HYGCEL research presentation

Modelling of electricity, hydrogen, CO_2, and end-products transportation

Lappeenranta, May 22, 2024

Presentations in this session

1. The role of hydrogen in the value chain and a transportation case example “Southeast-Ostrobothnia”
   - Christian Breyer, professor, LUT University

2. Case study: H_2 delivery to a steel mill
   - Satu Lipiäinen, postdoc researcher, LUT University

The role of hydrogen in the value chain and a transportation case example “Southeast-Ostrobothnia”

Topics of this presentation

- The role of hydrogen in the energy system
- Feasibility of hydrogen transportation
- The transportation case Southeast-Ostrobothnia”

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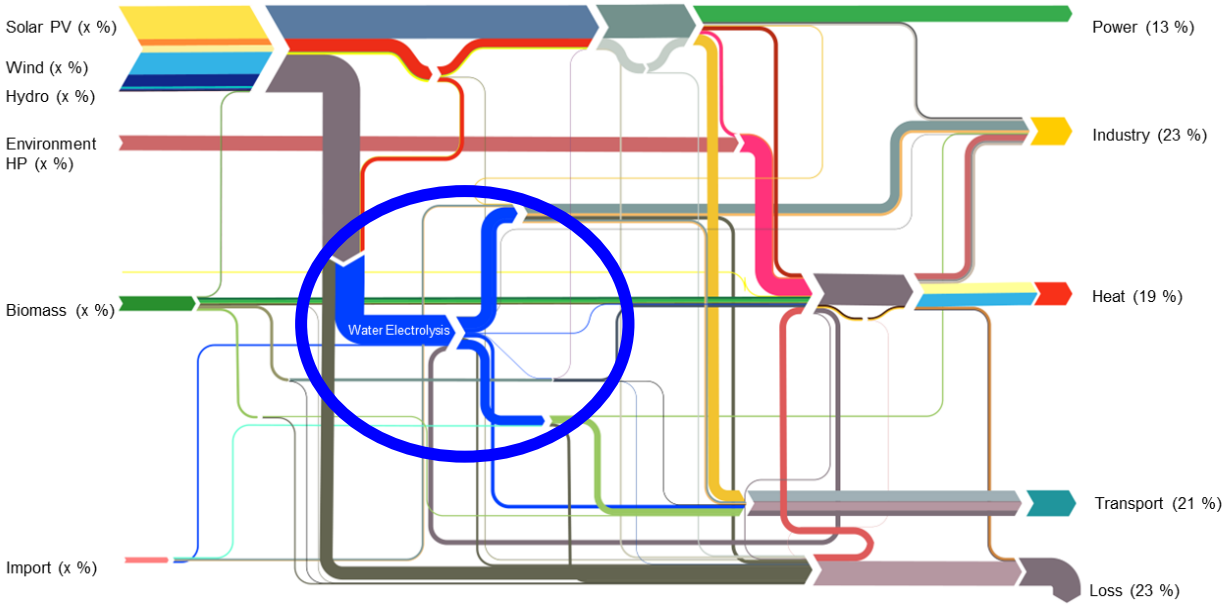
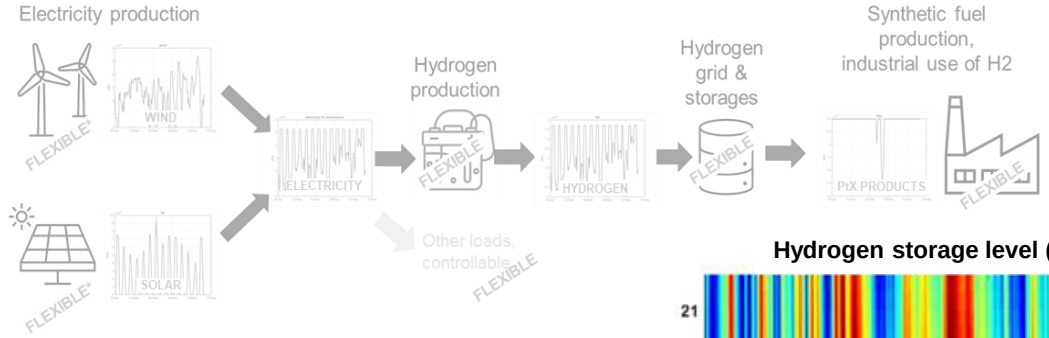
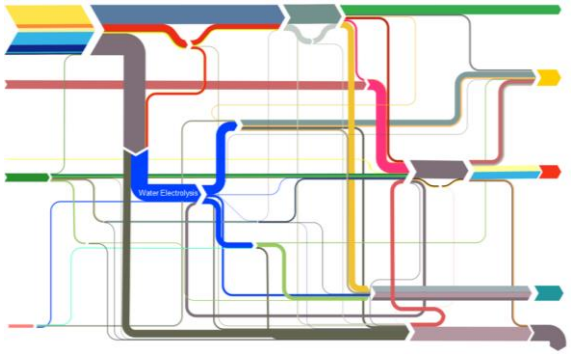
Role of Hydrogen in the Value Chain

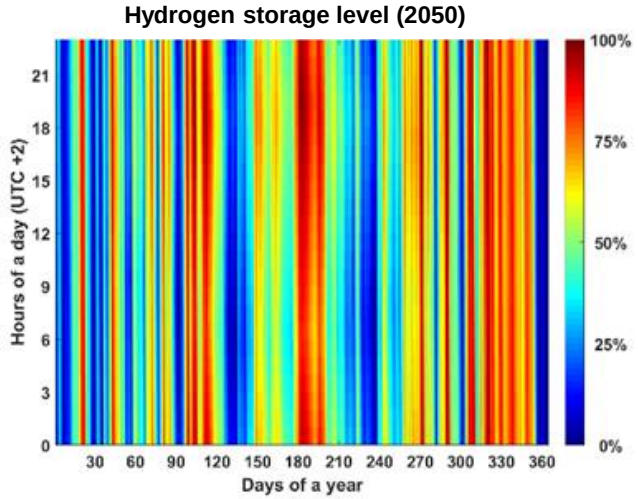


- **Hydrogen** is **important for applications** that cannot be directly electrified: e-fuels, e-chemicals, e-materials
- The **value chain** is complex and comprises several steps, such as electricity generation, transport, and **hydrogen** and final product production
- By far largest share of **hydrogen** is as an **intermediate** product for the **final** product, such as ammonia, methanol, kerosene jet fuel
- **Final products** are easier to transport as **hydrogen**

Flexibility provided by hydrogen storage



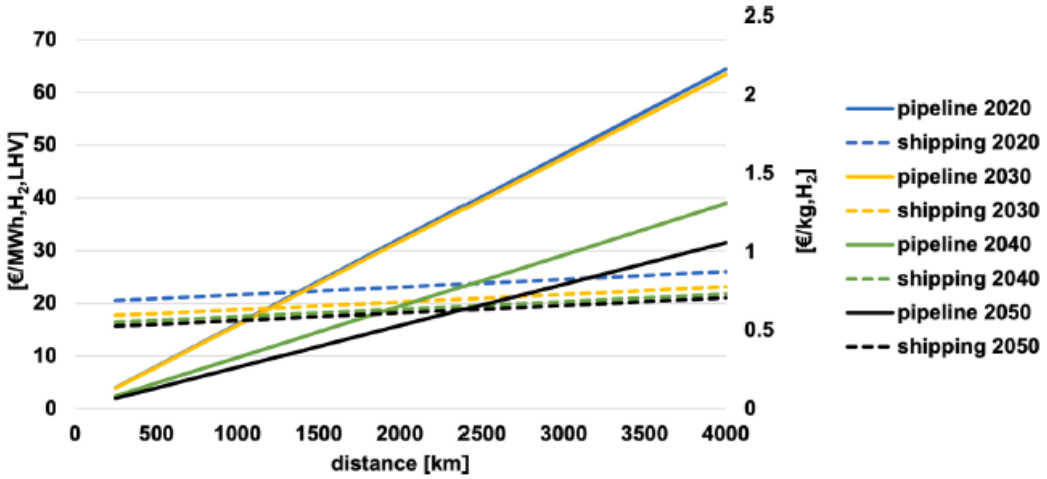




- Hydrogen storage **connects variable** renewable **electricity** with less flexible **demand** profiles such as PtX production
- Hydrogen storage **buffers** the low-cost renewable electricity for times of demand
- The **flexible** hydrogen storage for PtX production enables massive **additional benefits** for the **energy system**, avoiding inefficient and costly overdimensioning of renewable generation capacities.

Analysing transport costs

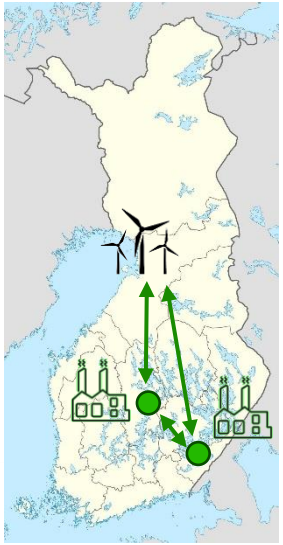
Cost of transporting H_2 by ship and pipeline



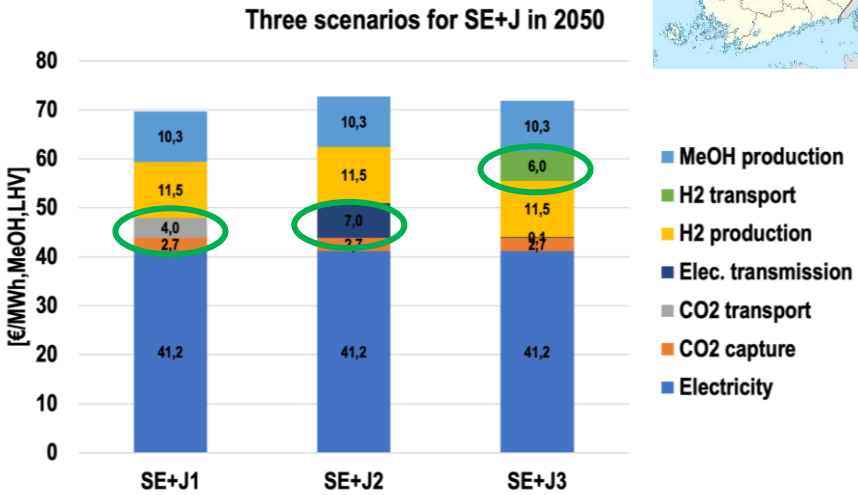
- **Transportation of final PtX products is more attractive than transportation of H_2**
  - 2000 km **hydrogen** transport by pipeline: about 15-20 €/$MWh_{H2,LHV}$
  - 2000 km **ammonia** transport by ship: about 1.5-2 €/$MWh_{NH3,LHV}$
- **Short distance** hydrogen transportation is **feasible**, whereas **long-distance** transportation might **not** be **attractive**
  - Short distance (several 100s km) transport is no cost burden
  - Long distance (> several 100s km) **transport** chains for hydrogen are **unlikely** due to high cost … it also means that Europe may not import hydrogen by ship from overseas

- Source: Galimova et al. (2023a; 2023b)
- Impact of international transportation chains on cost of green e-hydrogen: Global cost of hydrogen and consequences for Germany and Finland
- Feasibility of green ammonia trading via pipelines and shipping: Cases of Europe, North Africa, and South America

Transport case 1 – Southeast - Ostrobothnia



- Several **industrial cases involve** electricity and/or hydrogen **transmission** from wind sites to bio-CO_2 sites, or CO_2 transport from CO_2 sites to a wind site.
- We studied methanol production for the case of Finland combining **best wind resources in North Ostrobothnia** and **bio-CO_2 in the southeast**.
- **CO_2 transport** seems to be the **least cost** transport option.
- Transporting **H_2** or **electricity** cost almost the same, but **power lines** have **multiple valuable roles** in an **electrified energy system**.
- Despite slightly higher cost **sending the energy to Southeast Finland may be still attractive** for regional industry policy reasons.



Case study: H_2 delivery to a steel mill

Topics of this presentation

- Evaluation of energy transportation options from three perspectives: investment costs, energy use and greenhouse gas emissions

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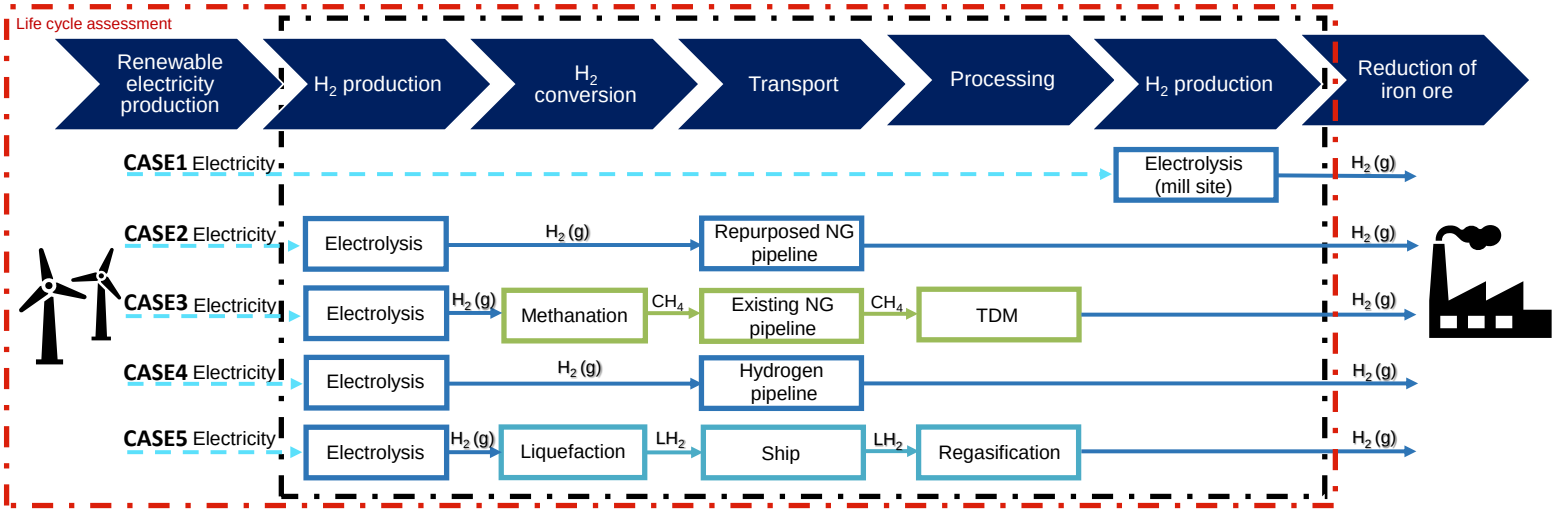
Case study: H_2 delivery to a steel mill

- The study evaluated 5 optional ways to provide hydrogen to a steel mill in Inkoo (144 000 t_{H2}/a / 5 TWh)
- Transport distance is 300 km cases except 500 km in shipping
- Three perspectives were studied: techno-economy, energy use, and greenhouse gas emissions

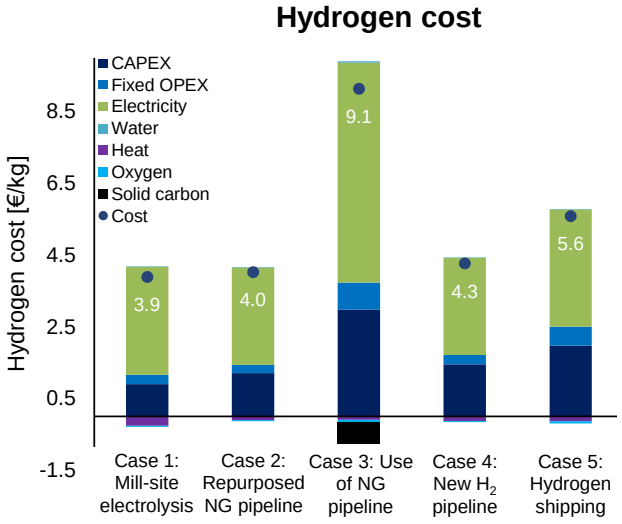


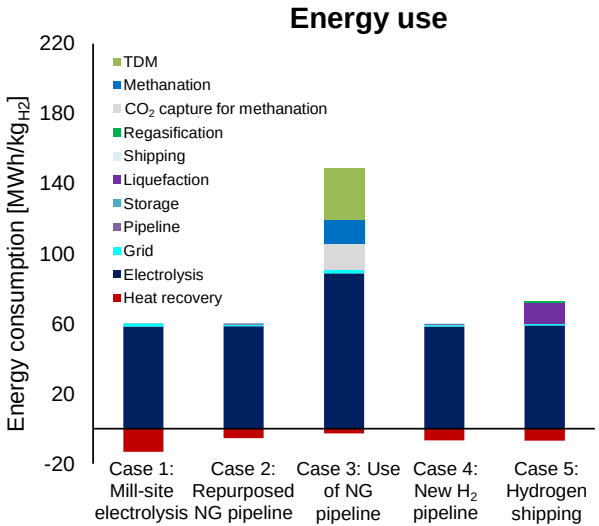
TDM = Thermal decomposition of methane
NG = Natural gas
LH_2 = Liquid hydrogen

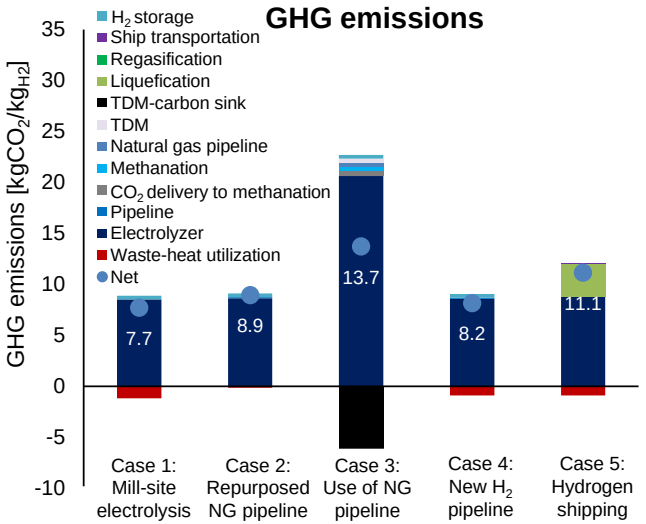
Lipiäinen, S., Sillman J., Vakkilainen, E., Soukka, R., Tuomaala, M. (2024) Hydrogen transport options for a large industrial user: Analysis on costs, efficiency, and GHG emissions in steel mills. Sustainable production and consumption. 441–13. https://doi.org/10.1016/j.spc.2023.11.021

Read more: https://www.lut.fi/en/hygcel

Complexity in the energy delivery increases costs and energy used in operations



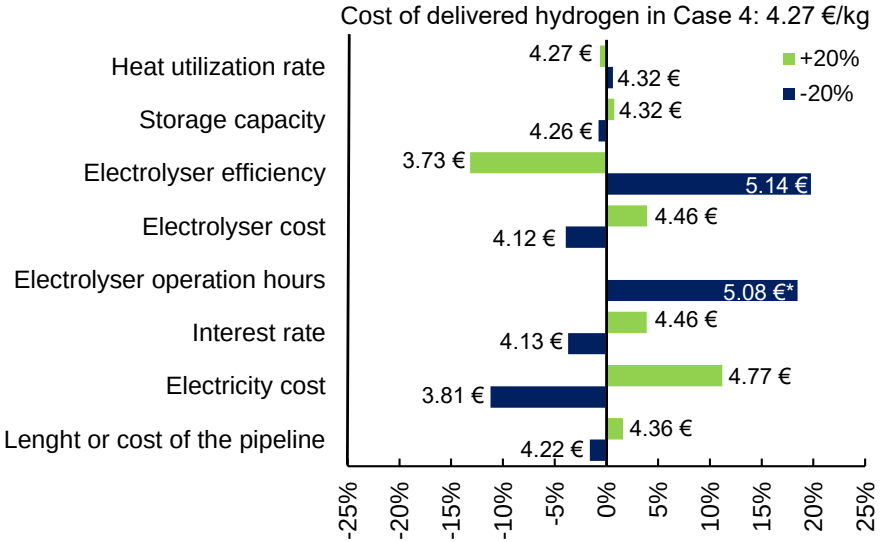


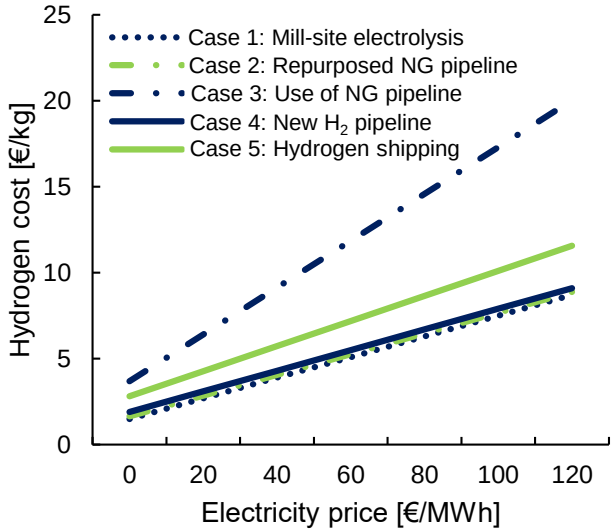


1) Lowest cost is achieved in electricity transport (electrolysis at the mill) and in pipeline transport as hydrogen
2) Transport as liquid H_2 or methane requires additional unit operations, which increases costs and energy use
3) Despite the methanation route (Case 3) is expensive and inefficient, it would provide an opportunity to utilize NG infrastructure and provide a carbon sink (black bar in fig).

- The emission benefit would require the use of fully renewable electricity

Evaluation from multiple perspectives provides a more comprehensive result





1) Results are sensitive to case-specific properties: H_2 volumes, transport distances, location of H_2 user and producer, available infrastructure, etc.
2) Especially the price of electricity affect the cost of transported H_2 very much
3) Open questions and uncertainties regarding hydrogen transport remain

Case study: H_2 delivery to a steel mill

Key messages

- There are notable differences among transportation options
  - Additional conversions need to be avoided when transporting inside Finland
- Each transportation case must be separately looked at