Hedging Against Uncertainty: A Minimal Methanol Backstop for Electrification Scenarios

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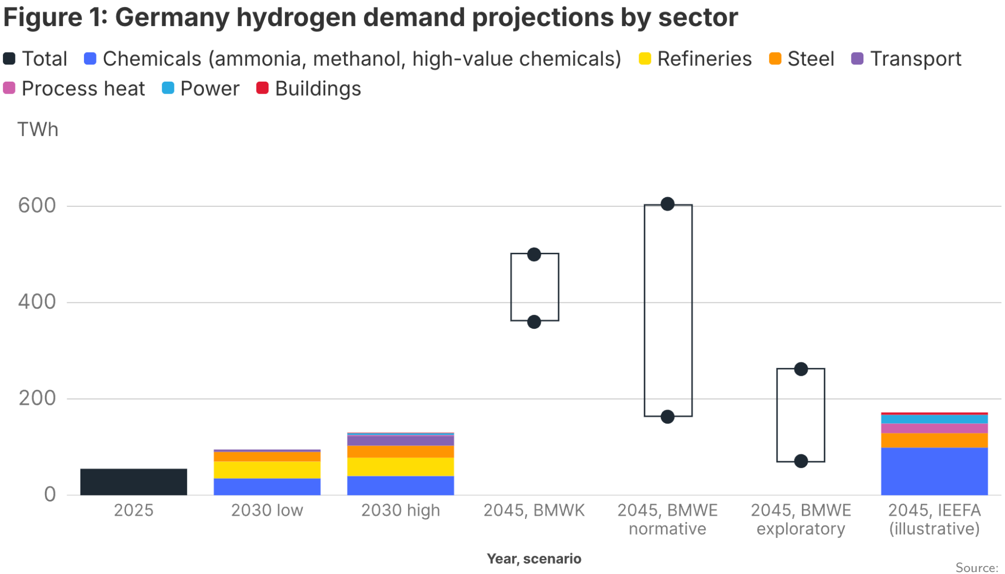
High hydrogen costs ⇒ reset of German demand projections



Source: IEEFA, 2026

Need adaptive planning and flexible alternatives

- Approved German **core hydrogen network** probably over-dimensioned
- Need **adaptive planning**
- Extension to South may need to be **paused from 2028**
- Explore flexible alternatives: **methanol**

Source: BNetzA, Approved network, 2024

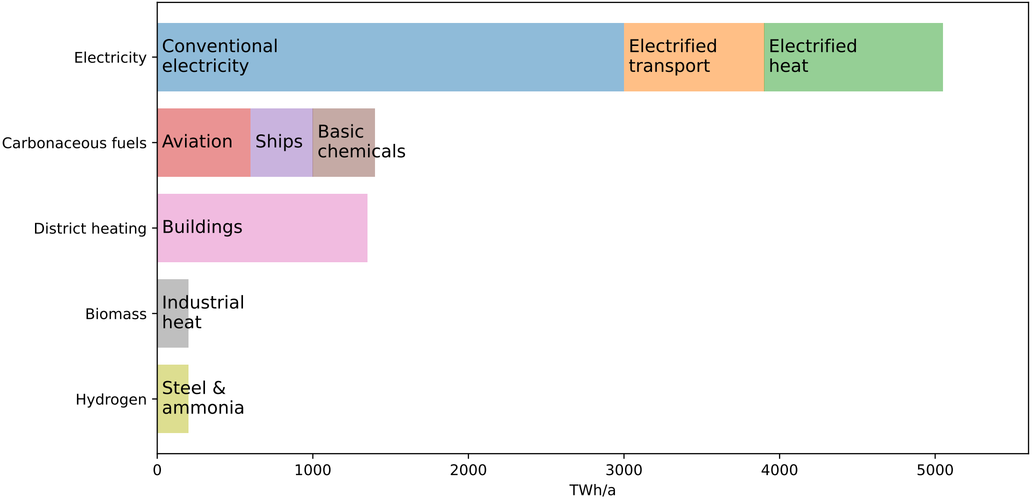
Which hydrogen demand sectors really need actual hydrogen?

All potential hydrogen demand sectors can be served by **electrification** or **hydrogen derivatives** (e-fuels like ammonia, methanol, etc.) that are easier to transport and store.

sector	electrify	derivatives	relocate
heavy duty trucks	✓		
process heat	✓	✓	
shipping	(✓)	✓	
aviation		✓	
high value chemicals		✓	
backup power & district heat		✓	
iron direct reduction			✓
ammonia			✓

⇒ There is **no strict need** to transport hydrogen, but it may be cost-optimal.

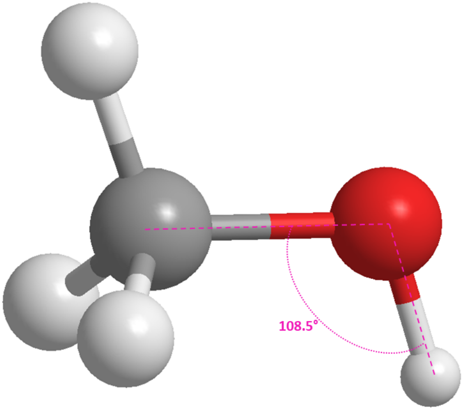
Net-zero final energy dominated by electricity and carbonaceous fuels



Introducing methanol

Methanol, the simplest alcohol CH_3OH can fit the bill for many non-electric sectors.

Advantages: liquid, easy to store/transport, widely traded, burns cleanly. Don't drink it!

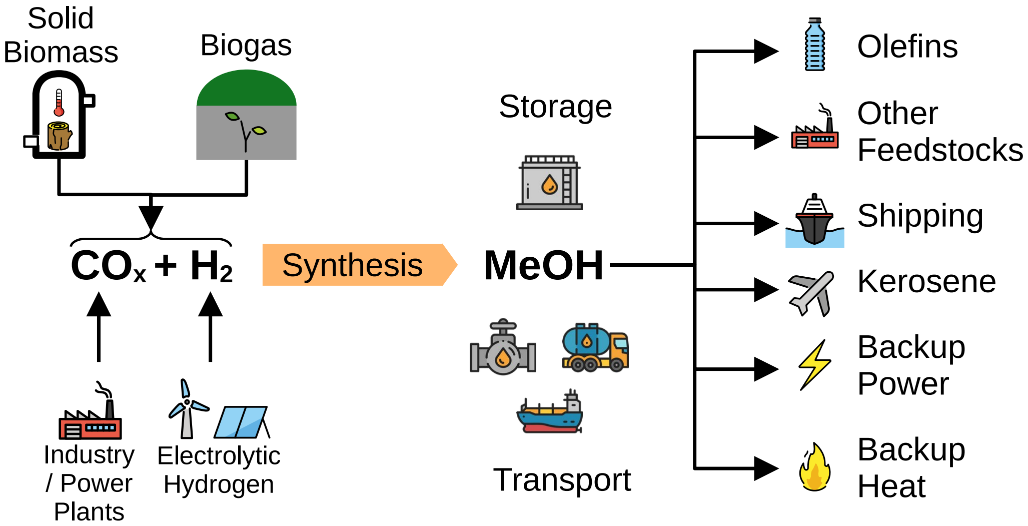


Source: Wikipedia; Yves Meur

Idea: 'Electrification plus minimal methanol backstop'

- **Electrify** as much as possible
- Hydrogen only in clusters or regional networks for **sectors where really needed** (e-biomethanol, ammonia, iron ore reduction)
- **Methanol as basis for carbonaceous fuels** for the rest (shipping, aviation, chemical industry, backup power & heat)
- Methanol is more easily **storeable and transportable** than hydrogen (liquid at RTP, no reliance on salt deposits, option to use vehicular transport)
- Methanol **avoids 4-dimensional chicken and egg problem** of GW hydrogen scale-up
- (E-)biomethanol can absorb sustainable carbon from **decentral biomass and wastes**, then be used directly in industry or dense fuels (carbon management)

Methanol as a platform for hard-to-electrify sectors



Source: Glaum et al, 2026

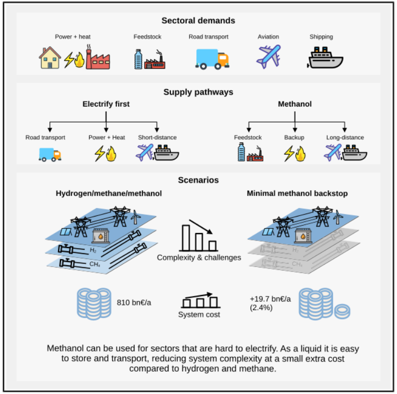
Paper on 'Minimal Methanol Backstop'

Joule

Article

A minimal methanol backstop for high-electrification scenarios

Graphical abstract



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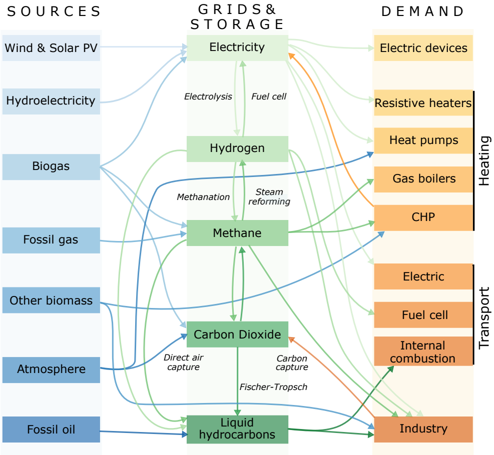
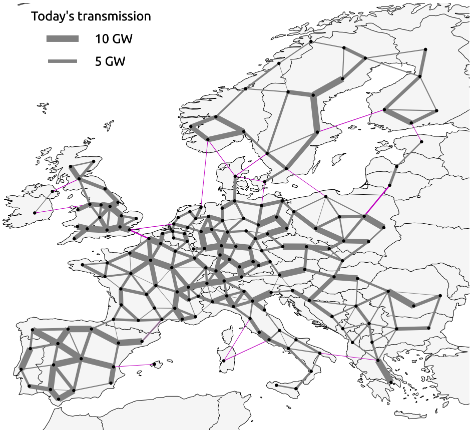
In brief

Green methanol offers a competitive, easy-to-handle alternative to hydrogen for decarbonizing the few energy sectors that cannot be directly electrified. A methanol-based net-zero energy system is just 2%–6% more expensive than a hydrogen-based one, helps to integrate sustainable biogenic carbon, and avoids the difficulties of scaling up hydrogen infrastructure.

Source: Glaum et al, 2026

Use **full energy system model** PyPSA-Eur with net zero CO_2 emissions, hourly modelling, 100 regions, biomass limited to wastes and residues, 200 $MtCO_2/a$ limit on sequestration.





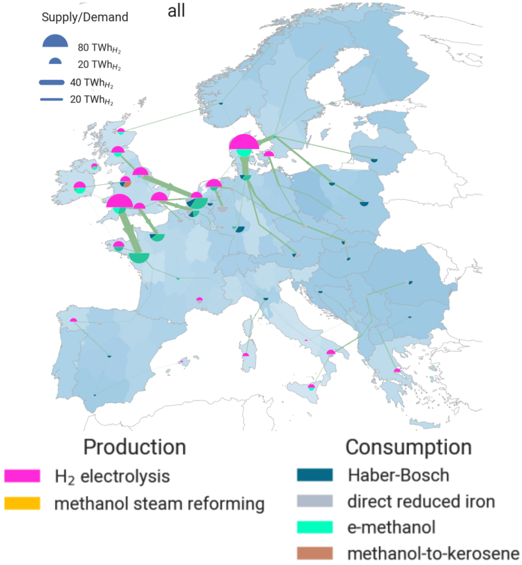
Five main scenarios remove gaseous energy networks

Scenarios contrast **gap-fillers for power and heat**: hydrogen, methane and methanol.

- **All Networks (all)**: both hydrogen and methane transmission networks
- **Only Methane Network (CH_4)**
- **Only Hydrogen Network (H_2)**
- **No Gaseous Fuel Networks (none)**
- **Minimal Methanol Backstop (min. MeOH)**: neither hydrogen nor methane transmission networks, and forbids gaseous distribution inside regions. Hydrogen only used captively inside industrial facilities for ammonia, steel, methanol and kerosene. Only solid biomass and methanol used for backup heat and power plants.

All scenarios allow the transport of oil, methanol, biomass, carbon dioxide and electricity.

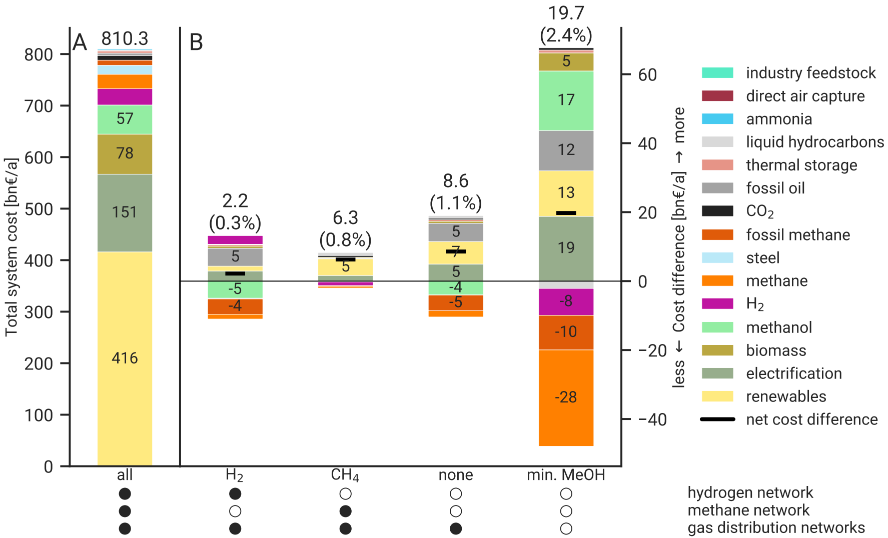
Hydrogen network for optimal 'All Networks' scenario



- Cost-optimal solution includes **H_2 network** connecting supply to inland industry
- Best **H_2 production** regions (Denmark, British Isles, Southern Europe) export H_2
- Main **H_2 demand** from steel, ammonia, methanol and FT

Source: Glaum et al, 2026

System cost: ‘minimal methanol’ only 2.4% more expensive



Source: Glaum et al, 2026

Energy balances: methanol use by shipping, MtO/A/K, backup

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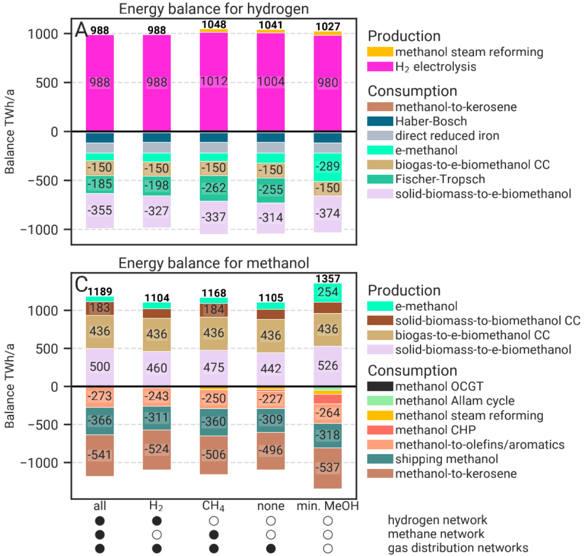
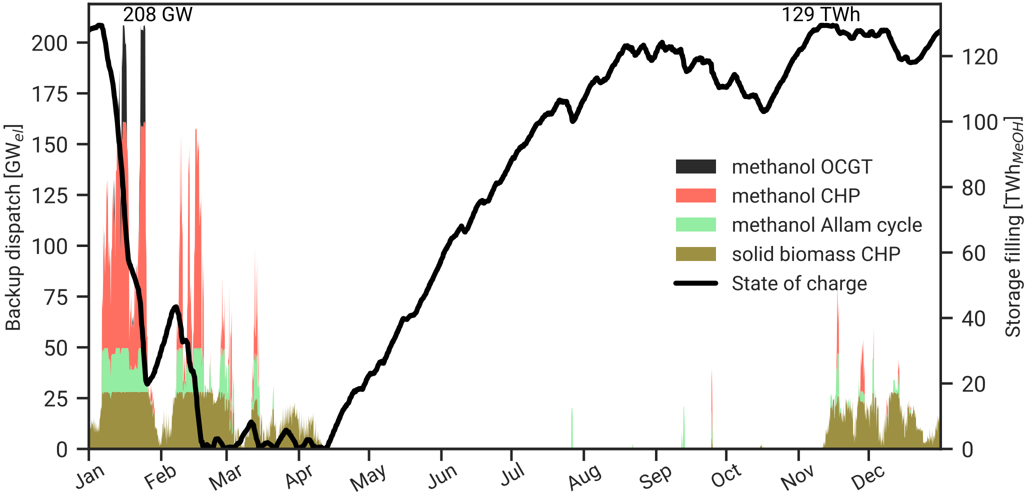


- **Hydrogen** sourced from electrolysis
- Consistently around 1000 TWh/a H_2 used for a mix of ammonia, steel, methanol and Fischer-Tropsch
- **Methanol** sourced primarily from biomass with H_2 addition
- Around 1100 TWh/a MeOH for chemicals, shipping and aviation; backup increases demand by 250 TWh/a

Source: Glaum et al, 2026

Methanol for backup power is used rarely

Backup power runs during **cold dark wind lulls**, primarily CHP to support district heating.



Source: Glaum et al, 2026

Sensitivity (CO_2 network, relocation, imports, sequestration, biomass)

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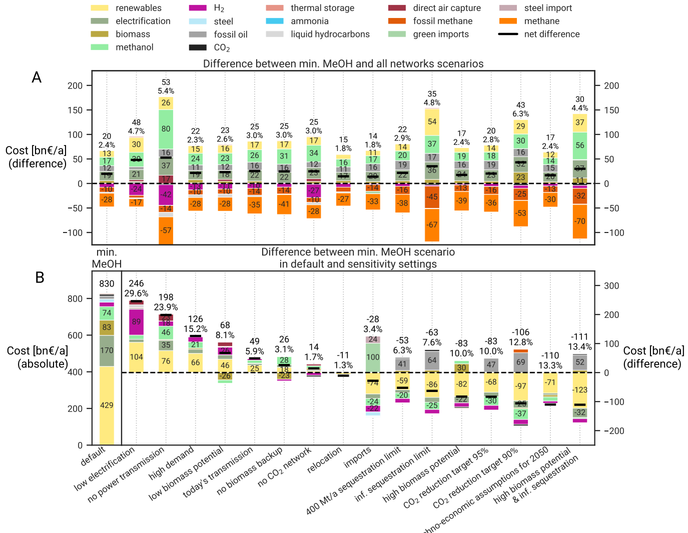
Cost increase to minimal methanol backstop (bottom row) **robust across sensitivity analysis.**



Source: **Glaum et al, 2026**

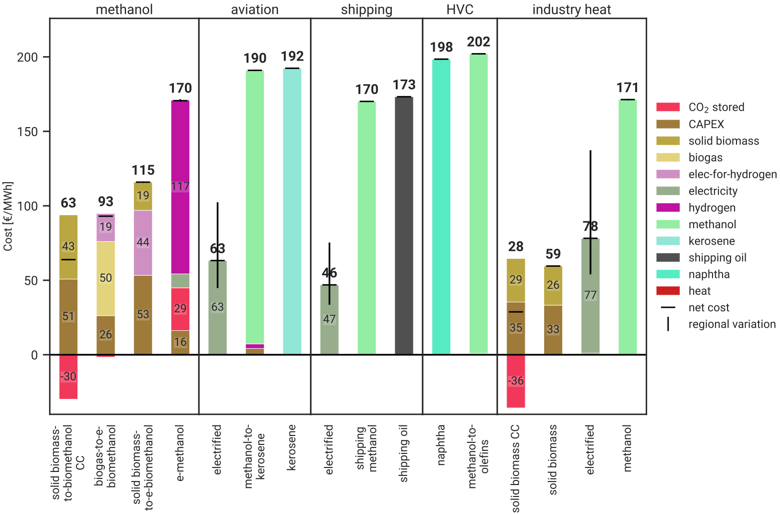
Conclusions

- Uncertainty around hydrogen demand requires **adaptive infrastructure planning**
- Methanol is a **scaleable and flexible** solution for hard-to-electrify sectors
- Green methanol may be needed in **large volumes** for shipping, chemicals and aviation
- Using methanol as a **gap filler** for backup power and heat is only **20 billion euros per year (2.4% of system cost)** more expensive than a methane/hydrogen system
- Methanol gives option to **de-link the scale-up** of infrastructures (storage, pipelines), avoid frictions of hydrogen, be a **drop-in replacement** for methane, allow **smoother transition**
- A **minimal methanol backstop** allows to develop PtX, while hedging against uncertainty

Backup

Production costs for different end use sectors

Biomethanol can be supplemented with green hydrogen to use excess CO_2: **e-biomethanol**.



Source: **Glaum et al, 2026**

Resilient solution: peaker capacity with methanol tanks

- Put turbines or motors to cover **winter peak** in each region, next to a giant **methanol tank**
- Can also run as **synchronous condenser** to provide reactive power, fault current, inertia
- Methanol tanks cost just 0.01-0.05 €/kWh
- Single 200,000 m^3 tank can store **880 GWh**
- Can be built **anywhere**, take up little space
- Can be dimensioned to provide **resilience** against low wind years, volcanos, infrastructure outages, sabotage, blackouts

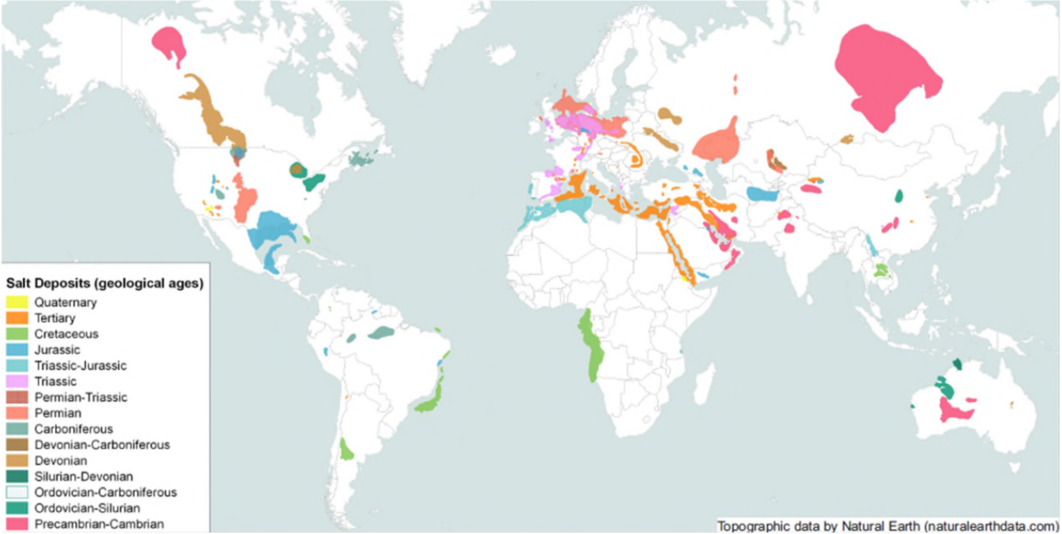
Source: Wikipedia

Challenges with hydrogen economy

A hydrogen economy comes with **several challenges**:

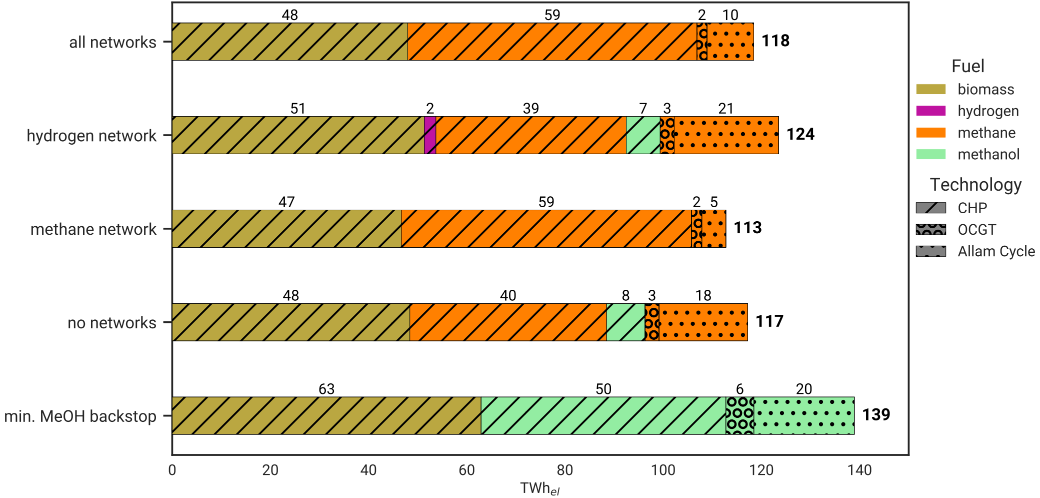
- The molecule **size is small**, making it easy to leak and e.g. embrittle steel
- The **volumetric density** is low, making storage and transport difficult
- Salt deposits needed for easy underground storage in caverns are **not widely available**
- Vehicular transport is **costly**, pipeline network is necessary
- Hydrogen is an **indirect greenhouse gas** with GWP100 of 11.6 ± 2.8
- The widespread usage of a new gas requires a **coordinated scale-up** of lumpy **GW-scale** pipelines, storage, supply and demand

Problem: salt deposits for hydrogen caverns are highly localised



Source: Solution Mining Research Institute

Dispatchable generation: switch from biomass+gas to methanol



Source: **Glaum et al, 2026**

Final energy supply dominated by electricity and methanol

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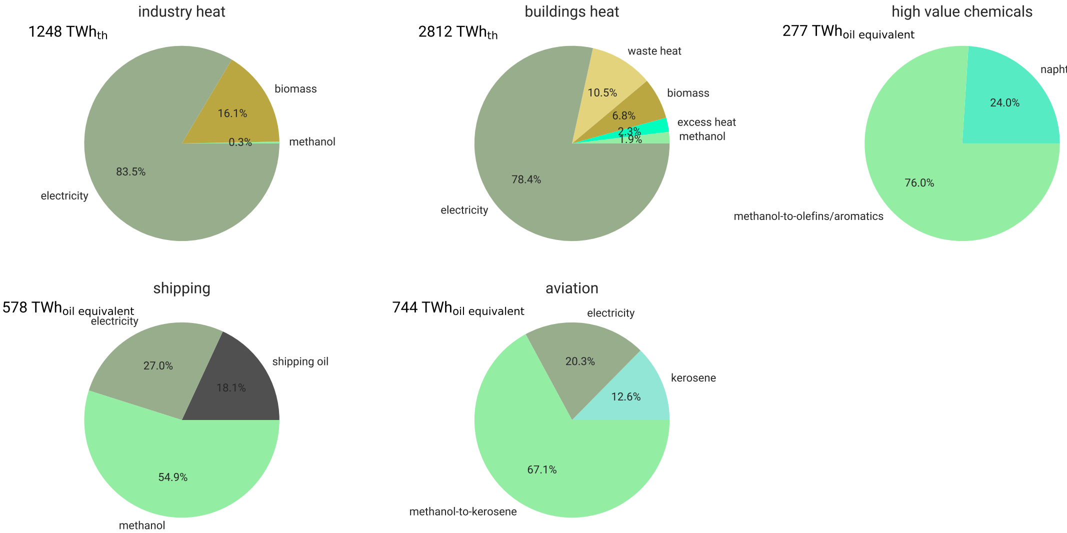
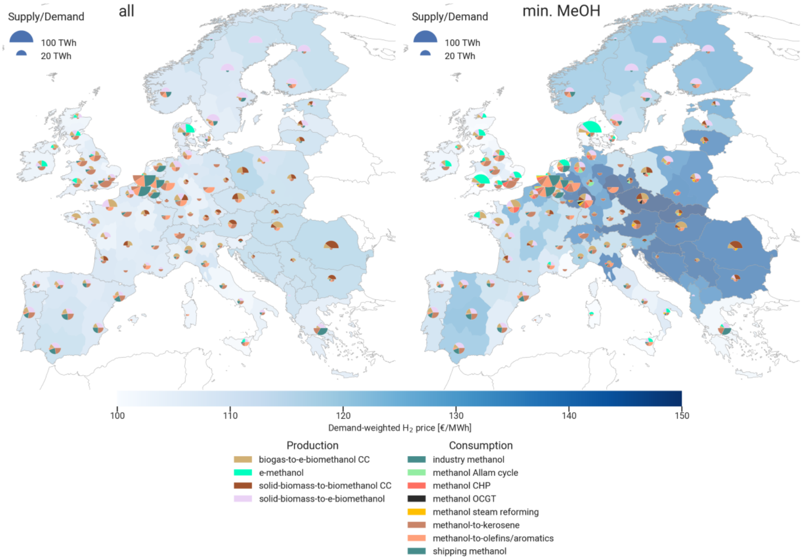


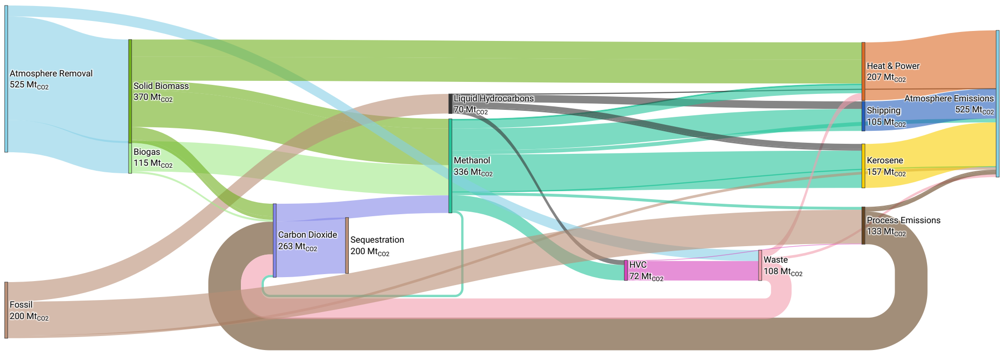
Source: **Glaum et al, 2026**

Biomethanol production is spread around the continent



Source: Glaum et al, 2026

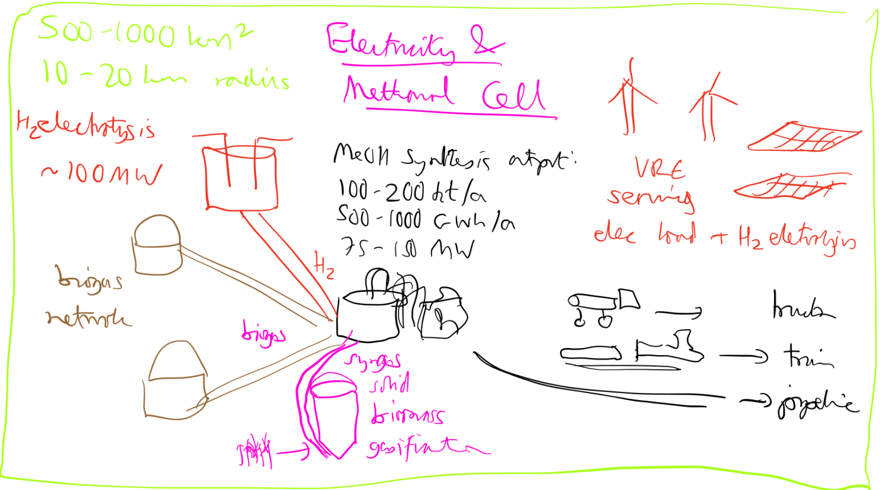
CO_2 flows in Sankey diagram



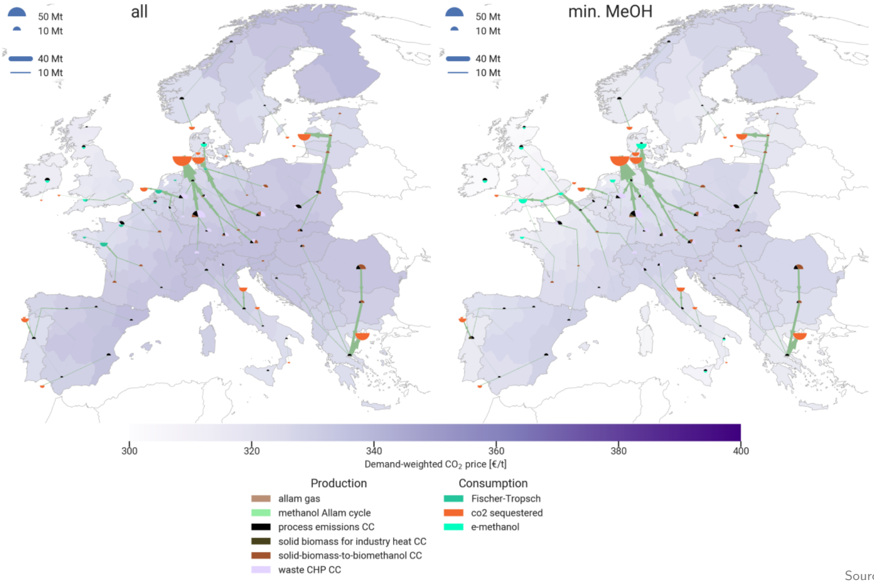
Source: Glaum et al, 2026

Methanol and electricity 'cell'

Methanol synthesis needs 100+ ktMeOH/a scale, collecting sustainable biomass over 500+ km^2, and VRE to serve 100+ MW electrolysis. Need 2000+ plants for 1400 TWh/a methanol.

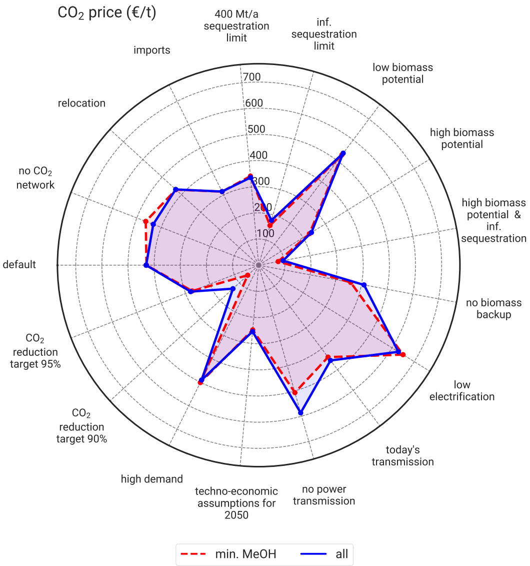


CO_2 network



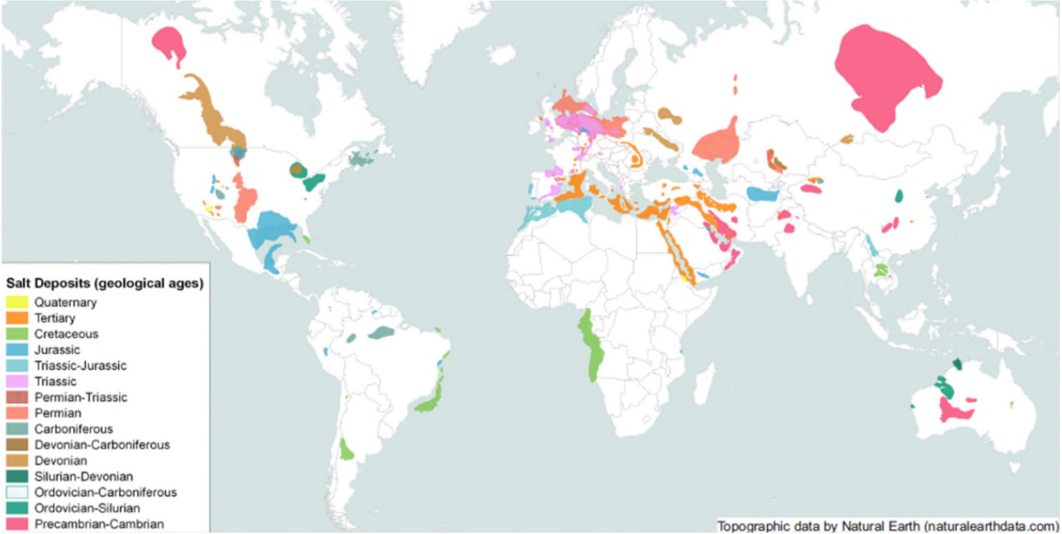
Source: **Glaum et al, 2026**

CO_2 prices in sensitivity runs



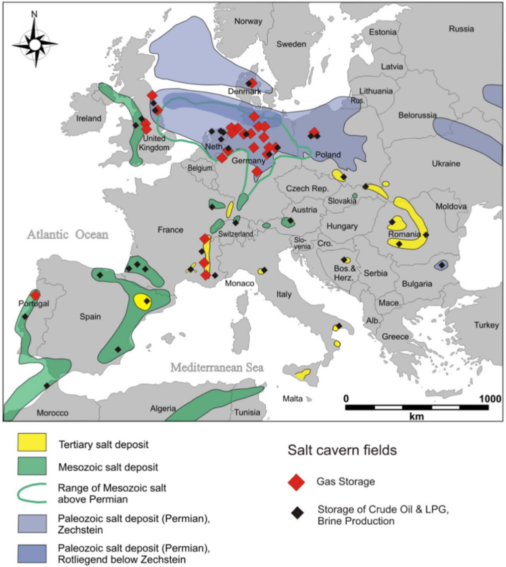
Source: **Glaum et al, 2026**

Problem: salt deposits for hydrogen caverns are highly localised



Source: Solution Mining Research Institute

Zoom on salt deposits in Europe and US



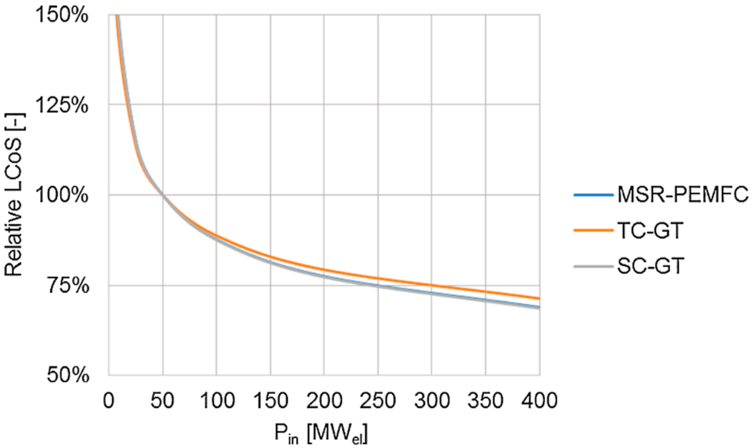
Large methanol tanks can be built cheaply anywhere

- Methanol tanks cost just 0.01-0.05 €/kWh
- Single 200,000 m^3 tank can store **880 GWh**
- Can be built **anywhere**, take up little space
- CO_2 and O_2 stored cryogenically
- Can be dimensioned to provide **resilience** against low wind years, volcanos and infrastructure outages

Source: Wikipedia

Scaleability down to 200 MW

Economies of scale remain down to 200 MW (electrolyser power). ⇒ Interesting for **smaller autarkic regions**, such as islands or data centres. Also good for **fast, modular iteration**.



Source: [Baak et al, 2018]

Pros and cons versus other chemical storage

- **Methane**: similar costs and efficiencies to methanol, can re-use existing infrastructure like methanol. Disadvantage of not being required in large volumes in climate-neutral scenarios, requiring pressurisation for storage and transport, leakage as greenhouse gas, needs GW economies of scale, could prolong fossil gas.
- **Ammonia**: has advantage of avoiding carbon cycle. But toxic, needs cryogenic storage, storage and transport is highly regulated, ammonia turbines have low TRL, nitrogen oxide emissions mean mitigation necessary, doesn't address need for carbonaceous molecules.
- **Liquid hydrogen**: LH_2 requires constant cooling power, large losses for liquefaction, doesn't address need for carbonaceous molecules.
- **Liquid organic hydrogen carrier**: LOHC similar to LH_2, but more expensive and lower TRL. Waste heat from power generation can be used for dehydrogenation.

What about methane and direct use of bioenergy?

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Methane

- There are very few sectors that need methane (beyond building heating until phase out is complete), whereas methanol has many uses; $CH_4 \Rightarrow$ lumpy pipelines
- Methane should be avoided in transport because of engine slippage, and in general because of leakage (possible to regulate, but in practice difficult)

Direct use of bioenergy

- Uses should be prioritised to: industrial feedstock, dense fuels for aviation and shipping, and carbon dioxide removal
- All of these needs can be met either with pure CO_2 (CDR) or methanol (MtO/A, MtK)
- Soak up all carbon close to source with biogas and e-H_2 in bio-e-methanol plants, or cellulosic ethanol, or gasification+synthesis
- Rare usage in CHP $\Rightarrow$ want low-capex plant using homogenous fuel (i.e. avoid solids)