Does Europe Need a Hydrogen Network?

Fabian Neumann, Elisabeth Zeyen, Marta Victoria, Johannes Hampp, Tom Brown

f.neumann@tu-berlin.de
Department of Digital Transformation in Energy Systems
Technical University of Berlin, Germany

Strommarkttreffen, Berlin

December 15, 2023

Technische Universität Berlin

Joule

CellPress
OPEN ACCESS

Article

The potential role of a hydrogen network in Europe

Fabian Neumann,[1,4,*] Elisabeth Zeyen,[1] Marta Victoria,[2,3] and Tom Brown[1]

SUMMARY

Europe's electricity transmission expansion suffers many delays, despite its significance for integrating renewable electricity. A hydrogen network reusing the existing gas network could not only help to supply the demand for low-emission fuels but could also balance variations in wind and solar energies across the continent and thus avoid power grid expansion. Our investigation varies the allowed expansion of electricity and hydrogen grids in net-zero CO_2 scenarios for a sector-coupled European energy system, capturing transmission bottlenecks, renewable supply and demand variability, and pipeline retrofitting and geological storage potentials. We find that a hydrogen network connecting regions with low-cost and abundant renewable potentials to demand centers, electrofuel production, and cavern storage sites reduces system costs by up to 26 bn€/a (3.4%). Although expanding both networks together can achieve the largest cost reductions, by 9.9%, the expansion of neither is essential for a net-zero system as long as higher costs can be accepted and flexibility options allow managing transmission bottlenecks.

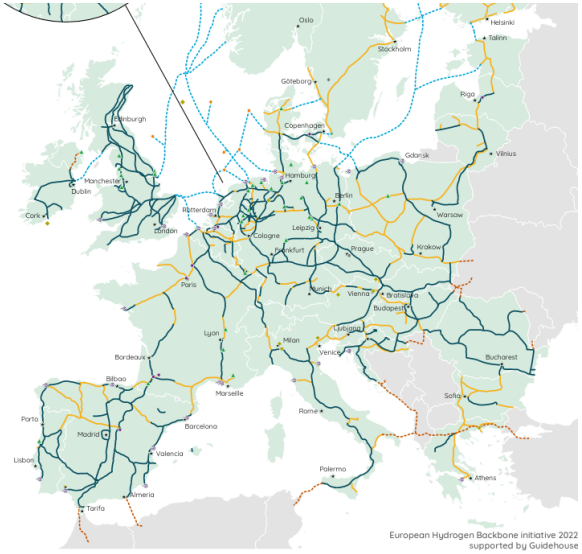
CONTEXT & SCALE

Many different combinations of infrastructure could make Europe carbon neutral by mid-century, but not all solutions meet the same level of acceptance. For example, power grid reinforcements have faced many delays, despite their value for integrating renewables. A hydrogen network reusing gas pipelines could substitute for moving cheap but remote renewables across the continent to where demand is.

We study trade-offs between new transmission lines and a hydrogen network in the European energy

Technische Universität Berlin

European Hydrogen Backbone



European Hydrogen Backbone initiative 2022
supported by Guidehouse

Source: European Hydrogen Backbone (April 2022)

CC BY

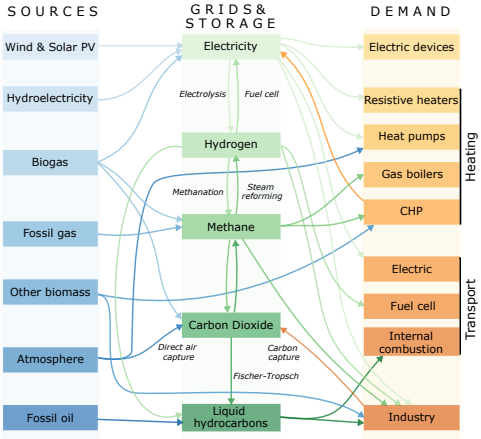
Hydrogen Network – Why?

1. Best **wind and solar potentials** are located in the periphery of Europe.
2. **Hydrogen demand** for industry (e.g. steelmaking and ammonia) located in areas with less attractive renewable potentials.
3. **Bottlenecks** in the electricity network and limited acceptance for reinforcement.
4. **CO_2 from point sources** for synthetic fuels located in Europe's industrial clusters.
5. Not all regions have right geological conditions to allow for cheap **underground storage**.

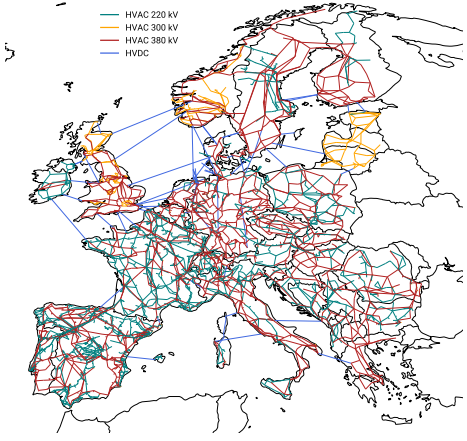
cc

PyPSA-Eur - An open sector-coupled energy system model of Europe

Europe with all energy and carbon flows,...



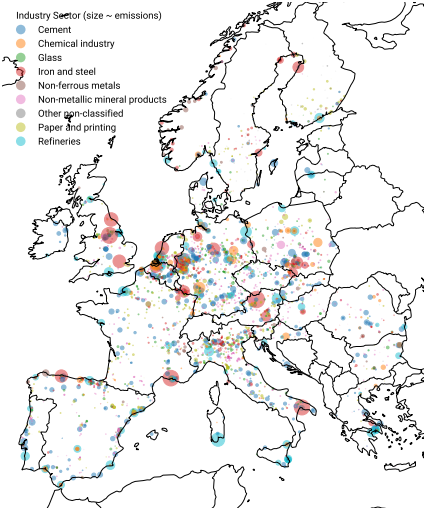
... bottlenecks in energy networks...

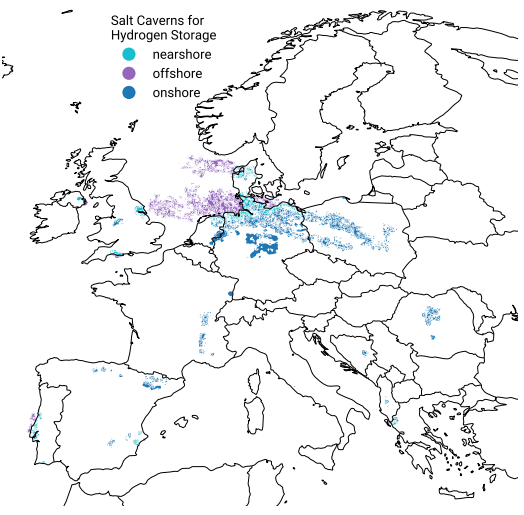


... and temporal variability in demand and supply.

Source: https://github.com/pypsa/pypsa-eur

Data: Industrial sites, salt caverns, transmission networks



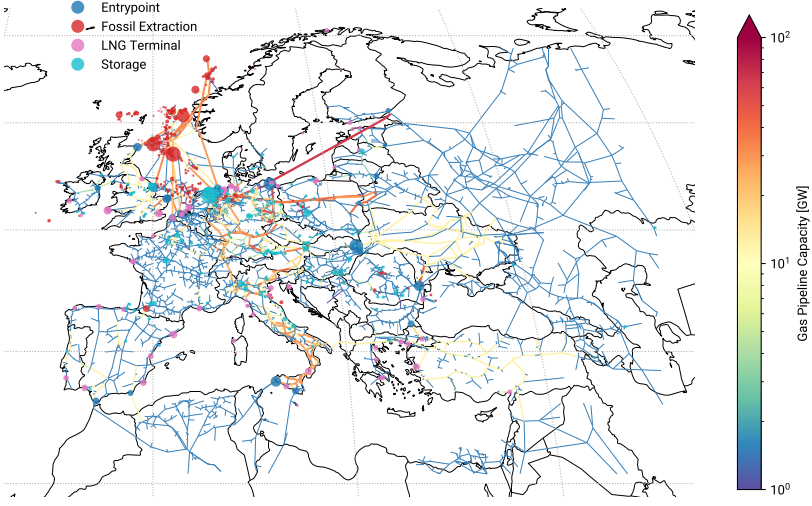


Source: Hotmaps Industrial Sites Database; Caglayan, 2019; SciGRID_gas

CC BY

Technische Universität Berlin

Data: Industrial sites, salt caverns, transmission networks

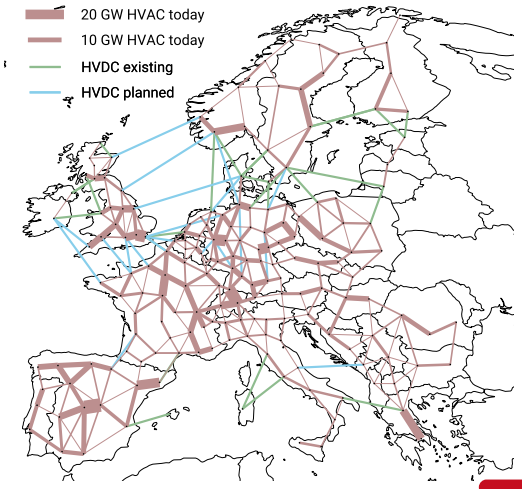


Source: Hotmaps Industrial Sites Database; Caglayan, 2019; SciGRID_gas

CC BY

Scenarios for a European energy system with net-zero CO_2 emissions

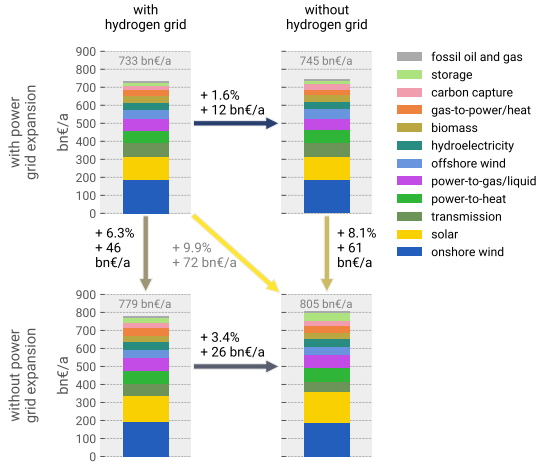
- Couple **all energy sectors** (power, heat, transport, industry, feedstocks, agriculture, int. aviation & shipping)
- Cluster to 181 regions, 3-hourly time series
- Reduce net CO_2 emissions **to zero**
- **Technology assumptions** for 2030 (DEA)
- CO_2 sequestration limited to **200 Mt/a**
- Vary allowed electricity and hydrogen **network expansion**
- First: Europe energy **self-sufficient**
- Later: Vary **import volumes and carriers**

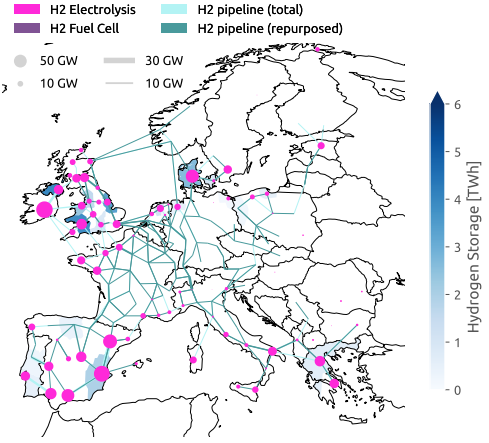


CC BY

Technische Universität Berlin

Comparison of power and hydrogen network infrastructure benefits

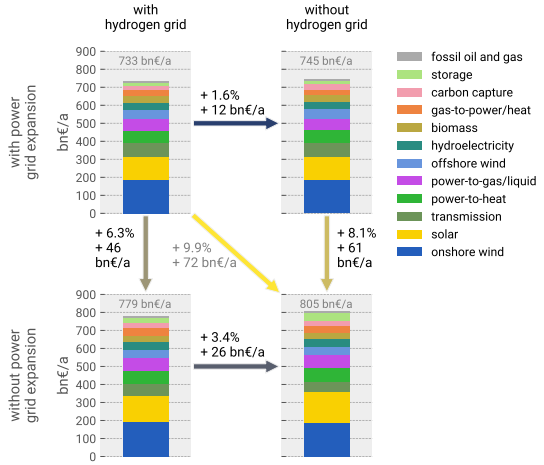


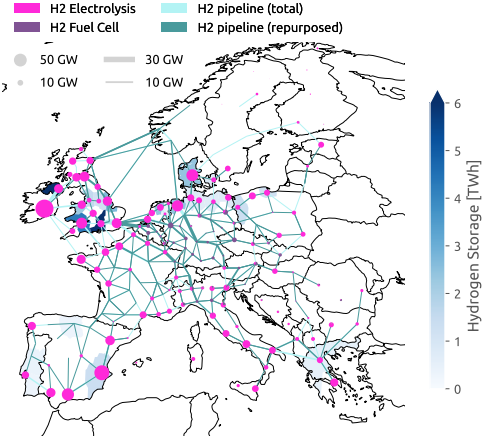


→ **Up to 69%** of hydrogen backbone can repurpose existing gas network

Technische Universität Berlin

Comparison of power and hydrogen network infrastructure benefits





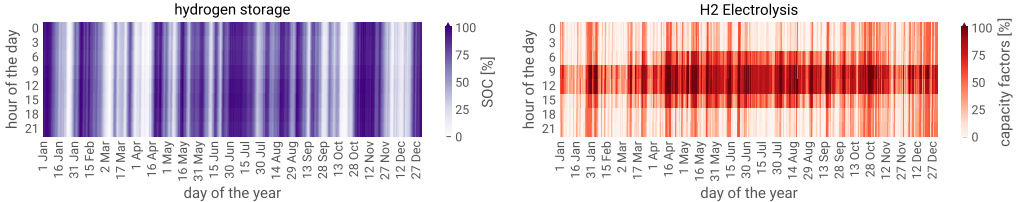
→ **Up to a third** of the gas transmisison network is retrofitted

Technische Universität Berlin

Two remarks on operational patterns of hydrogen technologies

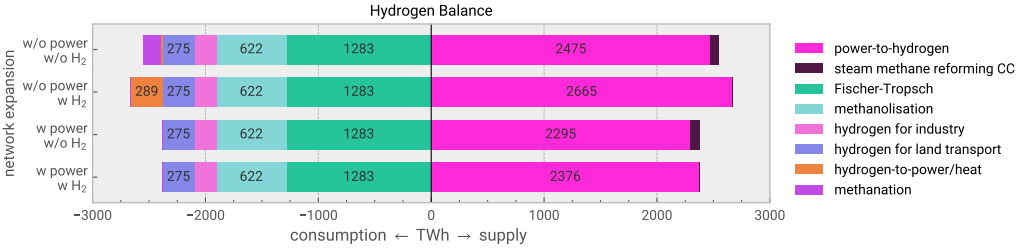
Hydrogen acts mainly as **intermediary buffer** between
variable electricity feed-in and other more stable PtX processes.

Flexible electrolyser operation important,
but requires local and dynamic price signals to become reality.



Technische Universität Berlin

Hydrogen balance – supply and demand

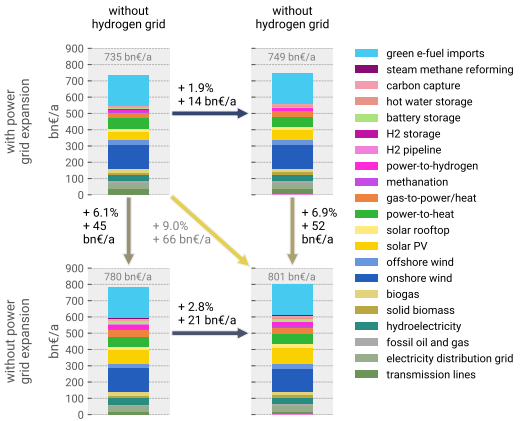


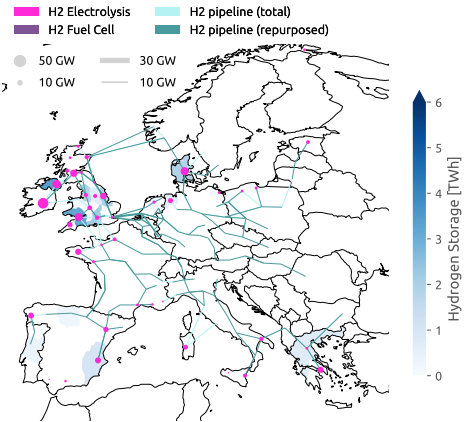
Mostly **green electrolytic hydrogen supply**. **Few direct uses of hydrogen** in the energy system, but it is used to synthesise other fuels and chemicals.

- ammonia for fertilizers
- direct reduced iron for steelmaking
- shipping and aviation fuels
- precursor to high-value chemicals
- backup heat and power supply
- some heavy duty land transport

cc

Do results change with synthetic fuels from outside Europe?

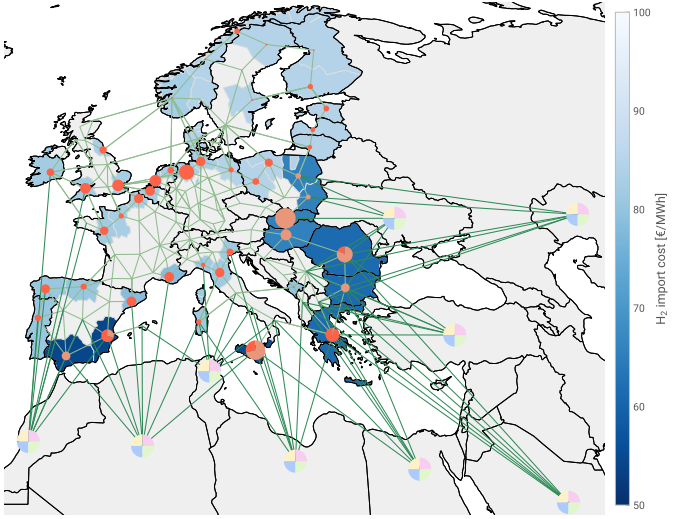


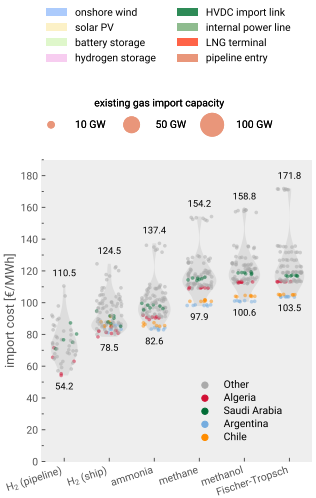


→ with all liquid hydrocarbons imported, **infrastructure needs** for networks and PtX drop

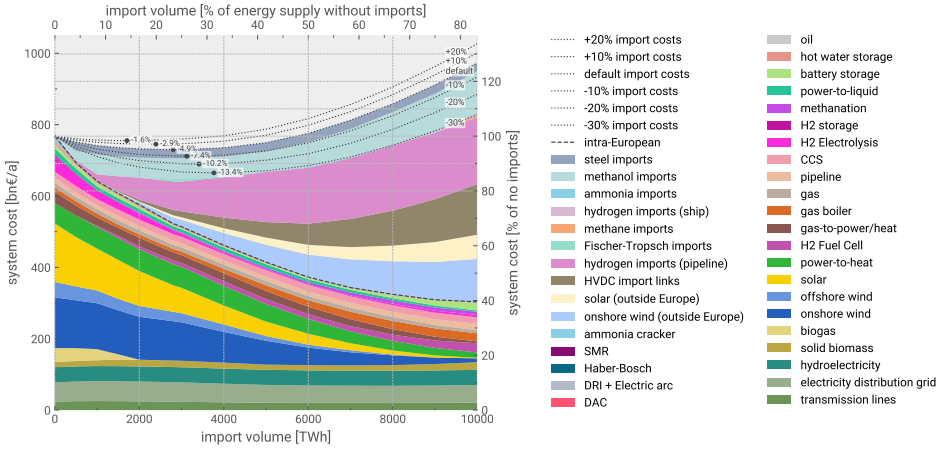
Technische Universität Berlin

Locations and costs for imports vary by energy carrier





Effect of increasing energy imports on costs and European infrastructure



→ 70% of the **5%** cost-benefit can be achieved with imports below **1000 TWh**

CC BY

Technische Universität Berlin

Wrap-Up

- Hydrogen network could **reduce system cost by up to 3.4%**, not as high as power grid
- Up to **69%** of hydrogen network uses **retrofitted gas network pipelines**
- No network expansion also feasible, but **at cost surcharge of 10%**
- Imports of green energy reduce cost of **net-zero European energy system by 5%**, and may change or diminsh the role of hydrogen network infrastructure.
- Other factors than costs might rather drive import strategy: **geopolitical** considerations, building **simple & easy-to-implement** systems, **reuse** of existing infrastructure, **resilience** of supply chains, **technology risk**, diversification, and land usage.

cc

Contact, License, Additional Resources

Unless otherwise stated, the graphics and text are Copyright ©F.N. 2023.

This work is licensed under a Creative Commons "Attribution 4.0 International" license.

Find the slides:
https://neumann.fyi/files/neumann-strommarkttreffen.pdf

Find out more about PyPSA:
https://pypsa.org

Find the open energy system model:
https://github.com/pypsa/pypsa-eur

Send an email:
mailto:f.neumann@tu-berlin.de

Technische Universität Berlin