ENVIRONMENTAL IMPACT OF SUSTAINABLE FUEL

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Hydrogen JOINT RESEARCH PLATFORM

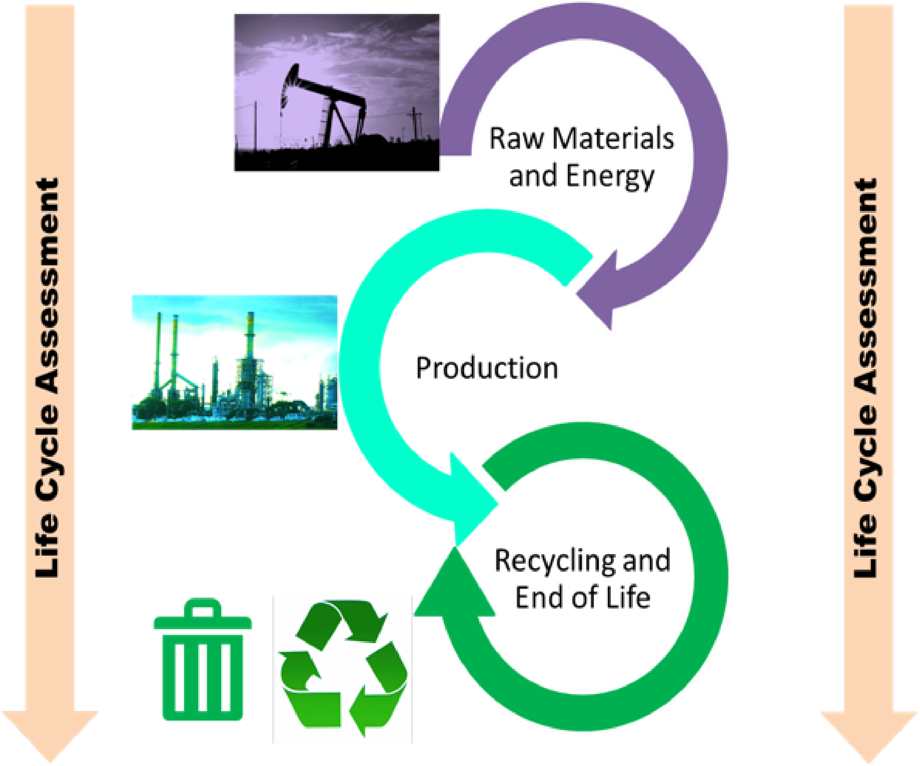
Outline

- Intro – LCA
- Carbon footprint for the Green hydrogen
- Carbon footprint of the sustainable fuels
  - Biofuels
  - E-fuels
  - Hydrogen
- Application in the car sector

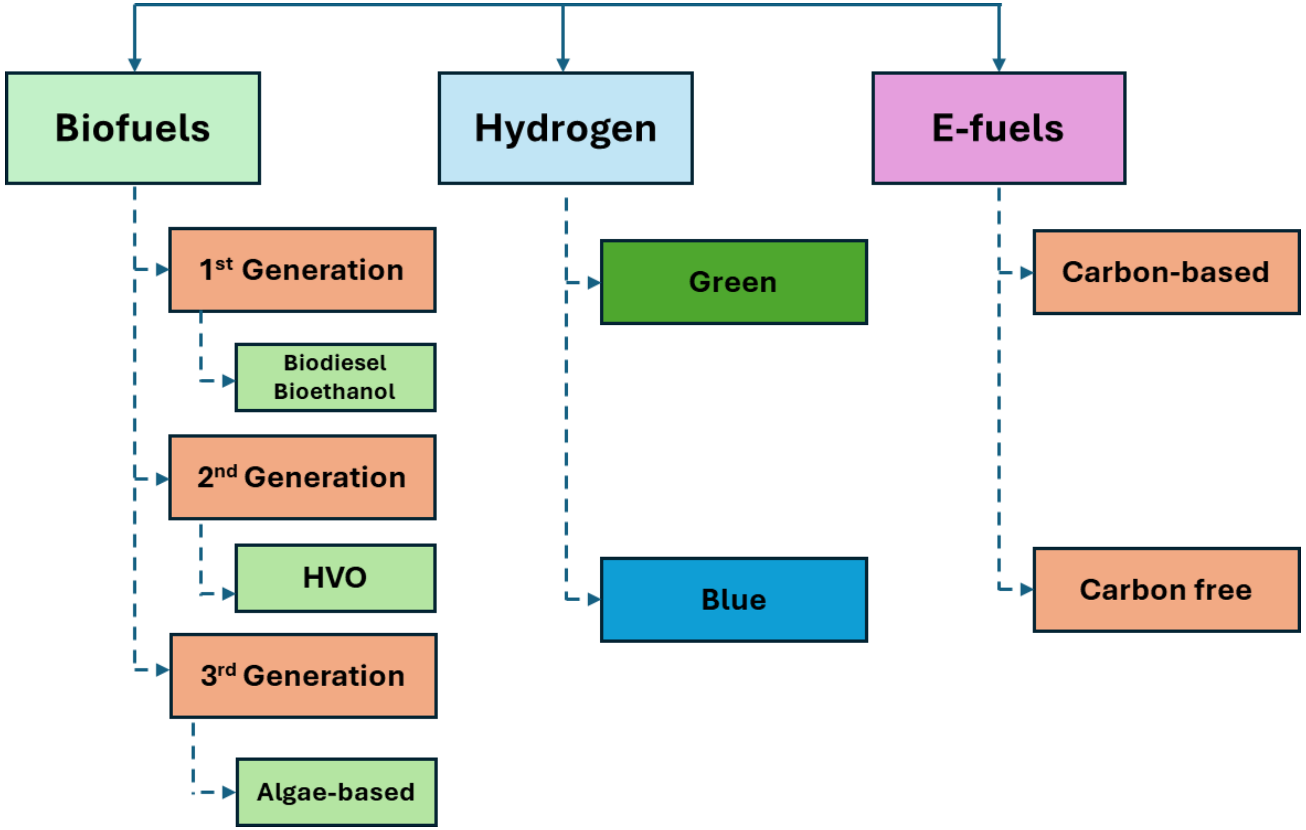
The carbon footprint of the sustainable fuels

- 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



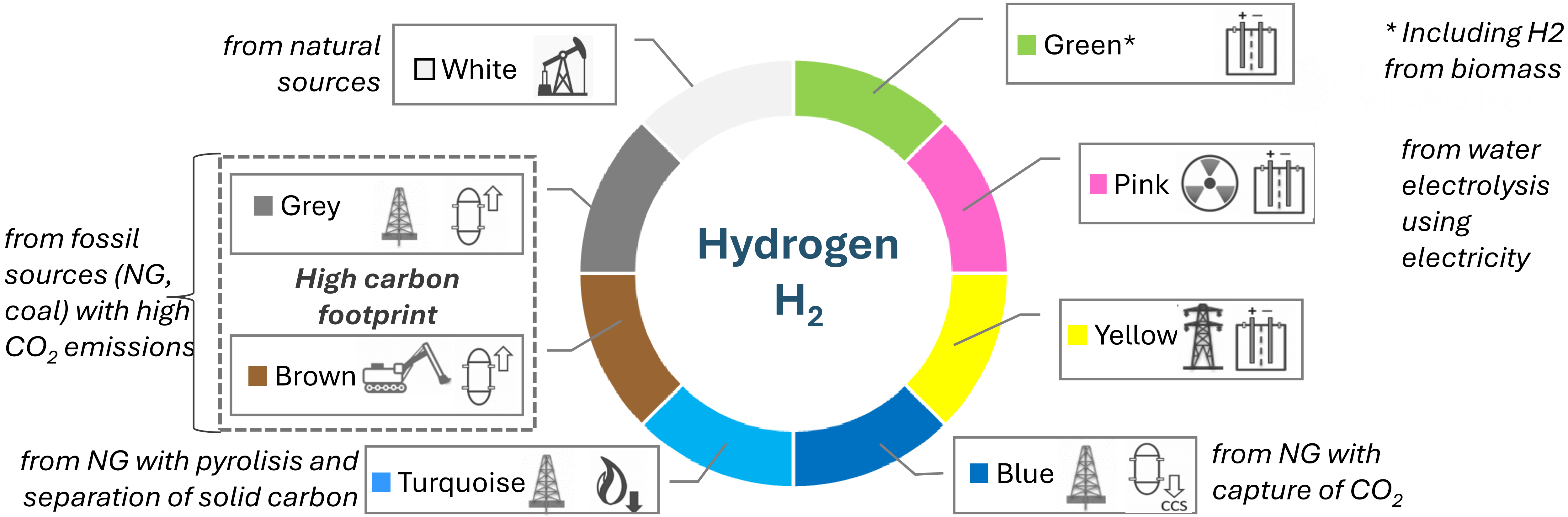
Sustainable fuels



The colored classification of H_2 pathways

Hydrogen is colourless, but its production pathways are often labelled with a color for an informal classification

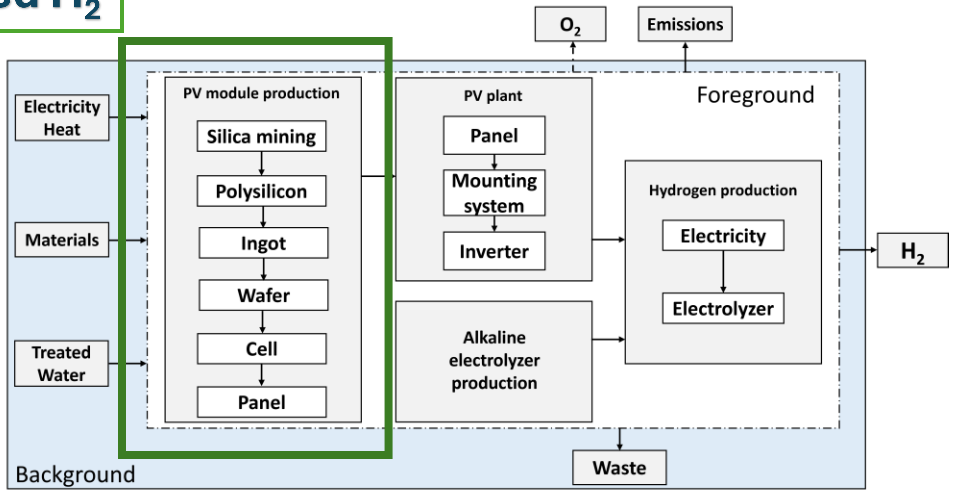
- A quantitative analysis allows to define two categories, with **low or high environmental footprint** in terms of equivalent CO_2 emissions, and the case of negative emissions for options such as biomass + CCS
- Among the '**low carbon**' alternatives, the most readily available are the 'green' (from renewables), 'blue' (NG+CCS), and 'pink' (from nuclear electricity)



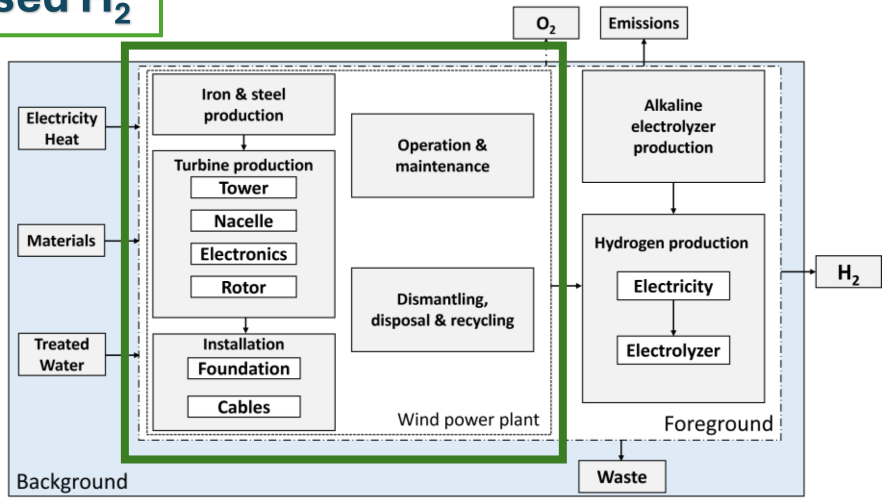
GREEN H_2- Research aim

- ➢ **A significant portion of the literature relies on outdated commercial databases, resulting in a wide range of varied outcomes.**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**
    - o 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



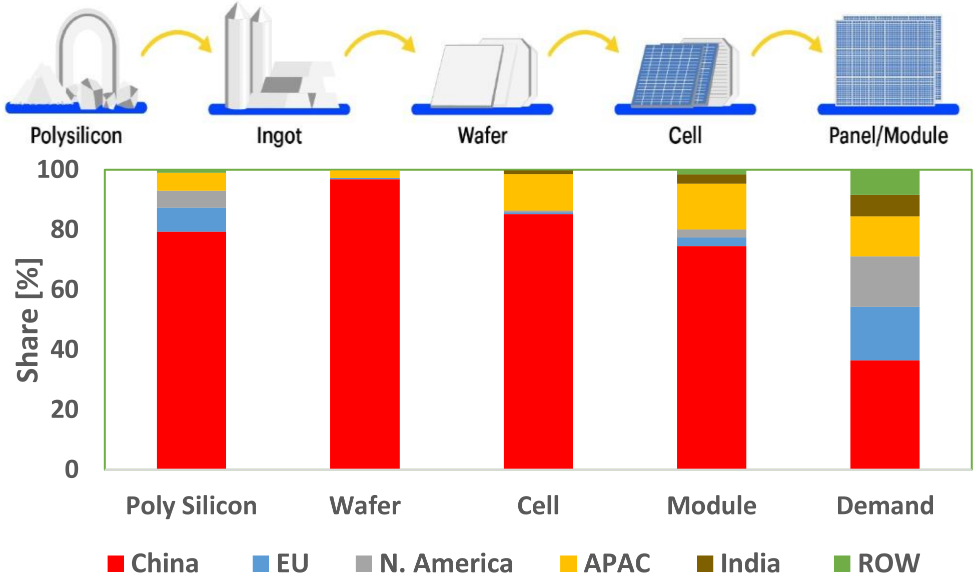
Wind-based H_2



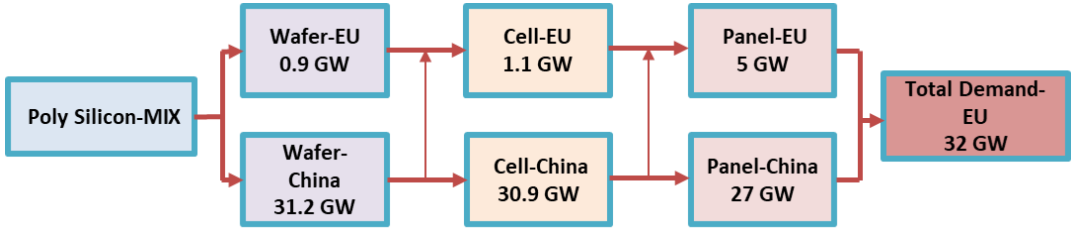
Updated PV and European wind turbine supply chain

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



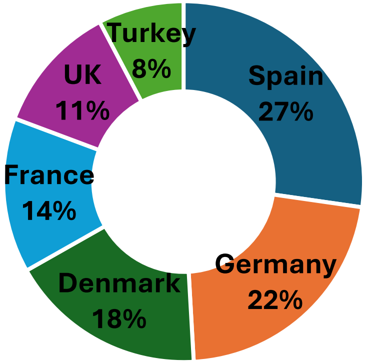
*Asia-Pacific region countries



Turbine

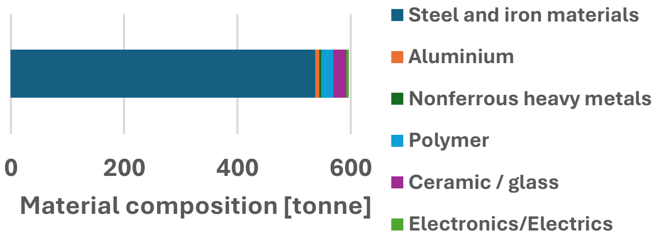
- Average of tower, blade & nacelle production capacity in Europe (2022)- assigning the electricity for manufacturing

Calculating the contribution of countries involved in turbine production



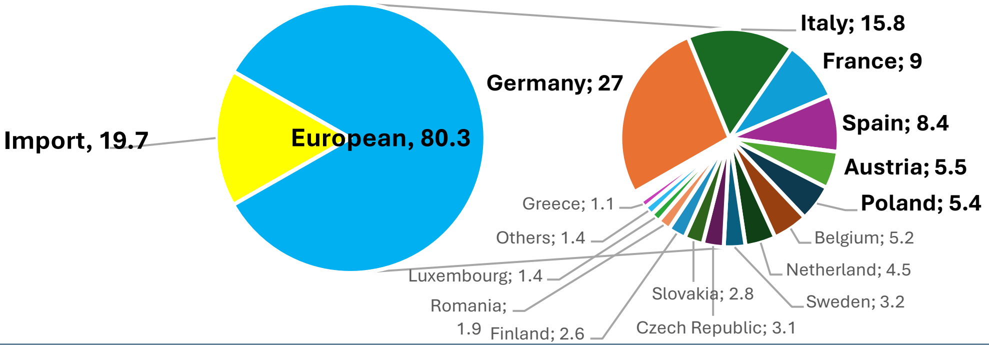
- Turbine material breakdown (3.45MW Vestas)

90% Steel & Iron



Steel

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

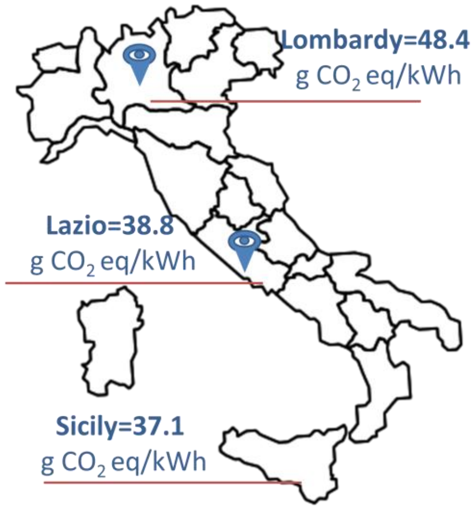


Source: *1. IEA (2022), Solar PV Global Supply Chains, IEA, Paris https://www.iea.org/reports/solar-pv-global-supply-chains, License: CC BY 4.0 2. IEA (2020),* Life Cycle Inventories and Life Cycle Assessments of Photovoltaic Systems 3. Rystad Energy – The State of the European Wind Energy Supply Chain – 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/

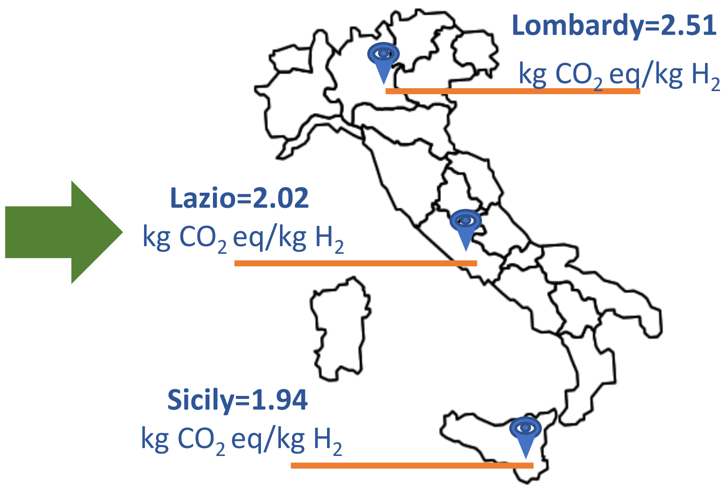
Results of LCA for H_2 production: the case PV or wind + electrolysis

- 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

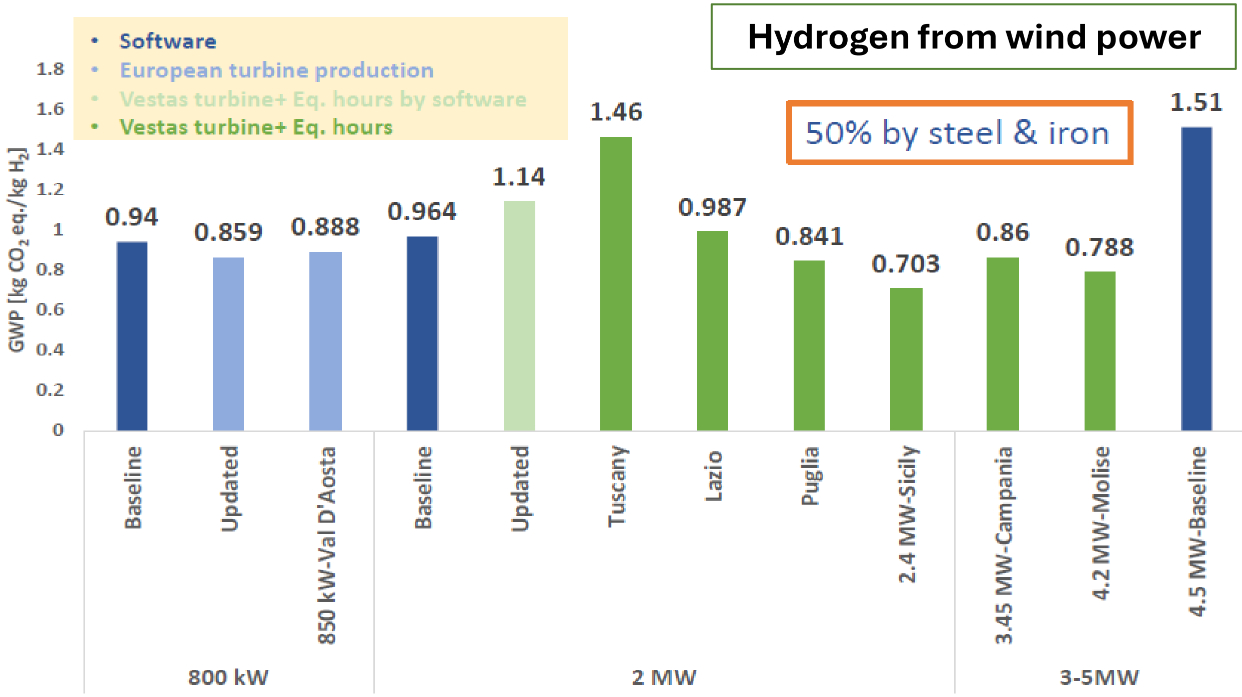
Electrical energy



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

➢ Biofuels

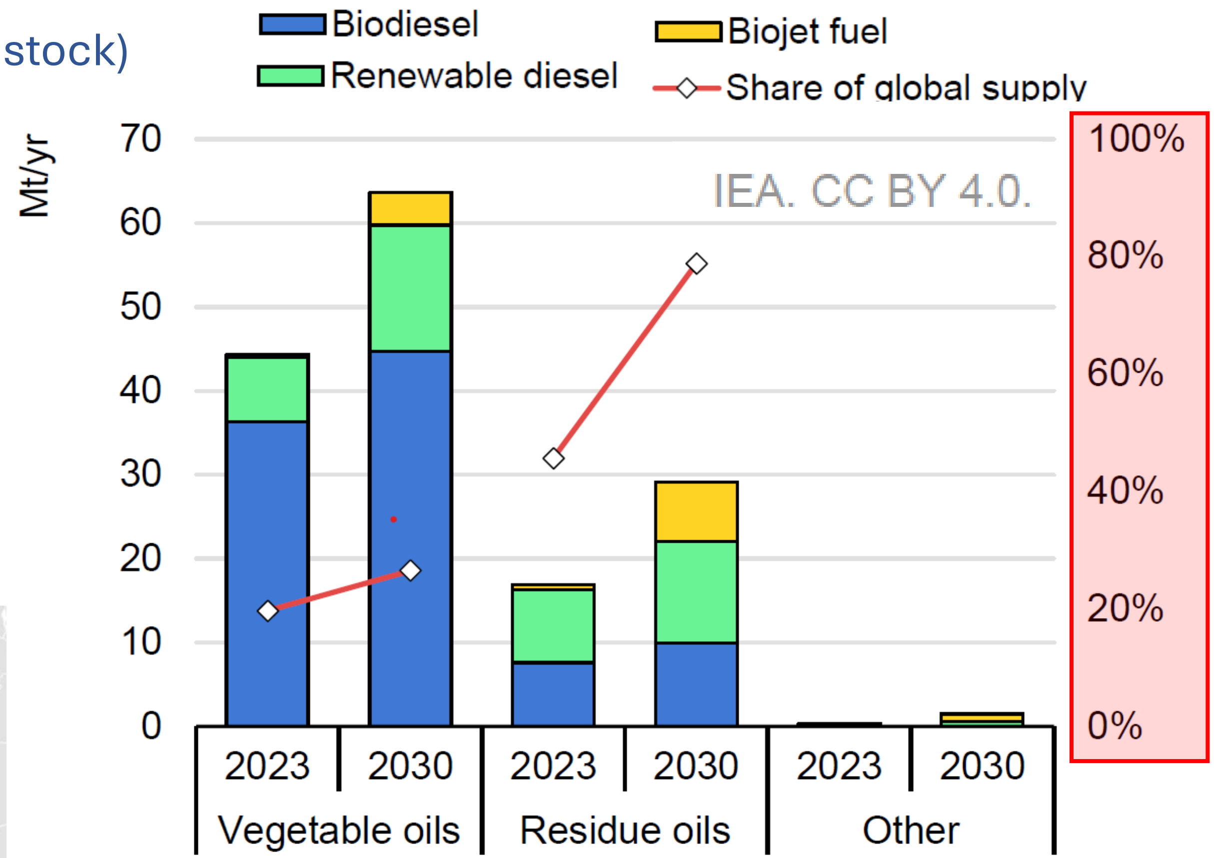
- Compatible with existing units but limited (availability of feedstock)
- Reaching sustainable supply limit by 2030
- 350-500 billion liters/y (IPCC AR6)
- ≈10% of current demand (4000 BL/y)

➢ Green H_2 and e-fuels

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

➢ 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)

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



Hydrotreated vegetable oil (HVO)

➢ A type of biofuel

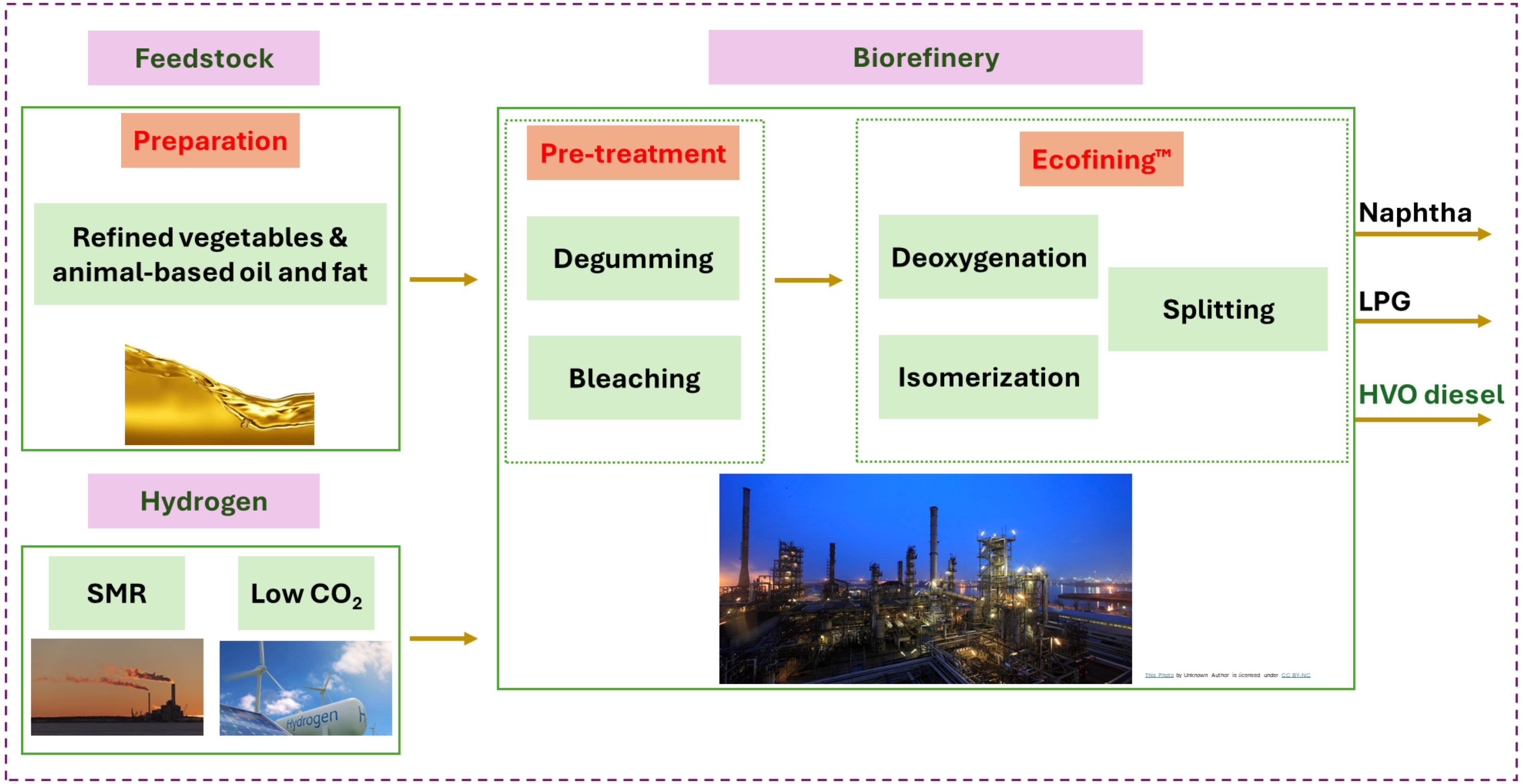
- Based on vegetable oils and animal fats
- Compatible with existing diesel engines with almost identical efficiency
- Positive contribution to waste management

➢ Co-production of

- HVO diesel
- Naphtha
- LPG

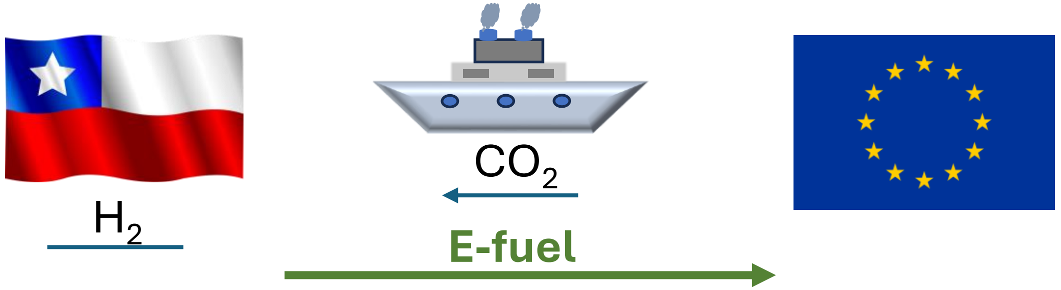
➢ H_2 supply

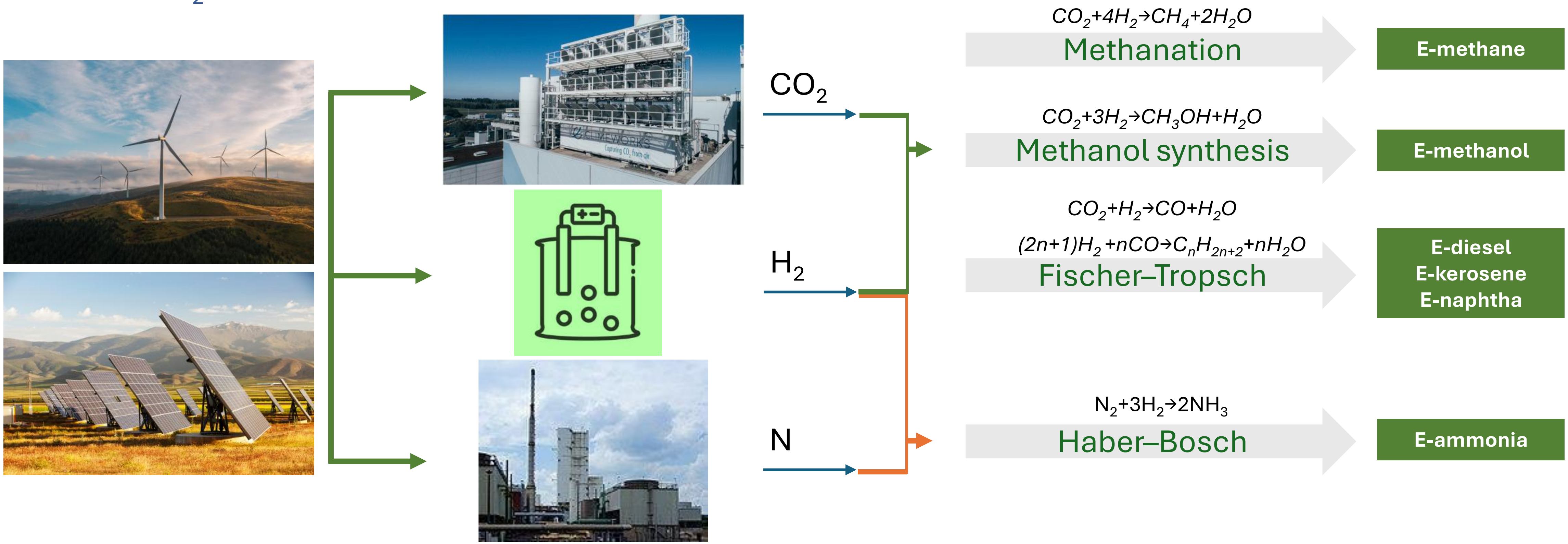
- Fossil-based (Reforming)
- **Can be substituted with green & blue H_2**



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





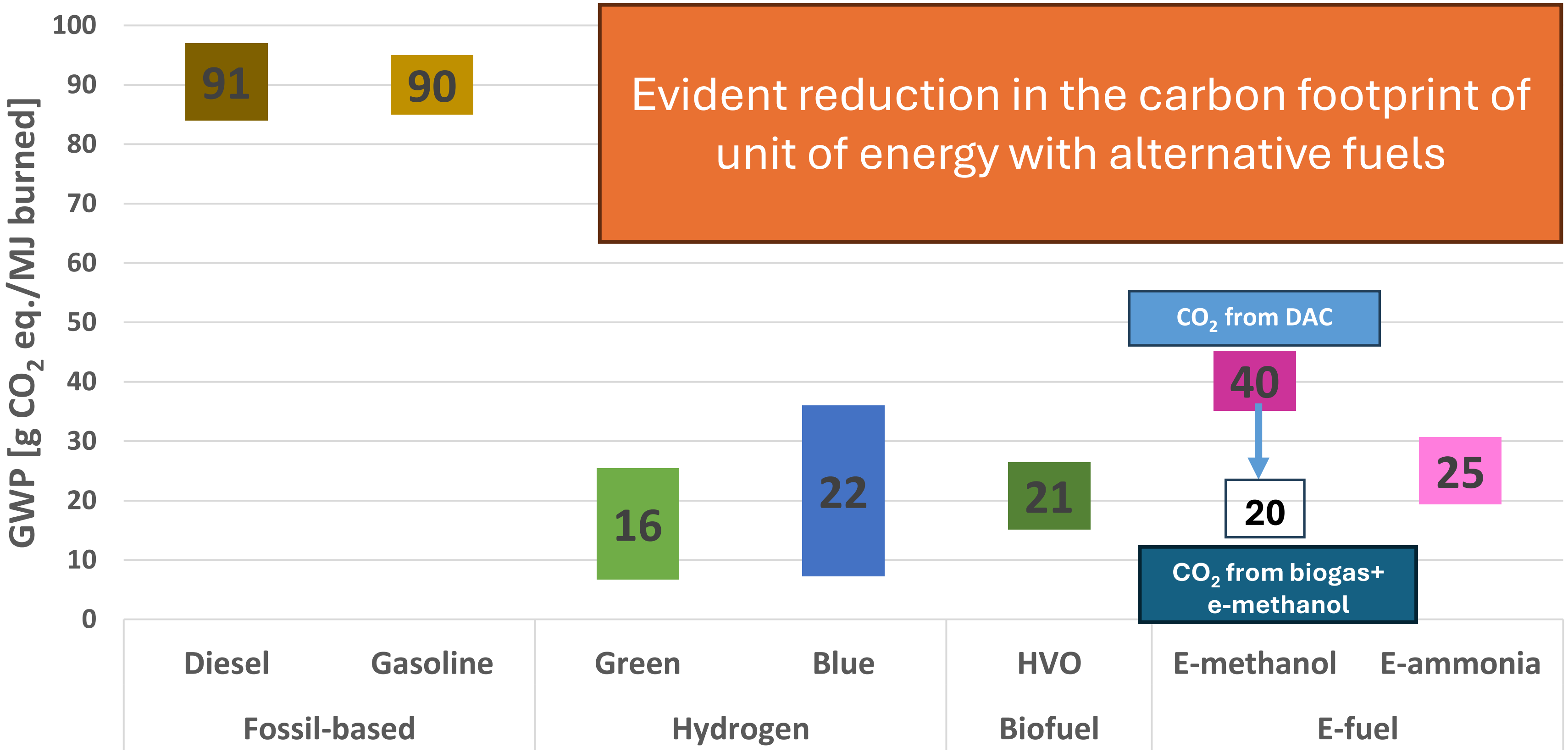
LCA of fuels

- **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

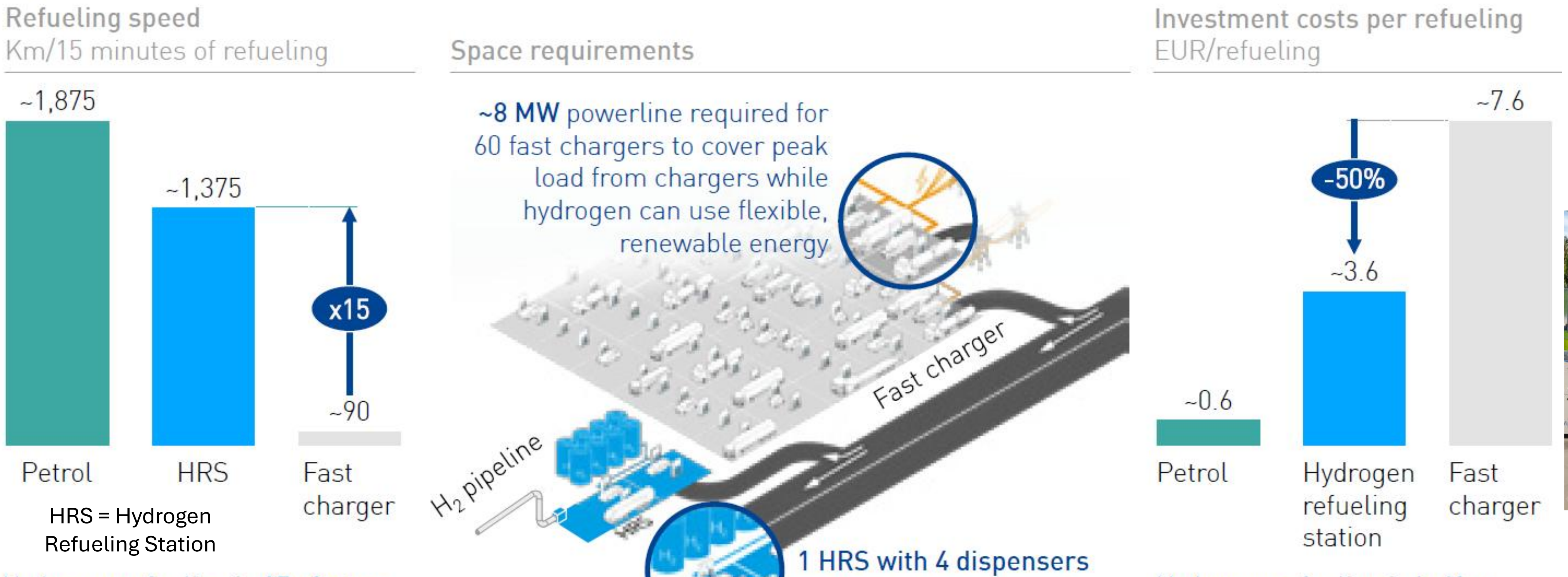
- **E-fuels**
  - H_2 supply from wind in Chile
  - Source of CO_2 : DAC & biogas



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



HRS = Hydrogen Refueling Station

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

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

Image courtesy of Hyundai, Honda

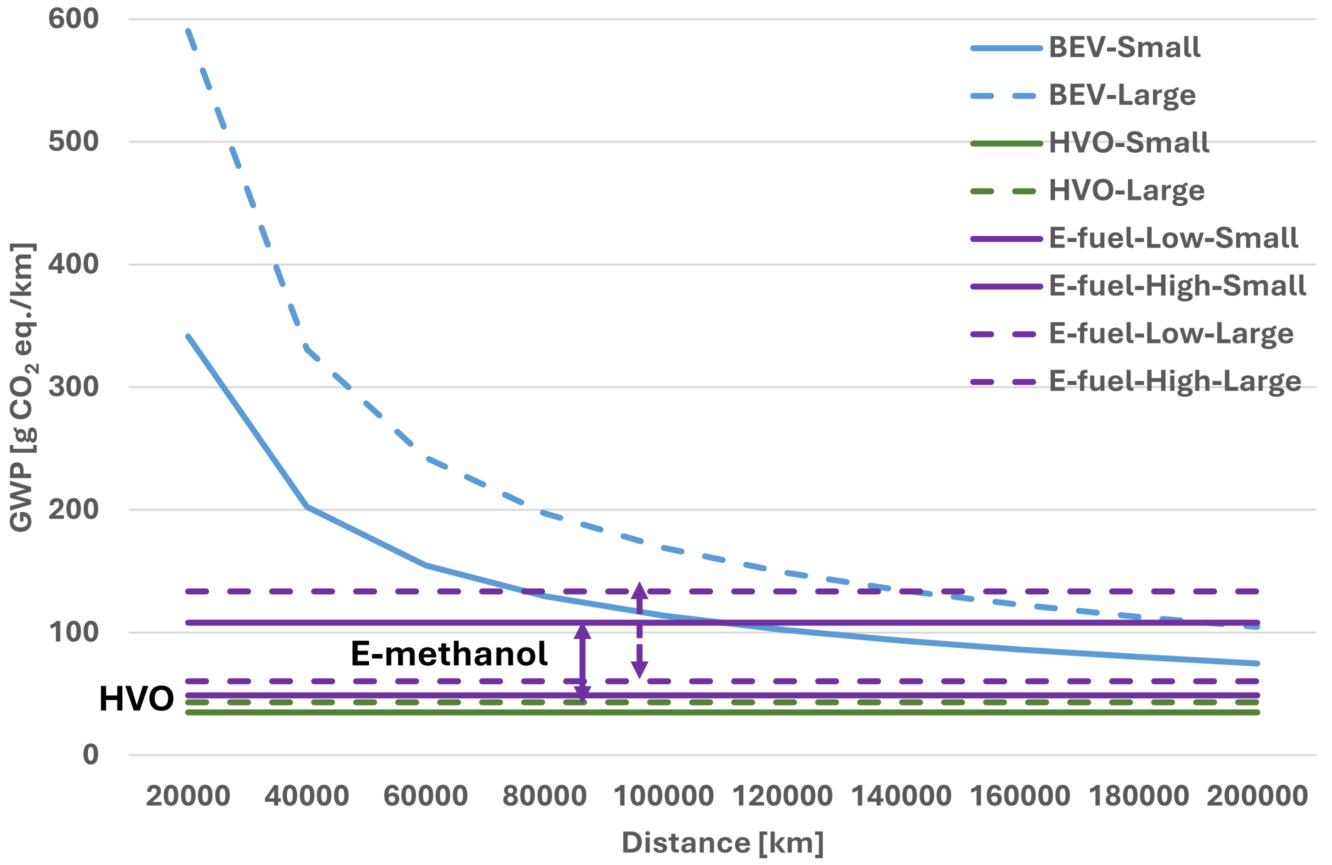
Assumptions: ICE range = 750 km/refueling, refueling time = 3 min. ; FCEV range: 600 km/refueling, refueling time = 5 min. ; BEV range = 500 km/refueling, refueling time = 60-75 min (80-100 kW fast charger) ; HRS at 1000 kg/d – Adapted from EU Hydrogen Roadmap - 2019

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.
- Hydrogen 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.
- Guaranteeing high mileage to electric vehicle customers (**a bigger battery) could lead to disadvantages**. The production of millions of battery packs will require millions of tons of CO_2 to be emitted, which could not be compensated for in the use phase
- **The sustainable fuels can decarbonize the transport sector from the first kilometer run** in well-known internal combustion engines (for several applications)

Thank you

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