

 FUTURECHEM EUROPE 2026 - FCE2026, OCTOBER 1, 2026, HELSINKI, FINLAND

CONNECTING CHEMICAL AND FOREST INDUSTRIES WITH BIOGENIC CARBON

Kristian Melin

Associate prof. Process and Plant Design

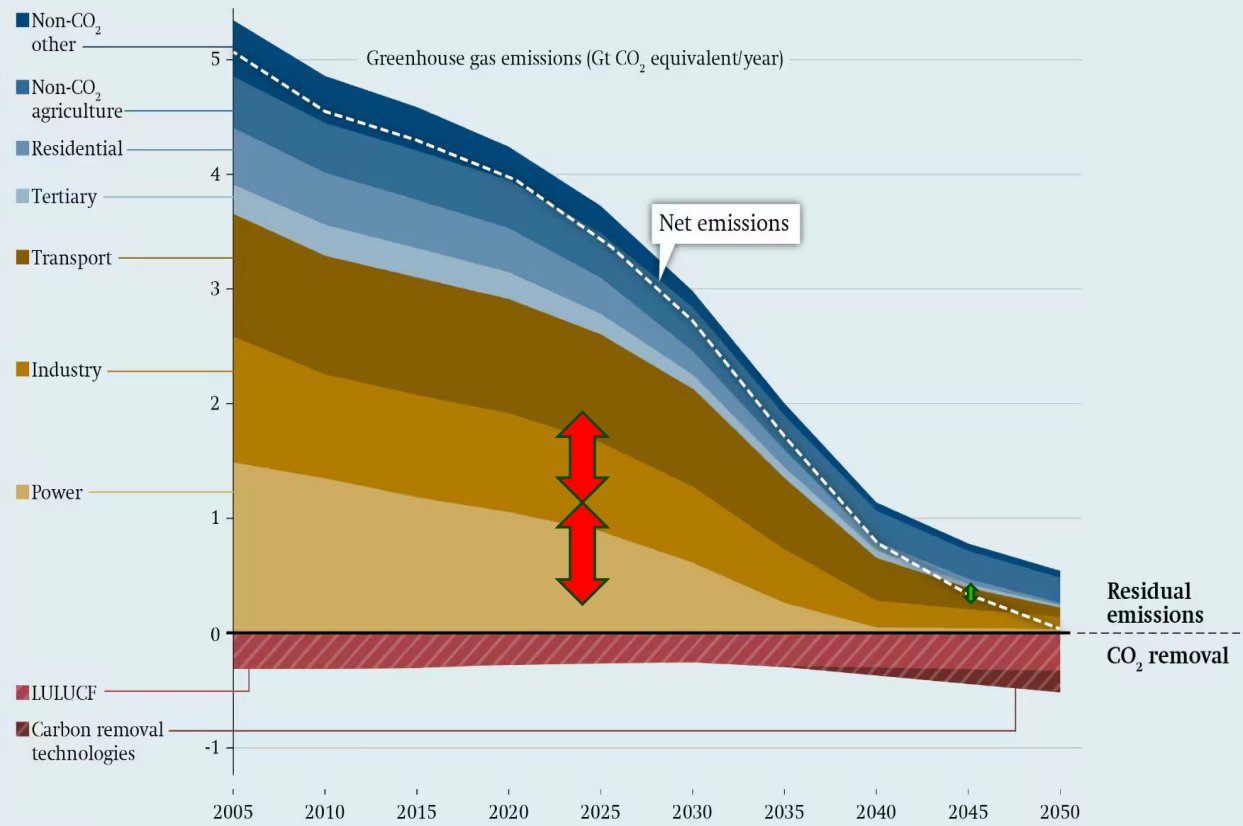
LUT University, Lahti Campus, Finland

Kristian.Melin@lut.fi, Tel: +358 (0)50 349 7383



THE ROLE OF BIOGENIC CARBON IN GHG MISSIONS REDUCTIONS

Illustrative emissions pathways to achieve a net-zero target in the EU



Translation and adaptation: 2020 Stiftung Wissenschaft und Politik (SWP)

➤➤ HOW TO REDUCE CO₂ emissions by 2045:

- Roughly 1 Gt CO₂ –eqv from Power sector?
- About 0.5 Gt CO₂ –eqv from Industry sector?
- Transport sector 0.7 Gt CO₂–eqv. reduction
- CO₂ capture from Point sources (10-20 vol-%) is typically 70-90 €/tCO₂ capture and 50-60 €/tCO₂ liquefaction, shipping, storage
- CO₂ reduction only with CO₂ capture ~200 billion € (110% EU Budget) if capture cost is ~90 €/ton
- Wind and solar power in power production, electrification of transport and heating reduce the main part of emissions cost-effectively
- A lot of carbon, however, is needed for aviation fuels and as feedstock for the chemical industry

World economic Forum, 2020. <https://www.weforum.org/stories/2020/11/heres-why-the-eu-needs-a-carbon-sink-strategy-for-climate-neutrality>

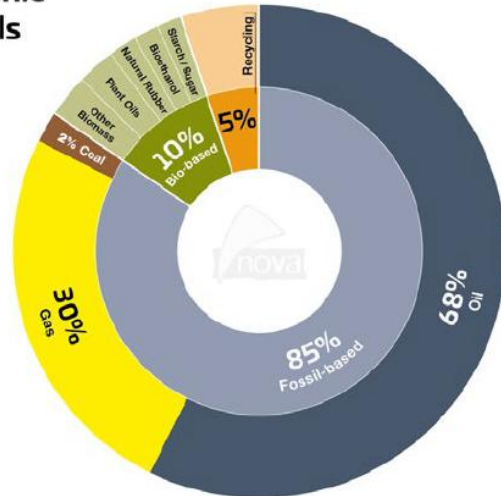
Yun S, Jang M and Kim J (2021) Techno-economic assessment and comparison of absorption and membrane CO₂ capture processes for iron and steel industry. Energy (Oxford) 229: 120778

.Suviranta, Roosa, Carbon capture integration to steam cracker furnaces – techno-economic evaluation, MSc. Thesis, 2021, LUTPub.

CARBON SOURCES TODAY AND ITS FUTURE NEED

Global Carbon Demand for Organic Chemicals and Derived Materials by Type of Feedstock

Total: 450 Mt embedded C/yr



Reference Years: 2015 – 2020

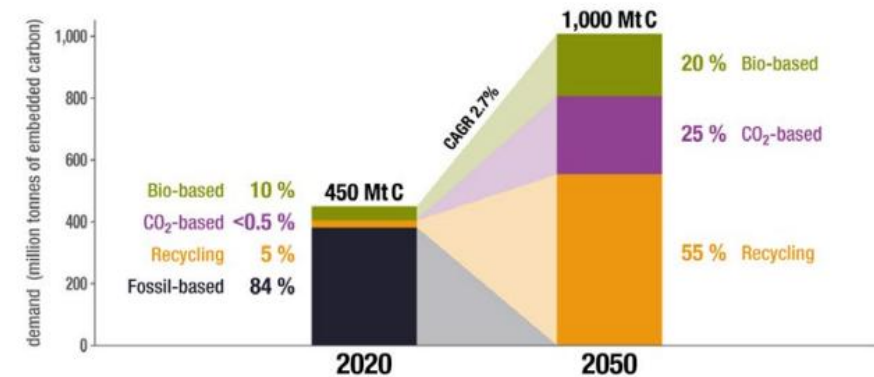
Main Sources: Piotrowski et al. (2015), Hundertmark et al. (2018), Levi and Cullen (2018), Skoczinski et al. (2021)
available at www.renewable-carbon.eu/graphics

© nova-Institute.eu | 2021

Figure 4: Current global demand for carbon embedded in organic chemicals and derived materials by type of carbon feedstock (nova-Institute 2021, based on various sources⁷)

➤➤ A big share of carbon originates from fossil feedstock today

Global Carbon Demand for Chemicals and Derived Materials in 2020 and Scenario for 2050 (in million tonnes of embedded carbon)



available at www.renewable-carbon.eu/graphics

© nova-Institute.eu | 2021

Figure 8: Scenario for the future global demand of embedded carbon for chemicals and derived materials in 2050 (nova-Institute 2021)

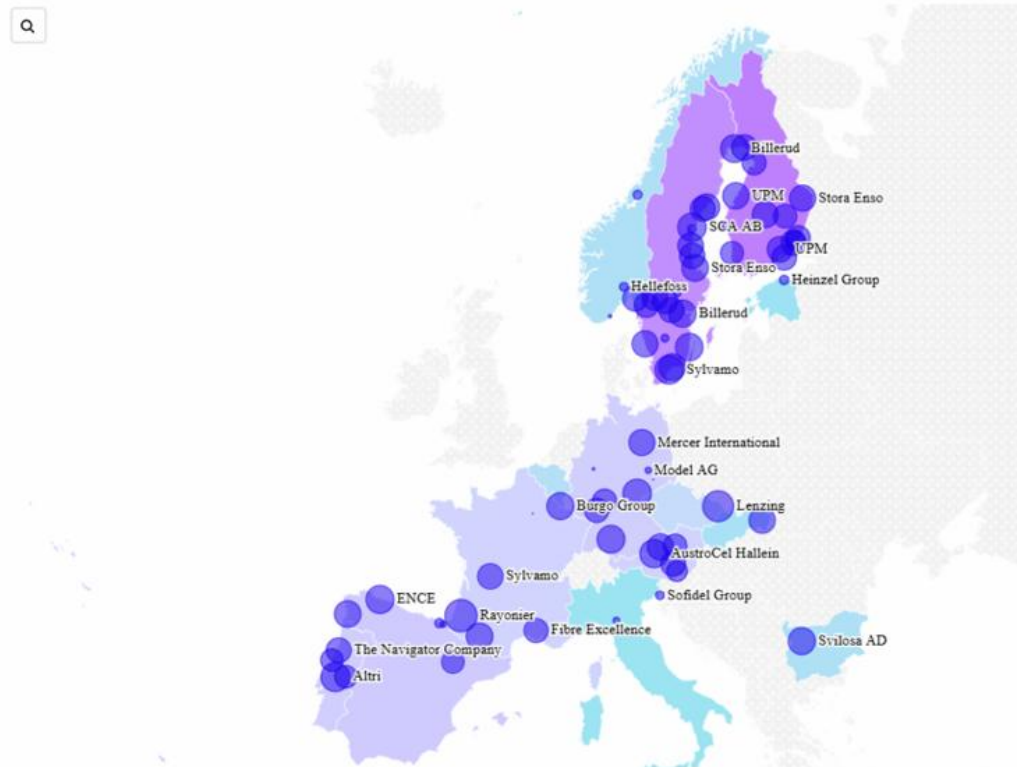
➤➤ The global demand for carbon in chemicals and derived materials is expected to rise in the future.

WHAT ROLE COULD THE FOREST INDUSTRY PLAY IN THIS?

Biogenic emissions of EU pulp mills

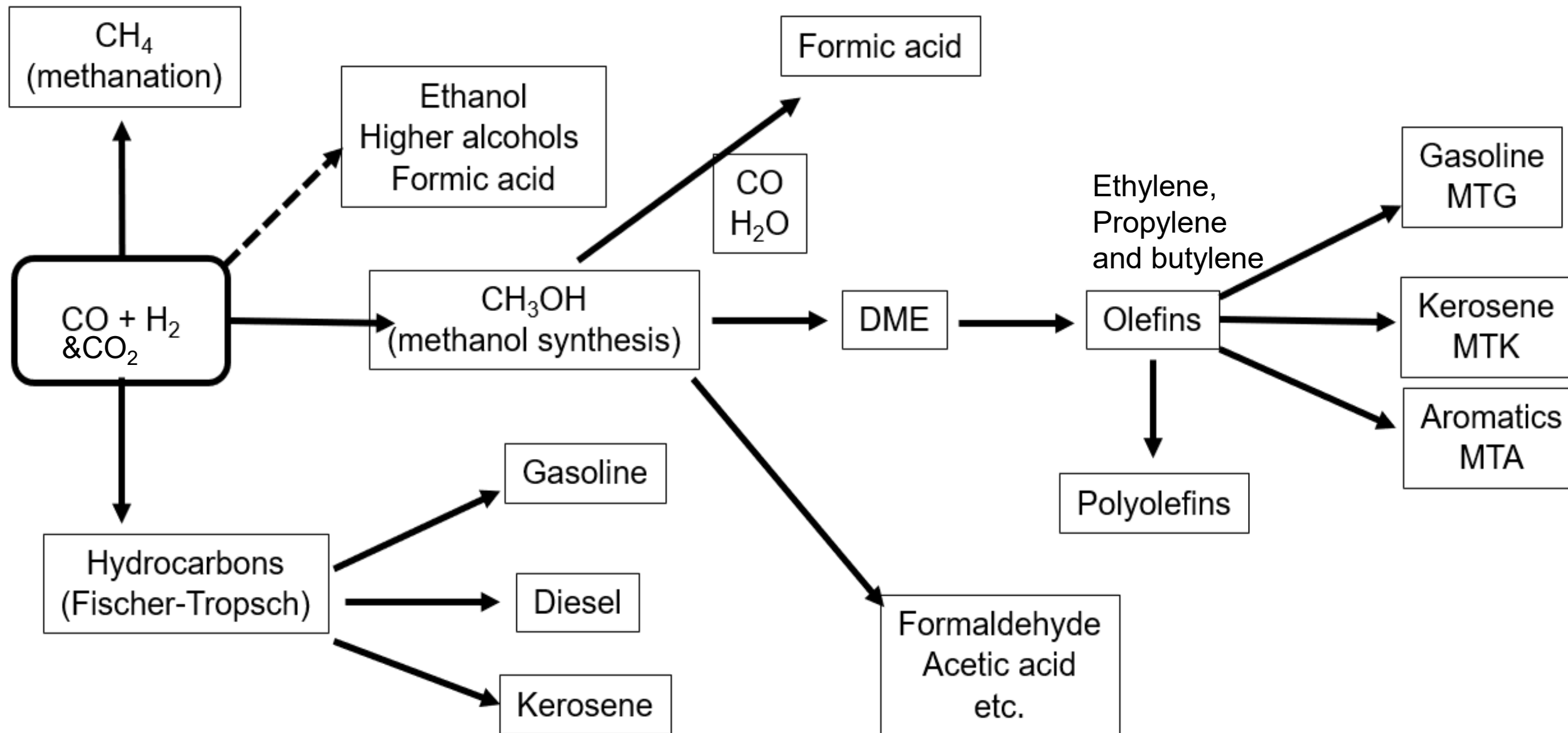
Country total biogenic emissions (MtCO₂e pa) 0 13

Mill biogenic emissions intensity (tCO₂e per tonne product) 0.6 3

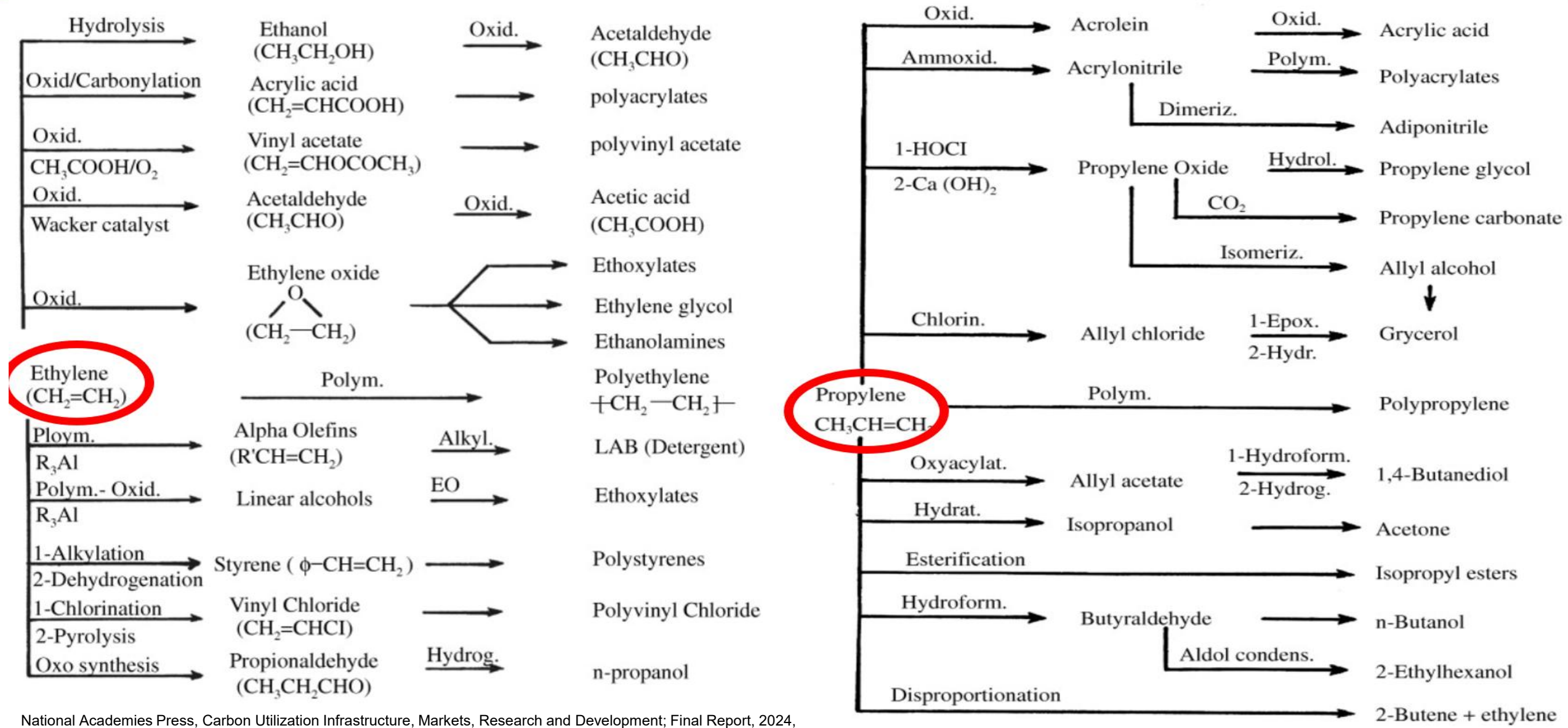


- ▶ Total biogenic CO₂ emissions in the EU are roughly 40 MT/per of which a significant share is in Finland and Sweden.
- ▶ Besides CO₂, the forest industry has side streams of biomass such as bark and black liquor (a side product of pulp production), which are normally combusted
 - ▶▶ but modern mills typically have a excess of energy => opportunities for direct conversion into fuels and chemicals instead of combustion + CO₂ capture + CO₂ hydrogenation into eChemicals

WHAT PRODUCT CAN BE PRODUCED FROM BIOGENIC CARBON AND HYDROGEN (1/2)?

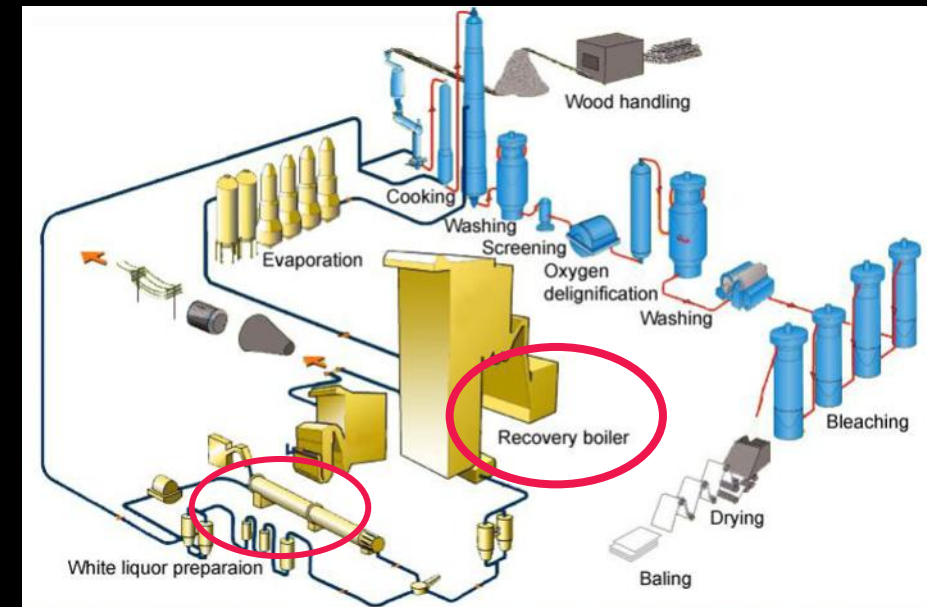


WHAT PRODUCT CAN BE PRODUCED FROM BIOGENIC CARBON AND HYDROGEN (2/2)?



BENEFITS OF CAPTURING FOREST INDUSTRY CO₂?

- Opportunity to produce for example millions of tons/a of new products from biobased CO₂
 - An amount of 1.6- 2.4 ton biogenic CO₂ is released per ton of pulp produced in Kraft Pulping
- Opportunity for new products fuels and chemicals methanol etc.
- A lot of waste heat available to regenerate from the CO₂ capture media



Source: circular-economy.europa.eu
2023, Äänekoski Bioproduct Mill

PULP MILL CO₂ EMISSIONS SOURCES

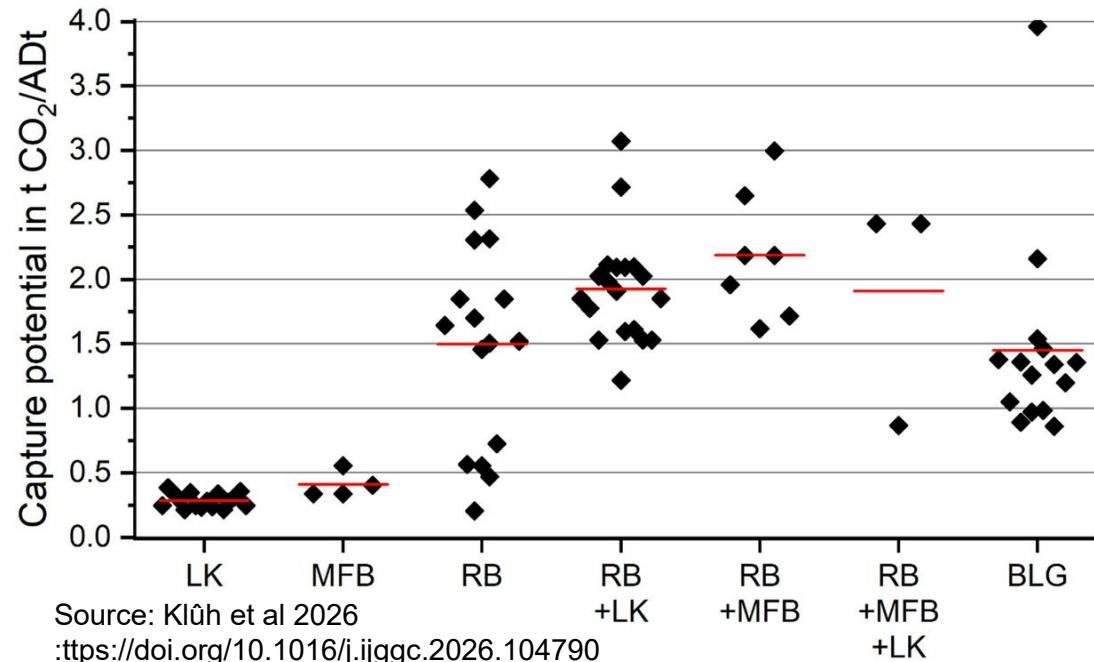


Common recovery boiler from Valmet, Finland



A lime kiln from ANDRITZ, Finland

- » Current Pulp mill CO₂ emissions come from:
 - » Biogenic (major part) : Combustion of Black liquor, bark, etc.
 - » Fossil fuel combustion, mainly in the lime kiln
- » The highest CO₂ emissions come from
 - » Recovery boilers and lime kilns



RECENT DEMONSTRATION OF CO2 CAPTURE AT PULP MILLS

Pulp mill	Technology provider	Type of technology	Start up	Type of plant	Capacity
Resolute Forest Products Inc. Saint-Félicien, Canada	CO ₂ Solutions Inc.	Enzyme assisted capture process	2018	Demo	30 tpd
Metsä Group Rauma, Finland	Andritz AG	Absorption	2025	Demo	-
Stora Enso Skutskär, Sweden	Saipem SpA	Enzyme assisted capture process	2024	Demo	2 tpd
Kruger Wayagamack Inc., Canada	Mantel Capture Inc.	Molten salt-based carbon capture	-	Demo	5 tpd
Mercer International Inc. Peace River, Canada	Svante Technologies Inc.	Solid sorbent	-	Demo	-
International Paper Vicksburg, USA	SLB Capturi, RTI International	Non-aqueous solvent technology (RTI)	2029	Demo	120 ktpa
Södra Varö, Sweden	Svante Technologies Inc.	Solid sorbent	2026	Demo	-
Mondi Hinton, Canada	-	Absorption	2029	Large scale	1.26 Mtpa
-	CO280 Solutions Inc. / Aker carbon capture	Absorption	2029	Large scale	0.8 Mtpa

Source: Klûh et al 2026 :<https://doi.org/10.1016/j.ijggc.2026.104790>

CASE STUDY FOR APPLYING DIFFERENT CO₂ CAPTURE TECHNOLOGIES IN TWO DIFFERENT PULP MILLS

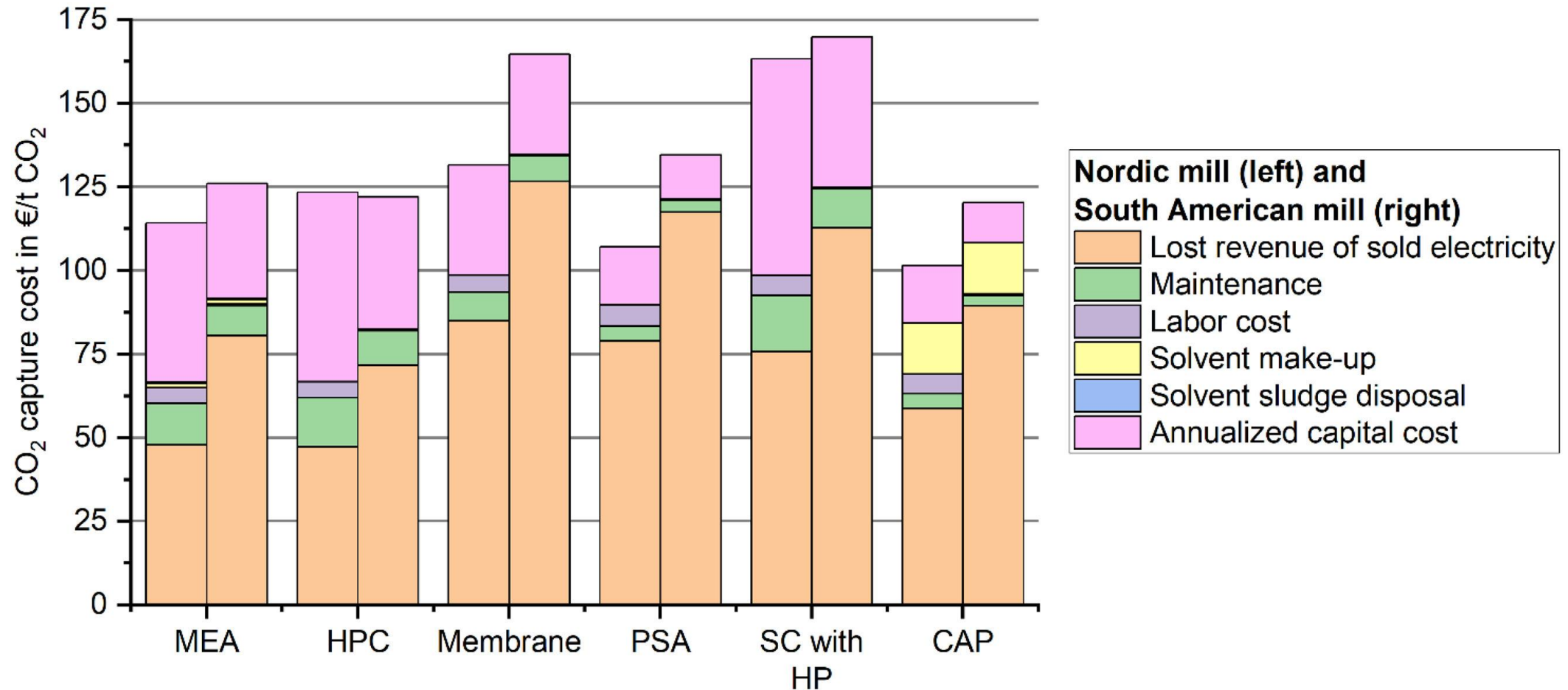
Parameters for the pulp Mills	Nordic pulp mill	South American pulp mill	Unit
Type	Integrated	Standalone	-
Annual pulp production	1,400,000	1,500,000	ADt/a
Mill electricity generation	234	165	MW ^{el}
Mill electricity consumption	92	89	MW ^{el}
Paper mill electricity consumption	120	-	MW ^{el}
Mill electricity fed to grid	22	76	MW ^{el}
Steam generation multifuel boiler	311	-	t/h
Steam generation recovery boiler	1,055	890	t/h
Steam use mill	1,109	660	t/h
Annual biogenic CO ₂ emissions	4,469	2,847	kt/a
Annual fossil CO ₂ emissions	142	171	kt/a
Annual operating hours	8,400	8,400	h/a

KEY PARAMETERS FOR DIFFERENT CO₂ CAPTURE TECHNOLOGIES

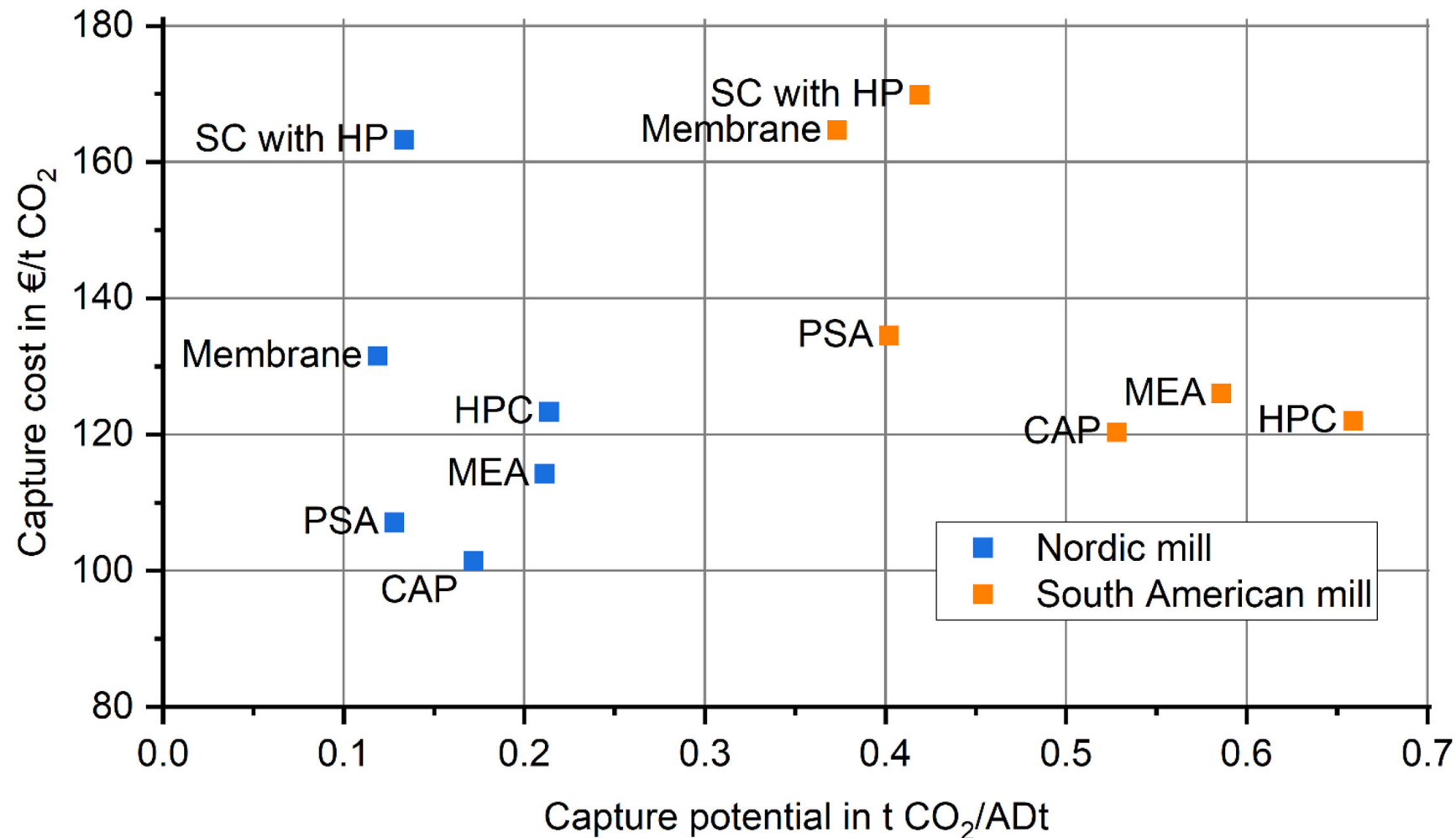
	MEA	HPC	Membrane	PSA	SC with HP	CAP
Electricity demand in MWh _{el} /t CO ₂	0.10	0.12	1.14	1.05	0.64	0.30
Thermal energy demand in MWh _{th} /t CO ₂	1.03	0.84	0	0	0	0.68
Temperature level of the steam supply, °C	130	117	-	-	75	115
Technology maturity level (TRL)	9	9	7	9	4–5	6–7

MEA = Monoethanolamine, HPC = Hot Potassium Carbonate, PSA = Pressure Swing Absorption, SC with HP Sodium Carbonate with Heat Pump and CAP Chilled Ammonia Process

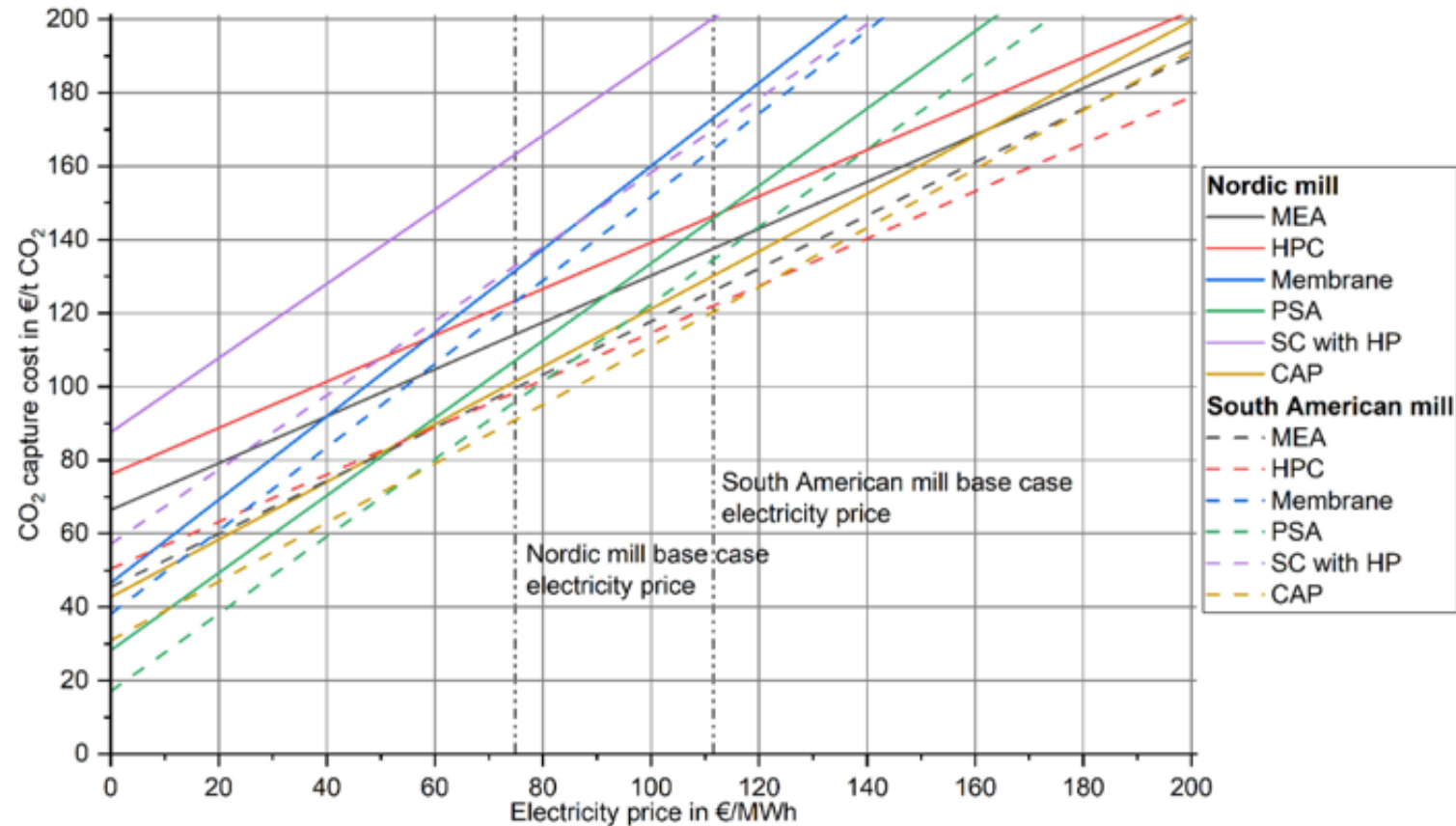
CASE STUDY RESULTS OF CO₂ CAPTURE COSTS



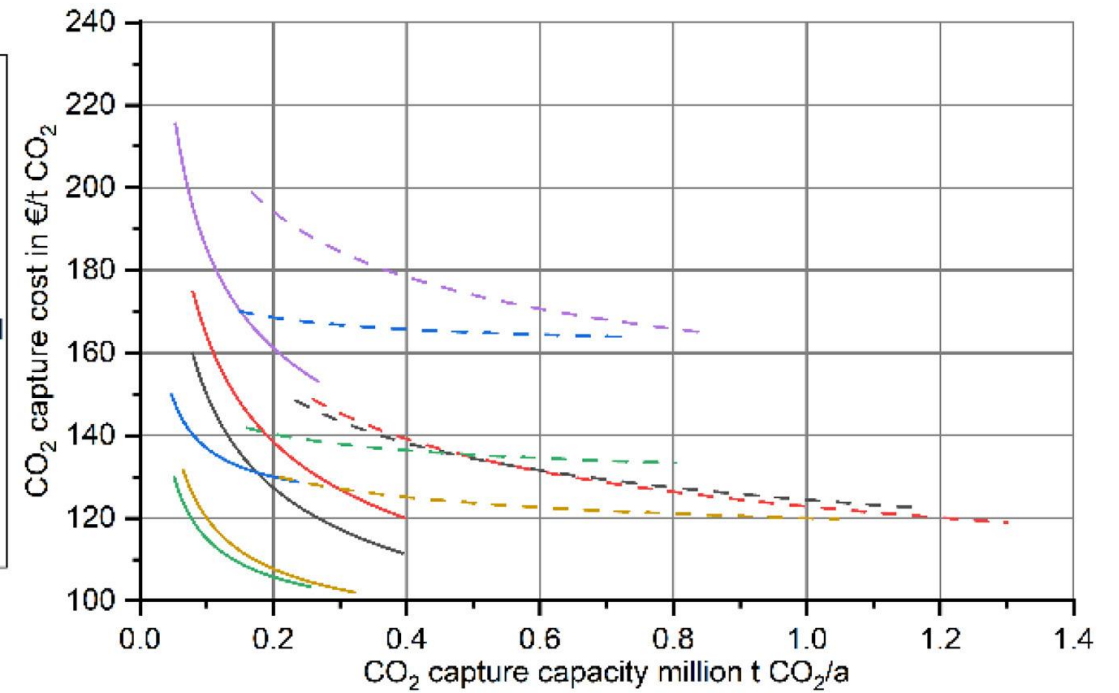
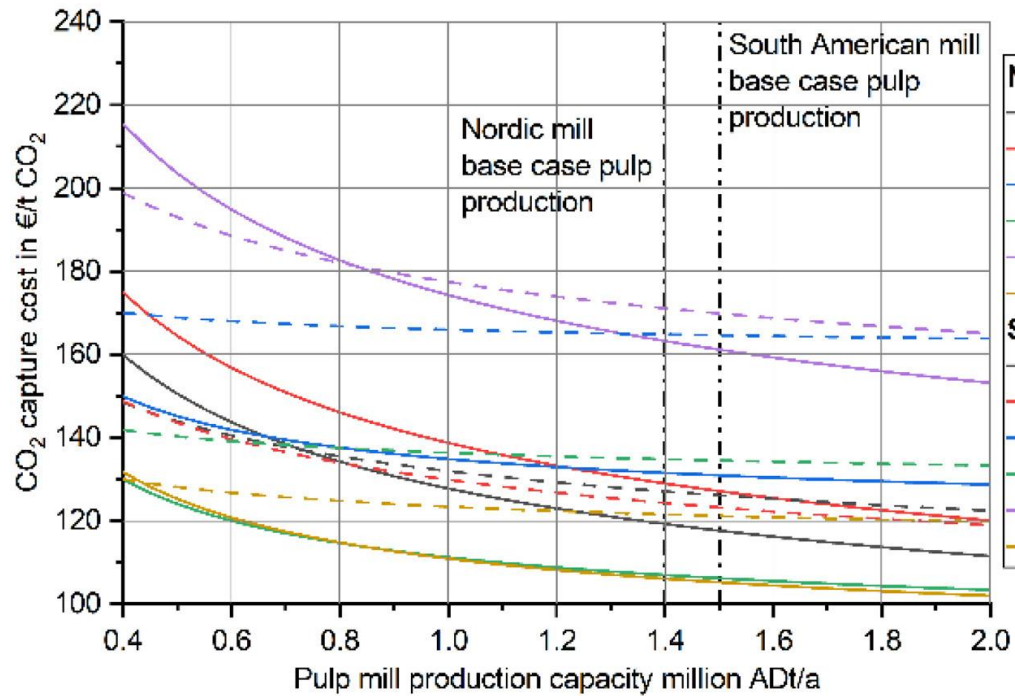
CO2 CAPTURE COST VS. POTENTIAL



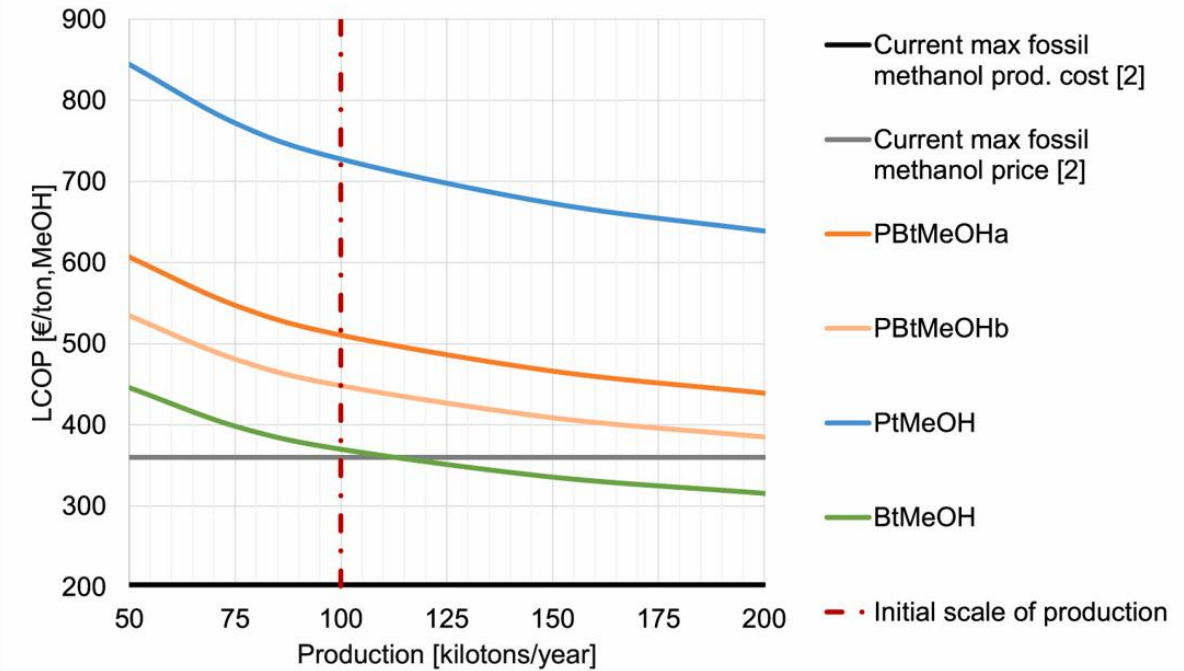
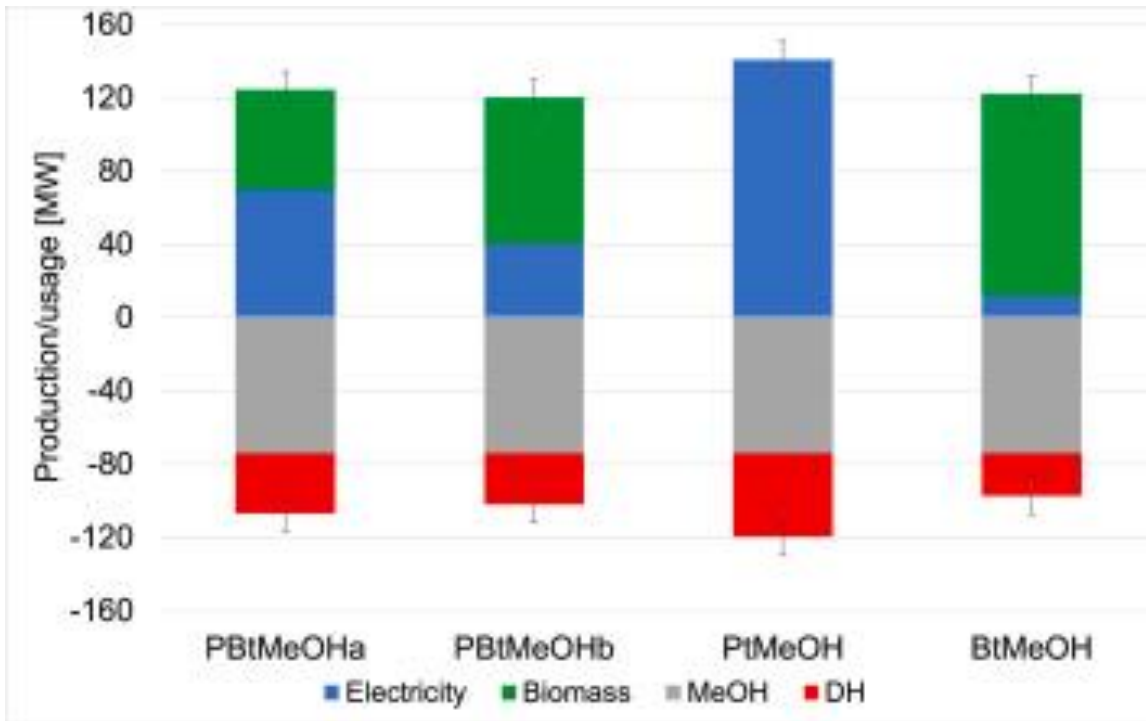
ELECTRICITY PRICE VS CO₂ CAPTURE COST



CO₂ CAPTURE COST VS. SCALE



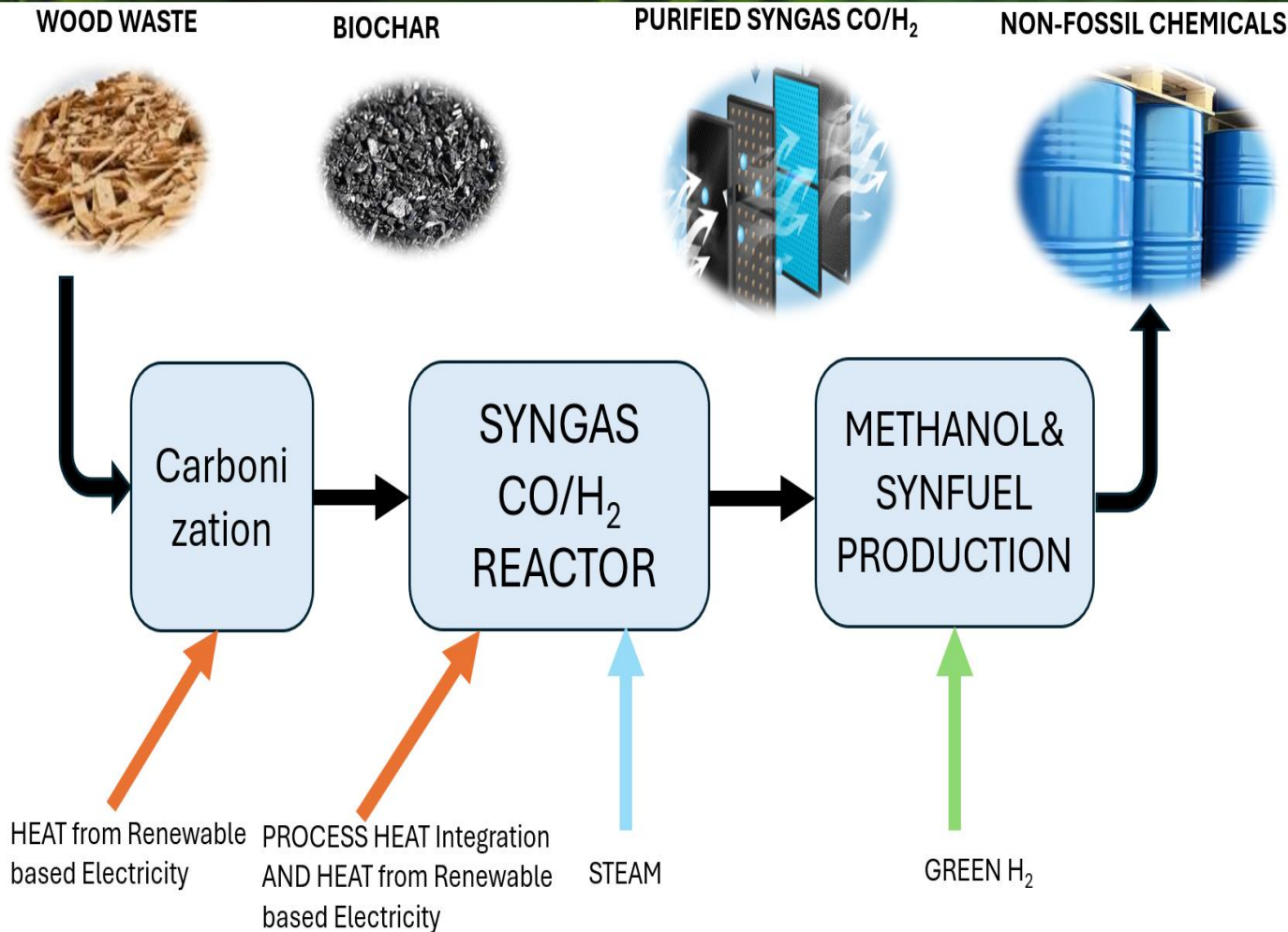
COMPARISON OF EFFICIENCY AND COST OF GASIFICATION VERSUS CO₂ CAPTURE



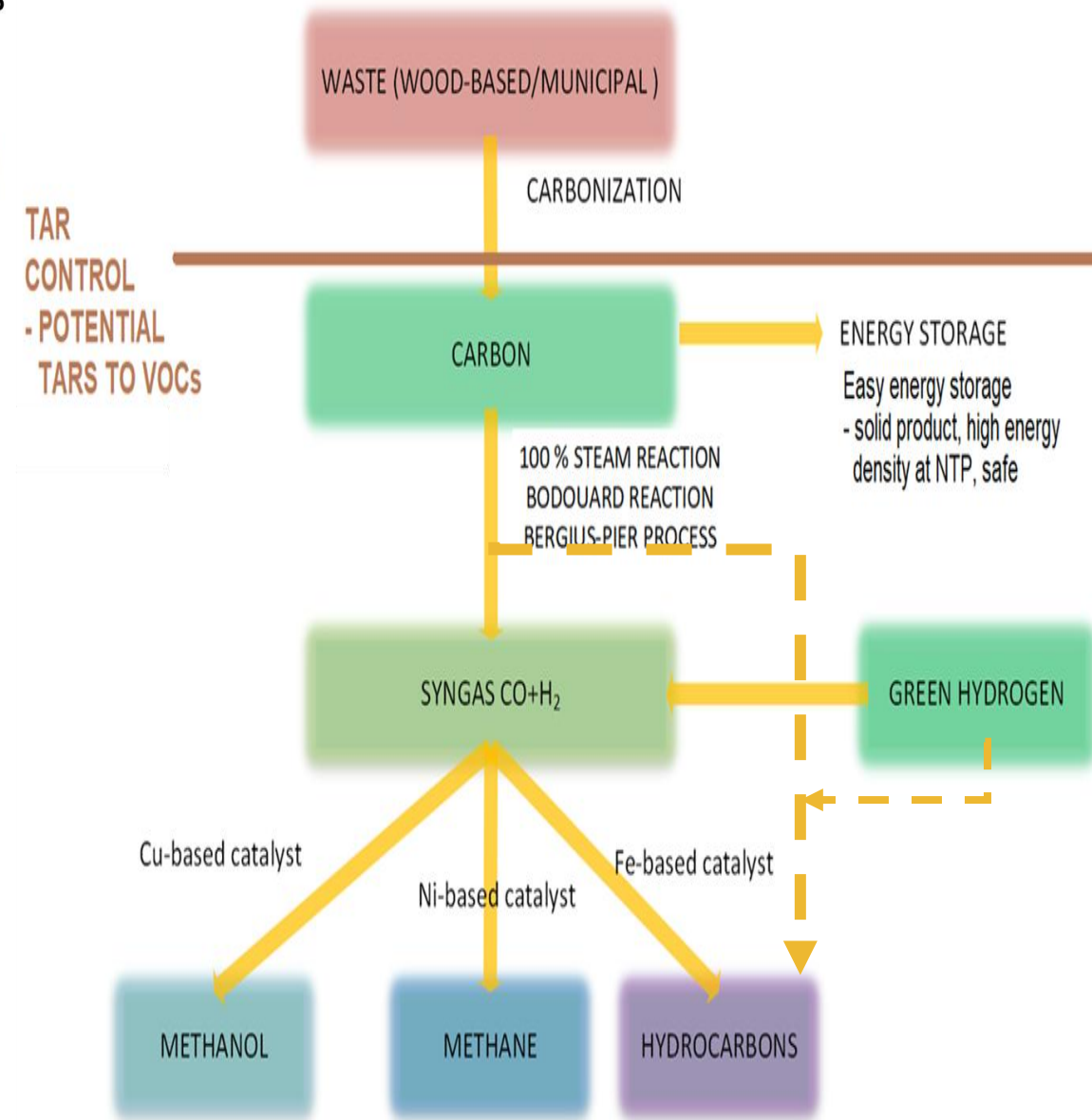
Source: Anetjarvi et al. 2023 <https://doi.org/10.1016/j.energy.2023.127202>

- Above 0 inputs to process (biomass and electricity) as MWs and below products, methanol, district heating.
- BtMeOH 'Methanol Through gasification, PTBMeOHa and b hydroegn supplemented gasification, PtMeOH power to Methanol

USING BIOCHAR INSTEAD OF HYDROGEN IS AN INTERESTING ALTERNATIVE WHEN BIOMASS IS AVAILABLE



A start-up Reduciner in Finland is producing Carbon monoxide from biochar+CO₂
more info: <https://www.reduciner.com/technology>



CONCLUSIONS

- » We can still produce most chemicals using existing chemical industry infrastructure, replacing oil or natural gas with either captured CO₂ and green H₂ from wind & solar power or with synthesis gas from biomass gasification
- » Challenges:
 - » A huge amount of green electricity would need to be produced and transported
 - » Cost of green Hydrogen
 - » Availability of biomass in regions where there is not a lot of forest residues and biomass residues from industry
- » Pulp mills are an important source of biogenic CO₂, especially in Finland and Sweden, which offer Millions of tons/year as point sources without additional need for wood input.
 - » Capturing CO₂ at pulp mills benefits from excess heat available to regenerate the CO₂ absorbent.
 - » However, capturing CO₂ reduces electricity production at the mill, and the steam availability limits the amount of CO₂ that can be captured without providing extra heat to regenerate the CO₂ absorbent.
- » Biomass residues from bark or black liquor offer a cheaper biogenic source but typically require larger changes to the pulping process that add to the system to flue gas.
- » Combination of plastic chemical recycling and CCU should be studied to reduce costs and electricity demand



ACKNOWLEDGEMENTS

»» Funding Through Business Finland Project: Mill-Integrated CO₂ capture



Thank you: Daniel Klüh from Klühbirnen Engineering and Eemeli Anetjärvi, Satu Lipiäinen, Katja Kuparinen, Mario Mero, Orlando Salcedo Puerto (also in Valmet), Ekaterina Sermyagina and Esa Vakkilainen from LUT!

Questions: Kristian.Melin@lut.fi