LCA of a wood chips-based organosolv biorefinery concept for the production of lignin mono- and oligomers by base-catalysed depolymerisation

Lukas Zeilerbauer[1], Johannes Lindorfer[1], Raphaela Süss[2,3], Birgit Kamm[2,4]

1 Energieinstitut an der Johannes Kepler Universität Linz, Altenbergerstraße 69, 4040 Linz
2 Kompetenzzentrum Holz GmbH, Altenbergerstraße 69, 4040 Linz
3 Institute for Chemical Technology of Organic Materials, Johannes-Kepler University,
4 Brandenburg University of Technology Cottbus-Senftenberg, Platz der deutschen Einheit 1, 03046 Cottbus

Introduction

In light of an ever decreasing amount of fossil fuels available to mankind the **valorisation of biogenic materials is a fast-growing research area.** Ideally, new concepts should focus on improving **treatment of existing streams** which undergo no or thermal valorisation. One of those streams is residual wood. Ideally, this waste stream could be used in making value-added chemicals. For valorising lignocellulosic waste streams the organosolv process (OP) is a promising approach, yielding C5 and C6 sugars as well as lignin in a high purity. In this work the base-catalysed depolymerisation (BCD) approach of Süss et al., is **scaled up with literature data and integrated into a biorefinery with annual capacity of 40,000 tons.** [1] Moreover, **the common work-up approach in the laboratory** utilising tetrayhydrofuran (THF) and ethyl acetate (EtOAc), which is found in nearly all works dealing with BCD of organosolv lignin, **is substituted with two alternative approaches and their environmental impacts are examined.** The products are benchmarked with chemicals based on fossil fuels which they might be able to substitute. For the LCA study the CML 2015 impact assessment method was used.

Process design

- The general process design can be seen in Figure 1.
- Organosolv pulping involves enzymatic hydrolysis and solvent recovery.
- The C5-fraction is used to obtain biogas which is used for steam generation
- The C6-fraction is „sold“ in this model and not subjected to further converison
- The obtained organosolv lignin is further depolymerised into monomers, and oligomers, following the BCD procedure described by Süss et al. [1] except for the work-up.
- On a lab scale the oligomers are washed with THF to separate them from char. Due to The novel BCD approach, only small quanitites (0.5 %) of coke are obtained, therefore this step is left out. The general work-up involving extracting the monomers with EtoAc is substituted with two novel approaches.

EPDV

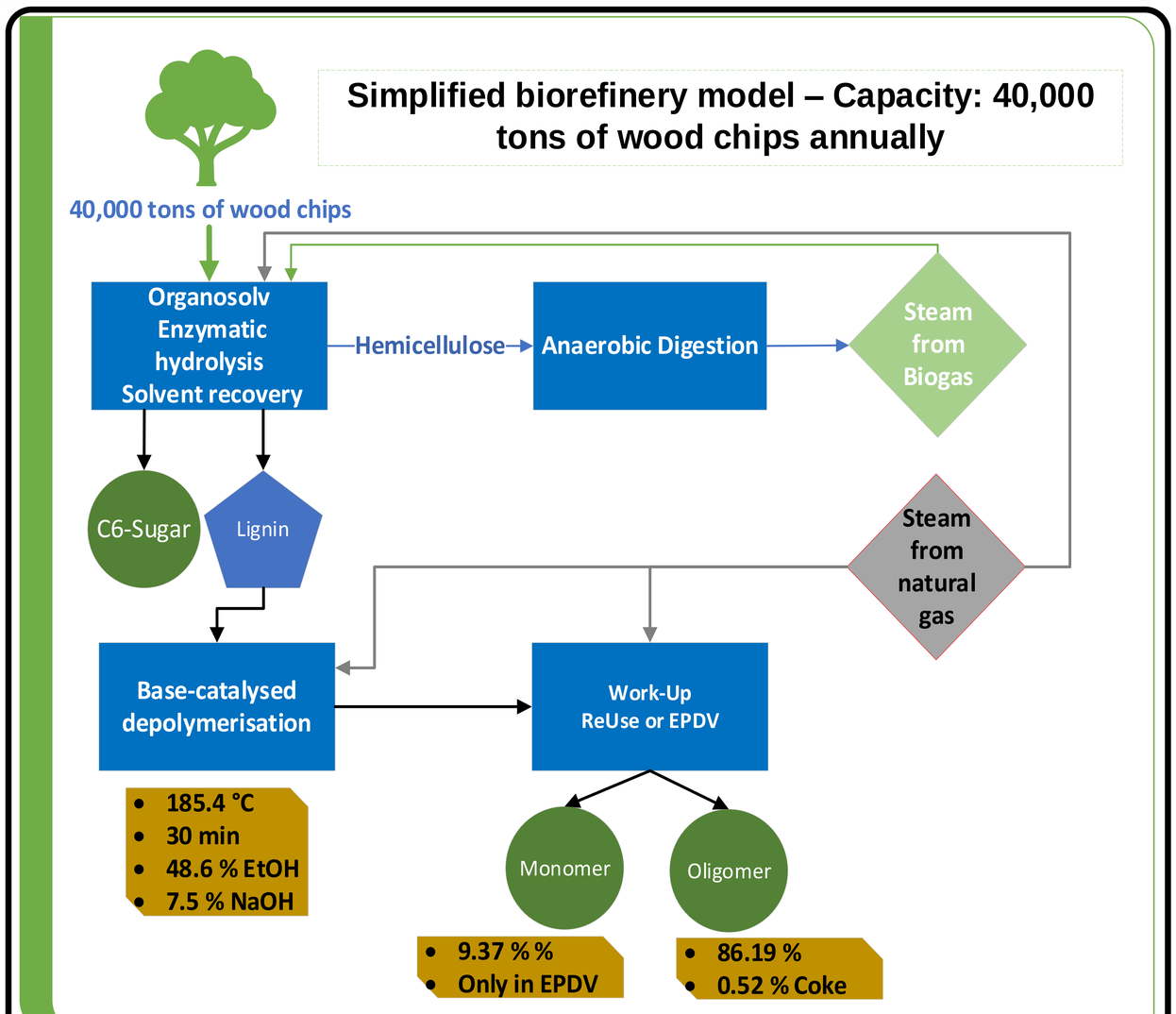
- One alternative work-up approach is the EPDV-approach described by Meng et al., (Extractive distillation and pervaporation) used to break the water/ethanol/EtOAc azeotrope. [2]
- The energy consumption was scaled down to fit this model‘s needs.

ReUse

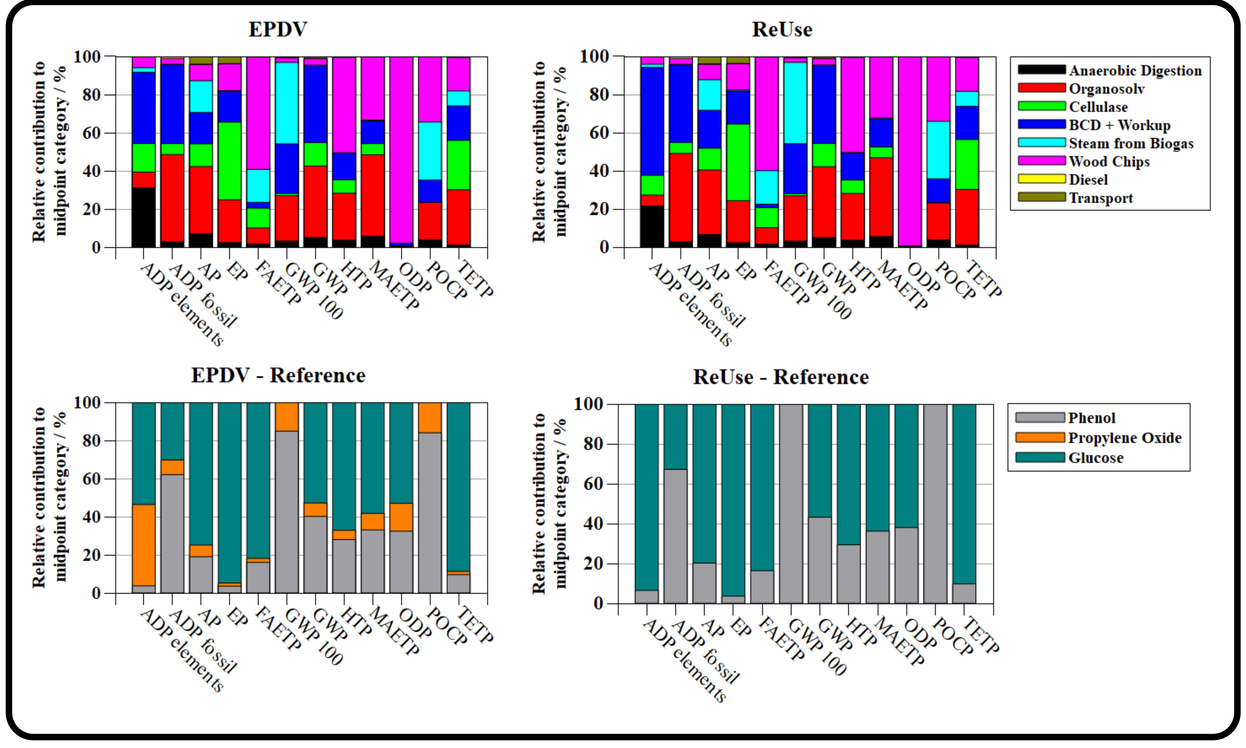
- The monomers were net recovered from the water/ethanol mixture.
- Instead, sodium hydroxide and solvent was added to restore initial conditions and to make another depolymerisation run, thus avoiding one energy-intensive distillation step.

LCA framework

- The functional unit of this LCA is a plant which valorises 40,000 of wood chips annually in a **cradle-to-gate approach** using **GaBi-software.**
- **Monomers** can be used to substitute **polypropylene glycol**, **oligomers** to substitute **phenol** in phenol-formaldehyde resins and the **C6 fraction** is used to substitute the production of glucose syrup from corn. Due to availability reasons, propylene oxide was used for the monomers, as it is the predecessor product of polypropylene glycol.



RESULTS



Normalised results for process designs and the respective reference scenarios.

Midpoint category	EPDV	Ref.	ReUse	Ref.
ADP elements	0.36	1.00	0.83	1.00
ADP fossil	0.46	1.00	0.44	1.00
AP	0.39	1.00	0.42	1.00
EP	0.17	1.00	0.14	1.00
FAETP	0.52	1.00	0.50	1.00
GWP 100	1.00	0.04	1.00	0.00
GWP excluding biogenic carbon	0.65	1.00	0.63	1.00
HTP	0.65	1.00	0.65	1.00
MAETP	0.84	1.00	0.98	1.00
ODP	1.00	0.00	1.00	0.00
POCP	1.00	0.58	1.00	0.45
TETP	0.24	1.00	0.20	1.00

Findings & Discussion

- It was shown that the **biorefinery has benefits in 9 out of 12 midpoint categories**, no matter which work-up.
- **Reusing the water/ethanol mixure once** has almost identical impacts as utilising EPDV. The only major difference being ADP elements, caused by the increased need for sodium hydroxide.
- The **GWP 100 yields significantly better values for the reference scencarios**. This is due to a negative impact for the production of glucose syrup from corn, which gives credit for the sequestration of carbon. However, a sequestration time of 100 years seems unlikely for fermentation products such as ethanol, thus the GWP excluding biogenic carbon seems to be a better indicator. In this case no credit given is for the production of glucose syrup from corn and the CO_2 from the combustion of biogas is not included, yielding a **possible saving of roughly 1/3 of the GHG-emissions** of the references.
- The LCA results show that the **best way of reducing the carbon footprint** is to **lower energy consumption**, as the impacts of the BCD + Workup are mostly related to the production of thermal energy. The ReUse approach could help to achieve said target if the solvent can be reused multiple times and **distillation energy can be reduced.**
- **The plant is not self-sufficient** as the biogas produced is not enough to power the operation, even the organosolv pulping needs additional thermal energy. An autarch plant would need serious energy savings efforts.
- For the other **environmental impacts no real hotspot** was determined as influences are distributed very evenly and a lot of them come from the wood chips themselves as they include forestry.

Acknowledgement

This work was part of the BioReduce project funded by the European Regional Development Fund (EFRE) and the province of Upper Austria.

Contact

Energieinstitut an der Johannes Kepler Universität Linz
Lukas Zeilerbauer
zeilerbauer@energieinstitut-linz.at
Altenberger Straße 69
A-4040 Linz
Tel.: +43 732 2468 5646
wwww.energieinstitut-linz.at

LCM 2021

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