Building Resilient Energy Infrastructure: Hydrogen, Import, and Carbon Management Strategies

https://resilient-project.github.io/

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Selection of Planned Developments

Computational Methods

- decomposition techniques
- large-scale stochastic optimisation
- **test robustness of system**

Carbon Management and Biomass Usage

- **CO_2 network and sequestration**
- circular carbon economy
- biomass usage options

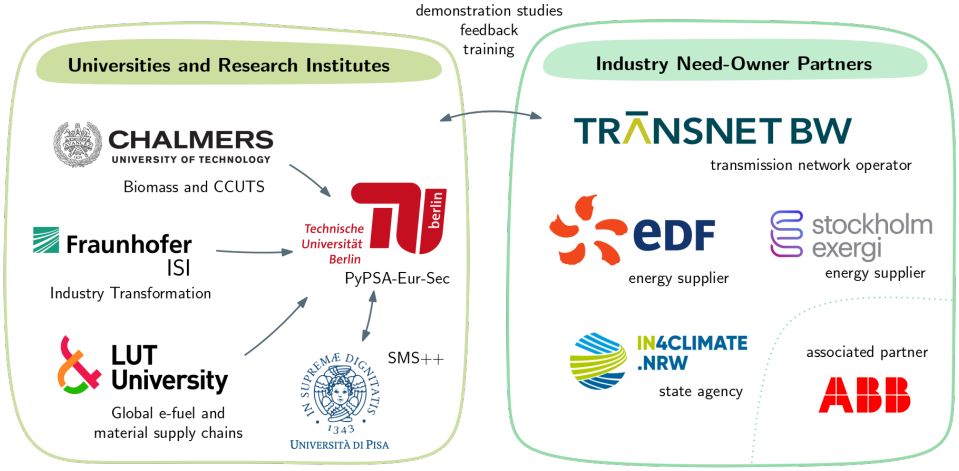
Industry Transformation

- fuel and process switching
- industry relocation & investment cycles
- new technologies (oxyfuel cement, etc.)

Global Green Fuel and Material Markets

- **imports of green energy and materials**
- **effects on European infrastructure**
- risks (geopolitical, technological, etc.)

RESILIENT Partners



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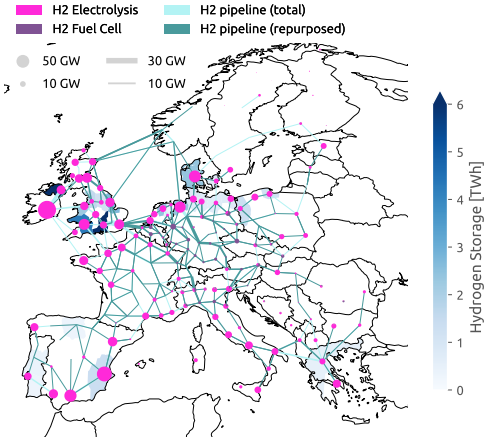
Does Europe need a hydrogen network?

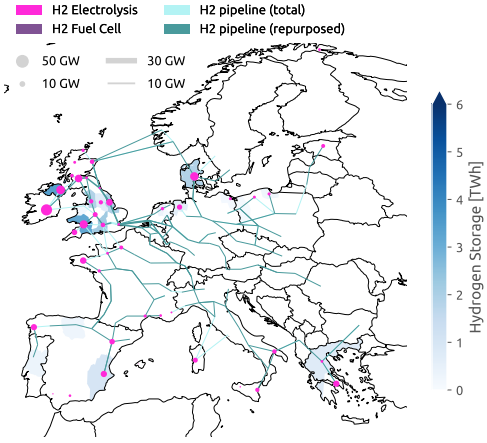
Self-sufficient Europe

(no power grid expansion)



All liquid fuels imported

(extreme thought experiment)



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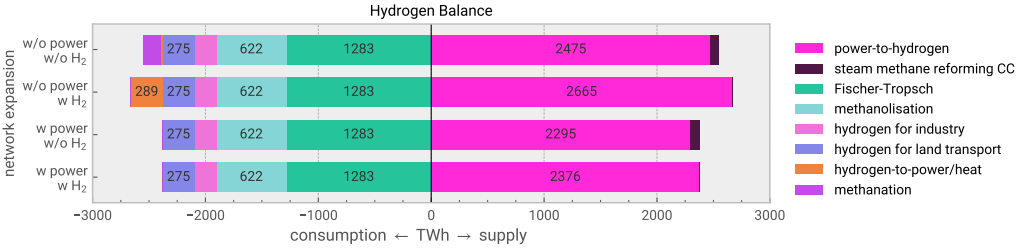
Why? Most hydrogen is used for derivative fuels and chemicals!



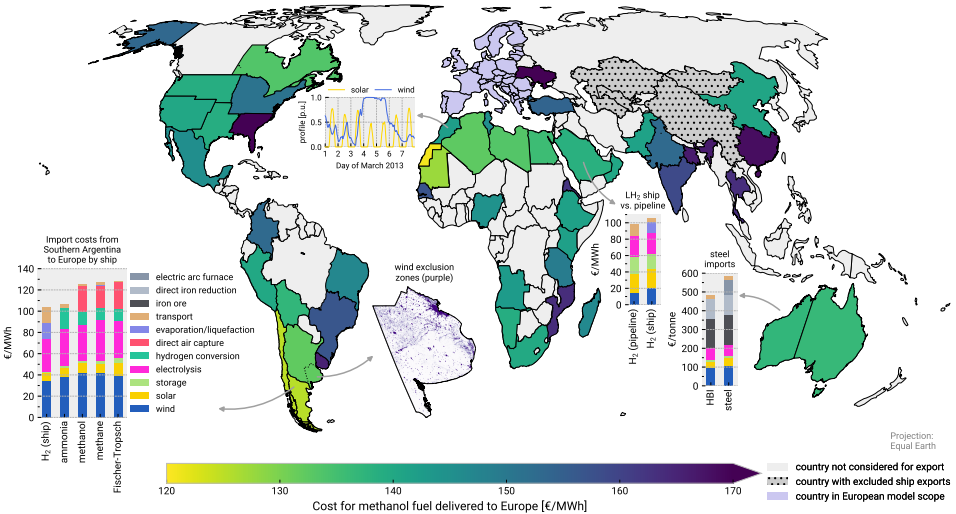
Few direct uses of hydrogen; mostly used used to synthesise other fuels and chemicals:

- 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

→ **Many alternatives** to transporting hydrogen.

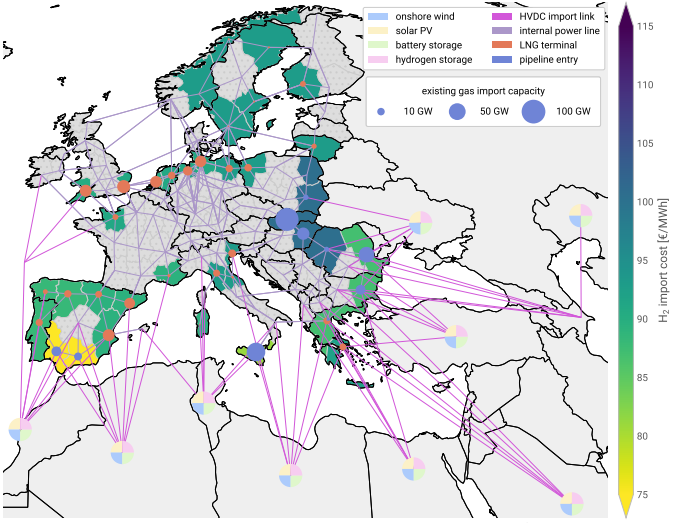
Reference: https://doi.org/10.1016/j.joule.2023.06.016

Letting optimisation decide about green energy imports…



Reference: Extension of Hampp & Brown, 2023;
https://doi.org/10.1371/journal.pone.0281380

. . . also leads to substantial imports of steel & hydrogen derivatives.



Reference: Neumann, Hampp, Brown, 2024
https://arxiv.org/abs/2404.03927

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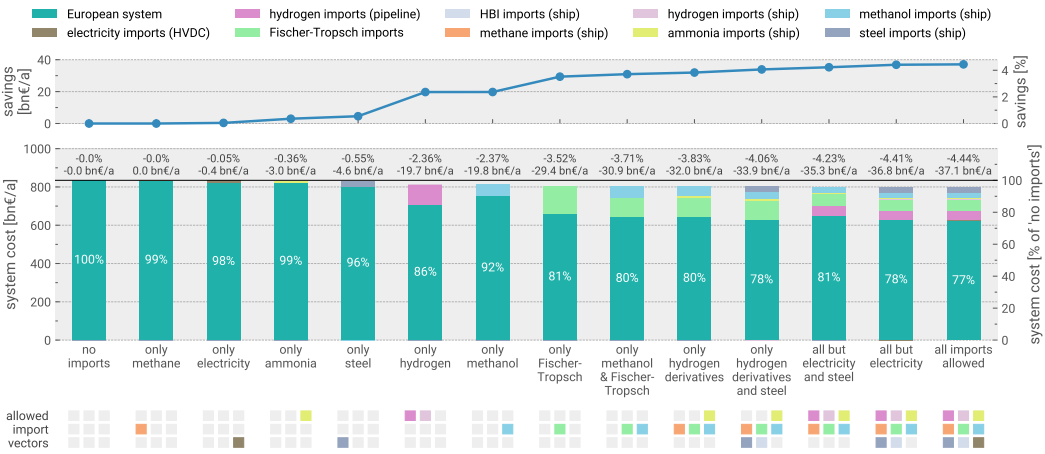
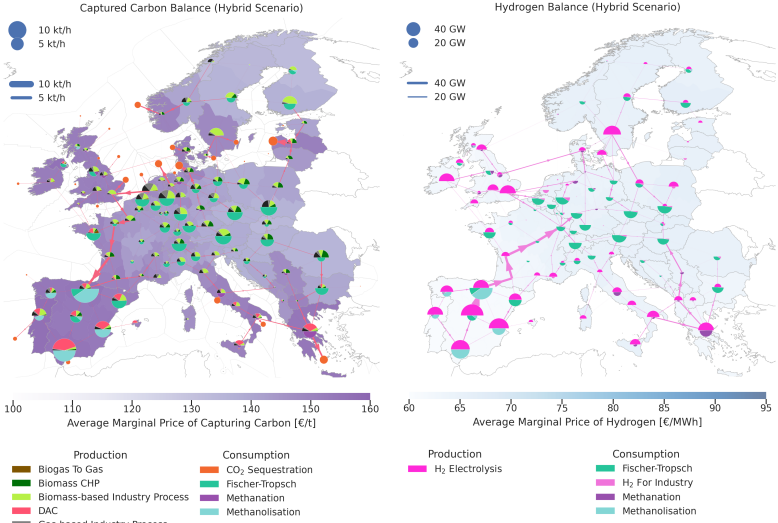
Cost savings depend on used **import vectors**.



→ In particular, import of carbonaceous H_2-derivatives and steel/HBI reduces costs.

Reference: Neumann, Hampp, Brown, 2024
https://arxiv.org/abs/2404.03927

Transporting CO_2 to H_2 or H_2 to CO_2 for fuel synthesis?



→ Preference for H_2 transport to industrial point sources in Central Europe.

→ CO_2 transport for sequestration at sea or for PtX in Spain.

Reference: Hofmann, Tries, Neumann, Zeyen, Brown, 2024; https://arxiv.org/abs/2402.19042v2

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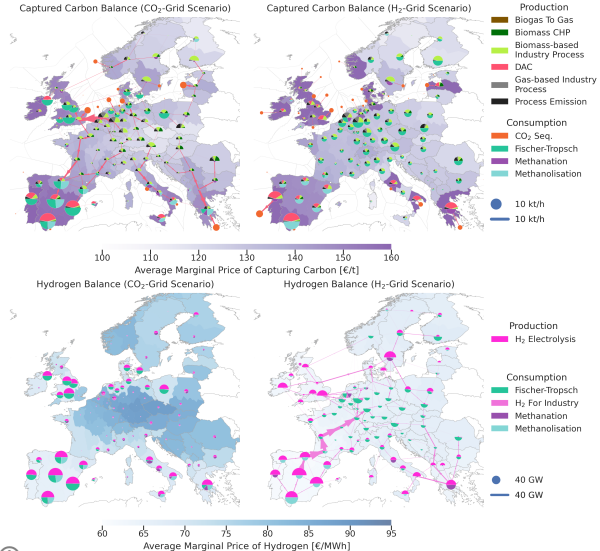
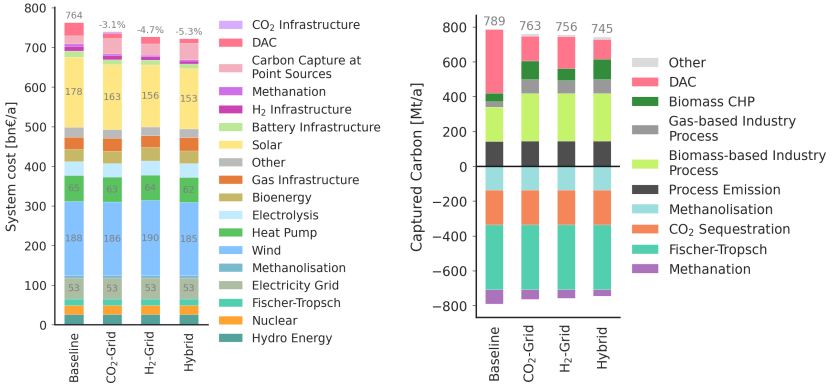
Complementarity of CO_2 pipelines and H_2 pipelines



- Alternative models with predominant transport of CO_2 also conceivable for a cost surcharge of 2-3%.
- Direct Air Capture (DAC) primarily in Southern Europe, provided that biogenic or fossil point sources in Europe are exhausted.

Reference: Hofmann, Tries, Neumann, Zeyen, Brown, 2024; https://arxiv.org/abs/2402.19042v2

Carbon management: capture, use, transport and sequestration



- **CCS** for process emissions (for instance, in cement industry)
- **CCU** for e-synfuels and e-chemicals (in particular, shipping, aviation, plastics)
- **CDR** for unabatable and negative emissions (to offset imperfect capture rates)

Reference: Hofmann, Tries, Neumann, Zeyen, Brown, 2024; https://arxiv.org/abs/2402.19042v2

Conclusion

1. **H_2 and CO_2 pipelines:** Paths comparable in terms of system costs, but with electricity grid expansion, the advantage of H_2 transport over CO_2 transport decreases.

2. **Energy imports:** Benefits most evident for imports of 1000-3000 TWh/year, especially for steel / HBI and liquid carbonaceous energy carriers, but with diminishing returns.

3. Infrastructure policy needs **coordination** between the various national and European hydrogen, import, and carbon management strategies.

4. Large **uncertainties**, but also considerable **maneuvering space** to consider non-cost factors: geopolitics, reuse of infrastructure, resilience of supply chains, diversification, and reduced land use.