CARBON CAPTURE

Solvent costs in the energy system

Markus Millinger, International Energy Workshop 2025, Nara, Japan

V Chanal, S Humpage, M Millinger (2025): Accounting for carbon capture solvent cost and energy demand in the energy system. Environmental Research Letters 20, 044047.

Carbon capture in scenarios

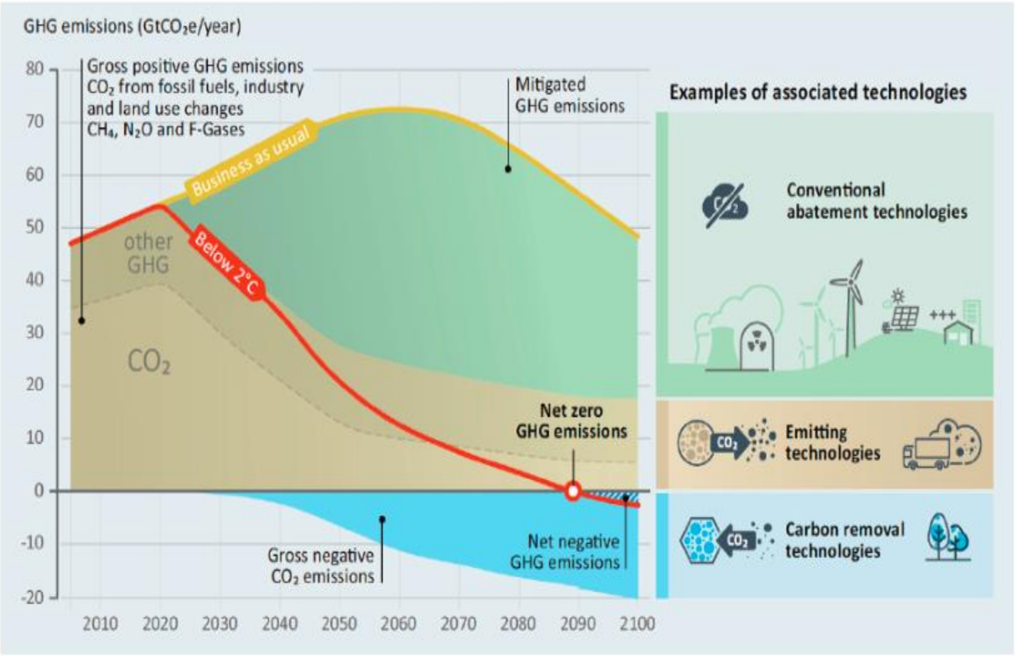
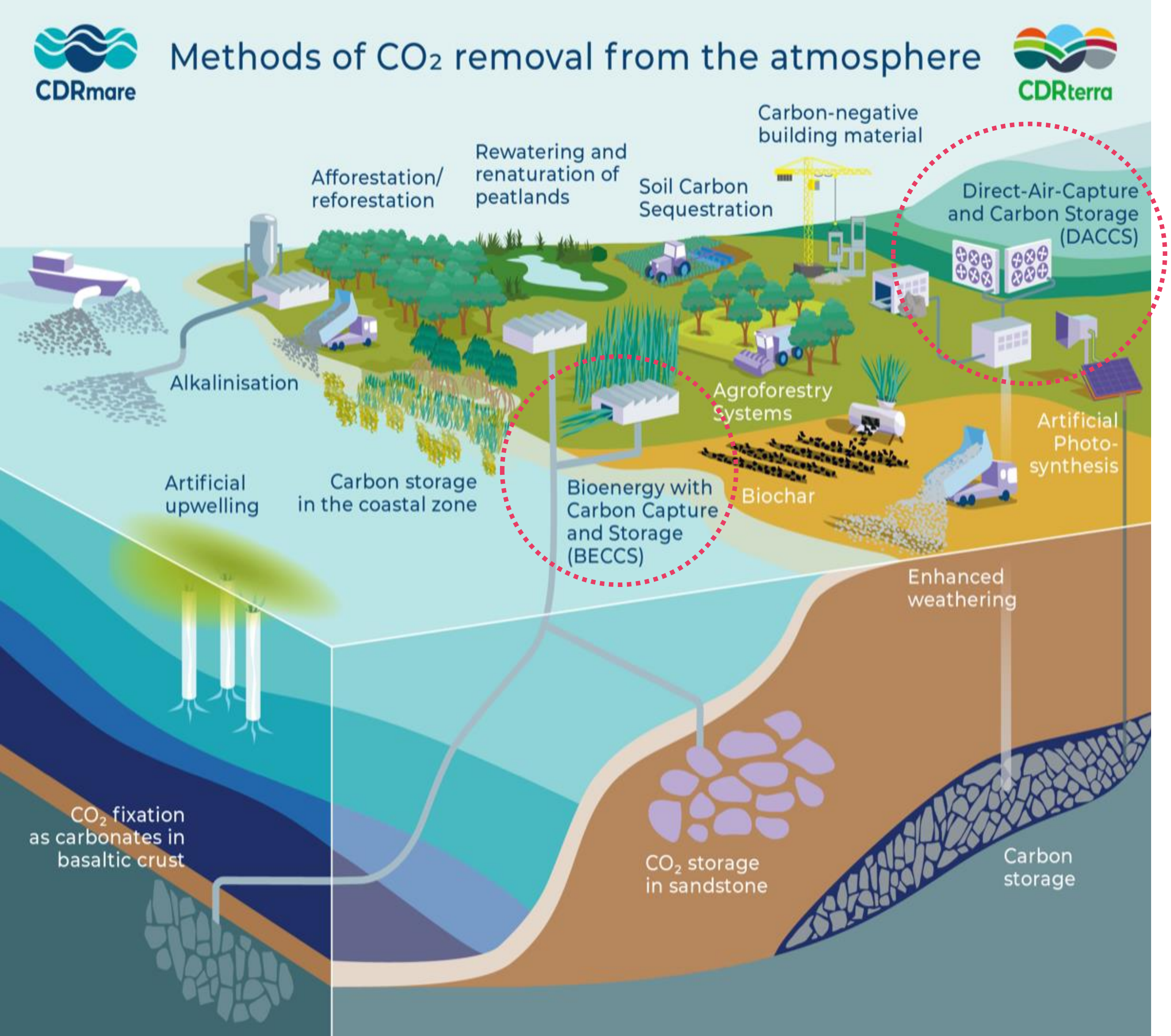


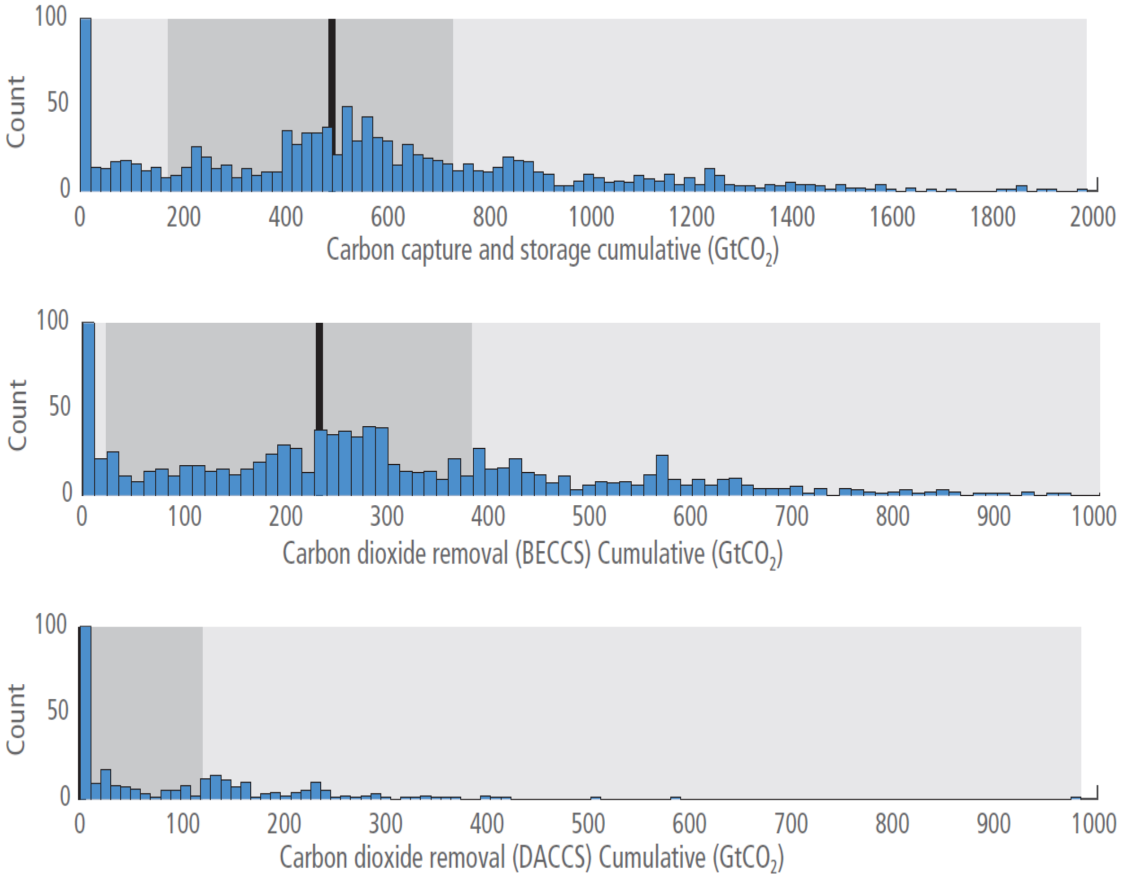
FIGURE 8.1 Scenario of the role of negative emissions technologies in reaching net zero emissions (UNEP, 2017).



Carbon capture in scenarios

- This study focuses on technical carbon dioxide removal (CDR): BECCS and DACCS
- Also CCU

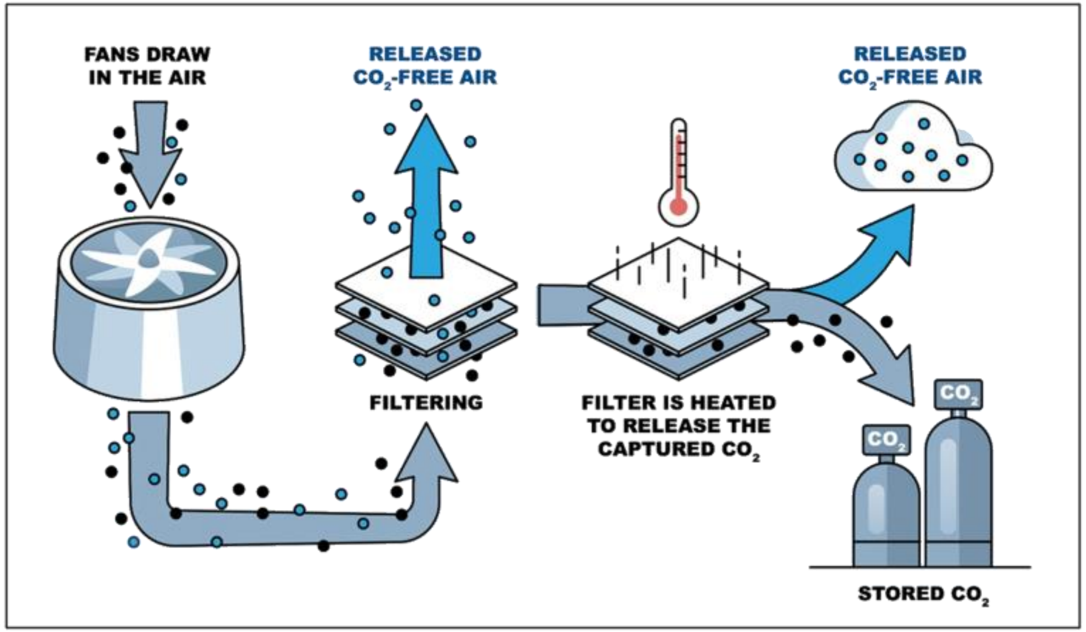
RI. SE



Carbon capture in scenarios

- In some scenarios up to some 2000 $GtCO_2$ CCS over the century (median ca 500 Gt)
  → Annual average CCS up to 54% of global emissions 2023 (anthropogenic non-LULUCF)
- BECCS median ca 230 $GtCO_2$
- DACCS up to ca 1000 Gt, but many scenarios do not include it

Riahi, K., R. Schaeffer, J. Arango, K. Calvin, C. Guivarch, T. Hasegawa, K. Jiang, E. Kriegler, R. Matthews, G.P. Peters, A. Rao, S. Robertson, A.M. Sebbit, J. Steinberger, M. Tavoni, D.P. van Vuuren, 2022: Mitigation pathways compatible with long-term goals. In IPCC, 2022: Climate Change 2022: Mitigation of Climate Change. Contribution of Working Group III to the Sixth Assessment Report of the Intergovernmental Panel on Climate Change [P.R. Shukla, J. Skea, R. Slade, A. Al Khourdajie, R. van Diemen, D. McCollum, M. Pathak, S. Some, P. Vyas, R. Fradera, M. Belkacemi, A. Hasija, G. Lisboa, S. Luz, J. Malley, (eds.)]. Cambridge University Press, Cambridge, UK and New York, NY, USA. doi: 10.1017/9781009157926.005



Carbon capture basics

- Syngas (pre-combustion), flue gas (post-combustion) or air (direct air capture)
- Solvent or sorbent binds CO_2 from gas
- Heated to release pure CO_2 (temperature differs between options)

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Unrealistic energy and materials requirement for direct air capture in deep mitigation pathways

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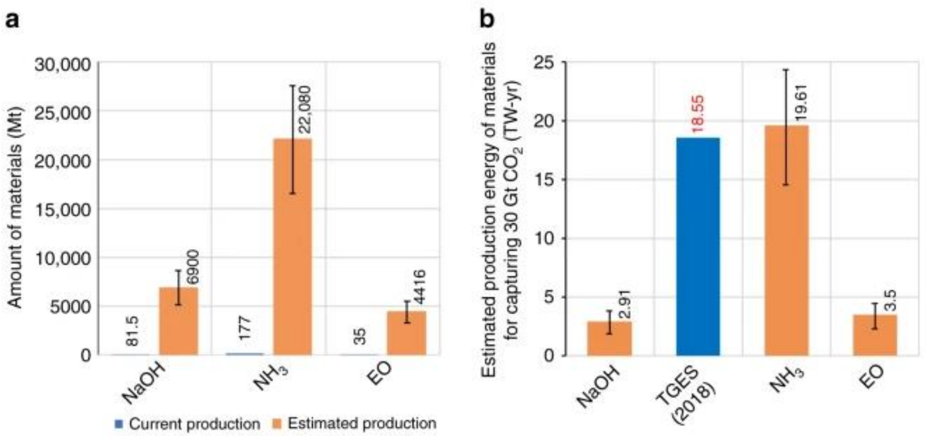
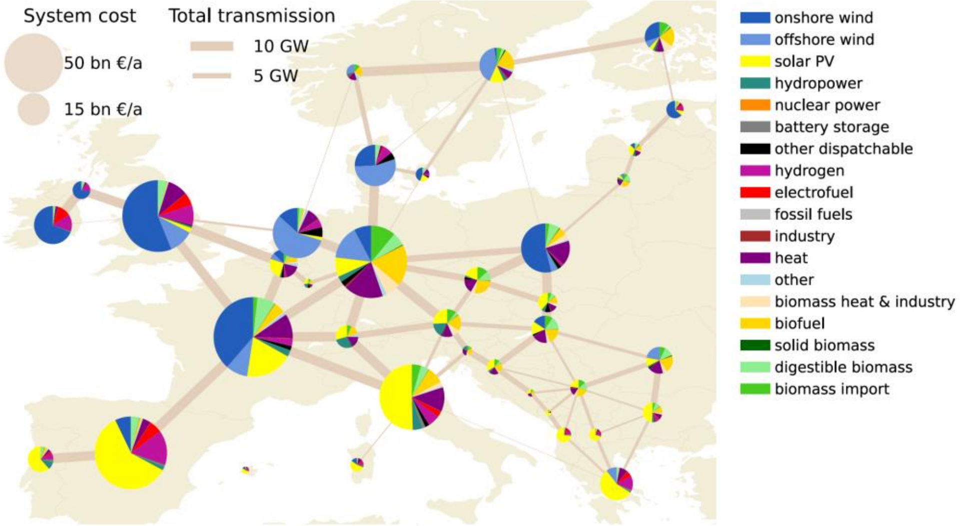
Fig. 2: Energy and materials requirement for DACC—current status and prospects.

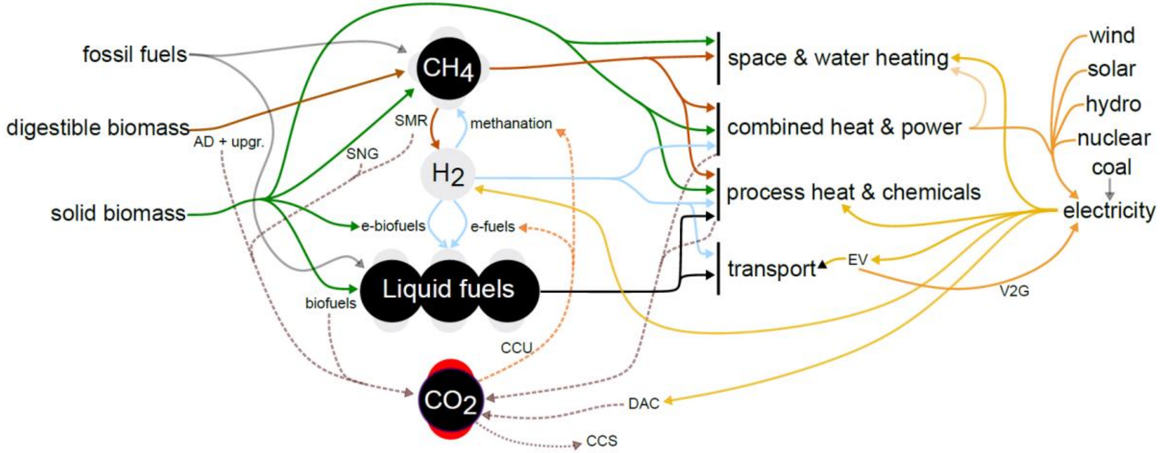


Energy and materials requirement of carbon capture?

- Chatterjee & Huang estimated energy required of global energy demand:
  - Solvent material production 12-20%
  - Solvent regeneration 34-51%

How do uncertainties for solvents affect carbon capture and energy system cost?



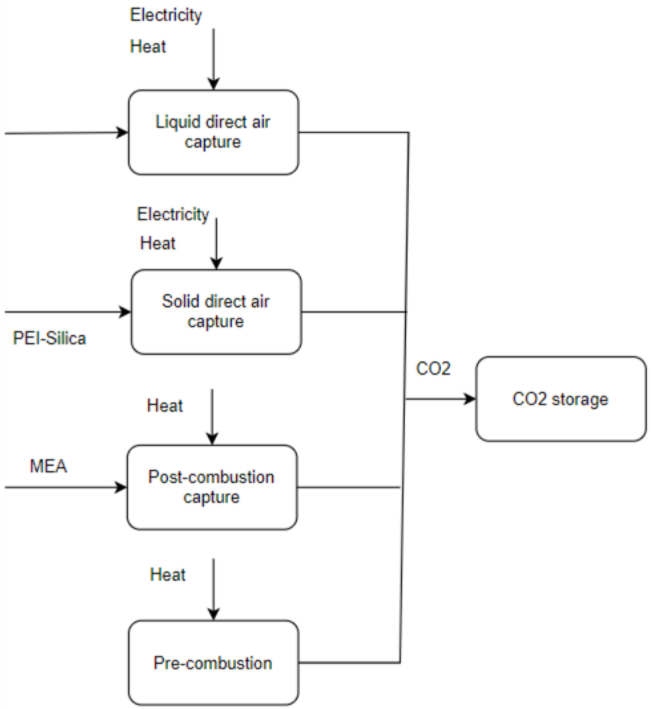


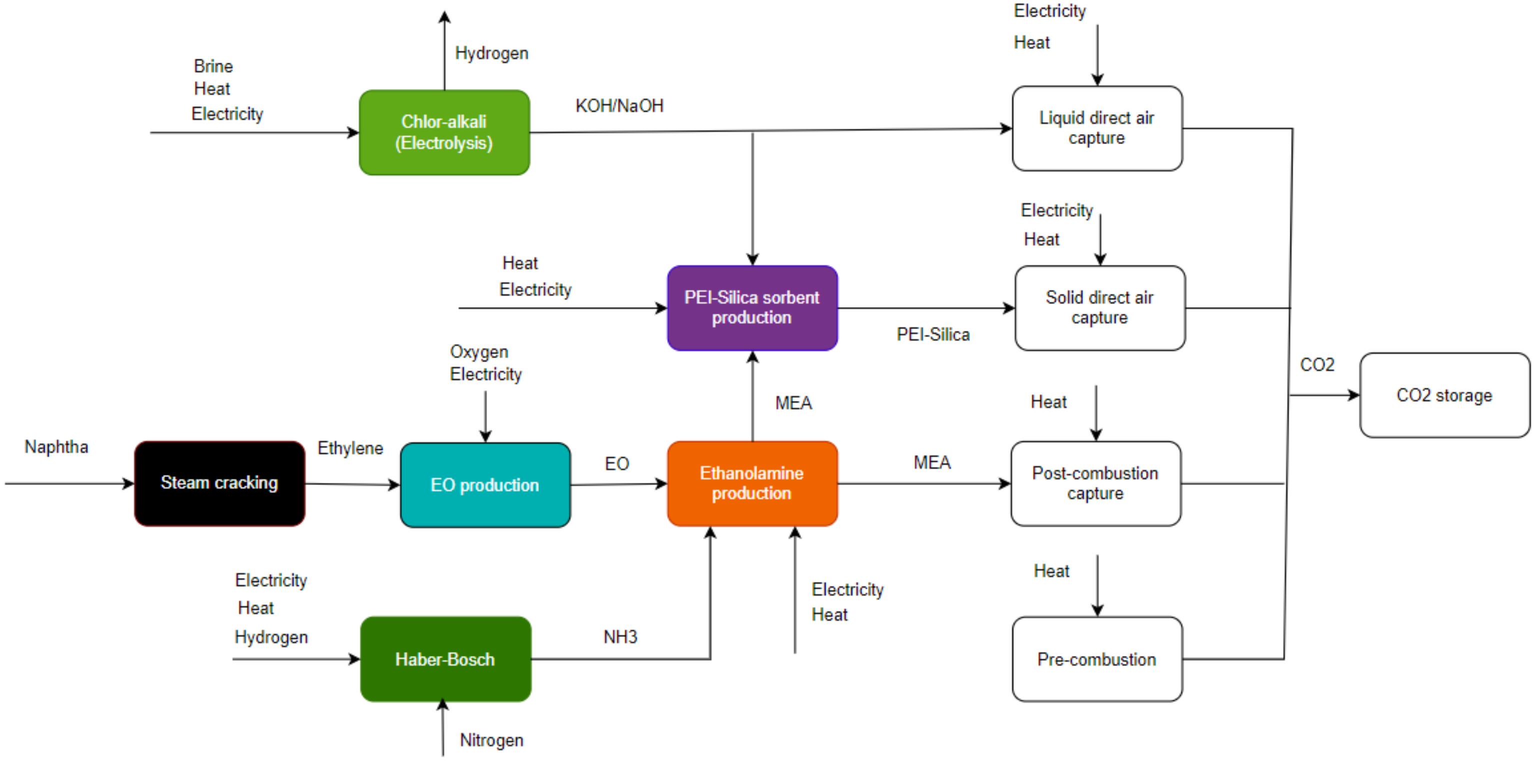
Millinger et al., Nature Energy 2025

Method and scope

- PyPSA-Eur-Sec
- Europe
- Details on solvents/sorbents

How do uncertainties for solvents affect carbon capture and energy system cost?


Electricity
Heat
Liquid direct air capture
Electricity
Heat
Solid direct air capture
PEI-Silica
CO2
CO2 storage
Heat
MEA
Post-combustion capture
Heat
Pre-combustion



Brine
Heat
Electricity
Hydrogen
Chlor-alkali (Electrolysis)
KOH/NaOH
Electricity
Heat
Liquid direct air capture
Electricity
Heat
Solid direct air capture
Heat
Electricity
PEI-Silica sorbent production
PEI-Silica
Oxygen
Electricity
MEA
CO2
CO2 storage
Naphtha
Steam cracking
Ethylene
EO production
EO
Ethanolamine production
MEA
Heat
Post-combustion capture
Electricity
Heat
Hydrogen
Haber-Bosch
NH3
Electricity
Heat
Heat
Pre-combustion
Nitrogen

Scenarios

- Emissions target
- With and without fossils
- More or less biomass
- S-DAC and L-DAC

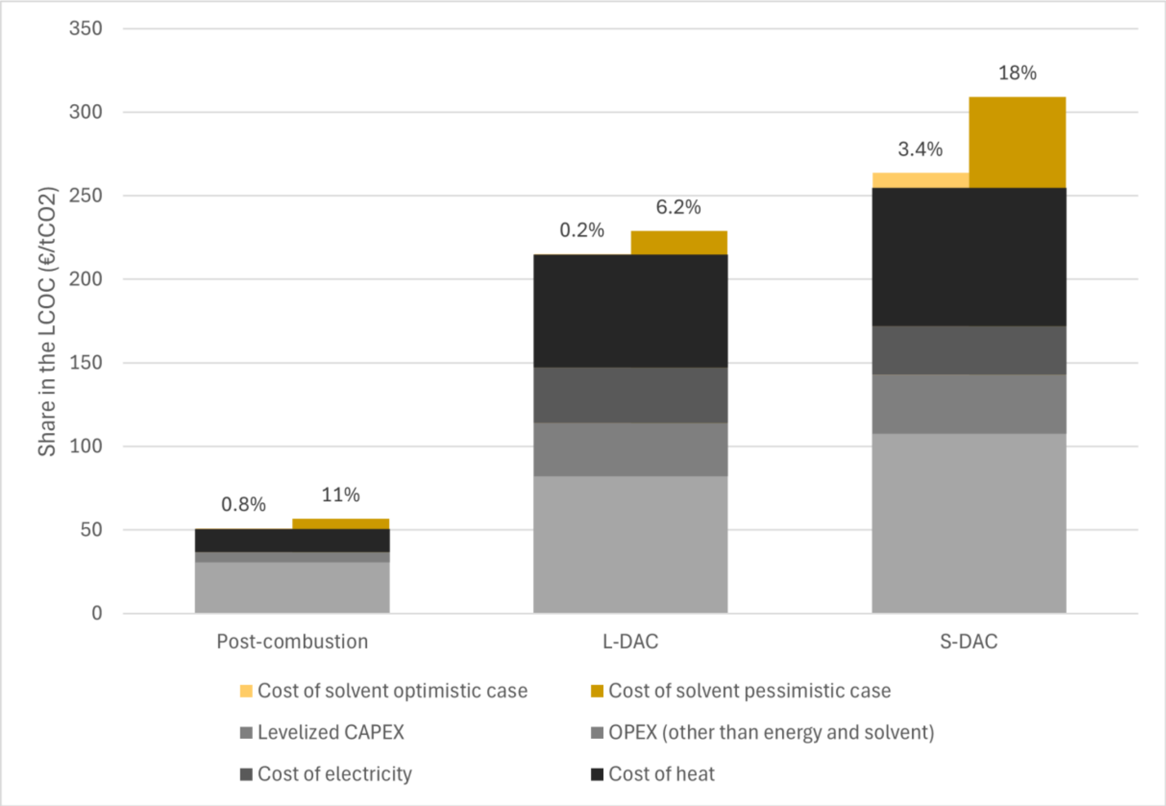
CO_2 emissions target	Renewable system	Biomass resources	
Net Zero	Allows fossil	Large (with imports)	More flexible
Net Negative (-10%)	Fully renewable	Small (only EU supply)	More constraining
8 scenarios			

Solvent consumption

- Solvents degrade and need to be replenished, but they differ in robustness (and other characteristics)
- Literature survey of solvent consumption ranges gives a wide range
- But still lower than in older literature (which was used by Realmonte et al. and Chatterjee & Huang)

Solvent	MEA	KOH	PEI-Silica sorbent
Lower consumption [$kg_{solvent}/t_{CO2}$]	0.27	0.4	2.3
Higher consumption [$kg_{solvent}/t_{CO2}$]	3.98	38	14

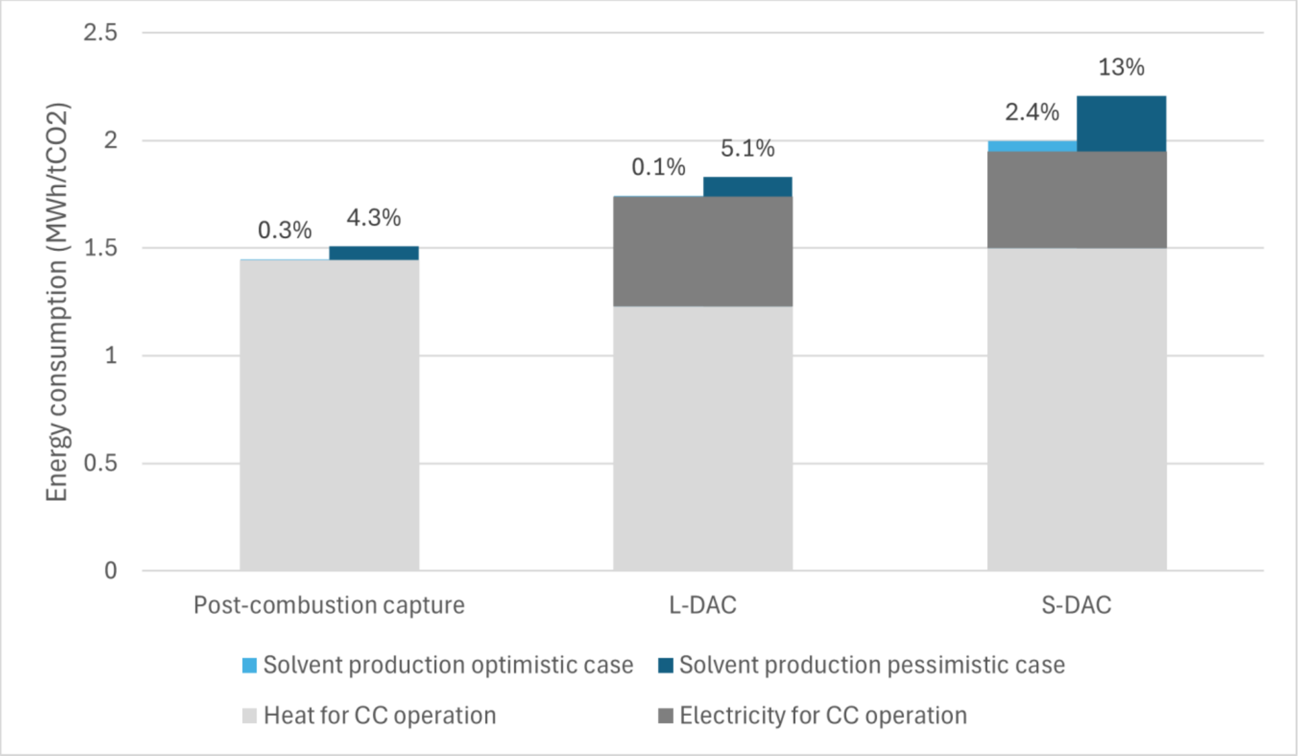
RI. SE



Impact on carbon capture cost

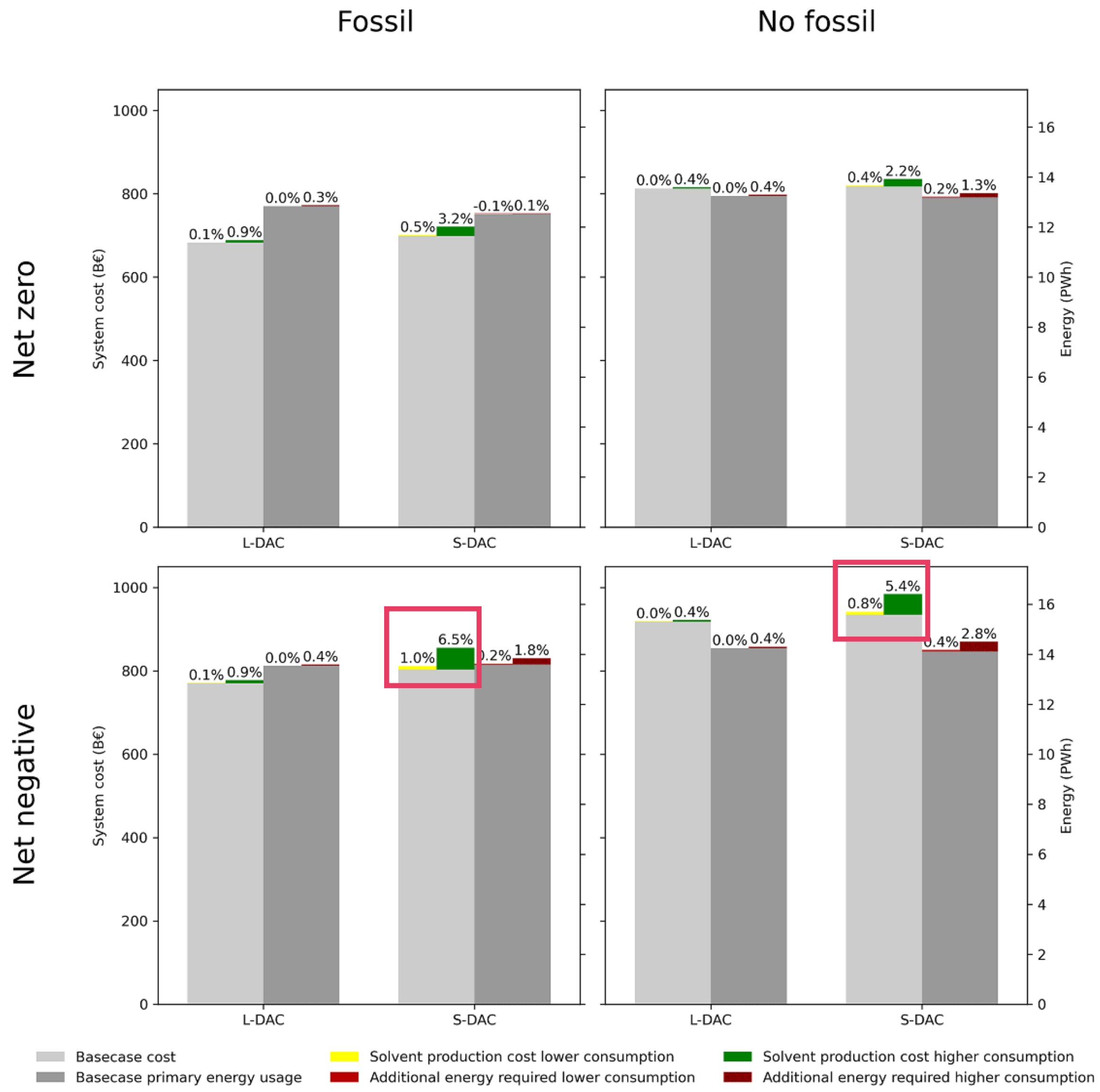
- Low impact in the optimistic case
- In the high uncertainty range there is especially a significant effect for S-DAC

Impact on carbon capture energy use



- Taking energy consumption for solvent production into account
- Again, low impact in the optimistic case
- S-DAC up to 13% higher energy consumption

RI. SE



Impact on energy system cost

- For post-combustion and L-DAC: generally low effect on energy system cost and energy consumption,
- S-DAC sorbent uncertainty affects energy system cost significantly – up to **6.5%** higher cost with negative emissions and high fossil use
- But, much less than Chatterjee (12-20% of total energy consumption vs. up to 2.8% here)

Solvent consumption

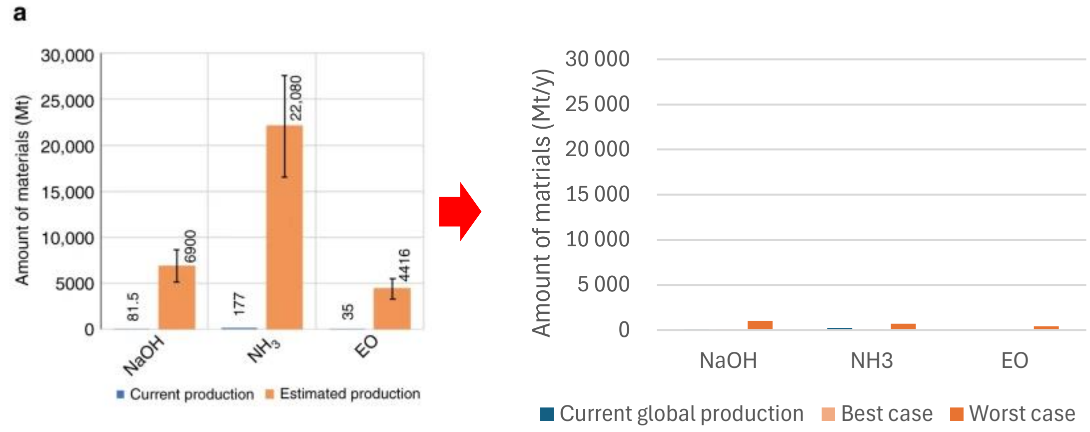
Material	MEA	KOH	PEI	EO	Ethylene	NH3
Best case results	2	2,1	0,9	1,5	1,3	2,6
Worst case results	14	28	5,4	11	8,9	19
Current global production	2,5	KOH: 9 NaOH: 82	0,014	31	225	240

Potential challenges

Material consumption

- How much material is needed if DAC is scaled up to 30 $GtCO_2$/a?
- To compare with Realmonte et al. and Chatterjee & Huang

Fig. 2: Energy and materials requirement for DACC–current status and prospects.



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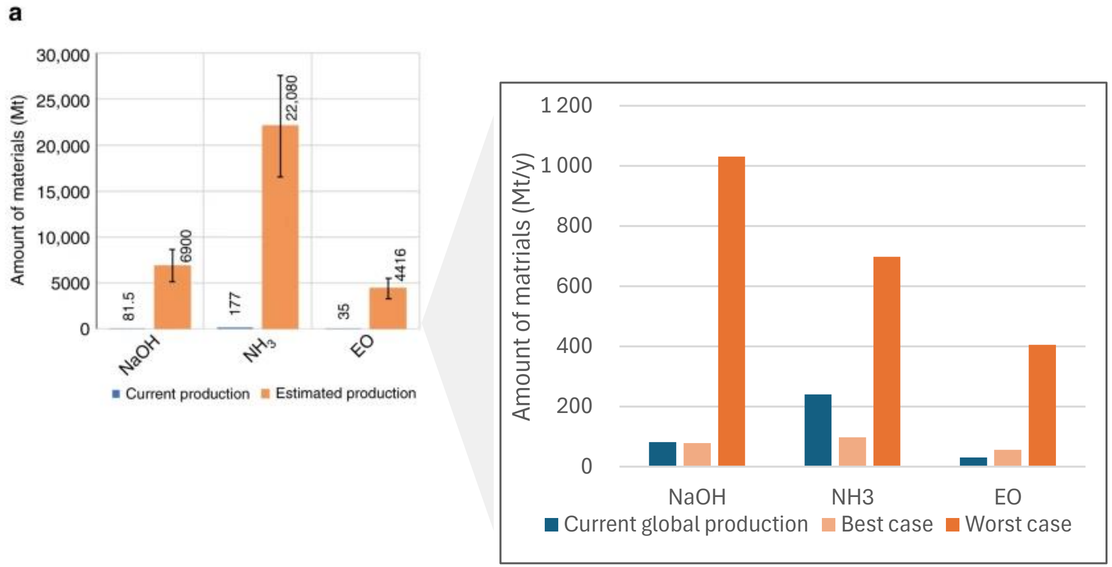

Conclusions

- Accounting for solvent production does not significantly affect energy consumption
- Uncertainties for S-DAC sorbent replenishment increase overall energy system cost by up to 6.5%
- Trade-off: S-DAC has benefits also (modular, low temperature for regeneration)

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Accounting for carbon capture solvent cost and energy demand in the energy system

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