Lehrstuhl für Energiesysteme
TUM School of Engineering and Design
Technische Universität München

Gefördert durch:
Bundesministerium für Forschung, Technologie und Raumfahrt
FONA Energie und Wasserstoff
H2 reallabor burghausen

Biogenic Feedstocks for SAF: Technical and Economic Perspectives

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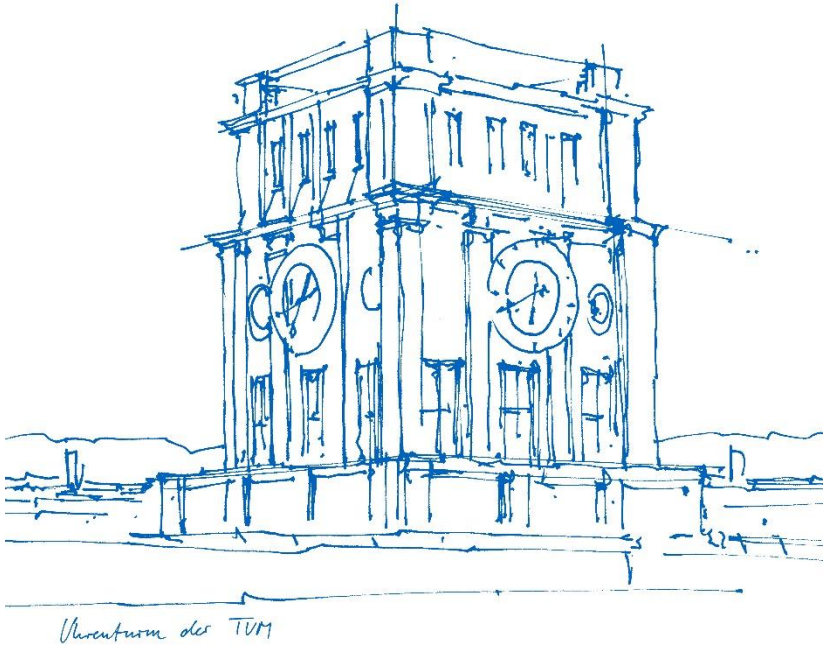
TUM School of Engineering and Design

Lehrstuhl für Energiesysteme

München, 06. Oktober 2026

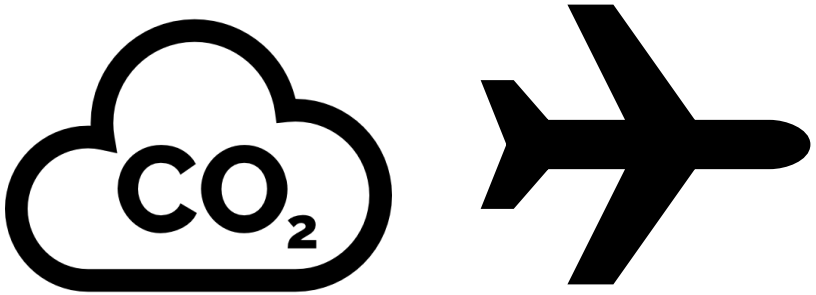


Motivation

Sustainable aviation fuel (SAF) is essential for defossilization of the aviation sector

CO_2 Emissions of aviation are rising [1]

~800 Mt



Why „Sustainable Aviation Fuels“ (SAF)? [2]

SAFs = „Drop-In“ fuels with reduced total emissions

High Energy Densities | **High TRL** | **Existing Infrastructure**

EU SAF quotas in ReFuelEU Aviation [3]

Year	2025	2030	2032	2035	2040	2045	2050
Share of SAF	2%	6%	6%	20%	34%	42%	70%
Minimum share of synthetic aviation fuels	0%	1.2%*	2%*	5%	10%	15%	35%

1) How high are SAF production potentials and costs?
2) How the (synthetic) SAF quota can be met?

SAF: Sustainable Aviation Fuel TRL: Technology Readiness Level

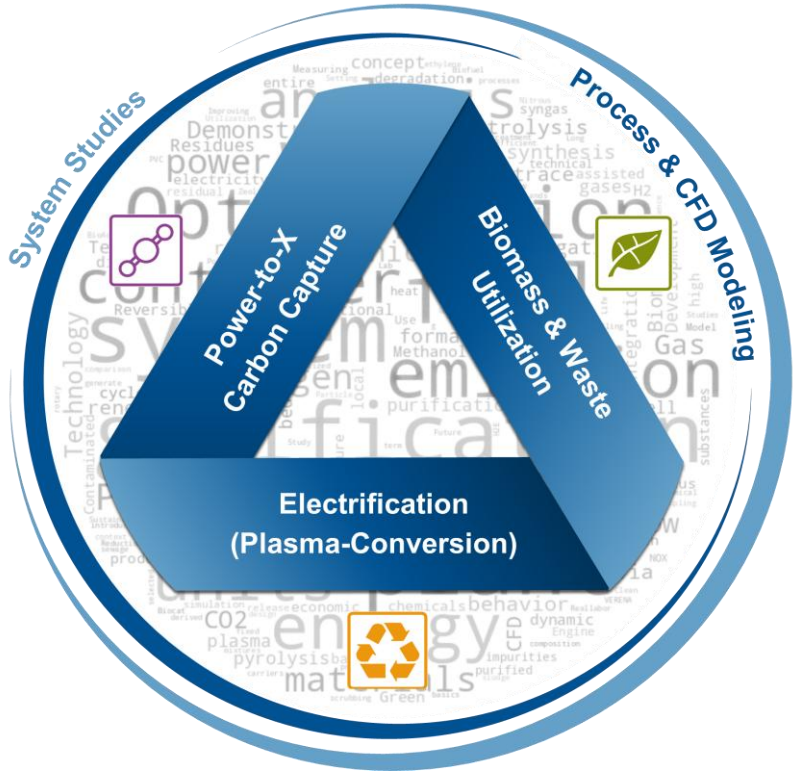
[1] Ng et al. 2021 „Global biorenewable development strategies for sustainable aviation fuel production“
[2] Mission possible partnership 2022 „Making net-zero aviation possible“
[3] NOW 2024 „ReFuelEU Aviation Regulation – How does it affect the aviation sector? “

Research Group Carbon Conversion Technologies (CCT)

Head of the group: Sebastian Fendt

- Research focus: **Development and integration of innovative processes for the sustainable utilization of carbon resources.**
- Goal: **Close the carbon cycle** (→ defossilization and reduction of GHG)
- **Three complementary sources of carbon**:
  - **Bio-based carbon** (biomass and biogenic residues)
  - **Captured carbon / CO_2** (DAC/CC)
  - **Recovered carbon** (recycling of waste)
- **Group structure:**
  - **Power-to-X and Carbon Capture**
  - **Biomass and Waste Utilization**
  - **Electrification and Plasma Conversion**
  - **System studies**
  - **Process and CFD modeling**

→ **Integrated experimental and simulative research approach across scales**



Agenda

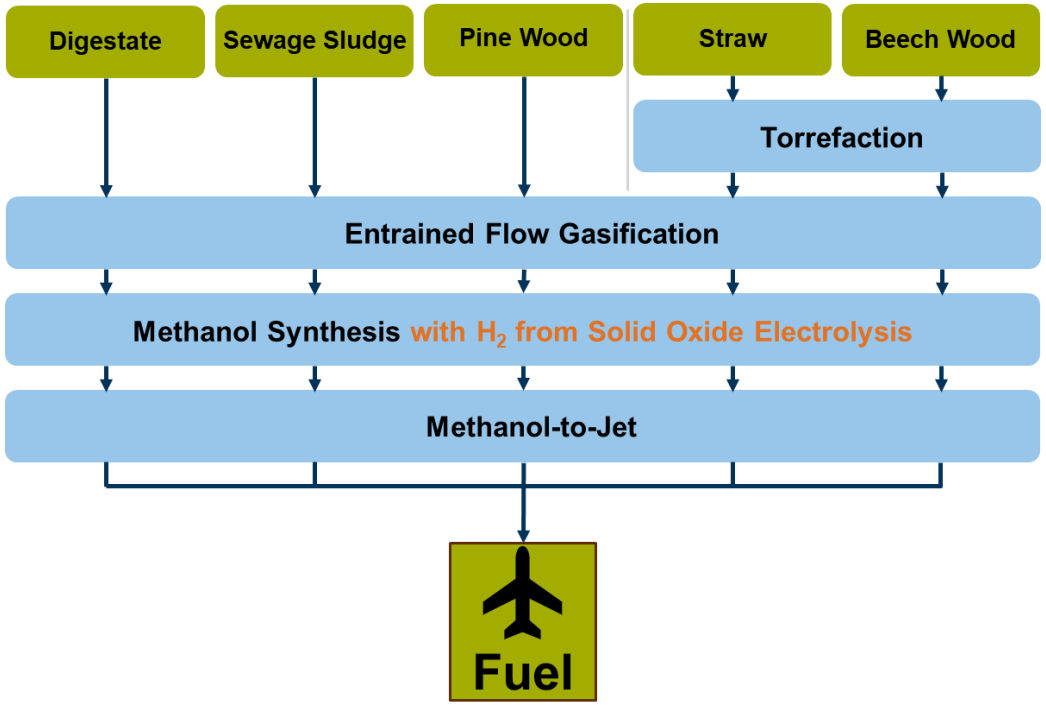
- Motivation
- Introduction of the Research Group
- Study Design
- Technical Results
- Economic Results
- Conclusion and Outlook

Study Design

How feedstock properties and availability impact the performance of a PBtJ Methanol-to-Jet process?

Power-and-Biomass to Jet (PBtJ): 1) Overcome carbon conversion limits (facing limited feedstock availability)

2) Enter e-Saf market and meet the synthetic SAF quota



Research Questions

- Impact of feedstock materials on the techno-economic performance?
- Impact of plant scale and feedstock availability on the economics?

Approach

- Process modeling in Aspen Plus
- Detailed economic analysis considering feedstock properties

Results published in Eyberg et al. 2026 (10.1016/j.apenergy.2026.128352)

Study Design

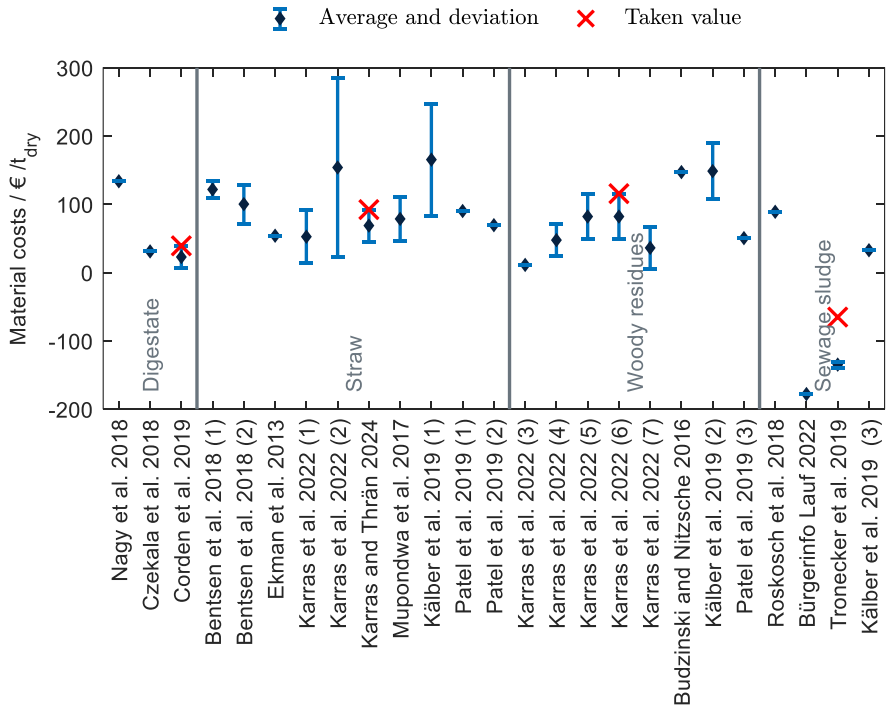
Raw materials differ strongly in terms of composition and purchase costs

Composition [1-3]

Parameter	Unit	Corn straw	Beech wood	Pine wood	Digestate	Sewage sludge
Proximate analysis on dry basis						
Volatiles	wt%	75.90	84.22	81.60	56.63	55.50
Fixed carbon	wt%	17.18	14.91	17.76	16.97	6.61
Ash	wt%	6.92	0.87	0.64	26.40	37.90
Moisture (as received)	wt%	50.00	35.00	7.61	10.24	3.20
Ultimate analysis on dry basis						
C	wt%	48.51	50.14	54.54	41.80	33.48
H	wt%	5.41	6.26	5.20	4.02	4.35
O	wt%	36.92	42.37	39.12	23.21	15.52
N	wt%	1.35	0.20	0.35	2.69	4.88
S	wt%	0.21	0.15	0.13	0.24	2.32
Cl	wt%	0.63	0.01	0.02	1.63	1.55
HHV/LHV on dry basis						
HHV	MJ/kg	19.25	19.70	21.48	16.77	14.40
LHV	MJ/kg	18.07	18.19	20.34	15.90	13.46

- Large differences in ash, carbon and hydrogen fractions
- Gas cleaning requirements set by impurity concentrations

Feedstock costs

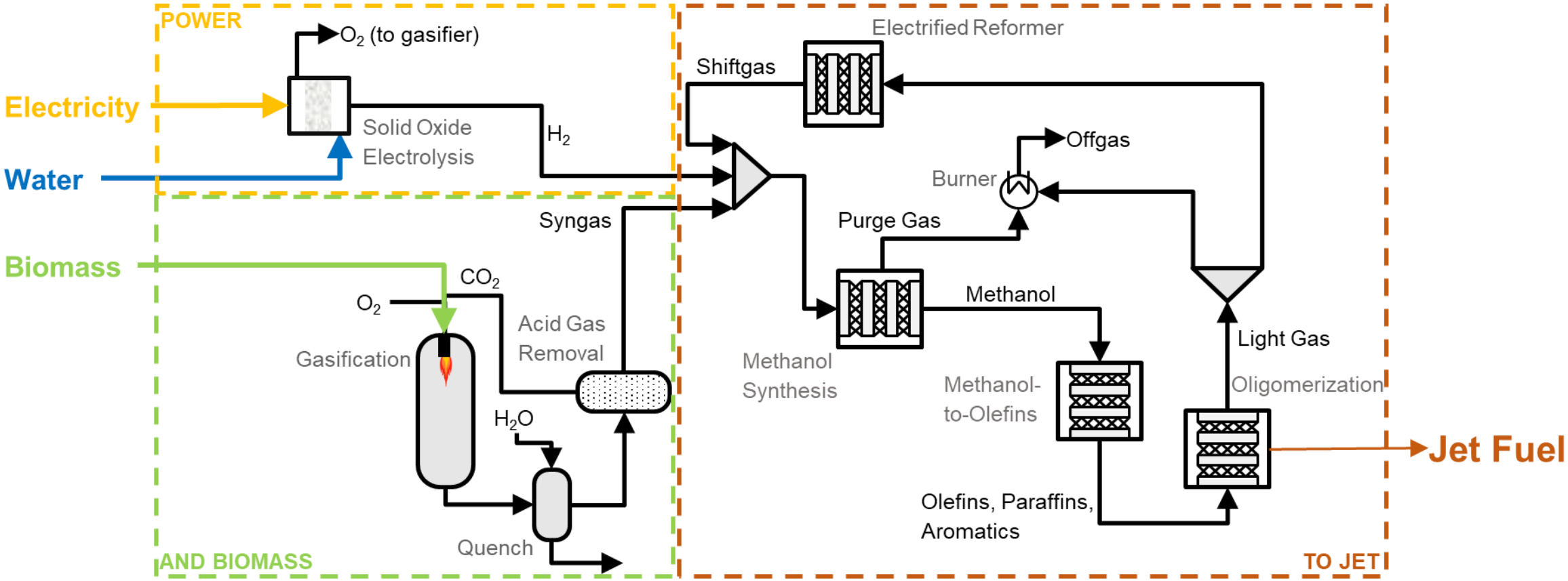


- Variations in cost data (→ Sensitivity analysis)
- Sewage sludge uptake generates income

[1] Liu et al. 2021 [2] Dossow et al. 2021 [3] Naim and Springmann et al. 2026 [4] Eyberg et al. 2026

Study Design

Process flowsheet of the Power-and-Biomass-to-Jet process



[1] Eyberg et al. 2026

Study Design

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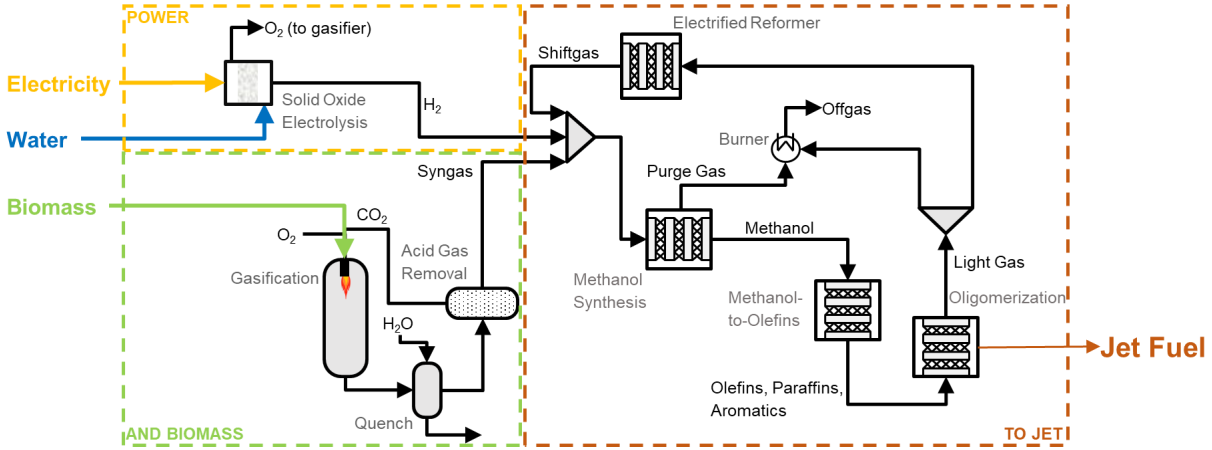
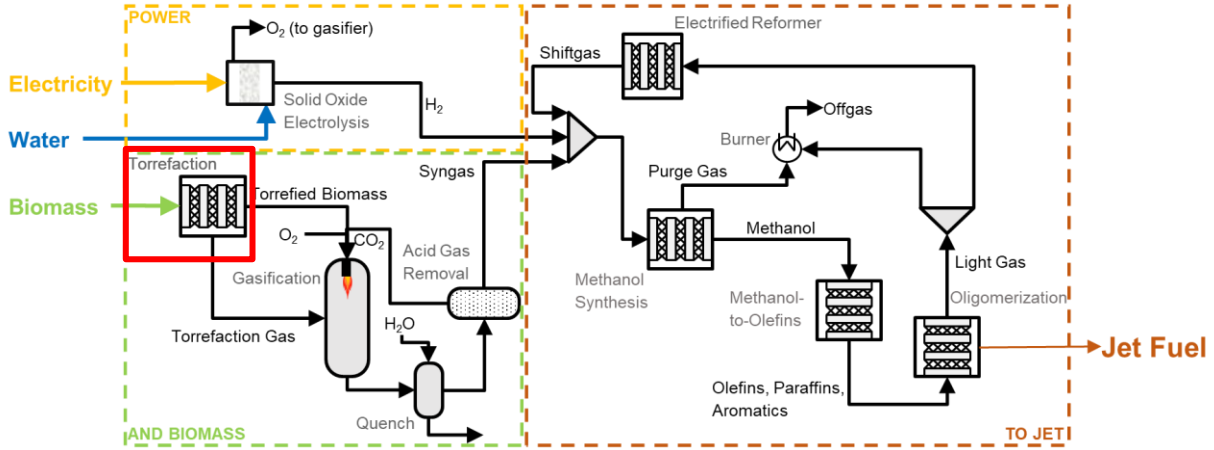


Without Torrefaction (pine wood, digestate, sewage sludge)



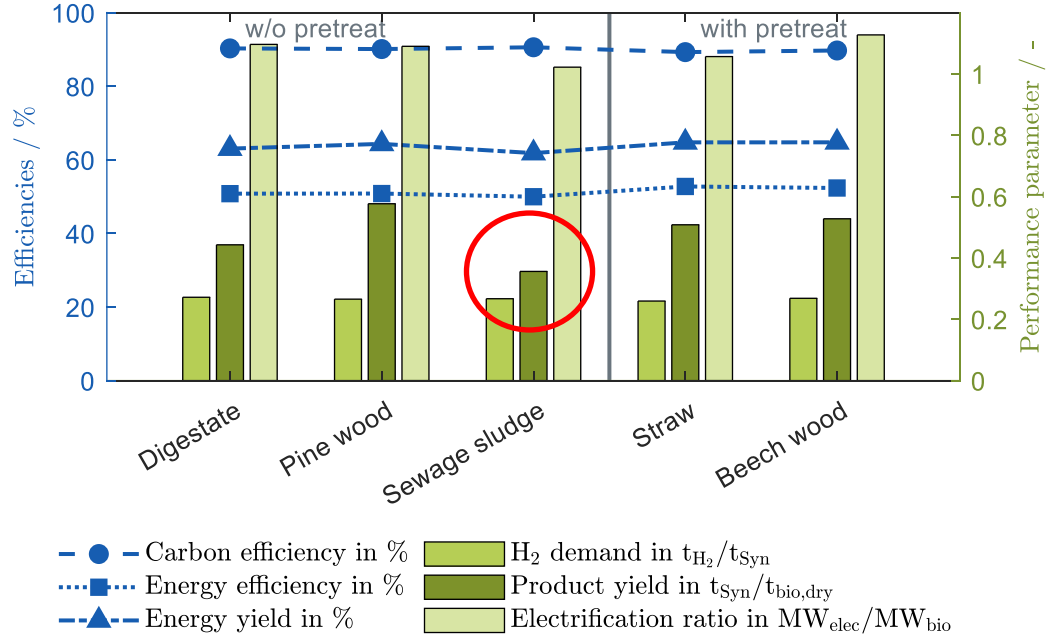
With torrefaction (beech wood, straw)

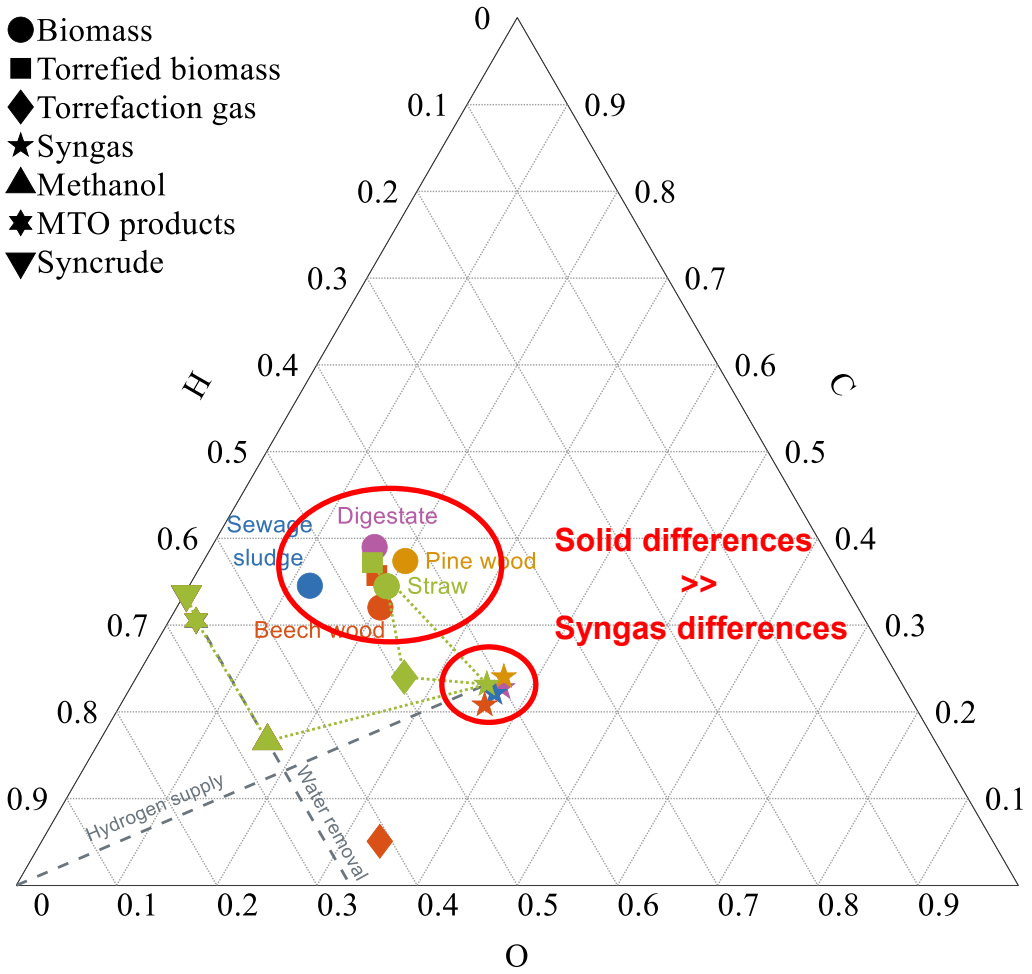
100 MW, 200 MW and 500 MW of feedstock are considered

[1] Eyberg et al. 2026

Technical results

The technical performance is only slightly influenced by the feedstock properties





- Small differences in efficiencies
- Product yield depends on ash content
- “Electrification ratio” depends on H/C and H/O ratio

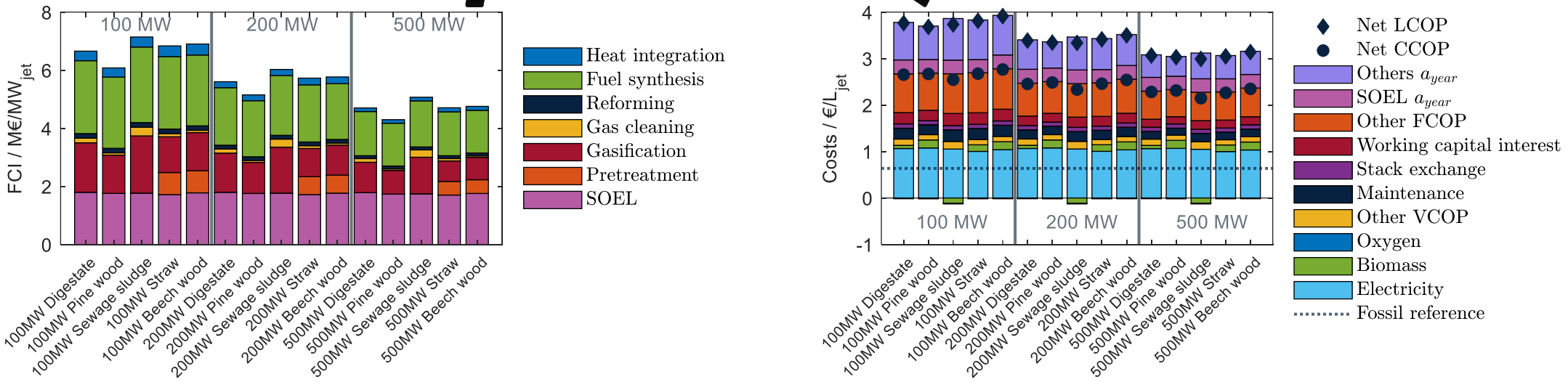
[1] Eyberg et al. 2026

Economic results

The capital investment and production costs depend more on the plant scale and less on the feedstock

$$a_{year} = \mathrm{FCI} \cdot \frac{\mathrm{i}(1+\mathrm{i})^{\mathrm{n_A}}}{\mathrm{i}(1+\mathrm{i})^{\mathrm{n_A}}-1}$$

$$\mathrm{LCOP} = \mathrm{VCOP} + \mathrm{FCOP} + a_{year}$$



- Strong economy-of-scale (except for SOEL)
- Main differences in the syngas generation
- Sewage sludge with highest capital costs

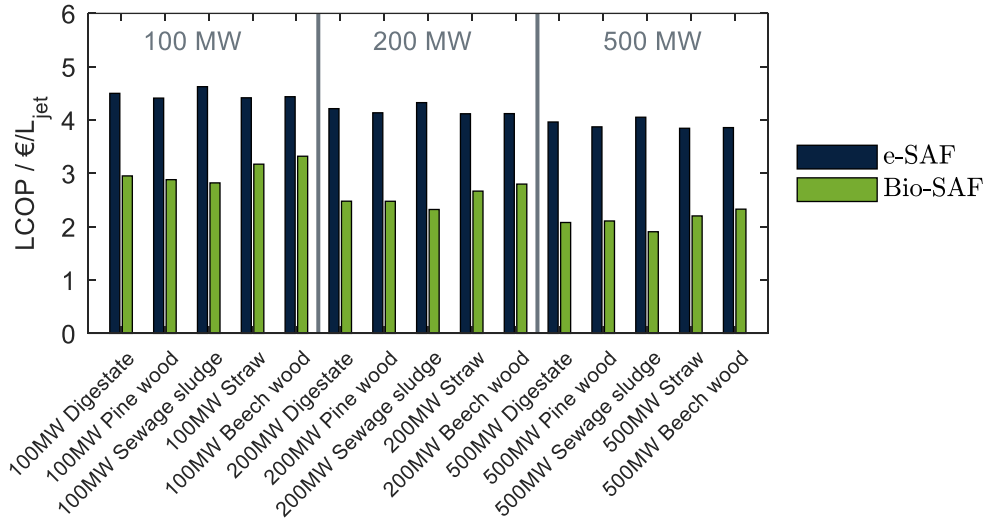
- Electricity costs and depreciation have a large share, biomass costs only have a minor fraction
- Lower costs at higher scales but limited by raw material availability

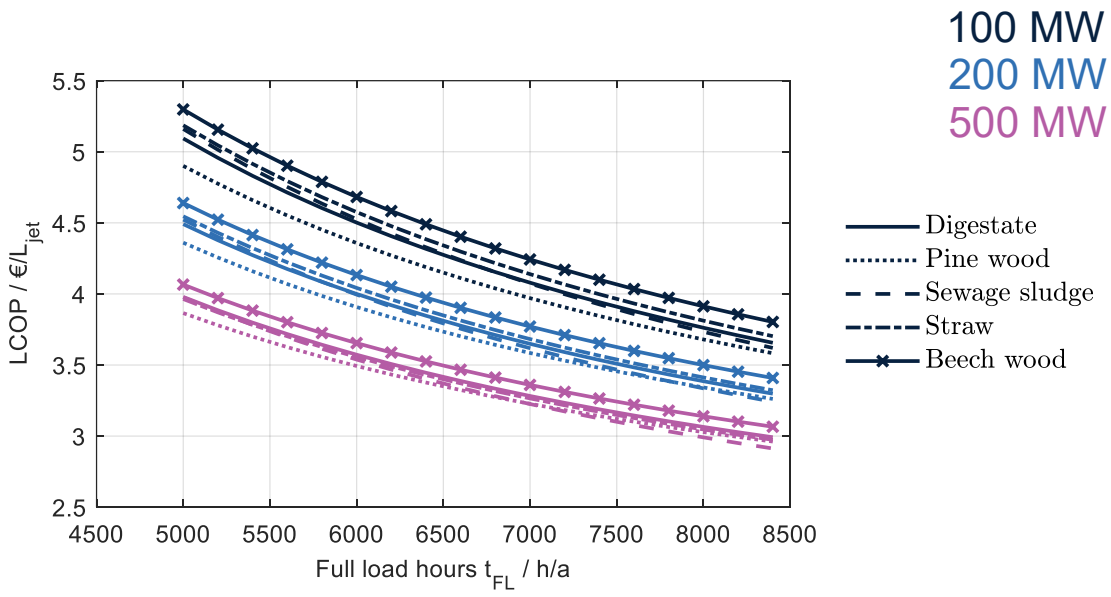
FCI: Fixed capital investment a_{year}: Annual depreciation i: Interest rate n_A: Ammortization period
VCOP: Variable costs of production FCOP: Fixed costs of production

[1] Eyberg et al. 2026

Economic results

E-SAF fraction dominates the costs and high full load hours are crucial





- Costs are split according to the energy shares
- e-SAF costs are ~50-100 % higher
- PBtL attractive to meet bio-SAF and e-SAF quota

- Reduced full load hours strongly increase the costs
- Stable gasifier operation is essential
- Large plants can tolerate reduced full load hours

[1] Eyberg et al. 2026

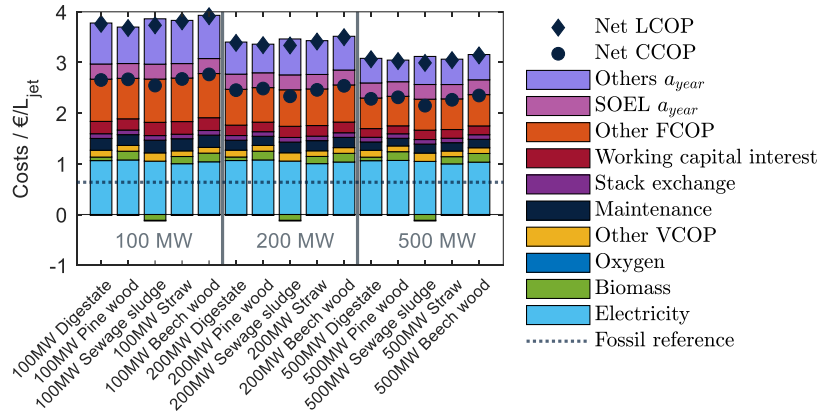
Conclusion and Outlook

How feedstock properties and availability impact the performance of a PBtJ Methanol-to-Jet process?

Conclusion

- Scaling and plant occupation are more important than the feedstock composition
- Choice of feedstock depending on availability and operating characteristics in the gasifier
- Production costs 4.5-6 x fossil costs

→ Suitable boundary conditions and technology improvements are required



Outlook

- The ReFuelEU-SAF quotas are creating pressure to expand the capacities, but higher jet fuel prices are indispensable
- Further research: comparison of different syngas to SAF conversion technologies

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Any Questions?

Acknowledgements

Weiss Naim[1], Sebastian Fendt[1], Hartmut Spliethoff[1]
[1]Chair of Energy Systems, Technical University of Munich, Germany

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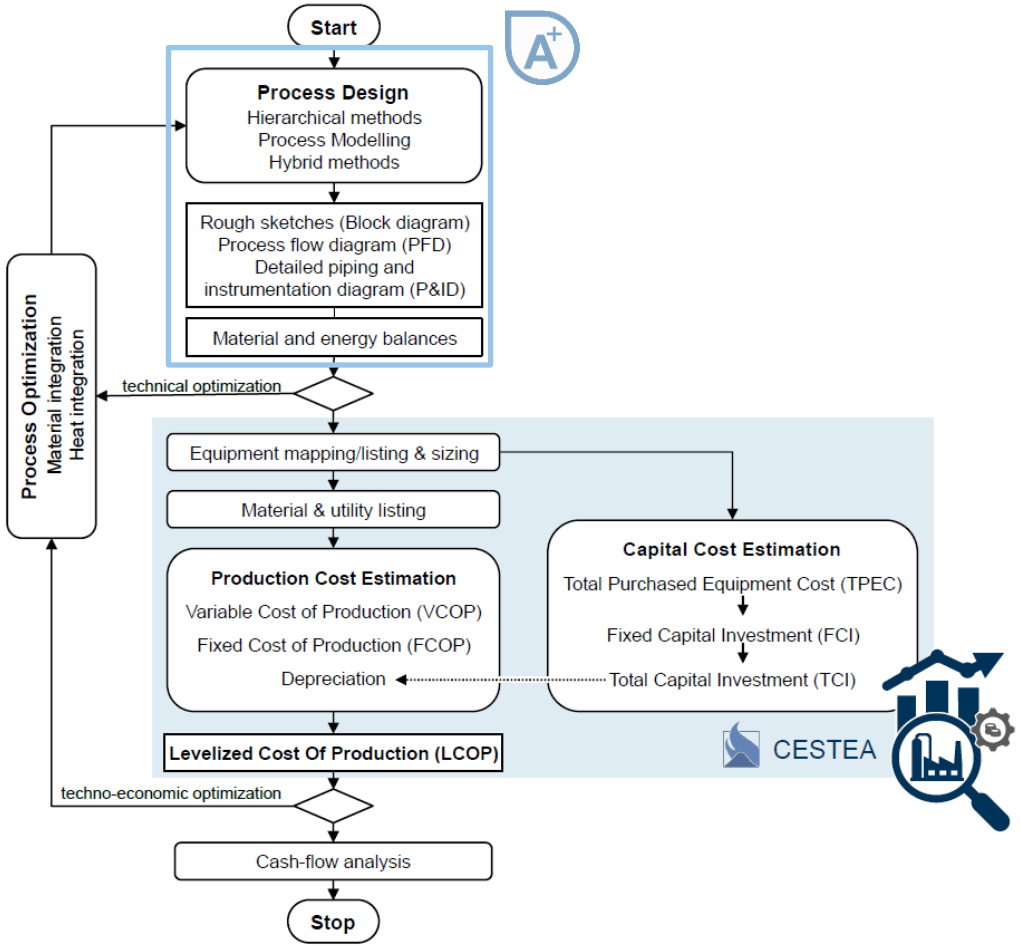
Methods

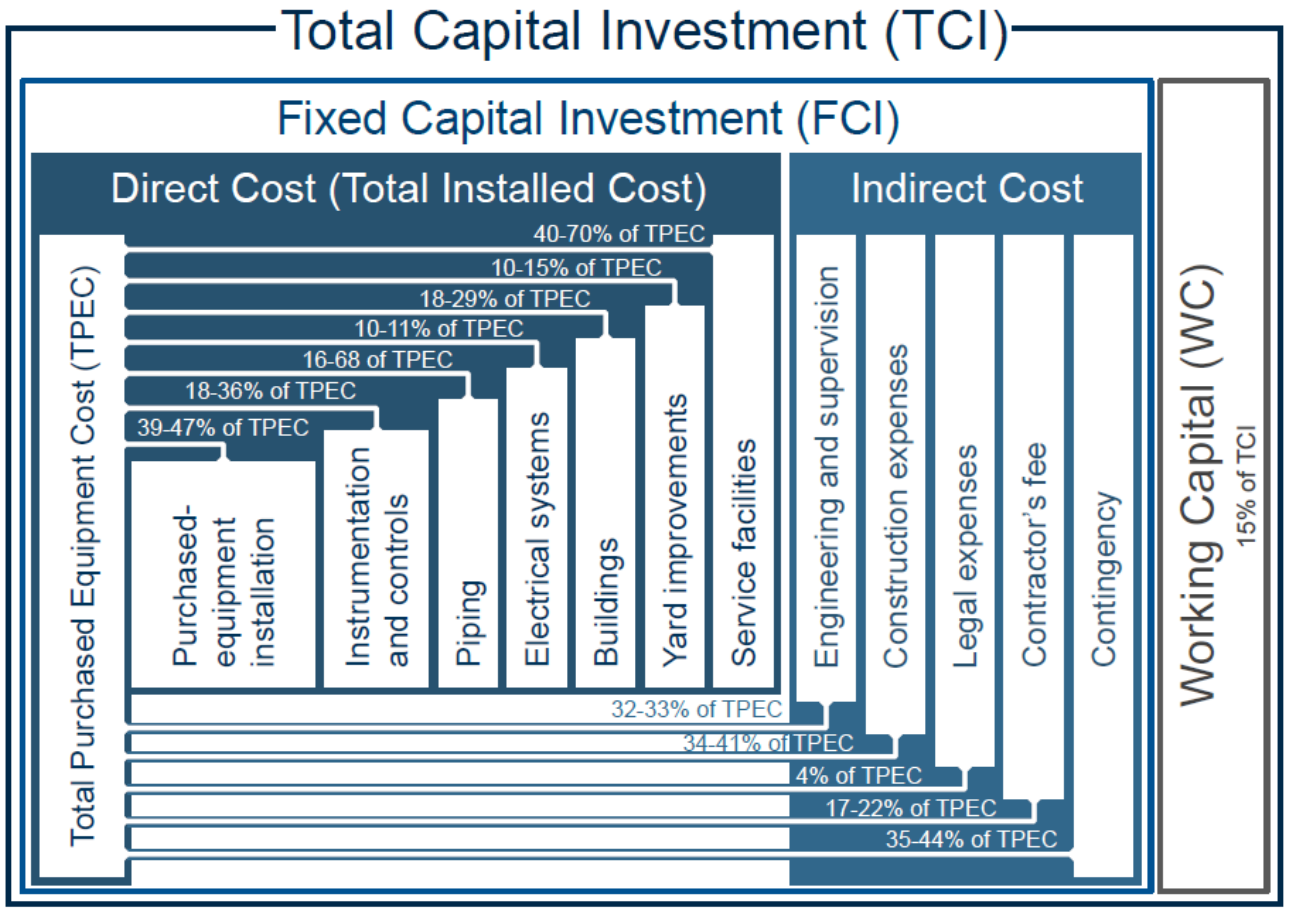
TUM CESTEA method - General



[1] Dossow et al. 2024

Methods

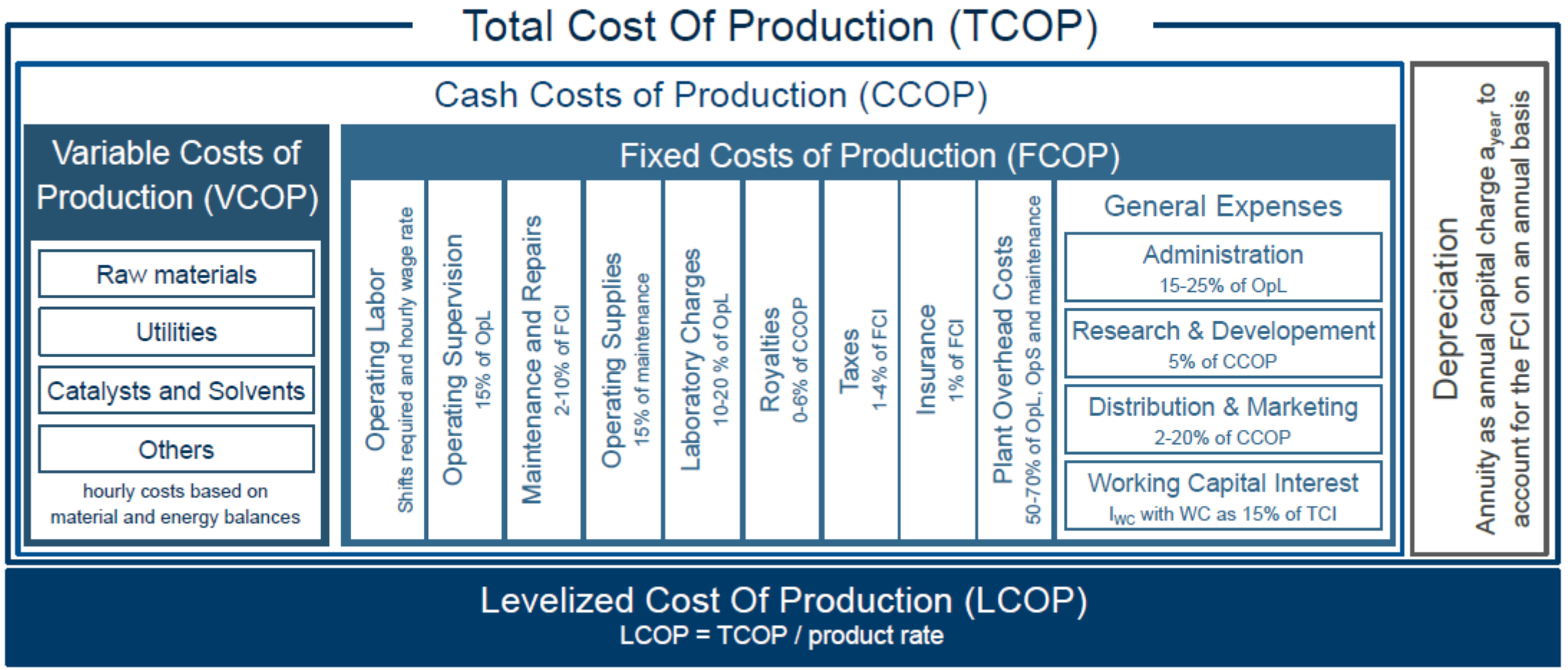
TUM CESTEA method - Investment costs



[1] Dossow et al. 2024

Methods

TUM CESTEA method – LCOP calculation



[1] Dossow et al. 2024

Study Design

LCOP calculation

$$\mathrm{LCOP} = \mathrm{VCOP} + \mathrm{FCOP} + a_{year}$$

VCOP

Category	Description	Costs/Revenues
Feedstock	Digestate (dried)	39.40 €/t_{dry}
	Pine wood[a]	127.39 €/t_{dry}
	Sewage sludge (dried)[b]	−65.00 €/t_{dry}
	Beech wood	115.81 €/t_{dry}
	Straw	92.45 €/t_{dry}
Energy	Electricity	0.10 €/kWh
	Steam	0.00 €/kWh
	Cooling water	0.10 €/m^3
	Chilled water	0.13 €/m^3
	Cryogenic cooling[c]	0.98 €/kWh
Water	Fresh water	2.07 €/m^3
	Demineralized water	4.14 €/m^3
	Waste water	10.00 €/m^3
By-products	Oxygen	−20.00 €/t

FCOP

Description	Estimation
Operating labor (OpL)[a]	3333 h/a · $(\dot{M}_{Syn})^{0.24}$ · n_P · 50 €/h [21, 101]
Operating supervision (OpS)	15 % of OpL
Maintenance[b]	3 % of FCI
Electrolyzer stack replacement[c]	40000 h lifetime [28], 30 % of EC [115], 12 % installation factor [127]
Operating supplies	15 % of maintenance[b]
Laboratory	15 % of OpL
Royalties	4 % of CCOP
Insurance	1 % of FCI
Property taxes	2 % of FCI
Plant overhead costs	60 % of OpL, OpS and maintenance[b]
Administration	20 % of OpL
Research and development	5 % of CCOP
Distribution and marketing	3 % of CCOP
Working capital interest	Eq. 9

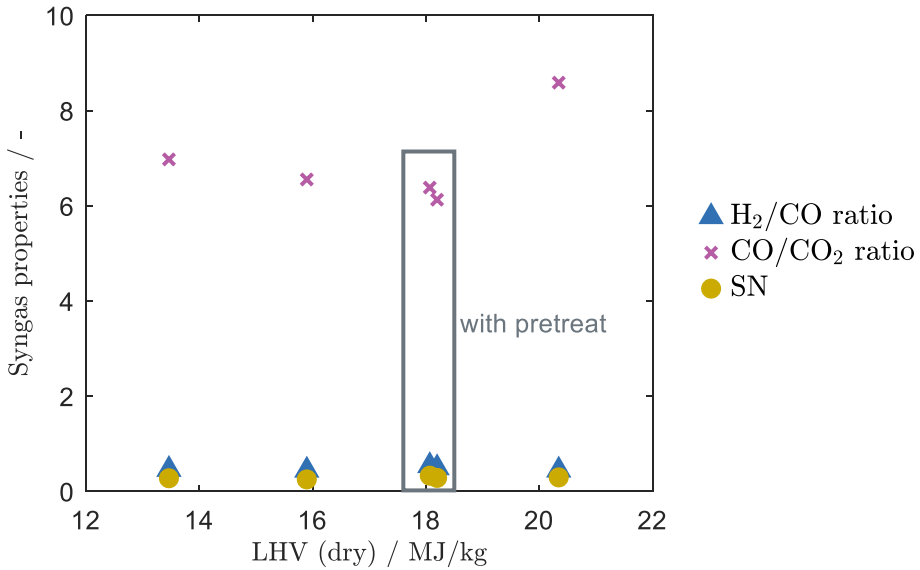
$$a_{year} = \mathrm{FCI} \cdot \frac{i\,(1+i)^{n_A}}{(1+i)^{n_A} - 1}$$

$$I_{WC} = \mathrm{WC} \cdot \frac{\left((1+i)^{PL} - 1\right)}{PL}$$

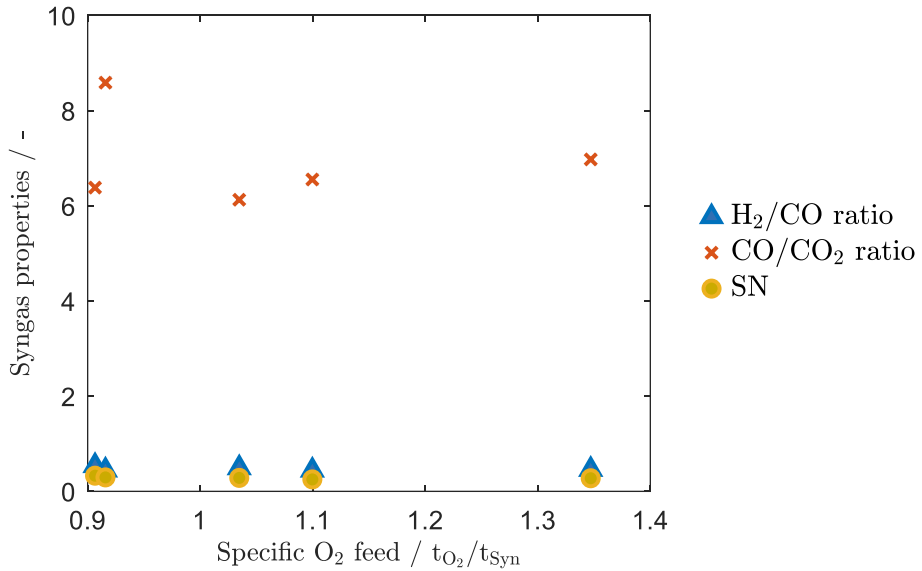
[1] Eyberg et al. 2026

Technical Results

Syngas properties



Sewage sludge < Digestate < Straw < Beech wood < Pine wood

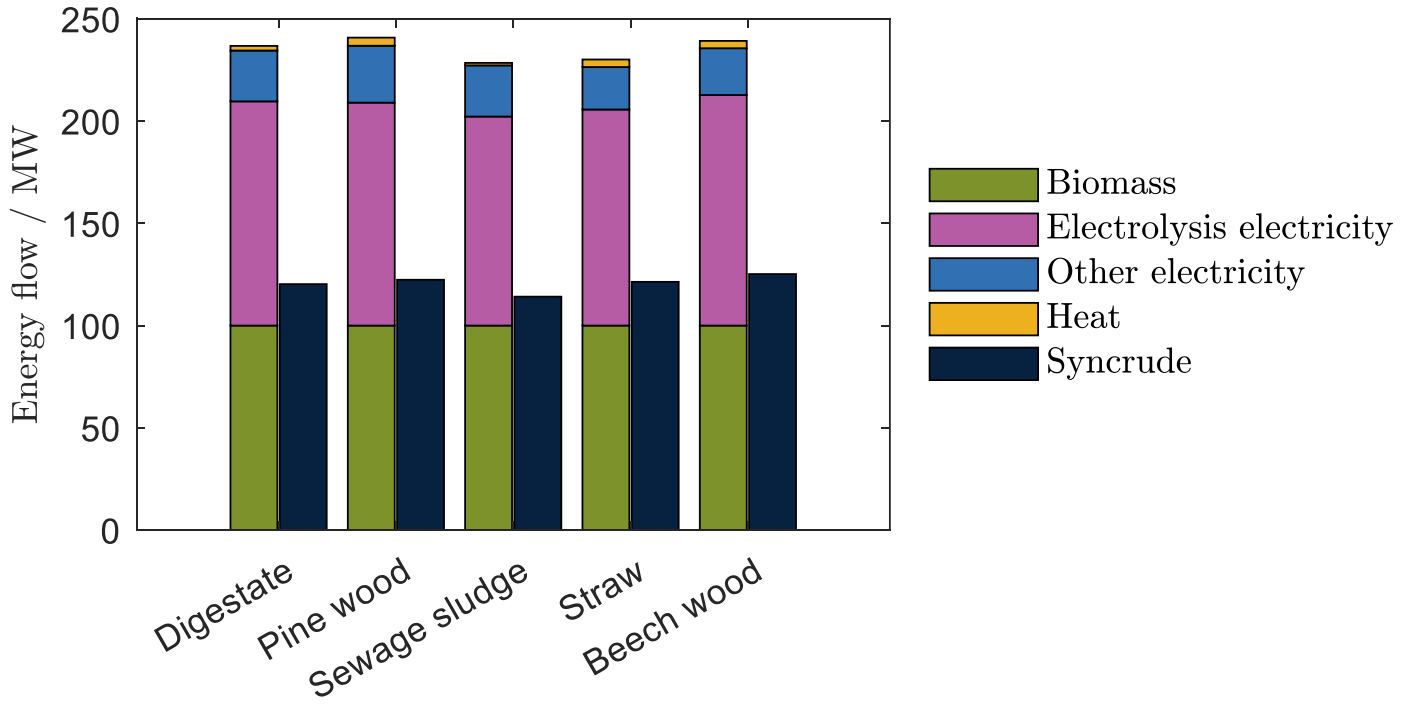


Straw < Pine wood < Beech wood < Digestate < Sewage sludge

[1] Eyberg et al. 2026

Technical results

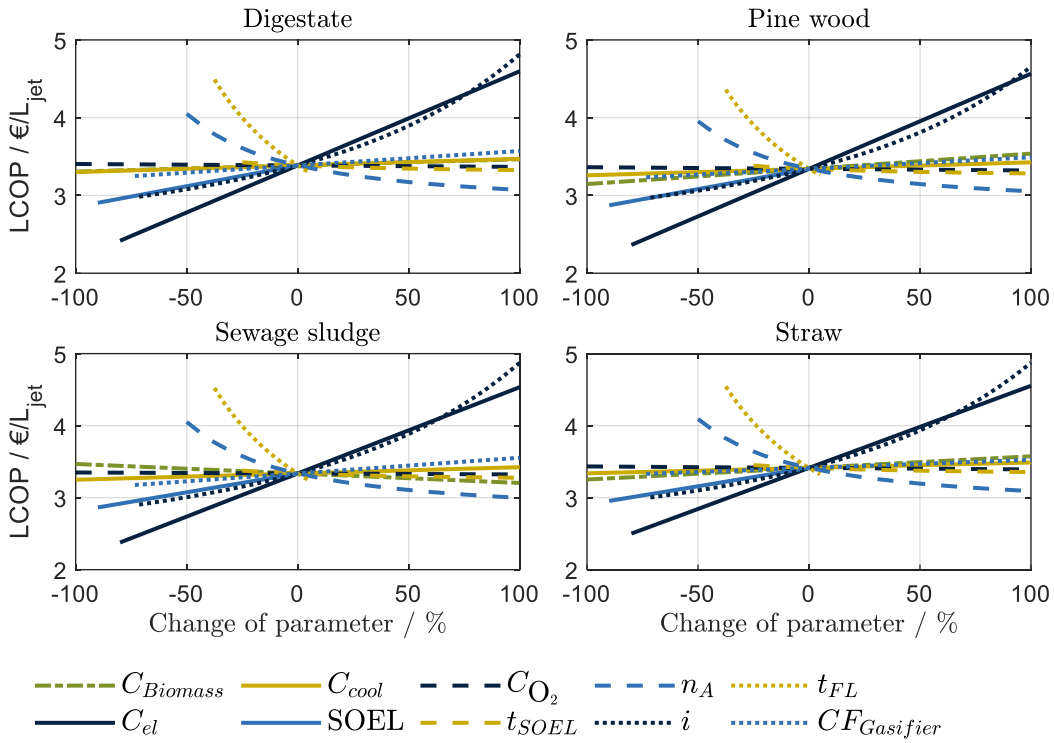
Energy demand of the PBtJ Methanol-to-Jet process



[1] Eyberg et al. 2026

Economic results

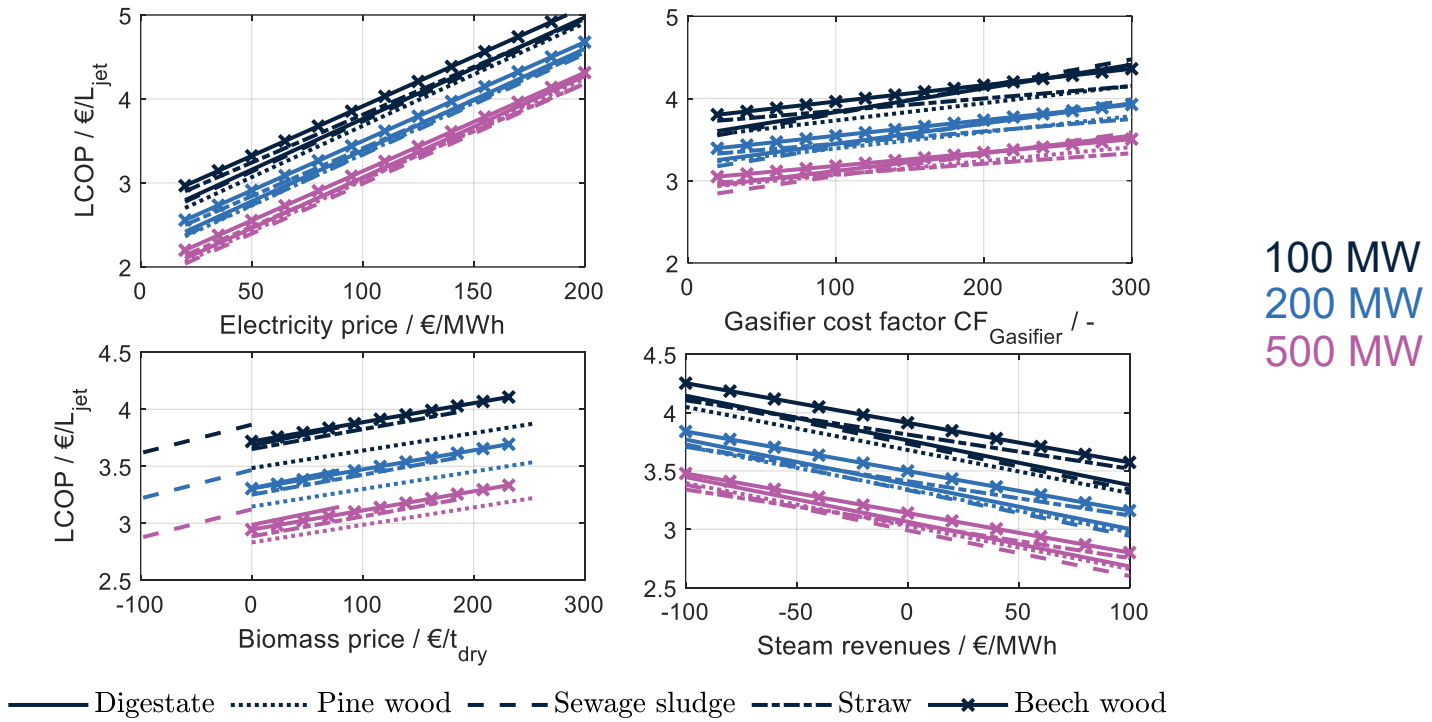
Sensitivity analysis (200 MW configurations)



[1] Eyberg et al. 2026

Economic results

Sensitivity analysis (one parameter)



100 MW
200 MW
500 MW

[1] Eyberg et al. 2026