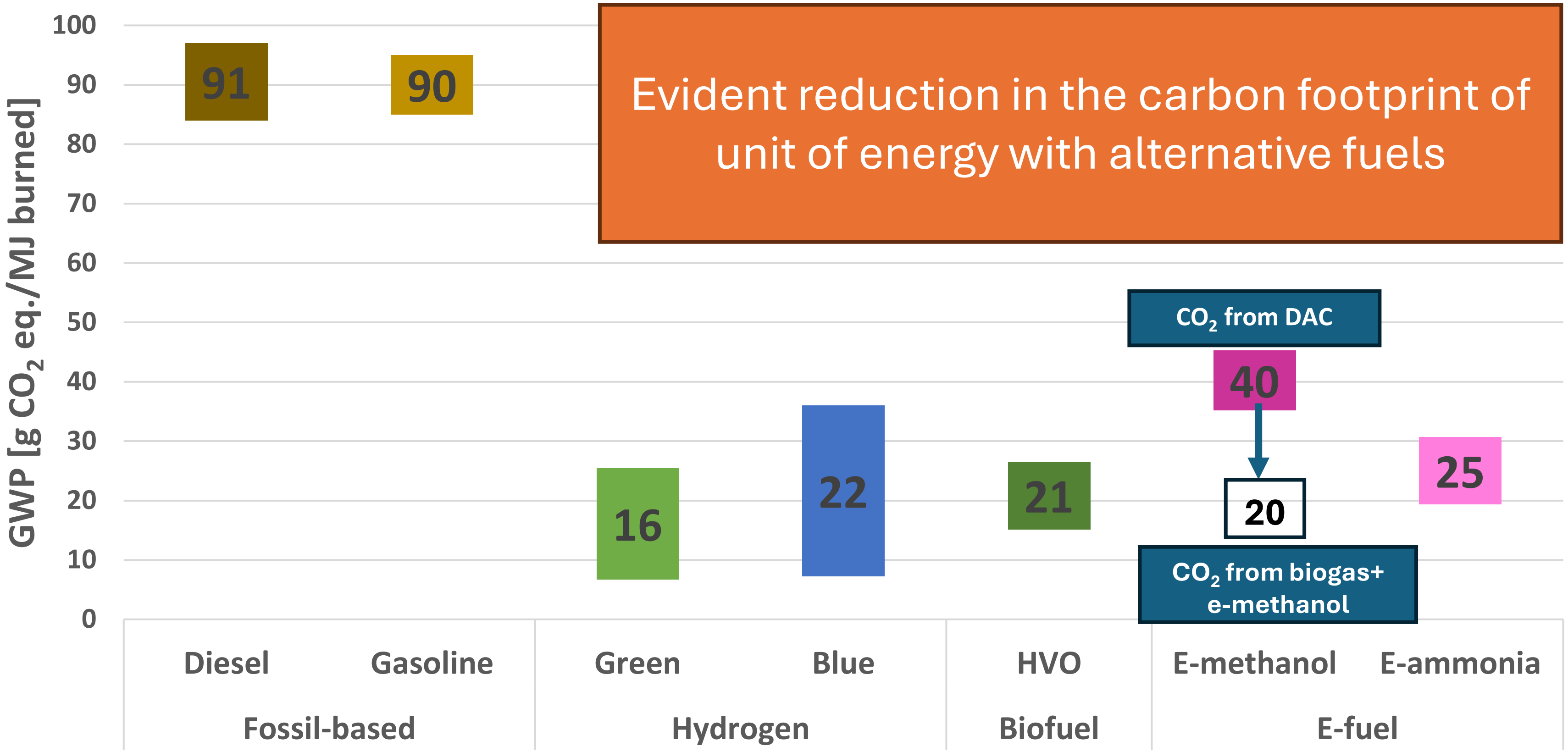
- Renewable electricity
- NG supply chain

✓ **HVO**

- Feedstock
- H_2 supply: SMR

✓ **E-fuels**

- H_2 supply from wind in Chile
- Source of CO_2 : DAC & biogas

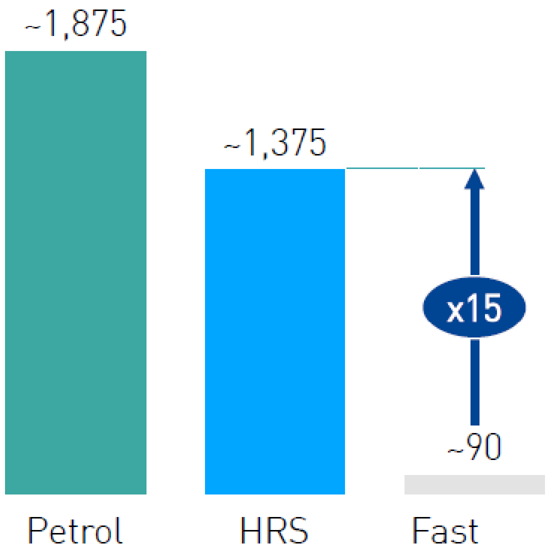


Evident reduction in the carbon footprint of unit of energy with alternative fuels

Hydrogen vehicles allow fast refueling in compact stations

- Fueling time is ~5 min (similar to gasoline / Diesel, and similar to NG vehicles)
- Expected low queueing issues, smaller footprint / CAPEX than large fast charging facilities

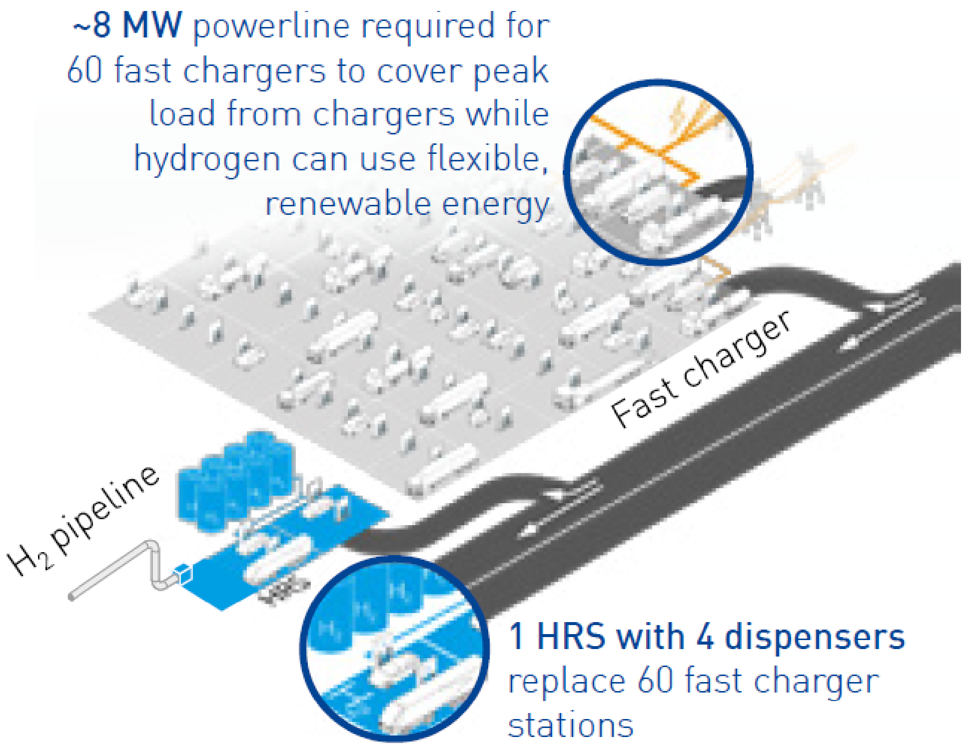
Refueling speed
Km/15 minutes of refueling



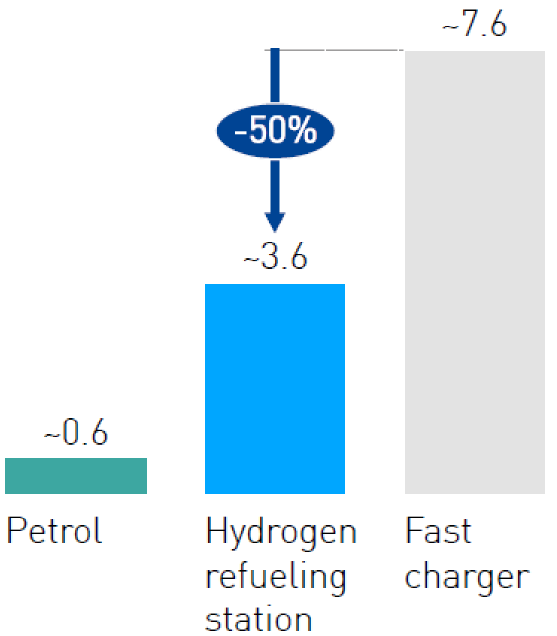
HRS = Hydrogen Refueling Station

Hydrogen refueling is **15x faster** than fast charging

Space requirements



Investment costs per refueling
EUR/refueling



Hydrogen refueling is **half as capital-intensive** as fast charging

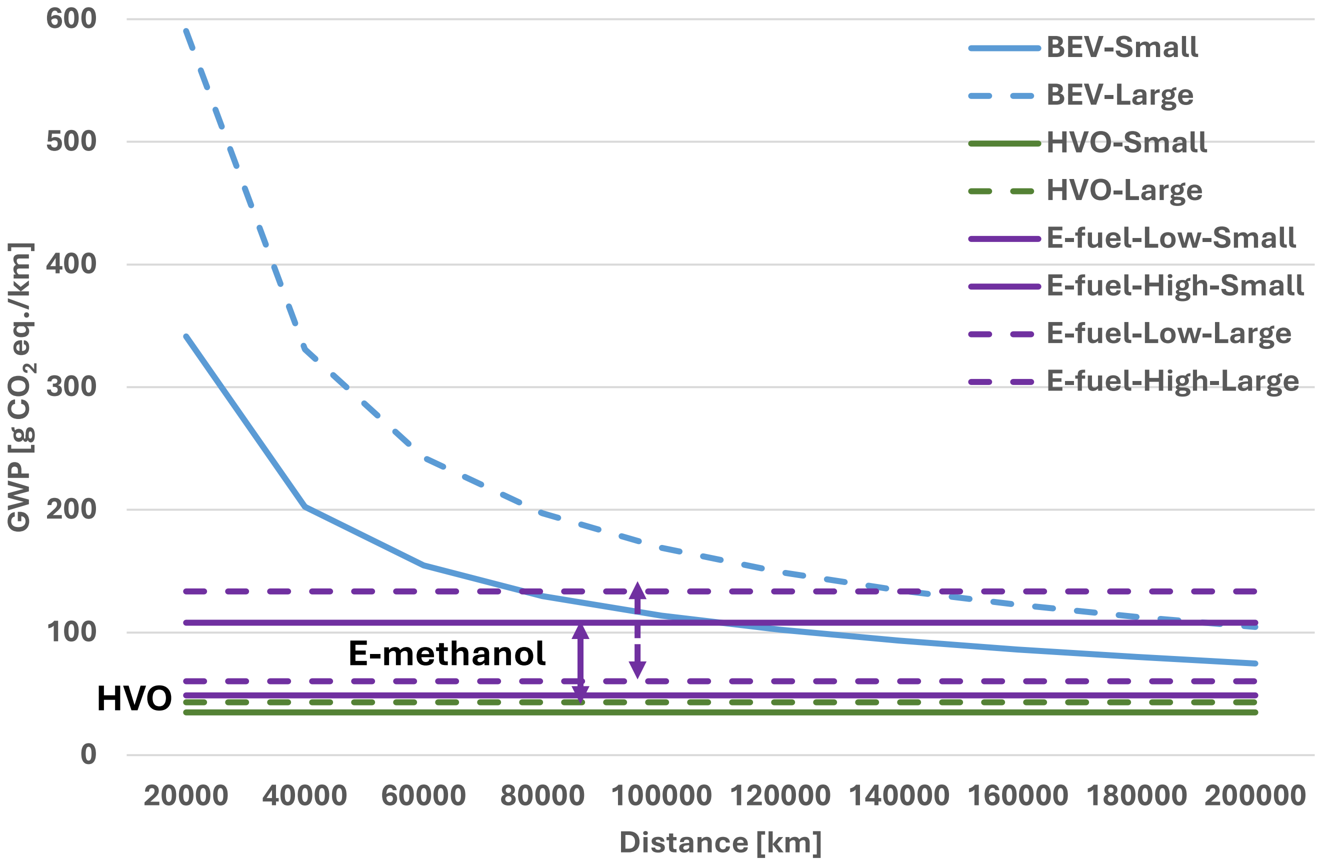
Image courtesy of Hyundai, Honda

Assumptions: ICE range = 750 km/refueling, refueling time = 3 min. ; FCEV range: 600 km/refueling, refueling time = 5 min. ; BEV range = 500 km/refueling, refueling time = 60-75 min (80-100 kW fast charger) ; HRS at 1000 kg/d – Adapted from EU Hydrogen Roadmap - 2019

Fuels in use

- **ICEV with gasoline/alternative fuels Vs. BEV (WTW) – passenger cars**
- Identical energy consumption for ICEV with gasoline, H_2, e-methanol
- Diesel has 20% lower fuel consumption than gasoline
- HVO 5% more than diesel
- Average green H_2(1.9 kg CO_2 eq./kg H_2)
- Average HVO, e-methanol with low and high scenarios
- Chinese LIB (NMC=130 kg CO_2 eq./kWh)
- Lifetime of vehicles equal to 10 years (200,000 km)
- EV charged and H_2 compressed with the Italian grid w. a decreasing C.F

	BEV		ICEV		
Vehicle type	LIB capacity [kWh]	Consumption-Electricity[kWh/100km]	Consumption-Gasoline [l/100km]	Energy consumption [MJ/100km]	Consumption H_2[kg/100km]
Small (A segment)	42	17.4	5.5	239	1.99
Large (D segment)	83.9	19.5	6.8	295	2.46



- BEVs outperform fossil-based ICEV after 60,000-100,000 km
- ICEV with HVO shows lower C.F. than alternatives
- C.F. of H_2-fueled ICEV in Italy is lower than that of BEVs
- C.F. of H_2-fueled ICEV in Italy is between e-methanol scenarios
- E-methanol-High has a lower C.F. than small BEV till 110,000 km
- E-methanol-High has a lower C.F. than small BEV till 140,000 km

1. Kolahchian Tabrizi, M., Bonalumi, D., & Lozza, G. G. (2024). Analyzing the global warming potential of the production and utilization of lithium-ion batteries with nickel-manganese-cobalt cathode chemistries in European Gigafactories. Energy, 288, 129622.
2. Bonalumi, D., & Kolahchian Tabrizi, M. (2022). Re-evaluation of the Global Warming Potential for the Production of Lithium-Ion Batteries with Nickel–Manganese–Cobalt Cathode Chemistries in China. Energy & Fuels, 36(22), 13753-13767.

Conclusions

- **Hydrogen** is an essential **feedstock** for **sustainable fuels**, and so is it. It is an **energy carrier** that can import renewable energy from uninhabited and remote areas, and its production can **avoid the curtailment of renewables** in case of overproduction in other types of areas.
- Electric vehicles decrease their carbon footprint, increasing mileage. **The smaller the battery, the lower the impact**: citycars for shared urban mobility can maximize the advantages.
- **The sustainable fuels can decarbonize the transport sector from the first kilometer run** in well-known internal combustion engines (for several applications)
- Sustainable Fuels enhance the value of existing infrastructure in Italy (13 refineries - including 2 biorefineries; 21’000+ fuel stations)1 and in EU (85 refineries - including 8 biorefineries; 137’000+ fuel stations) → transition possible with limited capital intensity
- e-Fuels enable the long-term development of ICEs, in which the national/EU components supply chain is strategic → preserves EU competitiveness in the value chains linked to fuels and automotive
- E-Fuels allow the development of fully domestic/EU supply chains, without reliance on components or raw materials controlled by a few countries → preserves the energy security of Europe

Thank you

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