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Process modelling and holistic assessment of HTL fuel production

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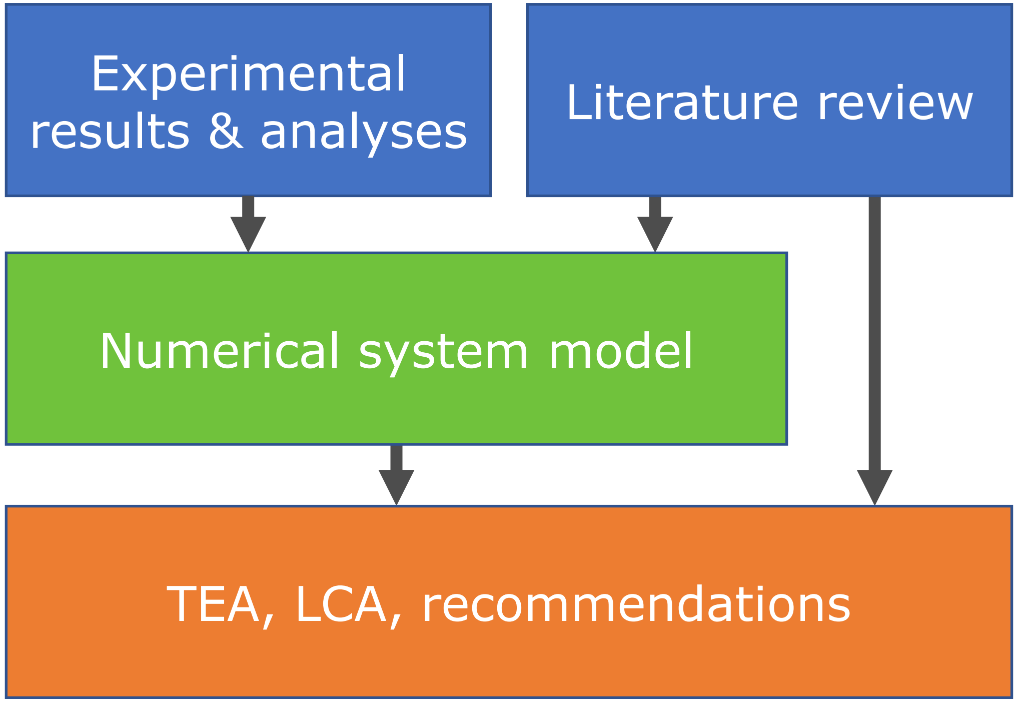
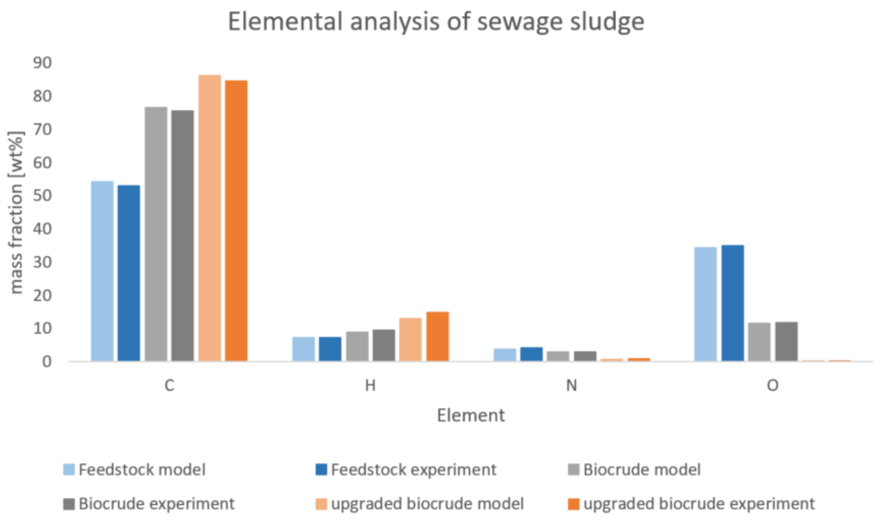
Motivation for system analysis and holistic assessment

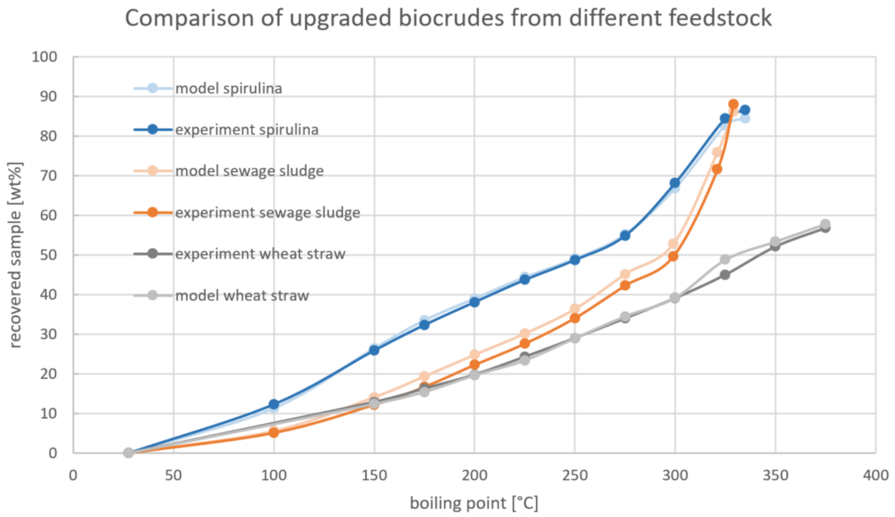
- ***Holistic assessment of jet fuel production via HTL***
  - Identification of risks and technological challenges
  - Production cost
  - Environmental impact
  - Socio-economic benefits

- ***Research questions***
  - Selection of feedstock
  - Treatment of solids and the aqueous phase
  - Process integration
  - Provision of process heat & hydrogen
  - Economies of scale
  - Regional aspects of plant location
  - …



Development of a numerical process model





- ***Modelling biomass conversion steps in Aspen Plus***
  - Established for different feedstock types (Sewage sludge, spirulina, lignocellulosic)
  - Taking into account thermodynamic and reaction kinetic data
  - Selection of model components representing biomass, biocrude and upgraded biocrude
- ***Reaction network***
  - HTL 272 reactions, upgrading 288 reactions, AP treatment via gasification 280 reactions
- ***Good reproduction of experiments***

L. Moser, C. Penke, V. Batteiger, An In-Depth Process Model for Fuel Production via Hydrothermal Liquefaction and Catalytic Hydrotreating, Processes 9 (2021) 1172. https://doi.org/10.3390/pr9071172.

Process configurations and scaling

Wet feedstocks

- Feedstock provision on-site
- Considering nutrient recovery
- Fuel production volume of 7.6 kt / year
- Investment costs of 22.9 M€

Dry feedstocks

- Feedstock transport
- Considering AP recycling (90 %)
- Fuel production volume of 90 kt / year
- Investment costs of 122.1 M€

Sewage sludge

- Available at waste water treatment plants
- Different disposal routes in Europe

Microalgae

- Scalable cultivated crop
- High investment costs, energy and fresh water demand result in very high feedstock costs

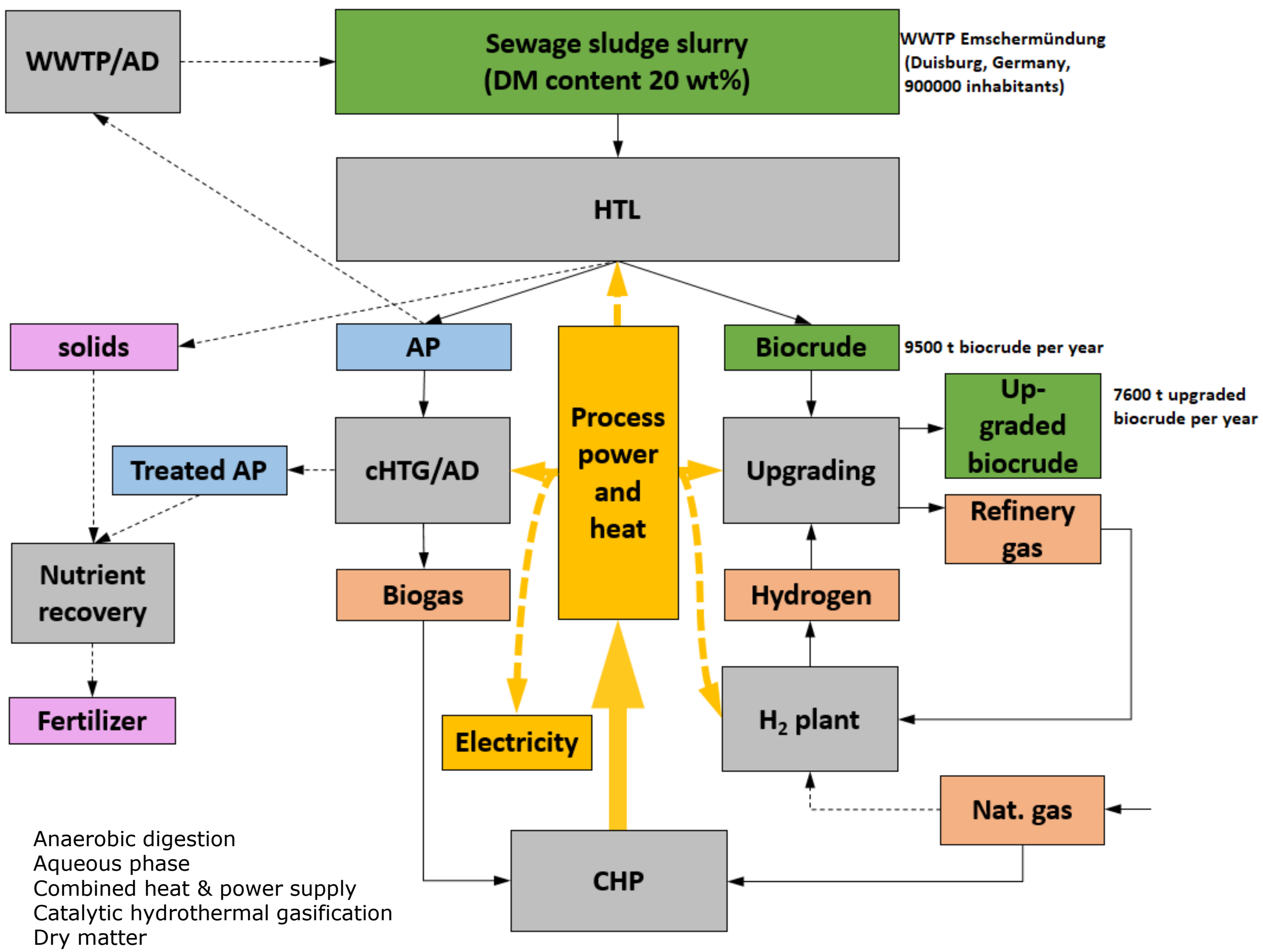
Cereal straw

- Available as agricultural by-product in major quantities
- Competing utilization processes

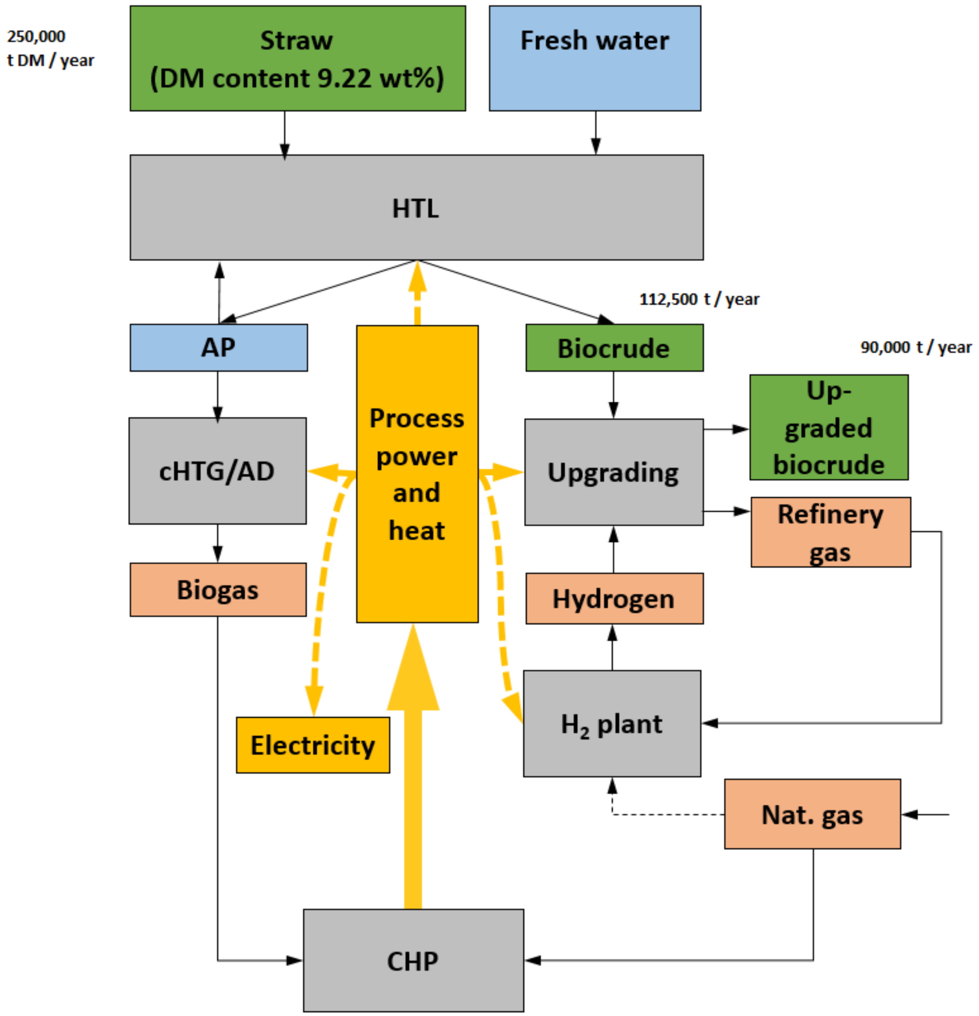
Miscanthus

- Scalable cultivated energy crop, theoretically available in large quantities
- Assumption: 30 % of agricultural areas can be used

Process schemes for HTL of sewage sludge and straw

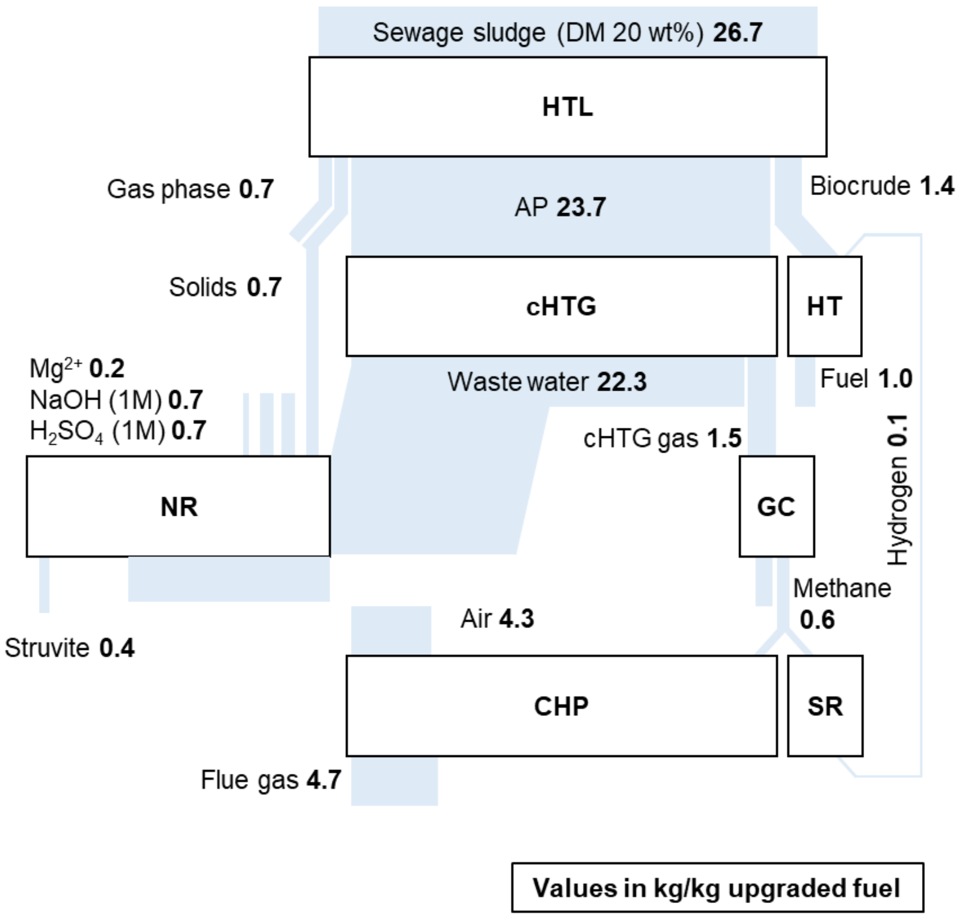


AD Anaerobic digestion
AP Aqueous phase
CHP Combined heat & power supply
cHTG Catalytic hydrothermal gasification
DM Dry matter
HTL Hydrothermal liquefaction
WWTP Waste water treatment plant

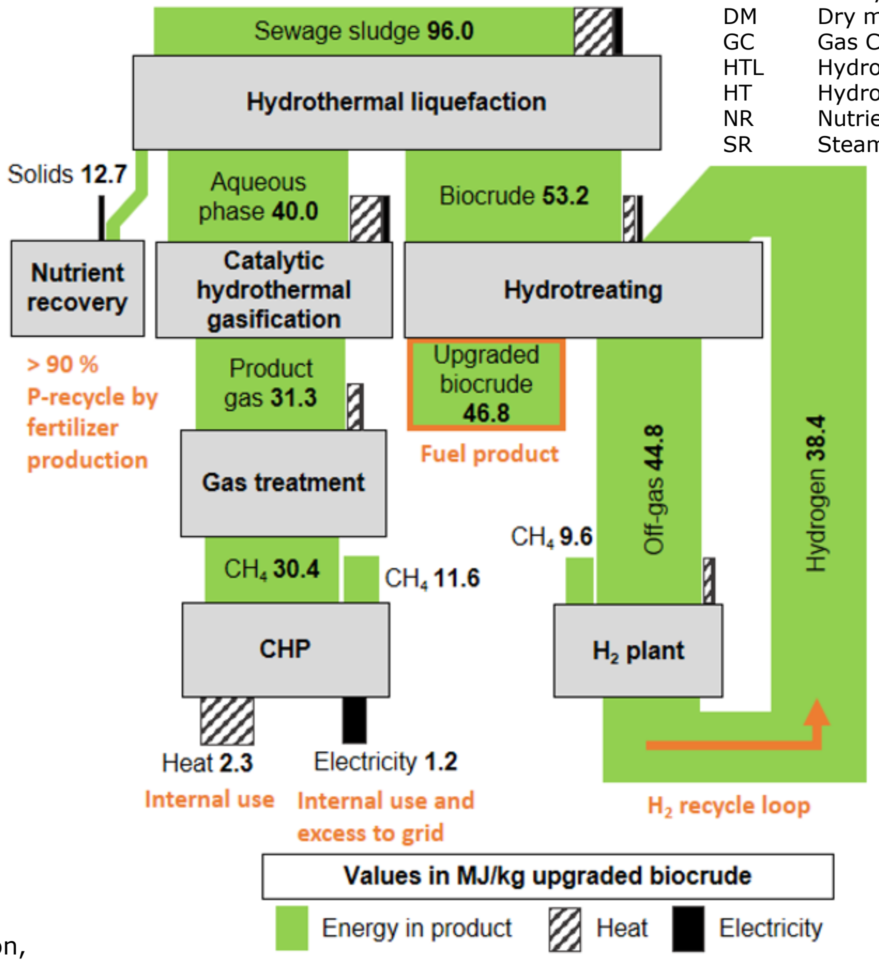


Mass and energy balances sewage sludge

Mass balance



Energy balance



CHP Combined heat & power supply
cHTG Catalytic hydrothermal gasification
DM Dry matter
GC Gas Cleaning
HTL Hydrothermal liquefaction
HT Hydro treating
NR Nutrient recovery
SR Steam reforming

C. Penke, L. Moser, V. Batteiger, Modeling of cost optimized process integration of HTL fuel production, Biomass and Bioenergy 151 (2021) 106123. https://doi.org/10.1016/j.biombioe.2021.106123.

TEA Input

- ***Interest rate based on country specific weighted average capital costs (WACC)***
  - Inflation of the value of money taken into account
  - Consideration of local investment risk
  - Wide range of WACC (e. g. 6.3 % in Greece; 2.1 % in the Netherlands)

- ***Plant lifetime 20 years, Operation: 8000 h/yr***
  - Plant downtime of about 9 % due to maintenance or repair

- ***Different types of jobs considered***

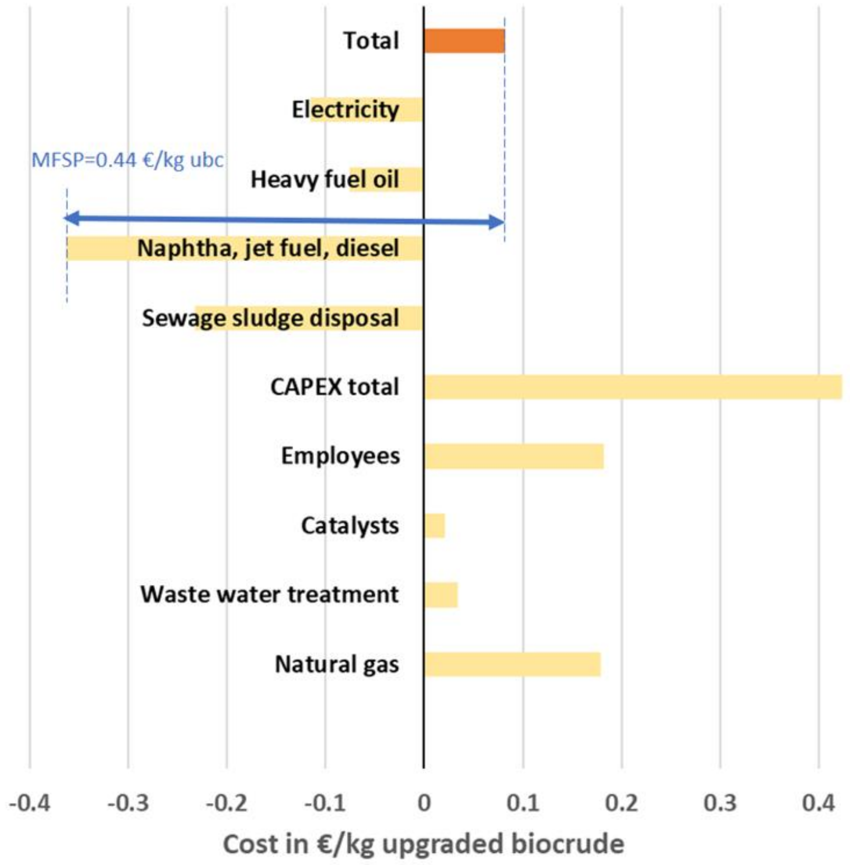
Large-scale HTL of straw:

90,000 t upgraded biocrude per year

Plant manger (x2)	Shift supervisor (x5)
Plant engineer (x5)	Shift operators (x20)
Lab manager (x2)	Facility manager (x3)
Lab technician (x5)	Administration (x3)

TEA results

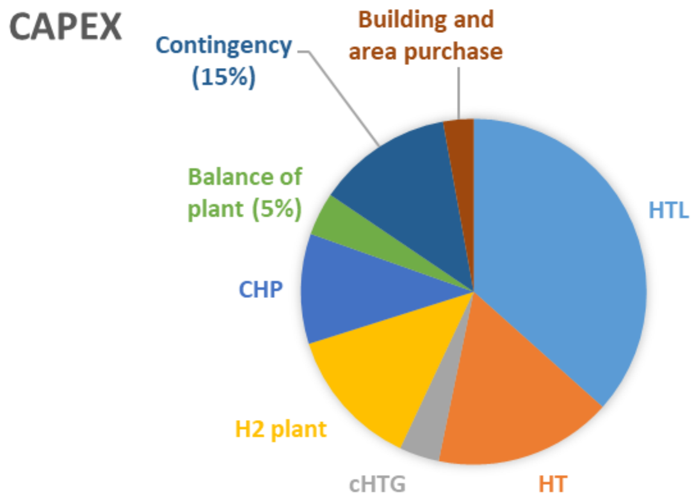
Feedstock sewage sludge



C. Penke, L. Moser, G. Özal, A. Habersetzer, V. Batteiger, HyFlexFuel Public Report - Report on techno-economic and environmental assessment, 2021.

Minimum fuel selling price

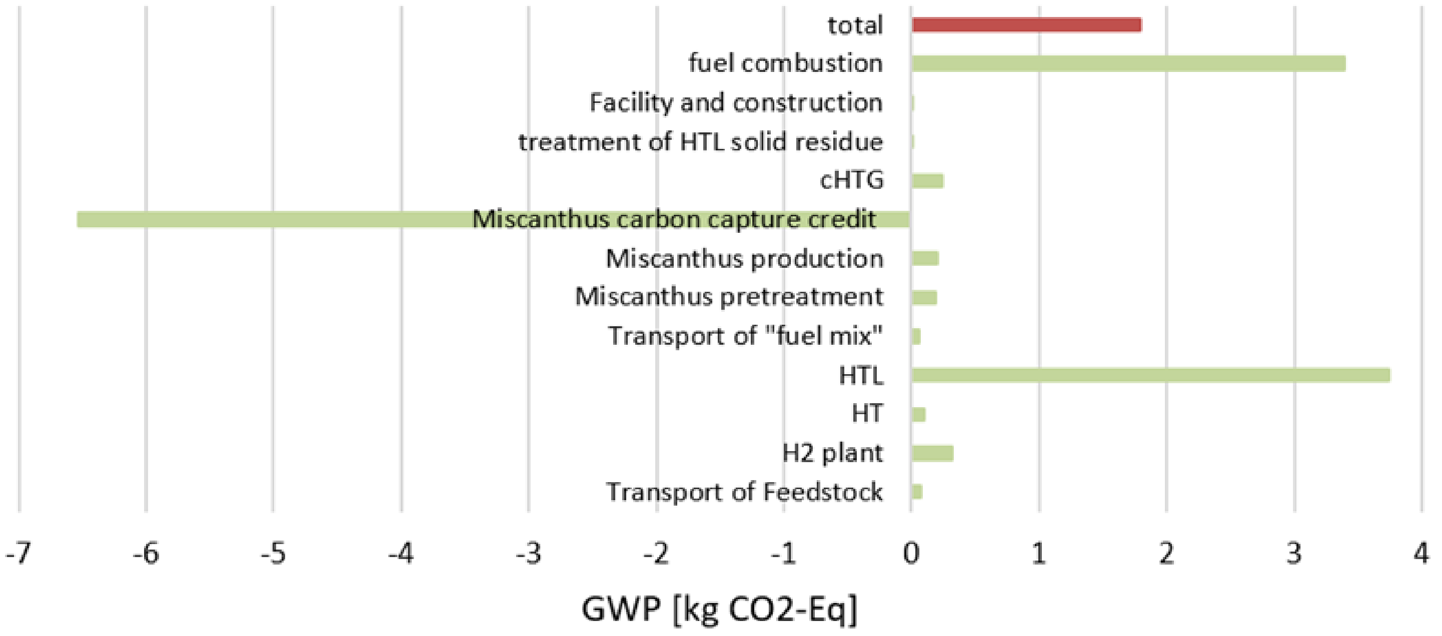
- Sewage sludge 0.44 €/kg ubc
- Miscanthus 0.75 €/kg ubc
- Cereal straw 0.44 €/kg ubc
- Microalgae 8.26 €/kg ubc



ubc = upgraded biocrude (= mixture of hydrocarbon fuels)

Specific GHG emissions of HTL jet fuel

Sources and sinks for HTL fuel production (miscanthus)



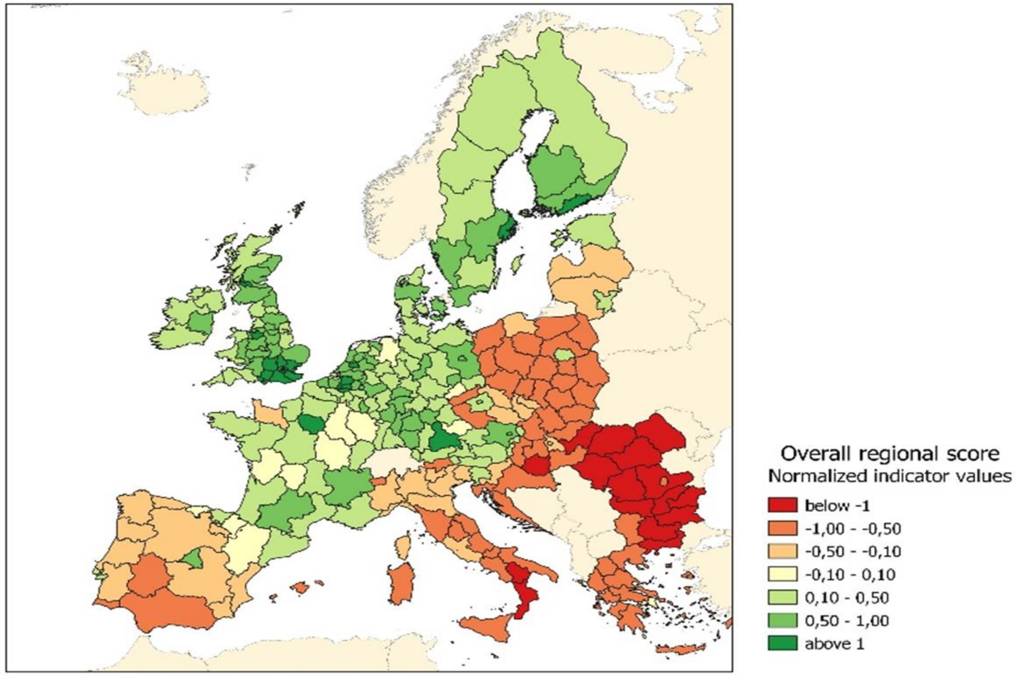
- **Sewage sludge**
  0.65 kg CO_2-Eq / kg ubc
- **Miscanthus**
  1.80 kg CO_2-Eq / kg ubc
- **Cereal straw**
  1.86 kg CO_2-Eq / kg ubc
- **Microalgae**
  5.34 kg CO_2-Eq / kg ubc

- ***Main contributors to GHG emissions: heat and hydrogen supply, as well as CO_2-containing off-gas evolving during conversion process***
- ***High potential for improvement by using green hydrogen, renewable heat and carbon capturing processes (e. g. CCS) -> negative carbon emissions possible***

Socio-economic benefits

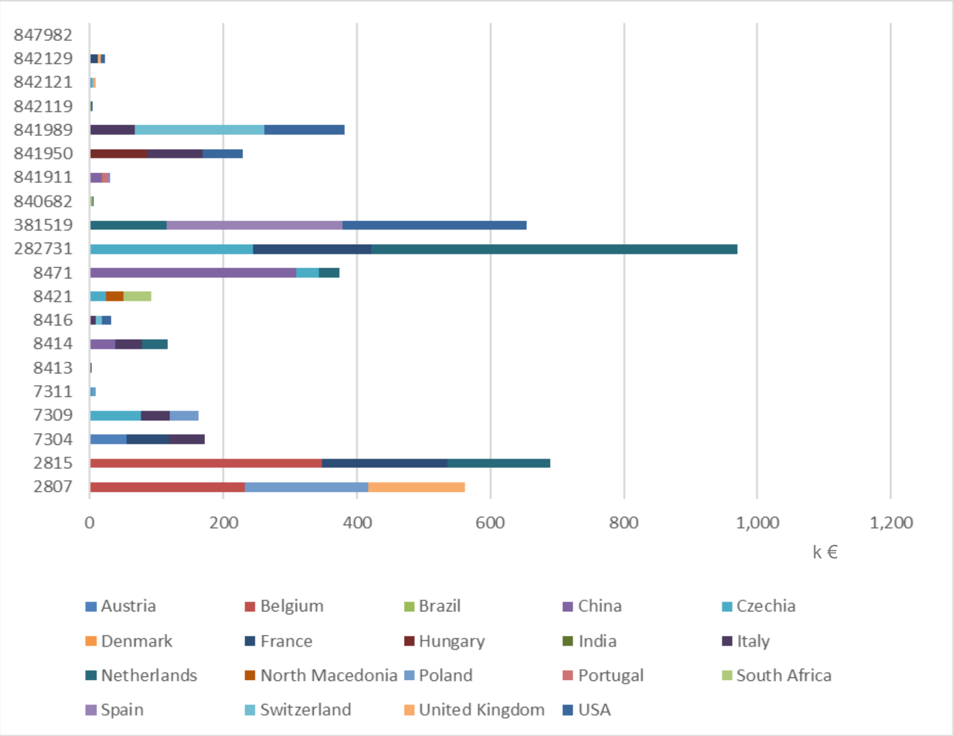
- ***Methodology adapted from Garett-Peltier et al.***
  - Purchasing and operating costs represent a demand for specific goods and service
  - This increase in demand creates additional demand along the respective value chains (e. g. additional economic values or generation of new jobs)

Regional competitiveness: Overall regional score



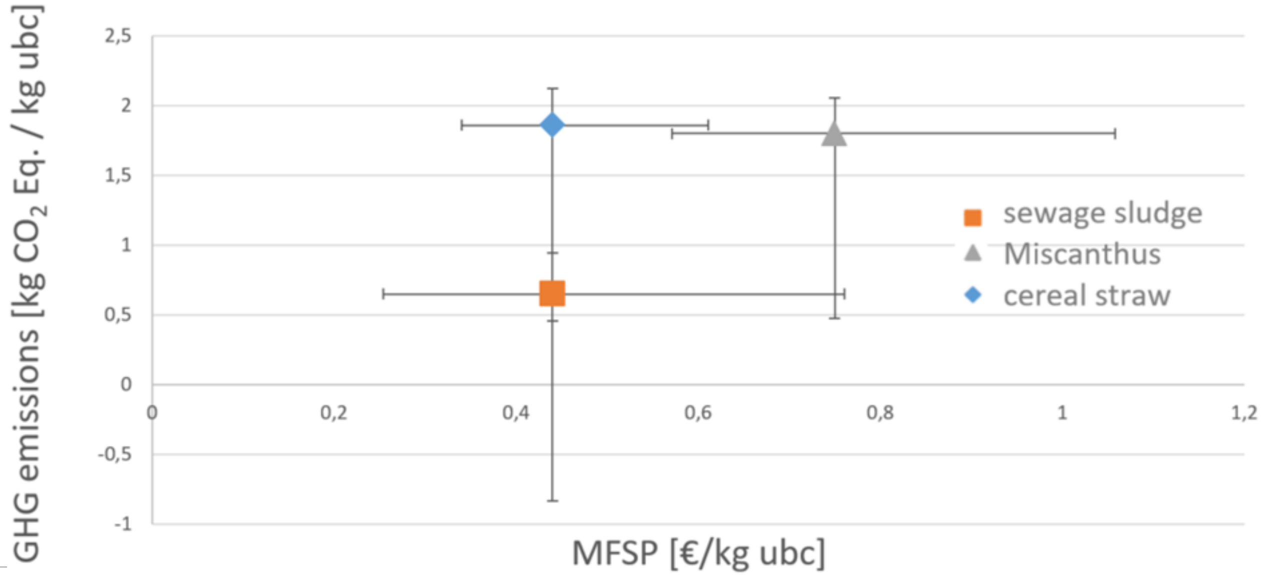
H. Garrett-Peltier, Green versus brown: Comparing the employment impacts of energy efficiency, renewable energy, and fossil fuels using an input-output model}, Economic Modelling 61 (2017) 439-447. https://doi.org/10.1016/j.econmod.2016.11.012.

Imports to Germany by commodity codes and exporting countries



Trade-Off between economical and ecological aspects

- ***Sewage sludge: Best overall performance, but limited feedstock potential***
- ***Cereal straw: Low fuel production costs (in large scale plants), ~50 % reduction in GHG emissions, moderate feedstock availability***
- ***Miscanthus: Moderate fuel production costs (in large scale plants), ~50 % reduction in GHG emissions, high feedstock availability***



- ***The three considered feedstock scenarios studied have lower GWP than conventional fuels***

Holistic assessment matrix

- ***Comparison of different HTL feedstock scenarios:***

	Miscanthus	Straw	Microalgae	Sewage sludge
Technology readiness				
Fuel production potential				
Production costs				
Reduction in GHG emission				
Land demand				
Water demand				
Social benefits				

- ***Fuel production by different feedstock types is associated with different advantages and disadvantages***

Conclusions

- ***Numerical process model of HTL fuel production chain established in Aspen Plus as basis for further system analyses***
- ***Energy and mass balances indicate importance of aqueous phase treatment for overall energy and carbon efficiency***
- ***If technological maturity is achieved: Upgraded biocrude may be produced at attractive cost levels (especially from waste streams)***
- ***Regional aspects of plant location: Feedstock availability, labour cost, and financing conditions have major effect on biocrude production costs***
- ***Significant reduction in GWP compared to conventional jet fuel in Europe, negative carbon emissions under favourable conditions possible***

Thank you!

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