

Hydrogen integration in Energy Systems.

The key to the acceleration of the energy transition?

Francesco Lombardi

Faculty of Technology, Policy and Management
Energy and Industry section

Hydrogen.

What is it?

- Oldest and **most abundant element** in the universe.
A gas (H₂) in standard conditions

	LHV (kWh/kg)	density (kg/m ³)
H ₂	33.3	0.08
CH ₄	13.8	0.65

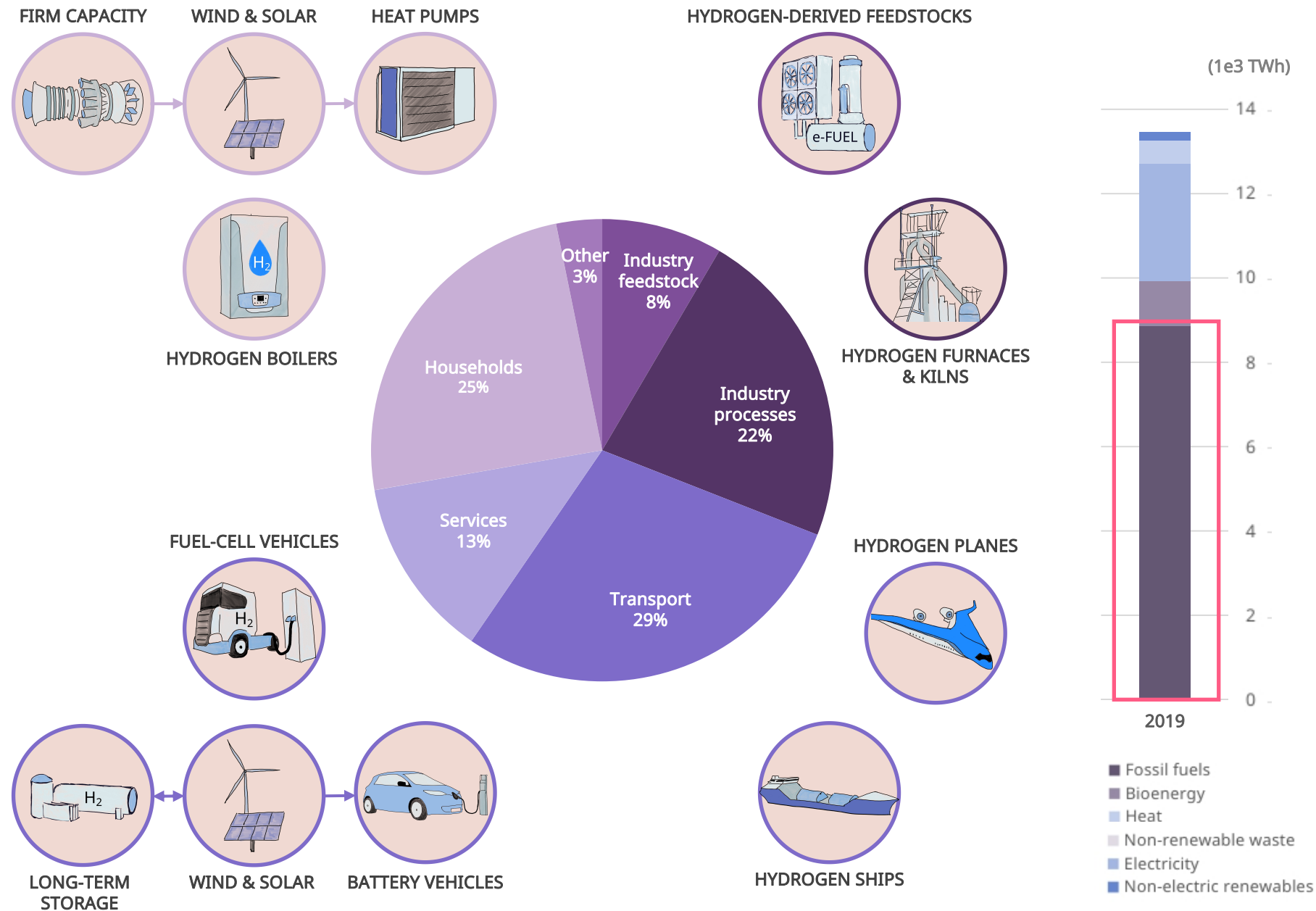
- It can be used as fuel to **burn without emitting CO₂**



- Or in **fuel cells** that generate electricity without combustion

Energy transition.

Why so much interest for hydrogen?



On Earth, hydrogen is mostly available in **molecular form** (water, organic compounds)

Hydrogen production.

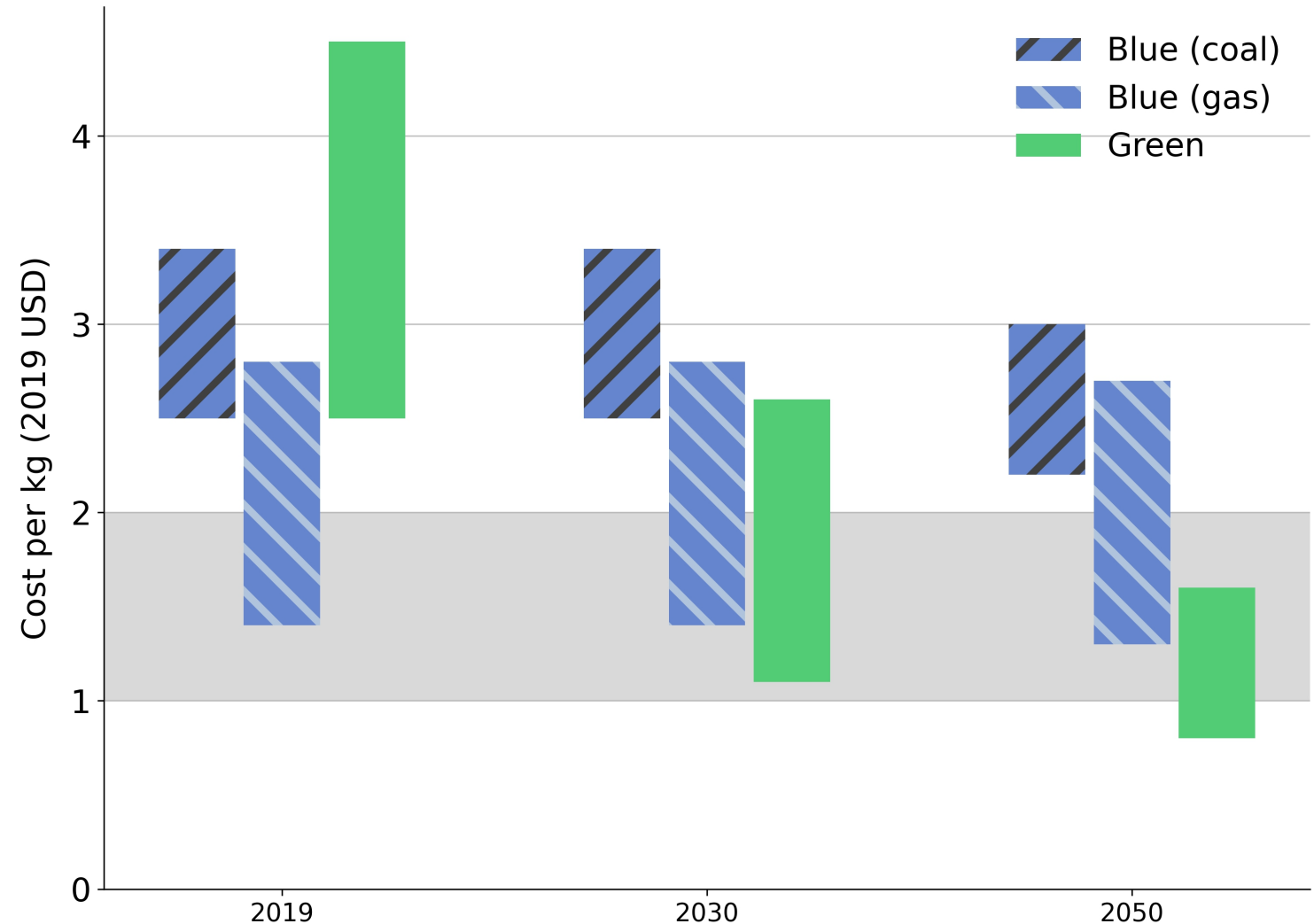
Each route its own colour

	Source	Process	CO _{2eq}
Black/ Brown	Coal	Gasification	18 - 20
Grey	Methane	Steam Methane Reforming (SMR)	9 - 11
Blue	Methane / Coal	SMR or Gasification with Carbon Capture and Storage (CCS)	0.18 - 6.1
Green	Renewable electricity	Electrolysis	0
Pink	Nuclear electricity	Electrolysis	0
Turquoise	Methane	Methane pyrolysis	0

Hydrogen production. Current and projected costs

High gas prices triple the cost of hydrogen production

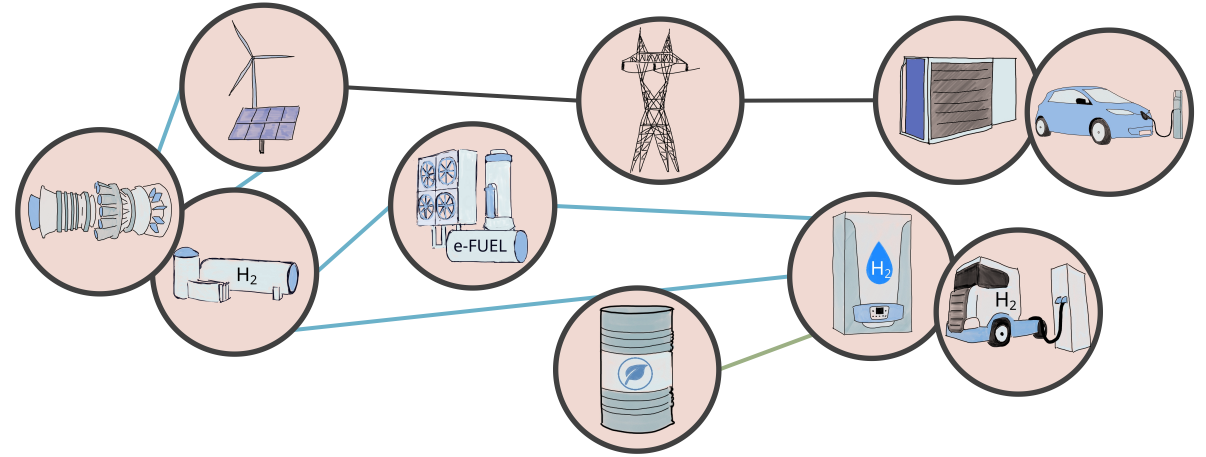
'Green hydrogen currently cheaper to produce in Europe than grey and blue H2 due to high natural gas and carbon prices'



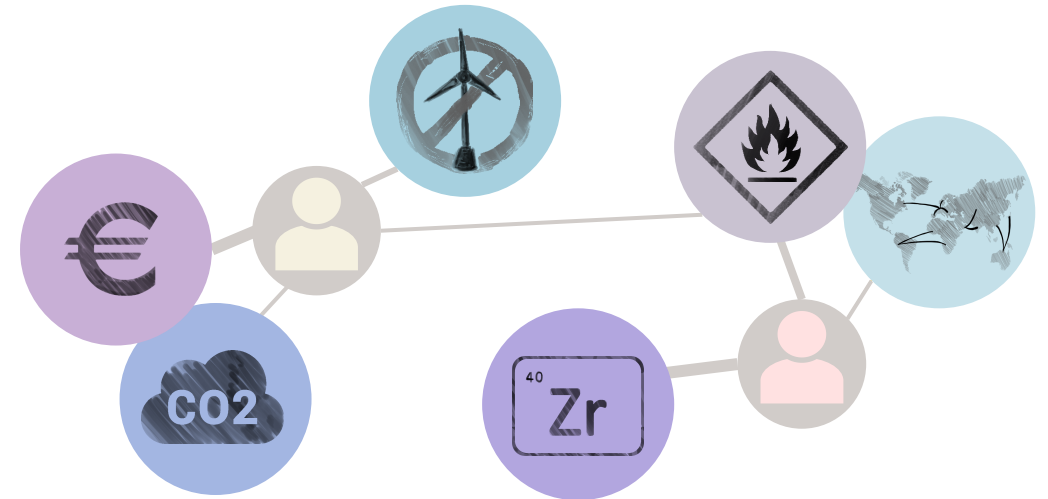
Hydrogen integration.

Need to handle complexity

1. TECHNOLOGY COMPLEXITY
to be captured
by models



2. DECISION COMPLEXITY
to be embraced
with approaches
that go beyond
techno-economic
aspects



Hydrogen.

Further reading

 flombardi.org

Selection of most-recent scientific articles and reports

- IRENA (2022). Geopolitics of the Energy Transformation: The Hydrogen Factor. irena.org/publications
- Van der Spek et al. (2022). Perspective on the hydrogen economy as a pathway to reach net-zero CO2 emissions in Europe. *Energy & Env. Science*. doi.org/10.1039/D1EE02118D
- Griffiths et al. (2021). Industrial decarbonization via hydrogen: A critical and systematic review of developments, socio-technical systems and policy options. *Energy Research & Social Science*. doi.org/10.1016/j.erss.2021.102208
- McDowell et al. (2021). The hydrogen economy: A pragmatic path forward. *Joule*. doi.org/10.1016/j.joule.2021.09.014
- Capurso et al. (2021). Perspective of the role of hydrogen in the 21st century energy transition. *Energy Conversion and Management*. doi.org/10.1016/j.enconman.2021.114898
- Noussan et al. (2021). The Role of Green and Blue Hydrogen in the Energy Transition—A Technological and Geopolitical Perspective. *Sustainability*. doi.org/10.3390/su13010298
- BloombergNEF (2020). Hydrogen Economy Outlook. data.bloomberglp.com
- Staffell et al. (2019) The role of hydrogen and fuel cells in the global energy system. *Energy & Env. Science*. doi.org/10.1039/c8ee01157e

Newspaper articles about current gas-price spikes impact on hydrogen price

- RechargeNews (Nov 2021). Green hydrogen now cheaper to produce than grey H2 across Europe due to high fossil gas prices. rechargenews.com/energy-transition
- ING (Oct 2021). High gas prices triple the cost of hydrogen production. think.ing.com/articles