DOC2025

8TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS

8TH DOCTORAL COLLOQUIUM BIOENERGY AND BIOBASED PRODUCTS

10TH - 12TH SEPTEMBER, 2025

UNIVERSITY OF STUTTGART

TAGUNGSREADER, NR. 35

#DOC2025

WWW.DOC-BIOENERGY.DE

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Dr. Christoph Krukenkamp (Administrative Managing Director)

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8th Doctoral Colloquium BIOENERGY AND BIOBASED PRODUCTS
10th - 12th September, 2025, University of Stuttgart

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8TH DOCTORAL COLLOQUIUM BIOENERGY AND BIOBASED PRODUCTS

10TH - 12TH SEPTEMBER, 2025

UNIVERSITY OF STUTTGART

Table of Content

SESSION THERMOCHEMICAL CONVERSION

SESSION BIOENERGY SYSTEMS ANALYSIS

SESSION SUSTAINABLE RESOURCE BASE

SESSION BIOREFINERIES & BIOFUELS

SESSION BIOCHEMICAL CONVERSION

SESSION CIRCULAR BIOECONOMY IN INDUSTRY

Save the Date – Doctoral Colloquium 2026

We are delighted to announce that the 9th Doctoral Colloquium on Bioenergy and Biobased Products will take place at the DBFZ in Leipzig on September 23–24, 2026. Find more information at: www.doc-bioenergy.de

Bonus: Skills training on 22 Sept 2026 - YES-Workshops on Storytelling & Pitch training

DBFZ

WELCOME / GREETINGS

8TH DOCTORAL COLLOQUIUM BIOENERGY AND BIOBASED PRODUCTS

Welcome note from our patron, Prof. Dr. Michael Nelles

Dear Participants of the 8th Doctoral Colloquium,

as the new patron of the Doctoral Colloquium BIOENERGY AND BIOBASED PRODUCTS, I am delighted to look back on a very successful event in Stuttgart. With a total of 74 participants, we were once again able to record a very well-attended event, which was also characterised by numerous exciting presentations, an interesting supporting programme and an overall very positive atmosphere. I would like to express my sincere thanks to all those involved and the organisers!

In order to reflect current political and economic developments, the thematic scope of this year's event was expanded to include research in the field of biotechnology and bioeconomy in industry. A new session focusing on 'Circular Bioeconomy in Industry' was set up for this purpose. Various doctoral students presented and discussed their projects on questions such as 'How can we expand industrial capacities to close a non-fossil carbon cycle?' and 'How can we decarbonise the steel industry?'. In a total of six sessions, 24 presentations and 31 scientific posters, the entire spectrum of possible uses for biomass was once again covered.

As patron, I am particularly impressed by the high quality of the presentations (including posters), the lively discussions and the keen interest in networking among the doctoral students, but also with the many participating professors. The increasing participation of international scientists, e.g. from Europe, Africa and Australia, is also particularly noteworthy. It has once again shown that our event has struck the right chord.

I would like to take this opportunity to congratulate all the winners of the 'Best Oral Presentation' and 'Best Poster' categories!

Prof. Dr. Michael Nelles, DBFZ/University of Rostock

My special thanks go to the organisers of the event, in particular Prof. Dr. Ralf Takors and Dr. Ludger Eltrop, as well as the many helpers who made this event possible. We are delighted to be able to host the next event at the DBFZ in Leipzig again. Please make a note of the dates, 23./24. September 2026. As always, all the important information can be found on the DOC website at www.doc-bioenergy.de

In this conference reader for the event, you will find all approved abstracts, slides and posters, as well as further information about the event. We hope you enjoy studying the exciting presentations and look forward to the next Doctoral Colloquium next year.

Prof. Dr. Michael Nelles
DBFZ / University of Rostock

Greetings from Prof. Dr. Ralf Takors and Dr. Ludger Eltrop

Dear Participants of the 8th Doctoral Colloquium,

on behalf of the organizing committee we like to thank you all for your active participation and engagement in the 8th Doctoral Colloquium BIOENERGY AND BIOBASED PRODUCTS here in Stuttgart. From our point of view this was an excellent event, with engaged participants, exciting scientific contributions and an inspiring atmosphere triggering a more intense exchange and transfer of knowledge. One of the important aims of our colloquium was to bring together all of you at an early stage of your career, but also with senior researchers and industry leaders to exchange knowledge and discuss research gaps and challenges. We also wanted to encourage networking and foster information exchange between scientific institutions that are working in relevant fields of bioenergy and biotechnology research.

During our colloquium we have discussed such issues and we also saw a number of case studies on integrated production and use of bioenergy and biotechnology. Through the keynotes we learned that bio-based processes and products are demanded by the industry and thus it is promising to go for a career in this sector. The title of the event from bioenergy to bio-based products showed the great variety of processes and pathways that we have in mind when conceptionalising the colloquium. Through your presentations and posters you showed the many approaches and opportunities that lie in this sector. You also showed your ambition for in-depth studies during your doctoral theses. With our colloquium we wanted to encourage you to become even stronger through sharing, interacting and transferring your knowledge to colleagues and partners.

In the last years, together with the DBFZ in Leipzig and other partner like the University of Rostock, Hohenheim, Erlangen, Göttingen and others, we

Prof. Dr. Ralf Takors/Dr. Ludger Eltrop, University of Stuttgart

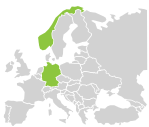
were able to set-up this series of exciting doctoral colloquia. At the University of Stuttgart, in collaboration with others like the Fraunhofer IGB, we have formed a research alliance, the Stuttgart Research Partnership (SRP) "ValBio - Valorization of Bioresources". The SRP ValBio endeavours to foster up-to-date research with a focus in biotechnology, bioenergy, bio-engineering and system analysis. At the University of Hohenheim a broad field of bio-based research areas is covered, that is implemented from laboratory scale via technical centers to large-scale practical pilot plants.

As organizers of this event we like to take this opportunity to thank you again for your engagement. We encourage you to pursue your career in this exciting field and we are available for any more assistance that is needed.

Looking forward to seeing you next year again.

Prof. Dr. Ralf Takors / Dr. Ludger Eltrop
Institute of Biochemical Engineering /
Institute of Energy Economics and
Rational Energy Use, University of Stuttgart

The recent history of the Doctoral Colloquium BIOENERGY AND BIOBASED PRODUCTS

1st Doctoral Colloquium BIOENERGY 2018	2nd Doctoral Colloquium BIOENERGY 2019	3rd Doctoral Colloquium BIOENERGY 2020	4th Doctoral Colloquium BIOENERGY 2021
Initiator and host: DBFZ, Leipzig	Host: FAU, Nuremberg	Host: DBFZ, Leipzig	Host: KIT, Karlsruhe
71 Participants	**51** Participants	**185** Participants	**70** Participants
 Participants from Germany	 Participants from Germany and Norway	Participants from Algeria, Austria, Brazil, France, Germany, India, Indonesia, Ireland, Mexico, Netherlands, Nigeria, Norway, Poland, Sweden, Switzerland, Turkey and USA	Participants from Austria, Brazil, Canada, China, Germany, Ghana, Greece, Iran, Nigeria, Poland, Russia, Syria, Thailand and Zambia
Scientific Advisory Board **9** Members representing **11** Institutions	Scientific Advisory Board **34** Members representing **27** Institutions	Scientific Advisory Board **46** Members representing **37** Institutions	Scientific Advisory Board **46** Members representing **37** Institutions

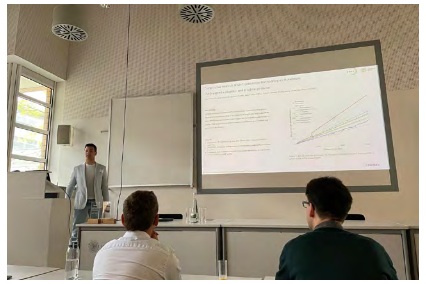
5th Doctoral Colloquium BIOENERGY 2022	6th Doctoral Colloquium BIOENERGY 2023	7th Doctoral Colloquium BIOENERGY AND BIOBASED PRODUCTS 2024	8th Doctoral Colloquium BIOENERGY AND BIOBASED PRODUCTS 2025
Host: DBFZ, Leipzig	Host: HAWK, Goettingen	Host: DBFZ, Leipzig	Host: University of Stuttgart
75 Participants	**42** Participants	**85** Participants	**74** Participants
Participants from Austria, Belgium, China, Columbia, Denmark, France, Germany, Ghana, Greece, India, Indonesia, Iran, Iraq, Italy, Norway, Pakistan, Phillipines, Republic of Cameroon, South Africa, Spain, Sweden and Switzerland	Participants from Austria, China, Columbia, Germany, Great Britain, India, Iran, Italy, Norway and Pakistan	Participants from Austria, China, Colombia, Denmark, Germany, Iran, Italy, Mali, Sweden and Switzerland	Participants from Germany, Australia, Denmark, France, Greece, India, Ireland, Italy, Portugal and South Africa
Scientific Advisory Board **46** Members representing **37** Institutions	Scientific Advisory Board **46** Members representing **37** Institutions	Scientific Advisory Board **46** Members representing **37** Institutions	Scientific Advisory Board **50** Members representing **39** Institutions

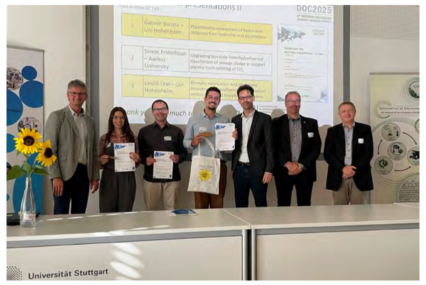
Impressions





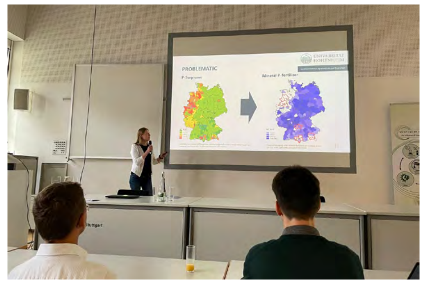


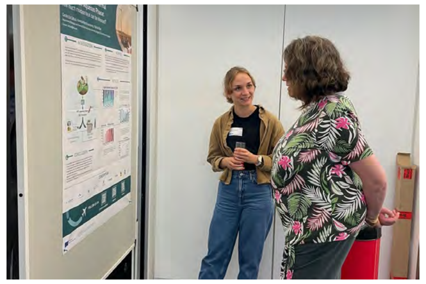


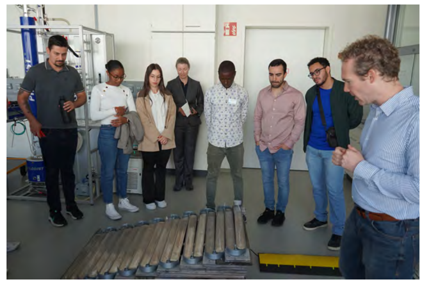





Pictures: Katja Lucke, Elena Angelova (DBFZ), University of Stuttgart

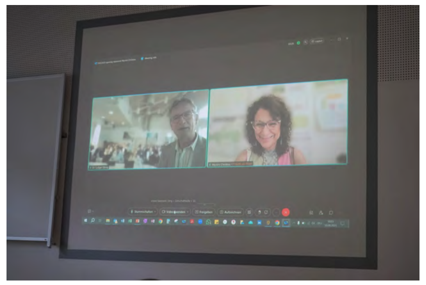













WELCOME SPEECH PATRON/
PROF. DR. MICHAEL NELLES

8TH DOCTORAL COLLOQUIUM BIOENERGY AND BIOBASED PRODUCTS

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8TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS

DOCTORAL COLLOQUIUM BIOENERGY AND BIOBASED PRODUCTS

Prof Dr Michael Nelles, Dr Elena Angelova

Welcome speach

DBFZ · University of Stuttgart Germany · ValBio · FNR Fachagentur Nachwachsende Rohstoffe e.V. · EERA European Energy Research Alliance BIOENERGY

10TH SEPTEMBER 2025, Stuttgart

DOC2025
8TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS

DOC2025 - Some facts and figures

09.09.2025 2

Some facts and figures

DOC2025
8TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS

09.09.2025 3

Some facts and figures

DOC2025
8TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS

1st Doctoral Colloquium BIOENERGY 2018	2nd Doctoral Colloquium BIOENERGY 2019	3rd Doctoral Colloquium BIOENERGY 2020	4th Doctoral Colloquium BIOENERGY 2021	5th Doctoral Colloquium BIOENERGY 2022	6th Doctoral Colloquium BIOENERGY 2023	7th Doctoral Colloquium BIOENERGY 2024	8th Doctoral Colloquium BIOENERGY AND BIOBASED PRODUCTS 2025
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23.09.2025 4

Background

DOC2025
8TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS

Focus

- addresses all components of the biomass conversion chain, from feedstock to conversion technologies to the resulting products and services. It also addresses overarching, e.g. economic, environmental or social aspects, and includes work on system analysis and system integration.

Goal

- transdisciplinary networking
- further qualification of junior researchers
- platform for exchange between young scientists and established researchers

Target audience

- PhD students
- post-docs
- scientific advisors
- supervisors

Role of the DBFZ

- initiation and organisation of a platform for exchange between young scientists and established researchers in the fields of bioenergy and bio-based products
- content patronage and coordination of the Scientific Advisory Board by Prof Dr Michael Nelles (until 2024, Prof Dr Daniela Thrän) and the DBFZ team
- website and communication
- organisation and implementation of the 1st, 3rd, 5th and 7th doctoral colloquium
- support of preparations for doctoral colloquiums in Nuremberg (2019), Karlsruhe (2021), Göttingen (2023) and Stuttgart (2025)

09.09.2025 5

DOC2025
8TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS

Programme committee & scientific advisory board

09.09.2025 6

Programme committee

DOC2025
8TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS

Session	Programme committee members
Sustainable resource base	**PD Dr Kurt Möller**, University of Hohenheim, Fertilization and Soil Matter Dynamics **Dr Omar Hijazi**, Technical University of Munich, Chair of Wood Science **Prof Andrea Monti**, UNIBO – University of Bologna **/ Walter Zegada Lizarazu**, Associate professor at University of Bologna
Thermochemical conversion	**Prof Dr Jürgen Karl**, University Erlangen-Nuremberg, Chair of Energy Process Engineering **Dr Kathrin Weber**, SINTEF, Department Thermal Energy **Prof Dr Volker Lenz**, DBFZ Deutsches Biomasseforschungszentrum gGmbH (German Biomass Research Centre)
Biochemical conversion	**Prof Dr Michael Nelles**, DBFZ & University of Rostock, Faculty of Agriculture and Environmental Sciences **Prof Dr Achim Loewen**, HAWK, University of Applied Sciences and Arts Hildesheim/Holzminden/Göttingen, Faculty of Resource Management **Prof Carsten Herbes,** Nuertingen Geislingen University, Institute for International Research on Sustainable Management and Renewable Energy (ISR) **Dr Hans Oechsner**, University of Hohenheim & State Institute of Agricultural Engineering and Bioenergy, Working Group Agricultural Engineering and Rural Construction Baden-Württemberg (ALB) e.V. (until 2025)

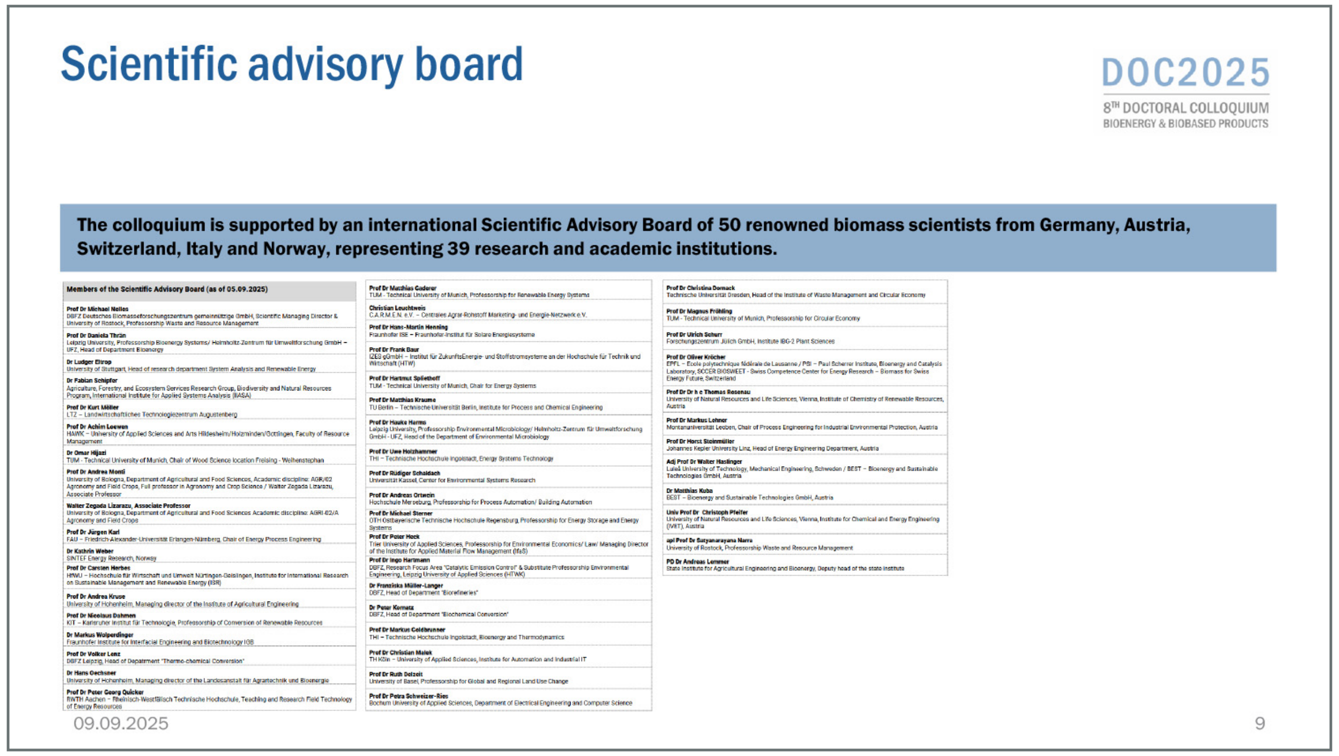
09.09.2025 7

Programme committee

DOC2025
8TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS

Session	Programme committee members
Biorefineries/ Biofuels	**Prof Dr Andrea Kruse**, University of Hohenheim, Institute of Agricultural Engineering **Prof Dr Nicolaus Dahmen**, Karlsruhe Institute of Technology (KIT), Institute of Catalysis Research and Technology (IKFT) **Dr Markus Wolperdinger**, Director Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB, Stuttgart
Bioenergy system analysis	**Prof Dr Daniela Thrän**, DBFZ, Department Bioenergy systems & UFZ, Department Bioenergy/University of Leipzig **Dr Ludger Eltrop**, University of Stuttgart, Department System Analysis and Renewable Energy **Dr Fabian Schipfer**, Technische Universität Wien, Institute of Chemical, Environmental & Bioscience Engineering
EERA European Energy Research Alliance BIOENERGY	**Myrsini Christou**, Joint Programmes Coordinator of EERA Bioenergy & Center for Renewable Energy Sources and Saving, Biomass Dpt., GREECE

8


Scientific advisory board
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BIOENERGY & BIOBASED PRODUCTS
The colloquium is supported by an international Scientific Advisory Board of 50 renowned biomass scientists from Germany, Austria, Switzerland, Italy and Norway, representing 39 research and academic institutions.
09.09.2025
9


DOC2025
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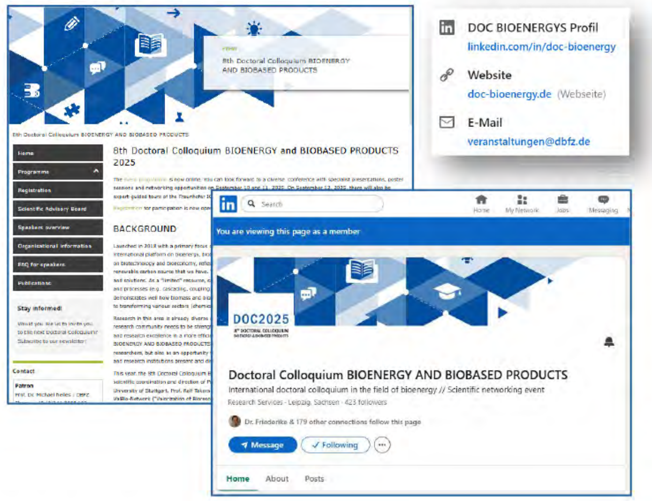
BIOENERGY & BIOBASED PRODUCTS
Awards
09.09.2025
10


Awards
DOC2025
8TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
Best Oral Presentation Award (2x): certificate, trophy, and prize money of €450 each
Best Poster Award: certificate, trophy, and prize money of €300
Prize money provided by the Federal Ministry of Agriculture, Food and Regional Identity (BMLEH) via the Agency for Renewable Resources (FNR).
CERTIFICATE FOR
BEST ORAL PRESENTATION - 1st Place
Max Mustermann
FNR
Fachagentur Nachwachsende Rohstoffe e.V.
With support from
Federal Ministry of Agriculture, Food and Regional Identity
by decision of the German Bundestag
11


DOC2025
8TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS
Outreach
09.09.2025
12

Outreach

DOC2025
8TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS



EERA Bioenergy Newsletters: https://www.eera-bioenergy.eu/publications/#newsletter

09.09.2025 13

Outreach

DOC2025
8TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS

Website: https://www.dbfz.de/en/doc-bioenergy

09.09.2025 14

Save the date

DOC2025
8TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS

DBFZ, Leipzig, on 23. + 24. Sep 2026

Bonus: skills training on 22 Sep 2026: YES-workshops on Storytelling & Pitch training

DOC2026
9TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS

09.09.2025 15

DOC2025
8TH DOCTORAL COLLOQUIUM
BIOENERGY & BIOBASED PRODUCTS

DBFZ Universität Rostock Traditio et Innovatio

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POSTERSESSION /
POSTER SPEED PRESENTATION

Santa Margarida Santos, Nova School of Science and Technology

Waste-derived Pellets – Influence of RDF: Biomass Ratio and Slow Pyrolysis on Pellet Properties and CO_2 Gasification

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NOVA School of Science and Technology
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Keywords: refuse-derived fuel, biomass, pellets, gasification

Introduction

The increasing volume of heterogeneous solid waste underscores the need for sustainable valorization routes. Refuse-derived fuel (RDF), produced from the high-calorific fraction of municipal or industrial waste, can be converted into pellets and chars for material and energy recovery, aligning with circular economy strategies. Combining slow pyrolysis and CO_2 gasification of RDF-biomass pellets produces H_2-rich syngas, providing a sustainable and innovative way to convert waste into renewable H_2.

However, its use in energy systems presents challenges due to variability in composition, low bulk density, chlorine emissions, and poor handling in waste-to-energy (WtE) plants. Co-pelletization with lignocellulosic biomass waste (BW) and thermochemical upgrading, such as slow pyrolysis, can mitigate these issues.

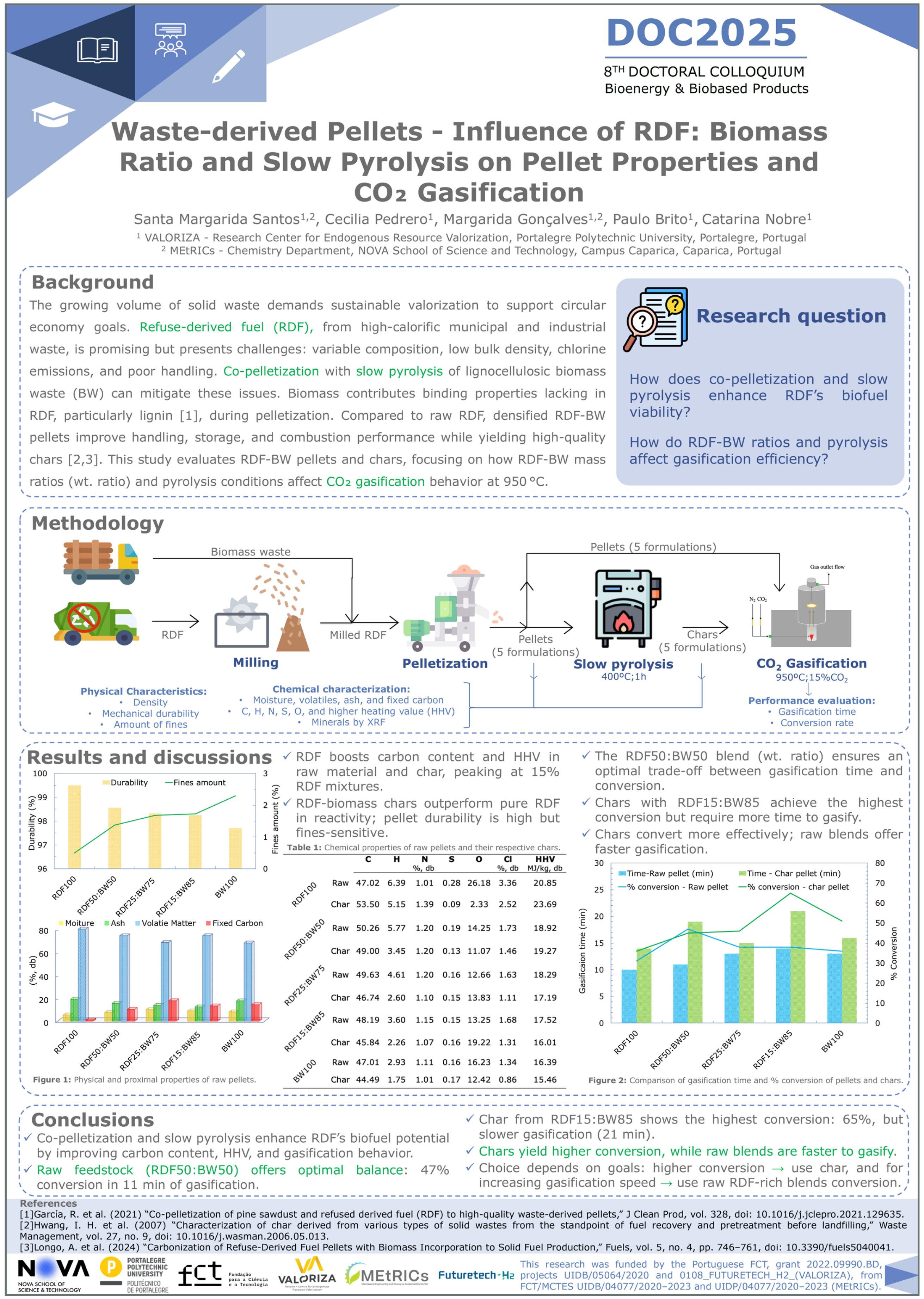
Biomass contributes binding properties lacking in RDF, particularly lignin. Compared to raw RDF, densified RDF-BW pellets improve handling, storage, and combustion performance while yielding high-quality chars. This study evaluates RDF-BW pellets and their pyrolyzed chars to optimize solid biofuels from endoflife waste. The influence of the RDF-BW ratio and slow pyrolysis on the physicochemical properties and behavior of CO_2 gasification at 950 °C is evaluated.

Approach/Methods

RDF and BW mixtures were pelletized using a 6 mm die semi-industrial unit (Andritz, Germany). RDF was milled (<10 mm) and blended with crushed BW in five ratios. All pellets were subjected to slow pyrolysis at 400 °C for 1 hour in a muffle furnace. Pellets and resulting chars were physically and chemically characterized. Gasification under CO_2 was simulated in a Thermogravimetric Analysis (TGA) to assess the conversion behavior of pellets and chars.

Results/Outlook

RDF addition enhanced pellet performance, increasing mechanical durability (97.7 % → 99.5%) and reducing fines (2.3 % → 0.5 %). Despite lower density, 32 % plastic content contributed to pellet integrity. RDF pellets showed a 16 % increase in higher heating value (HHV) (20.85 MJ/kg) and peaked in energy density at 11.5 GJ/m³. Chlorine levels rose, but slagging and fouling indices decreased, indicating improved thermal behavior. In chars, higher RDF content led to increases in C, H, and HHV (15.5 → 23.7 MJ/kg), though chlorine content reached 1.97 %. Simulation results of CO_2 gasification at 950 °C indicate that char gasification times are generally longer than those of raw pellets, while higher RDF content accelerates conversion. These findings confirm RDF's potential as a viable, high-performance alternative fuel when densified and thermochemically upgraded.



Holger Braun, Hochschule für Wirtschaft und Umwelt Nürtingen-Geislingen

Peat reduction in hobby gardening - Perspectives of hobby gardeners from gardening to product decision

Holger Braun, Prof. Dr. Carsten Herbes
Hochschule für Wirtschaft und Umwelt Nürtingen-Geislingen (HfWU)
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72622 Nürtingen, Germany
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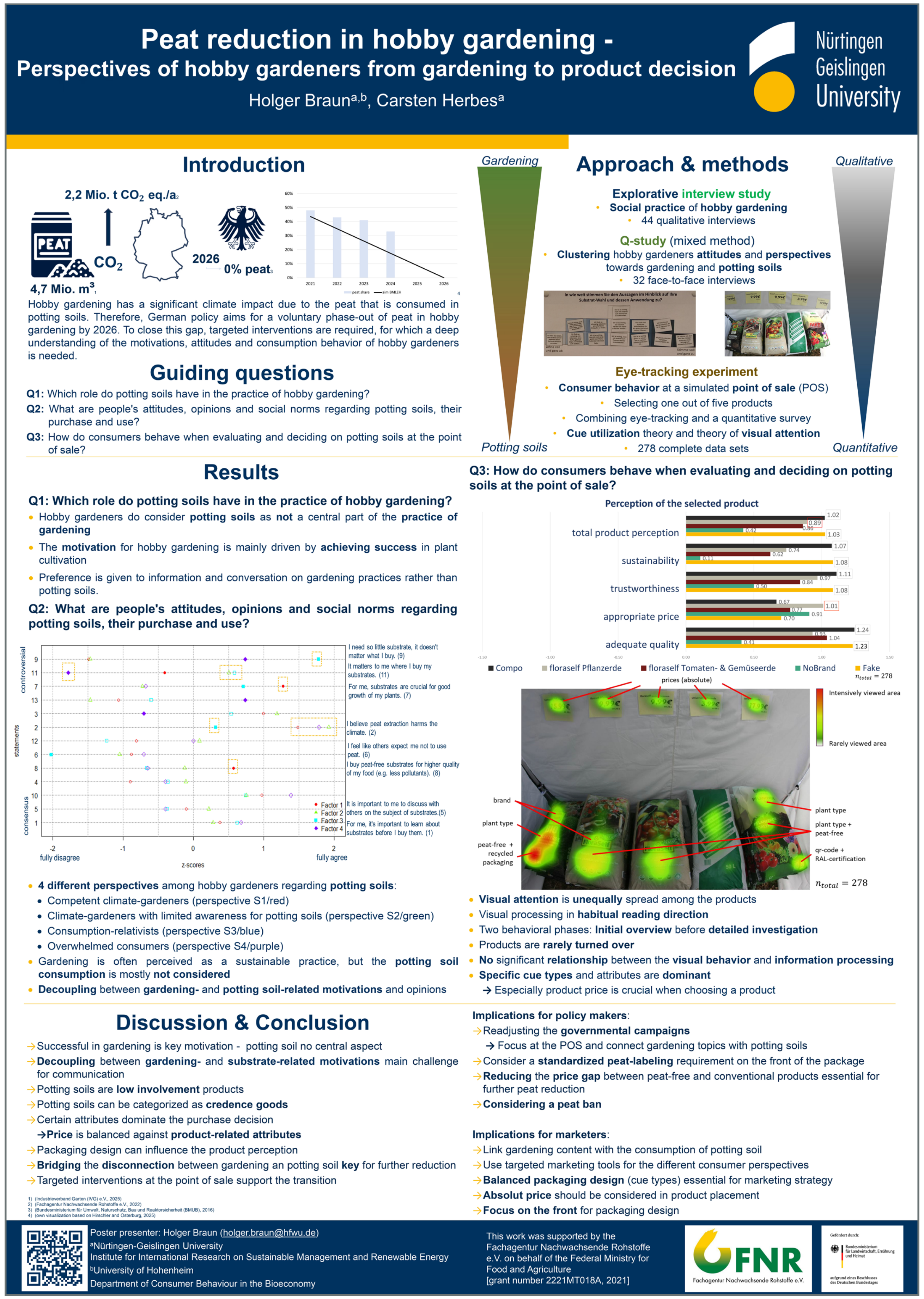
Keywords: peat reduction, sustainable consumption, consumer research, gardening

Introduction
Peat is still an important raw material for the production of potting soils used in hobby gardening. In 2021, the share of peat in potting soils in the German market was 48 %. Due to the negative climate impact of peat, the German government aims to eliminate peat in the hobby sector by 2026 through a voluntary replacement of peat by renewable bio-based resources. To support this voluntary transition, a comprehensive understanding of the general motivation and attitudes as well as behavior of hobby gardeners regarding potting soils is needed.

Approach/Methods
The aim of the dissertation project is therefore to provide this basic understanding through a series of studies. First, an exploratory qualitative interview study was conducted to investigate gardening practices and the role of potting soils. Based on this, a Q-study - a mixed-method approach - was carried out in order to identify the primary motives and attitudes towards gardening and the selection of potting soil. The third study focused on the actual purchasing behavior of hobby gardeners. A quantitative eye-tracking experiment was conducted to analyze the behavior of consumers when making their decision on potting soils at a simulated point of sale. Throughout the three studies, the perspective moved from a broad approach on gardening aspects towards a more focused product- and purchase-centered approach.

Results/Outlook
The results of the research provided important insights into gardening motivation and the role of potting soils in the practice of gardening. The primary motivation for hobby gardeners is to achieve success in plant cultivation, whether it is designing their garden with flowers or producing their own vegetables. Potting soils play only a secondary role.

Gardening is generally not associated with potting soils. Attitudes to gardening do not necessarily translate into attitudes to potting soils, i.e. environmentally conscious gardeners are not necessarily environmentally conscious in their buying decision. Potting soils are primarily a price-sensitive product segment, where packaging design elements such as certifications and layout can influence product decisions. The low level of involvement of hobby gardeners in potting soils and product decisions is a challenge, especially for the voluntary transition of consumption from peat-based to peat-free products. It is therefore crucial for policy makers and marketers to develop low-threshold communication channels to reach hobby gardeners with information about potting soils. Given the target of phasing out peat by 2026, we discuss various approaches and instruments to support this transition.



Kea Purwing, University of Hohenheim

Recovery of Phosphorus and Nitrogen from Biogas Digestate (NitroPhos2)

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70599 Stuttgart, Germany
E-Mail: kea.purwing@uni-hohenheim.de

Keywords: Biogas, Fertilizer, Phosphorus, Nitrogen, Nutrient Recovery

Introduction

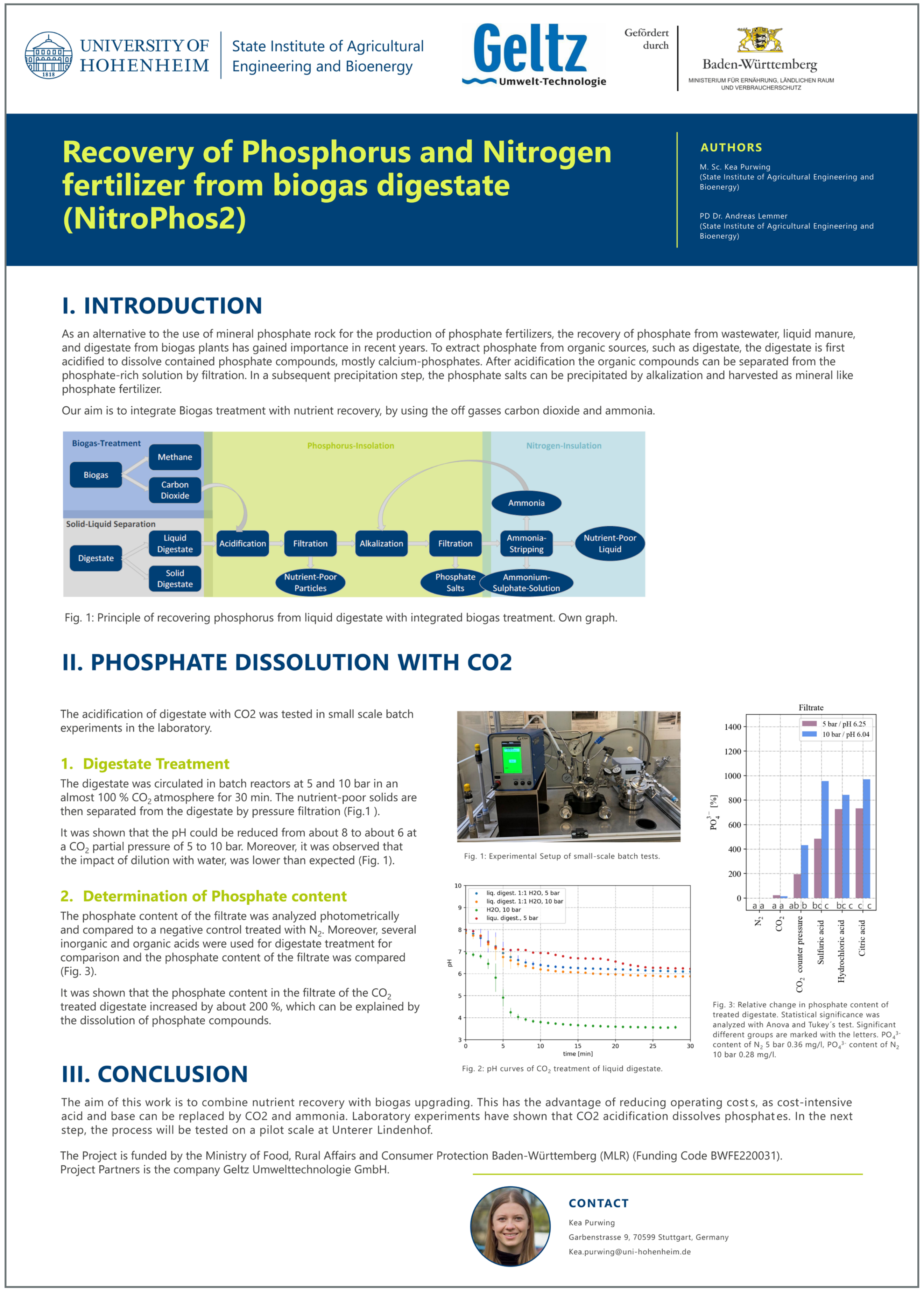
In Biogas plants, biogas is produced as an energy source and digestate occurs as a by-product. Digestate contains most of the nutrients, mainly ammonium nitrogen, phosphorus (P) and potassium. Phosphate (PO_4^{3-}) precipitation is a common process for recovering P from digestate. The PO_4^{3-} is first dissolved at low pH, separated from the particles and then precipitated at alkaline pH as PO_4^{3-} salt. Acidification can be done with liquid acids, and sodium hydroxide is used for subsequent alkalization. As an alternative to acidification with inorganic acids, CO_2 treatment can be used for treating sewage sludge. The aim of this work is to optimize nutrient recovery from digestate. It is examined whether CO_2 and NH_3 treatment is suitable for the recovery of PO_4^{3-} from digestate. Moreover, an innovative low pressure disc stripper is developed for energy efficient ammonia (NH_3) recovery.

Method

For P recovery, the treatment of liquid digestate (LD) with CO_2 was carried out in pressure-stable batch reactors at 5 and 10 bar between 5 and 45°C for 30 min. The pH value was measured and the PO_4^{3-} and P content of both phases was determined after pressure filtration. For N recovery by NH_3-stripping, energy savings should be reached by high surface area of rotating disks and with low pressure of 500-900 mbar. The Pilot plant for N and P recovery is realized at the research biogas plant in cooperation with the company Geltz Umwelttechnologie. The use of CO_2 up to 10 bar for acidification in P recovery enables the integration of biogas upgrading. NH_3 recovered from LD and lime is used for the subsequent alkalization and precipitation of PO_4^{3-} salt.

Result

When treating LD in the laboratory with 5-10 bar CO_2, the pH value was reduced from 8 to 6 with a minor influence of the temperature. LD contains several buffering compounds hindering a further acidification by stabilizing the pH. After CO_2 treatment at 15 °C, the P and PO_4^{3-} content in the filtrate increased by about 200 %, which can be explained by the dissolution of PO_4^{3-} compounds. The results show that P recovery from digestates with CO_2 is possible. Currently the experiments for NH_3 stripping by the low-pressure disc stripper are running and the construction of the pilot plant is almost completed.



Kanakasree Shivaprasad, University of Hohenheim

Circular Bio-Based Business models to create high-value bio-based products in integrated value chains - Potato Case Study

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Keywords: Bioeconomy; Agricultural biomass; Potato residues; Sustainability; Life Cycle Assessment

Introduction

The C4B project focuses on new valorization techniques for agricultural and forestry residual or waste materials, contributing to greater resource efficiency and replacement of fossil fuel-based products with more sustainable biobased alternatives. One promising case study within this initiative focuses on the utilization of potato pomace, a byproduct of potato processing, to produce bio-based products such as 5-hydroxymethylfurfural (HMF) and other valuable chemicals through on-farm small biorefineries thereby promoting sustainable value chains. In this context, the environmental sustainability assessment of biorefinery process is viewed as part of the strategy to reach this overarching goal.

Methodology

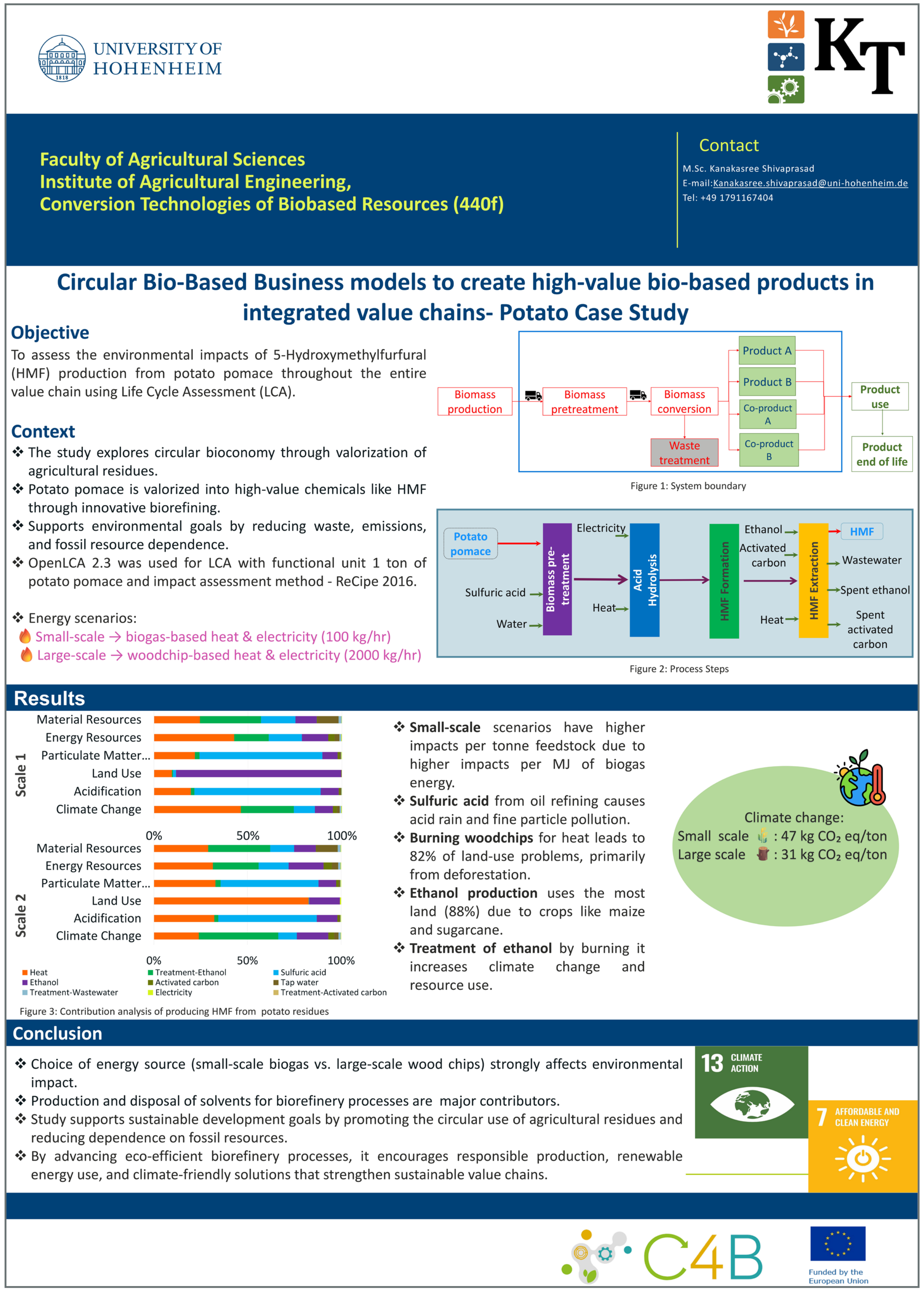
The aim of this study is to assess the environmental sustainability of the potato value chains through a detailed Life Cycle Assessment (LCA) methodology, utilizing OpenLCA software. The reference flow is defined based on mass, specifically as 1 ton of potato pomace and is considered to have no environmental impact. The analysis was conducted on two scales: small scale and large scale, utilizing heat and electricity sourced from a biogas plant and wood chips, respectively. The inventory includes potato pomace, sulfuric acid, activated carbon, tap water, ethanol, heat, and electricity, with the outputs being HMF.

The production process involves several stages, including biomass pretreatment, acid hydrolysis, HMF formation, and HMF purification. The selected impact categories for the life cycle assessment are ReCiPe 2016 v1.03 midpoint H and endpoint H.

Results

Small-scale scenario contributes to Climate change around 47.61 kg CO_2 eq per ton, while large-scale contributes to 31.9 kg CO_2 eq. Heat production using woodchips causes major land use impacts (82 %) in large scale due to deforestation and biomass cultivation. Sulfuric acid significantly contributes to acidification and particulate matter formation (52–67 %) in both scales, mainly from sulfur recovery in petroleum refining.

The selection of an energy source exerts a substantial influence on environmental outcomes. Small-scale scenarios exhibit higher impacts per unit of energy produced, whereas large-scale result in more pronounced land use impacts. Furthermore, the production and disposal of solvents employed in biorefinery processes constitute significant contributors to overall environmental burdens.



Tom Karras, Deutsches Biomasseforschungszentrum

Optimisation of straw supply: Influence of supply chain design on total logistics costs

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Keywords: logistic costs, straw transport, agricultural by-products, residual biomass

Introduction

The supply of biomass is a crucial aspect within the bioeconomy. In addition to the quantity, quality and characteristics of the biomass, available in a specific area, the logistical costs of collecting and transporting the biomass from the source to the demand side are also important, especially with regard to the economic analysis of biomass valorisation options.

Approach/Methods

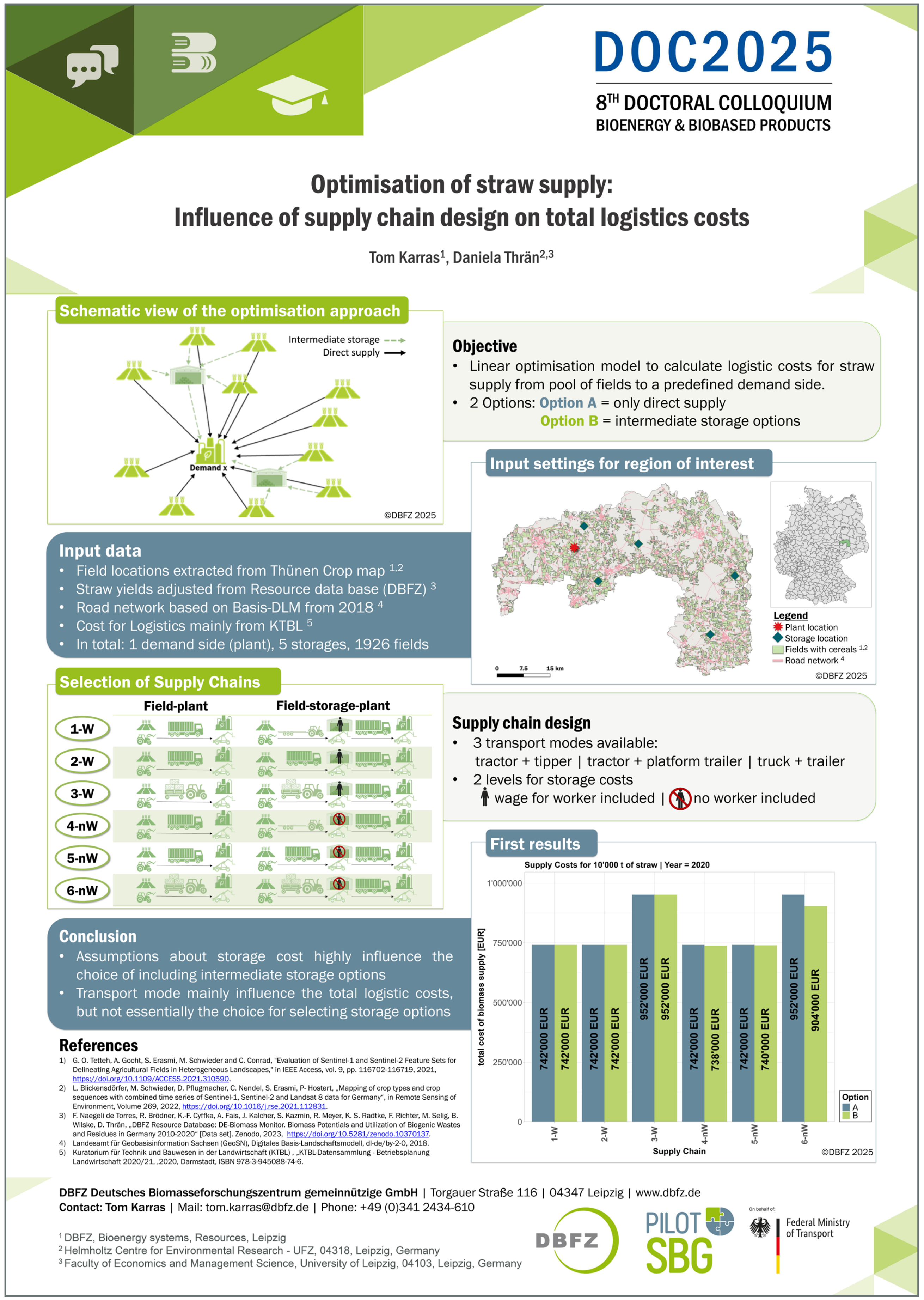
Biomass logistics from source to plant are optimised based on the objective function of minimising total logistics costs. These costs are the sum of supply costs at the source, handling costs, transport costs and optional storage costs at intermediate storage facilities, depending on the transport distance and tonnes of biomass handled. Straw is used in the case study because it is one of the most important biogenic by-products, residues and wastes in Germany in terms of its technical potential [1]. The field locations are derived from existing satellite data of the Thünen Institute [2] [3] and merged with the technical biomass potential of the counties [4]. The location of the theoretical biorefinery is based on the availability of cattle manure within a research area in central Germany. Transport distances are calculated using the existing road network and taking into account the loading capacity of transport and handling vehicles. With predefined supply chains, total logistics costs are modelled for different levels of straw demand at the plant to obtain cost supply curves.

Preliminary results

First model runs and preliminary results of the model indicate that the assumed storage costs strongly influence the inclusion of intermediate storage in the optimization solution. In addition, farm-level supply costs play an important role in the selection of fields for straw collection. The assumptions need to be validated in order to reach reliable results.

References

[1] Naegeli de Torres et al., „DBFZ Resource Database: DE-Biomass Monitor. Biomass Potentials and Untilisation of Biogenic Wastes and Residues in Germany 2010-2020," 2024.
[2] Tetteh et al., „Evaluation of Sentinel-1 and Sentinel- 2 Feature Sets for Delineating Agricultural Fields in Heterogeneous Landscapes," 2021.
[3] Blickensdörfer et al., „Mapping of crop types and crop sequences with combined time series of Sentinel-1, Sentinel-2 and Landsat 8 data for Germany. Remote Sensing of Environment," 2022.
[4] Brosowski et al., „Temporal and spatial availability of cereal straw in Germany - Case study: Biomethane for the transport sector.," 2020.



Fabian Orth, University of Hohenheim

Utilization of lignocellulose-rich substrates for biogas and fiber or cellulose extraction using innovative processes

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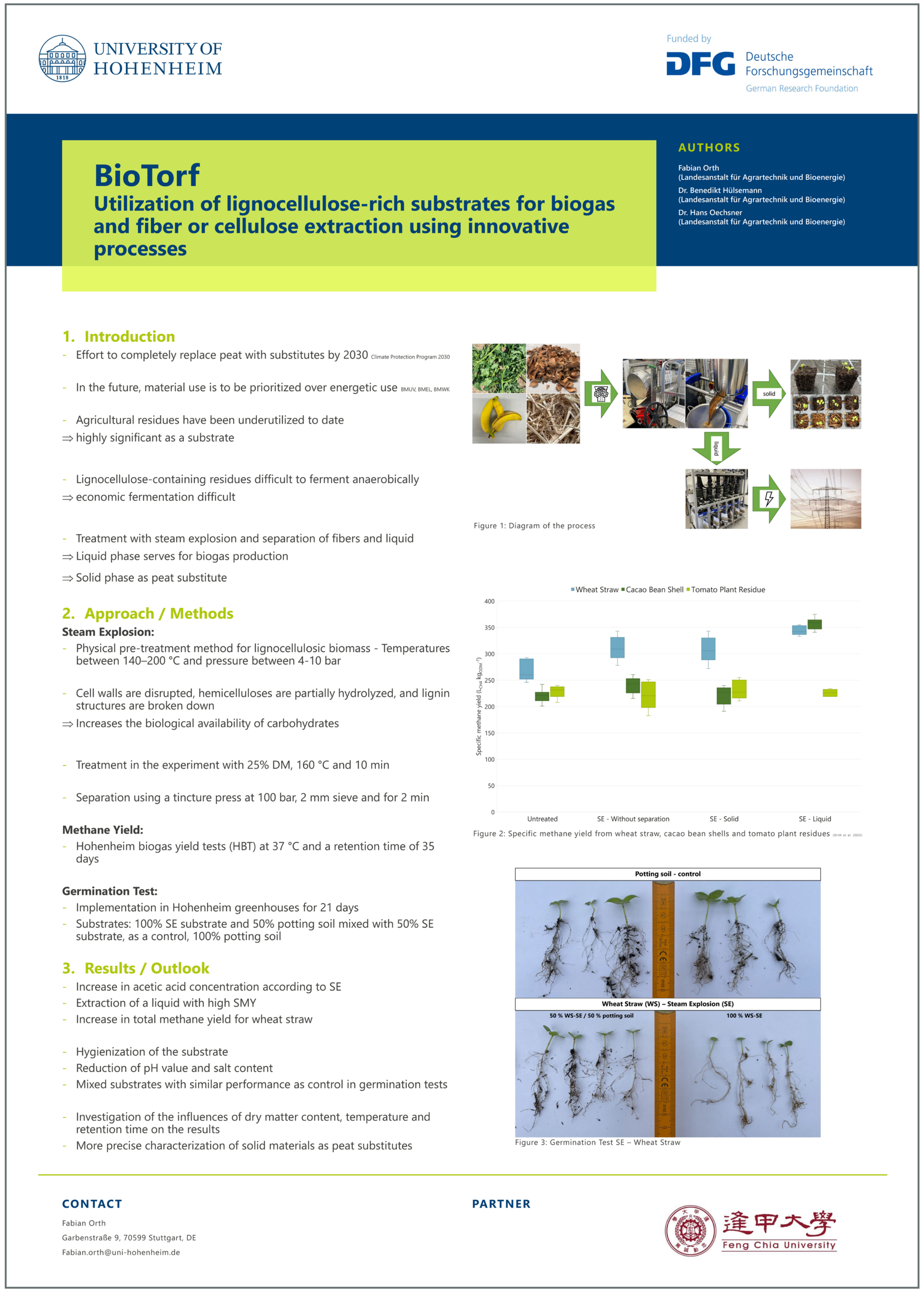
Keywords: peat substitute, methane production, bioeconomy, feedstock

Introduction
The sustainable utilization of biomass is of pivotal significance in achieving targets set forth in the context of climate change, in conjunction with the implementation of the energy transition. The key points of the national biomass strategy emphasize the utilization of materials over energy. Lignocellulosic agricultural by-products represent a resource which is under-utilized. Concurrently, thereis an increasing demand for sustainable substrate alternatives in horticulture, because the extensive utilization of peat is associated with significant ecological disadvantages. Considering the context, the objective of the project is twofold: firstly, to utilize lignocellulosic residues as a substitute for peat, and secondly, to harness these residues as a source of biogas.

Approach/Methods
The project investigates the application of steam explosion as a central processing technology. Subsequent to this, a solid/liquid separation process is implemented to yield fibers intended for substrate production, while the liquid phase is directed into a two-stage biogas plant. The substrates utilized encompass wheat and rice straw, cocoa bean shell, tomato plant residues and banana peels. The substrates are characterized, prepared, and the steam explosion conditions are systematically varied. The objective of this study is to analyze the effect of these parameters on the quality of the substrate (e.g. water holding capacity, pollutants, nitrogen balance) and the biogas potential of the liquid phase. Furthermore, both germination and planting experiments will be conducted. The results will be evaluated within the context of an overall system that is as energy efficient as possible.

Results/Outlook
Preliminary investigations suggest that the fiber-rich residues could have potential application as a growing medium. The liquid phase exhibits a high specific methane yield, which is a promising indicator for energy production. In the subsequent phases of the project, the feasibility of utilizing the solid portion as a peat substitute will be examined in greater detail, with specific attention devoted to its water holding capacity and the impact on plant growth. The objective is to establish a recycling solution that is optimized with respect to material and energy, and which has a balanced energy balance.



Yury Erofeev, SQUAKE

Comparative Analysis of GHG Calculation Methodologies in Aviation

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Keywords: Aviation emissions, GHG calculation, CSRD, Radiative Forcing Index, Non-CO_2 effects

The aviation sector faces increasing pressure to align greenhouse gas (GHG) emissions reporting with the Corporate Sustainability Reporting Directive (CSRD), which sets high demands for transparency, comparability, and scientific robustness in corporate disclosures. This study provides a detailed comparative analysis of eleven widely used GHG calculation methodologies for aviation, examining their alignment with CSRD requirements and their implications for both corporate sustainability strategies and regulatory compliance.

A multi-criteria analysis framework was applied to assess key dimensions: system boundaries (tank-to-wake vs. well-to-wake), inclusion of non-CO_2 effects through Radiative Forcing Index (RFI) factors, data granularity (flight-specific vs. aggregated averages), lifecycle coverage, booking class differentiation, and adherence to standards such as ISO 14083, the GHG Protocol, and CORSIA. By combining literature review with expert insights from industry practitioners, the analysis highlights the operational feasibility and data requirements of each methodology.

Results reveal pronounced differences in emissions estimates - particularly for long-haul flights - driven by methodological choices on RFI, treatment of upstream fuel emissions, and the extent of operational data integration. Comprehensive methodologies such as DEFRA, CO_2 emissiefactoren, and ADEME, which account for lifecycle stages and non-CO_2 impacts, deliver greater regulatory alignment but entail higher complexity and data demands. In contrast, simpler approaches like ICAO and EPA are more accessible yet risk significant underestimation of aviation's climate impact, potentially creating compliance gaps under CSRD.

The study concludes that greater harmonization of aviation GHG accounting is urgently needed to ensure comparability, credibility, and regulatory readiness. Standardizing treatment of non-CO_2 effects and lifecycle emissions, coupled with transparent documentation, would enhance the reliability of Scope 3 reporting and support meaningful climate action. For industry and policymakers alike, aligning on a narrow set of robust, implementable methodologies is a critical step toward achieving consistent, high-quality reporting and accelerating the sector's decarbonization.

SQUAKE DBFZ UNIVERSITÄT LEIPZIG

Comparative Analysis of GHG Calculation Methodologies in Aviation

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Main Finding

Aviation emissions calculators differ substantially—especially on long-haul. Methods that include non-CO_2 (via a radiative-forcing index, RFI) and well-to-wake (WTW) upstream factors report higher but more CSRD-ready numbers. Simpler TTW-only tools risk underestimation unless limits are disclosed and sensitivities are shown.

Methods

- Frameworks compared: ICAO, DEFRA/BEIS, ADEME/Base Empreinte, CO_2 emissiefactoren (NL), TIM (Travalyst), TREMOD/UBA, TU Chalmers, EPA, IATA CO_2 Connect, plus research/industry references.
- Standardized short/medium/long-haul profiles; native seat-class and cargo rules; native TTW/WTW and RFI settings.
- MCA (0–3 scale): boundary clarity; non-CO_2 handling; data granularity; documentation/audit trail; standards alignment.
- Sensitivities on class splits, distance corrections, factor vintages, and RFI ranges.

Background

- Aviation ≈2–3% of global CO_2; non-CO_2 effects (NO_x, contrails) amplify warming.
- CSRD/ESRS emphasize transparency, completeness, auditability (Scope 3 travel).
- Calculators vary by distance model, class/cargo allocation, energy scope (TTW vs WTW), and RFI policy.

Table 1: Factors considered or applicable by methodology (MCA scores and ranking).

Factor (0–3)	ICAO	TIM	DEFRA	TU Chalmers	ADEME	TREMOD	CO2 emissiefactoren	Base Empreinte	ICEC	IATA CO2 Connect	EPA
Airline/flight-specific	0	3	0	0	0	0	0	0	3	3	0
Cargo allocation	3	2	2	2	2	2	2	2	3	3	2
Passenger load	3	3	2	2	2	2	2	2	3	3	2
Booking class	3	3	0	3	0	0	3	0	3	3	0
Energy scope	0	3	3	0	0	3	3	0	0	0	0
Aircraft type	3	3	3	0	0	0	0	0	3	3	0
Aicraft capacity	3	3	0	0	3	0	0	3	3	3	0
CO2e	0	3	3	3	3	3	3	3	0	0	3
RFI (MCA score)	0	0	3	3	0	3	3	3	0	0	0
RFI (value, if fixed)[†]	—	—	1.7	1.7	—	3.0	1.7	1.9	—	—	—
Distance-based	3	3	3	3	3	3	3	3	3	0	3
Time-based	3	3	3	3	3	3	3	3	3	0	0
Equal-weight MCA score	1.91	2.64	2.00	1.73	1.45	1.73	2.00	1.73	2.18	1.64	0.91
Rank (1=best)	5	1	3	6	10	6	3	6	2	9	11

Notes: Scoring rubric per Methodology: 0=absent/unclear; 1=limited/implicit; 2=partial/conditional; 3=explicit/comprehensive. Equal-weight MCA score is the unweighted mean across factor rows using the 0–3 scores. [†]RFI values are shown for transparency and do not themselves enter the 0–3 scoring.

Key Results

- Divergence grows with distance; RFI + WTW drive the largest long-haul uplift.
- DEFRA, CO_2 emissiefactoren, ADEME provide broader scope but higher data demands.
- ICAO/EPA are suitable for screening, but omit non-CO_2 and much of WTW → lower values.
- CSRD-readiness correlates with explicit boundaries, optional/transparent RFI, provenance + versioning.

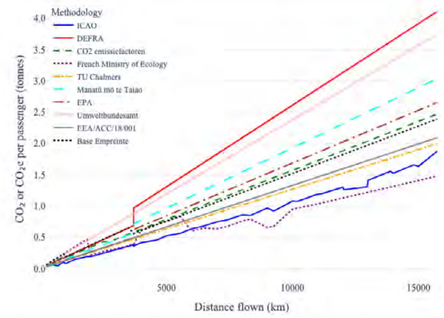

Figure 1: Comparison of CO_2 or CO_2e emissions per passenger across different methodologies as a function of distance flown.

Limitations

- Some calculators are proprietary; replication relies on published assumptions.
- Results reflect each tool's native logic (not fully harmonized).
- Factor vintages differ across sources; sensitivities mitigate but cannot remove this.

Table 2: Standards considered or applicable by methodology (MCA scores and ranking).

Standard (0–3)	ICAO	TIM	DEFRA	TU Chalmers	ADEME	TREMOD	CO2 emissiefactoren	Base Empreinte	ICEC	IATA CO2 Connect	EPA
CORSIA	3	3	0	0	0	0	0	0	3	3	0
ISO 14083	0	3	0	0	0	0	0	0	0	0	0
IATA RP 1726	0	3	0	0	0	0	0	0	0	3	0
DGAC	0	0	0	0	3	0	0	3	0	0	3
Umweltbundesamt	0	0	0	0	0	3	0	0	0	0	0
CAA	0	0	3	0	0	0	0	0	0	0	0
GHG Protocol	0	3	3	3	3	3	3	3	0	0	0
CSRD	0	3	3	3	3	3	3	3	0	0	3
Equal-weight MCA score	0.38	1.88	1.12	0.75	1.12	1.12	0.75	1.12	0.38	0.75	0.75
Rank (1=best)	10	1	2	6	2	2	6	2	10	6	6

Notes: Scores reflect documented integration/compatibility with each standard: 0=none; 3=explicit alignment or applicability. Equal-weight MCA score is the unweighted mean across standard rows using the 0–3 scores.

Future Work

- Test harmonized rules on flight-level data with observed fuel burn.
- Maintain open, versioned libraries for WTW factors, class splits, load factors, and RFI updates.
- Explore contrail-aware metrics alongside CO_2e for decision support.

References

- Lee, D.S. et al. (2021). The contribution of global aviation to anthropogenic climate forcing, 2000–2018. Atmospheric Environment 244, 117834.
- European Commission (2023). Regulation (EU) 2023/772 — European Sustainability Reporting Standards (ESRS).
- DEFRA (2024). UK Government GHG Conversion Factors for Company Reporting — Methodology Paper.
- ICAO (2024). Methodology: ICAO Carbon Emissions Calculator (v13), Technical Documentation.
- Jungbluth, N., Meili, C. (2019). Recommendations for calculating aviation GWP incl. Radiative Forcing Index. Int. J. Life Cycle Assess. 24:404–411.

8th Doctoral Colloquium BIOENERGY and BIOBASED PRODUCTS. Sep 2025 **yury.erofeev@squake.earth**

Lukas Richter, Deutsches Biomasseforschungszentrum

Coordinated Energy Systems in Decentralized Districts: Evaluating Biomass-Based Hybrid Systems within the Cellular Approach

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Keywords: Cellular Approach, Mixed-integer linear programming (MILP), Agent-Based Modelling, Sector Coupling

Introduction

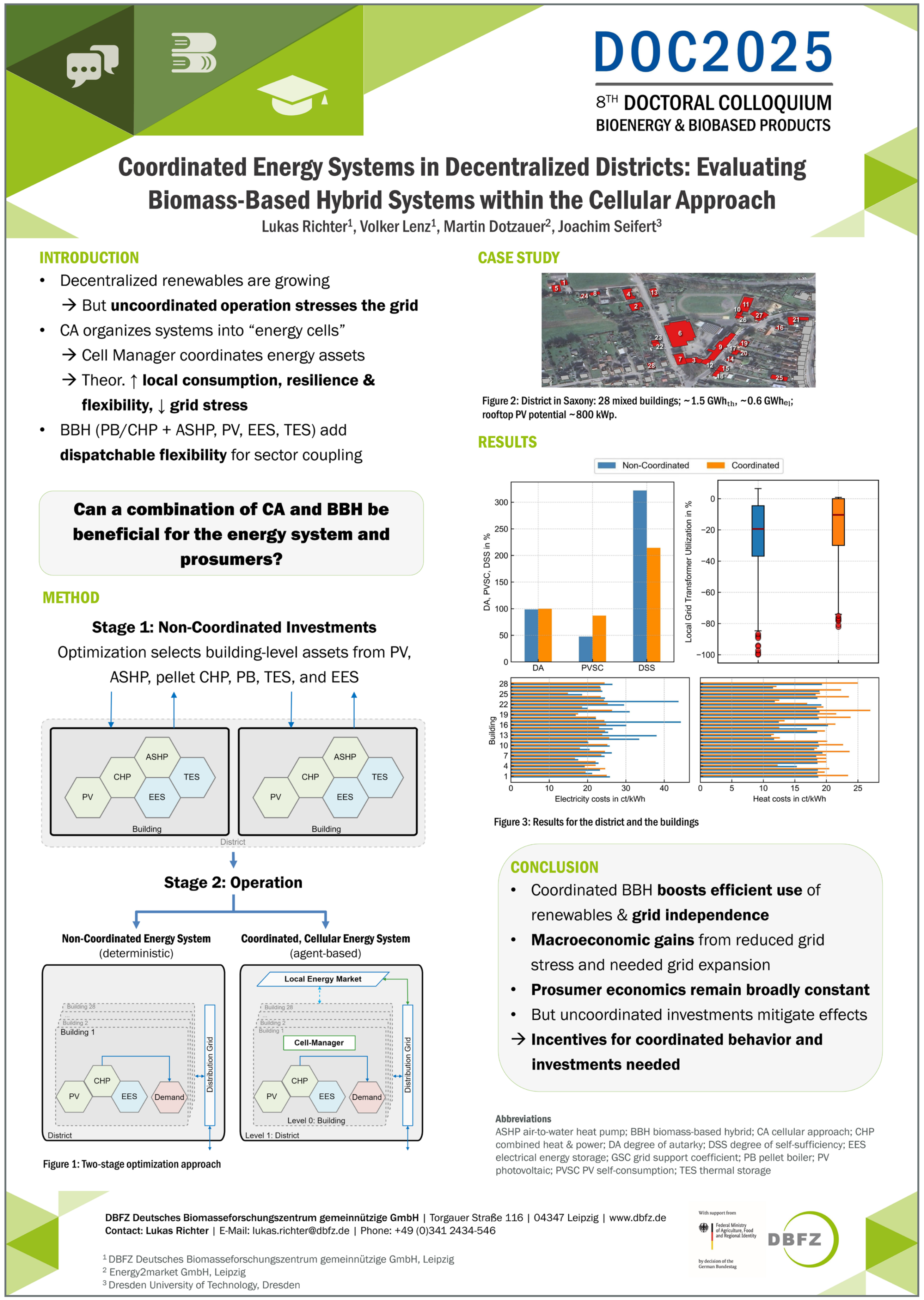
Decentralized renewable energy systems are a cornerstone of Germany's energy transition. However, their often uncoordinated expansion presents significant challenges for grid stability and the efficient supply and use of energy. Biomass-based hybrid systems, such as pellet boilers or CHPs combined with heat pumps, offer critical flexibility by providing dispatchable, sector-coupled heat and electricity. Within the Cellular Approach (CA), such hybrid systems can enhance both self-sufficiency and systemic efficiency. This study investigates how the coordinated operation of biomass-based hybrid systems within energy cells impacts grid stability, renewable integration, and economic performance compared to conventional non-coordinated setups.

Approach

The study applies a two-stage modeling framework to an urban district of 28 diverse buildings in Saxony. Investment optimization identifies optimal configurations of photovoltaic (PV) systems, air- source heat pumps (ASHP), pellet boilers (PB), and combined heat and power units (CHP) with optional thermal and electrical storage. Operational behavior is evaluated through deterministic (non- coordinated) and agent-based (coordinated) simulations. The coordinated model, implemented via the agent-based platform AMIRIS, features local energy markets and a cell manager responsible for balancing electricity and heat flows within the cell.

Results/Outlook

Results show that biomass-based hybrid systems, when coordinated within the CA, significantly improve local energy utilization and grid-friendliness. The coordinated setup increases PV self-consumption by ~40 percentage points and reduces transformer peak loads by ~20 percentage points. Biomass-CHP and pellet boiler systems, when complemented by heat pumps, enable flexible sector coupling, improving heat supply security and reducing electricity export surpluses. However, while technical advantages are evident, economic benefits for individual prosumers remain marginal, emphasizing the need for supportive market designs and incentives. Future research should address coordinated investment strategies to optimize the deployment of biomass-hybrid technologies in cellular energy systems.



Patrick Altendorf, University of Hohenheim

Small Anaerobic Plants for Agricultural Waste Utilization (KLAWIR)

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Keywords: biogas, cattle manure, anaerobic digestion, small-scale slurry digester, methane production

Introduction

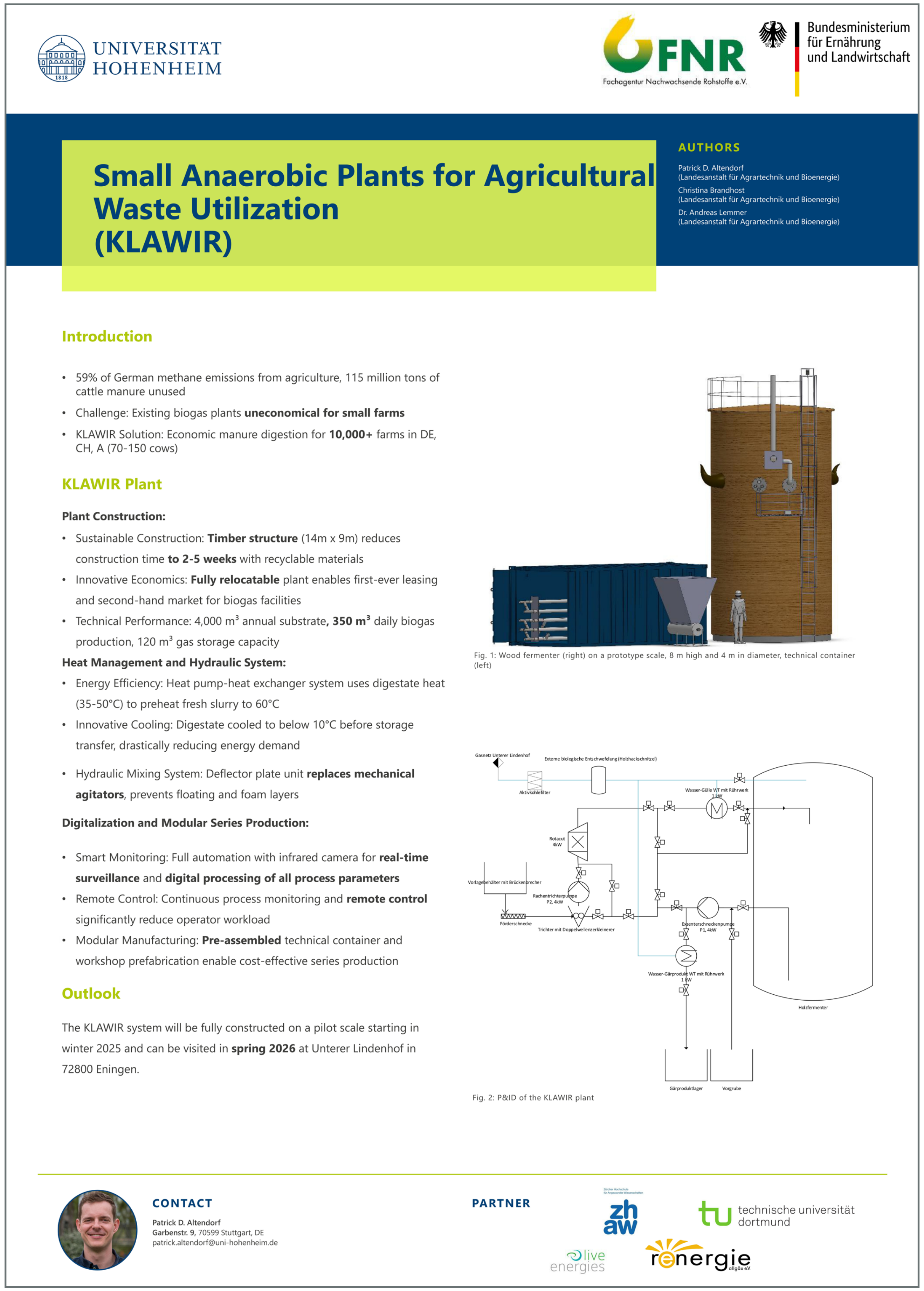
In Germany, 115 million tons of cattle slurry are produced annually, with two-thirds remaining untreated and significantly contributing to greenhouse gas emissions. A systematic energetic utilization of 80 % of this slurry could generate approximately 1.5 billion cubic meters of methanewith an energy content of nearly 15,000 gigawatt- hours - enough to power 2.6 million households. Although this enormous climate protection potential exists, only about one-third has been tapped so far, as economical cattle slurry fermentation remains challenging for small farms due to high costs.

Approach/Methods

The KLAWIR demonstration project develops an innovative solution for the economical fermentation of cattle slurry in small agricultural operations. The mobile, recyclable biogas plant with an 800m³ fermenter volume uses a sustainable wooden construction with a polymer membrane, enabling quick assembly and reusability, making leasingmodels feasible. Core elements of the technological optimization include: A closed heat management system with heat exchangers and heat pump that efficientlyrecycles process heat and drastically reduces heat requirements - crucial when processing low-energy cattle slurry. The hydraulic stirring system with deflector plates replaces complex mechanical agitators and prevents floating layers. Comprehensive digitalization with remote monitoring enables fully automated operation with minimal workload. The modular, highly standardized construction with apre-assembled technical container significantly reduces installation and operating costs. The plant processes over 4,000m³ of substrate annually with a 60-day retention time and produces 350m³ of biogas daily – an important contribution to unlocking the previously unused energy potential of cattle slurry.

Results/Outlook

The KLAWIR pilot plant, scheduled for full implementation in 2025, represents a breakthrough for small to medium-sized farms with 70-150 cattle - a segment comprising over 10,000 potential users in Germany alone. By combining sustainable construction with innovative heat management, hydraulic stirring, and comprehensive digitalization, the plant overcomes traditional economic barriers to cattle slurry fermentation. This technology could unlock the vast untapped potential of agricultural waste, potentially generating 15,000 gigawatt-hours from 1.5 billion cubic meters of methane while significantly reducing greenhouse gas emissions from livestock farming.



Ronja Wollnik, Deutsches Biomasseforschungszentrum

Measuring what counts: How indicators for bioeconomy regions can be adapted for biobased CO_2 removal

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Keywords: Assessment framework, Analytical hierarchical process (AHP), Carbon dioxide removal, Negative emissions, Regional analysis

Carbon dioxide removal (CDR) is indispensable forreaching climate neutrality. Its implementation in regional development plans is challenging, and driven by a diverse set of indicators. Bio-based CDR is put into focus in this work, i.e., natural sink enhancement, renewable long-lived building materials, and bioenergy with carbon capture and storage (BECCS) as well as combinations of those options into cascades. By constructing a holistic assessment framework and adapting it to specific system questions, decision support can be provided to regional actors.

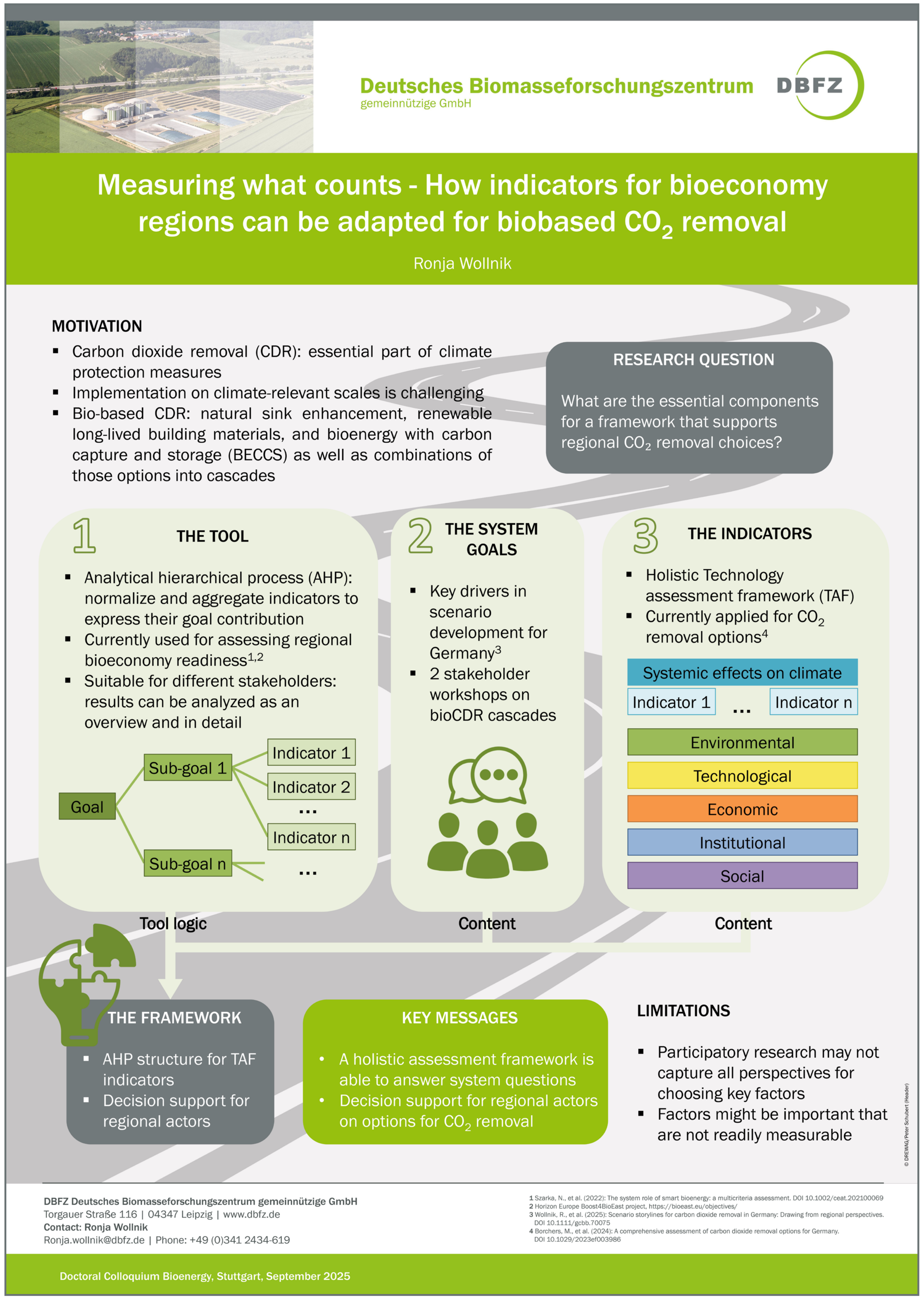
An analytical hierarchical process (AHP) tool was developed to capture characteristics anddevelopment opportunities for bioeconomy regions. Goals, sub-goals, and indicators were defined. For each indicator a bandwidth and normalization method were developed. The AHP tool was validated by testing input data for European partner countries in the Horizon project Boost4BioEast. Results can be analyzed as an overview and in detail, which allows for addressing the needs of various stakeholder groups. This tool constitutes the logical basis for the new bioCDR assessment framework.

The content of the framework is based on previous works on assessment frameworks for CDR, especially the Technology Assessment Framework (TAF). Regional indicators were selected by defining selection criteria and describing which indicators are suitable for transfer from a national to a local scale.

The system goals, i.e., the higher levels of the AHP tool, were defined in a participatory process. In scenario development, key drivers for the development of bioCDR in Germany were identified with regional stakeholders. In addition, two stakeholder workshops target specifically questions around the deployment of bioCDR cascades, i.e., biomass-based value chains that deliver negative emissions in German regions.

A limitation of the participatory research approach is the challenge to capture all perspectives. Plus, factors which are not readily measurable might be relevant to the assessment.

By focusing on biobased CDR cascades, regional actions can be streamlined to achieve both carbon removal and a range of co-benefits. A holistic assessment framework is able to answer system integration questions, and provide decision support for regional actors on options for biobased CO_2 removal.



Rojosoa Hasiniaina, International Institute for Water and Environmental Engineering

New method optimization thermochemical and physiocheimcals of foods and combutible waste with life cycle analysis model

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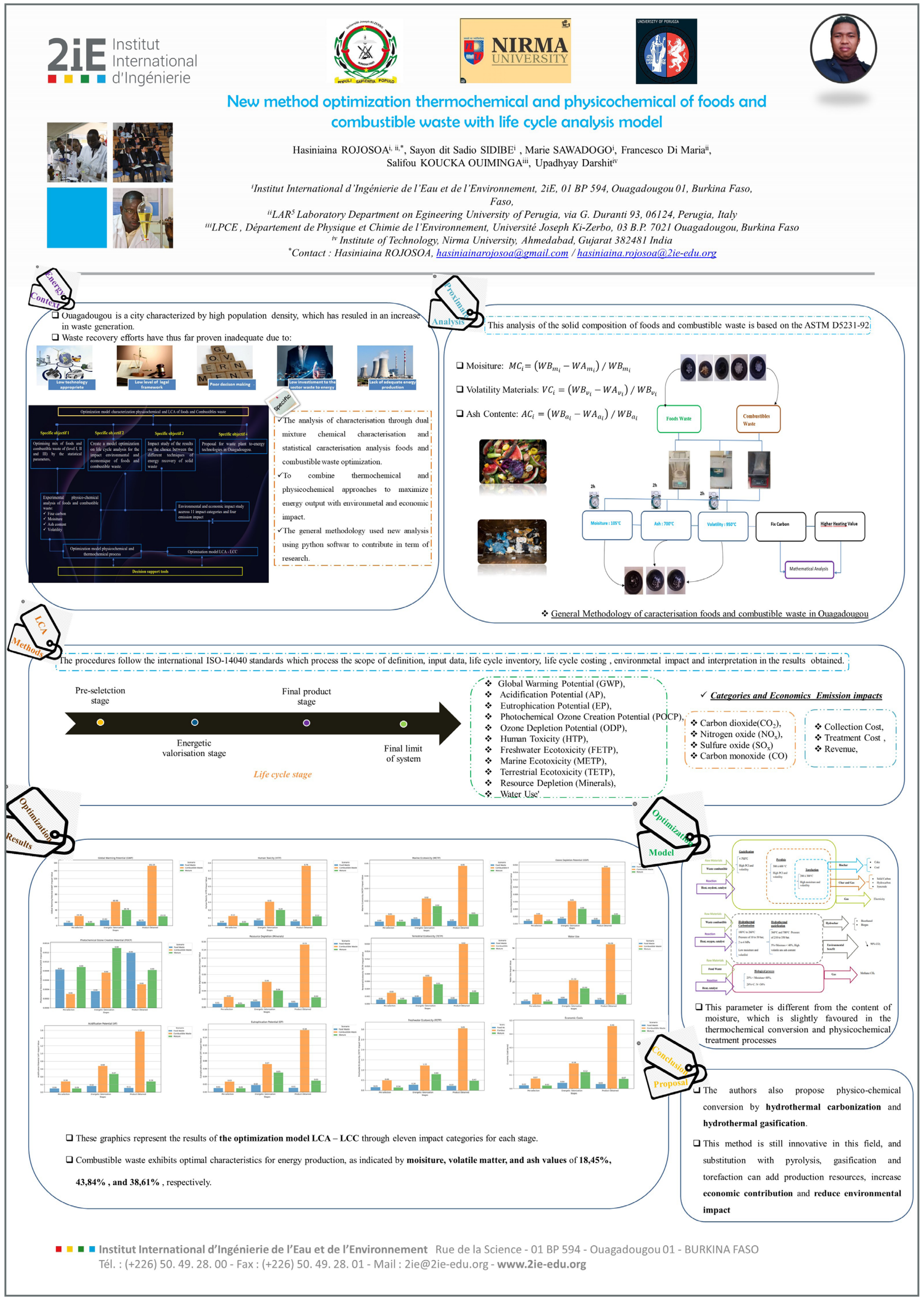
Keywords: Carbonization, Food Waste, Combustible Waste, Hydrothermal, Thermochemical, Physicochemical, Python

In Ouagadougou, waste-to-energy sector is still underdeveloped in terms of scientific knowledge. For this reason, the present study proposes a model based on physicochemical analysis of the different types of waste, which can provide useful information for choosing proper waste treatment technologies that minimize and Socio-Economic and Environmental Impact (SEEI). The data were analyzed and processed rigorously and innovatively using Python software to obtain accurate results.

The study has two objectives: First, it conducts a proximate analysis of food and combustible waste (FWC) performed by laboratory experimental apparatus. The second objective is to create a model based on Python Life Cycle Assessment to evaluate the SEEI of the stages involved in processing FCW. The results indicate the optimal mix of FCW based on the statistical physicochemical parameters. According to the model optimization results, combustible waste has a greater impact on the Global Warming Potential at the production stage with the maximum energy production of 10,322.56 MJ/kg per year or maximum hydrogene production of 28.52 %; however, the energetic valorization of food waste and the mix of FCW results in less environmental and economic cost.

The authors propose two methods: 1) biological treatment for the recovery of food waste and 2) a physicochemical treatment combined with thermochemical conversion through hydrothermal carbonization and gasification. This combination is as effective as converting 10 % into bioethanol or valorizing 50 % of the carbon in the waste mixture into biogas. This represents an innovative technology that can enhance the production of electrical energy while promoting sustainable SEEI.



Carolin Eva Schuck, Aarhus University

Wet Oxidation of Hydrothermal Liquefaction Aqueous Phase: How much reaction heat can be released?

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Keywords: Wet Oxidation, HTL Aqueous Phase, Differential Scanning Calorimetry

Introduction

Hydrothermal Liquefaction (HTL) represents a promising technology to convert biomass into energy-rich bio-crude, but additional treatment of the organic contaminated aqueous phase (AP) byproduct is necessary for improving commercial viability. A treatment method with potential for energy recovery is Wet Oxidation (WO), an advanced exothermic process capable of degrading organic species present in the HTL-AP. However, only little research dealing with values for the heat release for WO of HTL-AP exists, a crucial factor when considering heat utilization in an integrated HTL-WO process.

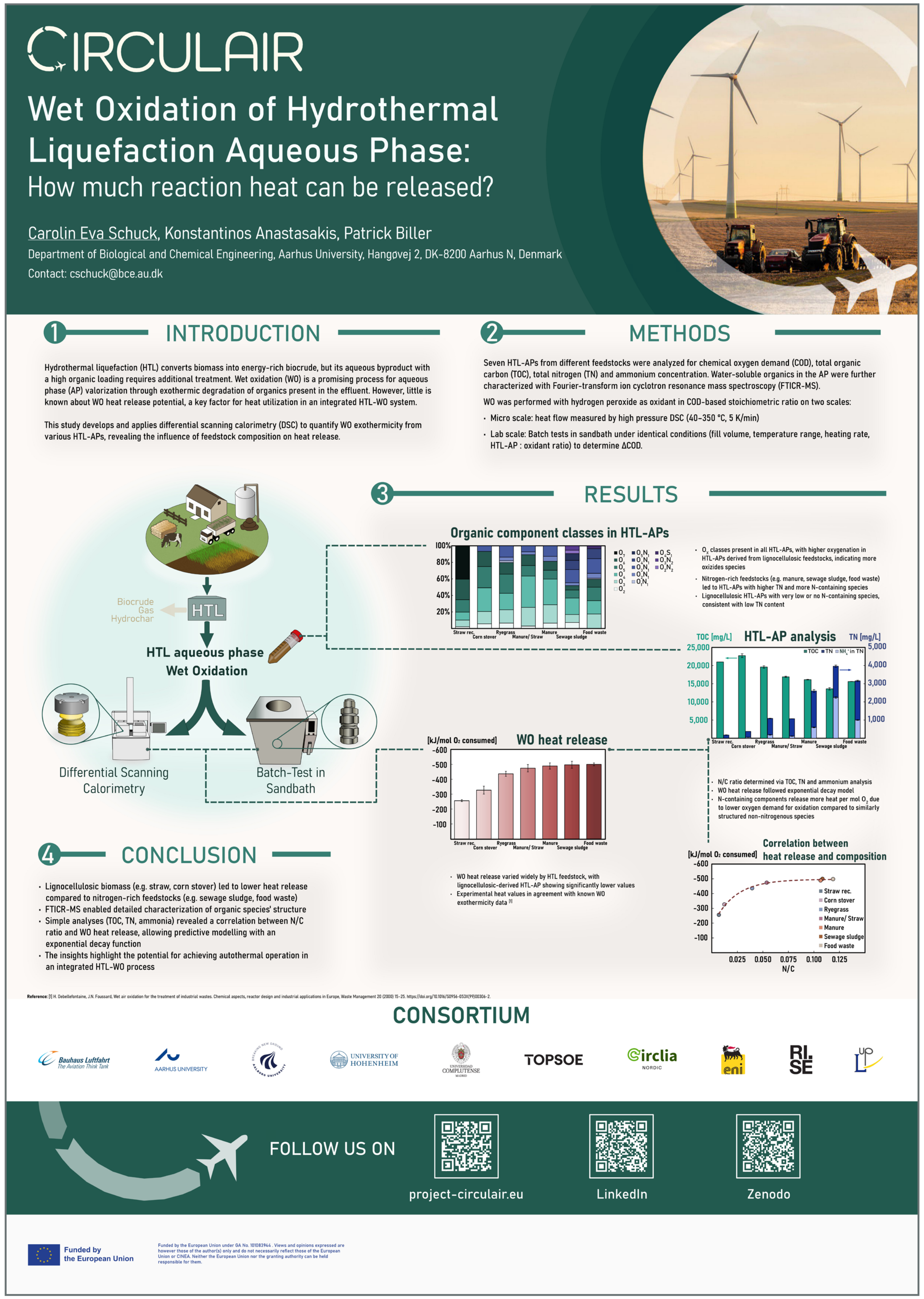
Approach/Methods

The study introduced a method to quantify WO heat release of HTL-APs derived from seven different feedstocks by exploiting Differential Scanning Calorimetry. AP samples were analyzed for Chemical Oxygen Demand before and after WO to account for the oxidation efficiency, as well as for the initial organic composition by different characterization techniques such as Fourier-Transform Ion Cyclotron Resonance Mass Spectrometry (FTICR-MS) to correlate the specific elemental composition with the observed heat release.

Results & Outlook

Results revealed a dependence of WO heat release on the HTL feedstock. Lignocellulosic-derived HTL-AP reached lower heat release values up to around 500 kJ/molO2 cons., while nitrogen-rich feedstock such as sewage sludge yielded nearly double. These findings suggest a correlation between organic composition and observed heat release, which can be explained with FTICR-MS data.

The study provides an understanding of the energy potential of WO treatment for HTL-AP. It gives an insight into the influential effect of feedstock selection on heat recovery and provides a basis for predicting autothermicity in an integrated HTL-WO process.



Emmanuel Bala, Karlsruhe Institute of Technology

The Hydrothermal Liquefaction (HTL) of Lignin - A Computational and Experimental Approach to the Adsorption Separation of High-end Value Aromatics

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Keywords: Hydrothermal Liquefaction, Lignin, Adsorption, Amberlite XAD-4, Deep eutectic solvents

Introduction

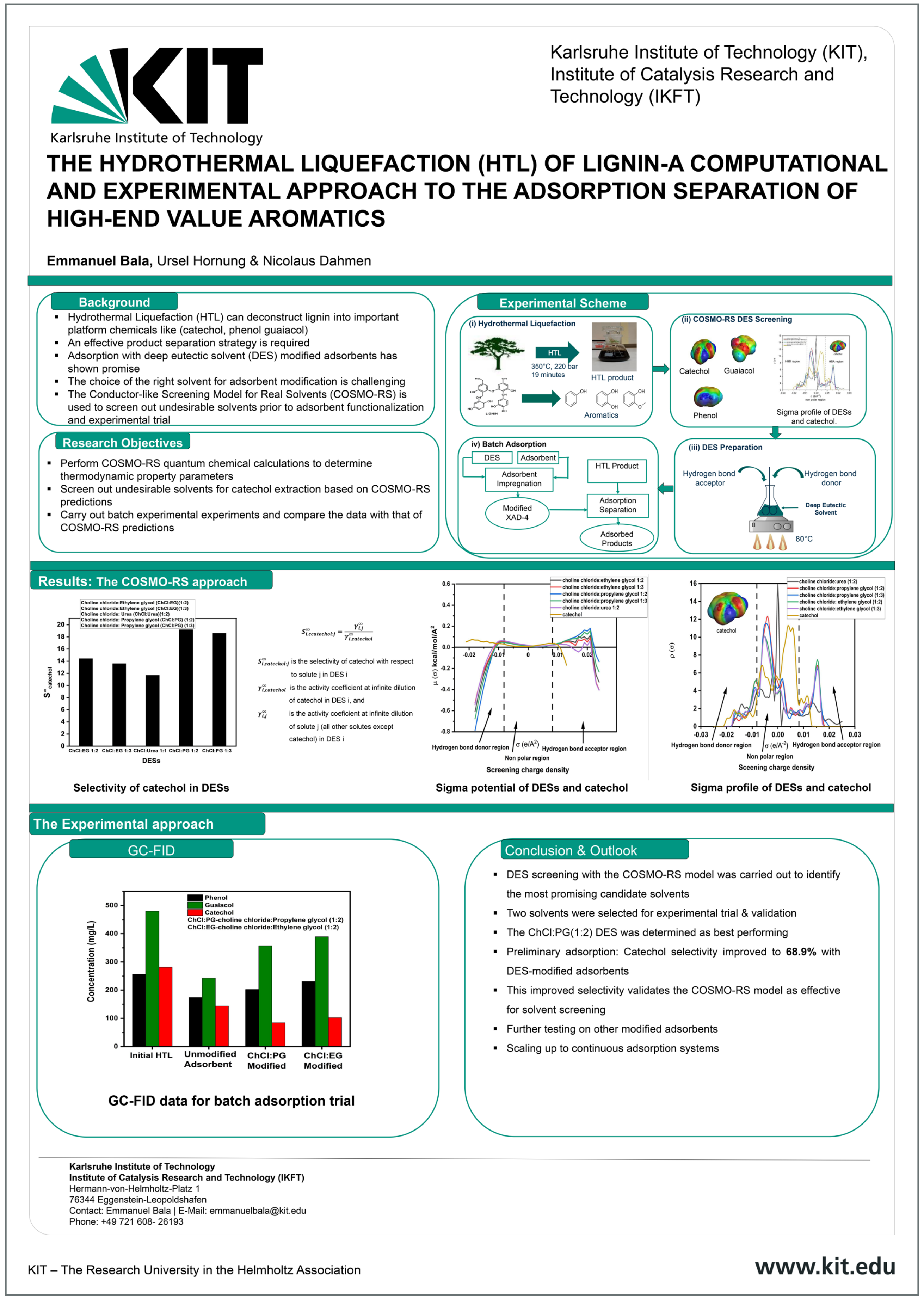
The deconstruction of lignin into its constituent aromatic molecules via thermochemical processes like hydrothermal liquefaction (HTL) provides a possible route to renewable aromatics for fuels and chemicals production. However, the complex nature of the resulting product mixtures poses a downstream separation challenge in view of selective product recovery. Deep eutectic solvent (DES) modified adsorbents might have the ability to address this issue, but owing to the large number of possible DESs to choose from, there is the problem of solvent selection for adsorbent modification. The Conductor-like Screening Model for Real Solvents (COSMO-RS) is a model that can screen out undesirable solvents without requiring much experimental data thereby eliminating extra laboratory time and costs. In this study, COSMO-RS was used to screen candidate DESs for adsorbent modification prior to experimental batch adsorption validation

Methods

Fifty-four DESs in varying molar ratios were tested using this model. Prior to COSMO-RS calculations, the geometry and surface charge density of all molecules were optimized using DFT. Molecular geometry optimization was carried out at XC-functional BP-86, a basis set TZP, small core and good numerical quality using the Amsterdam Density Functional (ADF) module of the Amsterdam Modeling Suite (AMS) 2024 software. Thereafter, COSMO-RS was carried out on all species and the DESs screened. To validate COSMO-RS predictions, preliminary batch adsorption experiments were performed with DES modified XAD-adsorbents on the product from lignin HTL with adsorbent loading as the parameter of interest.

Results

Initially, the activity coefficients, sigma profiles, and sigma potentials of the top ten solutes with the highest concentrations in the HTL product were calculated by COSMO-RS. Guaiacol was chosen as the target solute. Based on COSMO-RS results, the choline chloride: ethylene glycol (1:2) DES was chosen as the best-suited adsorbent modifier for guaiacol adsorption. Batch adsorption experiments carried out on the HTL product with the modified XAD-4 showed an increase in capacity and selectivity for guaiacol at all mass loadings. The modified XAD-4 (300 mg) had the highest guaiacol selectivity, with an equilibrium concentration of 121.5 mg/L representing an 85.25 % uptake.



Kassé Jean Hugues Angbé, Deutsches Biomasseforschungszentrum

Optimization of pyrolysis parameters for the production of high-quality biochar from cocoa pod husk using a response surface methodology

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Keywords: Cocoa pod Husk, Biochar, Pyrolysis, Optimization

Introduction

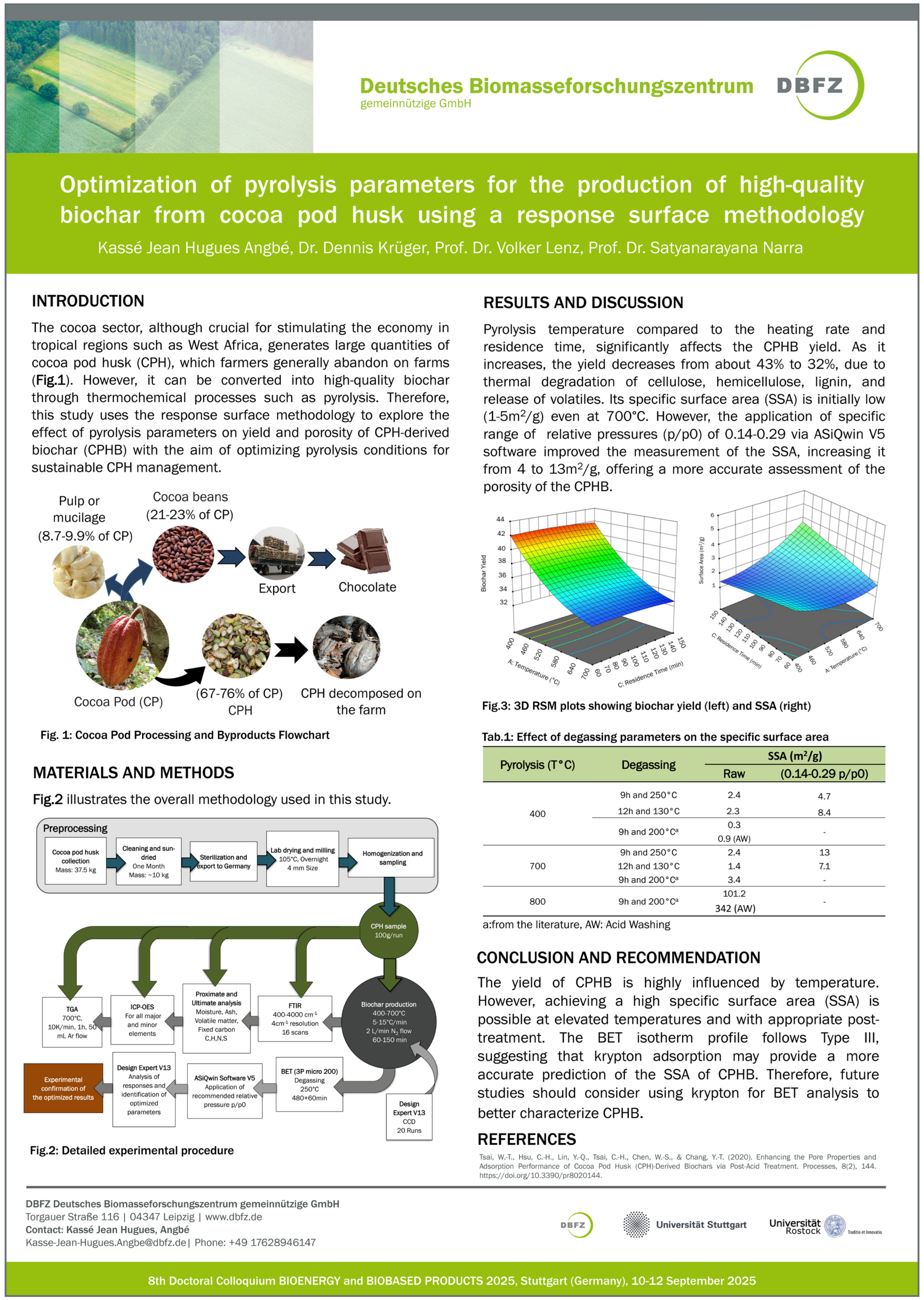
Agricultural waste management remains a major global challenge despite efforts to transitionto a circular economic model. Among sustainable recovery solutions, the conversion of agricultural residues mainly crops residues into biochar by pyrolysis is a more promising method. The cocoa sector, although very important for improving the economy in tropical regions such as West Africa, generates significant amount of residues mainly cocoa pod husk (CPH). CPH can be converted into high-quality biochar, but is generally abandoned on farms and contributes to greenhouse gas emissions and environmental degradation. Studies have shown that the quality of biochar strongly depend on pyrolysis conditions. However, most focused only on individual factors. To address this gap, the present study aims to investigate the influence of temperature, residence time and heating rate on CPH-derived biochar yield and porosity though central composite design (CCD) under Response Surface Methodology (RSM). By assessing optimal pyrolysis conditions, the study enhance the sustainable valorisation of CPH.

Methods

Fresh CPH was collected from farms and dried in Kpadapé, Togo in West Africa, and transported to the DBFZ, Germany. Prior to biochar production, CPH was cleaned, dried in an oven at 105°C and milled to particle size of up to 4 mm using a hammer mill. Preliminary characterizations were performed including, elemental analysis, Fourier-transform infrared spectroscopy (FTIR) and thermogravimetric analysis (TGA) to evaluate the physicochemical properties of CPH and compare them with the literature. To evaluate the influence of pyrolysis parameters on the product quality, RSM method was promoted. Three independent variables such as temperature, Heating rate and residence time in a range of 400-700°C, 5-15°C/min, and 60-150 min were respectively selected on the basis of CCD. In addition, the biochar derived from CPH was produced using a laboratory-scale muffle furnace fed with nitrogen flows of 2 L/min. Following the biochar production, yield was calculated.

Outlook

The next phase of this research will involve pore size, specific surface area, pores distribution and pore volume determination using Brunauer-Emmett-Teller (BET) method. The biochar willbe analysed to determine the effect of pyrolysis parameters on the structural and chemical properties of CPH derived biochar. Findings from this work will guide the optimization of CPH biochar production for practical applications such as soil health improvement and carbon sequestration. Future efforts will focus on extending the process and assessing the performance of biochar in real-world applications in the West African agricultural sector to improve crop productivity.



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DBFZ

Optimization of pyrolysis parameters for the production of high-quality biochar from cocoa pod husk using a response surface methodology

Kassé Jean Hugues Angbé, Dr. Dennis Krüger, Prof. Dr. Volker Lenz, Prof. Dr. Satyanarayana Narra

INTRODUCTION

The cocoa sector, although crucial for stimulating the economy in tropical regions such as West Africa, generates large quantities of cocoa pod husk (CPH), which farmers generally abandon on farms (**Fig.1**). However, it can be converted into high-quality biochar through thermochemical processes such as pyrolysis. Therefore, this study uses the response surface methodology to explore the effect of pyrolysis parameters on yield and porosity of CPH-derived biochar (CPHB) with the aim of optimizing pyrolysis conditions for sustainable CPH management.

Fig. 1: Cocoa Pod Processing and Byproducts Flowchart

MATERIALS AND METHODS

Fig.2 illustrates the overall methodology used in this study.

Fig.2: Detailed experimental procedure

RESULTS AND DISCUSSION

Pyrolysis temperature compared to the heating rate and residence time, significantly affects the CPHB yield. As it increases, the yield decreases from about 43% to 32%, due to thermal degradation of cellulose, hemicellulose, lignin, and release of volatiles. Its specific surface area (SSA) is initially low (1-5m^2/g) even at 700°C. However, the application of specific range of relative pressures (p/p0) of 0.14-0.29 via ASiQwin V5 software improved the measurement of the SSA, increasing it from 4 to 13m^2/g, offering a more accurate assessment of the porosity of the CPHB.

Fig.3: 3D RSM plots showing biochar yield (left) and SSA (right)

Tab.1: Effect of degassing parameters on the specific surface area

Pyrolysis (T°C)	Degassing	SSA (m^2/g) Raw	SSA (m^2/g) (0.14-0.29 p/p0)
400	9h and 250°C	2.4	4.7
	12h and 130°C	2.3	8.4
	9h and 200°C[a]	0.3 0.9 (AW)	-
700	9h and 250°C	2.4	13
	12h and 130°C	1.4	7.1
	9h and 200°C[a]	3.4	-
800	9h and 200°C[a]	101.2 342 (AW)	-

a:from the literature, AW: Acid Washing

CONCLUSION AND RECOMMENDATION

The yield of CPHB is highly influenced by temperature. However, achieving a high specific surface area (SSA) is possible at elevated temperatures and with appropriate post-treatment. The BET isotherm profile follows Type III, suggesting that krypton adsorption may provide a more accurate prediction of the SSA of CPHB. Therefore, future studies should consider using krypton for BET analysis to better characterize CPHB.

REFERENCES

Tsai, W.-T., Hsu, C.-H., Lin, Y.-Q., Tsai, C.-H., Chen, W.-S., & Chang, Y.-T. (2020). Enhancing the Pore Properties and Adsorption Performance of Cocoa Pod Husk (CPH)-Derived Biochars via Post-Acid Treatment. Processes, 8(2), 144. https://doi.org/10.3390/pr8020144.

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8th Doctoral Colloquium BIOENERGY and BIOBASED PRODUCTS 2025, Stuttgart (Germany), 10-12 September 2025

Hannah Storm, University of Stuttgart

Gasification of polyamide rich plastic waste in a fluidized bed reactor

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Keywords: gasification, fluidized bed, plastic waste, polyamide

Introduction

A critical task for the future will be the recycling of plastic waste. While the worldwide production of plastics increased steadily during the last decades, only about 1/3 of the in 2022 in the EU collected post-consumer plastic waste was recycled. [1] Especially for the mechanical recycling, mixed plastic waste streams are a challenge. Polyamide is a nitrogen rich, chemically very stable polymer. Due to its widespread use in composites and multicomponent materials, polyamide is difficult to sort and recycle from mixed plastic waste streams. [2] Thermochemical gasification represents a promising approach for the recycling of heterogeneous plastic waste streams, particularly non-recyclable mixed plastic fractions. [3] This study explores the utilization of product gas derived from the steam-gasification of polyamide-containing plastics in a bubbling fluidized-bed reactor as a potential carbon and energy source for subsequent microbial valorisation in a cascade bioreactor system.

Approach/Methods

Mixed plastic waste streams with varying polyamide (PA) content were gasified in a 20 kW electrically heated bubbling fluidized bed reactor, located at the Institute of Combustion and Power Plant Technology (IFK) at the University of Stuttgart. Steam was used as gasification agent and the bed material was quartz sand. The experiments were performed at operating temperatures ranging from 650 °C to 800 °C and under varying steam-to-carbon (S/C) ratios. Special attention was given to the formation of ammonia (NH_3). The resulting product gas was comprehensively characterized. Permanent gas components were quantified using an online gas analyser, light hydrocarbons were measured via micro gas chromatography (Micro-GC), and ammonia concentrations were determined by a gaschromatograph (GC). The influence of temperature, S/C ratio, and fuel composition on the gas composition was investigated. As a result, a tailormade syngas can be generated from plastic wastes for the following bioreactor system.

References

[1] Plastics Europe. 2024. The Circular Economy for Plastics, A European Analysis.
[2] Herzog, B., Kohan, M.I., Mestemacher, S.A., Pagilagan, R.U., Redmond, K. and Sarbandi, R. 2025.Polyamides. In Ullmann's Encyclopedia of Industrial Chemistry.
[3] Lopez, G., Artetxe, M., Amutio, M., Alvarez, J., Bilbao, J., Olazar, M. 2018. Recent advances in the gasification of waste plastics. A critical overview. Renewable and Sustainable Energy Reviews, Vol. 82, p. 576–596.

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8TH DOCTORAL COLLOQUIUM BIOENERGY AND BIOBASED PRODUCTS

Nishant Ranjan, Indian Institute of Technology Bombay

Investigation of Carbon Boundary Point in the Plastic-Biomass Co-gasification in a Downdraft Gasifier

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Keywords: waste-to-energy, gasification, plastic and biomass wastes, carbon boundary point

Introduction

The escalating global population and rising living standards have intensified concerns regarding both energy security and waste management. Fossil fuels, despite their dominance, are unsustainable due to their environmental impact and carbon intensity. Consequently, attention has turned to alternative energy sources such as biomass and plastic wastes, which possess significant calorific value. Among the available thermochemical conversion technologies, gasification offers a promising solution for converting such feedstocks into syngas. Specifically, downdraft co-gasification of biomass and plastic wastes is gaining traction as a decentralized energy solution.

Approach/Methods

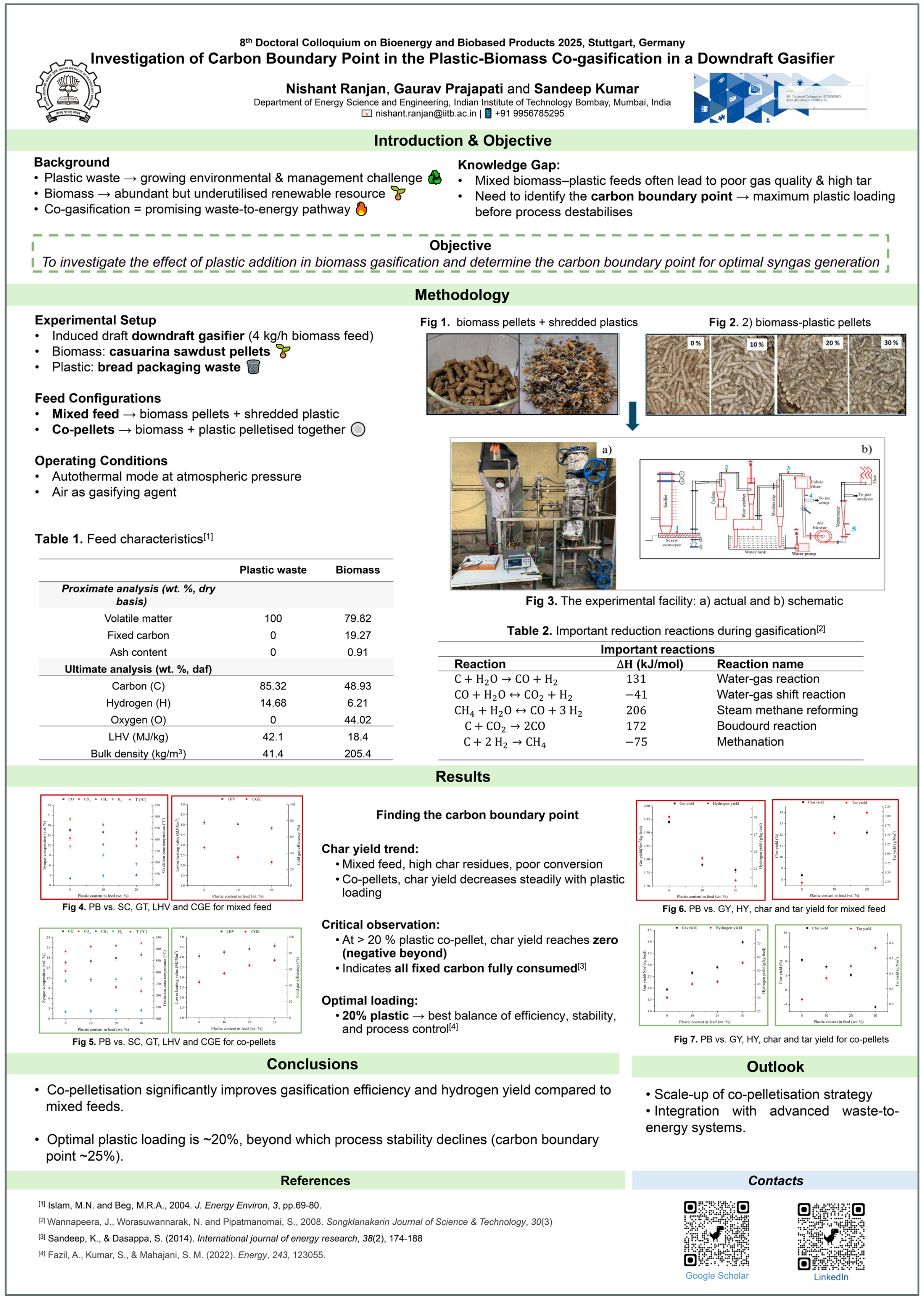
This study investigates the performance of downdraft co-gasification using biomass and plastic waste mixtures in an induced draft gasifier. Two distinct feeding modes were evaluated: (a) biomass pellets combined with shredded plastics and (b) biomass-plastic co- pellets. The gasifier was operated across varying plastic-to-biomass ratios, and key performance indicators—including gasification temperature, lower heating value (LHV) of syngas, cold gas efficiency, and unreacted char yield—were analyzed. Special focus was placed on understanding the thermochemical interactions at higher plastic content and their impact on conversion efficiency.

Results

The use of shredded plastic with biomass pellets (mode a) led to a decline in gasification performance, marked by an increase in unreacted char yield from 8.4 % to 13.1 %, indicating incomplete carbon conversion. In contrast, mode (b) using co-pelletised biomass-plastic feed showed enhanced gasification outcomes. With increasing plastic content up to 30 %, there was a notable rise in gasification temperature, syngas LHV, and cold gas efficiency. A key observation was the occurrence of a „carbon boundary point," beyond which no residual char remained. Specifically, unreacted char yield dropped from 8.4 % to -4.2 % as plastic content increased, suggesting complete utilization of char in post-pyrolysis reduction reactions.

Conclusion/Outlook

This study demonstrates that downdraft co-gasification of biomass and plastic wastes - particularly using integrated feeds - can serve as a viable method for sustainable syngas production. Enhanced performance metrics at higher plastic content underscore the compatibility of plastics in thermochemical conversion, provided the feed is well-integrated. The identification of the carbon boundary point adds further insight into optimizing gasifier operation. These findings support the development of decentralized waste-to-energy solutions and lay the groundwork for future scale-up and techno-economic evaluation.



8th Doctoral Colloquium on Bioenergy and Biobased Products 2025, Stuttgart, Germany

Investigation of Carbon Boundary Point in the Plastic-Biomass Co-gasification in a Downdraft Gasifier

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Introduction & Objective

Background
- Plastic waste → growing environmental & management challenge
- Biomass → abundant but underutilised renewable resource
- Co-gasification = promising waste-to-energy pathway

Knowledge Gap:
- Mixed biomass–plastic feeds often lead to poor gas quality & high tar
- Need to identify the **carbon boundary point** → maximum plastic loading before process destabilises

Objective
To investigate the effect of plastic addition in biomass gasification and determine the carbon boundary point for optimal syngas generation

Methodology

Experimental Setup
- Induced draft **downdraft gasifier** (4 kg/h biomass feed)
- Biomass: **casuarina sawdust pellets**
- Plastic: **bread packaging waste**

Feed Configurations
- **Mixed feed** → biomass pellets + shredded plastic
- **Co-pellets** → biomass + plastic pelletised together

Operating Conditions
- Autothermal mode at atmospheric pressure
- Air as gasifying agent

Table 1. Feed characteristics[1]

	Plastic waste	Biomass
Proximate analysis (wt. %, dry basis)		
Volatile matter	100	79.82
Fixed carbon	0	19.27
Ash content	0	0.91
Ultimate analysis (wt. %, daf)		
Carbon (C)	85.32	48.93
Hydrogen (H)	14.68	6.21
Oxygen (O)	0	44.02
LHV (MJ/kg)	42.1	18.4
Bulk density (kg/m^3)	41.4	205.4

Fig 1. biomass pellets + shredded plastics

Fig 2. 2) biomass-plastic pellets

0 % 10 % 20 % 30 %

a) b)

Gasifier
Screw conveyer
Cyclone
Water scrubber
Moisture trap
Water tank
Water pump
Fabric filter
To tar setup
Air blower
Venturimeter
To gas analysis
Flare

Fig 3. The experimental facility: a) actual and b) schematic

Table 2. Important reduction reactions during gasification[2]

Reaction	ΔH (kJ/mol)	Reaction name
$C + H_2O \rightarrow CO + H_2$	131	Water-gas reaction
$CO + H_2O \leftrightarrow CO_2 + H_2$	−41	Water-gas shift reaction
$CH_4 + H_2O \leftrightarrow CO + 3\,H_2$	206	Steam methane reforming
$C + CO_2 \rightarrow 2CO$	172	Boudourd reaction
$C + 2\,H_2 \rightarrow CH_4$	−75	Methanation

Results

Fig 4. PB vs. SC, GT, LHV and CGE for mixed feed

Fig 5. PB vs. SC, GT, LHV and CGE for co-pellets

Finding the carbon boundary point

Char yield trend:
- Mixed feed, high char residues, poor conversion
- Co-pellets, char yield decreases steadily with plastic loading

Critical observation:
- At > 20 % plastic co-pellet, char yield reaches **zero (negative beyond)**
- Indicates **all fixed carbon fully consumed**[3]

Optimal loading:
- **20% plastic** → best balance of efficiency, stability, and process control[4]

Fig 6. PB vs. GY, HY, char and tar yield for mixed feed

Fig 7. PB vs. GY, HY, char and tar yield for co-pellets

Conclusions
- Co-pelletisation significantly improves gasification efficiency and hydrogen yield compared to mixed feeds.
- Optimal plastic loading is ~20%, beyond which process stability declines (carbon boundary point ~25%).

Outlook
- Scale-up of co-pelletisation strategy
- Integration with advanced waste-to-energy systems.

References

[1] Islam, M.N. and Beg, M.R.A., 2004. *J. Energy Environ*, *3*, pp.69-80.
[2] Wannapeera, J., Worasuwannarak, N. and Pipatmanomai, S., 2008. *Songklanakarin Journal of Science & Technology*, *30*(3)
[3] Sandeep, K., & Dasappa, S. (2014). *International journal of energy research*, *38*(2), 174-188
[4] Fazil, A., Kumar, S., & Mahajani, S. M. (2022). *Energy*, *243*, 123055.

Contacts

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Turning Biogas into Chemicals: CO_2 and H_2-Powered Gas Fermentation with an evolved *Clostridium carboxidivorans* strain

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Keywords: Biogenic CO_2, Hexanol, Biogas, Gas Fermentation, Adaptive Laboratory Evolution

Introduction

Biogenic CO_2 from anaerobic digestion plants and biorefineries is a sustainable but underexploited carbon source. Gas fermentation by acetogenic bacteria enables its conversion into valuable chemicals. However, most Clostridium species prefer CO over CO_2, limiting their use in CO_2-based systems. As part of the EU GoodByO project, this work aim to develop a hexanol production process using raw biogas from ChainCraft® bioplant and green hydrogen, leveraging an evolved Clostridium carboxidivorans strain obtain via Adaptive Laboratory Evolution (ALE) in our laboratory. This adapted strain grows efficiently on CO_2 and H_2, producing hexanol as the main fermentation product. Here, we investigated the strain's hydrogen sulphide (H_2S) tolerance and evaluated its physiology on raw biogas and hydrogen. Additionally, bioprocess costs were reduced through ALE by removing yeast extract and adapting the strain to a minimal medium with three vitamins.

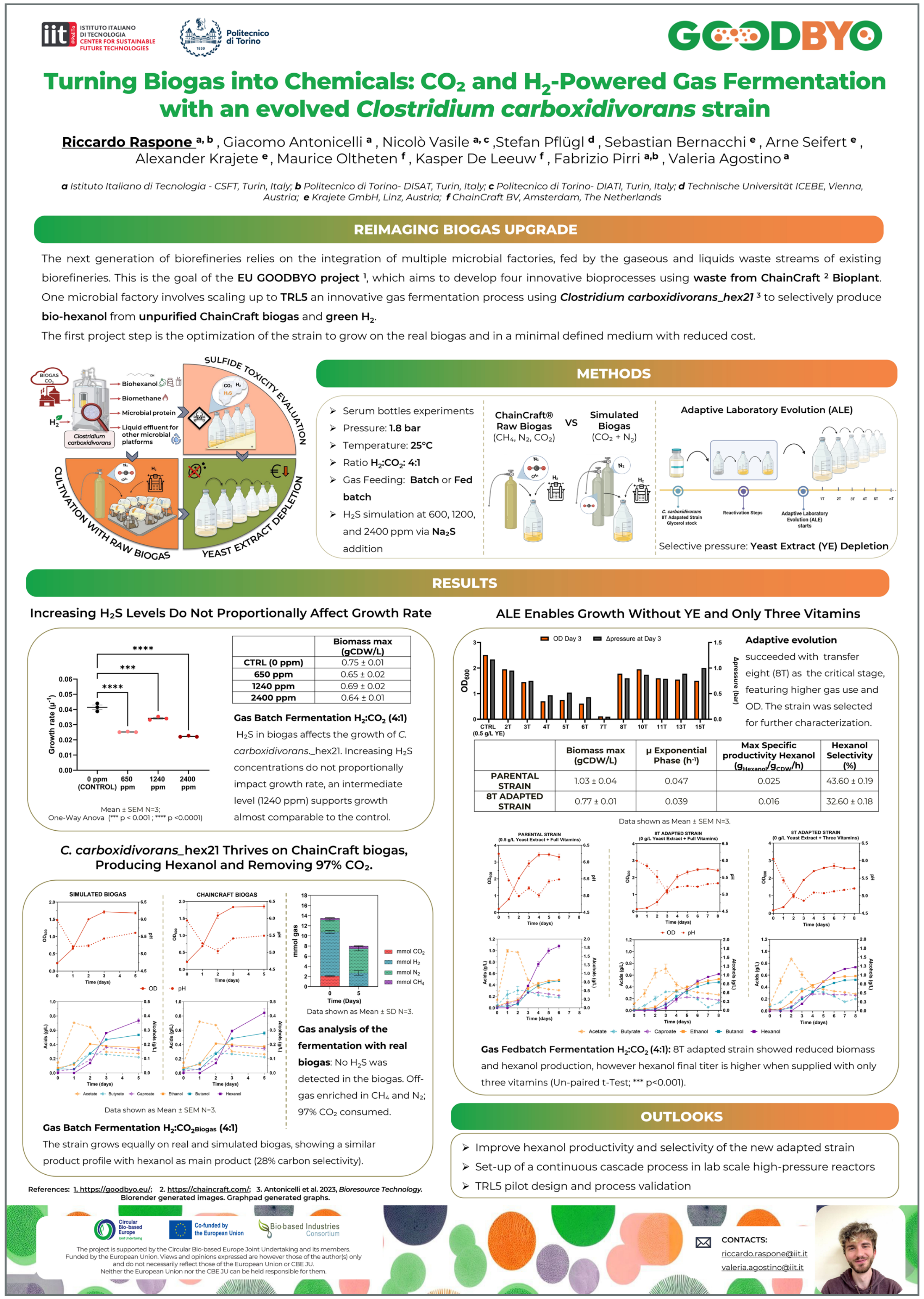
Methods

ALE was enabled through serial transfers in serum bottles with free-yeast extract medium, followed by whole-genome re-sequencing (WGrS) to uncover emerging mutations. Toxicity tests with 600, 1200, and 2400 ppm H_2S (via Na_2S in liquid addition) were conducted in serum bottles before biogas use. Growth and hexanol production on unpurified biogas were assessed in gas-fed batch fermentations, using synthetic biogas as a control.

Results

C. carboxidivorans was adapted to thrive in minimal medium with only biotin, pantothenic acid, and para-aminobenzoic acid, matching parental strain's growth rate. WGrS revealed no major genomic changes, suggesting regulatory or metabolic adaptation. H_2S had no impact on hexanol productivity, however growth exhibited a non-linear response, peaking at 1200 ppm. Raw and synthetic biogas fermentations showed comparable biomass and hexanol production, remaining unaffected by CH_4 or trace pollutants.

Overall, this study reports the first successful cultivation of C. carboxidivorans on real biogas, enabling simultaneous bio-CH_4 upgrading and biochemical production. Scaling bioprocesses with raw feedstocks and cost-effective media is crucial for an efficient industrial transition. Future work will focus on optimising continuous hexanol production in high-pressure bioreactors.



Julian Matlach, Deutsches Biomasseforschungszentrum

Influence of different substrates on the composting process and the generation of methane emissions

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Keywords: On-site approach, GHG emission measurement, biowaste utilization, anaerobic digestion, composting

Introduction

Depending on the recycling process, the biowaste treatment plants consist of fermentation and post- rotting or composting. There are several emission sources in biological waste treatment plants that can emit methane (CH_4), ammonia (NH_3) and nitrous oxide (N_2O). One of these is composting or downstream rotting. Unsuitable operating conditions can result in GHG- emissions in the form of CH_4 and N_2O during the composting process. An anaerobic milieu in the compost material can lead to CH_4 hotspots and cause high CH_4 emissions. According to the 6th IPCC report, the GWP100 of CH_4 is 27 CO_2-eq and is therefore a climate-damaging gas that should be avoided. N_2O, on the other hand, can form in the course of nitrification and denitrification in both aerobic and anaerobic conditions. N_2O has a GWP100 of 273 CO_2-eq. The loss of nitrogen in the form of NH_3 and N_2O is also a loss of nutrients in the fertilizer and should therefore be prevented from a resource protection perspective. What options are there for reducing greenhouse gas emissions from rotting processes?

Approach/Methods

In order to find out which operating parameters have a major influence on the generation of emissions during the composting process, several emission measurements were carried out at twelve biowaste treatment plants. In the KlimaBioHum project, various operating parameters were investigated along the four measurement phases. The GHG emissions were quantified using an open dynamic chamber measurement. For this purpose, a wind tunnel with the largest possible surface area was installed on the emission-active surface of the rotting material and flowed through with a defined volume flow. This results in a volume-specific emission factor that is related to the volume under the wind tunnel in order to obtain comparable data.

Results/Outlook

The highest greenhouse gas emissions in the rotting process were produced by the discontinuous dryfermentation plants (mean value = 250 kg CO_2/Mg-WM). An active aeration as an operational parameter by pressurized ventilation at the bottom of the compostheap showed the largest influence on the GHG emission situation during the composting process. For some parameter variations, no conclusive trends can yet be identified and there is still a need for further research in this area.

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Influence of different substrates on the composting process and the generation of methane emissions

Julian Matlach

BACKGROUND

In Germany, organic waste is collected separately into biowaste and green waste, which differ in composition: green waste contains woody, slowly degradable material with a wide C/N ratio, while biowaste is richer in easily degradable organic matter and has a narrower C/N ratio. Composting is an established aerobic treatment, while the anaerobic digestion of biowaste for energy recovery is becoming increasingly relevant; the resulting digestates are stabilized in a post-rotting process to produce finished compost.

A key challenge in composting is maintaining sufficient oxygen supply, since oxygen deficits create anaerobic zones that lead to methane emissions [1, 2], which, according to the *KlimaBioHum* study, account for around two-thirds of total greenhouse gases released.

This highlights the need to better understand how different feedstocks influence methane formation and how emission phases during composting can be identified.

EMISSIONS MEASUREMENT APPROACH

The open dynamic chamber method is used as an on-site approach to determine the mass-specific emission factors (EF). Emissions were measured with an wind tunnel covering a defined windrow surface (Fig. 1).

Gas concentrations of CH_4 were determined at the tunnel outlet and compared to inlet background. From the concentration difference (Δc) and the tunnel airflow (Q), the emission mass flow was calculated as: $\dot{m} = \Delta c \cdot Q$

Fig. 1: Open dynamic chamber method in the form of a wind tunnel measurement

Integrating these mass flows over time, assuming linear changes between measurements, yielded the EFs, expressed as the cumulative release per unit of feedstock.

RESULTS AND OUTLOOK

Throughout the composting process, the highest methane emissions were observed from green waste, averaging 4.66 ± 5.23 kg CH_4 Mg^{-1} wet material (WM). Digestate emitted 3.49 ± 3.17 5.23 kg CH_4 Mg^{-1} WM, while biowaste showed the lowest values with 1.03 ± 1.02 kg CH_4 Mg^{-1} WM (Fig. 2).

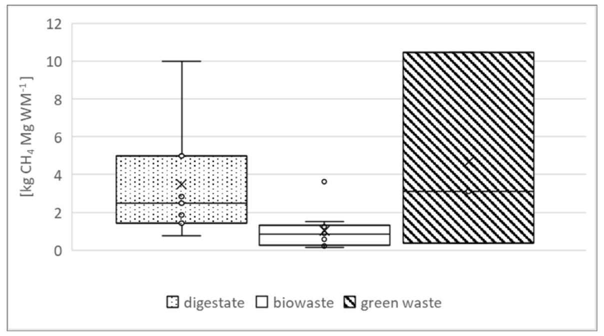

Fig. 2: EFs for different treated feedstocks in the composting process: digestate (n=7), biowaste (n=10) and green waste (n=3)

At commercial scale, a significant difference p<0,05 in CH_4 emissions between digestates and biowaste during composting was observed, consistent with the laboratory findings of Dietrich et al. (2020) [3].

Distinct substrate-specific emission dynamics were evident: digestates released most CH_4 emissions at the onset of the composting process, whereas green waste exhibited peak emissions towards its later stages (Fig. 3).

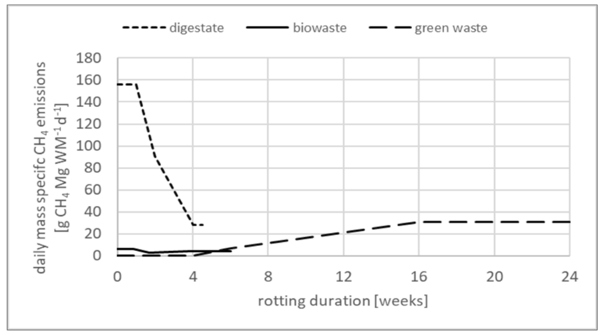

Fig. 3: Measurement setup and soft sensor of Biogas Plants

Variations in CH_4 formation during composting are attributable to physical and biological conditions. To counteract pronounced anaerobic phases, operational measures such as adjusted windrow dimensions, forced aeration, or more frequent turning should be applied to maintain aerobic conditions.

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REFERENCES
[1] Beck-Friis, B., Pell, M., Sonesson, U., Jönsson, H., and Kirchmann, H. 2000. Formation and Emission of N2O and CH4 from Compost Heaps of Organic Household Waster. Environmental Monitoring and Assessment 62, 3, 317-331
[2] Jäckel, U., Thummes, K., and Kämpfer, P. 2005. Thermophilic methane production and oxidation in compost. FEMS Microbiology Ecology 52, 2, 175-184
[3] Dietrich, M., Fongen, M., & Foereid, B. (2021). Anaerobic digestion affecting nitrous oxide and methane emissions from the composting process. Bioresource Technology Reports, 15, 100752. https://doi.org/10.1016/j.biteb.2021.100752

DBFZ

Abdullah Al Saadi, University of Rostock

Analysis of Biochar in Anaerobic Digestion Biomass Application: characterization of Biochar

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Keywords: Charcoal (AC), anaerobic digestion (AD), pyrolysis reactor, surface characterises, laser-induced breakdown spectroscopy (LIBS), proximate analysis

Introduction

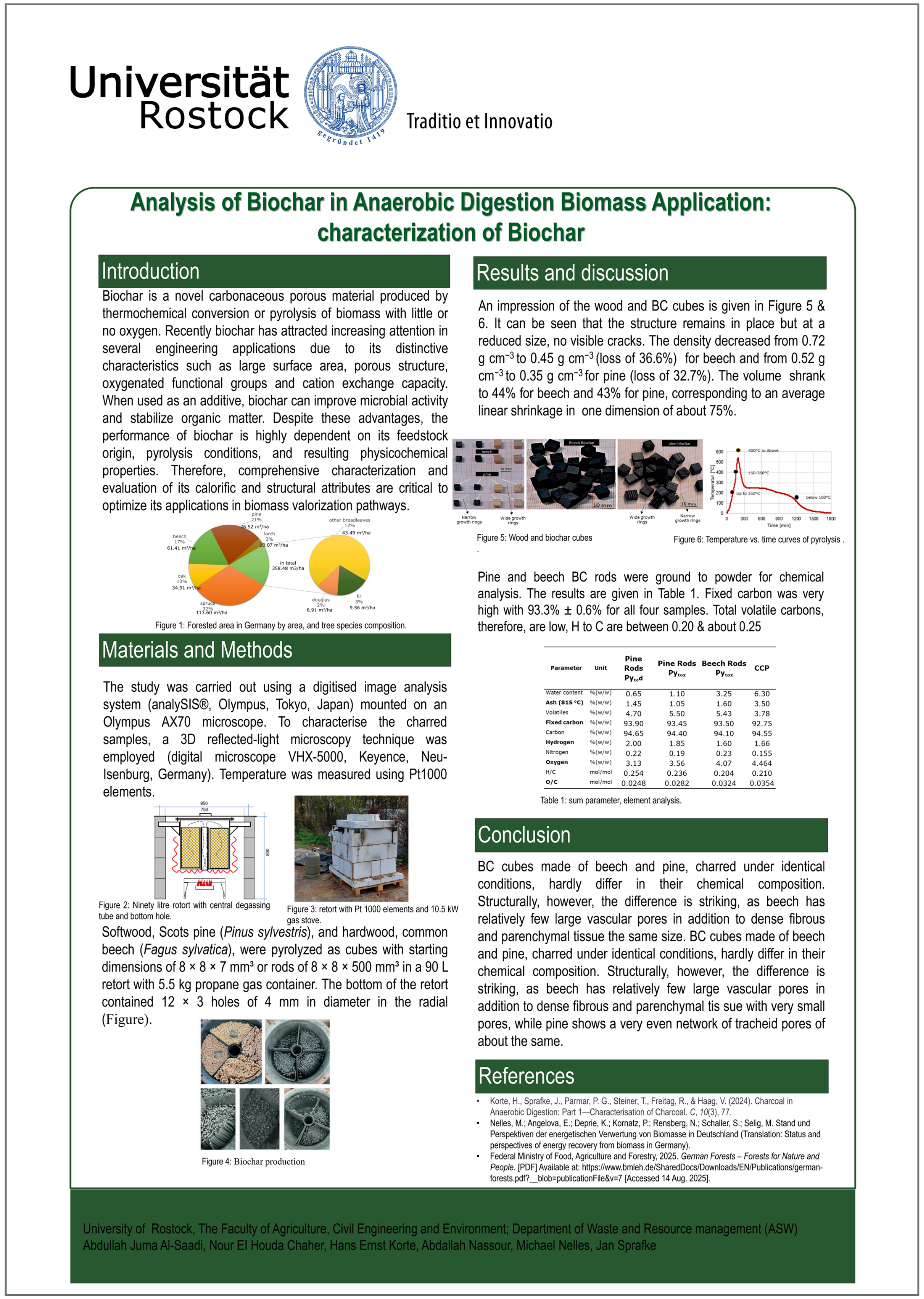
The need for sustainable energy solutions has brought anaerobic digestion (AD) to the forefront as a viable method for renewable biogas production. However, current AD processes often face challenges with biogas yield and process instability. This research addresses these gaps by exploring how charcoal's physical and chemical properties, such as surface area, porosity, and functional groups, can be optimized to enhance AD efficiency. Key research questions include: How do these properties influence the AD process? What are the ideal particle sizes and pyrolysis conditions for maximizing biogas output? What are charcoal's techno-economic and environmental implications in large-scale AD systems? A multi-phase strategy involving detailed charcoal characterization, pyrolysis trials, and life cycle assessment was adopted.

Approach/Methods

Two biomass types of pine (softwood) and beech (hardwood) were pyrolyzed under controlled conditions with two dimensions cubes of 8 × 8 × 7 mm^3 or rods of 8 × 8 × 500 mm^3. Pyrolysis retort in a 90 L vessel, the bottom of the retort contained 12 × 3 holes of 4 mm diameter. Temperature monitoring was performed with Pt1000 sensors and recorded via a Voltcraft DL-240K logger. Charcoal characterization followed European Biochar Certificate (EBC) guidelines. The surface area of BC were analyzed using Brunauer-Emmett-Teller (EBT) and 3D reflected light microscopy (VHX 500). Caloric value for biochar was measured with LIBS.

Results/Outlook

Charcoal properties varied significantly with biomass type and pyrolysis conditions. One hundred pine and beech wood cubes underwent a 1200-minute pyrolysis process in a propane-fueled retort, reaching a maximum temperature of 541 °C and a heating rate of 2.7 °C min−1. Pine biochar under reducing atmosphere exhibited superior characteristics: BET surface area of 279 m²/g, porosity of 77 %, and pore volume of ~3.0 cm³/g indicating strong potential for AD enhancement. The biochar samples had a high fixed carbon content of 93.3 % ± 0.6 %, low total volatile carbon, and H/C molar ratios ranging from 0.10 to 0.25, all meeting the EBC's top quality threshold of <0.40; O/C ratios were 0.0248 (Pyrred), 0.0282 (Pyrox, 14 % increase). LIBS provided accurate, rapid HHV estimates with high correlation to bomb calorimetry. These findings support the tailored use of pine-based charcoal for boosting biogas yield and stability. Future work will focus on microbial interactions and scale-up validation using LIBS for in-line quality control.


Universität Rostock
Traditio et Innovatio

Analysis of Biochar in Anaerobic Digestion Biomass Application: characterization of Biochar

Introduction

Biochar is a novel carbonaceous porous material produced by thermochemical conversion or pyrolysis of biomass with little or no oxygen. Recently biochar has attracted increasing attention in several engineering applications due to its distinctive characteristics such as large surface area, porous structure, oxygenated functional groups and cation exchange capacity. When used as an additive, biochar can improve microbial activity and stabilize organic matter. Despite these advantages, the performance of biochar is highly dependent on its feedstock origin, pyrolysis conditions, and resulting physicochemical properties. Therefore, comprehensive characterization and evaluation of its calorific and structural attributes are critical to optimize its applications in biomass valorization pathways.

Figure 1: Forested area in Germany by area, and tree species composition.

Materials and Methods

The study was carried out using a digitised image analysis system (analySIS®, Olympus, Tokyo, Japan) mounted on an Olympus AX70 microscope. To characterise the charred samples, a 3D reflected-light microscopy technique was employed (digital microscope VHX-5000, Keyence, Neu-Isenburg, Germany). Temperature was measured using Pt1000 elements.

Figure 2: Ninety litre rotort with central degassing tube and bottom hole.

Figure 3: retort with Pt 1000 elements and 10.5 kW gas stove.

Softwood, Scots pine (*Pinus sylvestris*), and hardwood, common beech (*Fagus sylvatica*), were pyrolyzed as cubes with starting dimensions of 8 × 8 × 7 mm³ or rods of 8 × 8 × 500 mm³ in a 90 L retort with 5.5 kg propane gas container. The bottom of the retort contained 12 × 3 holes of 4 mm in diameter in the radial (Figure).

Figure 4: Biochar production

Results and discussion

An impression of the wood and BC cubes is given in Figure 5 & 6. It can be seen that the structure remains in place but at a reduced size, no visible cracks. The density decreased from 0.72 g cm^{-3} to 0.45 g cm^{-3} (loss of 36.6%) for beech and from 0.52 g cm^{-3} to 0.35 g cm^{-3} for pine (loss of 32.7%). The volume shrank to 44% for beech and 43% for pine, corresponding to an average linear shrinkage in one dimension of about 75%.

Figure 5: Wood and biochar cubes

Figure 6: Temperature vs. time curves of pyrolysis .

Pine and beech BC rods were ground to powder for chemical analysis. The results are given in Table 1. Fixed carbon was very high with 93.3% ± 0.6% for all four samples. Total volatile carbons, therefore, are low, H to C are between 0.20 & about 0.25

Parameter	Unit	Pine Rods $Py_{te}d$	Pine Rods Py_{tox}	Beech Rods Py_{tox}	CCP
Water content	%(w/w)	0.65	1.10	3.25	6.30
Ash (815 °C)	%(w/w)	1.45	1.05	1.60	3.50
Volatiles	%(w/w)	4.70	5.50	5.43	3.78
Fixed carbon	%(w/w)	93.90	93.45	93.50	92.75
Carbon	%(w/w)	94.65	94.40	94.10	94.55
Hydrogen	%(w/w)	2.00	1.85	1.60	1.66
Nitrogen	%(w/w)	0.22	0.19	0.23	0.155
Oxygen	%(w/w)	3.13	3.56	4.07	4.464
H/C	mol/mol	0.254	0.236	0.204	0.210
O/C	mol/mol	0.0248	0.0282	0.0324	0.0354

Table 1: sum parameter, element analysis.

Conclusion

BC cubes made of beech and pine, charred under identical conditions, hardly differ in their chemical composition. Structurally, however, the difference is striking, as beech has relatively few large vascular pores in addition to dense fibrous and parenchymal tissue the same size. BC cubes made of beech and pine, charred under identical conditions, hardly differ in their chemical composition. Structurally, however, the difference is striking, as beech has relatively few large vascular pores in addition to dense fibrous and parenchymal tis sue with very small pores, while pine shows a very even network of tracheid pores of about the same.

References

- Korte, H., Sprafke, J., Parmar, P. G., Steiner, T., Freitag, R., & Haag, V. (2024). Charcoal in Anaerobic Digestion: Part 1—Characterisation of Charcoal. *C*, *10*(3), 77.
- Nelles, M.; Angelova, E.; Deprie, K.; Kornatz, P.; Rensberg, N.; Schaller, S.; Selig, M. Stand und Perspektiven der energetischen Verwertung von Biomasse in Deutschland (Translation: Status and perspectives of energy recovery from biomass in Germany).
- Federal Ministry of Food, Agriculture and Forestry, 2025. *German Forests – Forests for Nature and People*. [PDF] Available at: https://www.bmleh.de/SharedDocs/Downloads/EN/Publications/german-forests.pdf?__blob=publicationFile&v=7 [Accessed 14 Aug. 2025].

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Simon Hellman, Deutsches Biomasseforschungszentrum

A framework for fully automated, demand-oriented biogas plant operation: aspects of a model-based monitoring and control architecture

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Keywords: Biogas technology, ADM1, Flexibilization, Automation, Database

A promising approach towards optimizing agricultural anaerobic digestion (AD) plants in Germany involves producing biogas on demand. By adjusting substrate feeding based on electricity price forecasts, this has the potential to increase revenues for plant operators. To maintain stable process conditions, demand-oriented operation requires reliable AD process models and robust monitoring and control algorithms. While there exist methods for these individual tasks, a comprehensive soft- and hardware architecture that integrates all relevant components is lacking. This research introduces a framework that addresses this gap, enabling successful implementation of demand-oriented AD operation.

The proposed framework consists of several key components: an ADM1-R3 model (Weinrich and Nelles, 2021; DOI: 10.1016/j.biortech.2021.125124) simulates the nonlinear behavior of the AD process. Model parameters were calibrated on the basis of dynamic lab-scale experiments and global maximum likelihood estimation (Villaverde et al., 2019; DOI: 10.1093/bioinformatics/bty736). The model and its optimized parameters serve as the core of a multi-rate extended Kalman filter (MR-EKF), which acts as a state estimator. They are further incorporated in a model predictive controller (MPC), which optimizes substrate feeding based on electricity price forecasts.

The MR-EKF effectively smoothed noisy online measurements and incorporated delayed offline measurements to improve estimates of the system's dynamic process state. The MPC successfully tracked a dynamic methane reference trajectory by adjusting substrate dosing according to available substrates and feedings. The framework allows for interlinking the state estimator and MPC, enhancing model predictions, and enables re-calibration of model parameters using preprocessed measurement data. Experimental validation of the framework in a lab-scale setup is currently subject to investigation and expected to be completed soon.

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BIOENERGY & BIOBASED PRODUCTS

A framework for fully automated, demand-oriented biogas plant operation: aspects of a model-based monitoring and control architecture

Simon Hellmann[1,3], Terrance Wilms[2], Stefan Streif[3], Sören Weinrich[4,1]

INTRODUCTION

A promising approach towards optimizing agricultural anaerobic digestion (AD) plants involves producing biogas on demand, i.e. adjusting the substrate feeding based on electricity price forecasts. This can increase revenues for plant operators and has been demonstrated in full-scale [1]. To ensure stable process conditions, demand-oriented operation requires robust monitoring and control algorithms, which in turn require reliable AD process models. While there exist methods for these individual tasks, a comprehensive soft- and hardware architecture that integrates all relevant components is lacking.

Objective: Develop unified soft- and hardware architecture for demand-driven operation of AD

METHODS

The proposed framework consists of several components linked via an SQLite database: an ADM1-R3 model [2] simulates the nonlinear behavior of the AD process. Model parameters were calibrated through dynamic lab-scale experiments and maximum likelihood estimation [3]. The calibrated model form the core of a multi-rate extended Kalman filter (MR-EKF), which acts as a state estimator. They are further incorporated in a model predictive controller (MPC), which optimizes substrate feeding based on electricity price forecasts.

RESULTS

The framework connects the state estimator, user interaction with the lab operator, and the MPC in a central database. This enables transparent documentation of experimental conditions, and further enables automated re-calibration of model parameters using preprocessed measurement data. Experimental validation of the framework in a lab-scale setup is subject of current investigations and expected to be completed soon.

REFERENCES

[1] Mauky; Weinrich; Nägele; Jacobi; Liebetrau; Nelles. (2016): Model Predictive Control for Demand-Driven Biogas Production in Full Scale. Chemical Engineering & Technology 39 (4), 652–664.
[2] Weinrich; Nelles. (2021): Systematic simplification of the Anaerobic Digestion Model No. 1 (ADM1) - Model development and stoichiometric analysis. Bioresource Technology 333, 125124.
[3] Villaverde; Fröhlich; Weindl; Hasenauer; Banga. (2019) Benchmarking optimization methods for parameter estimation in large kinetic models. Bioinformatics, 35(5):830–838.

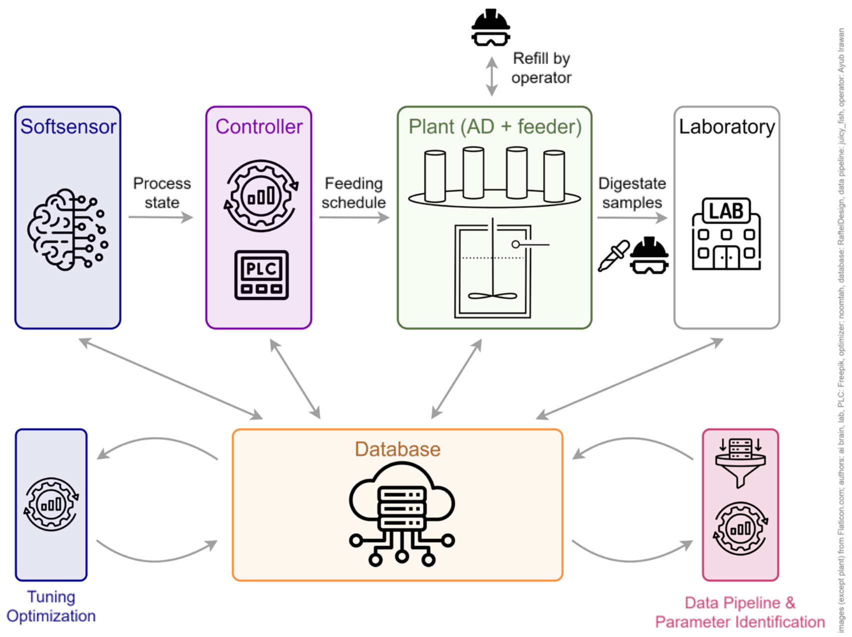

Fig. 1: Software architecture for model-based monitoring and control of a biogas plant.

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Frederik Bade, Helmhotz Centre for Environmental Research

Effect of digestate properties on foam formation during anaerobic digestion of triticale

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Keywords: Biogas, Grains, Antifoam strategies, Viscosity, Protease

Introduction

Biogas can play an important role in stabilizing the power grid as a flexibility option for balancing high residual loads. A cost-effective option for biogas flexibilization is flexible feeding. Substrates such as coarse grain enable short-time increase in production of biogas due to their high starch content. However, the use of coarse grains such as triticale increases the risk of foaming in biogas plants. Foaming can have negative consequences, such as clocking of gas pipes or sensor failure.

The role of the substrate in foam formation has already been investigated in detail, but the role of the digestate has not yet been studied. Therefore, the aim of this study was to investigate the influence of the digestate properties on foam formation during the anaerobic digestion of triticale and to develop effective countermeasures.

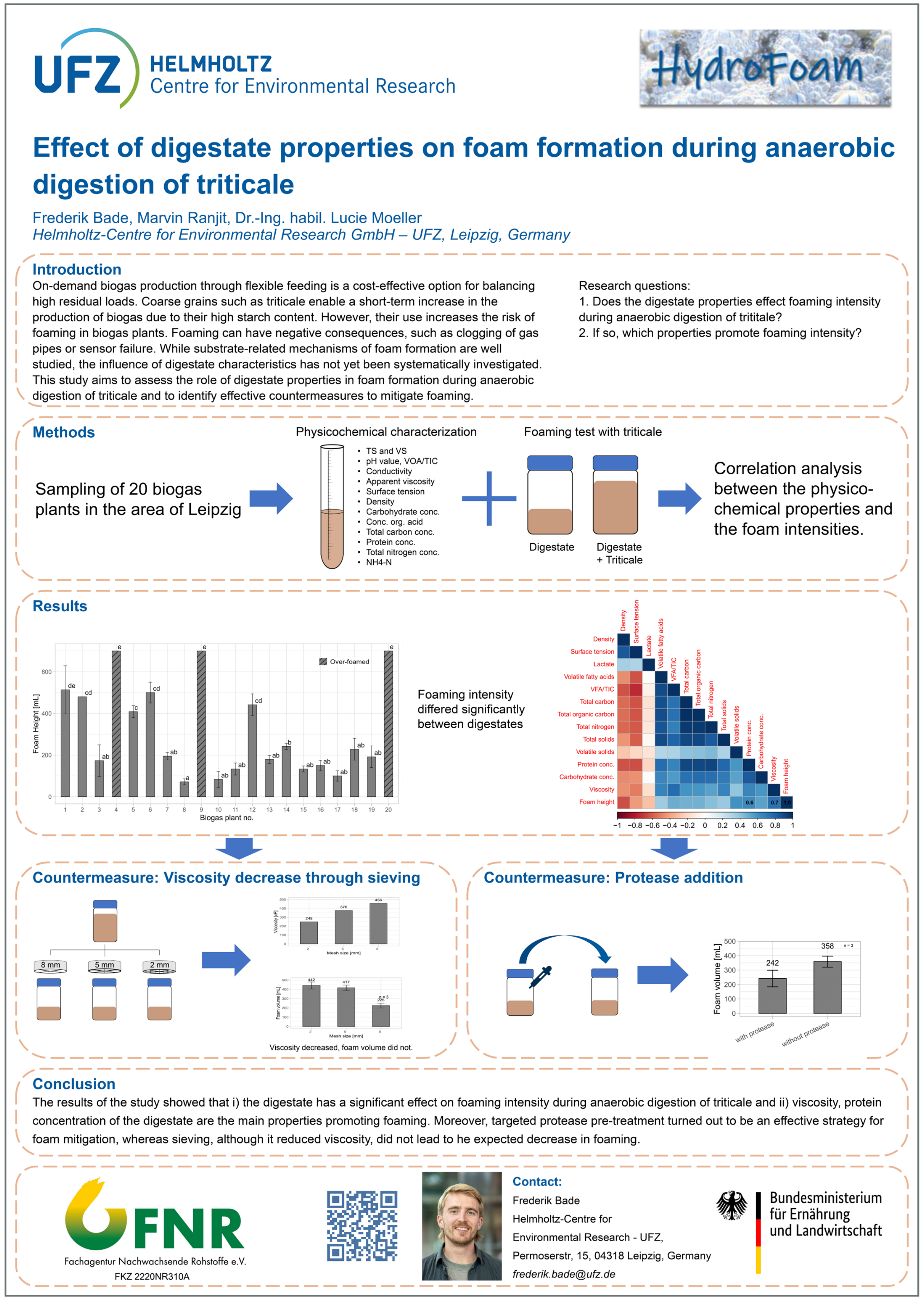
Methods

Digestates from 20 biogas plants in the area of Leipzig were collected and analyzed for their physicochemical properties, as well as for their foaming propensity in batch foaming experiments. Subsequent correlation analyses were carried out to determine the parameters of digestates that have an effect on the foaming intensity in combination with risky substrates. Based on these results, sieving of digestate and, thus, reduction of viscosity, as well as the addition of protease to the digestate were tested as strategies for foam reduction.

Results

Both physicochemical properties and foam formation varied significantly between the digestates tested. A strong correlation was found between foam formation and viscosity, protein concentration, and organic load of the digestates. Testing the effect of sieving showed that although the viscosity of the digestate was reduced, foam formation increased with decreasing viscosity. In contrast, the use of protease was shown to be a successful strategy to reduce foaming.

The results clarify which digestate properties play a key role in foam formation during anaerobic digestion of triticale. Moreover, targeted protease pre-treatment turned out to be an effective strategy for foam mitigation, whereas sieving showed not the expected effect on reduction of foaming.



Jeferson Vicente, University of Hohenheim

Valorisation of Paludiculture Biomass via a Two-Stage Furfural Synthesis Process

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Keywords: Paludiculture, Furfural, Bioeconomy, Hydrolysis

Introduction

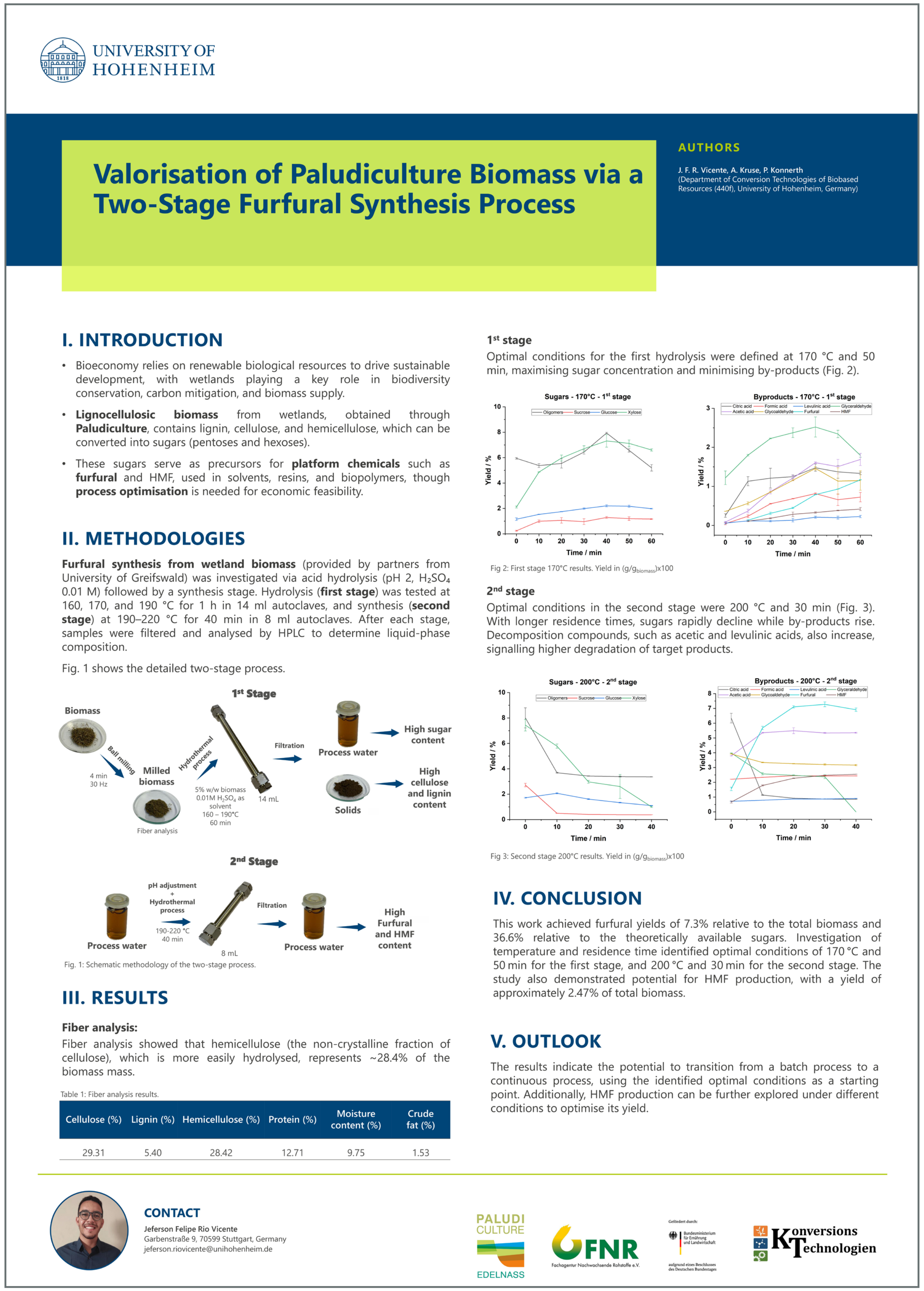
The bioeconomy targets the use of renewable biological resources as a foundation for sustainable economic development and social improvement. Thus, wetlands emerge as key ecosystems due to their capacity to conserve biodiversity, mitigate carbon emissions, and serve as biomass sources. This biomass can be transformed into high-value products, replacing fossil-based raw materials and contributing to circular economy models. Specifically, lignocellulosic biomass obtained through Paludiculture is composed of lignin, cellulose, and hemicellulose. The biopolymers cellulose and hemicellulose can be hydrolysed into pentoses and hexoses (sugars of five or six carbons, respectively). These monomers, also known as sugars, are precursors for platform chemicals such as furfural and hydroxymethylfurfural (HMF). Furfural, a compound widely used in the production of solvents, resins, and biodegradable polymers, requires process optimisation when derived from wetland biomass to ensure economic viability.

Approach/Methods

To evaluate and optimise the furfural synthesis from wetland biomass, an acid hydrolysis process (pH 2, H_2SO_4 0.01M) was conducted, followed by a furfural synthesis stage. To determine the optimal process parameters, the first stage was conducted at temperatures of 160, 170, and 190 °C for 1 hour using 14 ml autoclaves. The second stage was evaluated at 190 and 200 °C for 40 minutes in 8 ml autoclaves. After both processes, samples were filtered to obtain the liquid phase, which was subsequently analysed by HPLC to determine its composition.

Results/Outlook

The first stage enabled the biopolymers cleavage, leading to monomers release for furfural production. In the second stage, furfural synthesis was observed from the monomers generated in the first stage. Optimal results were achieved with conditions of 170°C for 50 minutes in the first stage and 200°C for 30 minutes in the second, yielding approximately 5.3 % furfural relative to the initial biomass mass, corresponding to 36.6 % of the total sugar content in the hydrolysate. These results validate the proposed two-stage hydrolysis approach for furfural synthesis from wetland biomass and point to further opportunities to produce other compounds, such as HMF, by adjusting parameters in the second reaction stage.



Leonhard Lenz, University of Hohenheim

Utilization of renewable raw materials for combined biogas and fiber production through ensiling and steam explosion pretreatment

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Keywords: silage, steam explosion, hop chaff, bioeconomy

Introduction

Large amounts of fossil resources are used for both energy and material production, whose consumption is harmful to the environment and climate. In transitioning to renewable energies such as wind and solar, balancing energies are needed due to theirfluctuations. One way to ensure this is through demand-oriented biogas production, for example using fixed-bed fermenters [1]. In addition to energy, materials such as packaging papers are also needed, with global demand for these doubling over the past 20 years [2]. An interesting approach to addressing both challenges simultaneously, in line with a bioeconomic concept, is the use of agricultural by-products and ecologically beneficial perennial crops for combined fiber and biogas production, following processing through ensiling and steam explosion pretreatment.

Approach/Methods

Hop residues, nettles, and alfalfa are used as substrates. Due to their moisture content, ensiling is suitable for preserving these seasonal materials for year-round use. To avoid fermentation issues like butyric acid formation - which can cause odor problems - silage additives such as lactic acid bacteria, molasses, and nitrate are tested to improve silage quality. Next, the silages undergo steam explosion pretreatment. Process parameters such as temperature (140–170 °C), reaction time (10–30 minutes), and dry matter content are optimized per substrate using response surface methodology. The focus is on optimizing fiber quality and methane yield. In the third step, fibers are tested for papermaking based on tensile strength (tear length). Process liquids are fermented in batch experiments and fixed-bed fermenters. Additionally, fiber suitability for wet-laid processing systems is evaluated

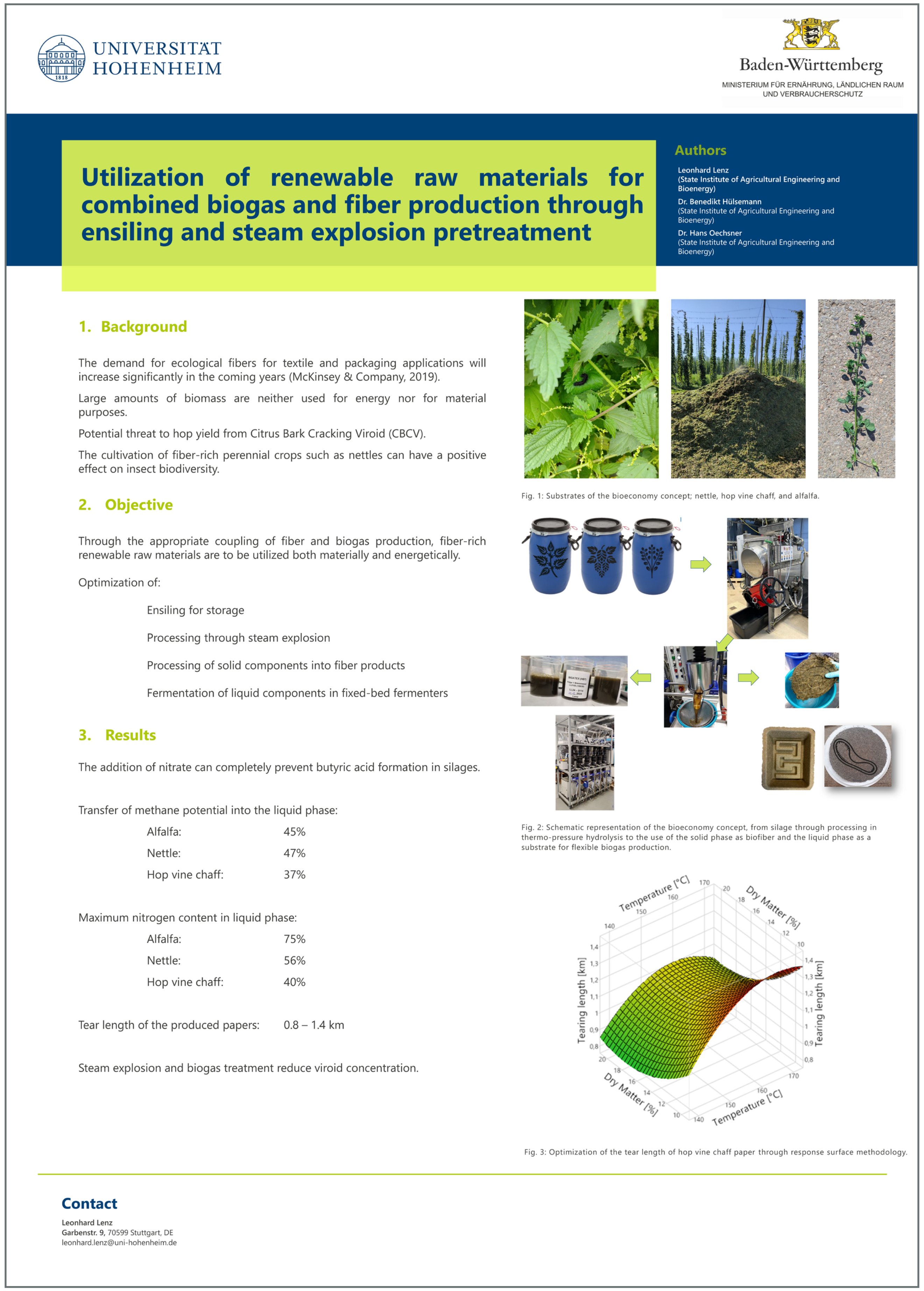
Results/Outlook

In hop chaff Nitrate effectively inhibits butyric acid formation after 90 days of storage. Paper made from hop chaff silage reached tensile strengths of up to 1.3 km, with about 38 % of the methane potential transferred to the liquid phase. For alfalfa, papers with tear lengths of 0.8 to 1.3 km were produced, with an average of 47 ± 4 % of the methane potential transferred into the liquid.

Sources

[1] Mauky, E.; Weinrich, S.; Jacobi, H.-F.; Nägele, H.-J.;Liebetrau, J.; Nelles, M. Demand-driven biogas production by flexible feeding in full-scale - Processstability and flexibility potentials. Anaerobe 2017, 46,86–95, doi:10.1016/j.anaerobe.2017.03.010

[2] Bern, P.; Lingquist, O. Pulp, paper, and packagingin the next decade: Transformational change.McKinsey & Company 2019, 8.



SESSION
THERMOCHEMICAL CONVERSION

Simon Fridolfsson, Aarhus University

Upgrading Biocrude from Hydrothermal Liquefaction of Sewage Sludge to Support Plasma Torch Splitting of CO_2

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Keywords: CO_2 valorization, Hydrotreatment, Biofuel

Introduction
Power-to-X solutions are widely discussed and are generally considered to play an important part in the green transition. The EU project EffiTorch is a Power-to-X concept for valorizing CO_2 into energy-rich CO without the need of hydrogen gas. This is done by feeding it into a microwave plasma torch and utilizing the reverse Boudouard Reaction: $CO_2 \rightarrow CO+12\ O_2$

However, to avoid reforming CO_2, the outgoing gases are quenched and additional carbon is added at the outlet to react with the produced oxygen, increasing the overall yield: $CO_2 \rightarrow CO+12\ O_2$

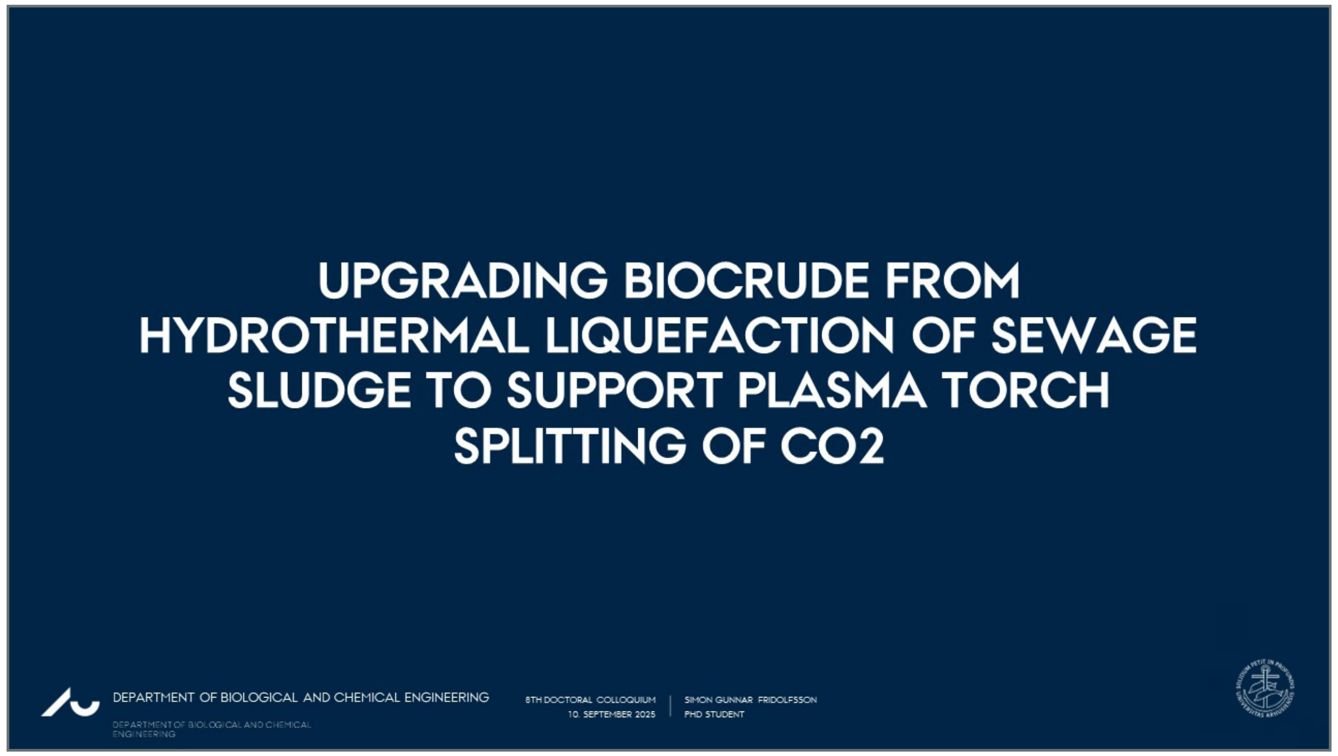
To ensure sufficient availability of carbon, an ultrasonic atomizer is used to atomize biocrude into tiny droplets. Biocrude is a black viscous liquid, which in many aspects resembles fossil crude oil. To atomize the biocrude however, its viscosity must be decreased. Moreover, the carbon content must be high to perform well as carbon source for the quenched gas.

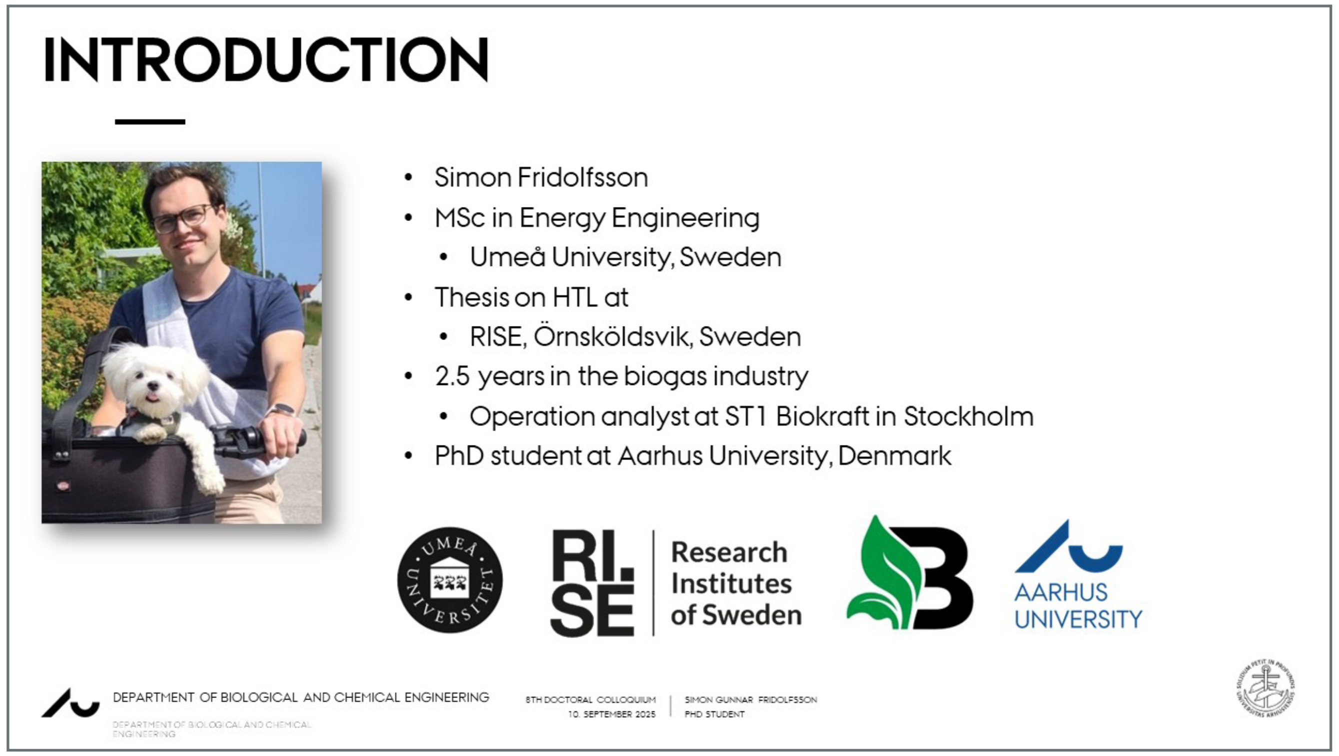
Method
The biocrude was derived from sewage sludge through hydrothermal liquefaction (HTL) at Aarhus University's (AU) pilot plant for continuous HTL. The present study will explore different pathways to meet the criteria necessary for the plasma torch setup to function:

- Distillation
- Solvent extraction
- Thermal treatment
- Hydrotreatment (HT)

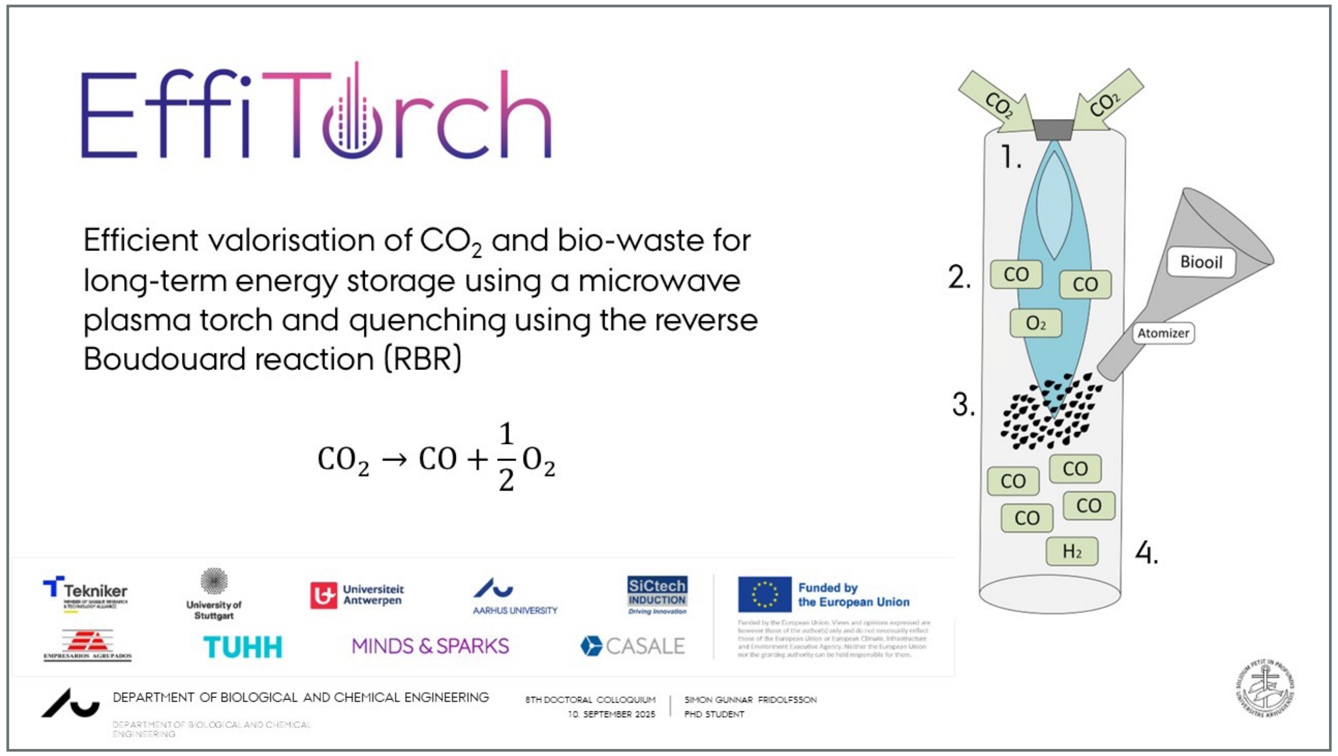
Each pathway except HT is done in batches at lab scale at AU's campus in Aarhus. The HT is done in a continuous flow reactor at AU's pilot facilities in Foulum.

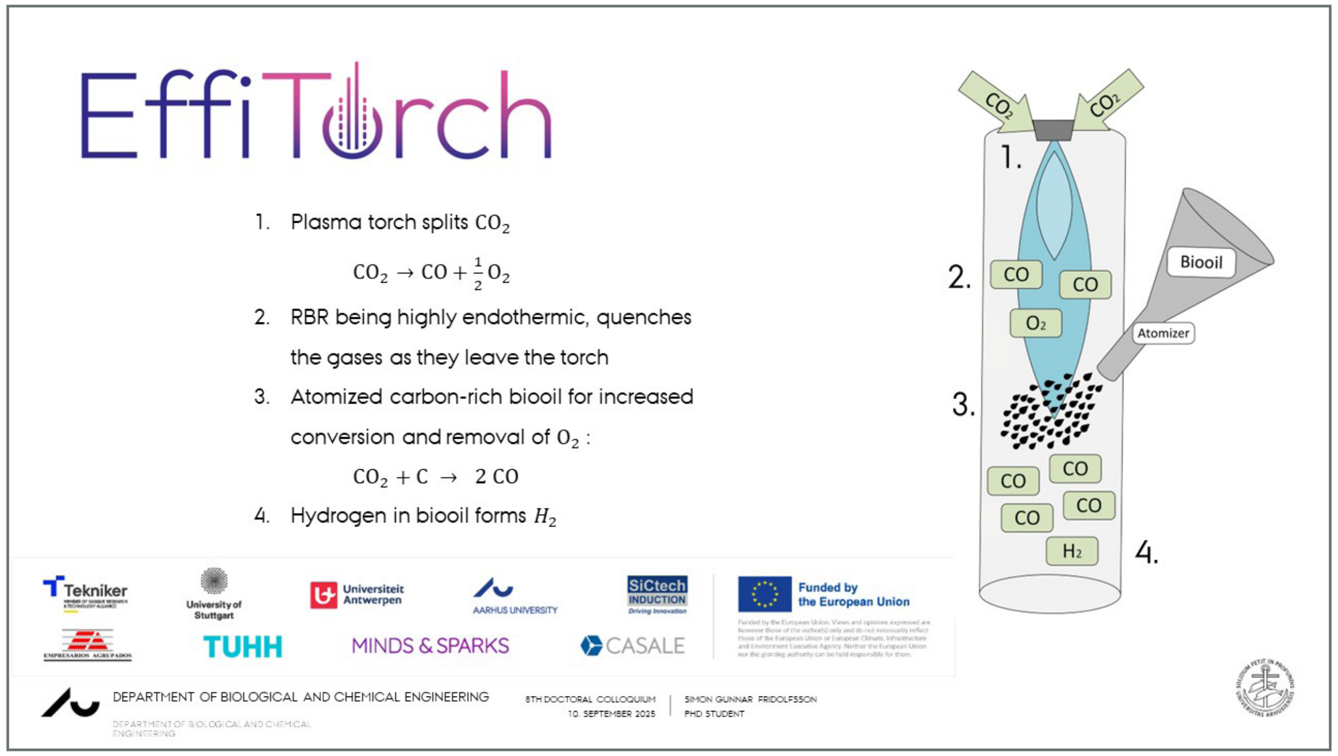
Outlook
Previous studies on biocrude have shown promise for all pathways. However, a comparison between all of them on the same batch of biocrude derived from sewage sludge has not been made before, which is therefore the aim of this study. HT will be of particular interest, as recent research has been shown it to significantly reduce not only viscosity, but the contents of sulfur, nitrogen and oxygen as well while maintaining a high carbon recovery. Though more research is needed for further understanding of reaction parameters' effects on the outcome and how to optimize the process depending on original feedstock as well as the requirements on the product. Hence, the next step is conducting several HT experiments with different conditions to expand the knowledge on how to optimize hydrotreatment of biocrude from sewage sludge.

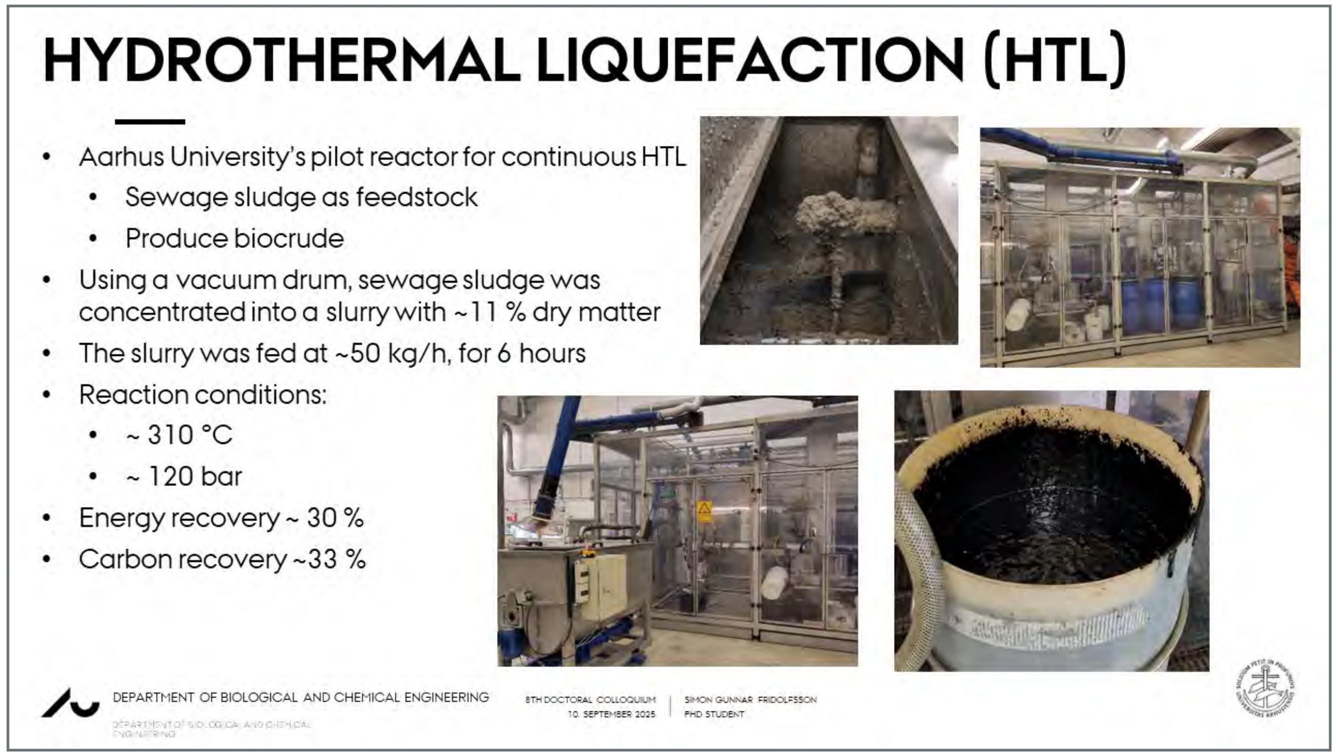





INTRODUCTION
Horizon Europe - EffiTorch
Hydrothermal Liquefaction
Biocrude
Upgrading of biocrude
Solvent extraction
Hydrotreatment
Conclusions
RI. SE Research Institutes of Sweden
AARHUS UNIVERSITY
DEPARTMENT OF BIOLOGICAL AND CHEMICAL ENGINEERING


EffiTorch
Efficient valorisation of CO_2 and bio-waste for long-term energy storage using a microwave plasma torch and quenching using the reverse Boudouard reaction (RBR)
$CO_2 \rightarrow CO + \frac{1}{2}O_2$
1.
2.
3.
4.
CO
O2
H2
Biooil
Atomizer
Tekniker
University of Stuttgart
Universiteit Antwerpen
AARHUS UNIVERSITY
SiCtech INDUCTION
Funded by the European Union
TUHH
MINDS & SPARKS
CASALE
DEPARTMENT OF BIOLOGICAL AND CHEMICAL ENGINEERING

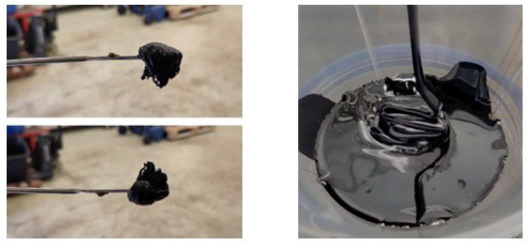

EffiTorch
1. Plasma torch splits CO_2
$CO_2 \rightarrow CO + \frac{1}{2}O_2$
2. RBR being highly endothermic, quenches the gases as they leave the torch
3. Atomized carbon-rich biooil for increased conversion and removal of O_2 :
$CO_2 + C \rightarrow 2\,CO$
4. Hydrogen in biooil forms H_2
CO
O2
H2
Biooil
Atomizer
Tekniker
University of Stuttgart
Universiteit Antwerpen
AARHUS UNIVERSITY
SiCtech INDUCTION
Funded by the European Union
TUHH
MINDS & SPARKS
CASALE
DEPARTMENT OF BIOLOGICAL AND CHEMICAL ENGINEERING

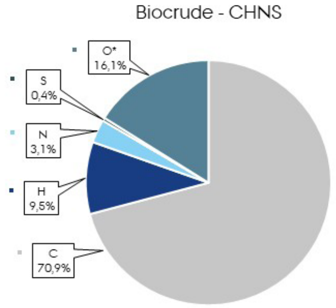

HYDROTHERMAL LIQUEFACTION (HTL)
Aarhus University's pilot reactor for continuous HTL
Sewage sludge as feedstock
Produce biocrude
Using a vacuum drum, sewage sludge was concentrated into a slurry with ~11 % dry matter
The slurry was fed at ~50 kg/h, for 6 hours
Reaction conditions:
~ 310 °C
~ 120 bar
Energy recovery ~ 30 %
Carbon recovery ~33 %
DEPARTMENT OF BIOLOGICAL AND CHEMICAL ENGINEERING

BIOCRUDE

- Biocrude was dissolved in acetone and filtered to remove hydrochar
- Some improvement but still very viscous
- Contains high levels of unwanted elements (O, S, and N)
  - 16 % Oxygen
  - 0.4 % Sulphur
  - 3 % Nitrogen
- Needs further treatment
  - Solvent extraction
  - Hydrotreatment

Raw, in room temperature   Filtered, at ~40 °C





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SOLVENT EXTRACTION

- Examined using heptane and hexane as solvents
- Standard test with solvent-to-oil ratios (SOR) of 40:1 (vol:wt)
  - Determine total asphaltene content
- Additional tests using SOR 20:1, 10:1, 5:1, and 2:1
- Experimental procedure
  - Tube revolver
  - 1 - 2 grams of biocrude
  - 24 and 48 h
  - Centrifuged
  - Repeated once

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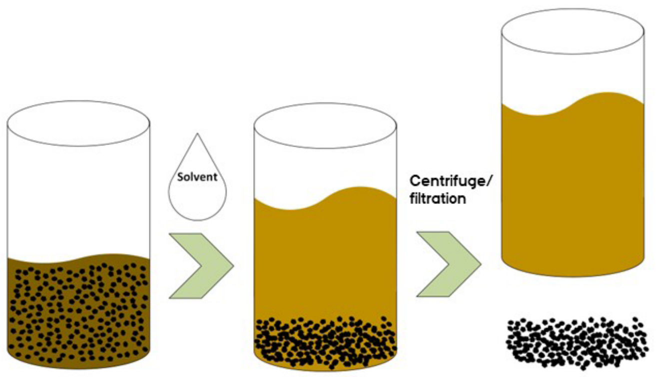
SOLVENT EXTRACTION

- Also called "*de-asphalting*"
  - Separate asphaltenes from the rest of the oil
- Asphaltenes
  - Defined as compounds not soluble in n-alkanes but soluble in toluene
  - Solid in ambient temperatures
    - Increases viscosity significantly
- High rate of asphaltene removal
  - Lowers oil yield
  - Likely increases oil quality



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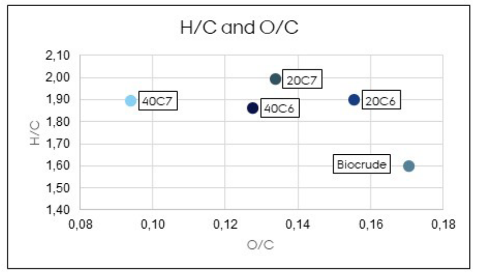
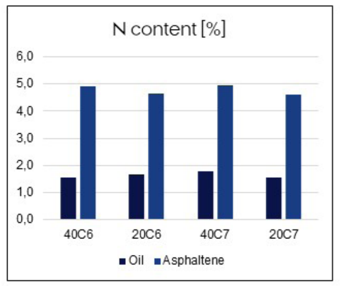
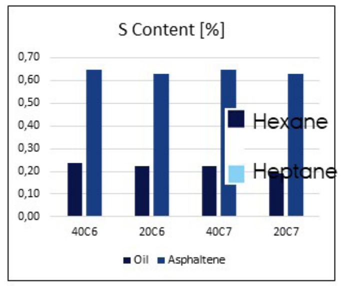
SOLVENT EXTRACTION

- Asphaltene content of about 45 wt. %
  - Little difference between heptane and hexane
- Increased oil quality
  - Denitrification 41 – 50 %
  - Desulfurization 42 – 56 %
  - Heptane generally outperforming hexane
    - H/C and O/C
    - Higher yield







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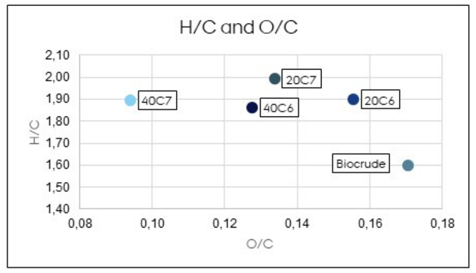

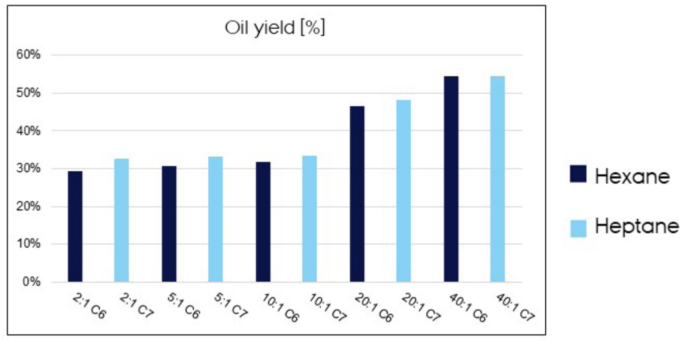

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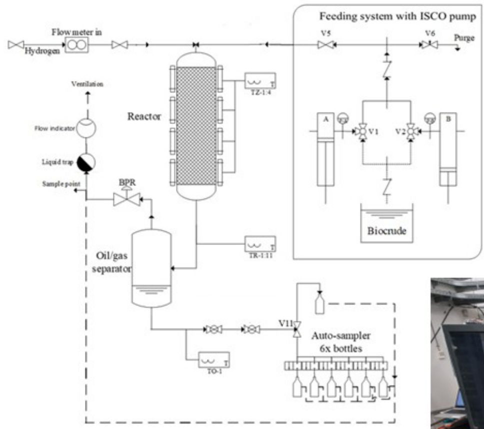
HYDROTREATMENT

- Continuous dual-bed pilot reactor
  - 70 ml reactor
  - 280 – 430 °C
  - 40 – 180 bar
- Experimental parameters
  - 20 g biocrude/h
  - 45 NL H_2/h
  - 80 bar
  - CoMo and NiMo catalysts
    - Sulphided in situ
  - 340, 360, 380, and 400 °C



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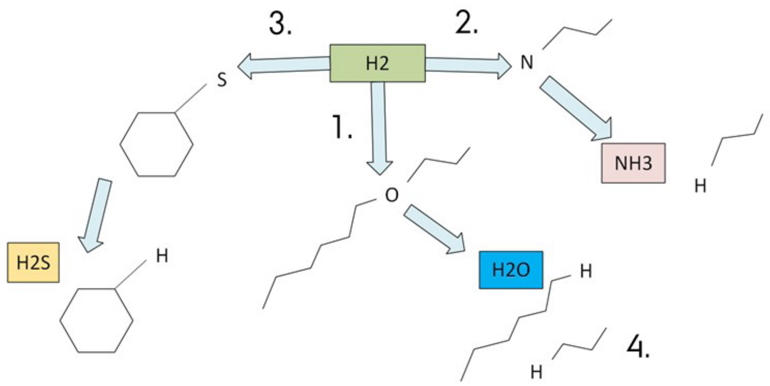
HYDROTREATMENT

- Hydro-
  1. deoxygenation
  2. denitrification
  3. desulphurisation
  4. *cracking*
- Established technology in refining of heavy crude oils
- HVO diesel – hydrotreated vegetable oils



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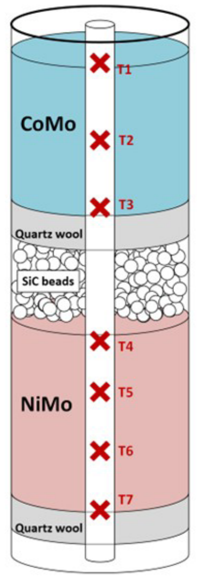

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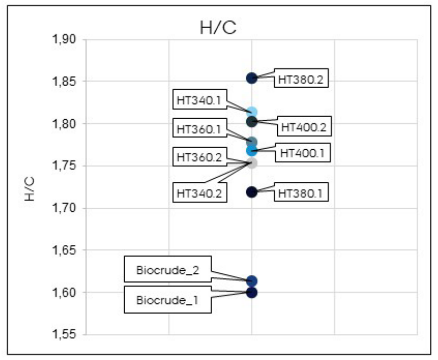
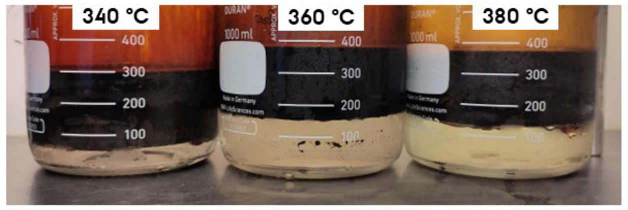
HYDROTREATMENT

- Significant decrease in viscosity
  - From thick tar to water-like
- CHNS
  - Significant increase in H/C
  - Reduction of N and S increases with temperature
    - *Denitrification 10 – 60 %*
    - *Desulphurisation 40 – 75 %*
- Increased water yield above 340 °C
  - Increased deoxygenation





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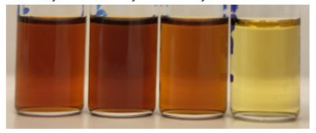
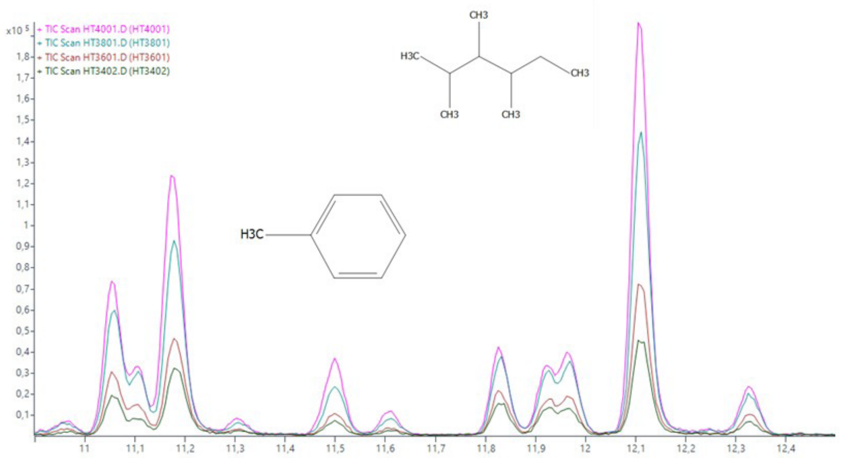
HYDROTREATMENT

- GC-MS
  - Hydrotreated products show big peaks for C12-C19 alkanes
- Increasing temperature
  - Lighter and more volatile compounds
  - Reduction of some heavier alkanes

340, 360, 380, 400 °C





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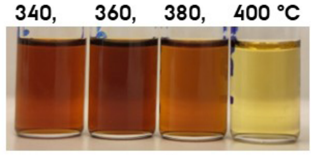

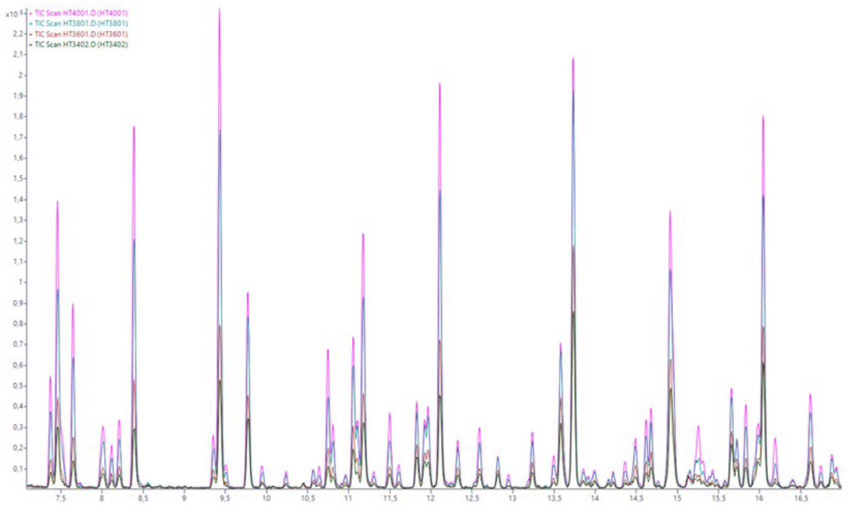

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CONCLUSIONS

- HTL biocrude
  - Needs further treatment for most industrial applications
- Solvent extraction
  - Significant reduction of N and S
  - Some reduction of O
  - Lowered viscosity
  - C7 gives faster extraction → Larger oil yield at low SOR
- Hydrotreatment
  - High yields of fuel range compounds
  - Significant reduction of N, S, and O
  - Greatly decreased viscosity

DEPARTMENT OF BIOLOGICAL AND CHEMICAL ENGINEERING · 8TH DOCTORAL COLLOQUIUM 10. SEPTEMBER 2025 · SIMON GUNNAR FRIDOLFSSON PHD STUDENT

Mariana Campos Fraga, Karlsruhe Institute of Technology

Ethanol Quenching in Fast-Pyrolysis of Sugarcane Bagasse and Straw: Implications for Bio-Oil Hydrodeoxygenation

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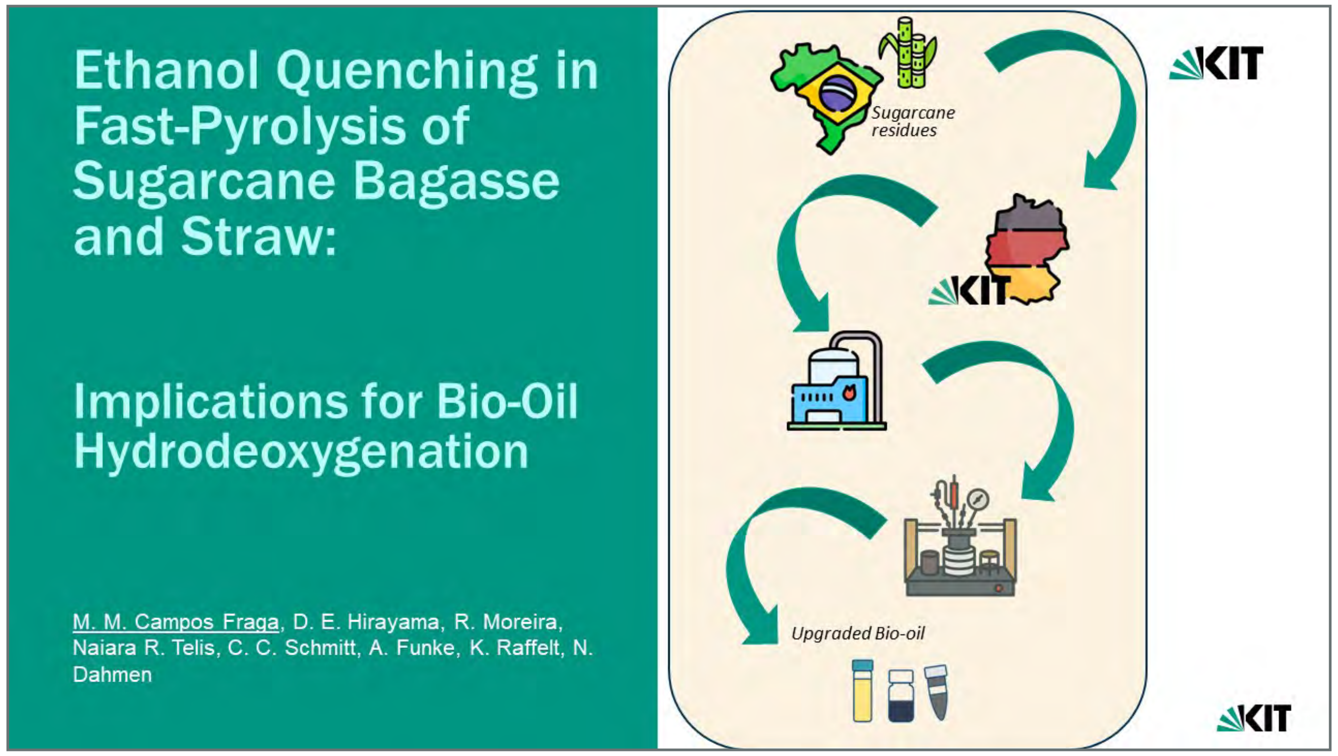
Keywords: biofuels, sugarcane, pyrolysis, straw, ethanol

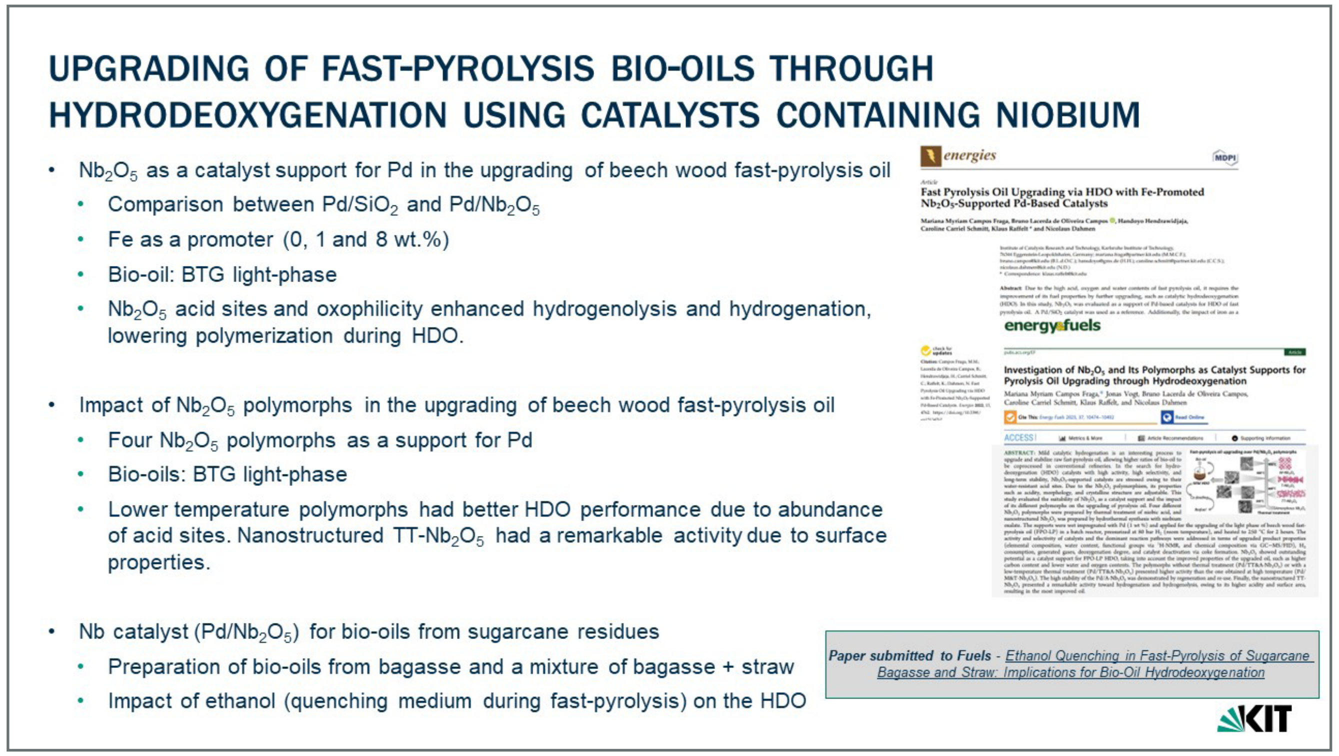
The development of biofuels from sugarcane residues is highly desirable, as hundreds of millions of tons of sugarcane bagasse and straw are co-generated every year by the industry of alcohol and sugar worldwide. Given the potential of processing biomass through fast pyrolysis followed by catalytic hydrodeoxygenation as a viable method for biofuel production, this study evaluated the impact of ethanol usage as a fast pyrolysis quenching media (QM) on the subsequent bio-oil upgrading through HDO. Hence, bio-oils from sugarcane bagasse mixed with sugarcane straw produced with ethanol (BS-ET) and without ethanol (BS) as a QM were upgraded through HDO with Pd/Nb2O5 catalyst. Furthermore, this study investigated the effect of straw addition to bagasse before the fast pyrolysis on the HDO.

The biomass used (sugarcane bagasse and straw) was collected in Brazil. The hydrotreatment of the bio-oils was carried out in a batch reactor at 250 °C, under an H2 atmosphere (80 bar at room temperature). The initial bio-oils and the upgraded products were characterized by several techniques.

The ethanol content in the initial bio-oils varied drastically: BG-ET (5 wt.%), BS-ET (24 wt.%), and BS (1 wt.%), which clearly influenced the behavior during the upgrading such as the single-phase HDO product of BS-ET and the two-phase product (aqueous phase and upgraded oil) from BG-ET and BS. Furthermore, BS yielded an extensively polymerized upgraded oil likely due to its high sugar content which are prone to polymerization, while the BS-ET resulted in a much less polymerized product. The ethanol quenching on BS-ET had an essential impact on the mitigation of polymerization by acting as a solvent on the HDO and therefore preventing direct contact between reactive species which could lead to chain elongation. Furthermore, ethanol reduced the concentration of reactive compounds and compounds prone to polymerization such as aldehydes and sugars owing to its diluent effect but even beyond, by changing the distribution and reactivity of several compounds in the fast pyrolysis. Related to the low polymerization degree of BS-ET, the generation of CO and CO_2 on the HDO of this bio-oil was diminished. Because of the absence of phase separation of BS-ET, the small polar oxygenated compounds remained on the upgraded oil, thus the lower deoxygenation degree compared with the upgraded oil from BG-ET and BS. On the other hand, because of the single-phase product, the BS-ET had the highest H/C ratio after the HDO.

Overall, the ethanol quenching on fast pyrolysis had a beneficial influence on the HDO, acting as a solvent, and a diluent and changing the phase equilibria and reactivity during fast pyrolysis.





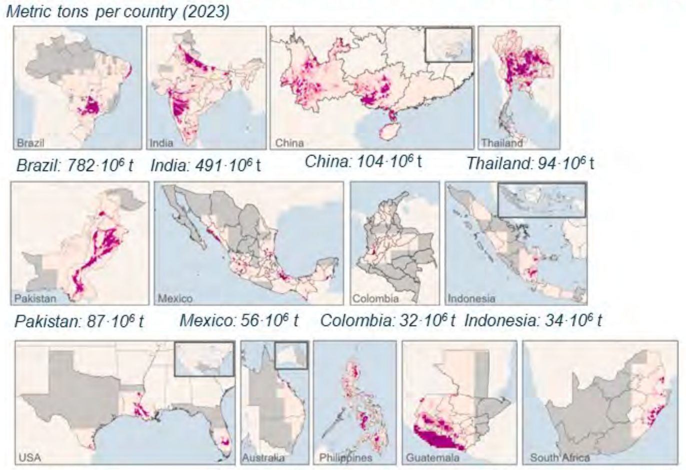
Agenda

1. Potential of sugarcane residues
2. Fast-pyrolysis of Sugarcane Bagasse and Straw followed by Hydrodeoxygenation
3. Ethanol Quenching on Fast-pyrolysis
4. Approach of This Study
5. Conclusions and Outlook

Sugarcane residues potential

Sugarcane maps for top 13 countries – 90% of total production (2019-2022)

Metric tons per country (2023)



Brazil: 782·10⁶ t India: 491·10⁶ t China: 104·10⁶ t Thailand: 94·10⁶ t

Pakistan: 87·10⁶ t Mexico: 56·10⁶ t Colombia: 32·10⁶ t Indonesia: 34·10⁶ t

USA: 30·10⁶ t Australia, Philippines, Guatemala and South Africa ~ 28 - 17·10⁶ t

Sugarcane world crop in 2023 ~ $2.025 \cdot 10^6$ t

~30%

Estimated bagasse amount ~ $607 \cdot 10^6$ t

~12%

Estimated straw amount ~ $243 \cdot 10^6$ t

Figure adapted from S. Di Tommaso et al. 2024 (https://doi.org/10.5194/essd-16-4931-2024).
Data from FAOSTAT database 2023 (https://www.fao.org/faostat/en/#data/QCL/visualize).
CNPEM – Guidelines for Sugarcane straw removal in Brazil, 2020

Sugarcane residues potential in Brazil

Brazil: 782 million tons of sugarcane ~ 38% of total world production

Bagasse ~ 234.6 million tons

Straw ~ 93.8 million tons

Mostly burned to produce energy

Installed capacity = 12.9 GW (2022)

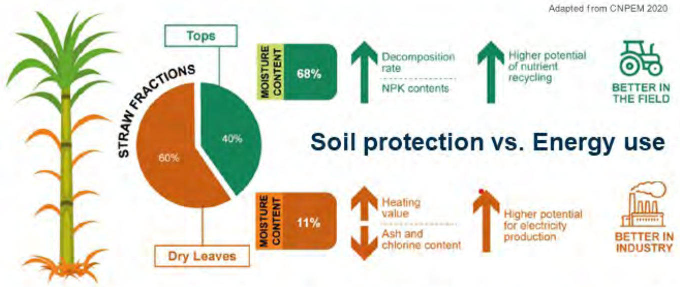
Direct combustion in boilers (Rankine cycle)

Modernization of thermal power plants

35 kWht⁻¹ (Back-pressure steam turbines)

182 kWht⁻¹ (Extracting condensing steam turbines)

Adapted from CNPEM 2020



Soil protection vs. Energy use

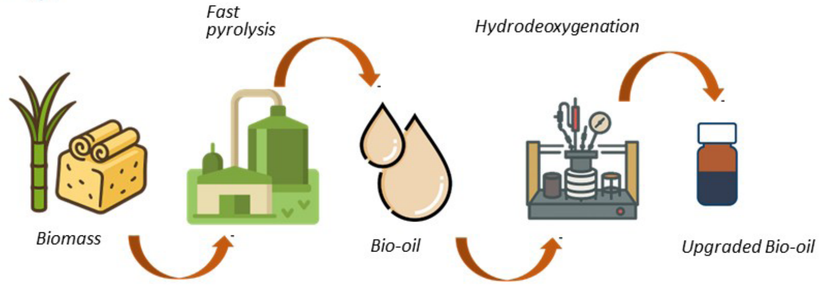
Mechanical Harvesting

No straw burning

Surplus of bagasse and straw

Coelho Junior et al. (2024), https://doi.org/10.1186/s42834-024-00223-z

Sugarcane Bagasse and Straw Fast-pyrolysis and Bio-oil Upgrading



2020 – Schmitt et al. (Germany/Brazil) – HDO of FPBO from Sugarcane bagasse.

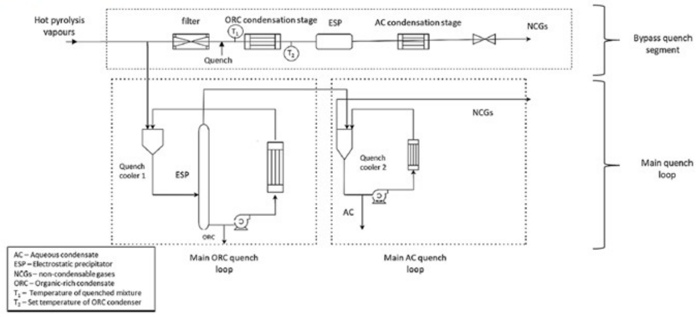
2022 – Martins Santos et al. (Brazil/Germany) – In-situ HDO of vapors from FP of Bagasse.

2018 – Santos et al. – Technoeconomic assessment of 1st and 2nd generation sugarcane biorefinery (using typical data).

2024 – Santos et al. – Energy assesment and heat integration (ASPEN PLUS) for the route FP + HDO of straw (using typical data from Poplar).

Ethanol Quenching on Fast-pyrolysis

Ethanol is continuously added to the stream of pyrolysis volatiles coming from the hot part of the reactor, right after the eletrostatic filter.



"Direct contact (quenching) condensation of fast pyrolysis vapors into fast pyrolysis bio-oils (FPBOs) is associated with the advantages of high efficiency, improved thermal performance and significant reduction in process cost. [...]

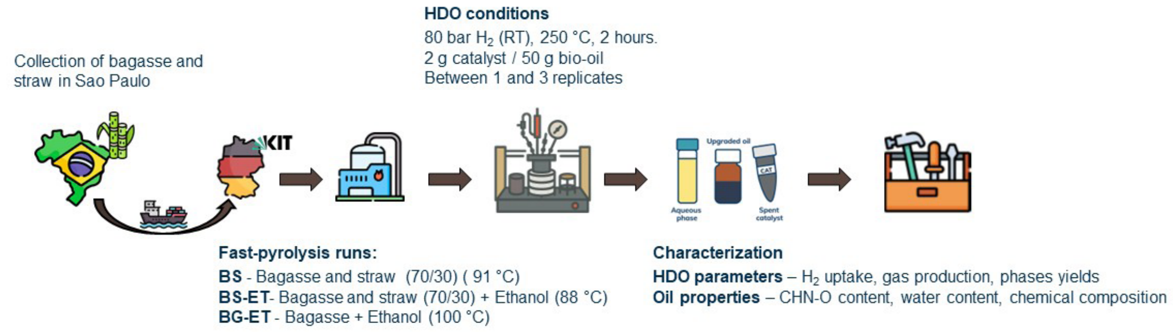
Ethanol quench recovered the highest yield of organic-rich condensate."

Parku et al. 2024

Parku et al. (2024), https://doi.org/10.1016/j.seppur.2024.126873

KIT

Methodology



Biomass	Pyrolysis quenching media	Abbreviation of bio-oil before HDO
Bagasse	Ethanol	BG-ET
Bagasse and Straw	Without quenching media	BS
Bagasse and Straw	Ethanol	BS-ET

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Goal of this study

Evaluate the effect of ethanol usage as a fast pyrolysis QM for sugarcane bagasse and straw on the subsequent bio-oil upgrading through mild catalytic hydrodeoxygenation (HDO).

1. Production of bio-oils through Fast-pyrolysis of Sugarcane Bagasse and Straw with and without ethanol (QM).
2. Upgrading of bio-oils via HDO with Pd/Nb_2O_5.
3. Characterization of bio-oils and upgraded products.

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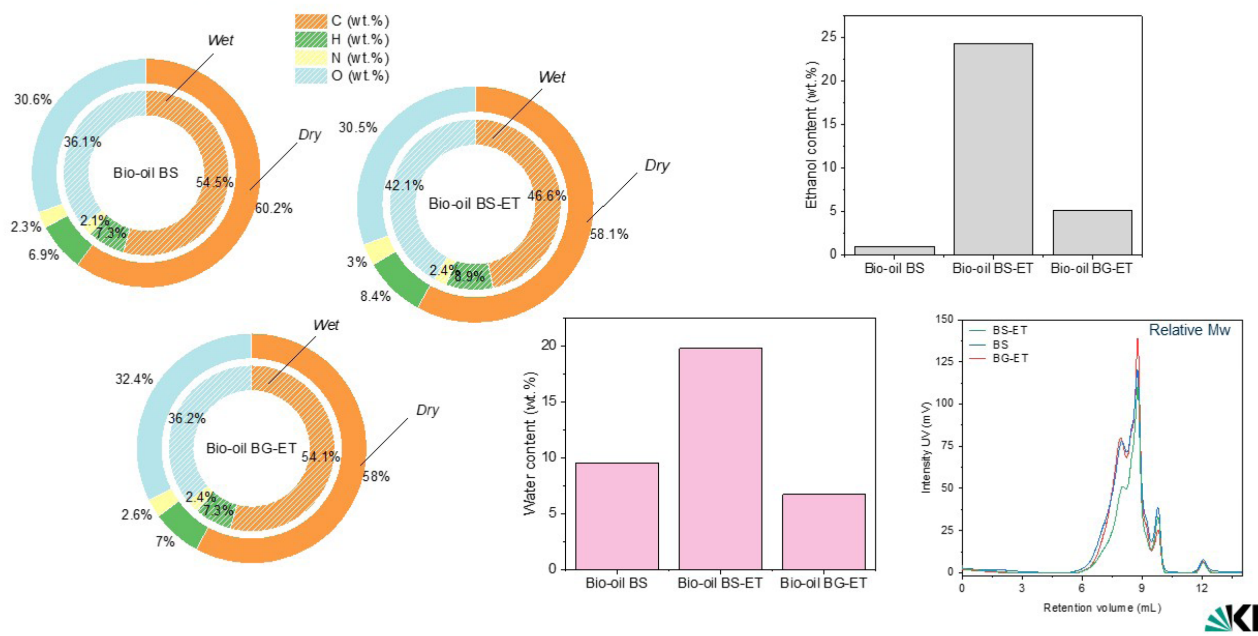
Bio-oils properties before HDO



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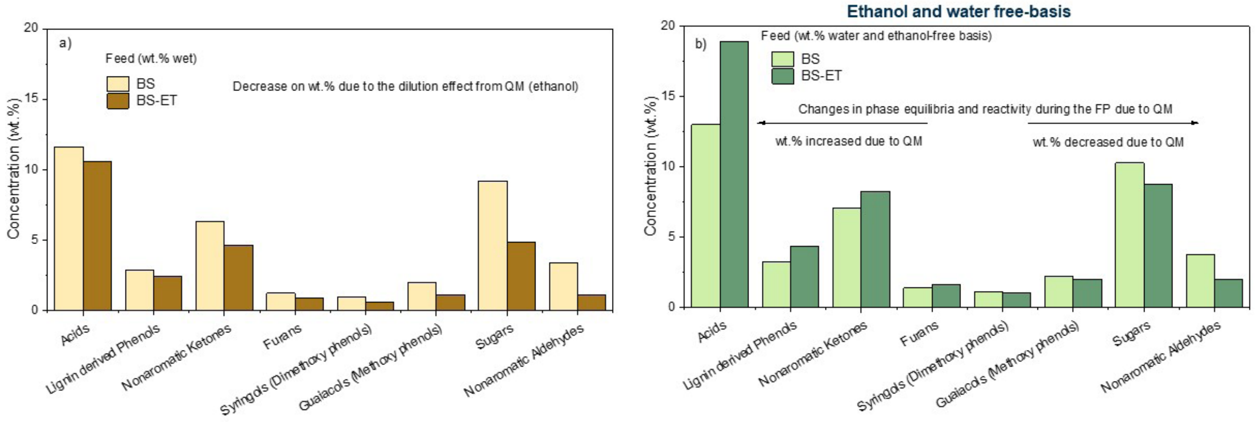
Bio-oils properties before HDO: Ethanol (QM) impact

Dilution effect and changes in phase equilibria/reactivity during fast-pyrolysis process



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Different bio-oils, Different HDO behaviors

Less compounds prone to polymerization

- Sugars,- Aldehydes (beyond dilution effect).

BS-ET

Upgraded single-phase

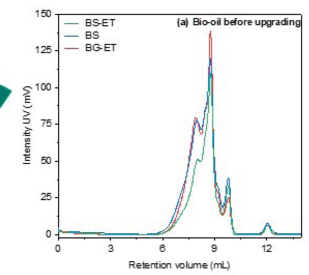
BG-ET

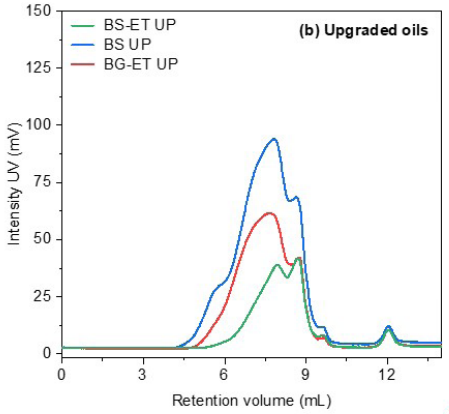
Aqueous phase + Upgraded oil

BS

Highly polymerized

Aqueous phase + Upgraded oil





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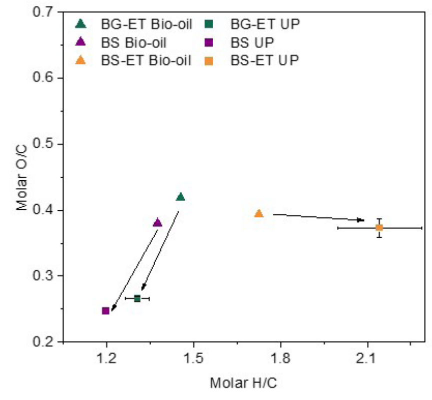
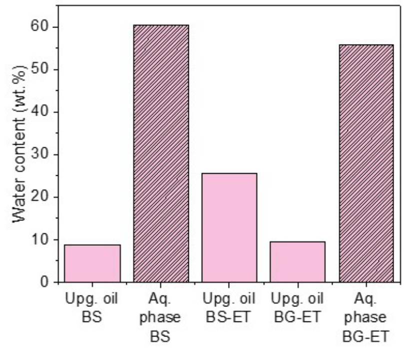
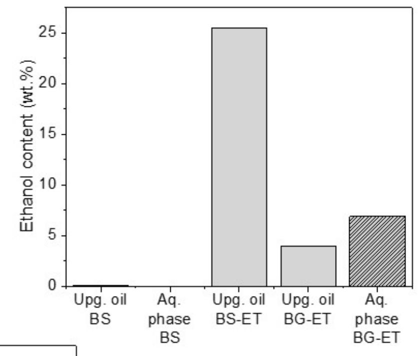
Characterization of upgraded products







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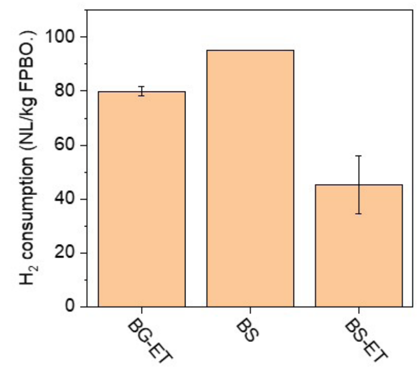
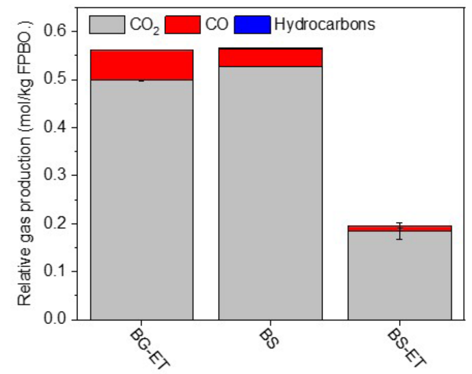
HDO parameters during upgrading

Lower H_2 consumption due to ethanol (QM)



Lower CO_2 on BS-ET associated to less polymerization due to less compounds such as sugars and aldehydes



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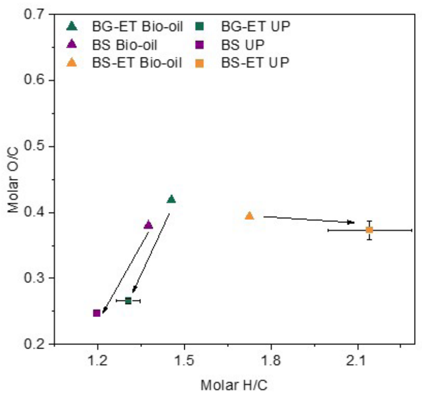
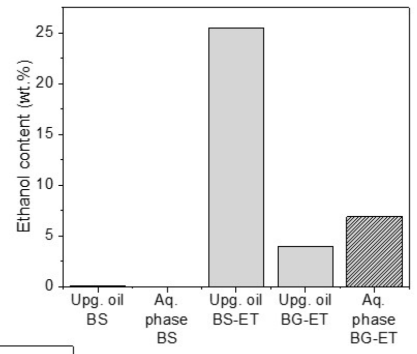
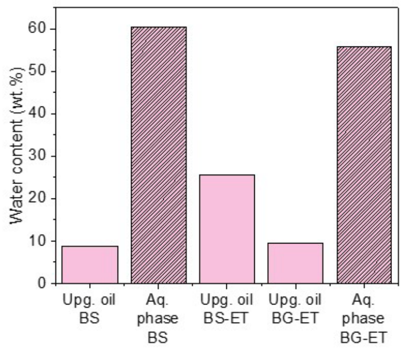
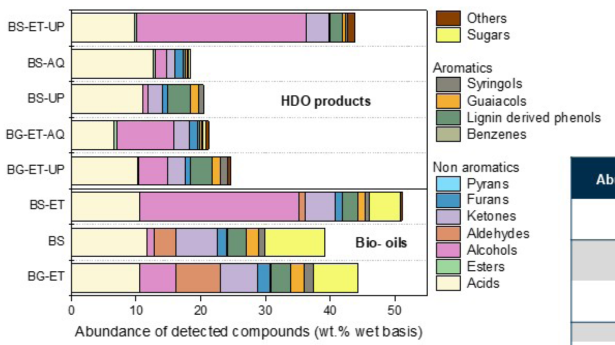






Chemical composition before and after HDO



Abundance of detected compounds in wt.%	BG-ET	BS	BS-ET	BG-ET -UP	BG-ET -AQ	BS-UP	BS-AQ	BS-ET-UP
Acetic acid	5.81	6.69	5.78	5.35	5.41	5.87	10.56	5.04
Propionic acid	4.77	4.95	4.82	4.83	0.83	5.14	1.35	4.70
Ethanol	5.17	1	24.31	3.98	6.87	0.10	0.05	25.51
Ethylene glycol	0.42	0.21	0.22	0.42	1.91	0.30	1.61	0.56
Hydroxy-acetaldehyde	6.31	2.83	0.94	0	0	0	0	0
2-Furaldehyde	0.23	0.31	0.18	0	0	0	0	0
Hydroxyacetone (acetol)	4.04	4.37	3.10	1.20	1.10	0	0.14	2.01
Levoglucosan	5.46	7.85	4.24	0	0	0	0	0
1,5-Anhydro-ß-D-xylofuranose	0.76	0.77	0.39	0	0	0	0	0
1,4:3,6-Dianhydro-α-D-glucopyranose	0.35	0.34	0.25	0	0	0	0	0
Anhydrosugar unknown	0.48	0	0	0	0.42	0	0.24	0
Cyclopentan-1-one and subst. cyclopentan-1-one	1.12	1.3	0.83	0.38	0.12	0.03	0.02	0.30
Cyclopentanone and subst. cyclopentanone	0	0	0	0.45	0.22	1.46	0.39	0.32
2-Pentanone and 2-Hydroxy-3-pentanone	0	0	0	0.17	0.11	0.20	0.06	0
4-Vinyl-phenol	2.05	1.16	1.19	0	0	0	0	0
4-Ethyl-phenol	0.47	0.76	0.67	2.57	0.23	2.23	0.15	1.26
γ-Butyrolactone	0.18	0.25	0.15	0.59	0.51	0.67	0.67	0.27
2(5H)-Furanone	0.52	0.43	0.18	0	0	0	0	0

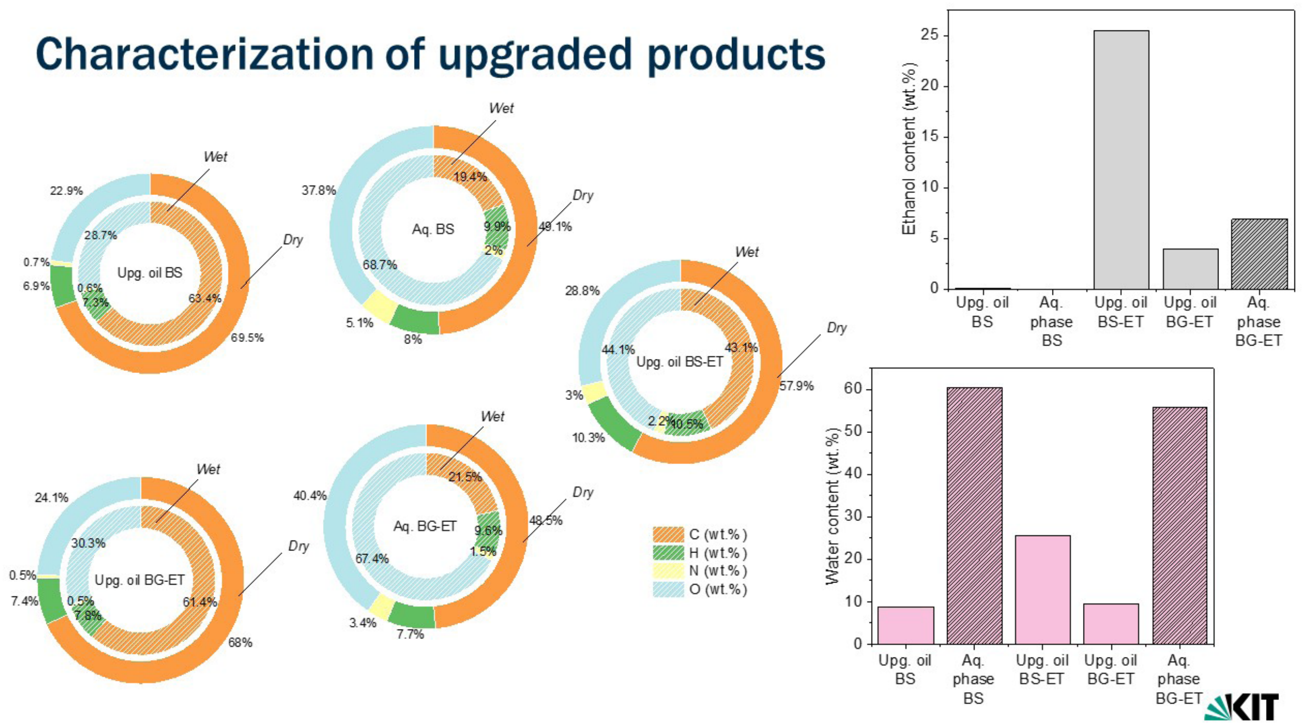
Relevant points…

- The ethanol content varied drastically: BS-ET: 24 wt.%; BG-ET: 5 wt.% and BS: 1 wt.%.
- BS-ET led to a single-phase product while BG-ET and BS had phase separation during HDO. The BS-ET had also less polymerization, and the lowest CO_2 generation despite the lowest H_2 consumption.
- The performance of BS-ET during the HDO was related to:
  - High ethanol content from quenching.
  - Straw added to the bagasse (catalytic behavior of straw).
- Ethanol impact:
  - As a solvent – avoiding contact between reactive species and preventing their reaction into larger molecules.
  - As a diluent – reducing the concentration of reactive molecules (e.g. sugars, aldehydes, methoxy and dimethoxy-phenols, furanic compounds).
  - In the phase equilibria (distribution) and reactivity of some compounds during the fast-pyrolysis (wt.% ethanol free basis).

Conclusions and Outlook

- Bio-oils from sugarcane residues were successfully hydrotreated over Pd/Nb_2O_5 producing upgraded oils with higher hydrogen content, smaller contents of compounds prone to polymerization, and smaller oxygen content.
- The ethanol as a QM had a beneficial impact on mitigating polymerization by reducing the number of reactive molecules and avoiding contact between them. The bio-oil with higher ethanol content was achieved over lower quenching temperatures (88 °C).
- Straw had possibly a beneficial impact due to the catalytic behavior of the ash, therefore the reduction of several reactive compounds on both BS and BS-ET. But QM was essential to reduce sugar and avoid polymerization.
- The reduction of reactive molecules promoted by ethanol was beyond the dilution effect, tracing back to its influence on the fast pyrolysis.
- More studies are recommended to compare the ethanol as QM and eluent in the HDO. Further studies are necessary to understand better the effect of the quenching temperature and consequently to establish the optimum ethanol content from the HDO perspective.

Characterization of upgraded products



Gabriel Batista, University of Hohenheim

Phytotoxicity assessment of hydrochar obtained from hydrothermal liquefaction

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Keywords: Agriculture, soil amendment, germination assay, pyrolysis, organic molecules

Introduction

Thermochemical processes are pivotal technologies for valorizing biomass into valuable chemicals and products. Among many processes, hydrothermal liquefaction (HTL) converts wet biomass into several products, mainly biocrude. However, side streams are also generated during HTL. Hydrochar (HC), the solid by-product, is the most under-investigated side stream, and its valorization pathway is still unclear. This work uses lab-scale germination assays to assess the interaction between HTL-HC and plants. Treatments to improve HC properties as a possible soil amendment were also evaluated.

Methods

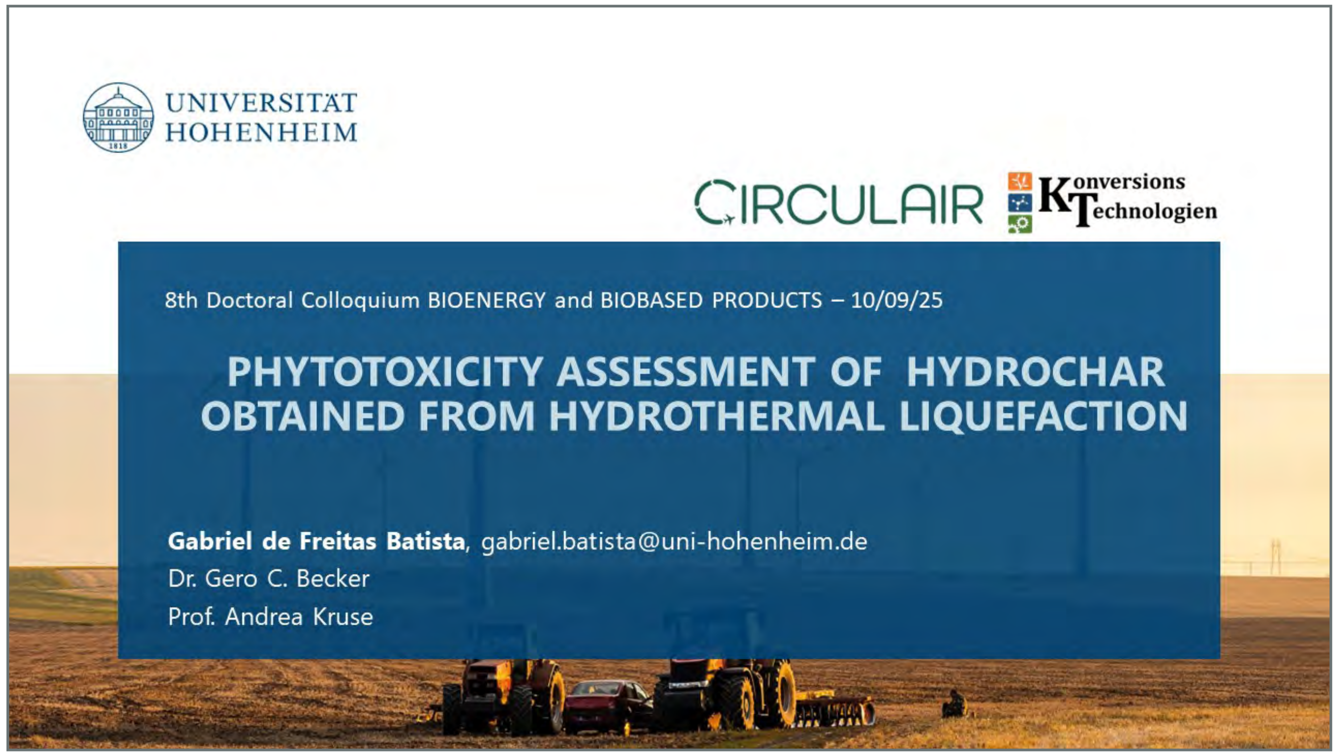
The HTL was conducted at Aarhus University on a pilot-scale HTL plant using a 50/50 wt % mixture of straw and manure. The operational parameters were as follows: Dry matter = 11.2 %; T = 325 °C; P = 17 MPa; Flow = 55 kg/h; Retention time = 18 min. The obtained hydrochar (HTL-HC) was collected in-line and dried at 105 °C. Three different treatments were applied to enhance the HTL-HC agricultural properties: (a) Water washing and Pyrolysis for 2 hours at (b) 300 °C and (c) 500 °C. The four obtained materials were subjected to germination assays with Lepidium sativum seeds, according to BS EN 16086-2:2011 standard. Experiments were carried out in triplicate. As a response, germination and root index were evaluated.

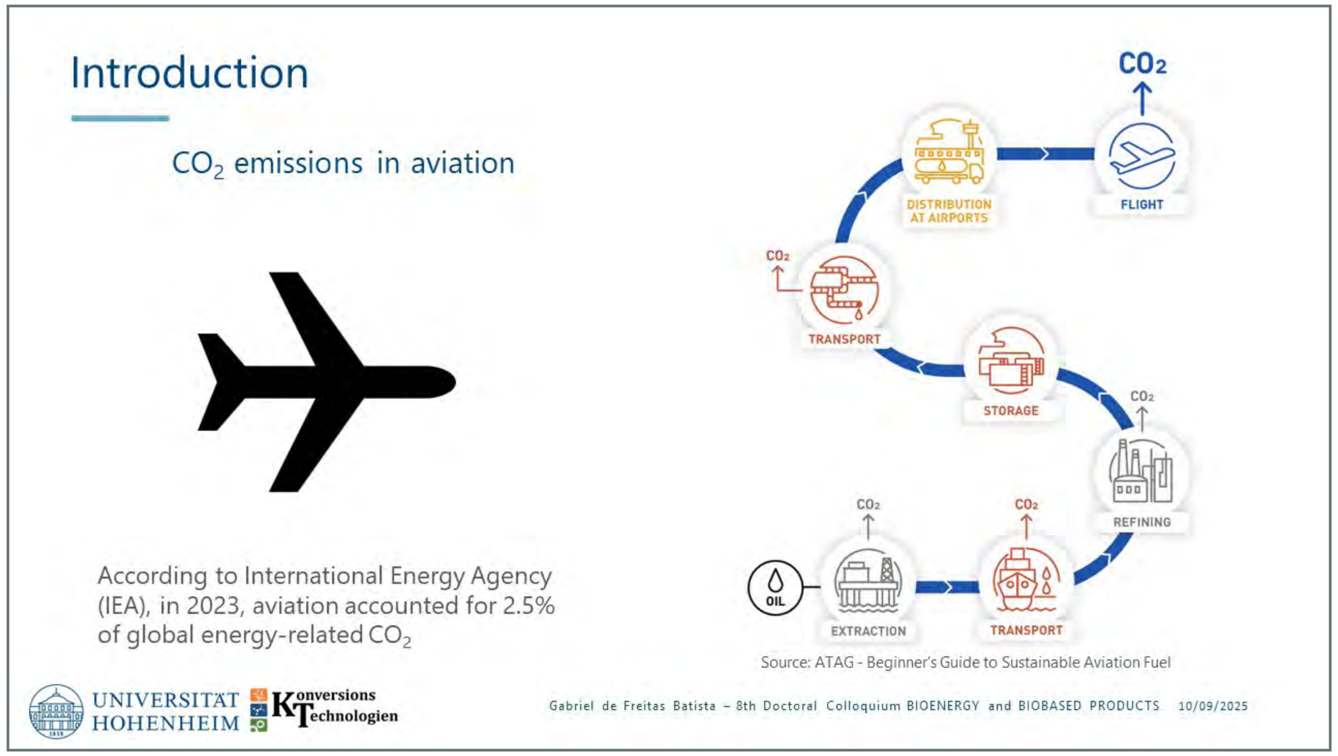
Results

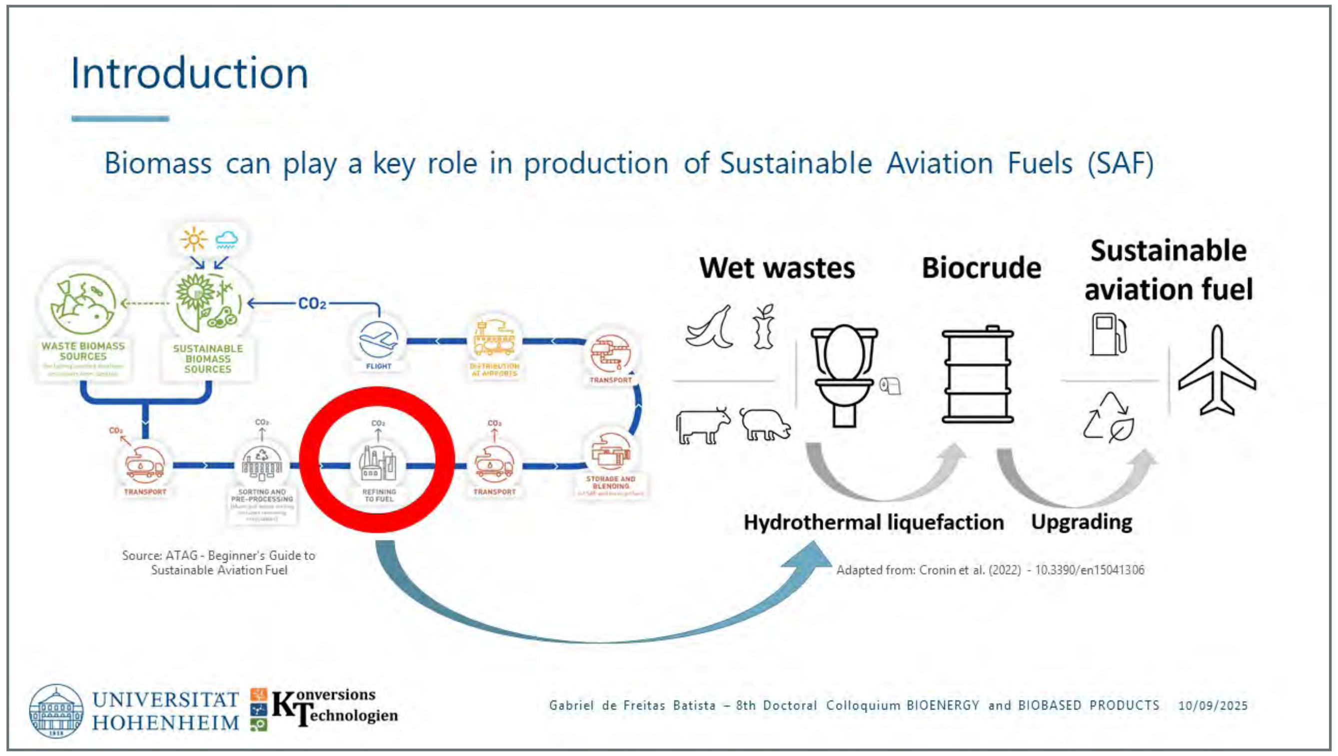
When applied to the germination test, raw HTL-HC caused negative plant growth. No impact was observed on seed germination. However, root length was ~70 % shorter than the control. Washing the HTL-HC reduced phytotoxicity, resulting in ~20 % shorter root lengths than the control. Pyrolysis emerged as the most suitable hydrochar treatment. Materials pyrolyzed at 300 and 500 °C no longer showed phytotoxicity. Average root lengths were similar to the control, with a slight increase of 2 % and 5 %, respectively.

Outlook

The results show that HTL-HC was phytotoxic for Lepidium sativum seeds in its native form. One possible reason was the presence of phytotoxic organic substances generated during HTL, likely organic compounds, adsorbed on the HTL-HC surface. The treatments presented were effective in removing HTL-HC phytotoxicity. These results are a milestone that provides information that may enable future hydrochar application in agricultural systems.






Introduction
Biomass can play a key role in production of Sustainable Aviation Fuels (SAF)
CO2
WASTE BIOMASS SOURCES
SUSTAINABLE BIOMASS SOURCES
Source: ATAG - Beginner's Guide to Sustainable Aviation Fuel
Wet wastes
Biocrude
Sustainable aviation fuel
Hydrothermal liquefaction
Upgrading
Adapted from: Cronin et al. (2022) - 10.3390/en15041306
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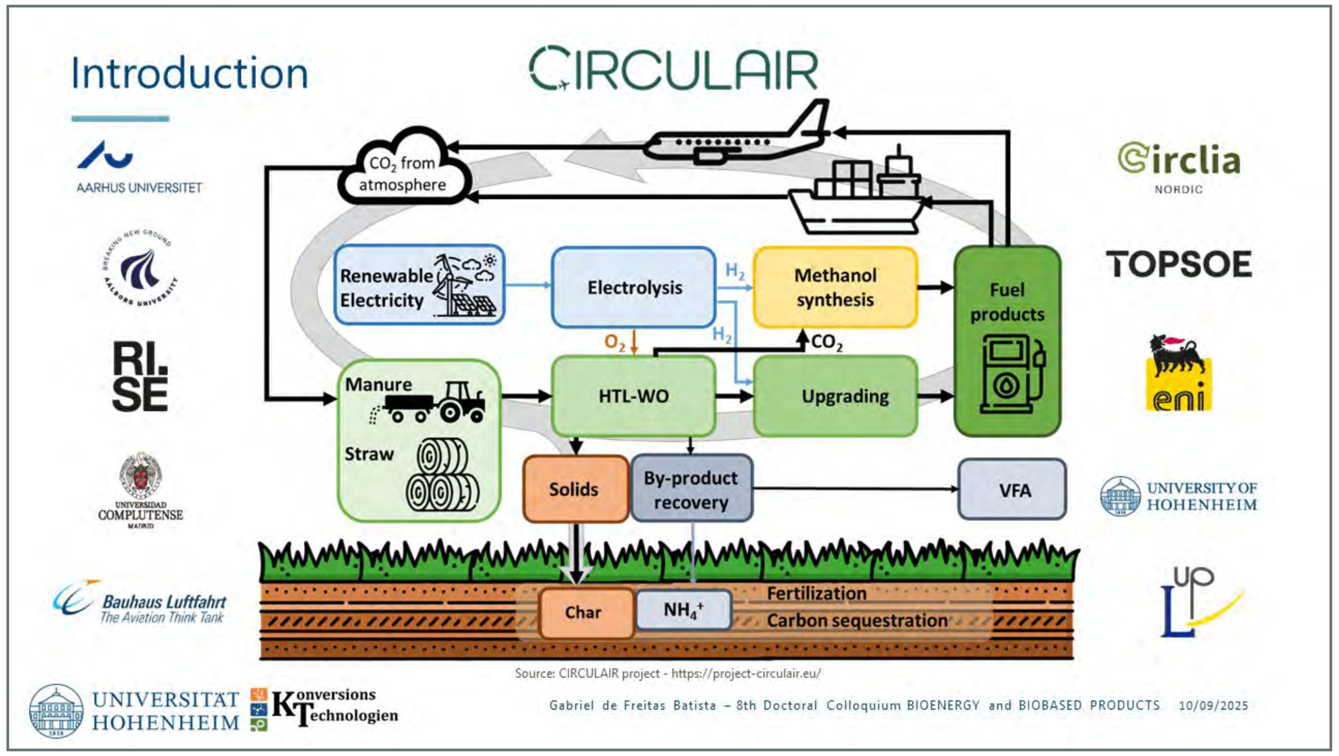
Introduction
CIRCULAIR
AARHUS UNIVERSITET
CO2 from atmosphere
Renewable Electricity
Electrolysis
H2
Methanol synthesis
Fuel products
O2
H2
CO2
Manure
Straw
HTL-WO
Upgrading
Solids
By-product recovery
VFA
Char
NH4+
Fertilization
Carbon sequestration
Circlia
NORDIC
TOPSOE
eni
RI. SE
UNIVERSIDAD COMPLUTENSE MADRID
UNIVERSITY OF HOHENHEIM
Bauhaus Luftfahrt
The Aviation Think Tank
Source: CIRCULAIR project - https://project-circulair.eu/
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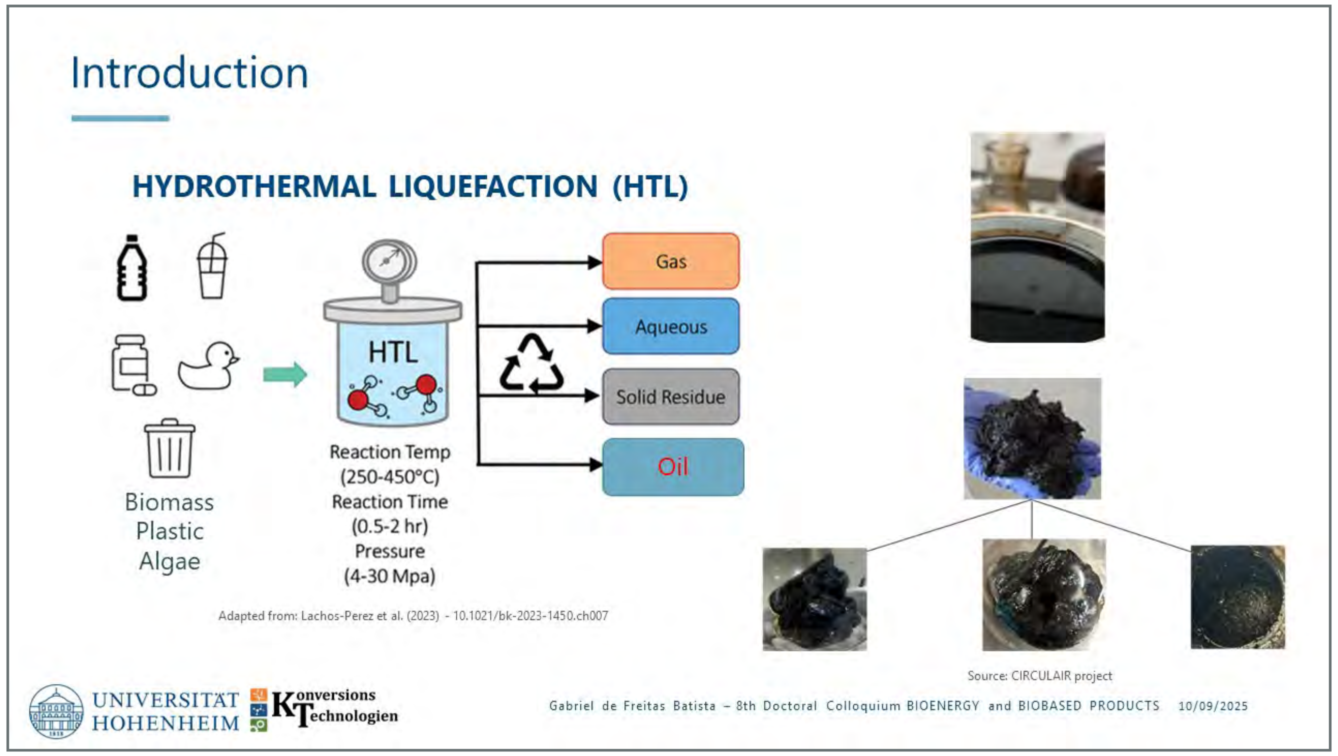
Introduction
HYDROTHERMAL LIQUEFACTION (HTL)
HTL
Gas
Aqueous
Solid Residue
Oil
Biomass
Plastic
Algae
Reaction Temp
(250-450°C)
Reaction Time
(0.5-2 hr)
Pressure
(4-30 Mpa)
Adapted from: Lachos-Perez et al. (2023) - 10.1021/bk-2023-1450.ch007
Source: CIRCULAIR project
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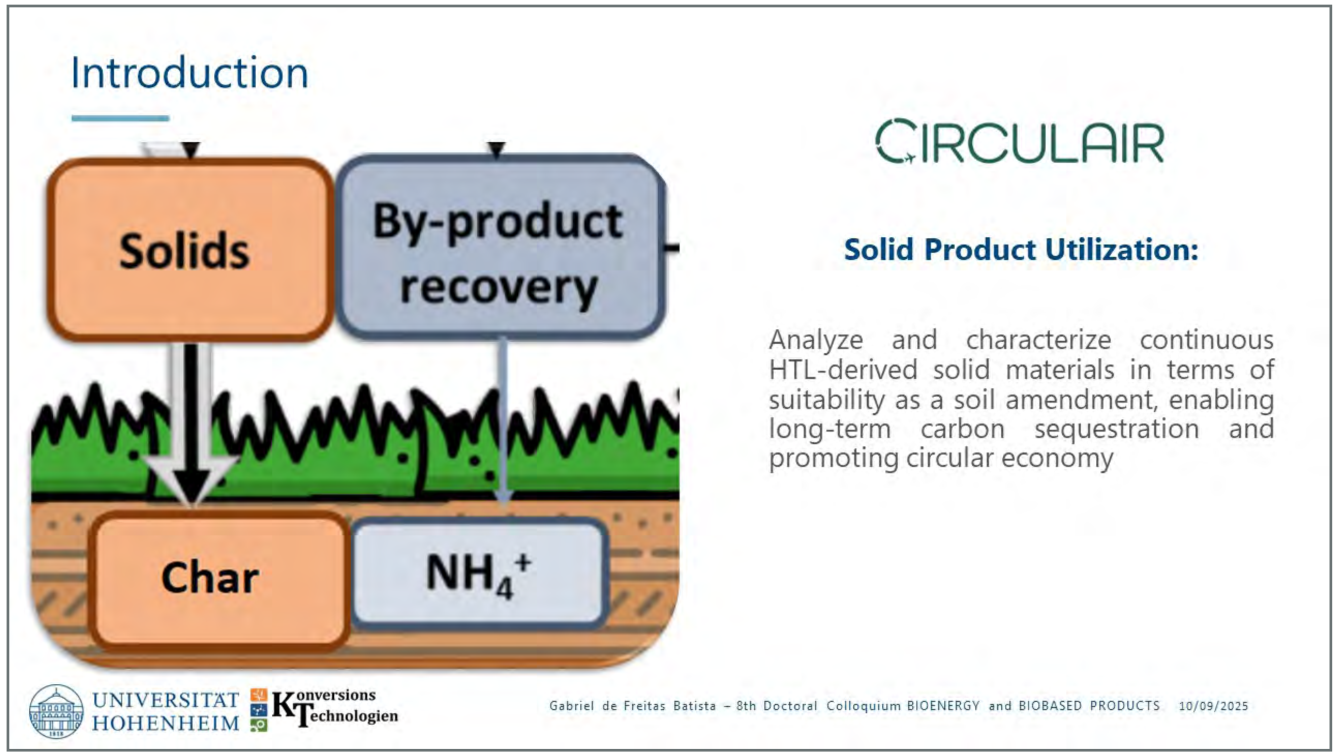
Introduction
Solids
By-product recovery
Char
NH4+
CIRCULAIR
Solid Product Utilization:
Analyze and characterize continuous HTL-derived solid materials in terms of suitability as a soil amendment, enabling long-term carbon sequestration and promoting circular economy
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Methodology – Hydrochar production

Hydrothermal liquefaction plant

Continuous pilot plant
Dry matter: 15%
T = 325 ºC
P = 17 MPa
Flow = 55 kg/h
Time = 18 min

AARHUS UNIVERSITET

Aarhus University - HTL pilot plant
Department of Biological and Chemical Engineering
www.bce.au.dk/biorefining
Photo: Ida Marie Jensen, Aarhus Universitet

Characterization techniques

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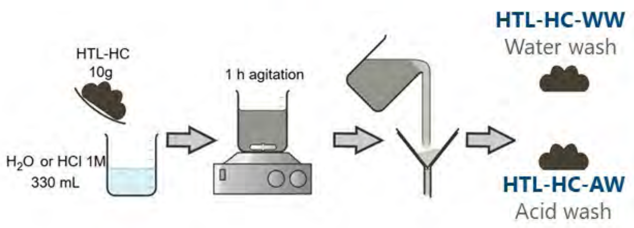
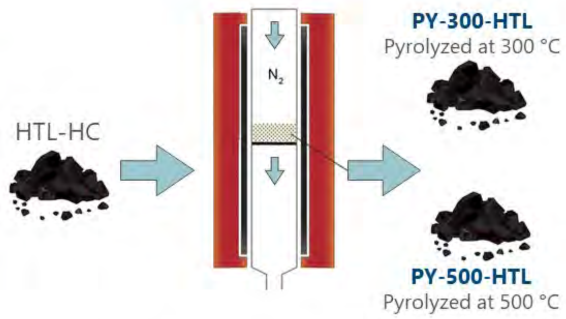
Methodology – HTL-HC modification

Washing treatment:



Pyrolytic treatment:



Temperature: 300 or 500 °C
Time: 2 h
Heating rate: 300 °C/h

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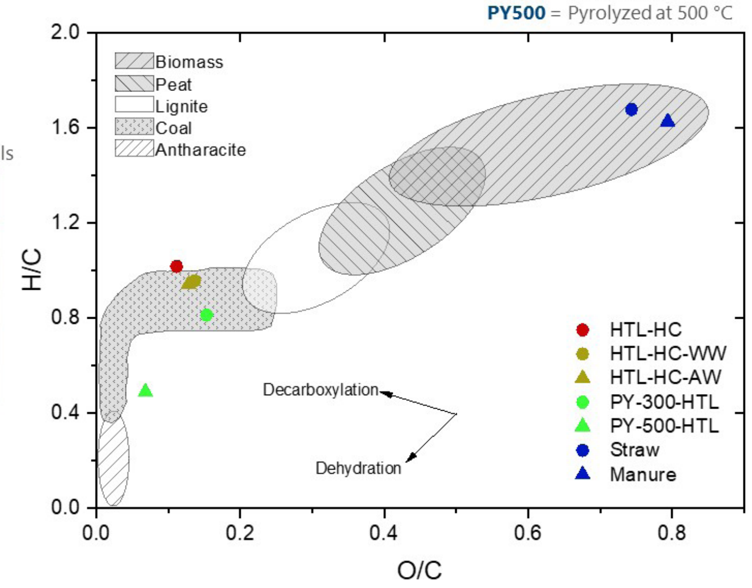
Results – Hydrochar characterization

WW = Water wash
AW = Acid wash
PY300 = Pyrolyzed at 300 °C
PY500 = Pyrolyzed at 500 °C

Table 1: Physicochemical characterization of the materials

Sample	pH	E.C. (mS/cm)	Ash (wt%)
HTL-HC	6.6	3.4	19.7
HTL-HC-WW	6.9	0.9	19.1
HTL-HC-AW	6.5	1.0	16.6
PY-300-HTL	7.4	2.0	21.0
PY-500-HTL	8.4	1.8	27.4

n = 2 ; All analysis standard deviation ≤ 5%



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Results – Hydrochar characterization

Table 2: ICP-OES characterization of the materials

Sample	Ca	Fe	P	K	Mg	Na	Cr	Ni	Cd	Pb	Hg
			g/kg						mg/kg		
HTL-HC	26.8	2.5	13.8	6.5	11.4	3.8	150.1	72.5	< LOD	< LOD	< LOD
HTL-HC-WW	29.0	2.5	14.8	3.7	13.3	2.4	139.1	74.4	< LOD	< LOD	< LOD
HTL-HC-AW	20.2	2.4	10.5	2.1	12.8	1.3	137.2	64.5	< LOD	< LOD	< LOD
PY-300-HTL	28.5	2.5	14.0	6.4	11.0	4.2	152.3	75.2	< LOD	< LOD	< LOD
PY-500-HTL	36.8	2.9	17.1	6.8	18.5	4.5	173.0	97.9	< LOD	< LOD	< LOD

n = 2 ; All analysis standard deviation ≤ 10%

- Suitable concentration of nutrients for a soil amendment
- Acid washing leached a fraction of HTL-HC nutrients
- Concerning concentration of heavy metals

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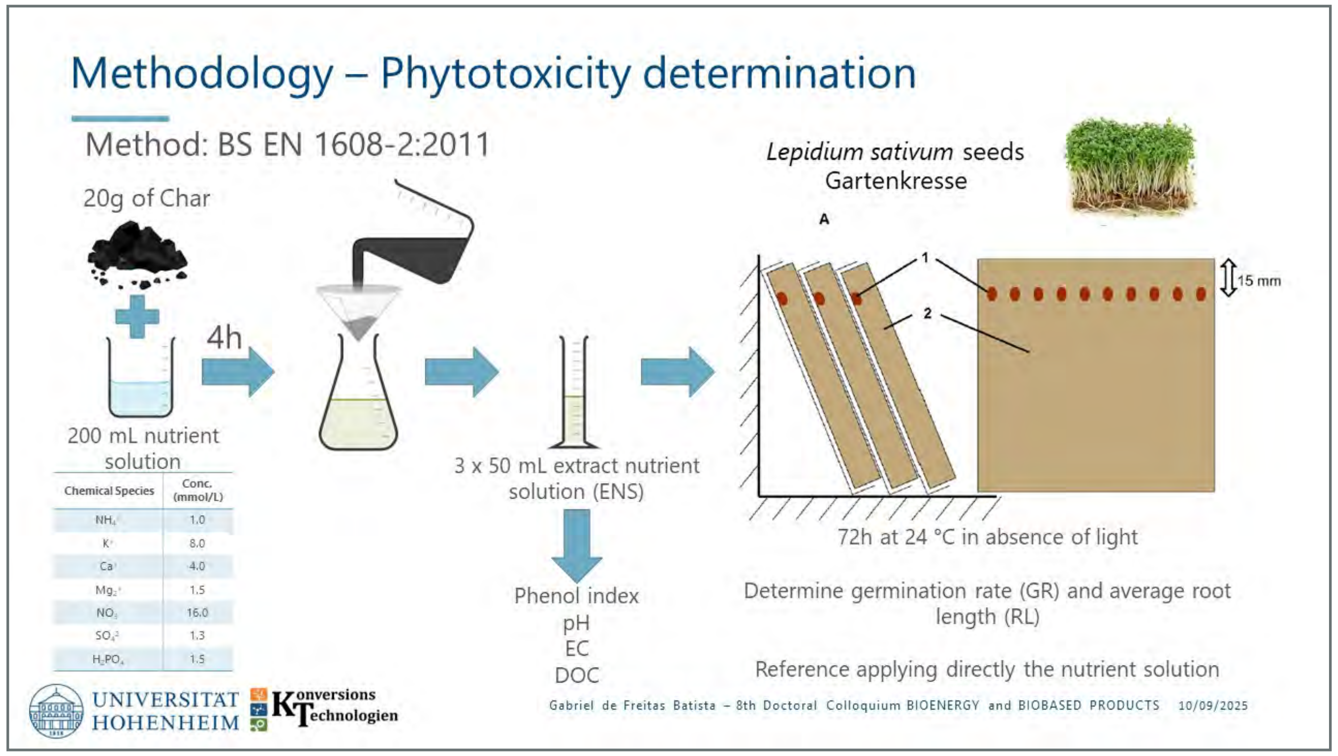
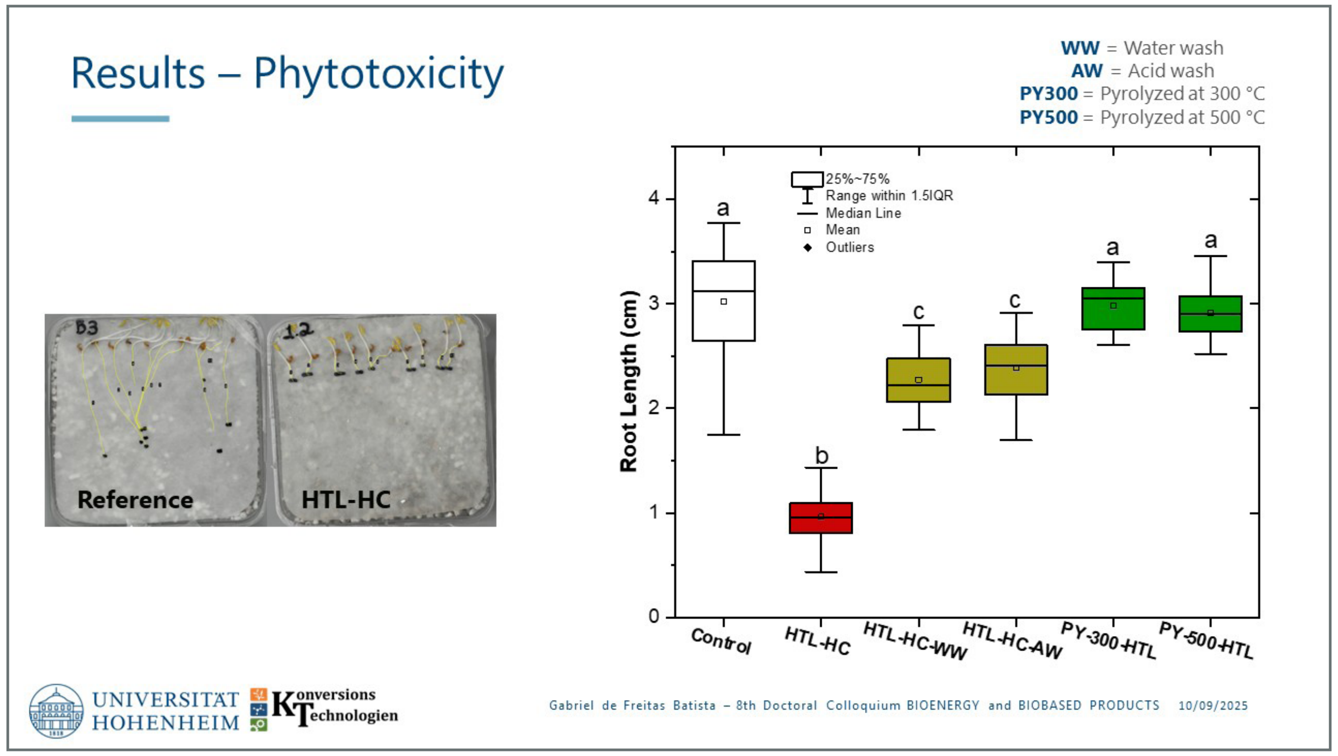
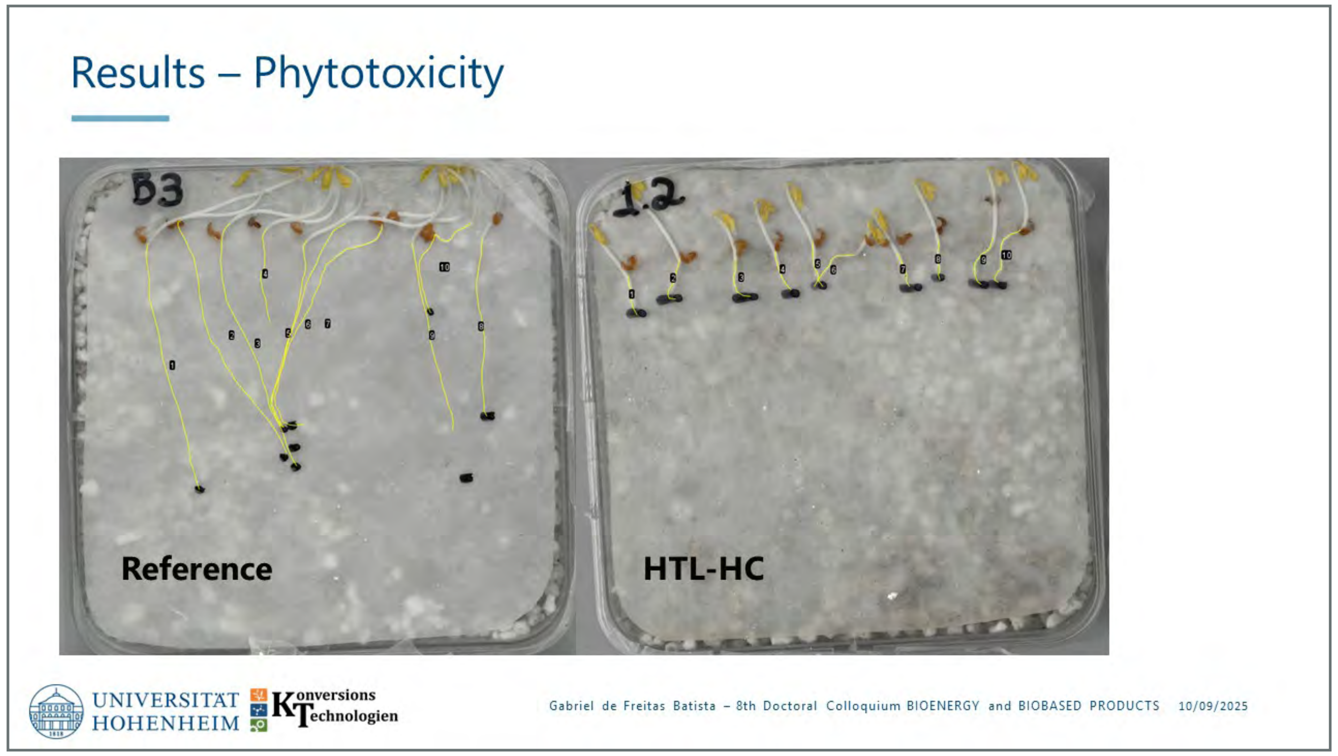
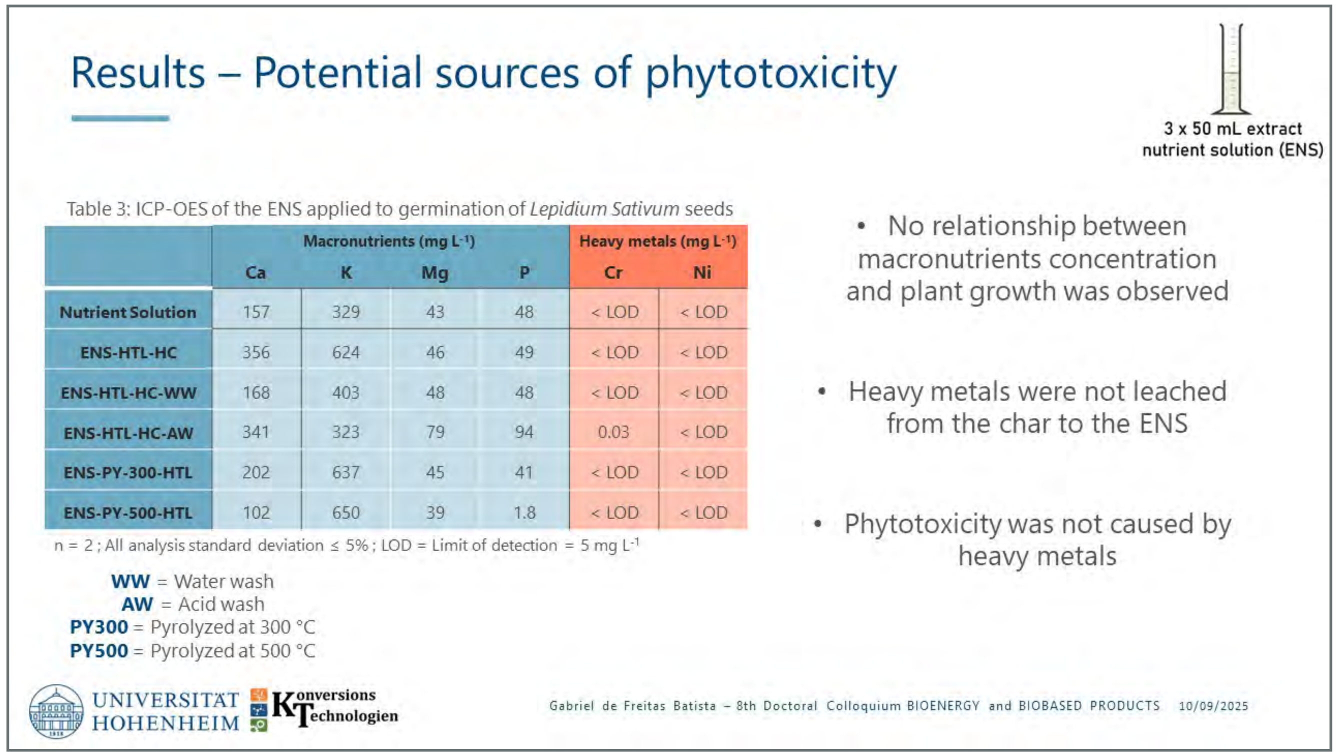


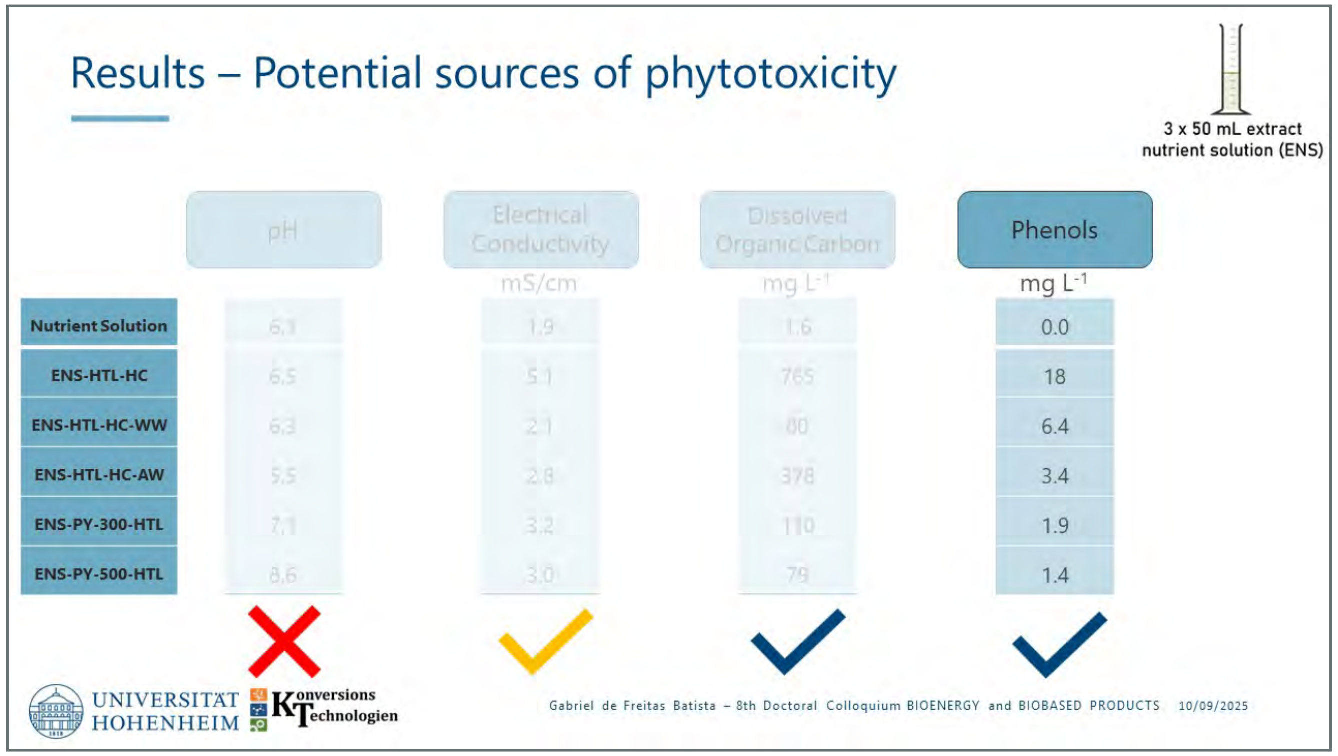
Chemical Species	Conc. (mmol/L)
NH_4^+	1.0
K^+	8.0
Ca^+	4.0
Mg_2^+	1.5
NO_3^-	16.0
SO_4^{2-}	1.3
H_2PO_4	1.5







	Macronutrients ($mg\ L^{-1}$)				Heavy metals ($mg\ L^{-1}$)	
	Ca	K	Mg	P	Cr	Ni
Nutrient Solution	157	329	43	48	< LOD	< LOD
ENS-HTL-HC	356	624	46	49	< LOD	< LOD
ENS-HTL-HC-WW	168	403	48	48	< LOD	< LOD
ENS-HTL-HC-AW	341	323	79	94	0.03	< LOD
ENS-PY-300-HTL	202	637	45	41	< LOD	< LOD
ENS-PY-500-HTL	102	650	39	1.8	< LOD	< LOD


Results – Potential sources of phytotoxicity
3 x 50 mL extract
nutrient solution (ENS)
pH
Electrical Conductivity
mS/cm
Dissolved Organic Carbon
mg L-1
Phenols
mg L-1
Nutrient Solution 6.1 1.9 1.6 0.0
ENS-HTL-HC 6.5 5.1 765 18
ENS-HTL-HC-WW 6.3 2.1 80 6.4
ENS-HTL-HC-AW 5.5 2.8 378 3.4
ENS-PY-300-HTL 7.1 3.2 110 1.9
ENS-PY-500-HTL 8.6 3.0 79 1.4
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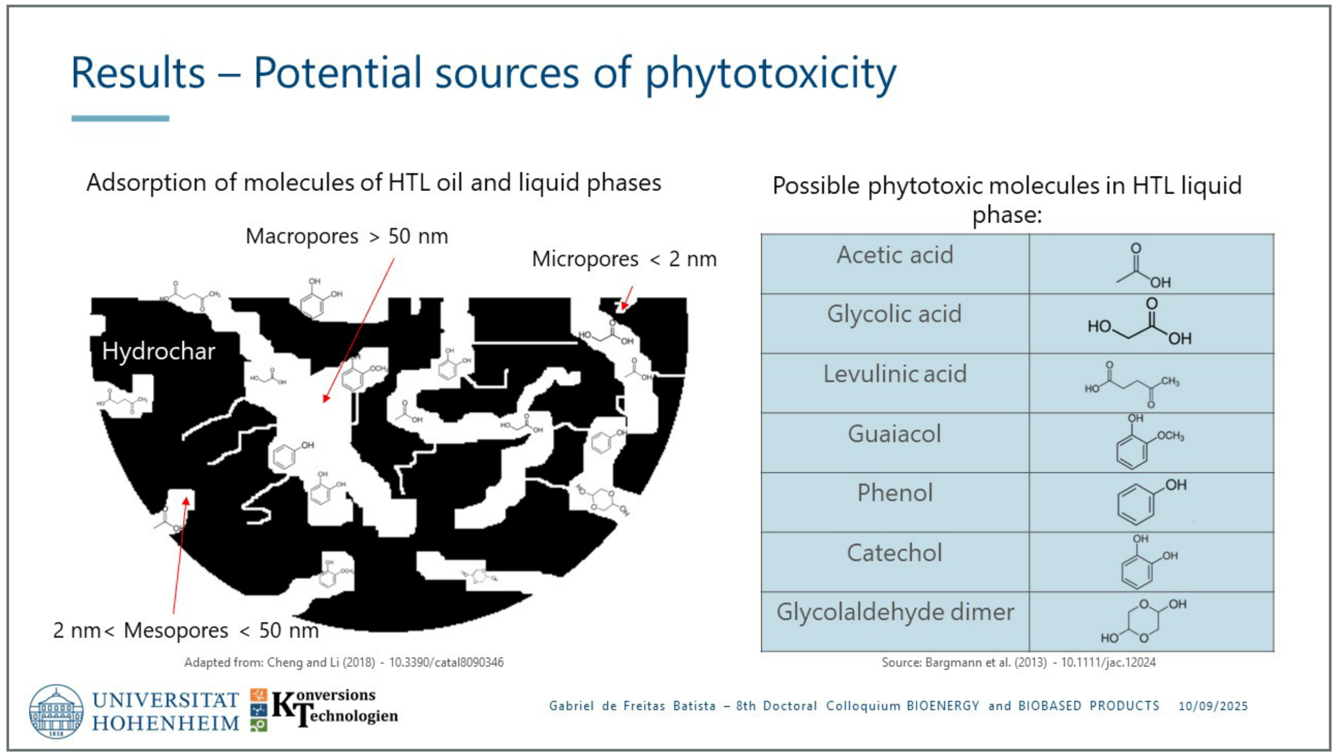
Results – Potential sources of phytotoxicity
Adsorption of molecules of HTL oil and liquid phases
Macropores > 50 nm
Micropores < 2 nm
Hydrochar
2 nm< Mesopores < 50 nm
Adapted from: Cheng and Li (2018) - 10.3390/catal8090346
Possible phytotoxic molecules in HTL liquid phase:
Acetic acid
Glycolic acid
Levulinic acid
Guaiacol
Phenol
Catechol
Glycolaldehyde dimer
Source: Bargmann et al. (2013) - 10.1111/jac.12024
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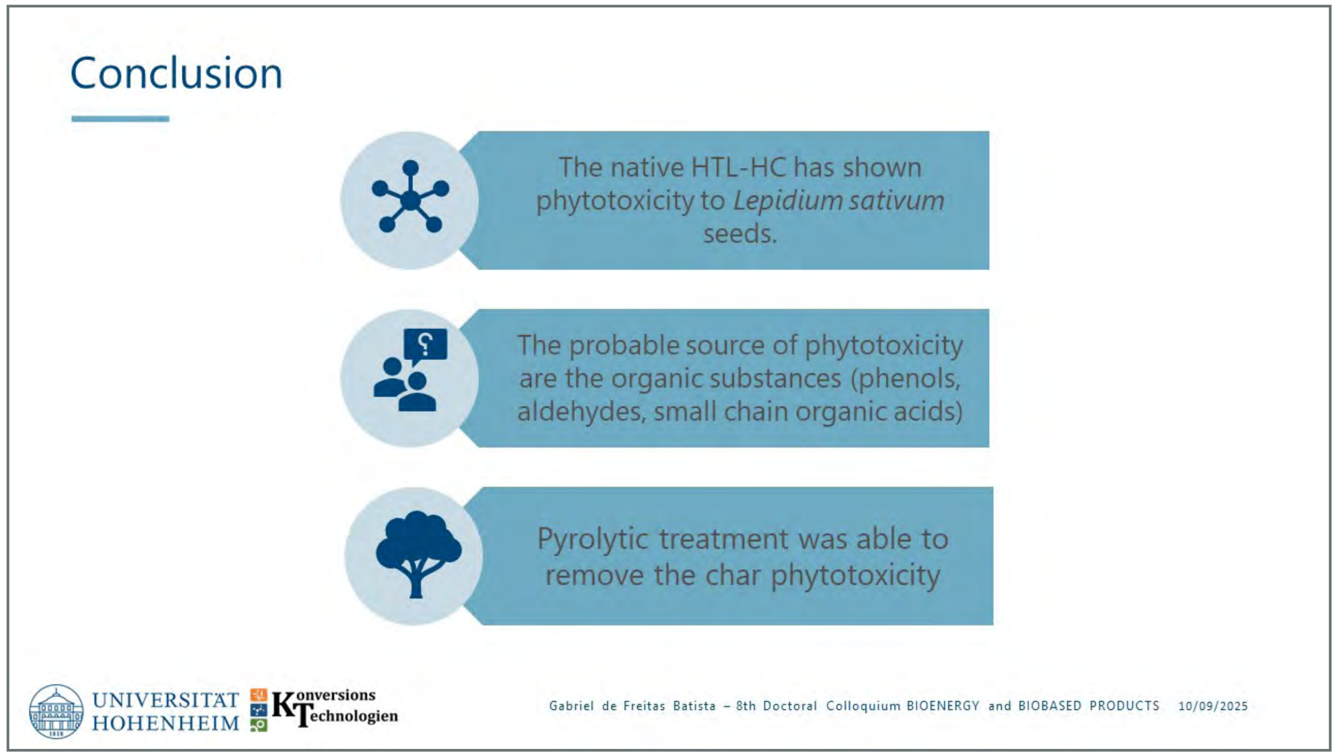
Conclusion
The native HTL-HC has shown phytotoxicity to Lepidium sativum seeds.
The probable source of phytotoxicity are the organic substances (phenols, aldehydes, small chain organic acids)
Pyrolytic treatment was able to remove the char phytotoxicity
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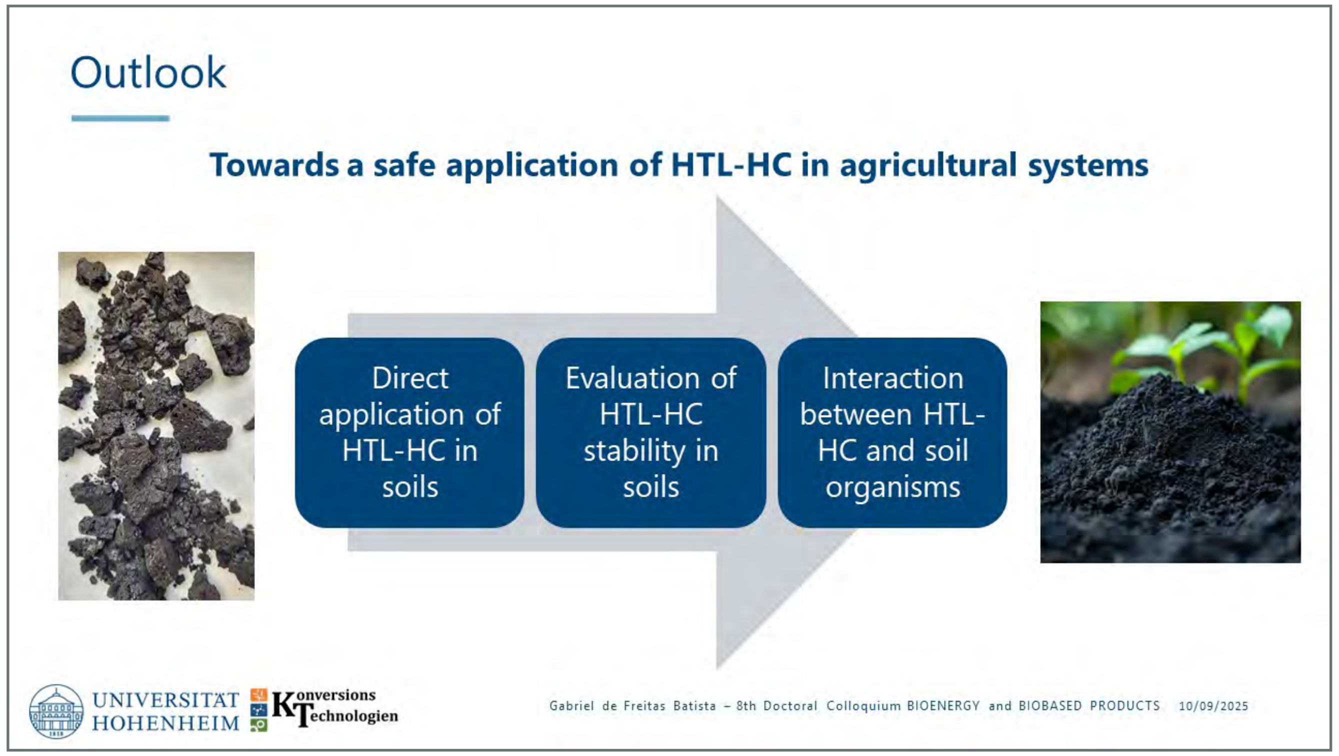
Outlook
Towards a safe application of HTL-HC in agricultural systems
Direct application of HTL-HC in soils
Evaluation of HTL-HC stability in soils
Interaction between HTL-HC and soil organisms
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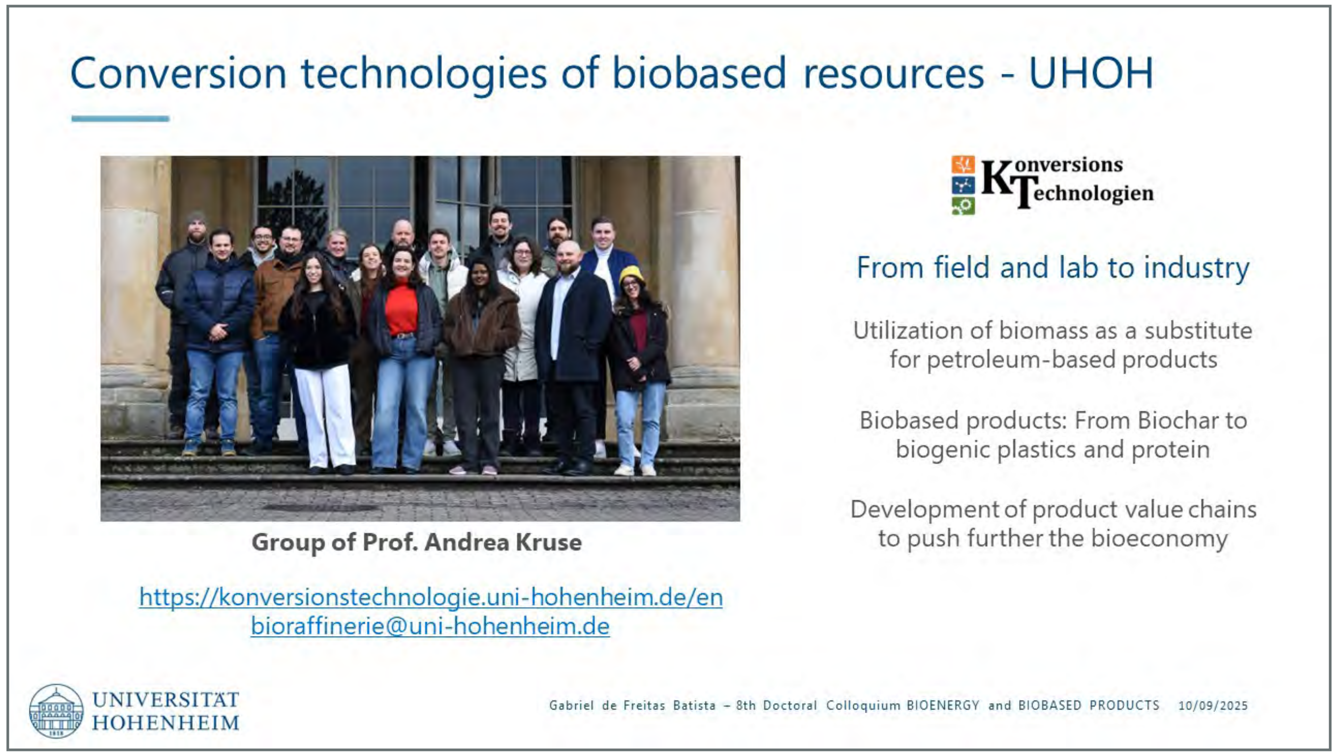

8TH DOCTORAL COLLOQUIUM BIOENERGY AND BIOBASED PRODUCTS

Rafiandy Dwi Putra, Deutsches Biomasseforschungszentrum

Reduction Behavior of Carbon Composite Agglomerates (CCA) with Hydrogen: A Thermodynamic Study

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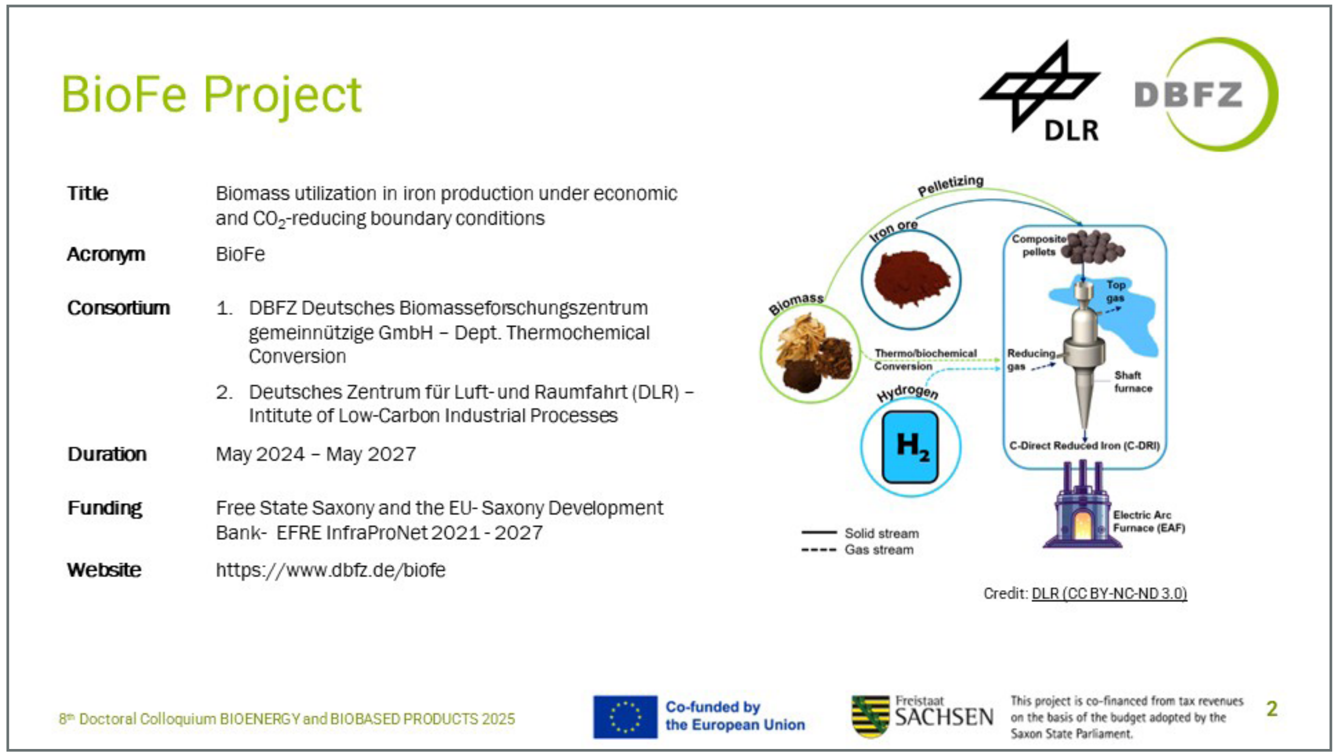
Keywords: Direct reduction, biochar, thermodynamic, Factsage

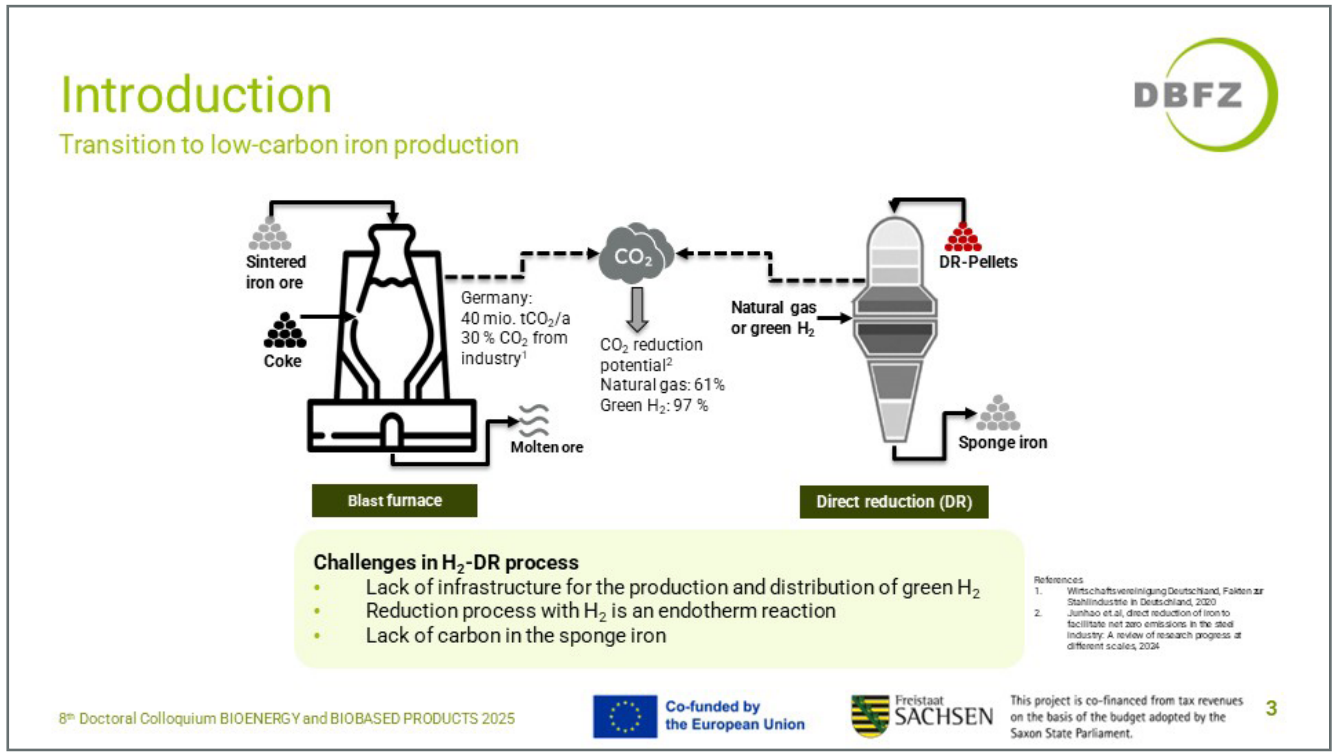
The steelmaking industry stands as a substantial contributor to total CO_2 emissions within the European Union (EU), accounting for approximately 5 % of the total. To mitigate the environmental impacts of the steelmaking process, hydrogen-based direct reduction-electric arc furnace (DR-EAF) route is widely regarded as one of the most promising pathways for decarbonizing steelmaking process. Despite its huge emission reduction potential, the widespread industrial application of the DR-EAF route still faces some challenges. At the moment, the infrastructure for the production and distribution of green hydrogen remains underdeveloped. Given these challenges, the use of biochar from biogenic residues as reductants in the iron reduction process becomes more relevant. In addition, biochar can be used as a carbon carrier that enables the slag foaming process in EAF, which is crucial for improving the energy efficiency of the furnace.

In this context, this study investigates the reduction behaviour carbon composite agglomerates (CCA), composed of iron ore and biochar, under various operating temperatures and reducing gases using thermodynamic analysis.

A comprehensive equilibrium analysis was carried out using Factsage 8.2, employing the Equilib module in combination with the, FToxid, FTmisc, and FactPS databases. The thermodynamic analysis is based on minimizing the total Gibbs energy of the system to predict the chemical reactions that occur in the system and the products that are formed. The system was modelled as a multi-phase, consisting Fe2O3 (hematite), biochar (carbon and mineral elements), and a mixture of gaseous species (CO, CO_2, H_2, H_2O, and N_2). The model incorporates solid-solid and gas-solid reactions involving several key species, such as Fe2O3, Fe3O4, FeO, Fe, C, CO, CO_2, H_2, H_2O and N_2. Input parameters included varying Fe/C mass ratios, temperatures ranging between 600 °C and 1200 °C and a fixed atmospheric pressure of 1 atm. Equilibrium states were calculated for each process conditions and the amounts of species were analysed to determine reduction degree, residual carbon content, and gaseous emissions.

The simulation is expected to identify thermodynamically favourable operating conditions that achieve high degrees of reduction with excess carbon, which is necessary for further process in EAF. The results of the simulation lay the groundwork for experimental validation and reactor-scale design. The thermodynamic model will support the understanding of hybrid reduction systems that combine biochar with hydrogen or biomass derived syngas.




Introduction
Transition to low-carbon iron production
DBFZ
Sintered iron ore
Coke
Germany: 40 mio. tCO_2/a 30 % CO_2 from industry[1]
CO_2
CO_2 reduction potential[2] Natural gas: 61 % Green H_2: 97 %
Natural gas or green H_2
DR-Pellets
Molten ore
Sponge iron
Blast furnace
Direct reduction (DR)
Challenges in H_2-DR process
Lack of infrastructure for the production and distribution of green H_2
Reduction process with H_2 is an endotherm reaction
Lack of carbon in the sponge iron
8th Doctoral Colloquium BIOENERGY and BIOBASED PRODUCTS 2025
Co-funded by the European Union
Freistaat SACHSEN
This project is co-financed from tax revenues on the basis of the budget adopted by the Saxon State Parliament.
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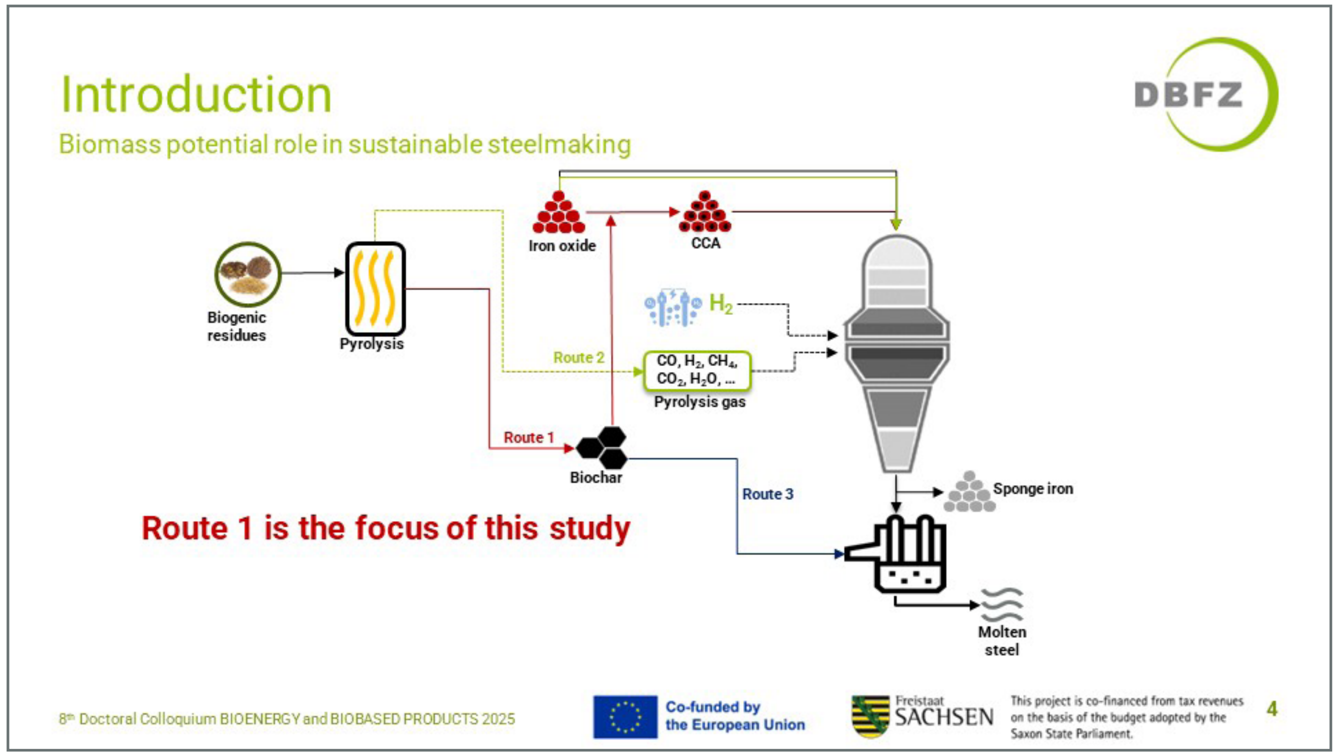
Introduction
Biomass potential role in sustainable steelmaking
DBFZ
Biogenic residues
Pyrolysis
Iron oxide
CCA
H_2
Route 2
CO, H_2, CH_4, CO_2, H_2O, ...
Pyrolysis gas
Route 1
Biochar
Route 3
Sponge iron
Molten steel
Route 1 is the focus of this study
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Co-funded by the European Union
Freistaat SACHSEN
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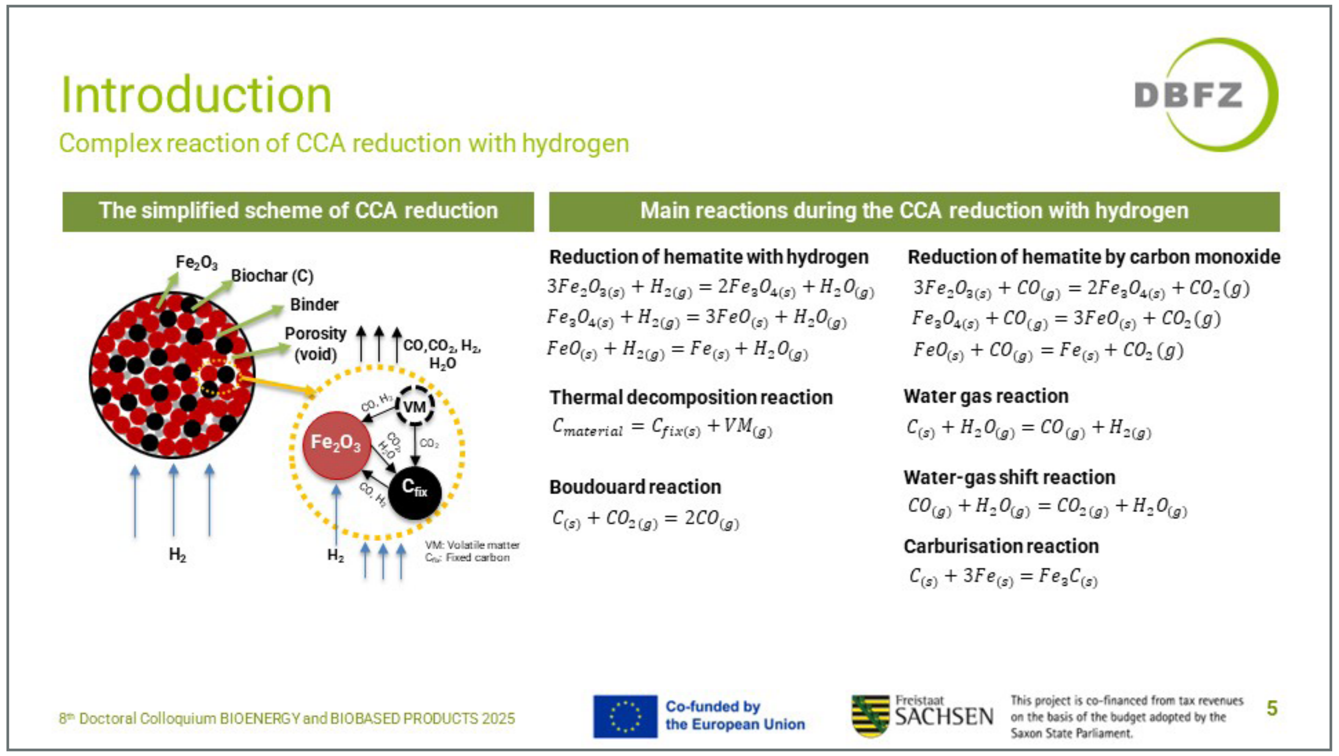
Introduction
Complex reaction of CCA reduction with hydrogen
DBFZ
The simplified scheme of CCA reduction
Fe_2O_3
Biochar (C)
Binder
Porosity (void)
CO, CO_2, H_2, H_2O
VM
Fe_2O_3
C_{fix}
H_2
H_2
VM: Volatile matter
C_{fix}: Fixed carbon
Main reactions during the CCA reduction with hydrogen
Reduction of hematite with hydrogen
$3Fe_2O_{3(s)} + H_{2(g)} = 2Fe_3O_{4(s)} + H_2O_{(g)}$
$Fe_3O_{4(s)} + H_{2(g)} = 3FeO_{(s)} + H_2O_{(g)}$
$FeO_{(s)} + H_{2(g)} = Fe_{(s)} + H_2O_{(g)}$
Reduction of hematite by carbon monoxide
$3Fe_2O_{3(s)} + CO_{(g)} = 2Fe_3O_{4(s)} + CO_2(g)$
$Fe_3O_{4(s)} + CO_{(g)} = 3FeO_{(s)} + CO_2(g)$
$FeO_{(s)} + CO_{(g)} = Fe_{(s)} + CO_2(g)$
Thermal decomposition reaction
$C_{material} = C_{fix(s)} + VM_{(g)}$
Water gas reaction
$C_{(s)} + H_2O_{(g)} = CO_{(g)} + H_{2(g)}$
Boudouard reaction
$C_{(s)} + CO_{2(g)} = 2CO_{(g)}$
Water-gas shift reaction
$CO_{(g)} + H_2O_{(g)} = CO_{2(g)} + H_{2(g)}$
Carburisation reaction
$C_{(s)} + 3Fe_{(s)} = Fe_3C_{(s)}$
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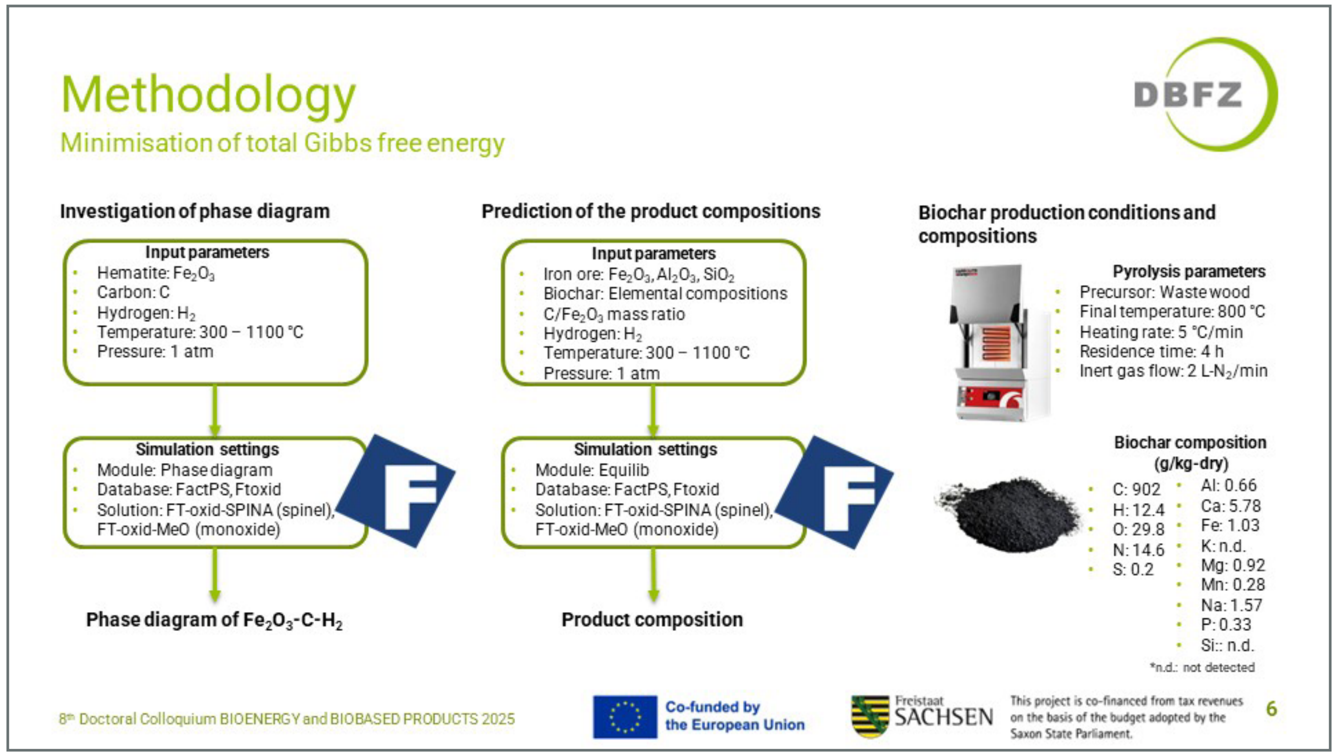
Methodology
Minimisation of total Gibbs free energy
DBFZ
Investigation of phase diagram
Input parameters
Hematite: Fe_2O_3
Carbon: C
Hydrogen: H_2
Temperature: 300 – 1100 °C
Pressure: 1 atm
Simulation settings
Module: Phase diagram
Database: FactPS, Ftoxid
Solution: FT-oxid-SPINA (spinel), FT-oxid-MeO (monoxide)
Phase diagram of Fe_2O_3-C-H_2
Prediction of the product compositions
Input parameters
Iron ore: Fe_2O_3, Al_2O_3, SiO_2
Biochar: Elemental compositions
C/Fe_2O_3 mass ratio
Hydrogen: H_2
Temperature: 300 – 1100 °C
Pressure: 1 atm
Simulation settings
Module: Equilib
Database: FactPS, Ftoxid
Solution: FT-oxid-SPINA (spinel), FT-oxid-MeO (monoxide)
Product composition
Biochar production conditions and compositions
Pyrolysis parameters
Precursor: Waste wood
Final temperature: 800 °C
Heating rate: 5 °C/min
Residence time: 4 h
Inert gas flow: 2 L-N_2/min
Biochar composition (g/kg-dry)
C: 902
H: 12.4
O: 29.8
N: 14.6
S: 0.2
Al: 0.66
Ca: 5.78
Fe: 1.03
K: n.d.
Mg: 0.92
Mn: 0.28
Na: 1.57
P: 0.33
Si:: n.d.
*n.d.: not detected
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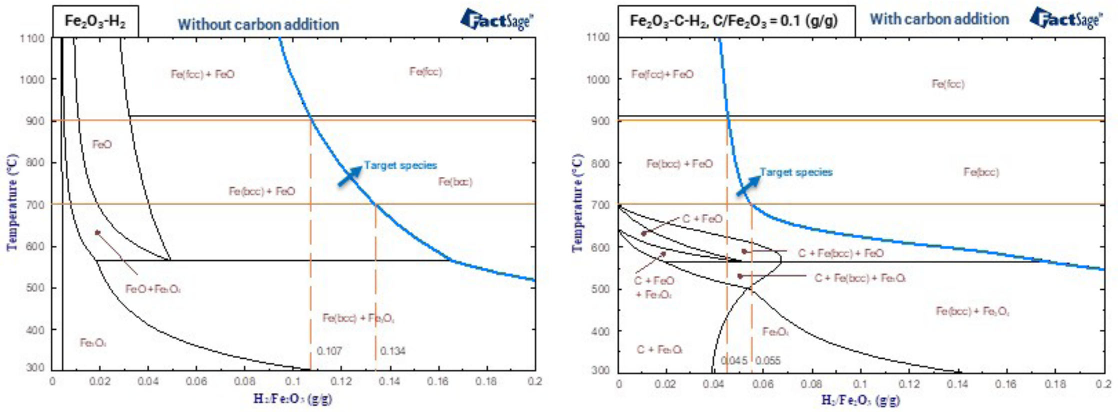
Results

DBFZ

Hydrogen gas demand with carbon addition



- The introduction of biochar causes the Fe-line to shift to the left, suggesting that less H_2 is necessary to fully convert iron oxide to metallic iron.
- At 700 °C, an H_2/Fe_2O_3 ratio of 0.134 is required for the complete conversion to metallic Fe. The addition of 10 % carbon to CCA reduces the required H_2/Fe_2O_3 ratio to 0.055, equivalent to a reduction of around 59 %. At 900, the H_2-reduction is 58 %.

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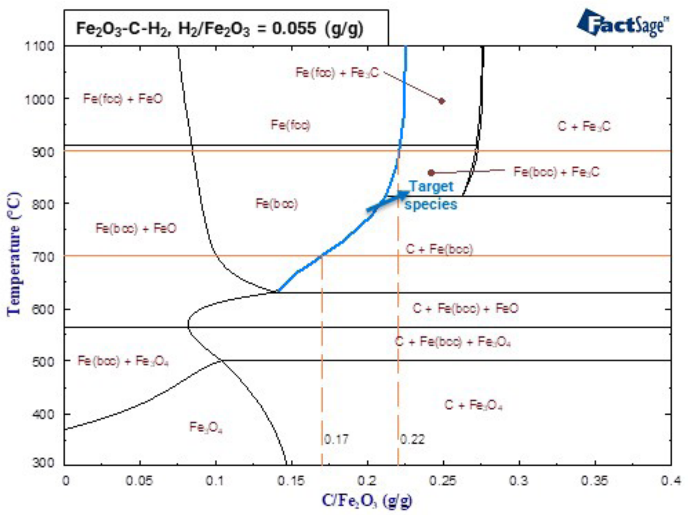
Results

DBFZ

Carbon deposition in the product

- CCA can act as a carburising agent
- At 700 °C, a minimum C/Fe_2O_3 ratio of 0.17 g/g is required to deposit carbon in the product. With increasing temperatures. 22 wt.% of carbon is needed to carburize iron at 900 °C.
- The carburisation reaction (Fe → Fe_3C) will only occur, if there is still residual carbon in the solid and at temperatures above 814 °C



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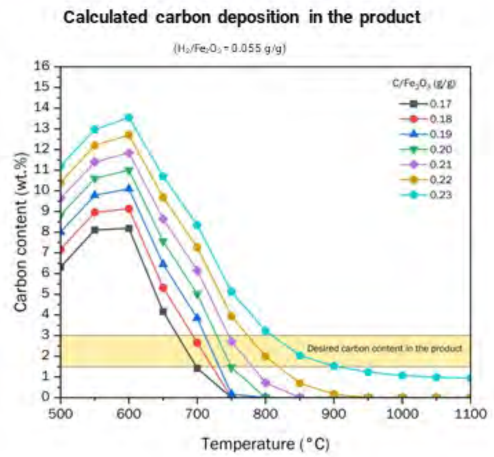
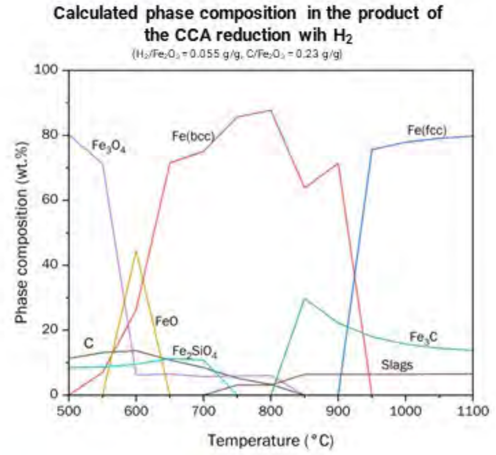
Results

DBFZ

Expected product composition based on the equilibrium calculation





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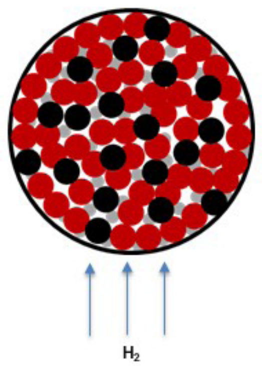
Conclusion

DBFZ

3 A minimum of 22 % of carbon is required to the CCA to ensure carbon deposition in the hydrogen-based direct reduction iron.

4 The combinations of the reduction temperature and biochar-iron ore ratio was determined to produce iron pellets with a desired carbon content



1 Biochar can act as a reducing agent and carbon carrier in the direct reduction process

2 Adding biochar to make CCA can reduce the hydrogen demand for the reduction reaction

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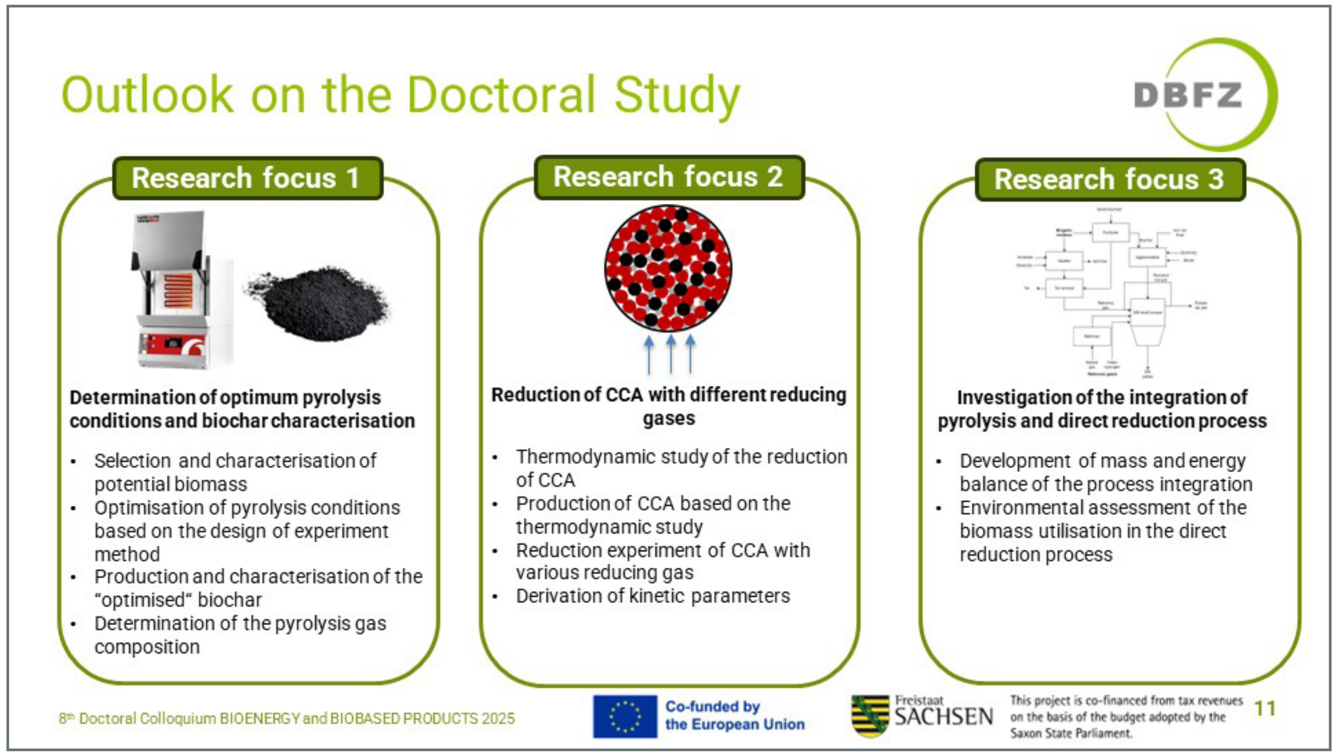
Outlook on the Doctoral Study
DBFZ
Research focus 1
Determination of optimum pyrolysis conditions and biochar characterisation
• Selection and characterisation of potential biomass
• Optimisation of pyrolysis conditions based on the design of experiment method
• Production and characterisation of the "optimised" biochar
• Determination of the pyrolysis gas composition
Research focus 2
Reduction of CCA with different reducing gases
• Thermodynamic study of the reduction of CCA
• Production of CCA based on the thermodynamic study
• Reduction experiment of CCA with various reducing gas
• Derivation of kinetic parameters
Research focus 3
Investigation of the integration of pyrolysis and direct reduction process
• Development of mass and energy balance of the process integration
• Environmental assessment of the biomass utilisation in the direct reduction process
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11


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Smart Bioenergy – Innovations for a sustainable future
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SESSION
BIOENERGY SYSTEMS ANALYSIS

Fatou Balleh Jobe, University of Rostock

Quantitative Assessment of CO_2 Emissions and the Potential for Carbon Capture, Storage, and Utilization in Biogas Plants of Mecklenburg-Vorpommern and Denmark

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Keywords: Net-zero emissions, BECCS, Technological readiness

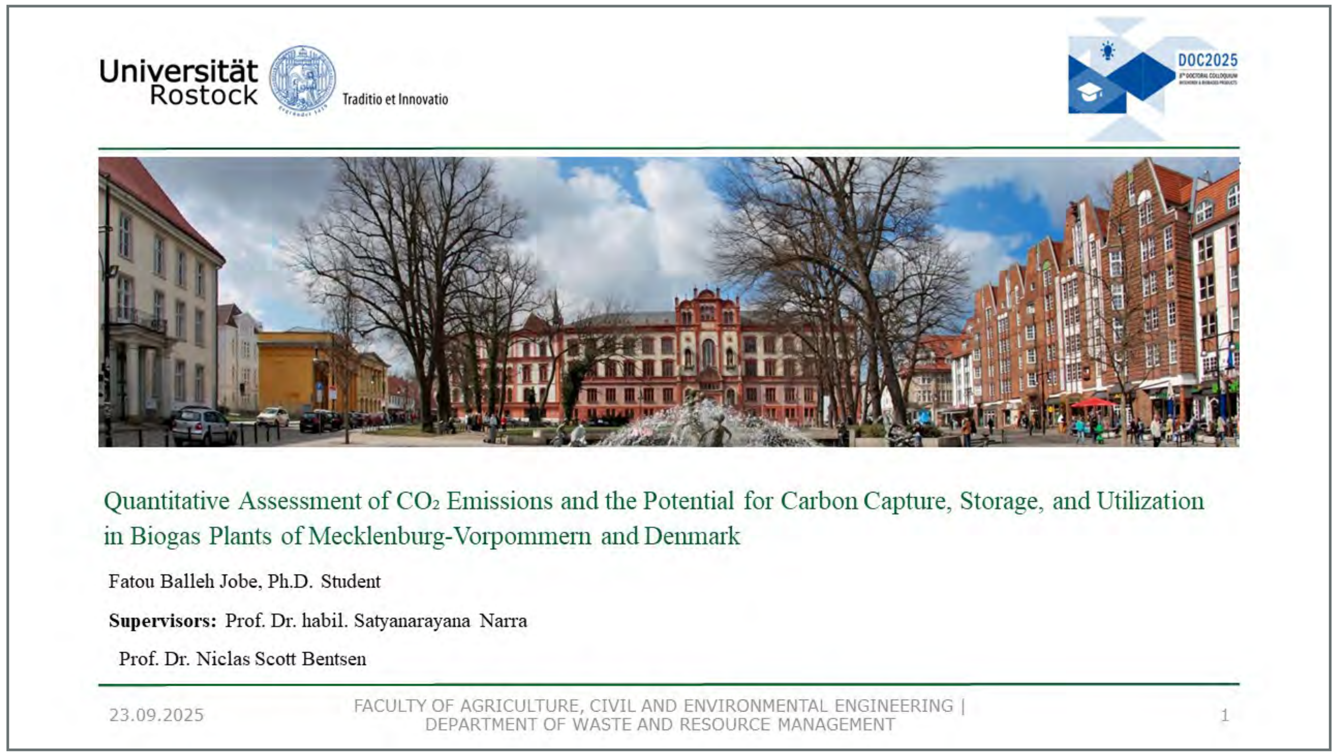
Bioenergy generation is a widely adopted approach that is considered to be carbon-neutral. Even though it is neutral, the CO_2 released from biomass-generated energy contributes to the same atmospheric effects as CO_2 obtained from fossil fuels. Bioenergy with Carbon Capture and Storage (BECCS) is a decarbonization tool for mitigating climate change.

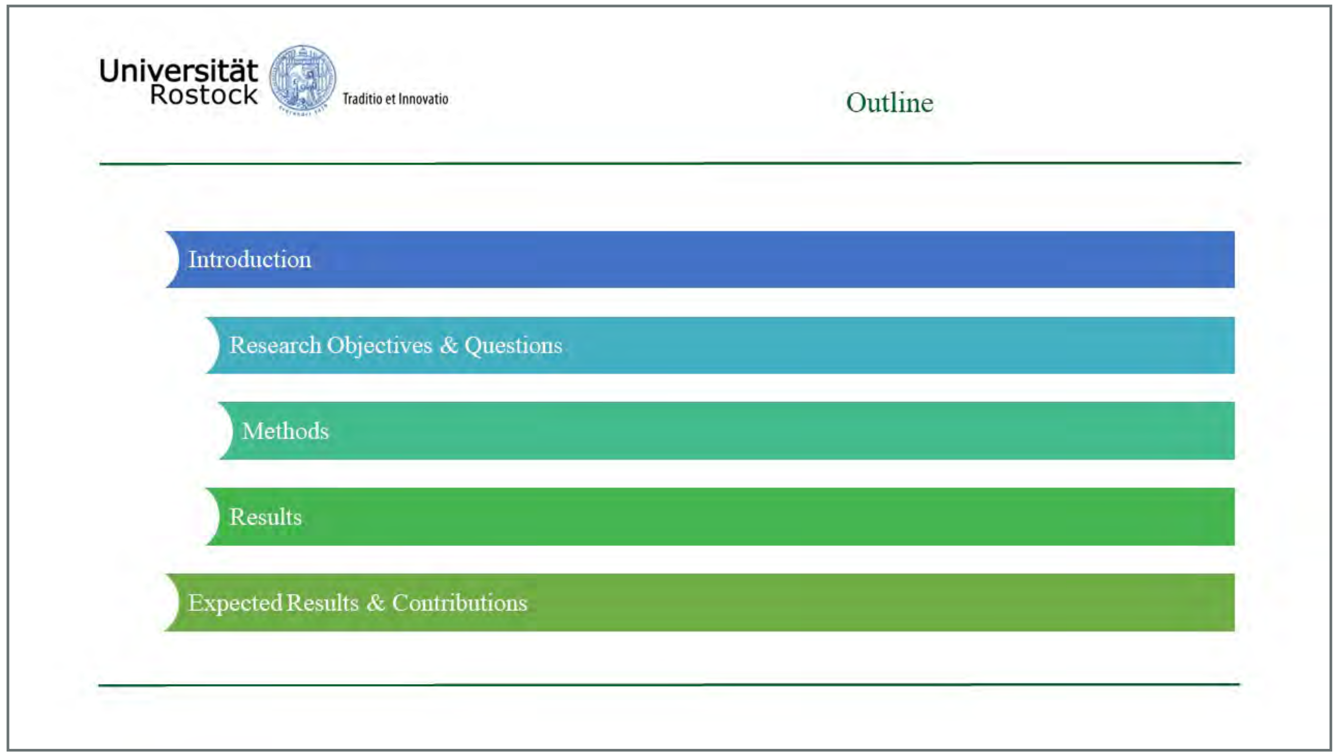
This advanced technology involves capturing, transporting, and storing the resulting CO_2 produced from any energy pathway derived from a biogenic source such as biofuels, electricity, heat, or hydrogen. Carbon capture technologies used in bioenergy include absorption, adsorption, membrane separation, chemical looping, cryogenic distillation, and hydrate-based separation. These carbon capture and storage (CCS) technologies are being modified to fit into bioenergy technologies making up BECCS technologies. Based on the literature BECCS technologies being investigated comprise woody biomass combustion, fermentation, gasification, biogas upgrading, municipal solid waste combustion or landfill gas combustion with CCS, and algae-based BECCS through thermochemical processes.

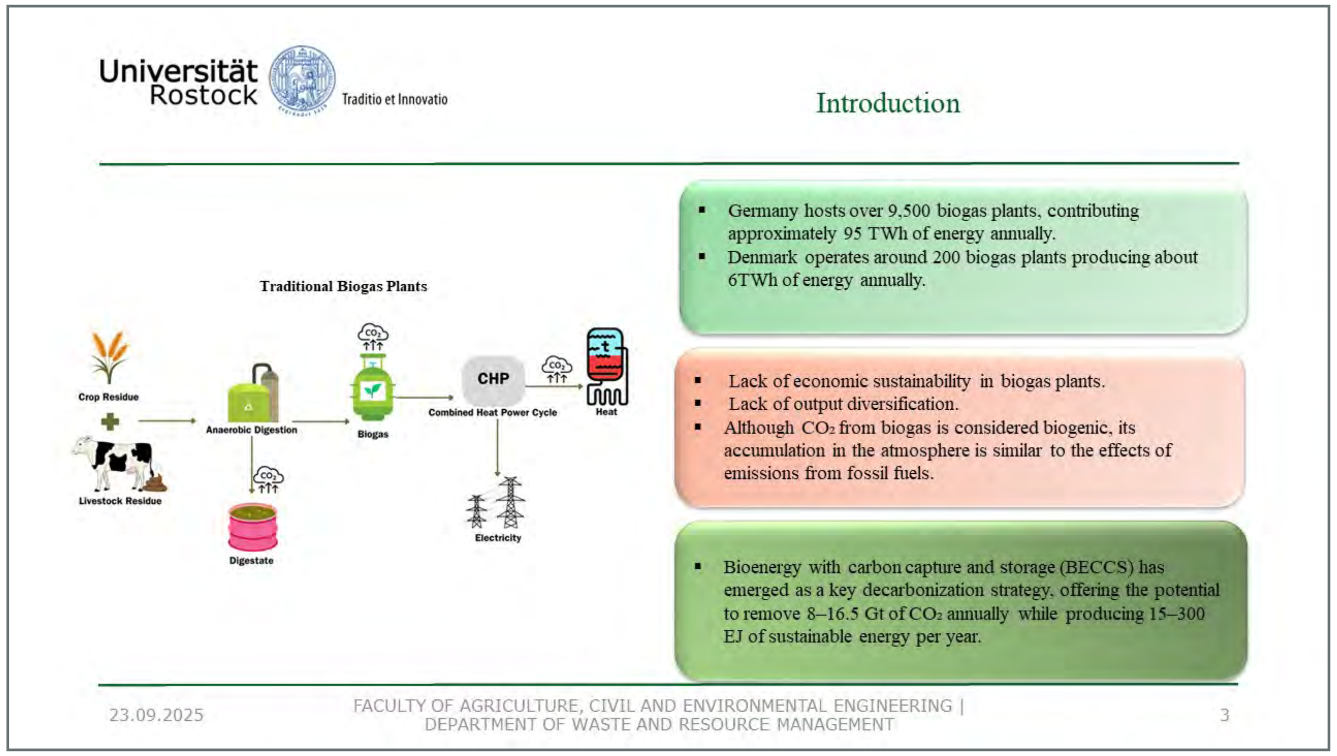
According to the International Energy Agency, the current rate of biogenic CO_2 capture is about 2 million tonnes per year. Based on these 60 million tonnes of CO_2 is estimated to be captured annually by 2030. While the 2050 net-zero scenario requires capturing approximately 185 million tonnes of CO_2 per year, implying that more BECCS projects must be implemented. Although BECCS is currently more prevalent in bio-ethanol/methanol production its usage in other forms of biofuels and electricity generation is gradually increasing.

The potential to capture and sequester carbon from bioenergy generated from the organic fraction of municipal solid waste and agricultural residue is lower than the amount required to achieve the net-zero scenario. Meeting this target puts pressure on the utilization of first, second, and third-generation biomass leading to environmental sustainability and economic concerns. These challenges include sustainable biomass, land use change, soil erosion, biodiversity loss, and water use. Some literatures highlight economic challenges such as price increases on agricultural commodities through competition for land.

From a technological perspective, low energy efficiency due to the high energy consumption of BECCS technologies is also a major challenge. To mitigate these challenges various possible solutions have been proposed such as the use of vertical farming as a possible solution to mitigate land use challenges.



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Introduction
Traditional Biogas Plants
Crop Residue
Livestock Residue
Anaerobic Digestion
Digestate
Biogas
CHP
Combined Heat Power Cycle
Heat
Electricity
▪ Germany hosts over 9,500 biogas plants, contributing approximately 95 TWh of energy annually.
▪ Denmark operates around 200 biogas plants producing about 6TWh of energy annually.
▪ Lack of economic sustainability in biogas plants.
▪ Lack of output diversification.
▪ Although CO_2 from biogas is considered biogenic, its accumulation in the atmosphere is similar to the effects of emissions from fossil fuels.
▪ Bioenergy with carbon capture and storage (BECCS) has emerged as a key decarbonization strategy, offering the potential to remove 8–16.5 Gt of CO_2 annually while producing 15–300 EJ of sustainable energy per year.
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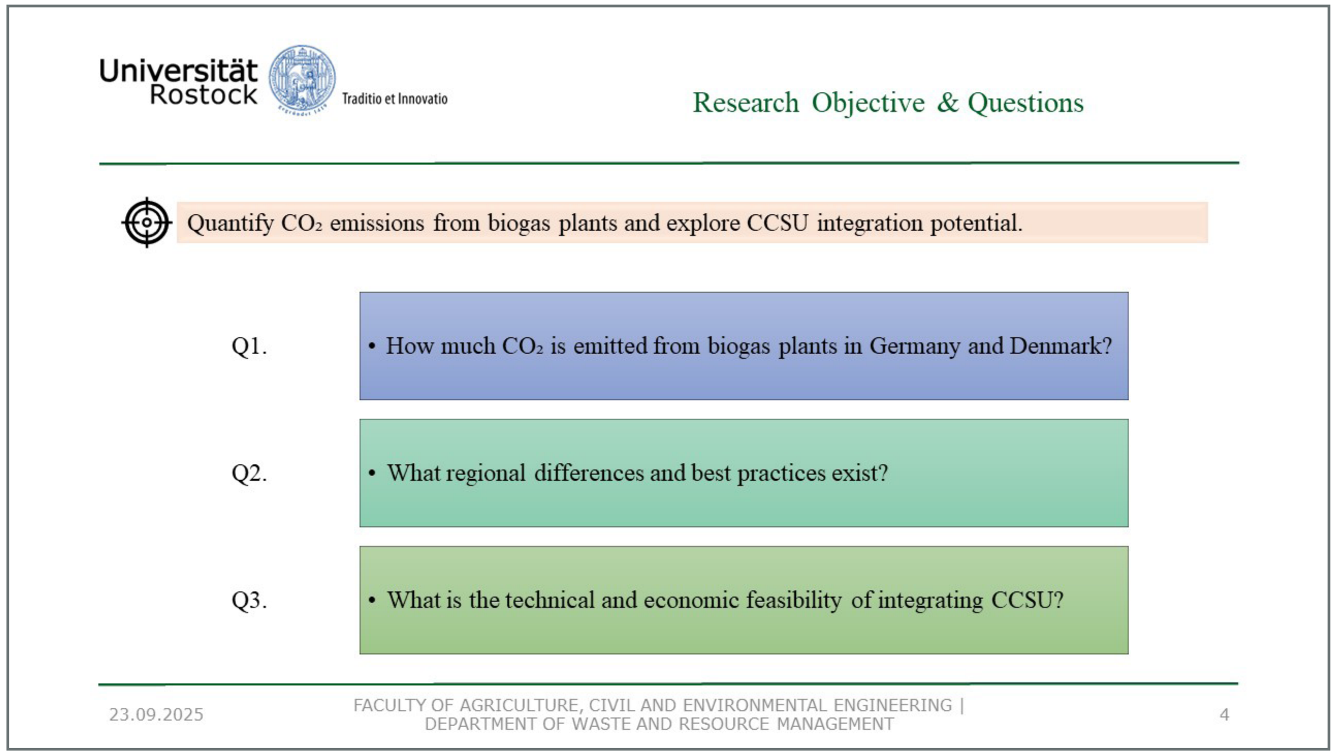
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Research Objective & Questions
Quantify CO_2 emissions from biogas plants and explore CCSU integration potential.
Q1. • How much CO_2 is emitted from biogas plants in Germany and Denmark?
Q2. • What regional differences and best practices exist?
Q3. • What is the technical and economic feasibility of integrating CCSU?
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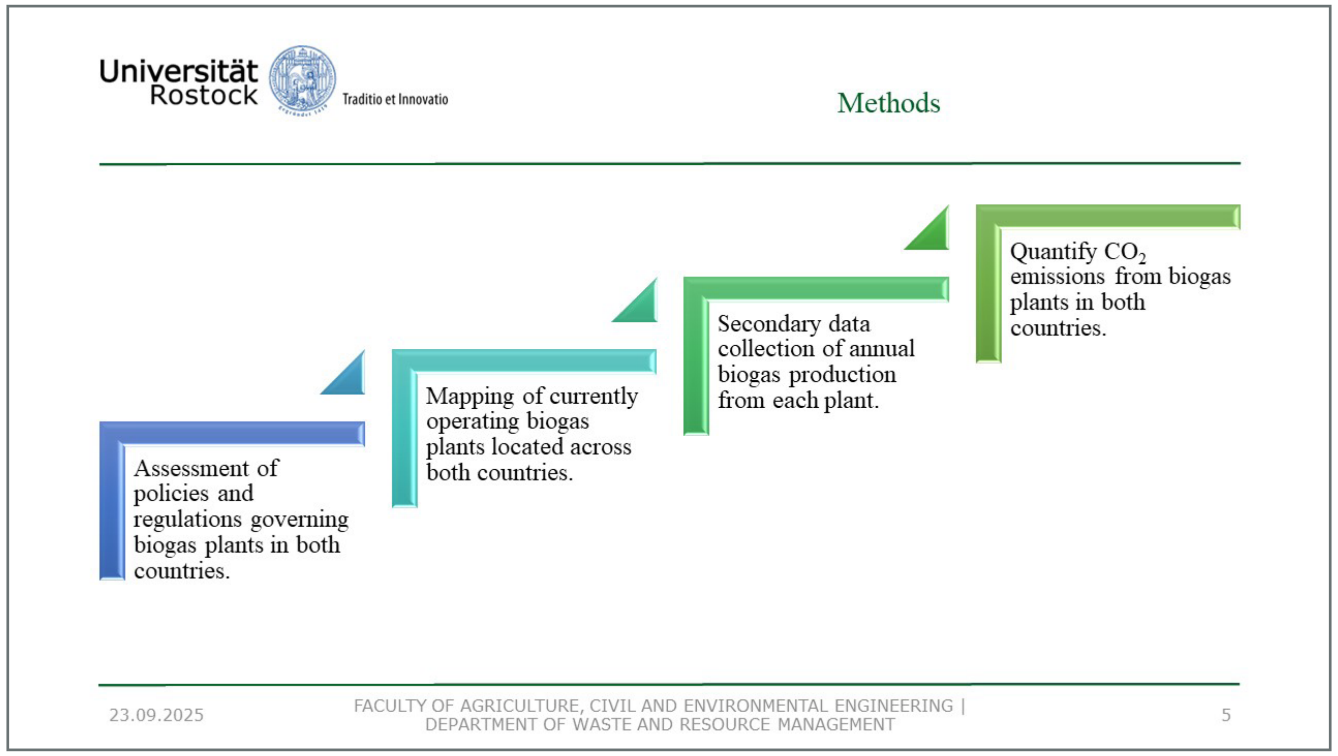
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Methods
Assessment of policies and regulations governing biogas plants in both countries.
Mapping of currently operating biogas plants located across both countries.
Secondary data collection of annual biogas production from each plant.
Quantify CO_2 emissions from biogas plants in both countries.
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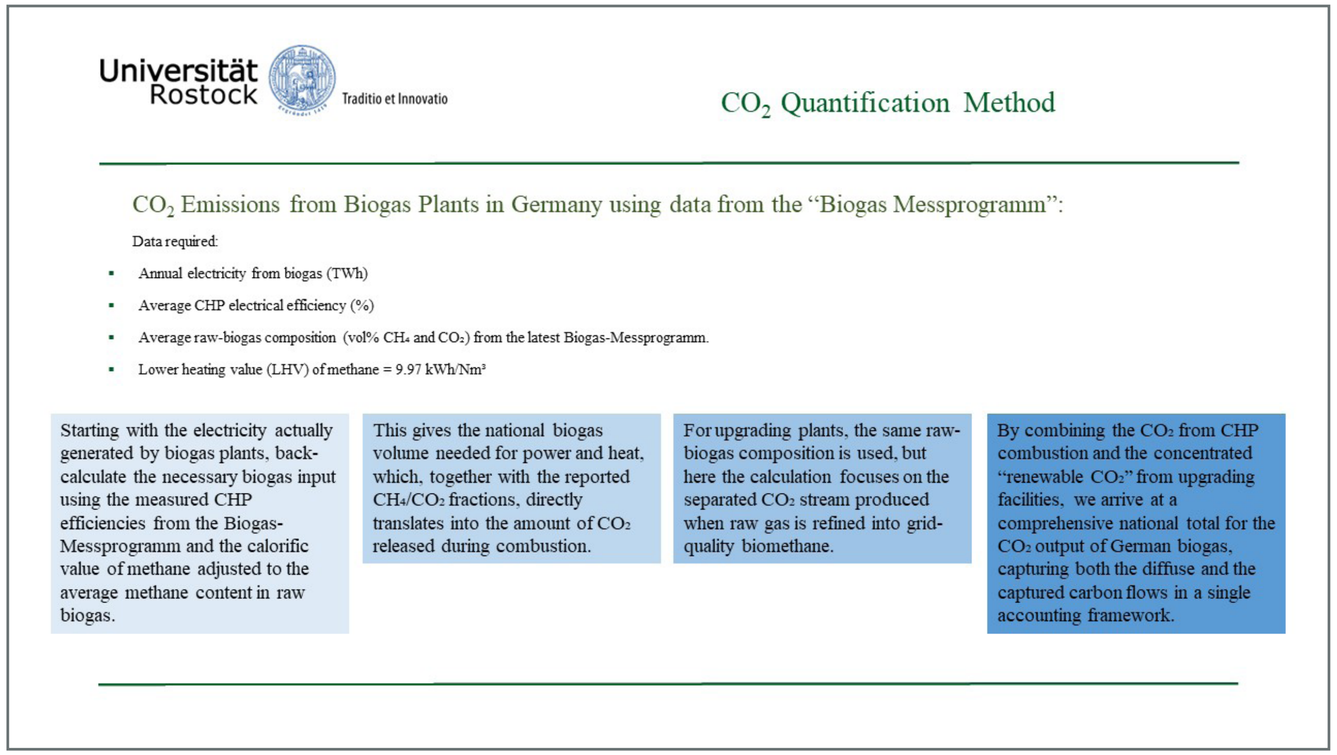
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CO_2 Quantification Method
CO_2 Emissions from Biogas Plants in Germany using data from the "Biogas Messprogramm":
Data required:
• Annual electricity from biogas (TWh)
• Average CHP electrical efficiency (%)
• Average raw-biogas composition (vol% CH_4 and CO_2) from the latest Biogas-Messprogramm.
• Lower heating value (LHV) of methane = 9.97 kWh/Nm³
Starting with the electricity actually generated by biogas plants, back-calculate the necessary biogas input using the measured CHP efficiencies from the Biogas-Messprogramm and the calorific value of methane adjusted to the average methane content in raw biogas.
This gives the national biogas volume needed for power and heat, which, together with the reported CH_4/CO_2 fractions, directly translates into the amount of CO_2 released during combustion.
For upgrading plants, the same raw-biogas composition is used, but here the calculation focuses on the separated CO_2 stream produced when raw gas is refined into grid-quality biomethane.
By combining the CO_2 from CHP combustion and the concentrated "renewable CO_2" from upgrading facilities, we arrive at a comprehensive national total for the CO_2 output of German biogas, capturing both the diffuse and the captured carbon flows in a single accounting framework.

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Germany vs Denmark Policies

Germany	Denmark
The EEG, in place since 2000, originally offered feed-in tariffs (FITs) (20-year contracts, guaranteed grid priority) to incentivize biogas electricity generation.	Biogas injected into the grid or used for CHP receives a feed-in subsidy.
Subsidies shift from long-term operations toward one-time investment grants.	High share of manure feedstock is required for support eligibility.
The BioSt-NachV (sustainability ordinance) requires larger biogas plants (≥ 2 MW thermal) to meet sustainability criteria under the Renewable Energy Directive	Methane leakage inspections are mandatory.
	Denmark has one of Europe's highest CO_2 taxes by 2030, making biogas financially attractive compared to fossil gas.

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Germany vs Denmark Biogas Plants

Germany	Denmark
Has approximately 9,500 plants of which majority are small to medium farm scale that are typically decentralized.	Has approximately 200 plants that are on a larger scale and centralized.
Uses more of crop residues, such as maize, with a mixture of animal manure.	Has strict regulations on the use of energy crops and prefers the use of livestock manure with organic industrial or household waste.
The majority of plants are for electricity generation via CHP, with fewer focusing on upgrading.	Main priority of their plants focus on biomethane upgrading and injection into the natural gas grid, whiles electricity generation plays a secondary role.
Its environmental integration focuses more on energy security.	Its environmental integration focuses on the circular economy and manure management.

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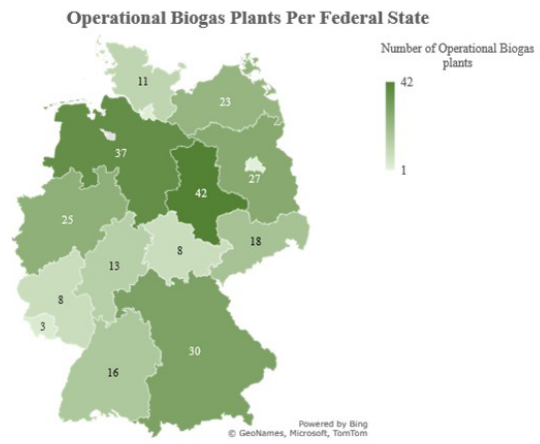
Results

Operational Upgrading Biogas Plants in Germany by the Federal State

German Federal States	Number of Operational Biogas plants
Baden-Württemberg	16
Bayern	30
Berlin	1
Brandenburg	27
Hamburg	2
Hessen	13
Mecklenburg-Vorpommern	23
Niedersachsen	37
Nordrhein-Westfalen	25
Rheinland-Pfalz	8
Saarland	3
Sachsen	18
Sachsen-Anhalt	42
Schleswig-Holstein	11
Thüringen	**8**

https://www.marktstammdatenregister.de/MaStR/Einheit/Einheiten/OeffentlicheEinheitenuebersicht#gaserzeugung Accessed on 05.08.2025



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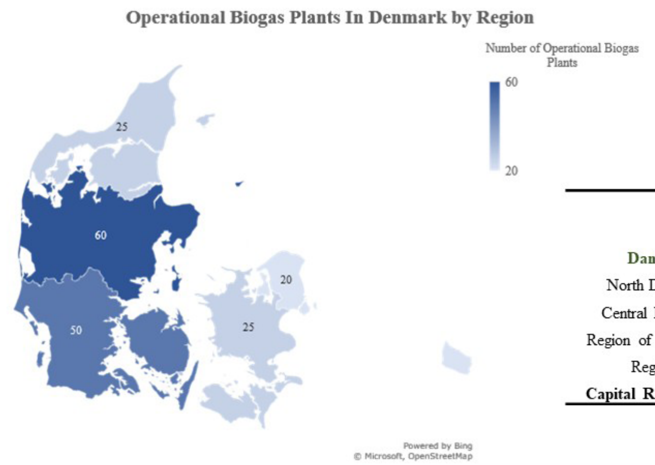
Results



Operational Biogas Plants in Denmark by Region

Danish Regions	Number of Operational Biogas Plants	References
North Denmark Region	25	[1], [2], [3]
Central Denmark Region	60	[1], [2], [3]
Region of Southern Denmark	50	[1], [2], [3]
Region Zealand	25	[1], [2], [3]
Capital Region of Denmark	20	**[1], [2], [3]**

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Results

Total Biogas Production and CO_2 Emission Estimates		
Country	**Total Biogas Production (energy)**	**Total CO_2 Emissions**
Germany 2022	81 TWh/yr	28 Mt CO_2/yr
Denmark 2023	8.8 TWh/yr	1.25 Mt CO_2/yr

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Expected Results & Contributions

1. Collect plant-specific data on biogas production, feedstock types, byproducts, and usage of all outputs.
2. Quantification of plant-specific emissions from both countries.
3. Comparison of calculations from secondary data with data collected from a selected biogas plant as a case study.
4. Assess the technical and economic feasibility of integrating CCSU.

Submit the article for publication by December 2025.

Use data from this objective to start simulations for the next paper.

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References

1. A. I. Biogas ApS AU-Vindmøller et al., "Landbrug Agri Energy Vrå."
2. "Biogas Outlook 2023 Production and use of biogas in Denmark 2022-2035." [Online]. Available: www.biogas.dk.
3. "biogas_2020_06_eng".
4. Bundesnetzagentur (BNetzA). (n.d.). Core energy market data register (MaStR). https://www.bundesnetzagentur.de/EN/Areas/Energy/CoreEnergyMarketDataRegister/start.html
5. Danish Energy Agency. (2020, June). Biogas in Denmark – Status June 2020. https://biogasclean.com/wp-content/uploads/2021/02/biogas-in-denmark-june-2020.pdf
6. Biogas Denmark. (2023, June 20). Biogas Outlook 2023. https://www.biogas.dk/wp-content/uploads/2023/06/Biogas-Outlook-2023-English-20-June-2023.pdf
7. Danish Energy Agency. (2024). Biogas in Denmark. https://ens.dk/en/energy-sources/biogas-denmark
8. Fachverband Biogas e.V. (2023, September 27). Return to Germany's pace is needed – Stagnation instead of expansion in the German biogas sector. https://www.members.biogas.org/edcom/webfvb.nsf/id/en-return-to-germanys-pace-is-needed--stagnation-instead-of-expansion-in-the-german-biogas-sector
9. M. Fridahl and M. Lehtveer, "Bioenergy with carbon capture and storage (BECCS): Global potential, investment preferences, and deployment barriers," Energy Res Soc Sci, vol. 42, pp. 155–165, 2018, doi: 10.1016/j.erss.2018.03.019.
10. N. S. Bentsen, "Carbon debt and payback time – Lost in the forest?," 2017, Elsevier Ltd. doi: 10.1016/j.rser.2017.02.004.
11. U. Epa, "Greenhouse Gas Reporting Program, Emission Calculation Methodologies." [Online]. Available: http://www.epa.gov/ghgrp
12. M. Gustafsson and J. Ammenberg, "IEA Bioenergy Task 37-A perspective on the state of the biogas industry from selected member countries," 2022.
13. "I. Energy Agency, "Germany 2020 - Energy Policy Review." [Online]. Available: www.iea.org/t&c/

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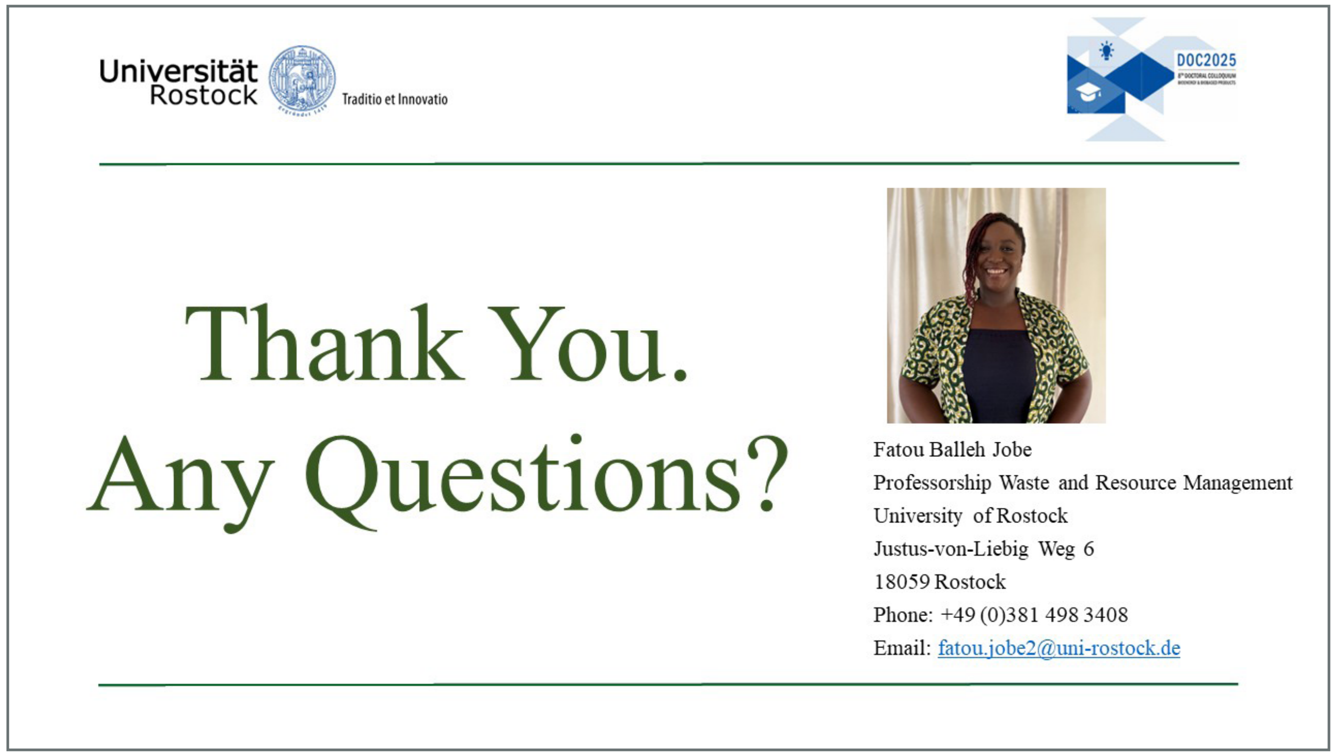
I would also like to express my sincere gratitude to both of my supervisors for their patience and unwavering guidance as I continue to navigate my research endeavors. Their support has been instrumental in my progress.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Thank You.
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Lars Bippus, University of Stuttgart

Prospective Life Cycle Assessment as a Tool for Enhancing Sustainability in Biomanufacturing Processes

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Keywords: Life Cycle Assessment, Biomanufacturing, Environmental Sustainability, Biosurfactants, Process Development

Introduction

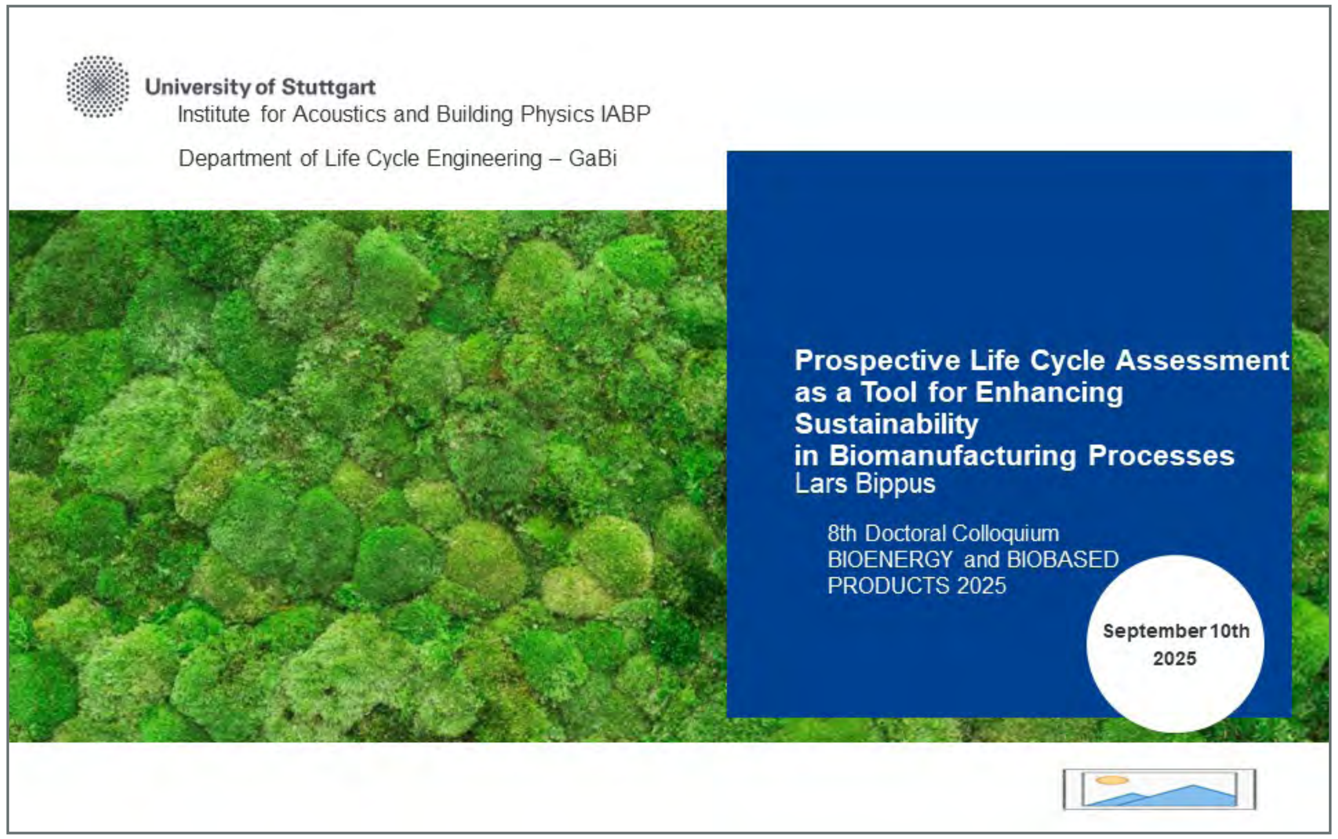
For the transition towards a bioeconomy, sustainable production is crucial for the development of biobased products such as for microbially produced biosurfactants. To quantify environmental sustainability aspects of products and processes, Life Cycle Assessment (LCA) is an internationally recognized method to analyze potential environmental impacts. The need for comprehensive environmental sustainability data in biotechnological process development emphasizes the importance of prospective LCA in biomanufacturing to identify improvement opportunities and guide technical bioprocess development.

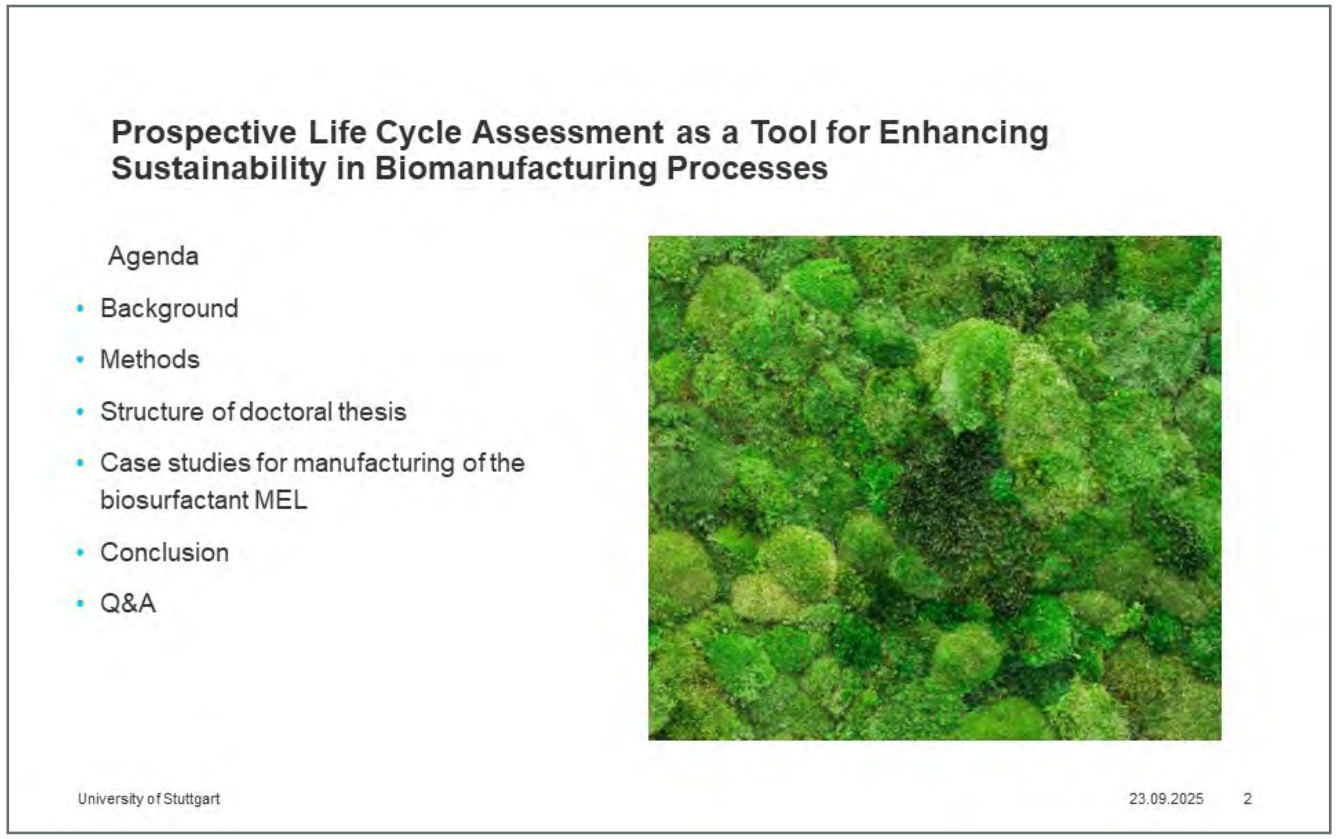
Approach/Methods

This research analyzes the environmental impacts associated with the fermentation and downstream processing of biobased products for the example of microbial biosurfactants using prospective LCA. This approach examines the entire production chain, from substrates, to final product purification of the biosurfactants from the culture broth, focusing on major environmental impact sources including substrate provision, bioreactor energy consumption, and solvent use in the purification. The analysis integrates aspects of the process development for technical development at an early stage to enhance the accuracy of environmental impact assessments.

Results / Outlook

The findings reveal that substrate provision, the electricity consumption for the bioreactor operation, especially the aeration, and the purification steps significantly influence the environmental footprint of biosurfactants, particularly in the impact category climate change. The study identifies hotspots within the production process and suggesting targeted strategies for process optimization, but also approaches to improve the accuracy of the LCA. Therefore, upscaling and the utilization of domain models used for bioprocess development such as kinetic models and process simulations offer potential for in-depth analyses that contribute to a better understanding of the environmental aspects in biomanufacturing. By integrating environmental considerations at an early stage in product development, this approach contributes to guide sustainable bioprocess design and helps to make informed decision to enhance the environmental sustainability in biomanufacturing.





Introduction and motivation

- **Sustainable production** is crucial for transition to a sustainable bioeconomy.
- **Biomanufacturing** promotes resource efficiency and reduce environmental impacts.
- Evaluating environmental sustainability for biomanufacturing faces **challenges in early development stages** such as representative data.
- A **forward-looking approach** is needed for informed decisions for sustainability process design, particularly in developing processes.

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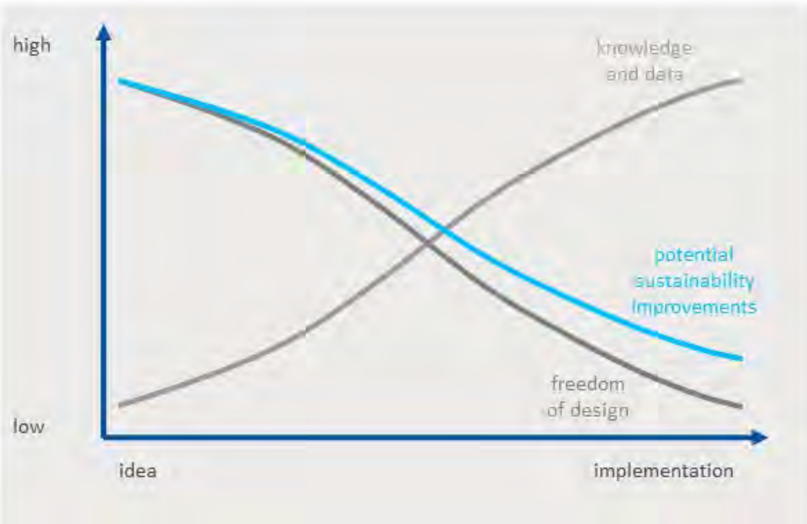
Background
LCA in product and process development

- Focus on **process development:** improving environmental aspects in process development.
- **Environmental data** is necessary to identify potentials for sustainability improvement.
- In **early development stages**, knowledge and data are limited.



Own illustration based on Frenzel et al (2022) DOI: 10.1051/e3sconf/202234911007 and Bhander et al. (2003) - DOI: 10.1002/ep.670220414

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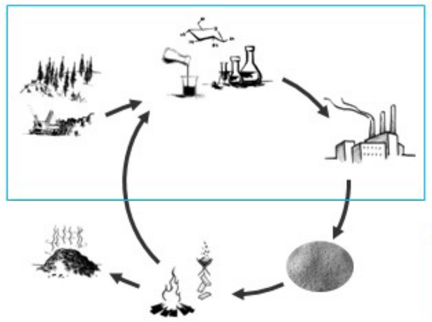
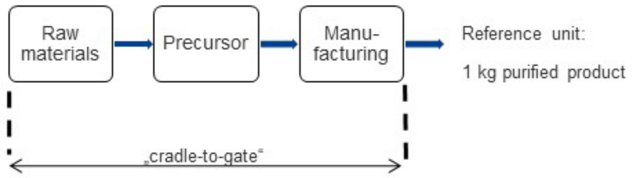
Methods
Prospective Life Cycle Assessment

- Life Cycle Assessment (LCA) evaluates sustainability across the entire product lifecycle
- Standardized method to quantify potential environmental impacts
- Prospective LCA = forward looking approach within LCA framework



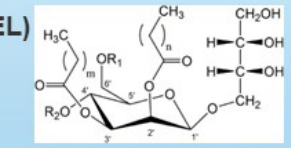
Concept of life cycle thinking, illustrations by Jan Paul Lindner



System boundaries and reference unit

Example of mannosylerythritol lipids (MEL)

- Microbial biosurfactant
- Produced in aerated bioreactor
- Substrates glucose and vegetable oil



General structure of di-acylated mannosylerythritol lipids (MEL)

University of Stuttgart

Structure of the doctoral thesis
Cumulative dissertation

Methods

- **Prospective** LCA modelling adapted to address main aspects for aerobic fermentations with a cradle-to-gate approach
- Using data from laboratory experimental fermentation and process models for **upscaling for a prospective analysis**
- Exchange **with process designers** to support technical development and guide eco-design

Case studies for the example of biosurfactant production: mannosylerythritol lipids (MEL)

1. Assessing a comprehensive **fermentation model** using scenario analysis and kinetic models
2. Assessing comprehensive **purification routes** with scenario analysis
3. Assessing **aeration or alternative raw material** in more detail

progress

Discussion and synopsis

- Development of an a parametrized LCA model for aerobic fermentations to identify key influencing factors
- Integrating LCA in biomanufacturing process design, especially for processes in development
- Future research needs to optimize biomanufacturing processes

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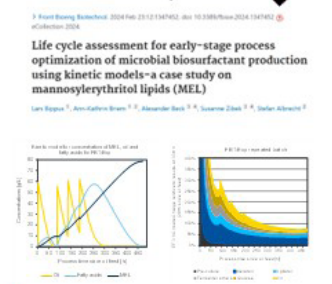
Structure of the thesis – culuative dissertation

Introductory text
- Requirements on the LCA regarding its usability for eco-design
- Requirements on process data and domain models to set up a prospective life cycle inventory
- Methods and analysis of the product systems from an environmental view in the individual papers
- Discussion and synopsis
- Research gaps and further approaches

0

Literature review on LCA of bio-surfactants

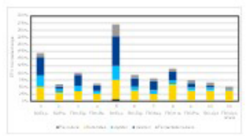
1



- System analysis for fermentation
- Hotspots, scenario analysis and kinetic models
- Improved understanding through integration of the kinetic model

2

Prospective Life Cycle Assessment for downstream processing in biomanufacturing – purification routes for the biosurfactant MEL



- System analysis for purification
- Hotspots, scenario analysis
- Comparison of purification routes and influencing parameters to environmental aspects

3

tbd

Options:

1. Focus on alternative raw materials
2. Focus on aeration
3. Focus on automatization or process control
4. Focus on using domain models for detailing LCA models

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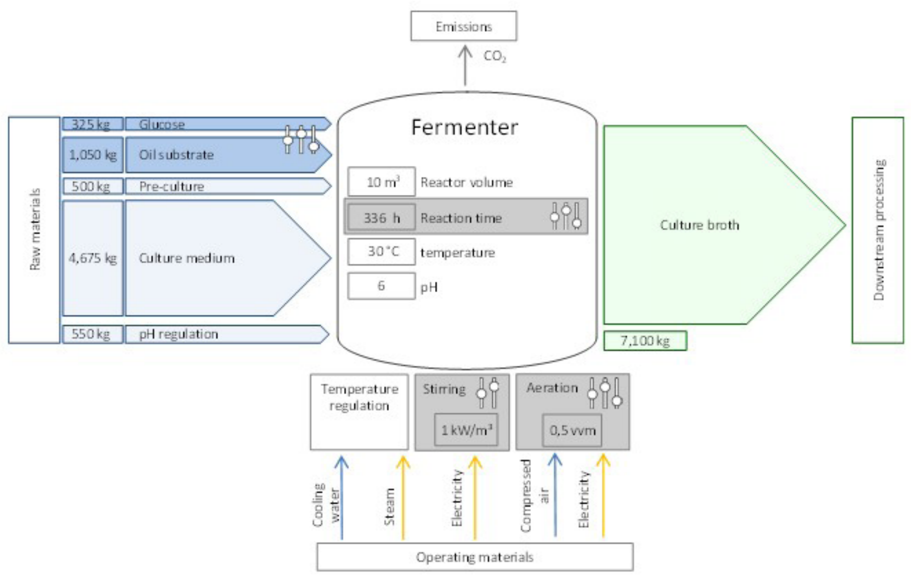
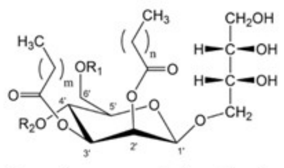
1. Case study MEL fermentation

Example of biosurfactant production: fermentation of MEL



Schematic process flowchart and process conditions for fermentation of MEL



General structure of di-acylated mannosylerythritol lipids (MEL)

University of Stuttgart

1. Case study MEL fermentation

Example of biosurfactant production: Prospective LCA of MEL fermentation

- **Data collection with process designer** via standardized mass balance sheet
- **Upscaling** the experimental laboratory scale data for a 10 m³ pilot scale bioreactor via dimensionless process metrics
- Development of a comprehensive **parameterized software model**
- **Scenario** modelling using process metrics
- Using **time series** detailed process analysis e.g. product concentration over time modelling using process metrics

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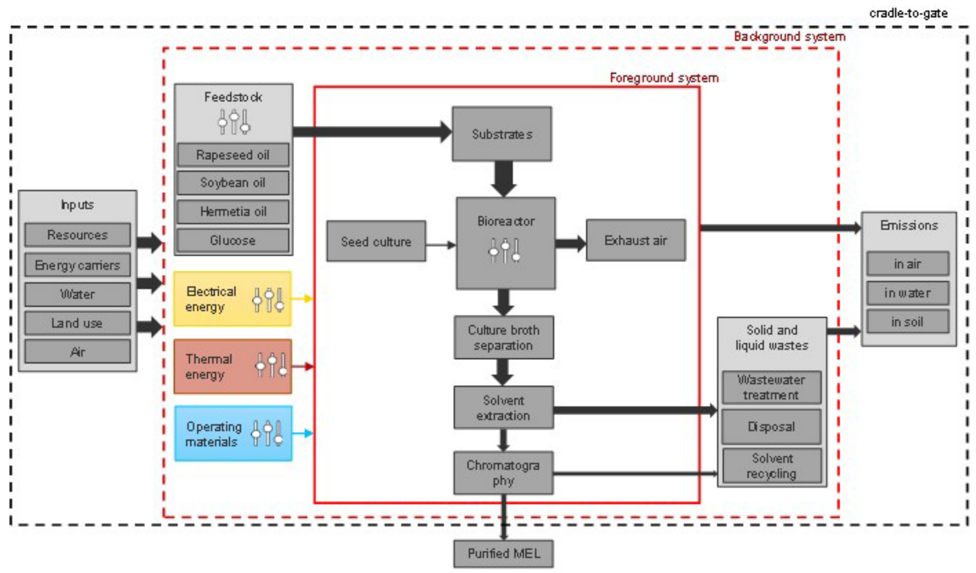
1. Case study MEL fermentation

Example of biosurfactant production: Prospective LCA of MEL fermentation



Process flow chart for MEL fermentation and purification with system boundaries

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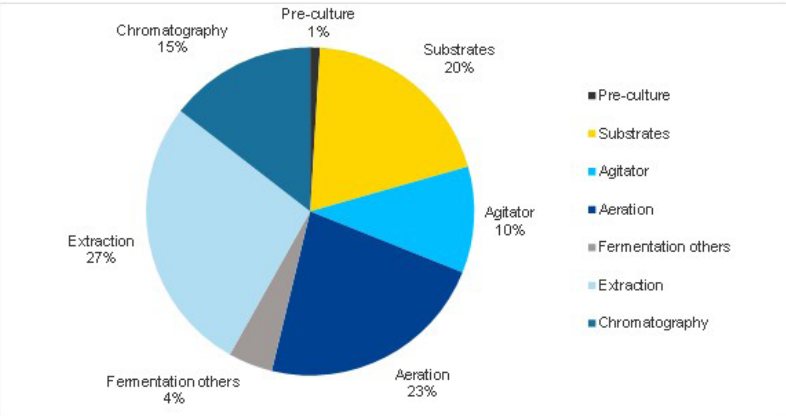
1. Case study MEL fermentation

Results for hotspots for impact category Climate Change

- Contribution analysis to identify most relevant process steps and materials
- Highlights priorities to improve processes and to detail LCA model components



Contribution analysis of the fermentation and purification processes for MEL production for the upscaled laboratory experiment FB1-Exp (scenario 3) in the impact assessment category EF 3.1 Climate Change, total

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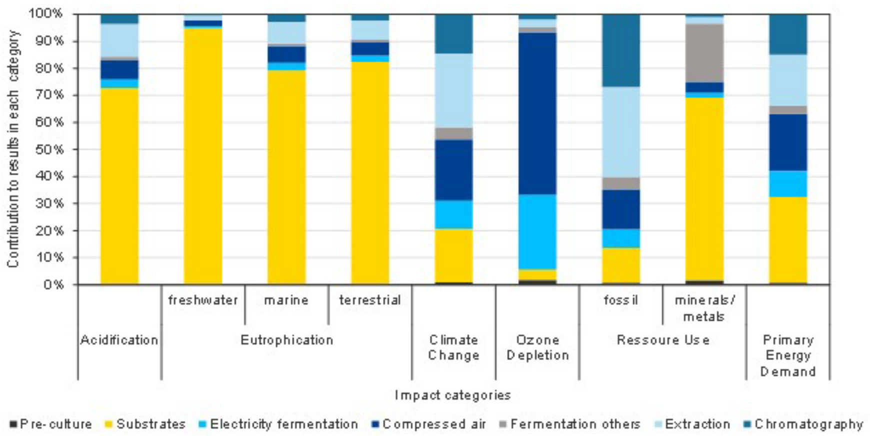
1. Case study MEL fermentation

Results for hotspots for selected impact categories

- Several impact categories allows for board understanding of environmental aspects
- Draw attention to potential trade-offs between environmental aspects



Contribution analysis for selected impact categories for the fermentation and purification processes for MEL production

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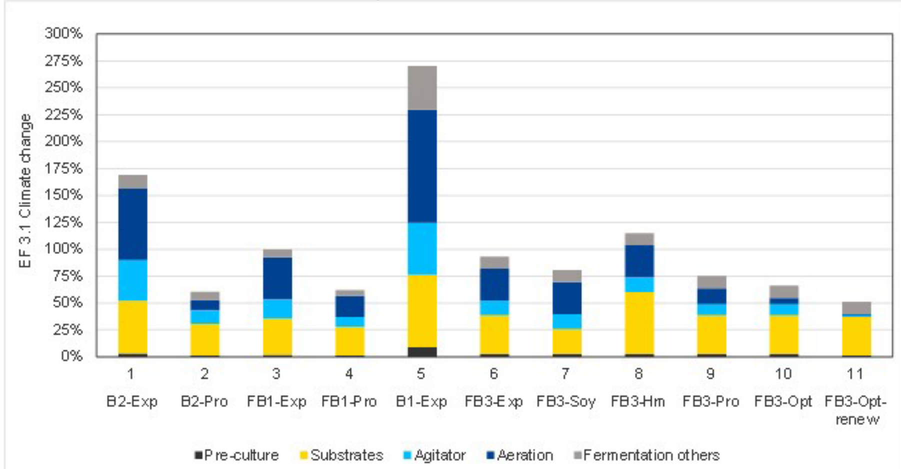
1. Case study MEL fermentation

Results for scenario analysis

- Track progress and compare process adaptions: trend to environmental improvements
- Allows for conservative estimates and optimistic outlooks



Scenario analysis for process optimization scenarios in the category EF 3.1 Climate Change, impacts are normalized to the baseline scenario FB1-Exp described in the previous section

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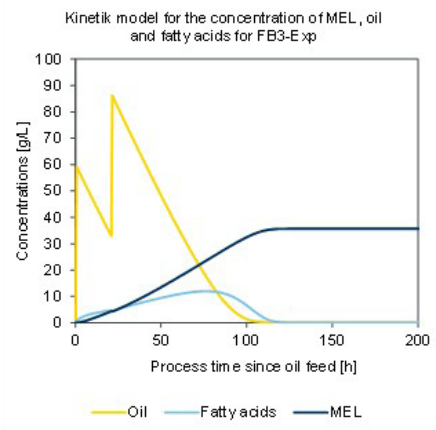
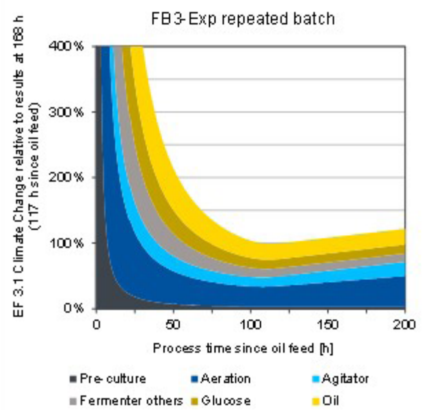
1. Case study MEL fermentation

Results using kinetic models for LCA



Concentrations in bioreactor



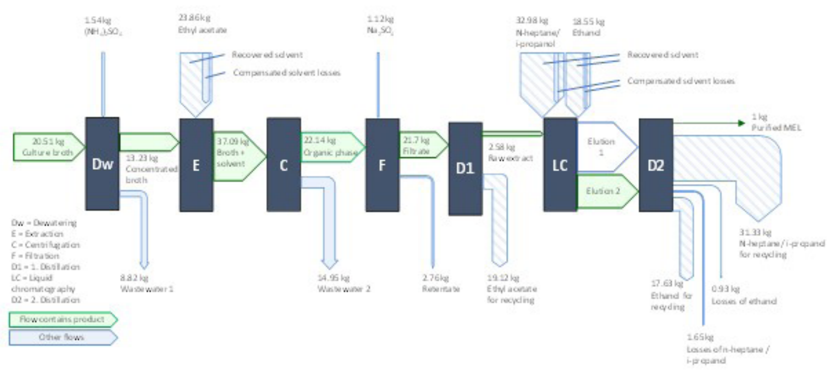
EF 3.1 Climate change normalized to results after 113h

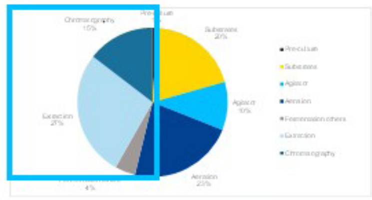
- addresses trade-off between higher yield and additional aeration and stirring during longer fermentation
- minimum indicates the time to end fermentation for minimizing the environmental impact category in the category EF 3.1 under the considered conditions

2. Case study MEL purification

Prospective LCA downstream processing for biosurfactant MEL

- Findings of screening for downstream processes: high relevance of purification
- Purification variants with process modules to be arranged with options for certain steps e.g., for dewatering or final purification step as chromatography or microfiltration





Example of a possible purification route, based on Bippus et al. (2023) – DOI: 10.3389/fbioe.2024.1347452

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3. Detail analysis of bioreactor aeration or raw materials

Options under consideration

Aeration and process control

- Evaluation of **aeration equipment and conditions** such as required aeration rate
- Quantifying benefits through **improved process control**: aeration and agitation according to oxygen uptake

Alternative raw materials

- Assessment **of agro-industrial by-products** or **PtX** raw materials for biotechnological processes
- Quantify impacts through **land use** and on biodiversity, regionalization of models

Detailing process models

- Using further process models, simulation or **digital twins** to improve accuracy of LCA results
- Using of process models to create **LCA data for a specific design problems**

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Conclusions

- Development of an approach to set up a parametrized LCA model for aerobic fermentations reflecting the key influencing parameters
- Potential and challenges of integrating LCA into development of emerging biomanufacturing processes
- Future research for environmental improvements of manufacturing design and expanded raw material sources

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University of Stuttgart
Germany

Thank you!

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University of Stuttgart
Institute for Acoustics and Building Physics IABP
Department of Life Cycle Engineering GaBi

I am looking forward to the Q&A!

ALLIANZ BIOTENSIDE
GEFÖRDERT VOM
FKZ: 031B1059H
Bundesministerium für Bildung und Forschung

Niloufar Hasanpour Seyedlar, University College Cork

Building Trust and Trade-Offs: Public Preferences for Anaerobic Digestion Plants in Ireland

Niloufar Hasanpour Seyedlar, Bernadette Power, Geraldine Ryan, Prof. Dr. Jerry D. Murphy, Archishman Bose, Richard O'Shea
University College Cork
College Road
Cork T12 K8AF, Ireland
E-mail: Niloufar.hasanpourseyedlar@ucc.ie

Keywords: Anaerobic digestion, Social acceptance, Choice-based conjoint analysis, Latent class

The transition to renewable energy requires not only technological and policy advances but also societal support. Anaerobic digestion (AD) is a central technology in Europe's circular bioeconomy, yet it faces persistent local opposition linked to odour, traffic, landscape change, and waste management concerns. This study investigates the social acceptance of AD in Ireland through a national choice-based conjoint (CBC) survey of 685 respondents, generating 10,960 evaluations (685×2×8). Respondents evaluated trade-offs across key attributes of AD projects, including plant size and distance, ownership models, opportunities for individual and community participation, local benefits, and governance mechanisms. Latent class analysis revealed three distinct stakeholder groups: Principled Opponents (13.2 %) who reject AD irrespective of design, Cautious Localists (25.6 %) whose support depends on community ownership, tangible local benefits, and meaningful engagement, and Community-Minded Supporters (61.2 %) who consistently favour projects reflecting community values and democratic decision-making.

Across all groups, proximity emerged as a decisive factor, with strong resistance to facilities located within 2 km of homes, highlighting distributive justice concerns regarding burden-sharing. Ownership patterns also shaped attitudes: corporate-led projects were opposed, while community and cooperative ownership received broad support. Market simulations showed that acceptance rates rose to about 30 % among Localists and Supporters when projects combined favourable features like medium-scale plants over 2 km from housing, community ownership, discounted energy benefits, and joint decision-making boards.

These findings demonstrate that acceptance is not uniform but segmented and shaped by distributive and procedural justice considerations. Policies that assume uniform community responses risk failure, whereas strategies that empower communities, ensure fair benefit distribution, and incorporate inclusive governance mechanisms can foster durable support. The study advances methodological contributions to renewable energy acceptance research by applying CBC to AD projects, while also offering practical guidance for policymakers seeking socially robust pathways for the broader renewable energy transition.

We are sorry, no slides avalailable

SESSION
SUSTAINABLE RESOURCE BASE

8TH DOCTORAL COLLOQUIUM BIOENERGY AND BIOBASED PRODUCTS

Elisa Cerza, University of Perugia

Sustainable valorization of biomass waste: hydrochars for catalysis and environmental remediation

Elisa Cerza, Assunta Marrocchi
University of Perugia
Via Elce di Sotto, 8, Italy
E-mail: elisa.cerza@dottorandi.unipg.it

Keywords: biomass waste, waste valorization, chemical catalysis, pollutant removal, hydrochar

Introduction

Fossil fuels depletion and their environmental impact are issues that require a shift towards renewable resources; lignocellulosic biomass waste is a valid alternative. Biochars are biomass-derived carbonaceous materials that find applications in fields such as catalysis, electronics or environmental remediation. A sustainable approach for their synthesis is hydrothermal carbonization, which takes place at 180-250°C in the presence of water. [1] The solid product is a unique type of biochar - with distinct surface functionalities and tuneable properties. This project is focused on the sustainable conversion of biomass waste into high- value hydrochars (HC), minimizing environmental impact and unlocking new functionalities for industrial and environmental technologies.

Methods

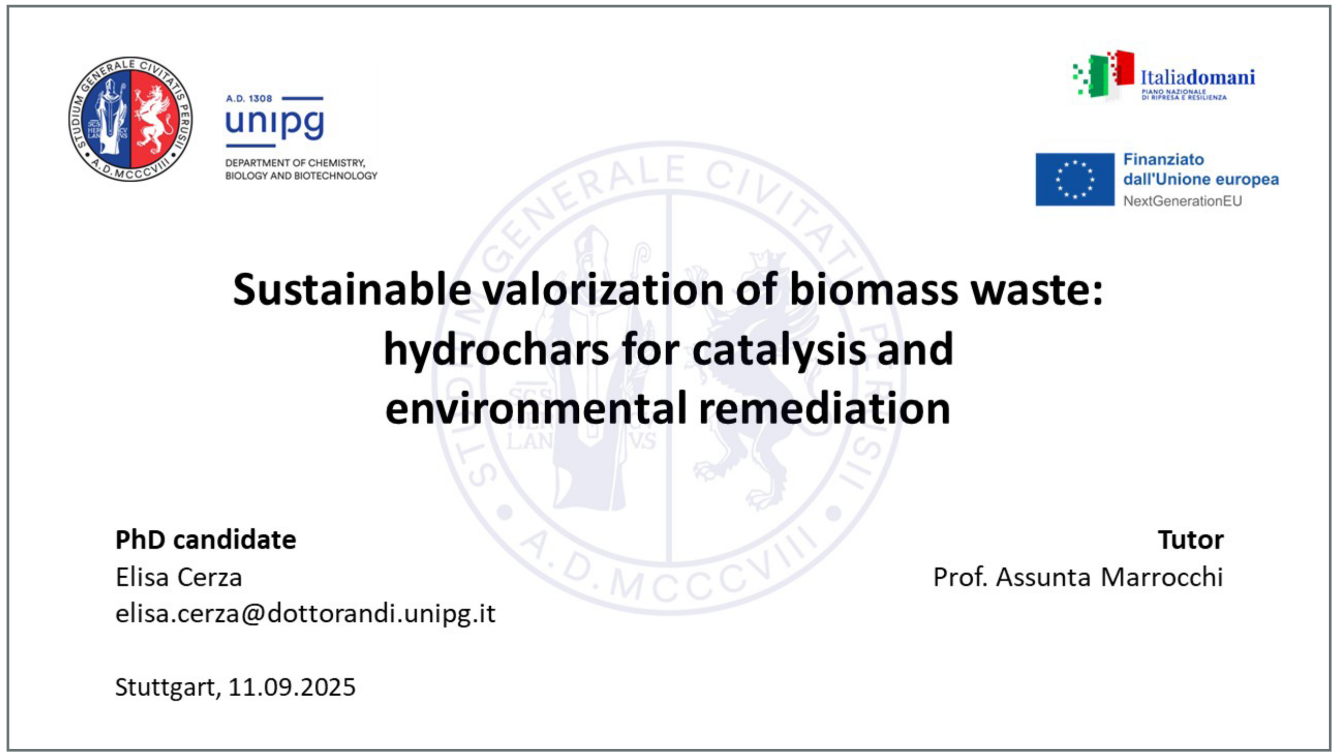
HCs were obtained from pine needles (PN), brewer's spent grain (BSG) and grape pomace (GP) under varying conditions of temperature, time and solid-to-liquid ratio. In some cases, N-containing groups were also introduced to modify the properties. The resulting HCs have been characterized by, e.g., bulk density, elemental and BET surface area analysis. Next, they were tested for a range of potential applications.

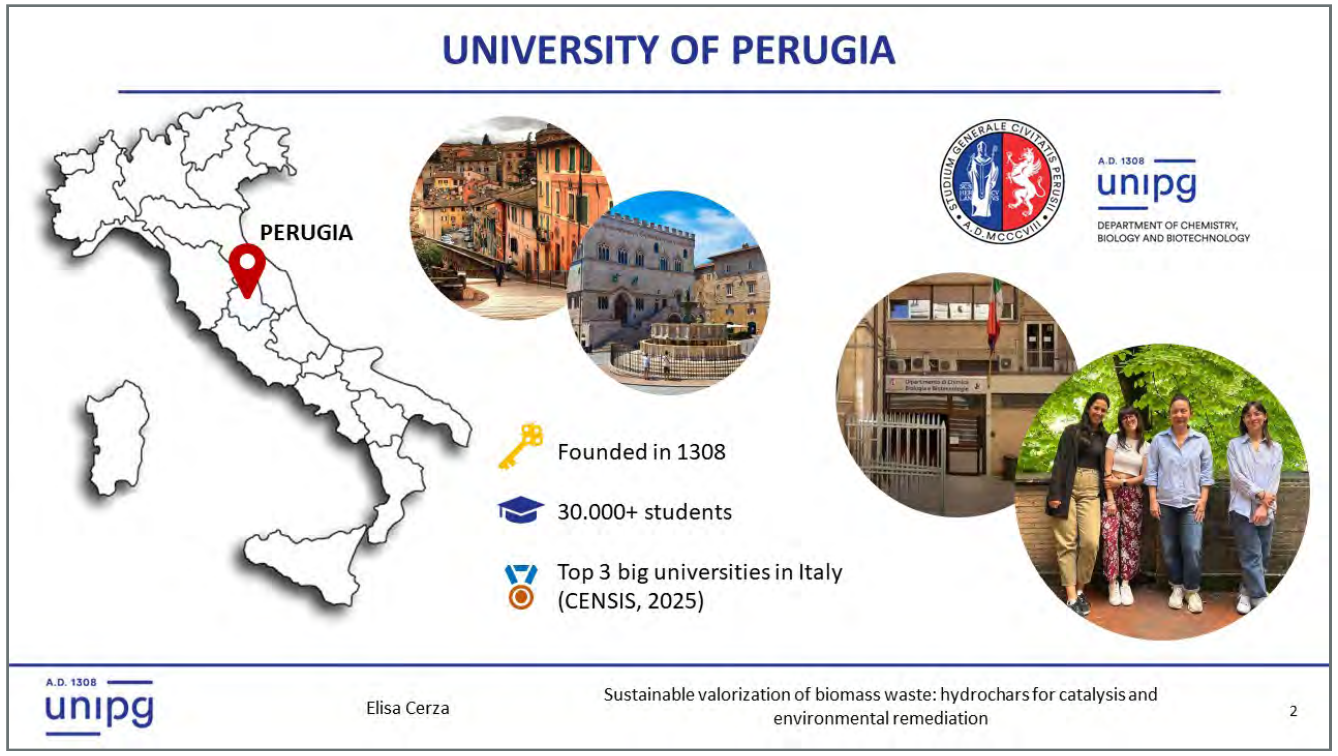
Outlook

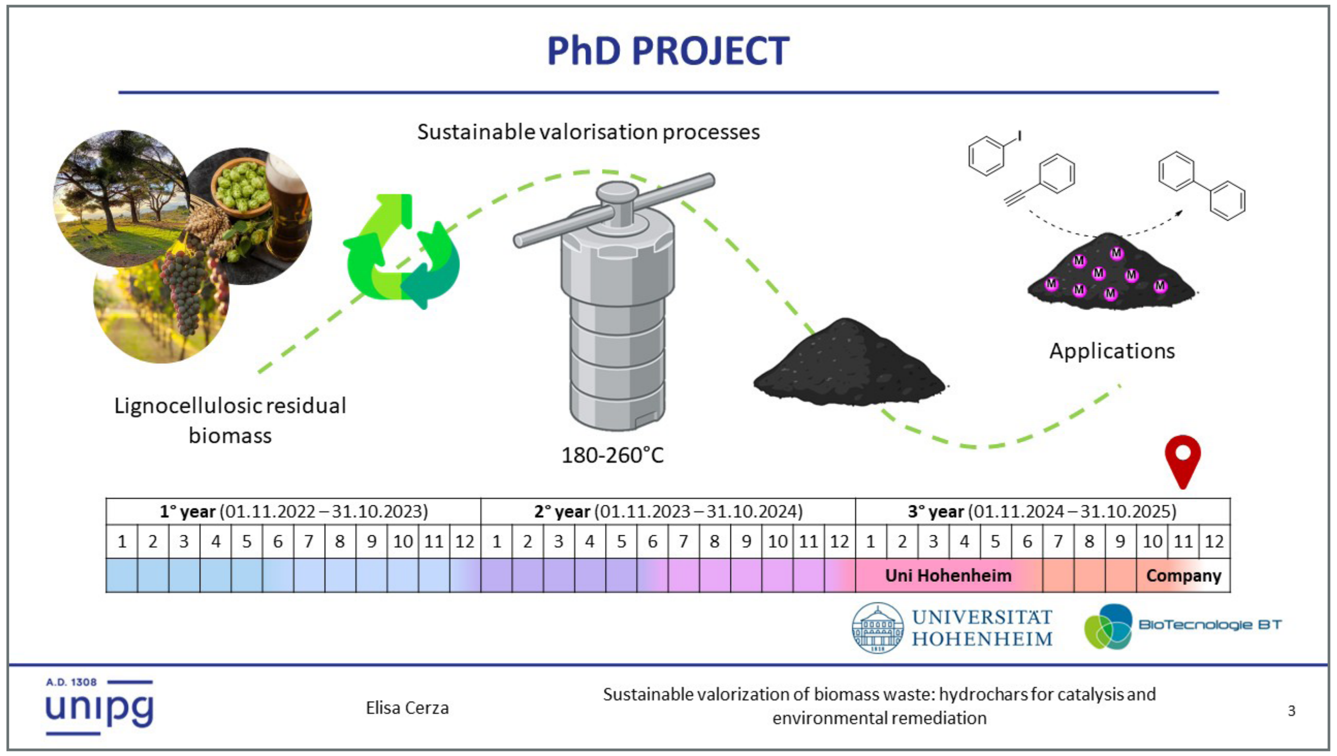
PN-derived HCs demonstrated promising performance in various applications. Initially, they were used as supports for a Pd catalyst in cross-coupling reaction, yielding good to excellent conversion. In the field of electrocatalysis, they were enriched with N- functionalities. The resulting N-doped HCs exhibited excellent activity in O_2 and CO_2 reduction reactions. [2] HCs were also effectively used as adsorbent for inorganic and organic species. They demonstrated high efficiency in multi-element adsorption of heavy metals such as Pb, Cd and Zn in soil. Also, HCs showed strong potential for the removal of organic contaminants like dyes. These results highlight HCs as sustainable, versatile alternatives to fossil- derived materials. Notably, they can be produced under mild, environmentally friendly conditions, reinforcing their value in circular bioeconomy and green chemistry approaches.

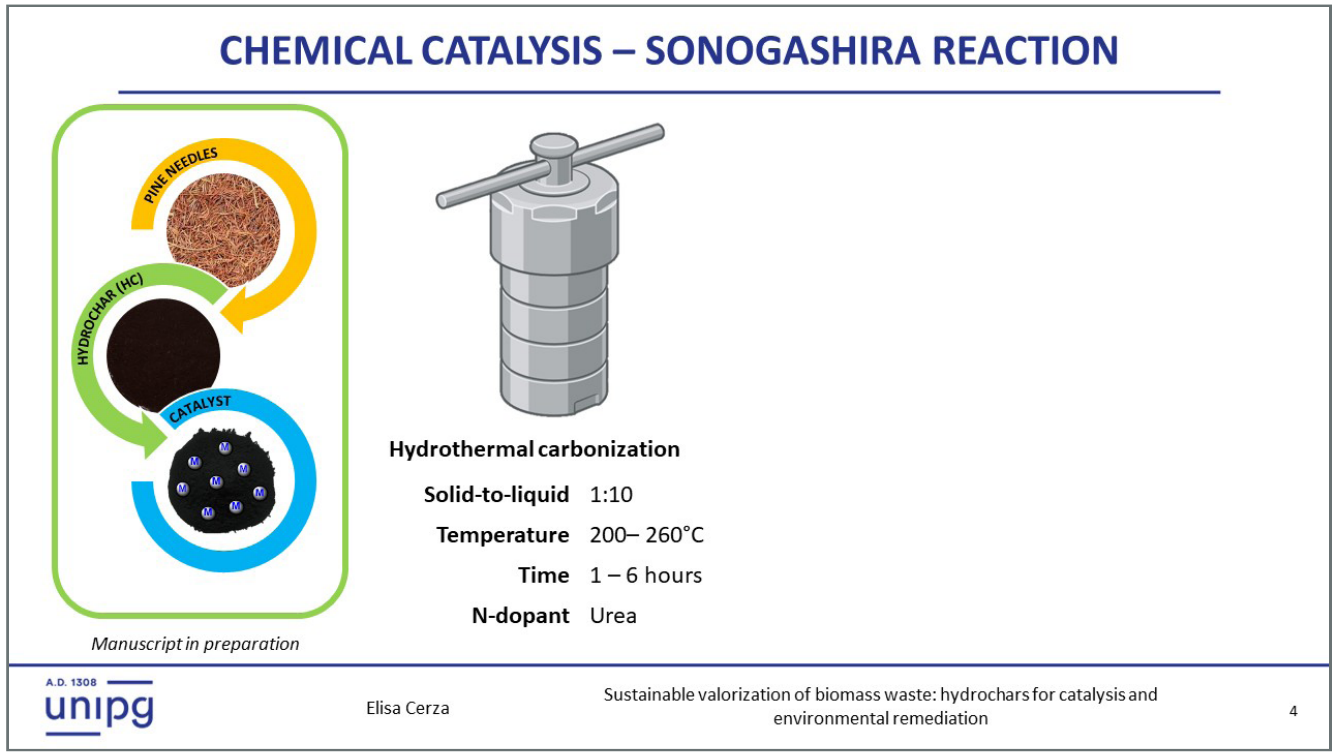
References

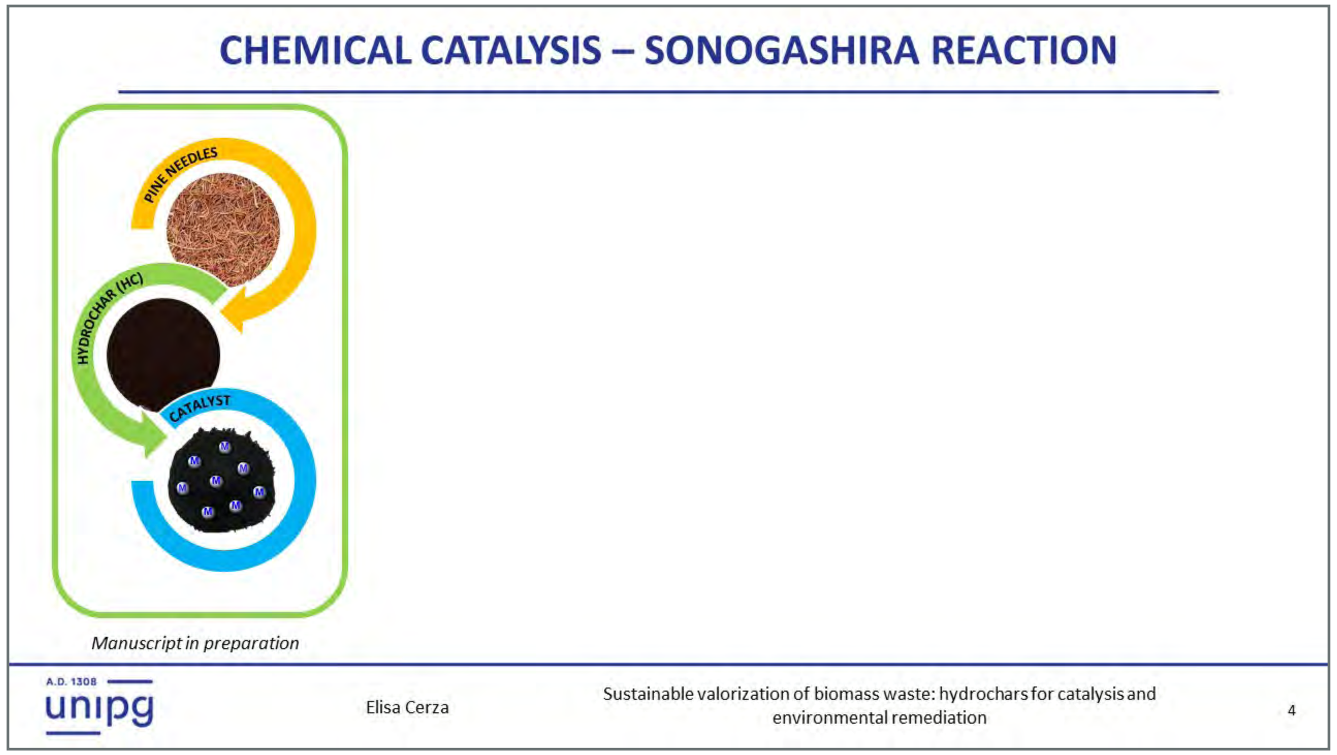
[1] P. J. Arauzo et al, Energies, 2018, 11,3226
[2] E. Cerza et al, Molecules, 2024, 29,3286

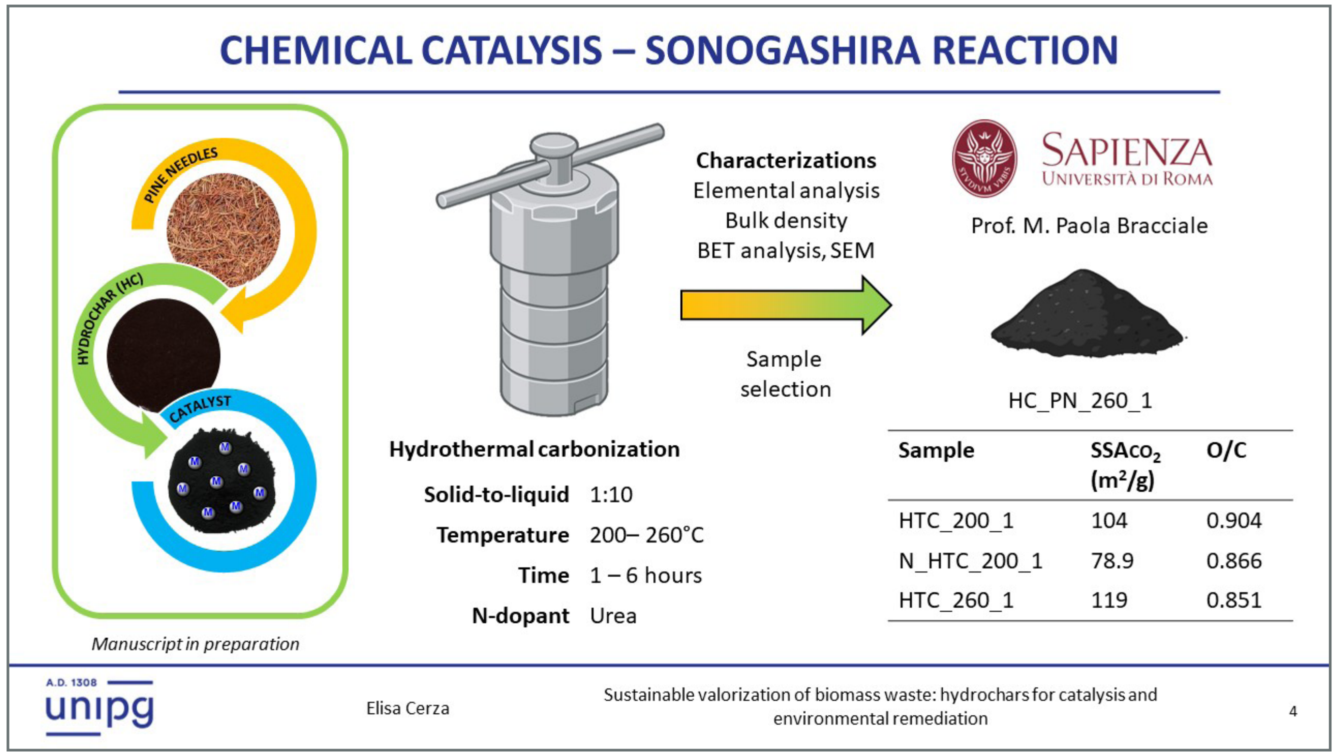


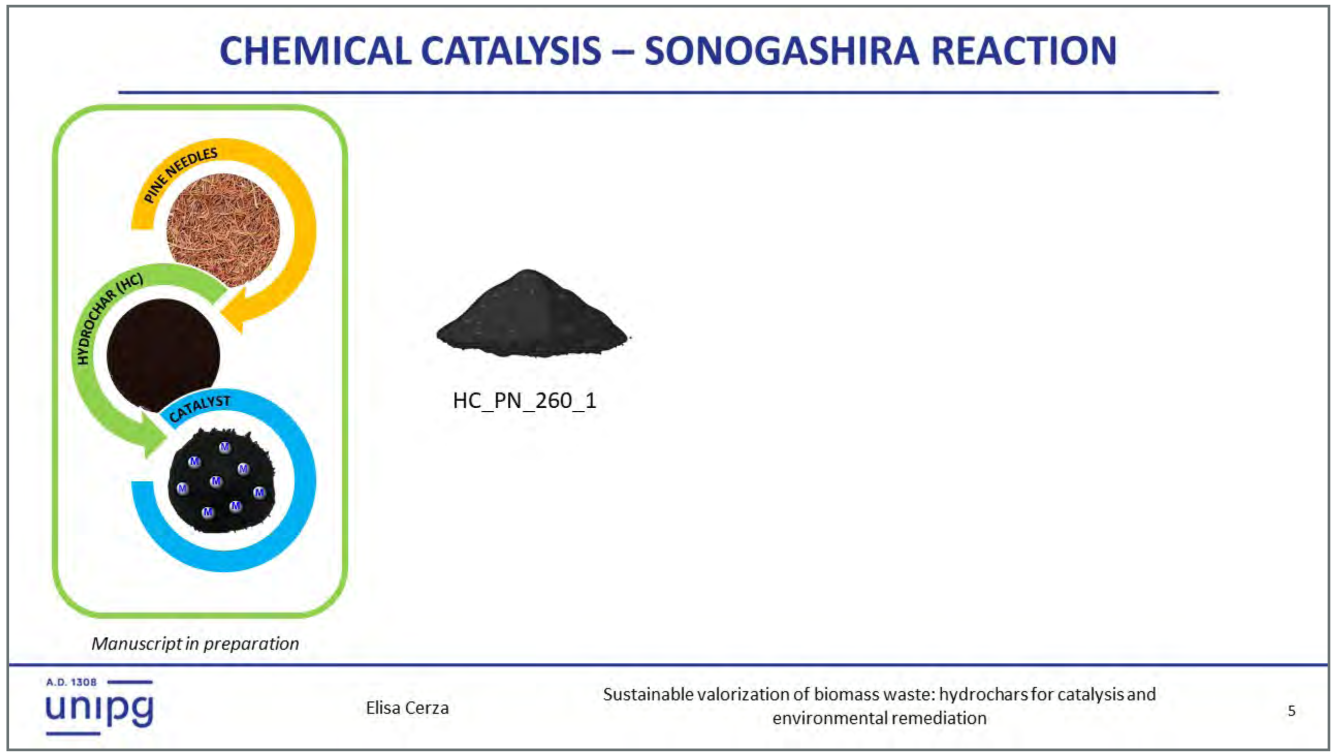


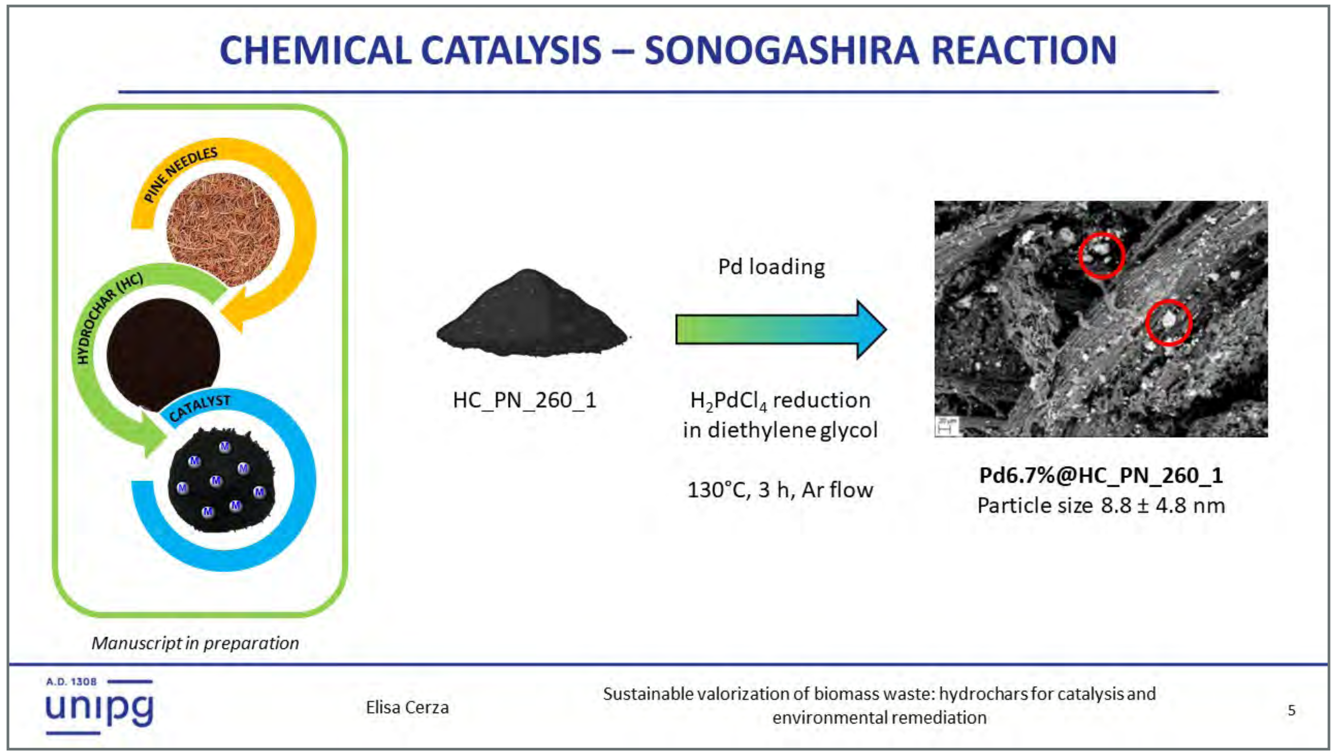

PhD PROJECT
Sustainable valorisation processes
Lignocellulosic residual biomass
180-260°C
Applications
1° year (01.11.2022 – 31.10.2023)
2° year (01.11.2023 – 31.10.2024)
3° year (01.11.2024 – 31.10.2025)
1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12 1 2 3 4 5 6 7 8 9 10 11 12
Uni Hohenheim
Company
UNIVERSITÄT HOHENHEIM
BioTecnologie BT
unipg
Elisa Cerza
Sustainable valorization of biomass waste: hydrochars for catalysis and environmental remediation
3


CHEMICAL CATALYSIS – SONOGASHIRA REACTION
PINE NEEDLES
HYDROCHAR (HC)
CATALYST
Hydrothermal carbonization
Solid-to-liquid 1:10
Temperature 200– 260°C
Time 1 – 6 hours
N-dopant Urea
Manuscript in preparation
unipg
Elisa Cerza
Sustainable valorization of biomass waste: hydrochars for catalysis and environmental remediation
4


CHEMICAL CATALYSIS – SONOGASHIRA REACTION
PINE NEEDLES
HYDROCHAR (HC)
CATALYST
Manuscript in preparation
unipg
Elisa Cerza
Sustainable valorization of biomass waste: hydrochars for catalysis and environmental remediation
4


CHEMICAL CATALYSIS – SONOGASHIRA REACTION
PINE NEEDLES
HYDROCHAR (HC)
CATALYST
Characterizations
Elemental analysis
Bulk density
BET analysis, SEM
SAPIENZA UNIVERSITÀ DI ROMA
Prof. M. Paola Bracciale
Sample selection
HC_PN_260_1
Hydrothermal carbonization
Solid-to-liquid 1:10
Temperature 200– 260°C
Time 1 – 6 hours
N-dopant Urea
Sample | SSA$_{CO_2}$ (m^2/g) | O/C
HTC_200_1 | 104 | 0.904
N_HTC_200_1 | 78.9 | 0.866
HTC_260_1 | 119 | 0.851
Manuscript in preparation
unipg
Elisa Cerza
Sustainable valorization of biomass waste: hydrochars for catalysis and environmental remediation
4


CHEMICAL CATALYSIS – SONOGASHIRA REACTION
PINE NEEDLES
HYDROCHAR (HC)
CATALYST
HC_PN_260_1
Manuscript in preparation
A.D. 1308 unipg
Elisa Cerza
Sustainable valorization of biomass waste: hydrochars for catalysis and environmental remediation
5


CHEMICAL CATALYSIS – SONOGASHIRA REACTION
PINE NEEDLES
HYDROCHAR (HC)
CATALYST
HC_PN_260_1
Pd loading
H_2PdCl_4 reduction in diethylene glycol
130°C, 3 h, Ar flow
Pd6.7%@HC_PN_260_1
Particle size 8.8 ± 4.8 nm
Manuscript in preparation
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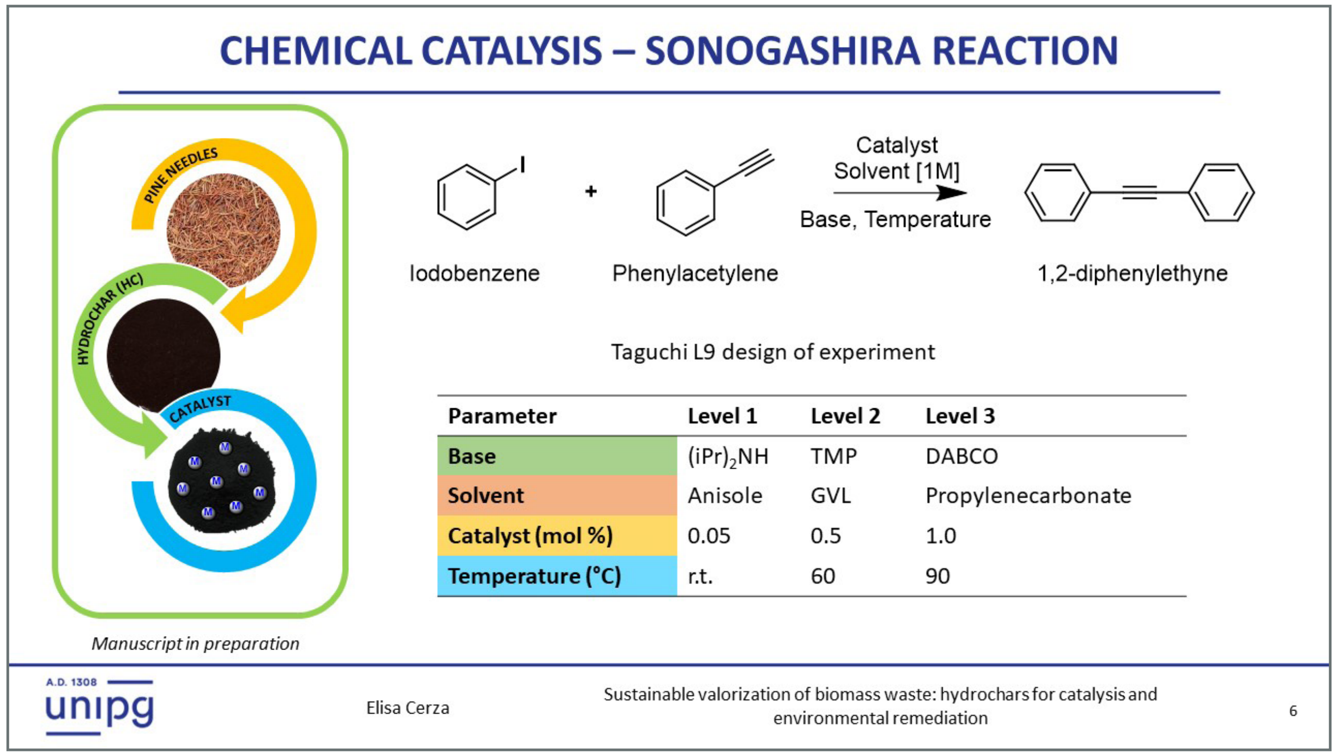
Sustainable valorization of biomass waste: hydrochars for catalysis and environmental remediation
5


CHEMICAL CATALYSIS – SONOGASHIRA REACTION
PINE NEEDLES
HYDROCHAR (HC)
CATALYST
I
+
Catalyst
Solvent [1M]
Base, Temperature
Iodobenzene
Phenylacetylene
1,2-diphenylethyne
Taguchi L9 design of experiment
Parameter | Level 1 | Level 2 | Level 3
Base | $(iPr)_2NH$ | TMP | DABCO
Solvent | Anisole | GVL | Propylenecarbonate
Catalyst (mol %) | 0.05 | 0.5 | 1.0
Temperature (°C) | r.t. | 60 | 90
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Elisa Cerza
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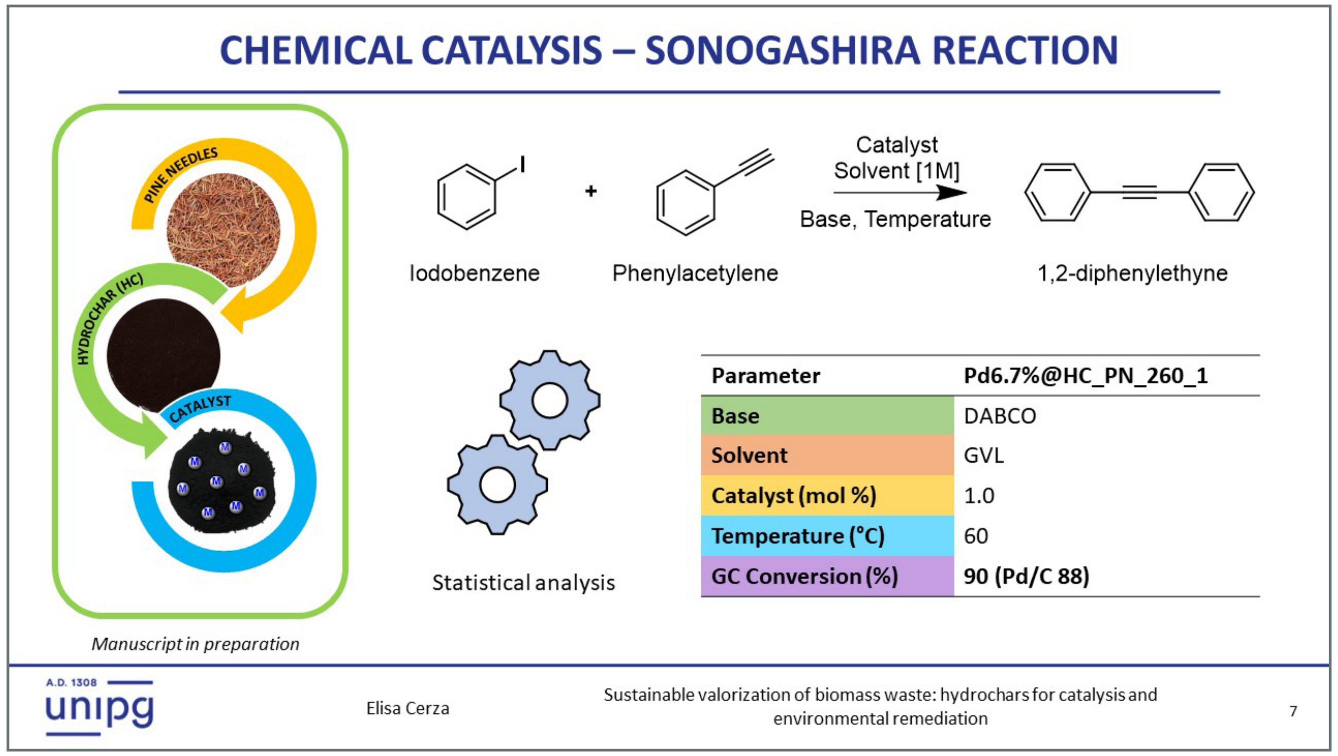
CHEMICAL CATALYSIS – SONOGASHIRA REACTION
PINE NEEDLES
HYDROCHAR (HC)
CATALYST
I
+
Catalyst
Solvent [1M]
Base, Temperature
Iodobenzene
Phenylacetylene
1,2-diphenylethyne
Statistical analysis
Parameter | Pd6.7%@HC_PN_260_1
Base | DABCO
Solvent | GVL
Catalyst (mol %) | 1.0
Temperature (°C) | 60
GC Conversion (%) | 90 (Pd/C 88)
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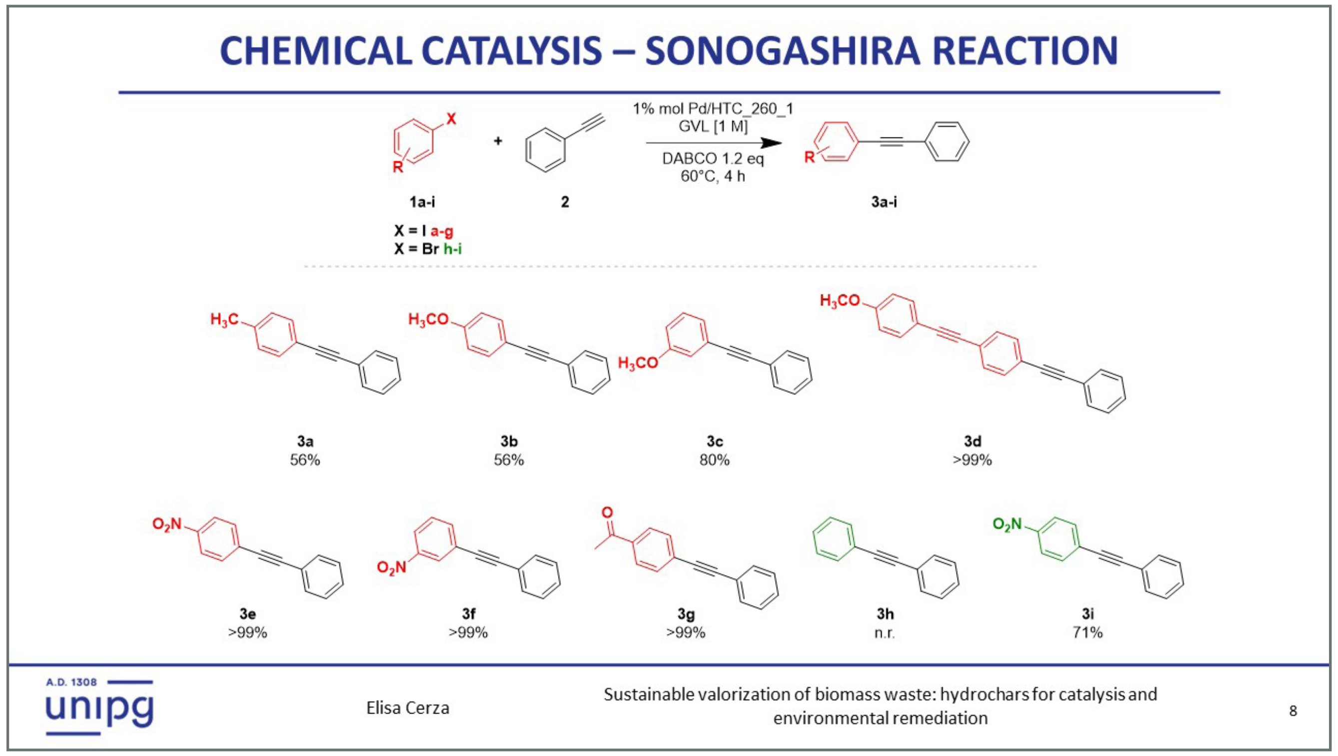
Sustainable valorization of biomass waste: hydrochars for catalysis and environmental remediation
7


CHEMICAL CATALYSIS – SONOGASHIRA REACTION
1% mol Pd/HTC_260_1
GVL [1 M]
DABCO 1.2 eq
60°C, 4 h
1a-i
2
3a-i
X = I a-g
X = Br h-i
3a
56%
3b
56%
3c
80%
3d
>99%
3e
>99%
3f
>99%
3g
>99%
3h
n.r.
3i
71%
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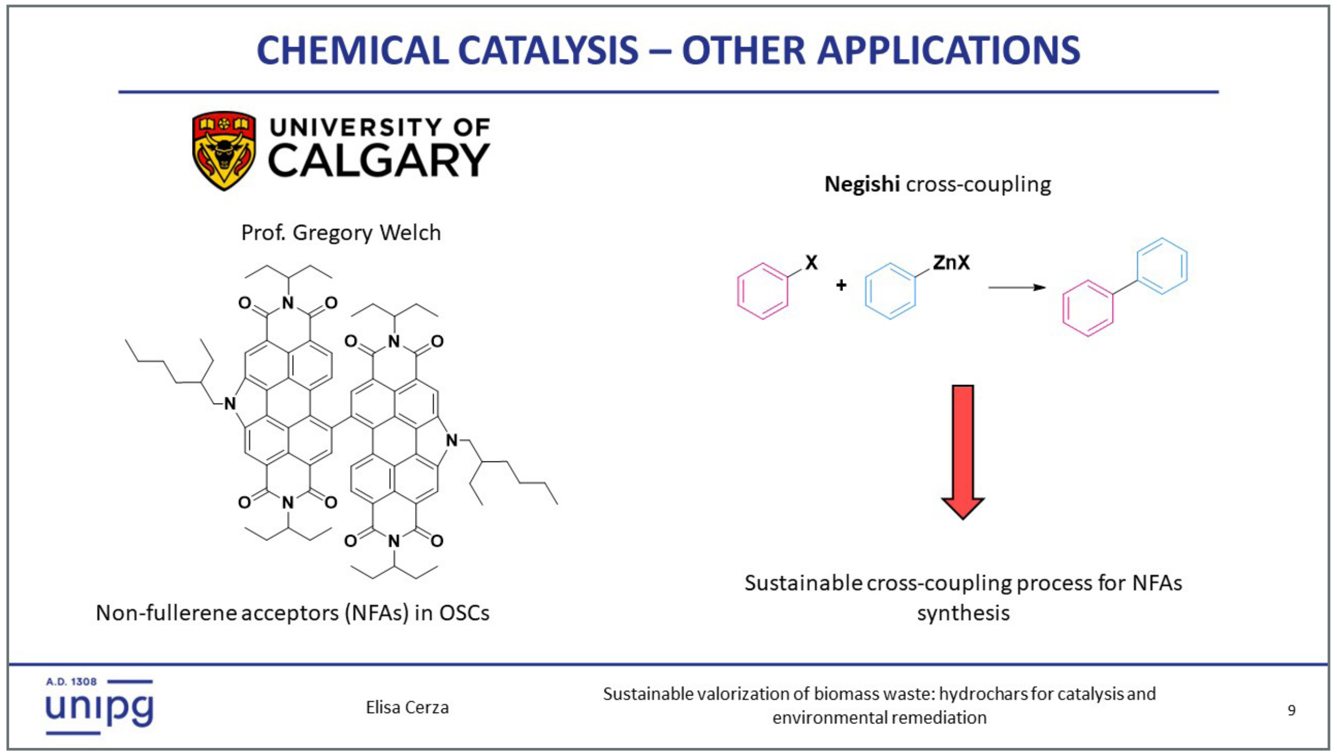
8


CHEMICAL CATALYSIS – OTHER APPLICATIONS
UNIVERSITY OF CALGARY
Prof. Gregory Welch
Negishi cross-coupling
Non-fullerene acceptors (NFAs) in OSCs
Sustainable cross-coupling process for NFAs synthesis
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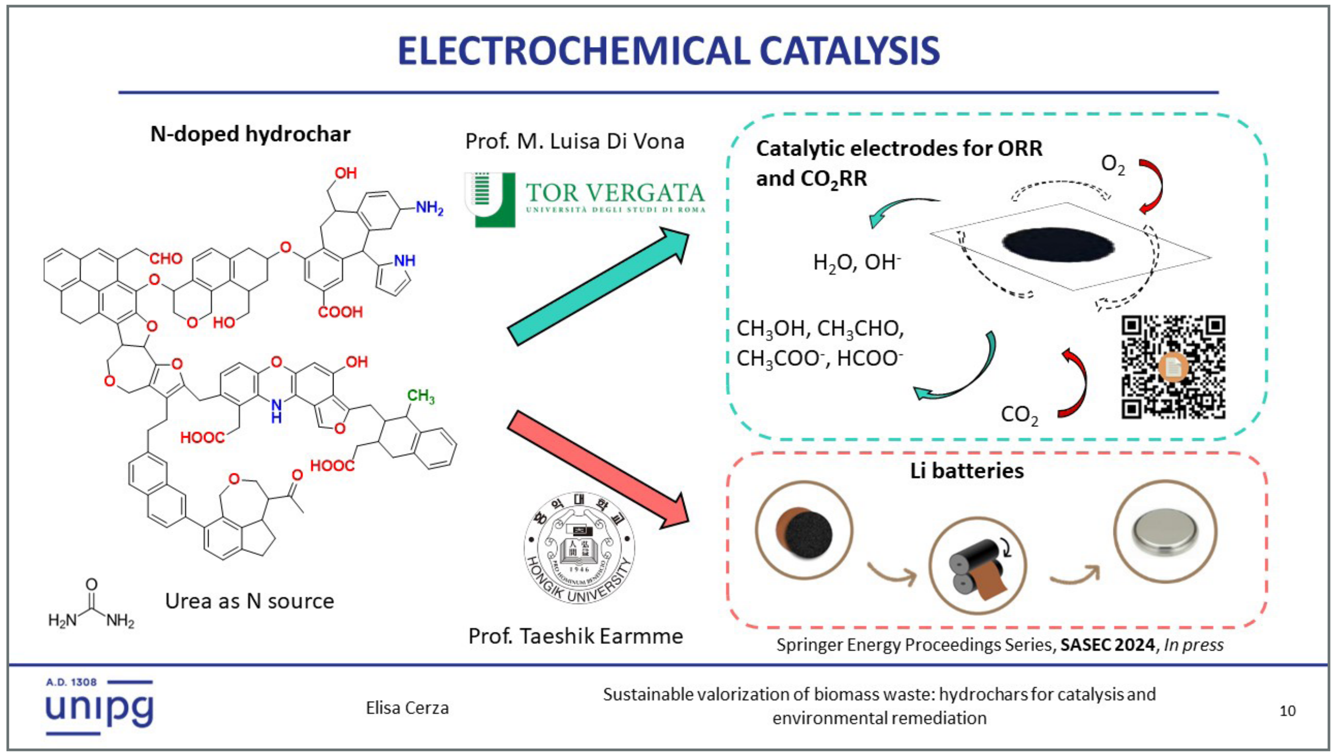
Sustainable valorization of biomass waste: hydrochars for catalysis and environmental remediation
9


ELECTROCHEMICAL CATALYSIS
N-doped hydrochar
Urea as N source
Prof. M. Luisa Di Vona
TOR VERGATA
Prof. Taeshik Earmme
Catalytic electrodes for ORR and CO2RR
H2O, OH-
CH3OH, CH3CHO, CH3COO-, HCOO-
CO2
O2
Li batteries
Springer Energy Proceedings Series, SASEC 2024, In press
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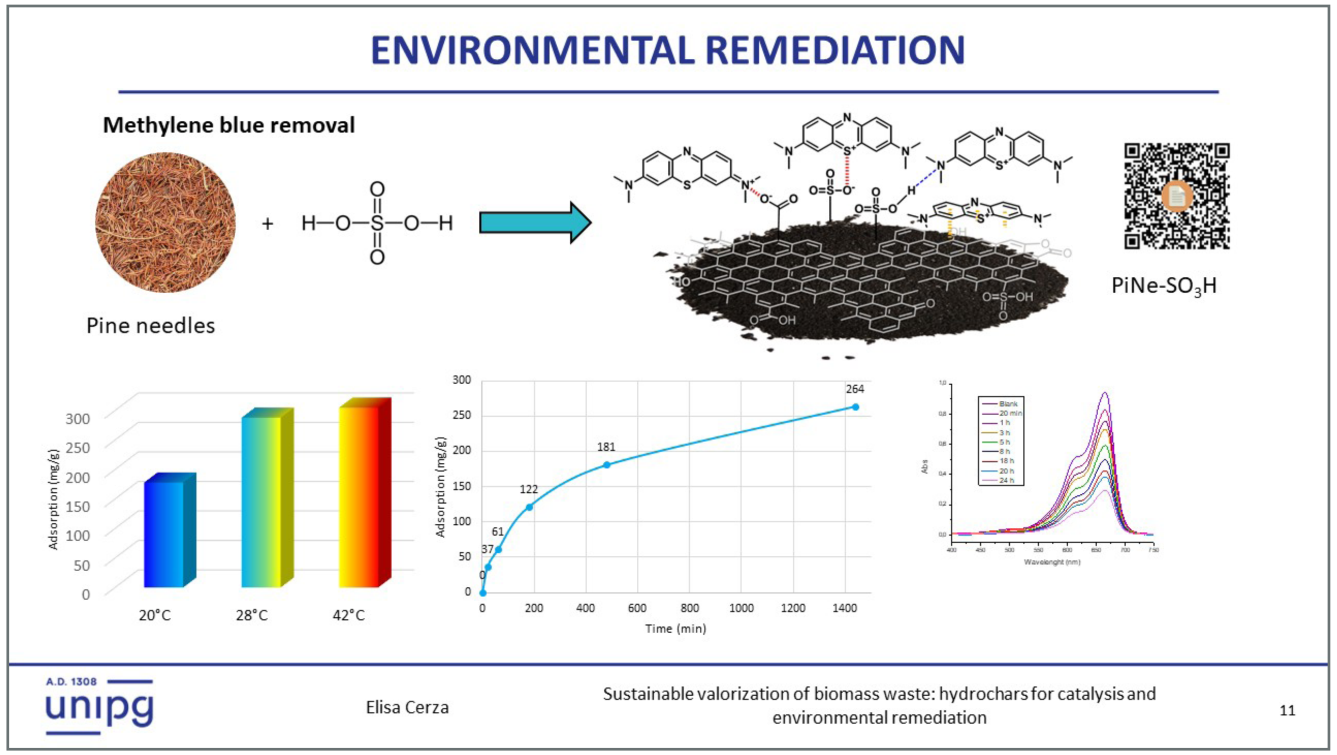
Sustainable valorization of biomass waste: hydrochars for catalysis and environmental remediation
10


ENVIRONMENTAL REMEDIATION
Methylene blue removal
Pine needles
PiNe-SO3H
20°C
28°C
42°C
Adsorption (mg/g)
Time (min)
264
181
122
61
37
A.D. 1308
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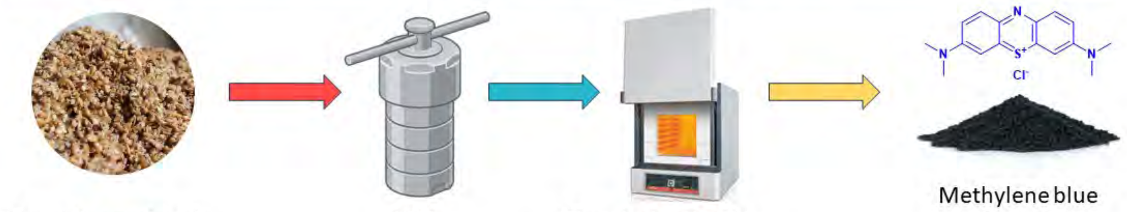
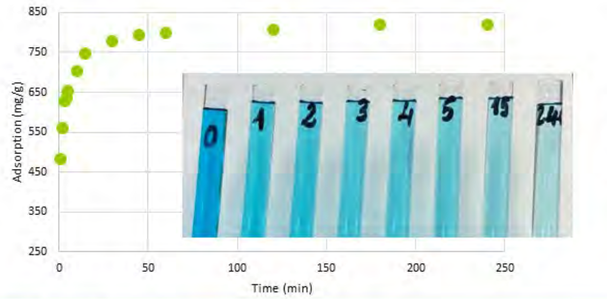
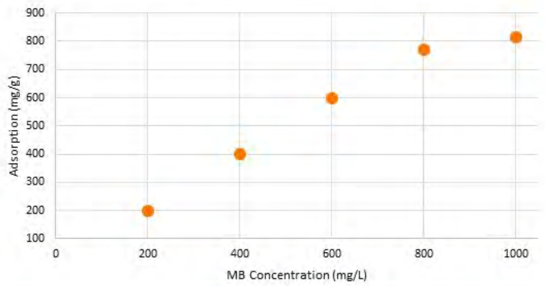
11

ENVIRONMENTAL REMEDIATION



Brewer's spent grain — HTC — Chemical activation — Methylene blue adsorption





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ENVIRONMENTAL REMEDIATION

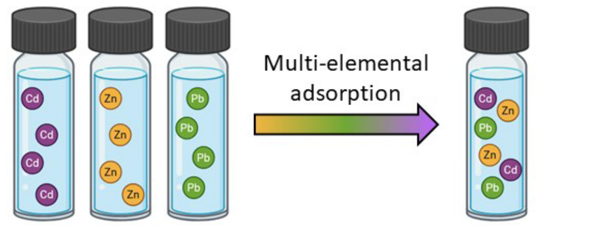
Pine needles

Grape pomace

Brewer's spent grain

Factors	Level 1	Level 2	Level 3
Feedstock	PN	BSG	GP
HTC time (h)	1	3	6
HMs concentration (mg/L)	5	10	20
Adsorption temperature (°C)	15	25	35

Best conditions
Feedstock: PN
Time: 6 hours
Concentration: 20 mg/L
Adsorption temperature: 25°C



20.0 mg/g — 18.9 mg/g — 19.7 mg/g

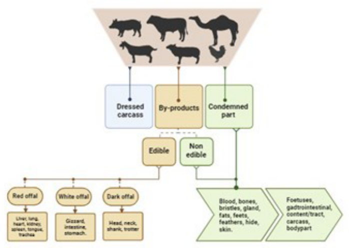
Affinity: Cd > Pb > Zn

Manuscript submitted

unipg — Elisa Cerza — Sustainable valorization of biomass waste: hydrochars for catalysis and environmental remediation — 13

SIDE PROJECTS

BIOTHEREP



Slaughterhouse waste valorisation review

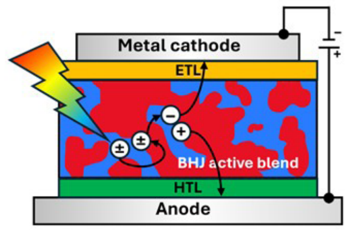
Resources, Conservation & Recycling, *manuscript accepted*

LEAP-RE

Slaughterhouse waste digestate-derived biochars paper

Manuscript in preparation

Organic Solar Cells: Fundamental Principles, Innovative Materials, Sustainability, and Future Prospects
(Book Chapter)



Elsevier, *In press*

unipg — Elisa Cerza — Sustainable valorization of biomass waste: hydrochars for catalysis and environmental remediation — 14

CONCLUSIONS

Lignocellulosic biomass waste **valorisation**

Hydrochar as a sustainable option

Catalyst support → C-C reactions

Environmental **remediation** → contaminant **adsorption**

Waste-derived hydrochar

Test more residual biomass

Other metal catalysts and more C-C reactions

Different pollutants

unipg — Elisa Cerza — Sustainable valorization of biomass waste: hydrochars for catalysis and environmental remediation — 15

8TH DOCTORAL COLLOQUIUM BIOENERGY AND BIOBASED PRODUCTS

Christoph Siol, Deutsches Biomasseforschungszentrum

Assessing Sustainable Straw Utilization: Balancing Field Retention, Industrial Applications, and Circular Resource Flows

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DBFZ Deutsches Biomasseforschungszentrum gemeinnützige GmbH
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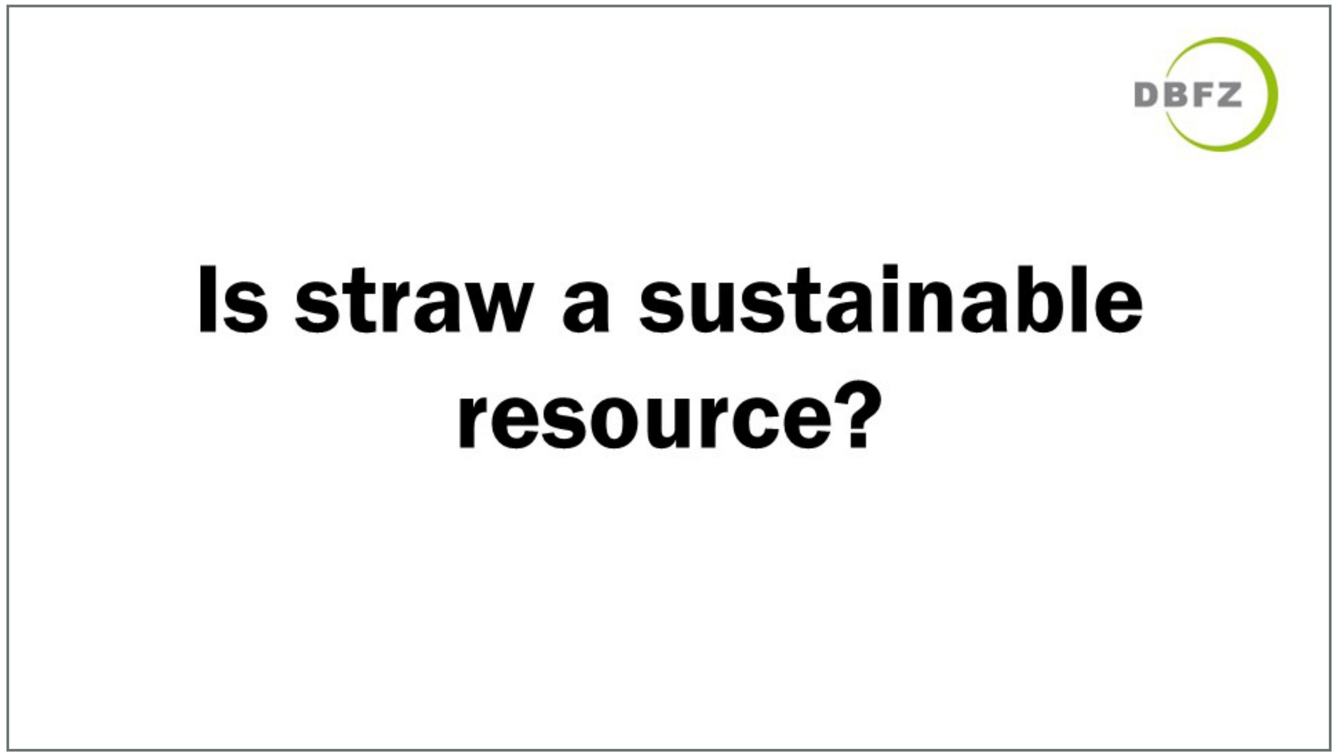
Keywords: LCA, LCSA, soil-system modeling, agro-system modeling, SUARes

Agricultural residues like cereal straw offer considerable potential as sustainable resources for industrial applications. However, assessing their sustainable use requires addressing complex trade-offs between on-field straw retention and its industrial utilization. While field retention can maintain soil health and fertility, it may also limit socio-economic opportunities from unused biomass. Conversely, industrial utilization, such as for bioenergy or bio-based materials, can support renewable resource strategies and rural economies, yet may deplete soil carbon and nutrition balances unless offset by compensatory practices. This project addresses these challenges through the development of a comprehensive assessment model and framework, enabling the site-specific sustainability assessment across diverse straw utilization scenarios.

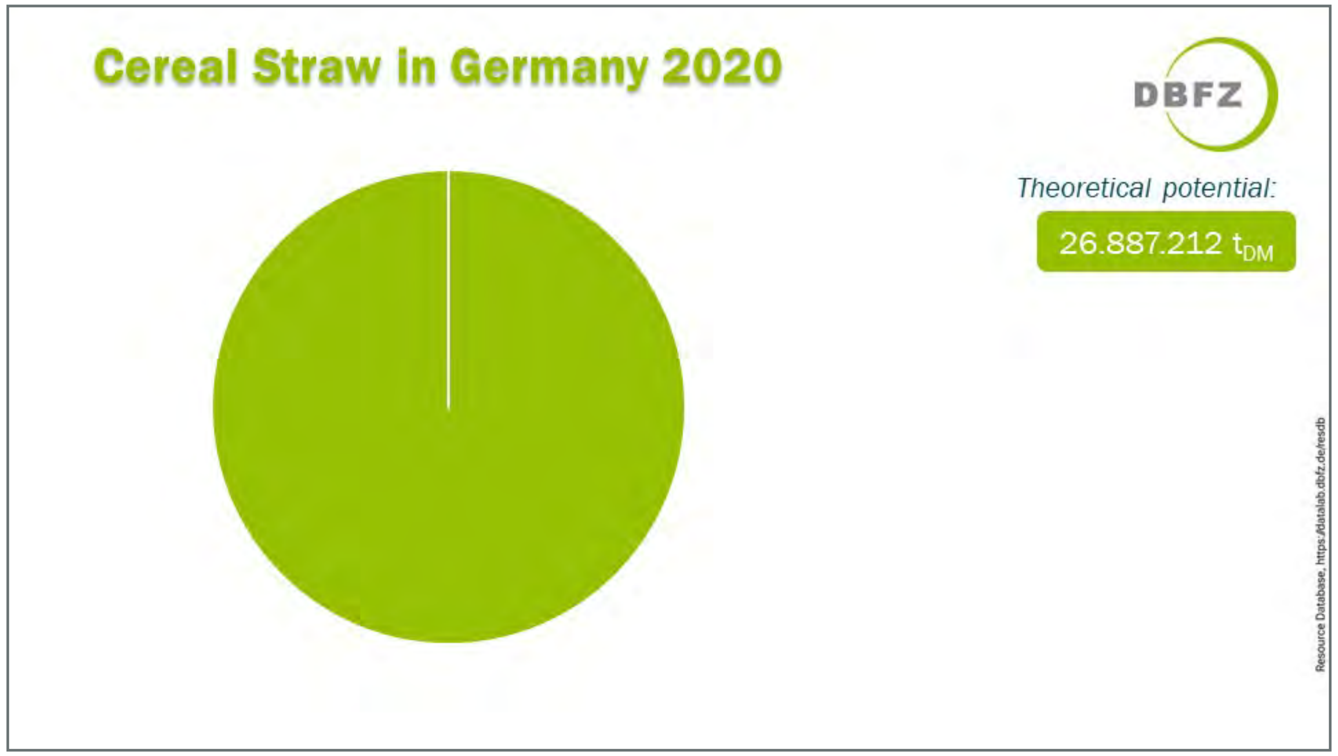
Initial work comprised two systematic literature reviews: one on Life Cycle Assessment (LCA) of agricultural and forestry residues, emphasizing discrepancies of considering agricultural residues being waste or by-products, and another on integrating ecosystem models within LCA, identifying key models, indicators, and applications. Based on these insights, a novel sustainability assessment framework was developed, grounded in the UN Sustainable Development Goals (SDGs) and Planetary Boundaries. Indicators were selected through mapping to approximately 50 SDG targets and subgoals, drawing indicators from FAO Bioeconomy and Agrifood Systems, ReCiPe2016, ILCD, IMPACT World+, and openLCA SoCa indicator sets.

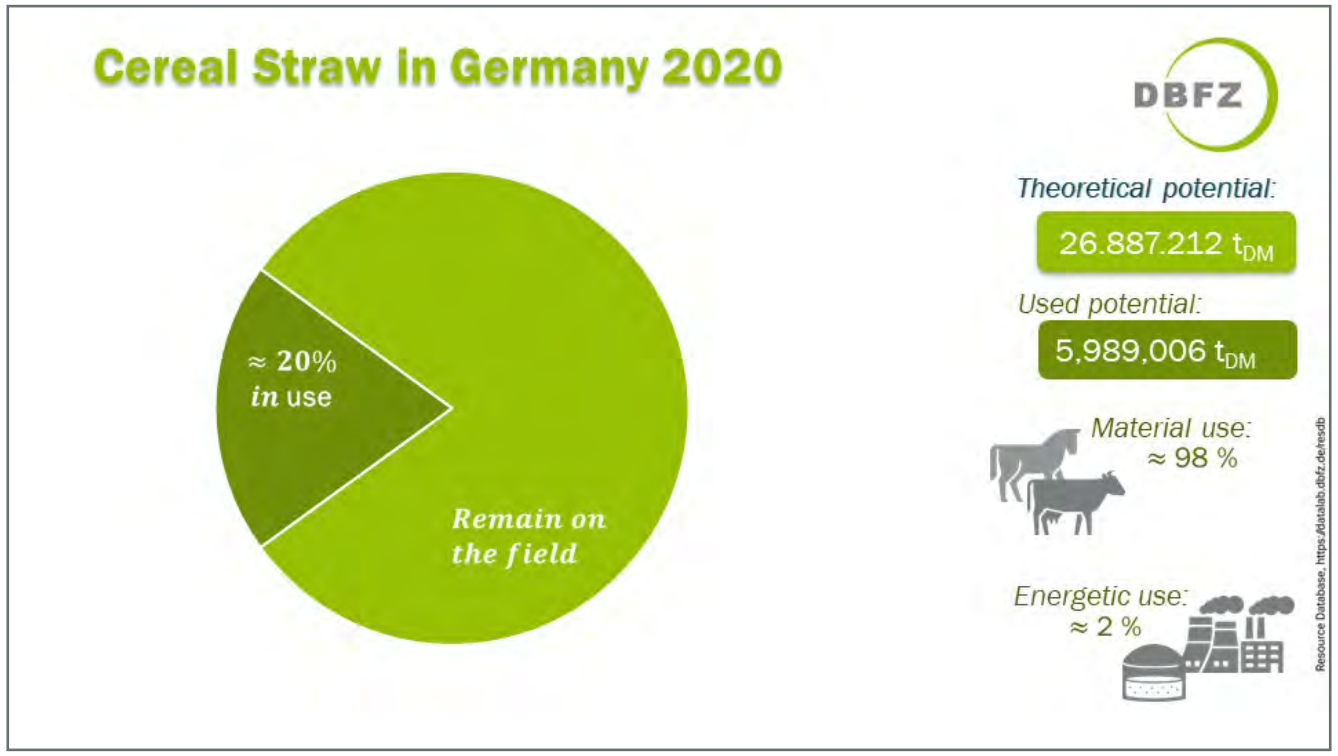
The framework emphasizes site-specific and management-sensitive socio-ecological indicators, such as soil organic carbon dynamics, fertilizer efficiency, erosion risk potential, GHG emissions, rural economic development, and crop yields, simulated via ecosystem models like APSIM Next Generation and DayCent. Publicly available geodata (e.g., SoilGrids, NASA Power, MODIS LandCover, DLR CropTypes) support location-specific modeling and sustainability assessment.

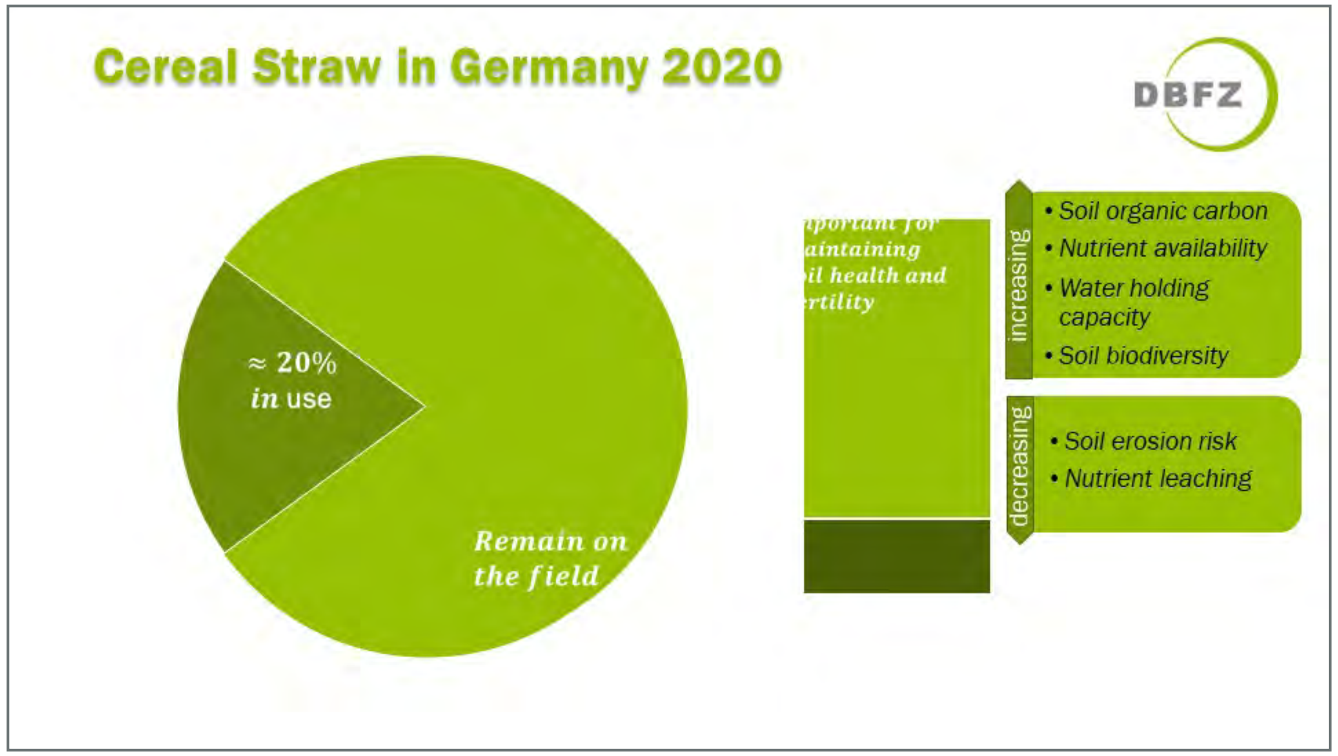
The model automates data input, scenario building, and simulation of different extraction rates and utilization options across whole crop rotations and can be applied to almost every single agricultural parcel in Germany. Scenarios include on-site straw retention, industrial applications and the potential return of processing residues (e.g., digestate, biochar) to the field, simulating potential mitigation effects of negative impacts caused by straw removal. Coupled with LCA databases (e.g. EcoInvent), the framework is tested in a proof-of-concept study.

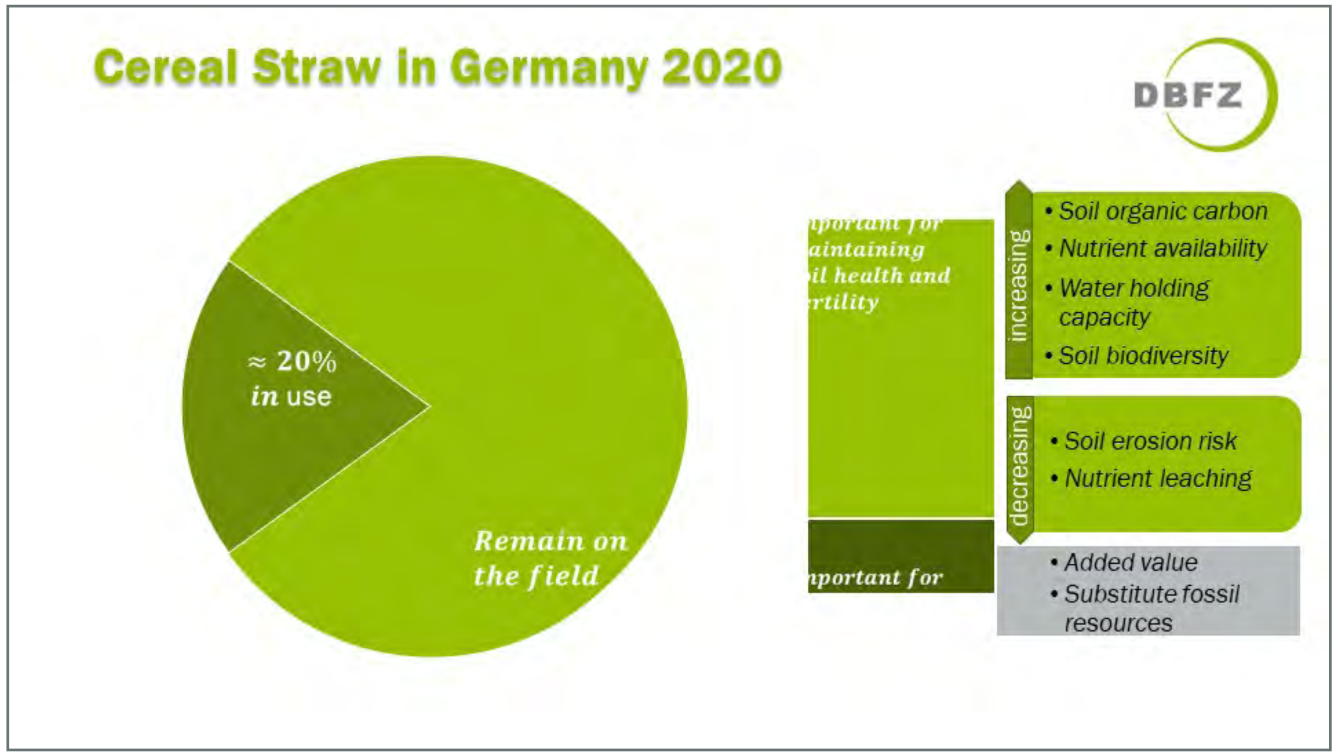


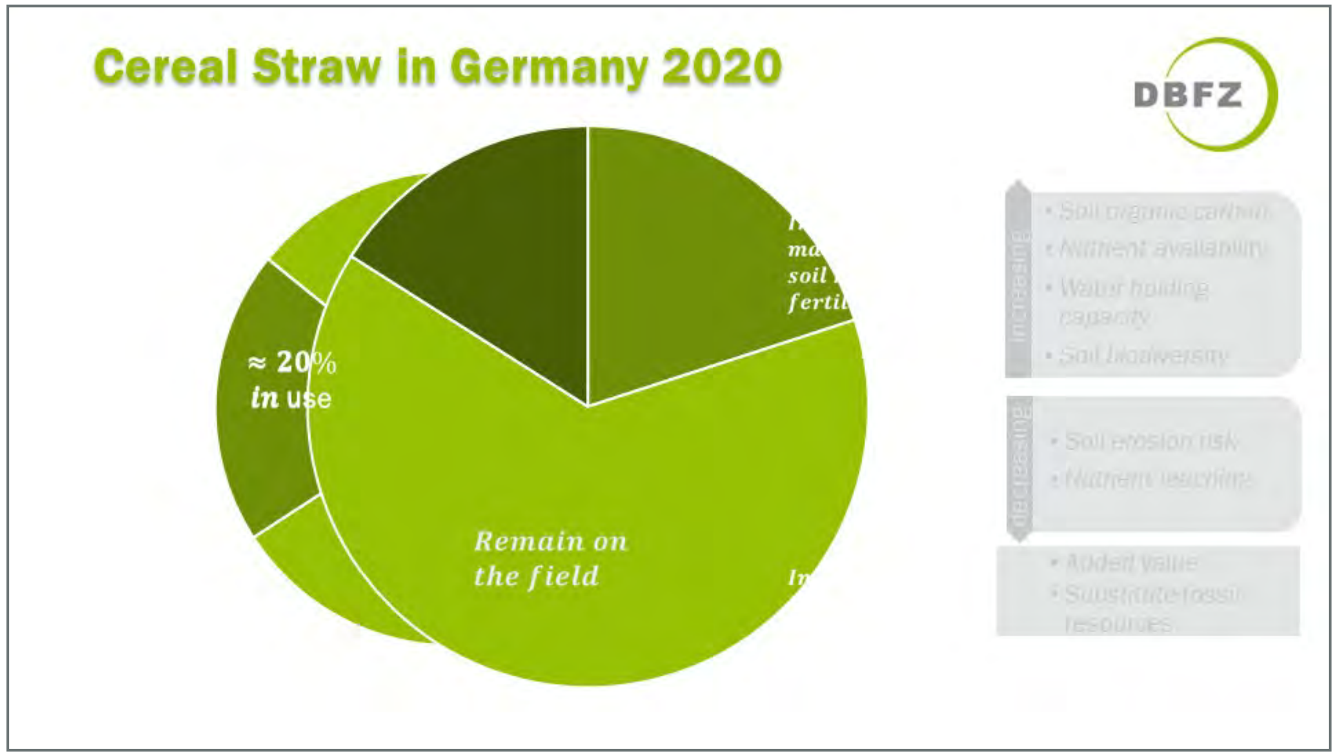

DBFZ
Is straw a sustainable resource?
... it depends


Cereal Straw in Germany 2020
DBFZ
Theoretical potential:
26.887.212 t_{DM}
Resource Database, https://datalab.dbfz.de/resdb


Cereal Straw in Germany 2020
DBFZ
≈ 20%
in use
Remain on
the field
Theoretical potential:
26.887.212 t_{DM}
Used potential:
5,989,006 t_{DM}
Material use:
≈ 98 %
Energetic use:
≈ 2 %
Resource Database, https://datalab.dbfz.de/resdb


Cereal Straw in Germany 2020
DBFZ
≈ 20%
in use
Remain on
the field
increasing
• Soil organic carbon
• Nutrient availability
• Water holding capacity
• Soil biodiversity
decreasing
• Soil erosion risk
• Nutrient leaching

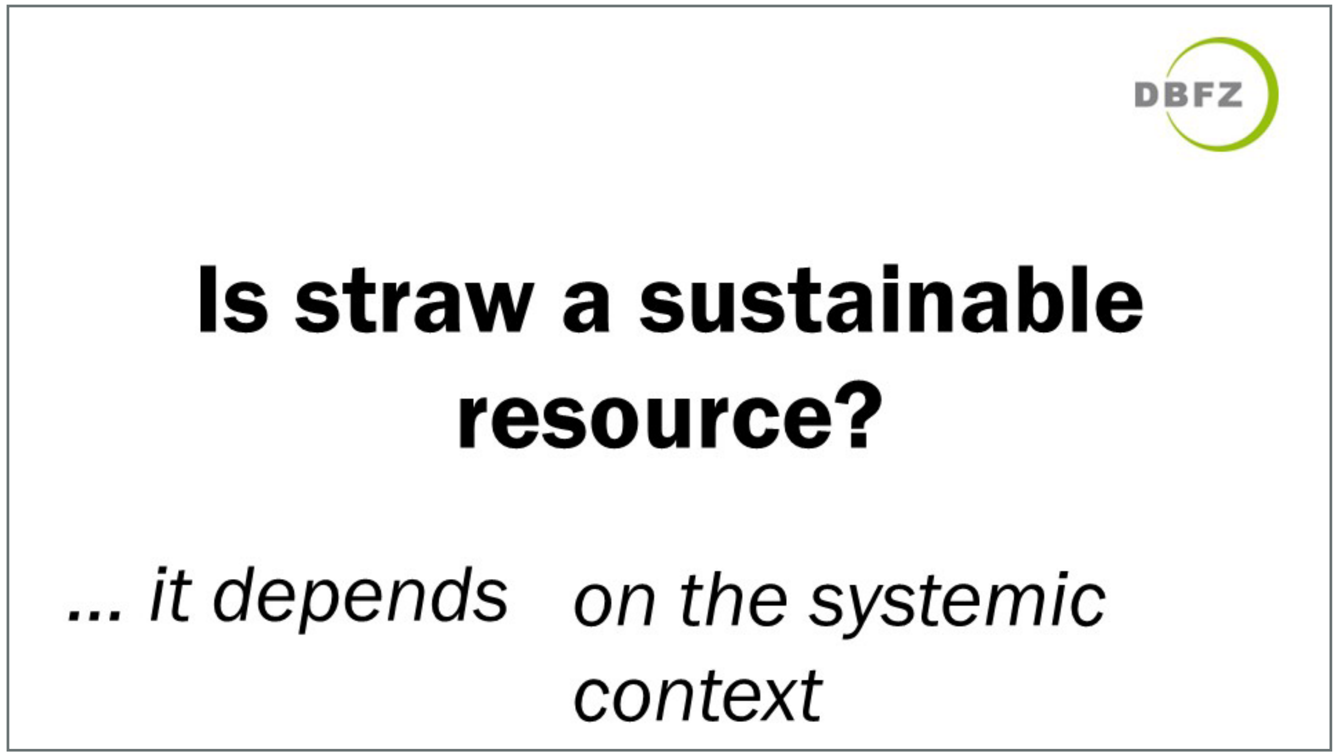

Cereal Straw in Germany 2020
DBFZ
≈ 20% in use
Remain on the field
increasing
• Soil organic carbon
• Nutrient availability
• Water holding capacity
• Soil biodiversity
decreasing
• Soil erosion risk
• Nutrient leaching
• Added value
• Substitute fossil resources

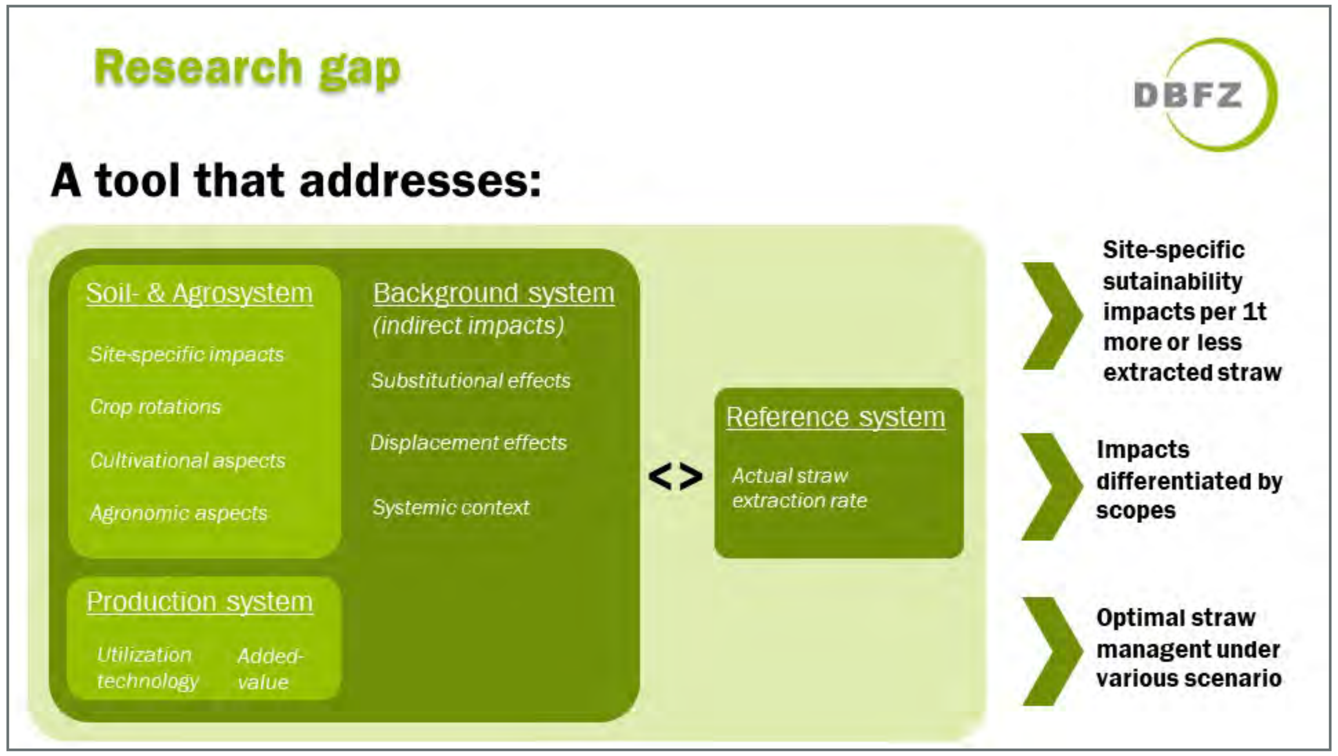

Cereal Straw in Germany 2020
DBFZ
≈ 20% in use
Remain on the field

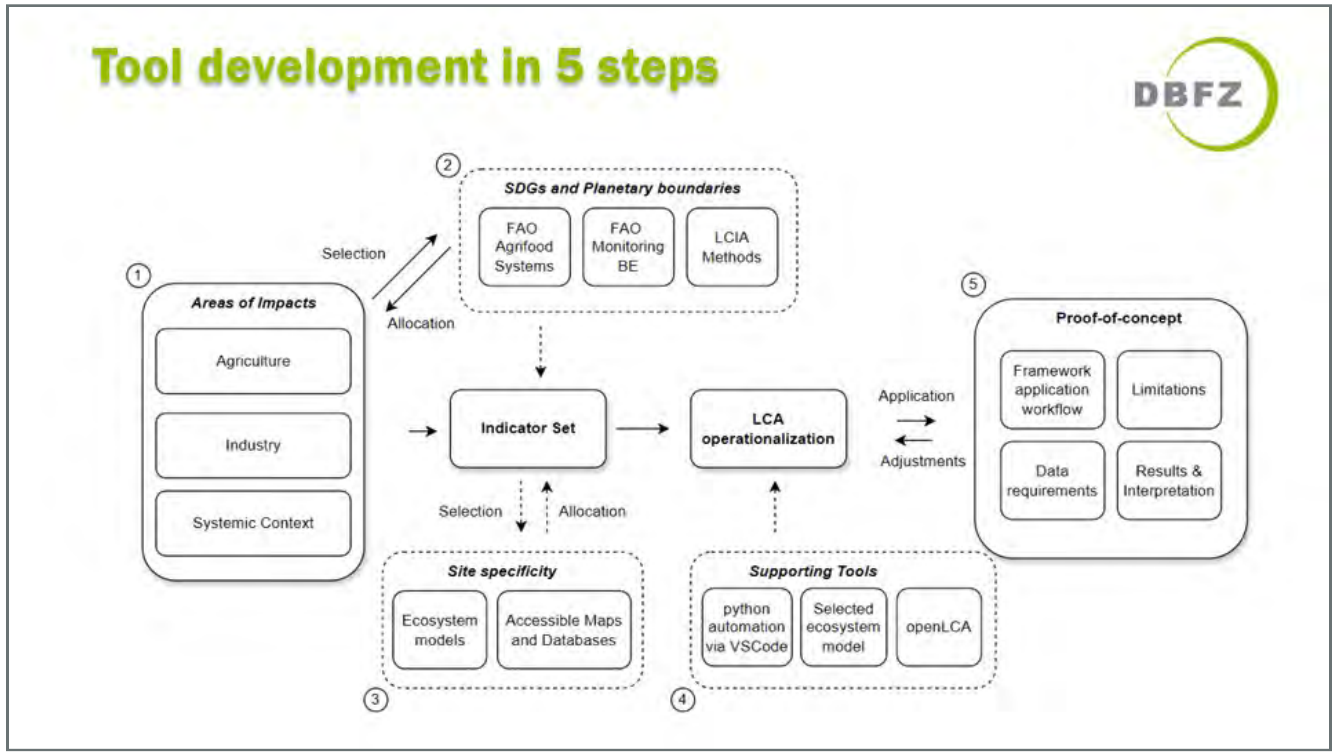

DBFZ
Is straw a sustainable resource?
... it depends

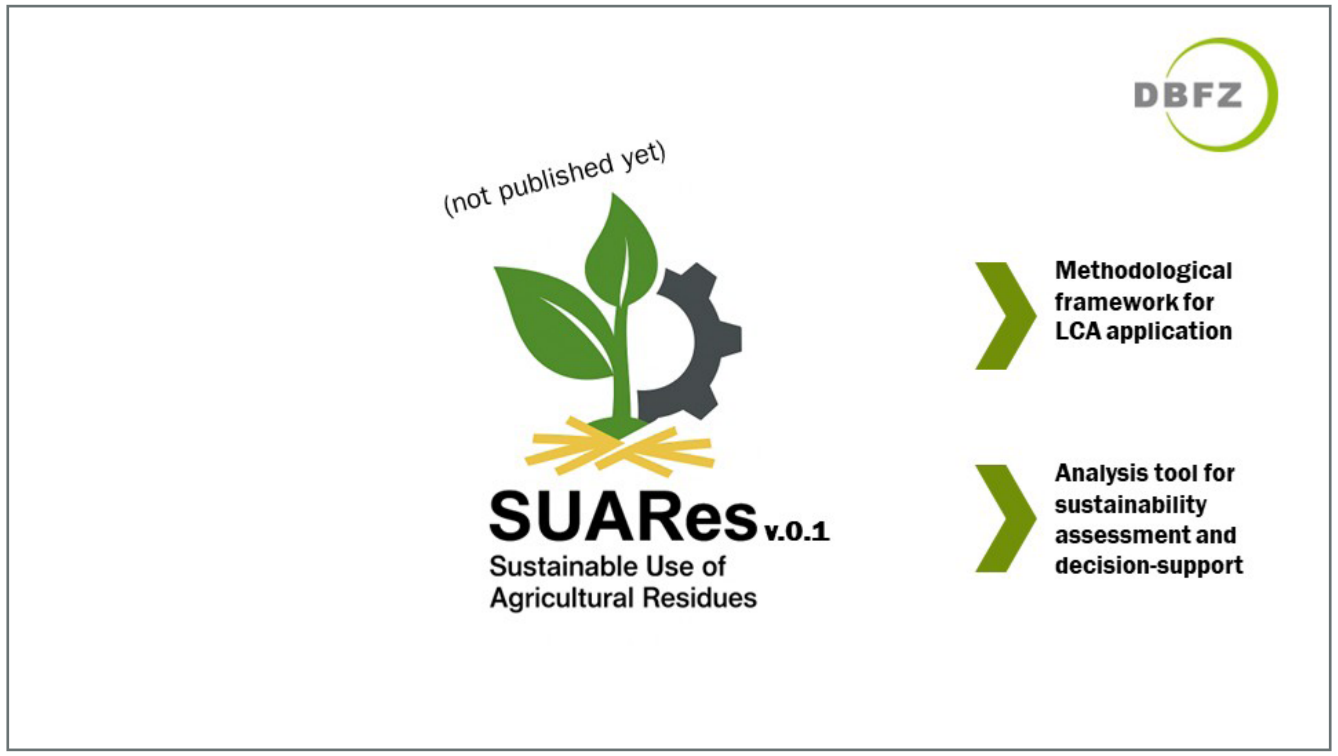

DBFZ
Is straw a sustainable resource?
... it depends on agricultural aspects

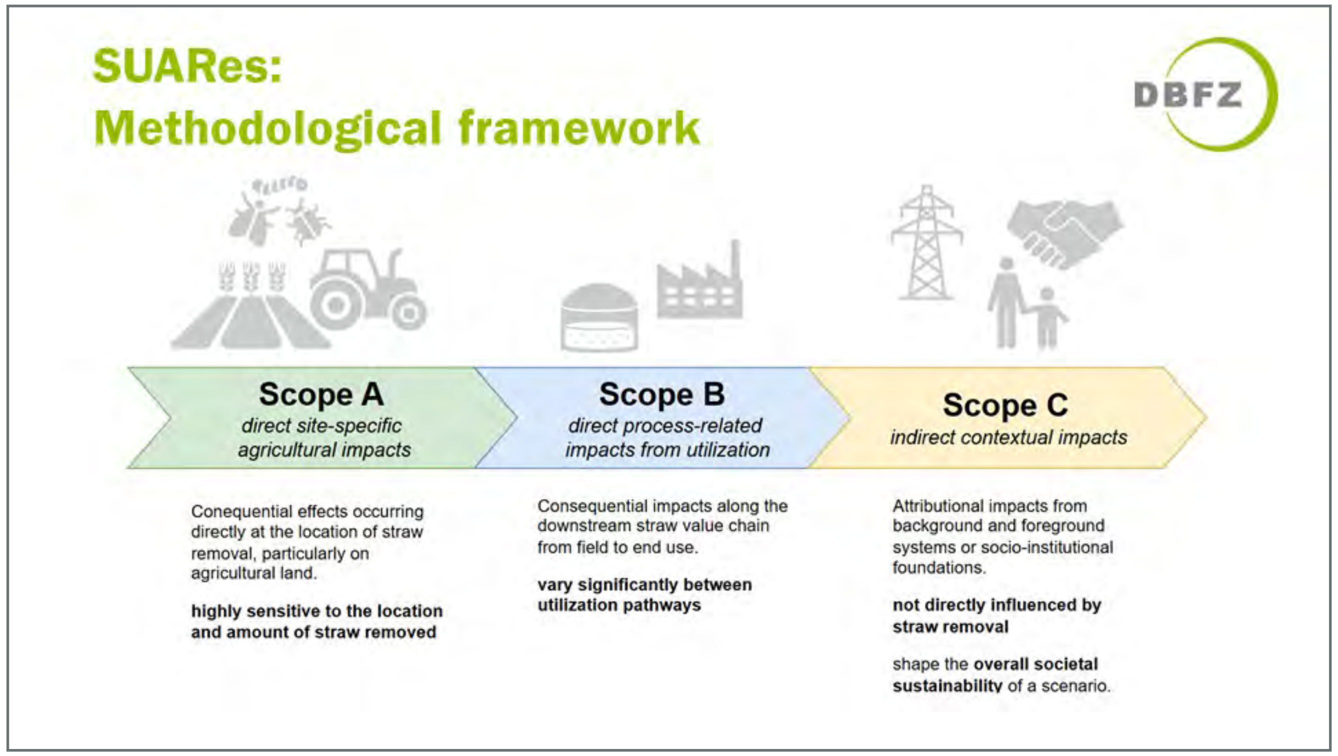

DBFZ
Is straw a sustainable resource?
… it depends
on utilization technologies

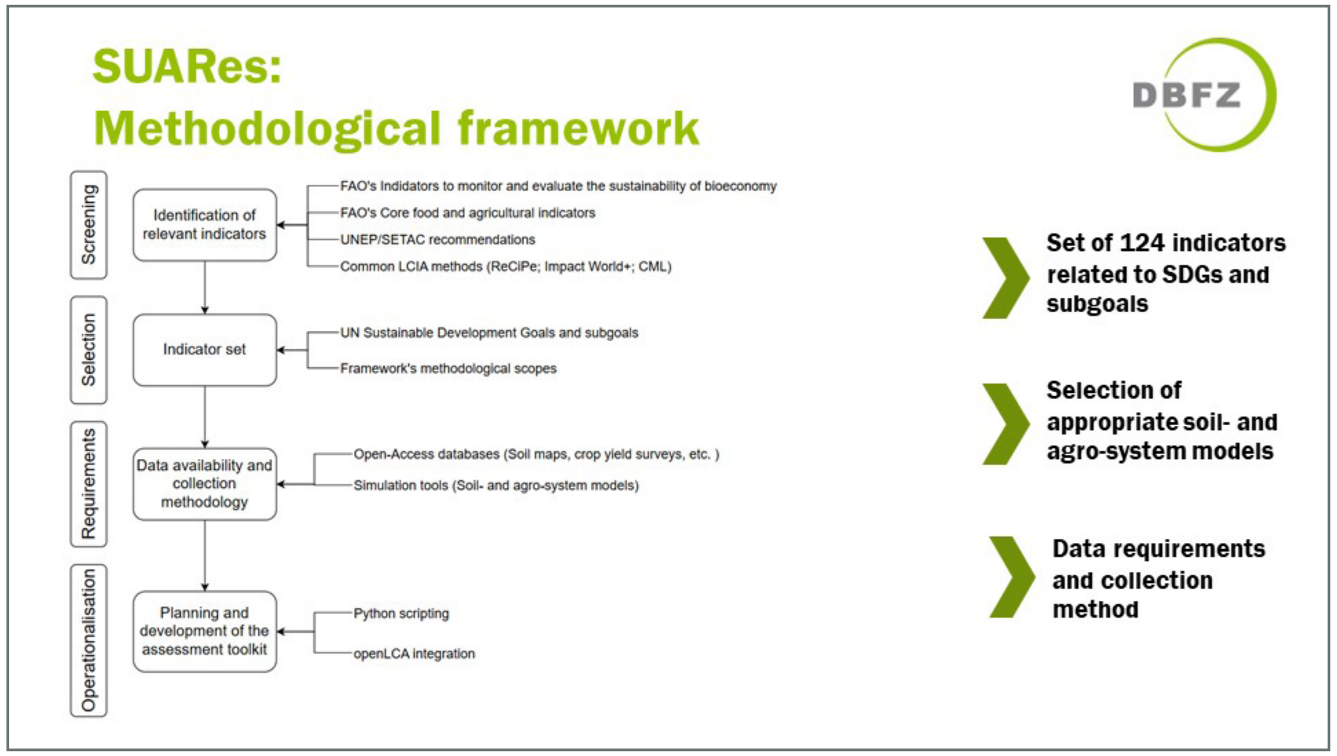

DBFZ
Is straw a sustainable resource?
… it depends
on the systemic context

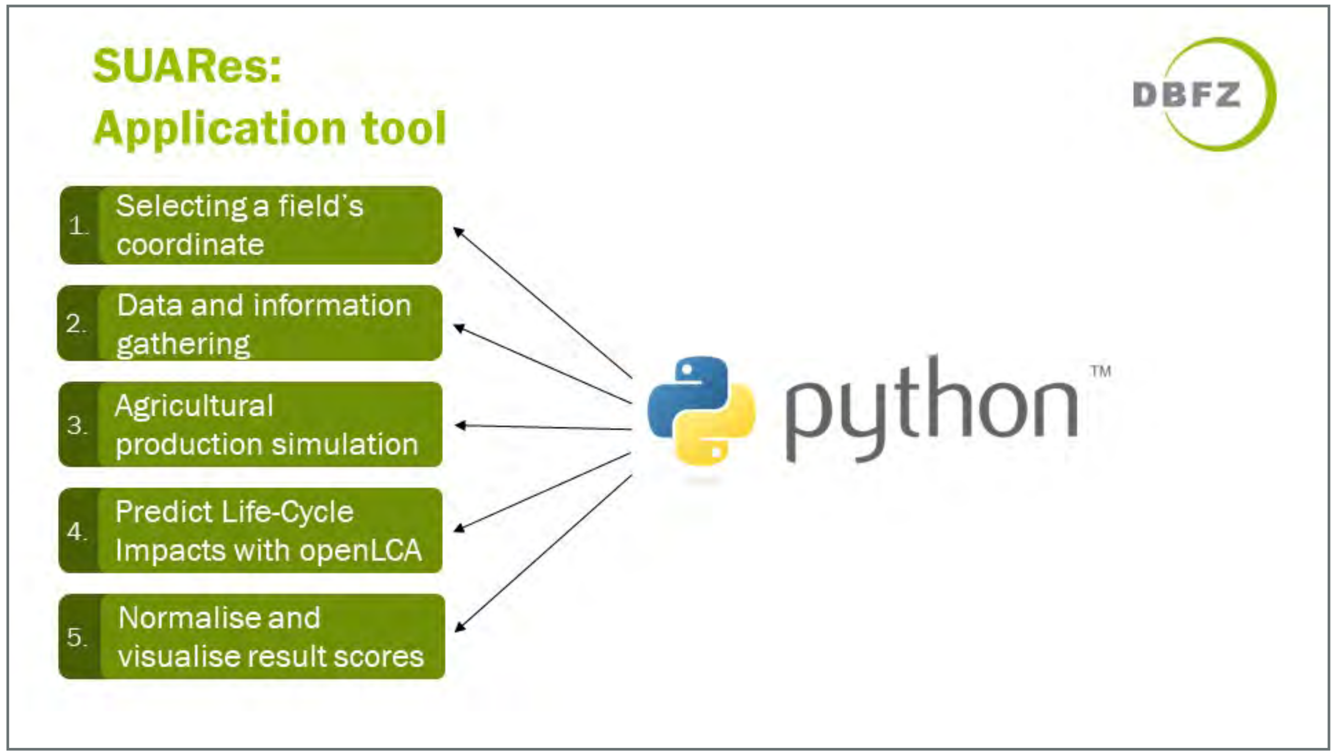

Research gap
DBFZ
A tool that addresses:
Soil- & Agrosystem
Site-specific impacts
Crop rotations
Cultivational aspects
Agronomic aspects
Background system (indirect impacts)
Substitutional effects
Displacement effects
Systemic context
Production system
Utilization technology
Added-value
<>
Reference system
Actual straw extraction rate
Site-specific sustainability impacts per 1t more or less extracted straw
Impacts differentiated by scopes
Optimal straw managent under various scenario

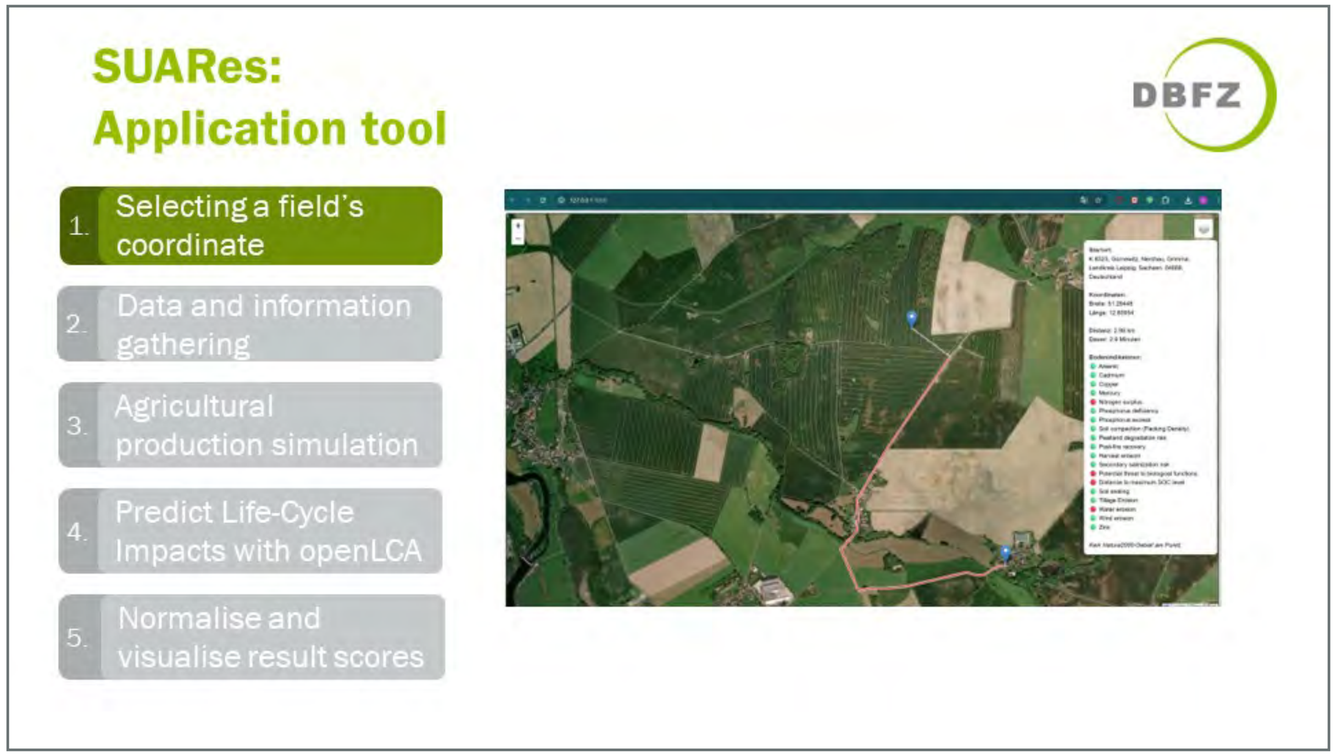

Tool development in 5 steps
DBFZ
1
Areas of Impacts
Agriculture
Industry
Systemic Context
Selection
Allocation
2
SDGs and Planetary boundaries
FAO Agrifood Systems
FAO Monitoring BE
LCIA Methods
Indicator Set
LCA operationalization
Selection
Allocation
3
Site specificity
Ecosystem models
Accessible Maps and Databases
4
Supporting Tools
python automation via VSCode
Selected ecosystem model
openLCA
Application
Adjustments
5
Proof-of-concept
Framework application workflow
Limitations
Data requirements
Results & Interpretation

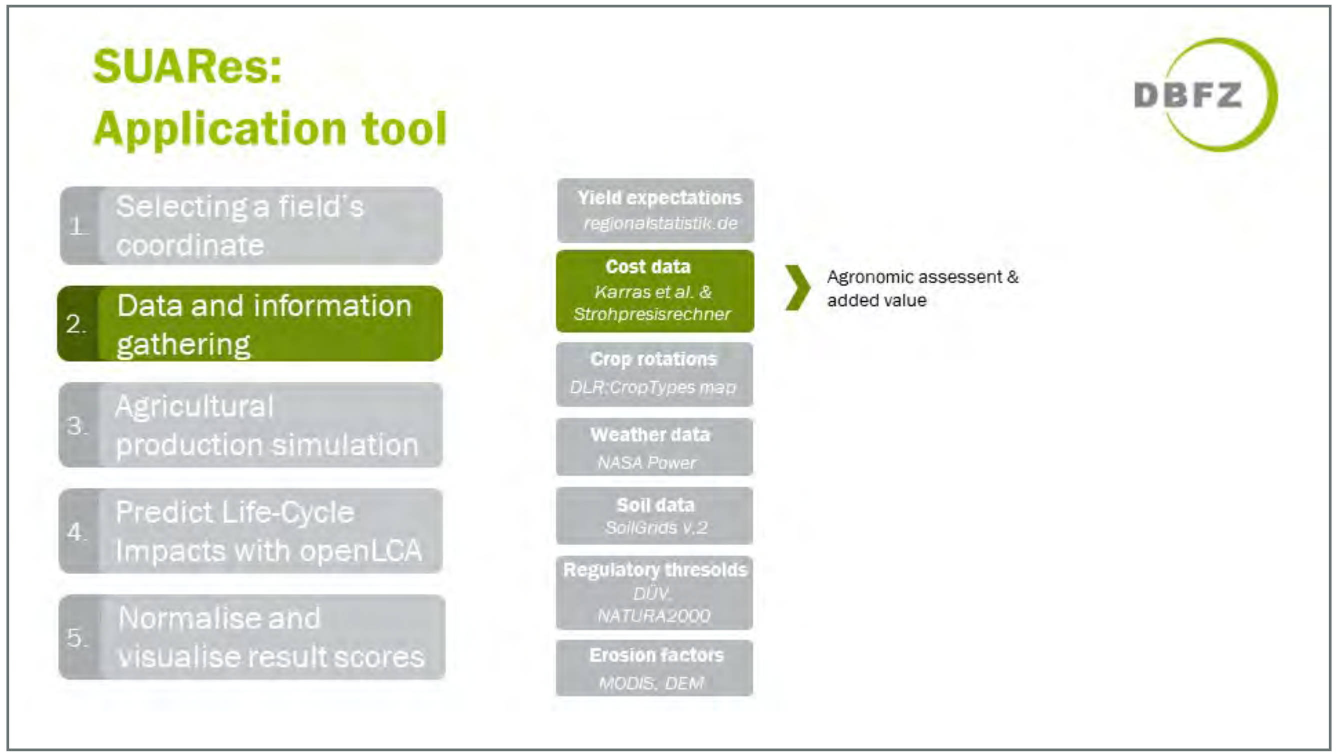

DBFZ
(not published yet)
SUAResv.0.1
Sustainable Use of Agricultural Residues
Methodological framework for LCA application
Analysis tool for sustainability assessment and decision-support

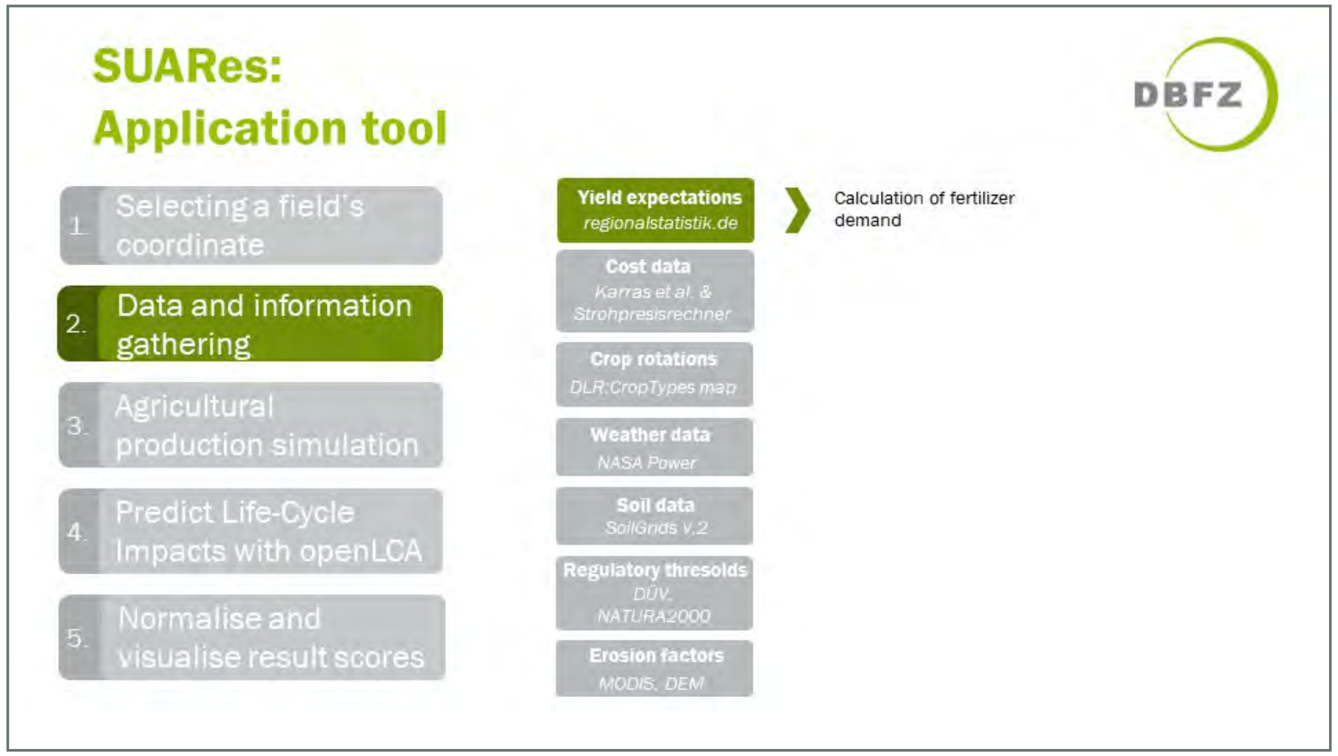

SUARes:
Methodological framework
DBFZ
Scope A
direct site-specific agricultural impacts
Scope B
direct process-related impacts from utilization
Scope C
indirect contextual impacts
Conequential effects occurring directly at the location of straw removal, particularly on agricultural land.
highly sensitive to the location and amount of straw removed
Consequential impacts along the downstream straw value chain from field to end use.
vary significantly between utilization pathways
Attributional impacts from background and foreground systems or socio-institutional foundations.
not directly influenced by straw removal
shape the overall societal sustainability of a scenario.

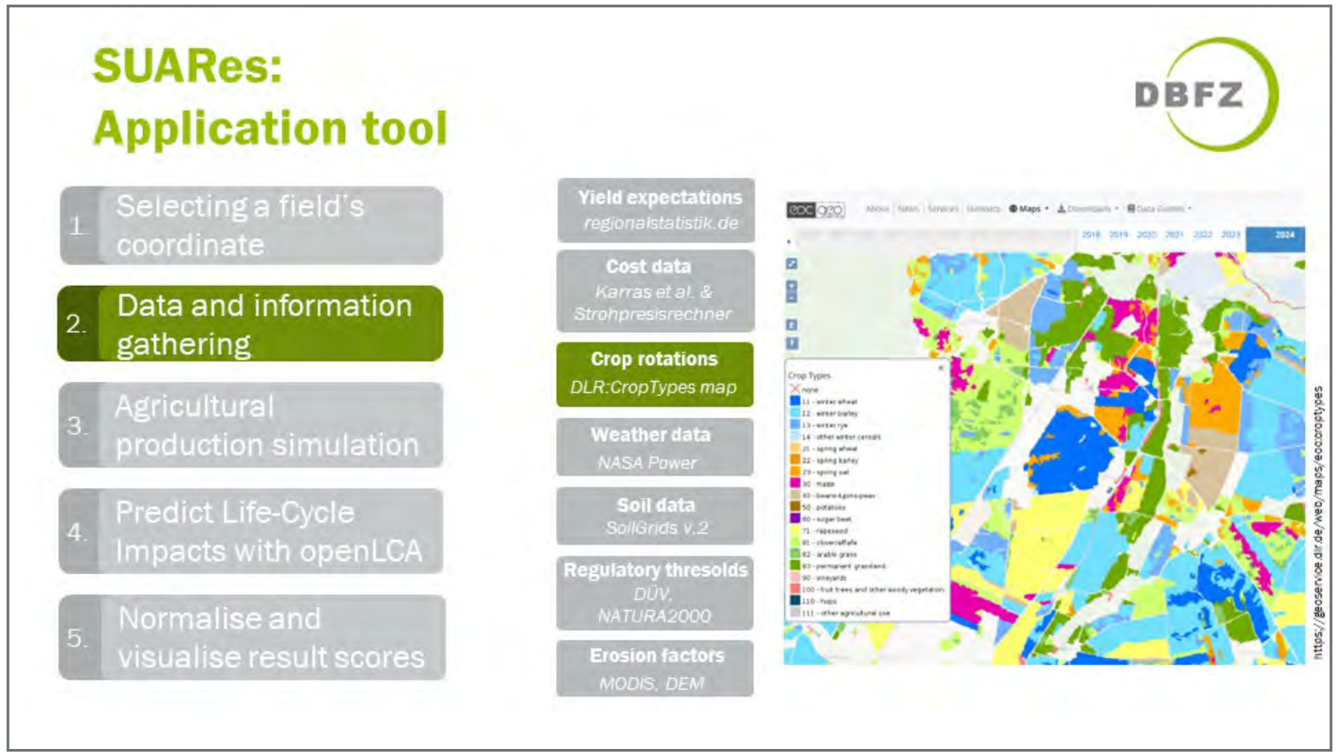

SUARes:
Methodological framework
DBFZ
Screening
Selection
Requirements
Operationalisation
Identification of relevant indicators
FAO's Indidators to monitor and evaluate the sustainability of bioeconomy
FAO's Core food and agricultural indicators
UNEP/SETAC recommendations
Common LCIA methods (ReCiPe; Impact World+; CML)
Indicator set
UN Sustainable Development Goals and subgoals
Framework's methodological scopes
Data availability and collection methodology
Open-Access databases (Soil maps, crop yield surveys, etc.)
Simulation tools (Soil- and agro-system models)
Planning and development of the assessment toolkit
Python scripting
openLCA integration
Set of 124 indicators related to SDGs and subgoals
Selection of appropriate soil- and agro-system models
Data requirements and collection method


SUARes:
Application tool
DBFZ
1. Selecting a field's coordinate
2. Data and information gathering
3. Agricultural production simulation
4. Predict Life-Cycle Impacts with openLCA
5. Normalise and visualise result scores
python™

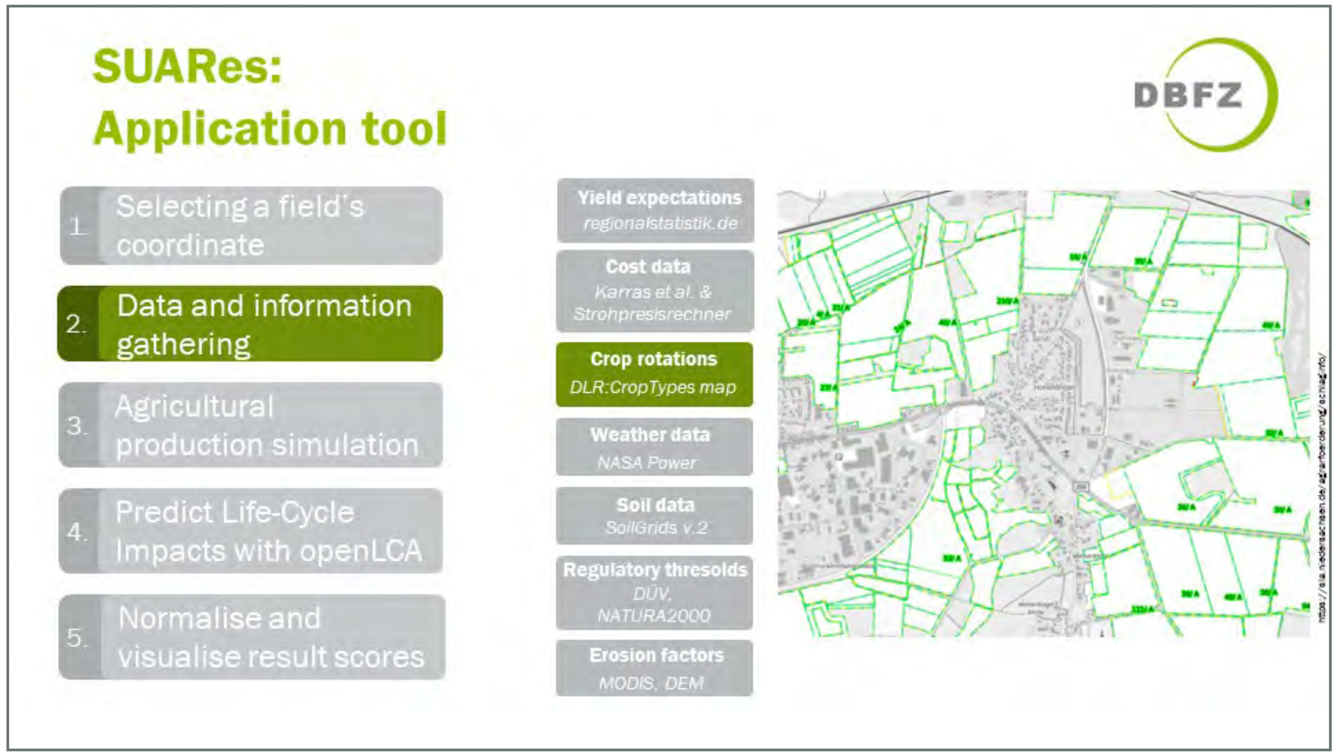


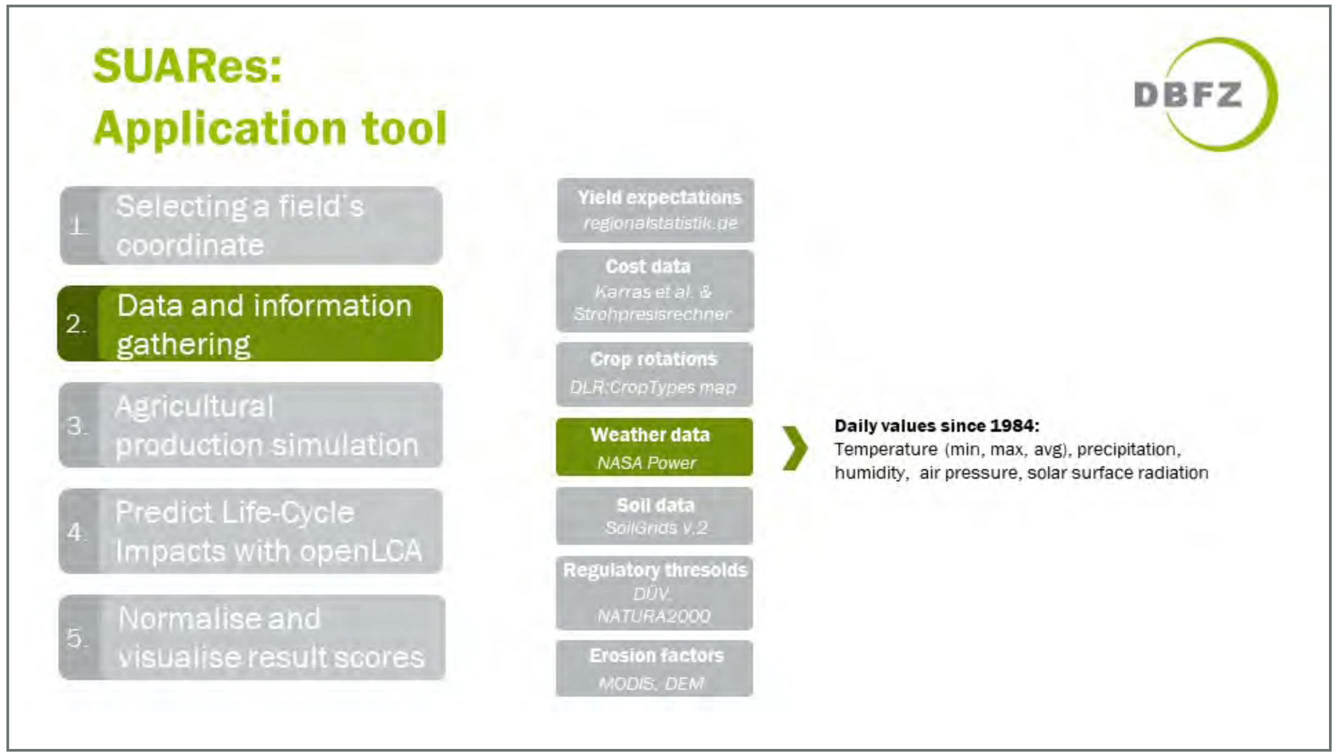






8TH DOCTORAL COLLOQUIUM BIOENERGY AND BIOBASED PRODUCTS


SUARes:
Application tool
1. Selecting a field's coordinate
2. Data and information gathering
3. Agricultural production simulation
4. Predict Life-Cycle Impacts with openLCA
5. Normalise and visualise result scores
Yield expectations
regionalstatistik.de
Cost data
Karras et al. & Strohpreisrechner
Crop rotations
DLR:CropTypes map
Weather data
NASA Power
Soil data
SoilGrids v.2
Regulatory thesolds
DÜV, NATURA2000
Erosion factors
MODIS, DEM


SUARes:
Application tool
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Yield expectations
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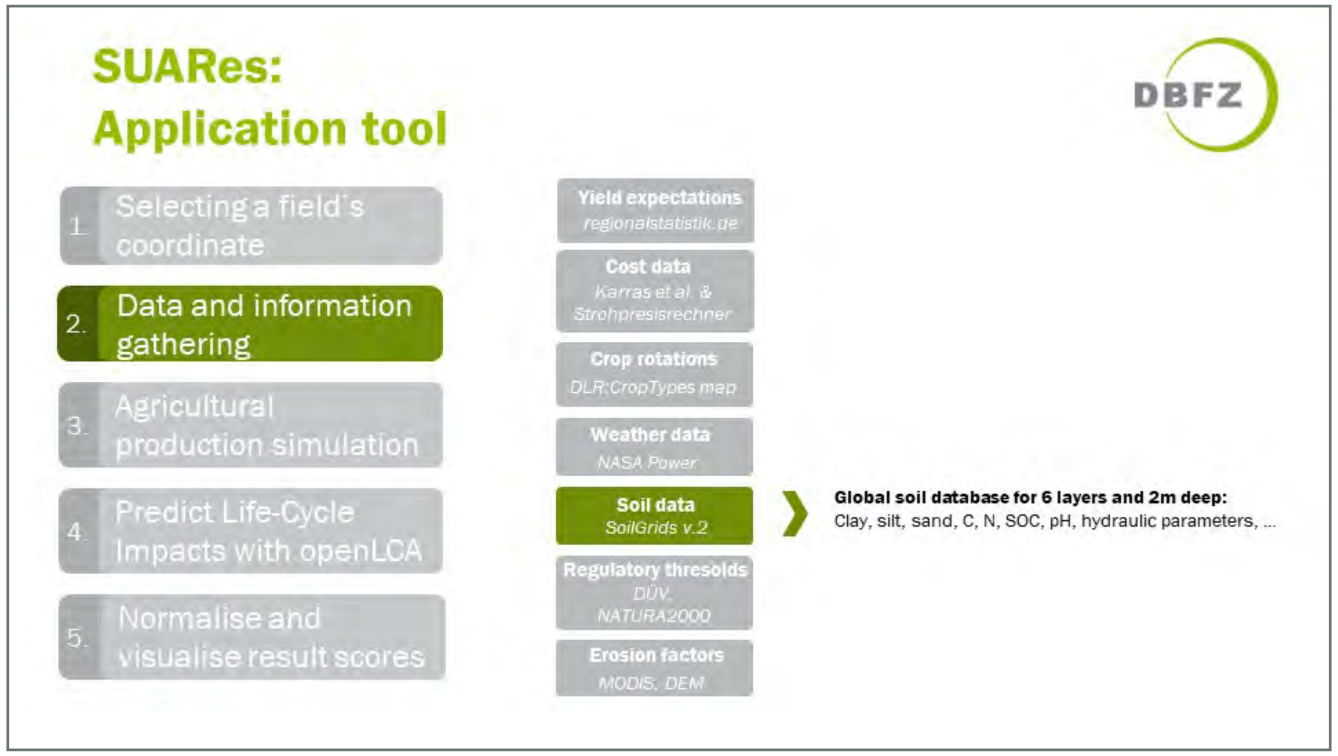
Weather data
NASA Power
Soil data
SoilGrids v.2
Regulatory thesolds
DÜV, NATURA2000
Erosion factors
MODIS, DEM
Daily values since 1984:
Temperature (min, max, avg), precipitation, humidity, air pressure, solar surface radiation


SUARes:
Application tool
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Yield expectations
regionalstatistik.de
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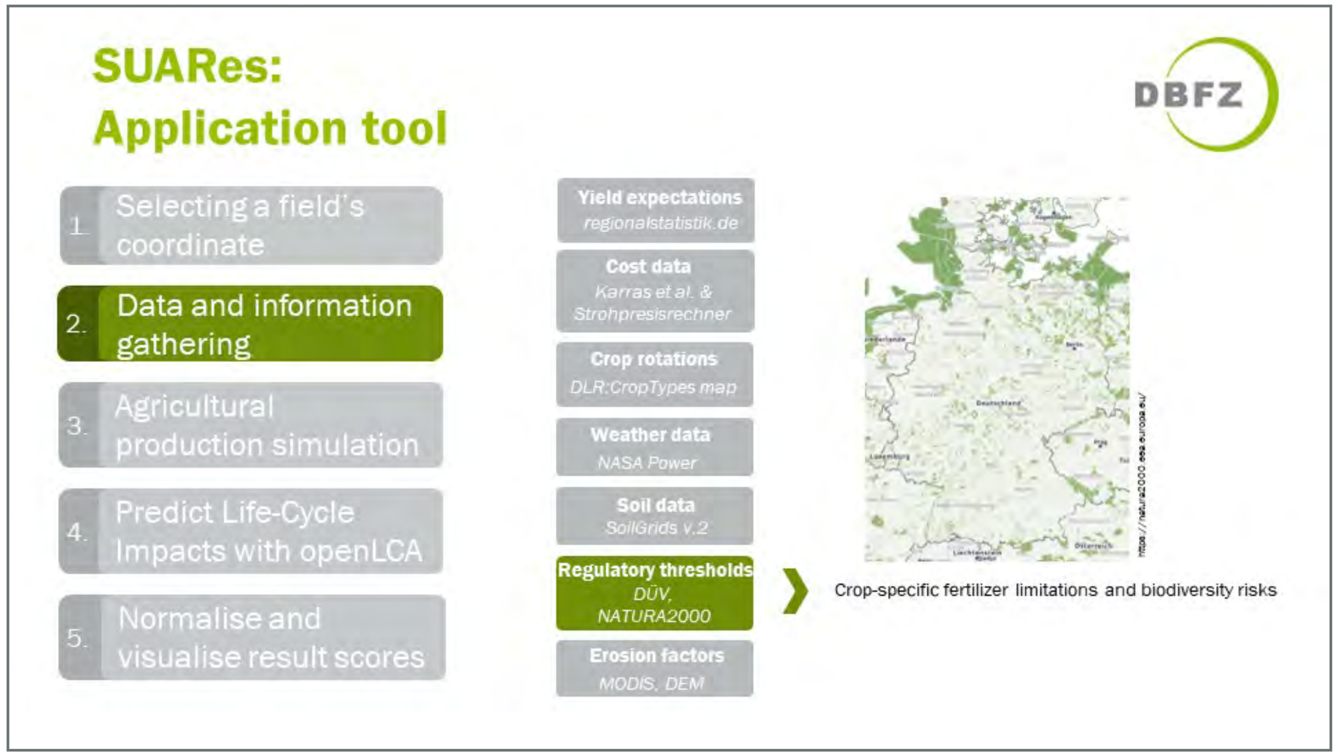
Karras et al. & Strohpreisrechner
Crop rotations
DLR:CropTypes map
Weather data
NASA Power
Soil data
SoilGrids v.2
Regulatory thesolds
DÜV, NATURA2000
Erosion factors
MODIS, DEM
Global soil database for 6 layers and 2m deep:
Clay, silt, sand, C, N, SOC, pH, hydraulic parameters, ...


SUARes:
Application tool
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regionalstatistik.de
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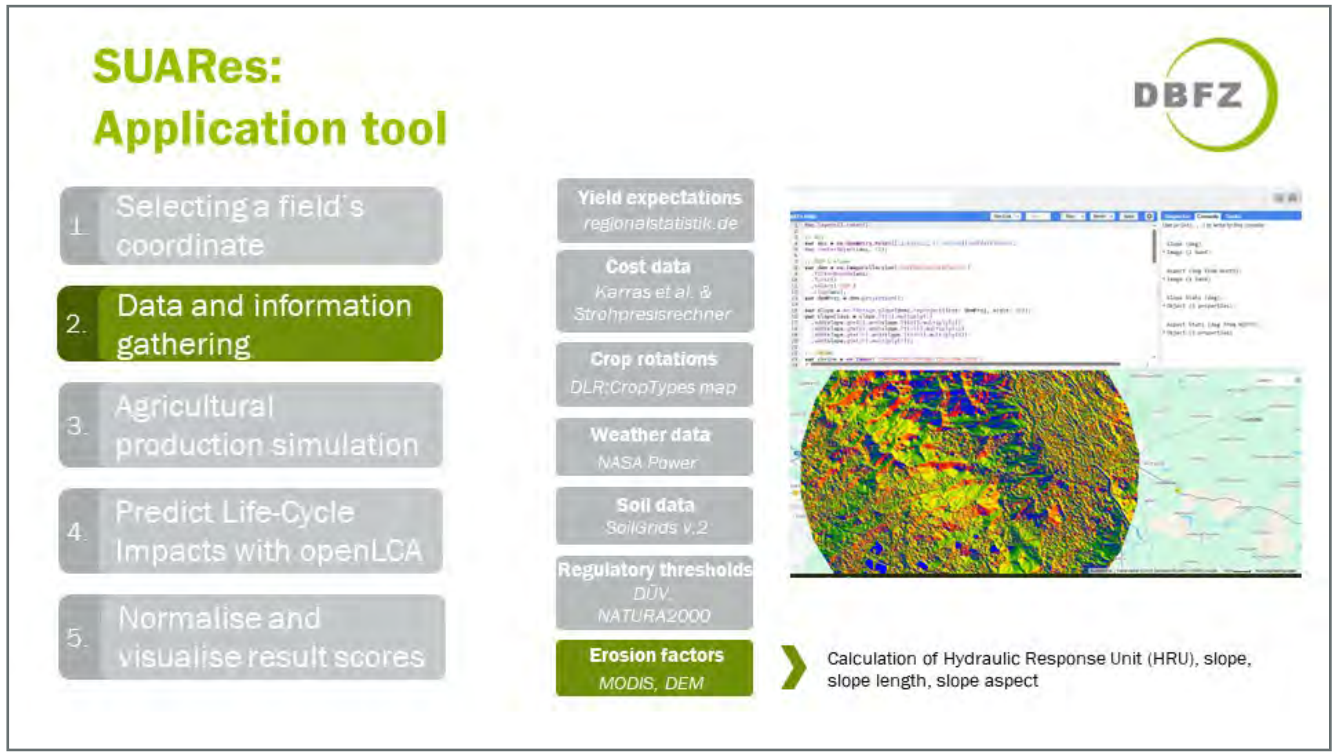
Karras et al. & Strohpreisrechner
Crop rotations
DLR:CropTypes map
Weather data
NASA Power
Soil data
SoilGrids v.2
Regulatory thresholds
DÜV, NATURA2000
Erosion factors
MODIS, DEM
Crop-specific fertilizer limitations and biodiversity risks


SUARes:
Application tool
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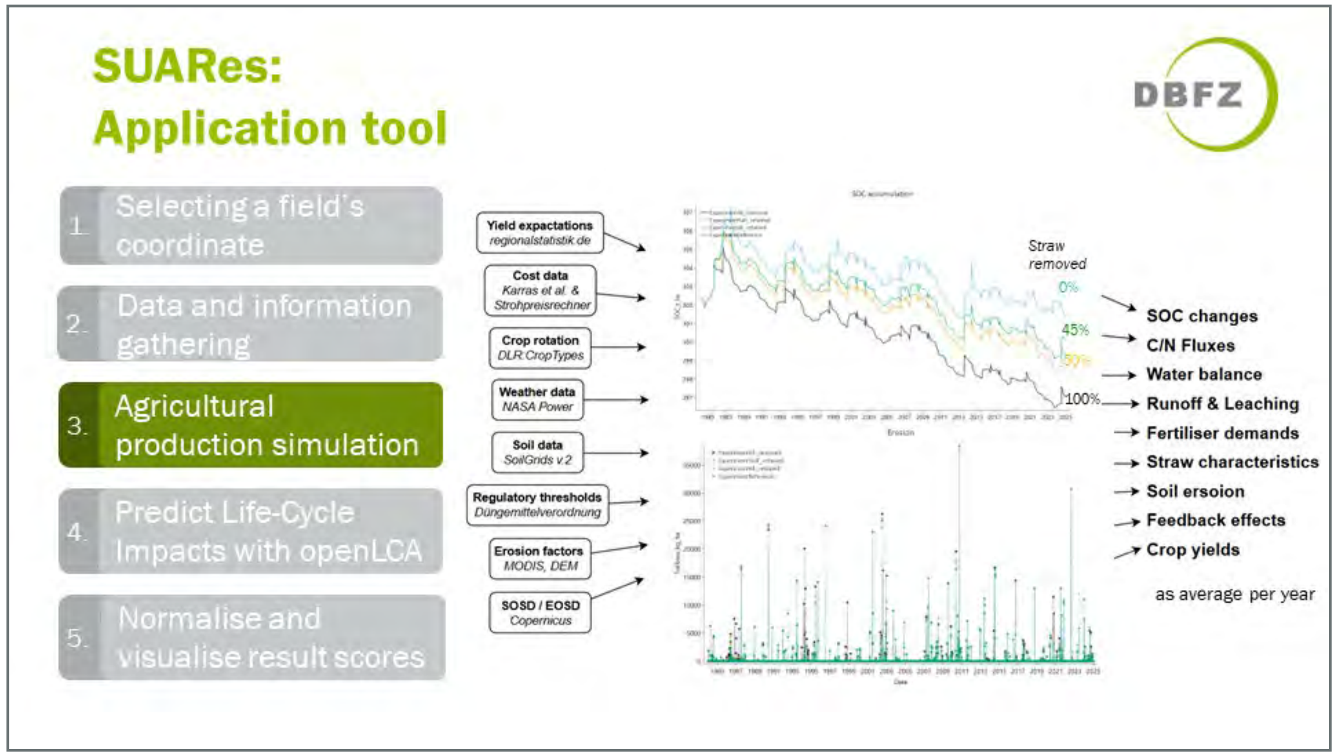
4. Predict Life-Cycle Impacts with openLCA
5. Normalise and visualise result scores
Yield expectations
regionalstatistik.de
Cost data
Karras et al. &
Strohpresisrechner
Crop rotations
DLR:CropTypes map
Weather data
NASA Power
Soil data
SoilGrids v.2
Regulatory thresholds
DÜV,
NATURA2000
Erosion factors
MODIS, DEM
Calculation of Hydraulic Response Unit (HRU), slope, slope length, slope aspect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Application tool
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1. Selecting a field's coordinate
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Yield expectations
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Crop rotation
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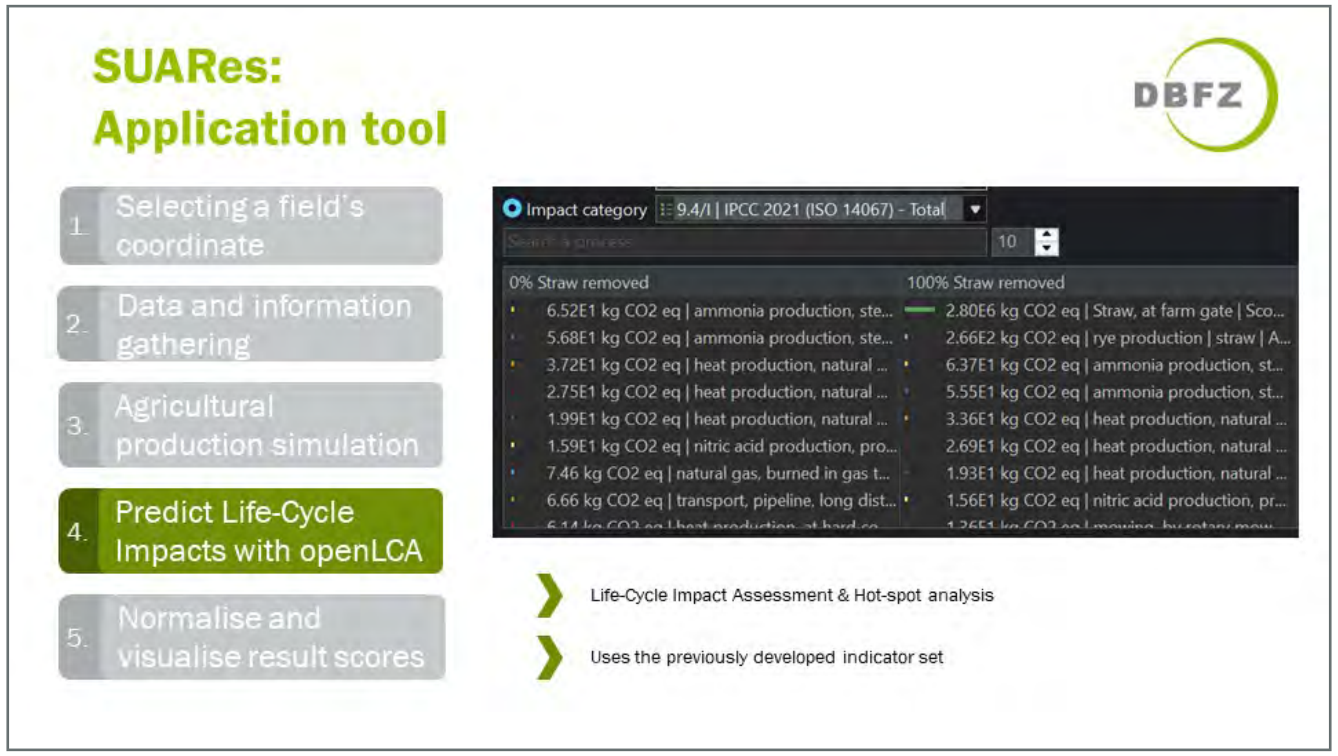
Weather data
NASA Power
Soil data
SoilGrids v.2
Regulatory thresholds
Düngemittelverordnung
Erosion factors
MODIS, DEM
SOSD / EOSD
Copernicus
Straw removed
0%
45%
50%
100%
SOC changes
C/N Fluxes
Water balance
Runoff & Leaching
Fertiliser demands
Straw characteristics
Soil ersoion
Feedback effects
Crop yields
as average per year


SUARes:
Application tool
DBFZ
1. Selecting a field's coordinate
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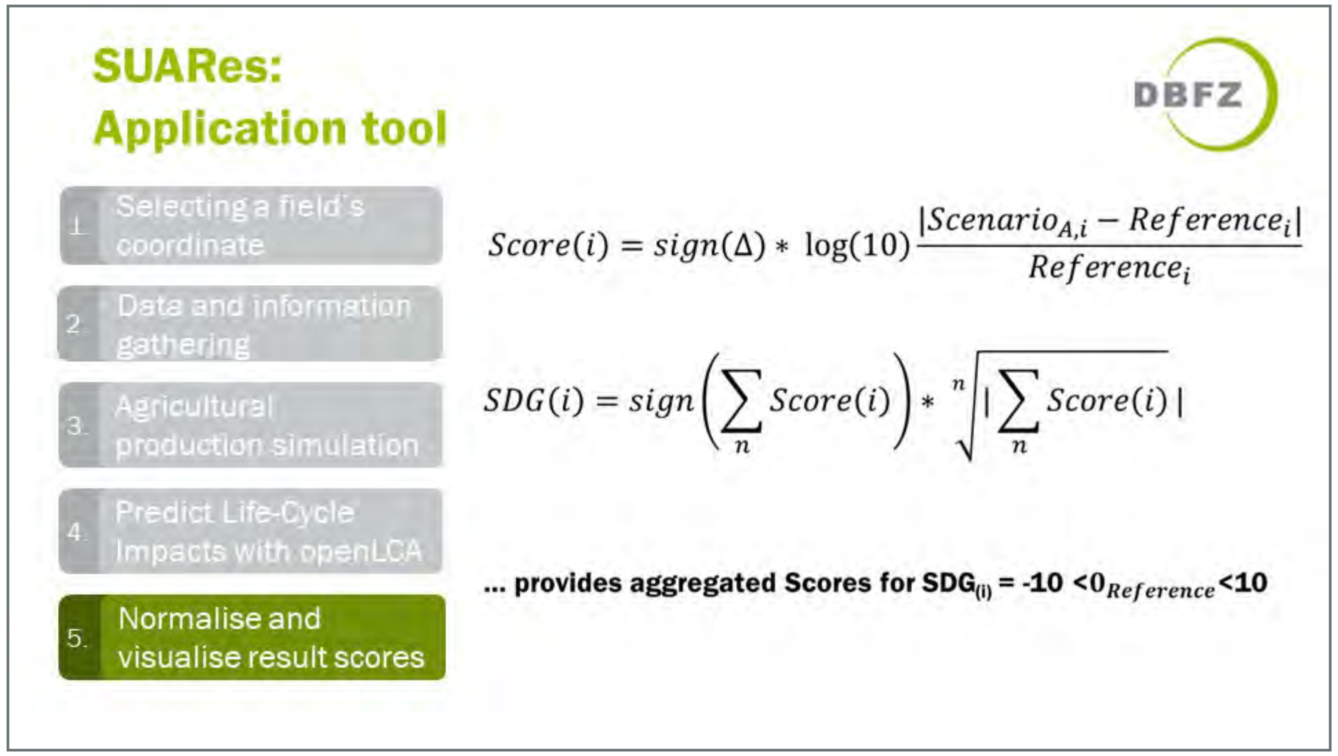
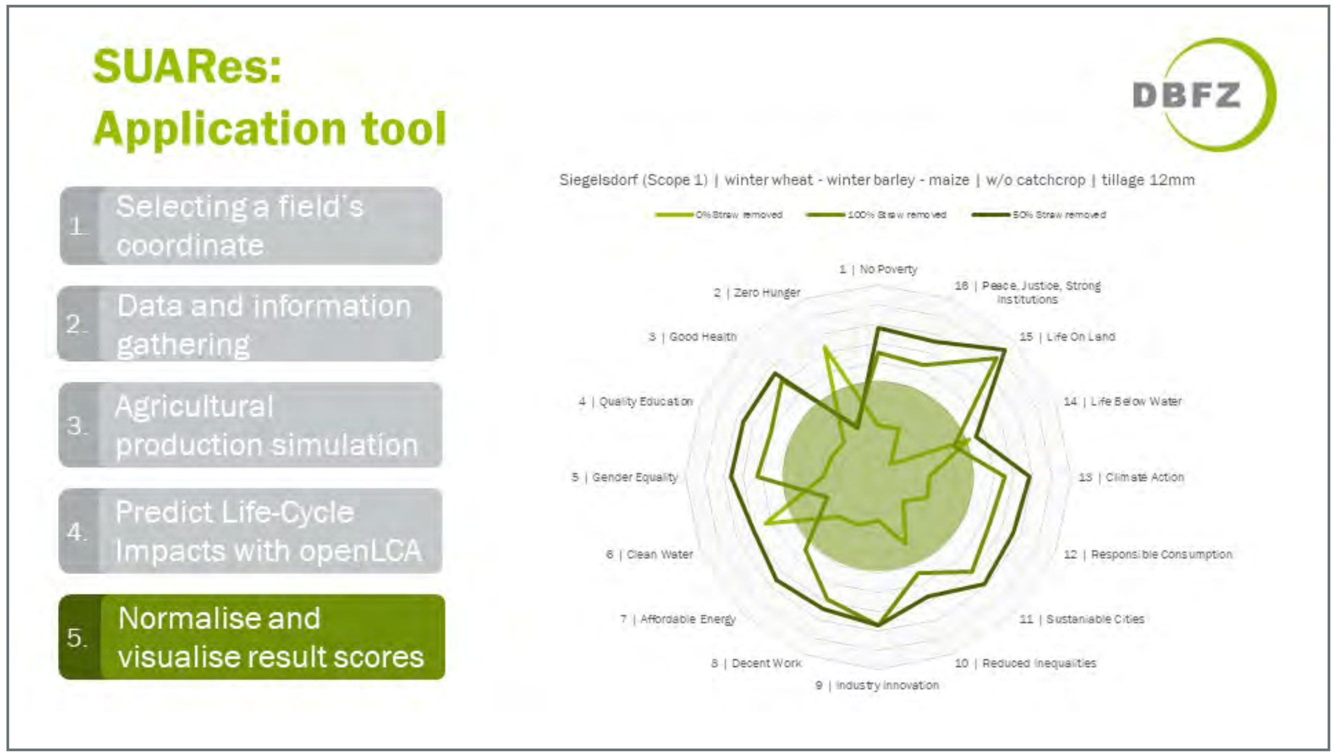
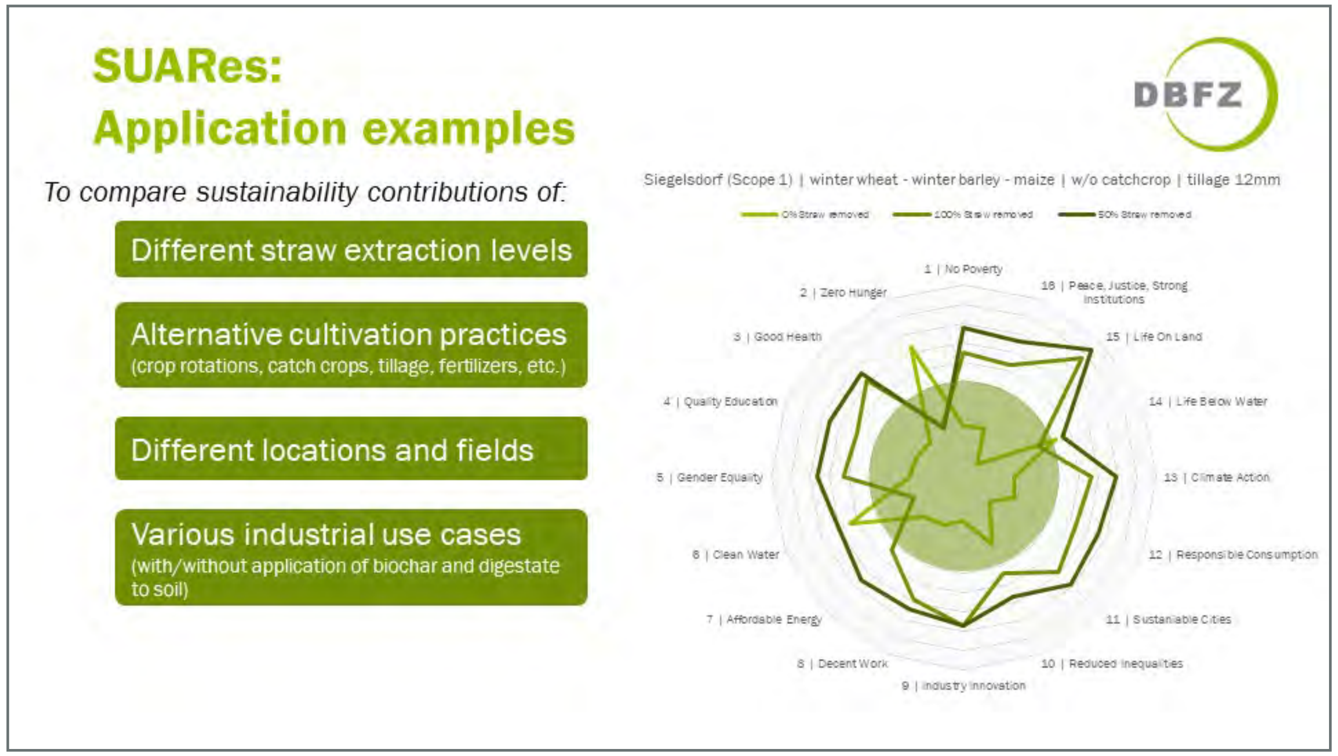
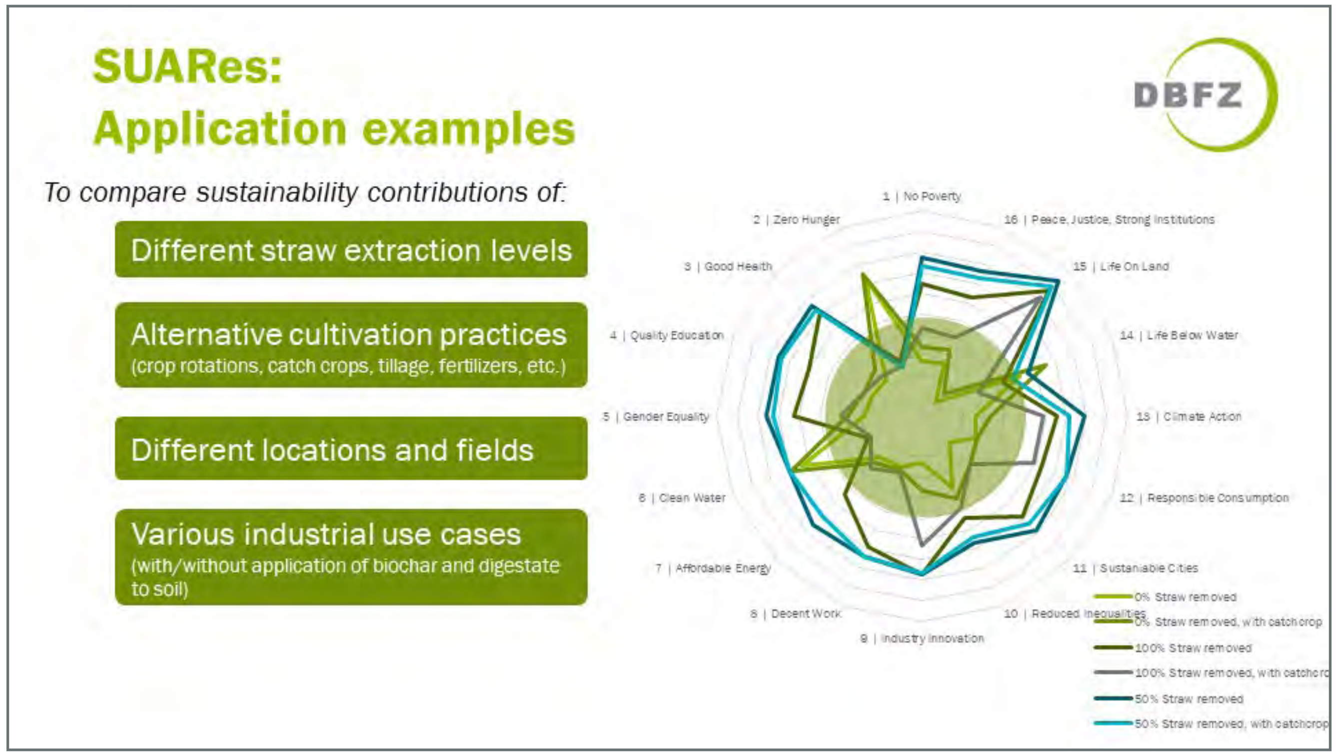
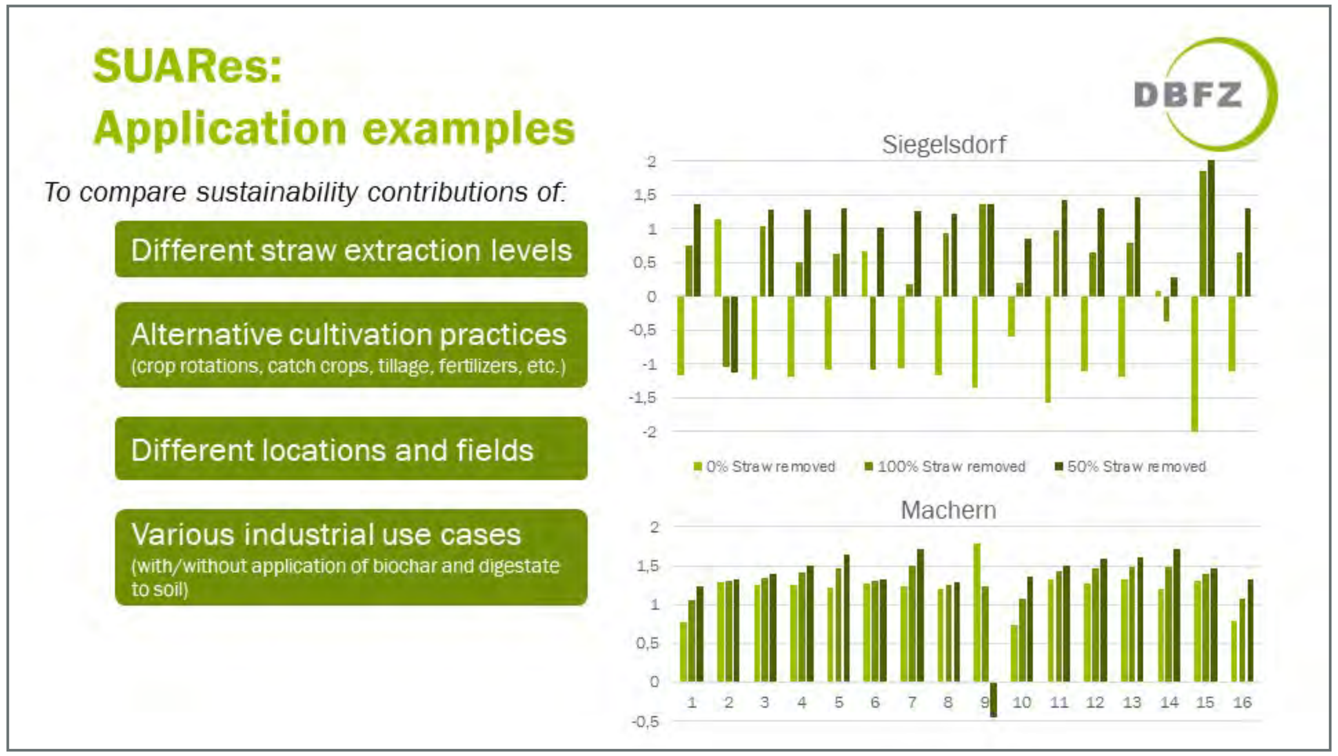
3. Agricultural production simulation
4. Predict Life-Cycle Impacts with openLCA
5. Normalise and visualise result scores
Impact category 9.4/I | IPCC 2021 (ISO 14067) - Total
10
0% Straw removed
6.52E1 kg CO2 eq | ammonia production, ste...
5.68E1 kg CO2 eq | ammonia production, ste...
3.72E1 kg CO2 eq | heat production, natural ...
2.75E1 kg CO2 eq | heat production, natural ...
1.99E1 kg CO2 eq | heat production, natural ...
1.59E1 kg CO2 eq | nitric acid production, pro...
7.46 kg CO2 eq | natural gas, burned in gas t...
6.66 kg CO2 eq | transport, pipeline, long dist...
100% Straw removed
2.80E6 kg CO2 eq | Straw, at farm gate | Sco...
2.66E2 kg CO2 eq | rye production | straw | A...
6.37E1 kg CO2 eq | ammonia production, st...
5.55E1 kg CO2 eq | ammonia production, st...
3.36E1 kg CO2 eq | heat production, natural ...
2.69E1 kg CO2 eq | heat production, natural ...
1.93E1 kg CO2 eq | heat production, natural ...
1.56E1 kg CO2 eq | nitric acid production, pr...
Life-Cycle Impact Assessment & Hot-spot analysis
Uses the previously developed indicator set


SUARes:
Application tool
DBFZ
1. Selecting a field's coordinate
2. Data and information gathering
3. Agricultural production simulation
4. Predict Life-Cycle Impacts with openLCA
5. Normalise and visualise result scores
$Score(i) = sign(\Delta) * \log(10) \frac{|Scenario_{A,i} - Reference_i|}{Reference_i}$
$SDG(i) = sign\left(\sum_n Score(i)\right) * \sqrt[n]{|\sum_n Score(i)|}$
... provides aggregated Scores for $SDG_{(i)}$ = -10 < $0_{Reference}$ < 10

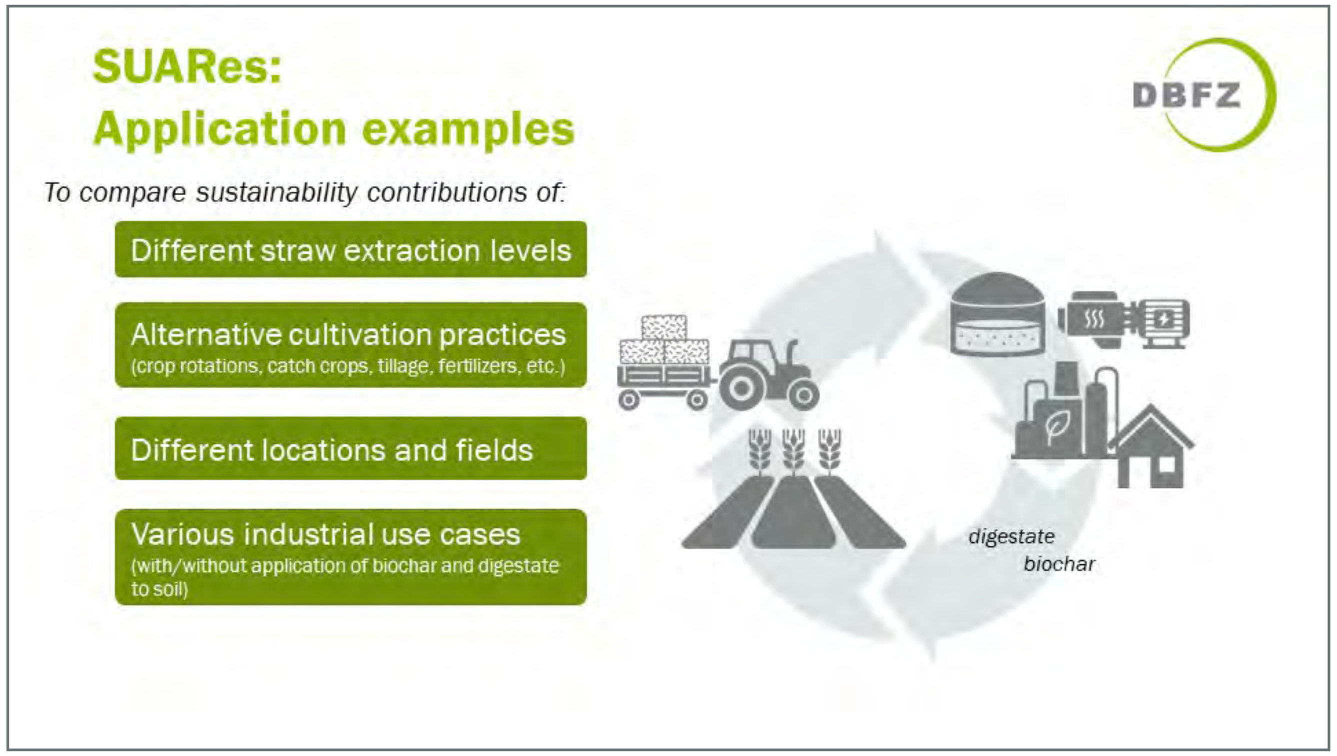


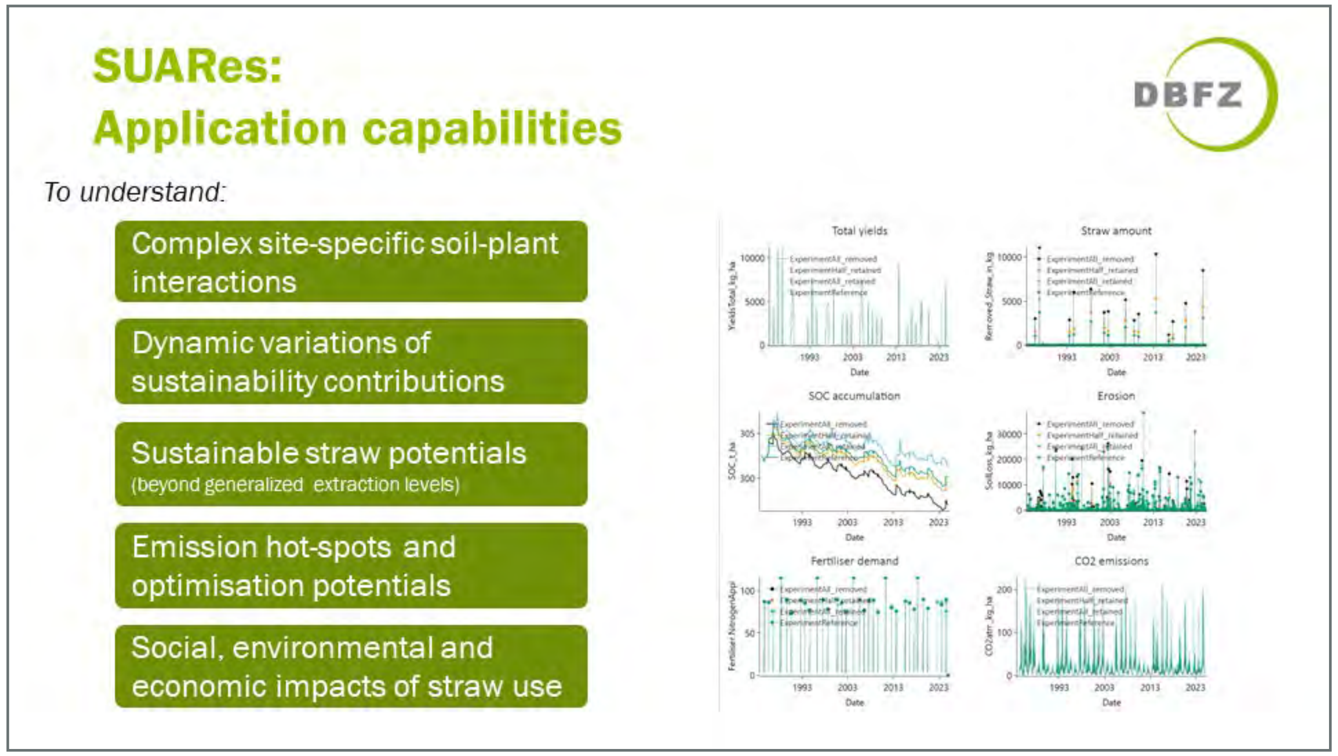


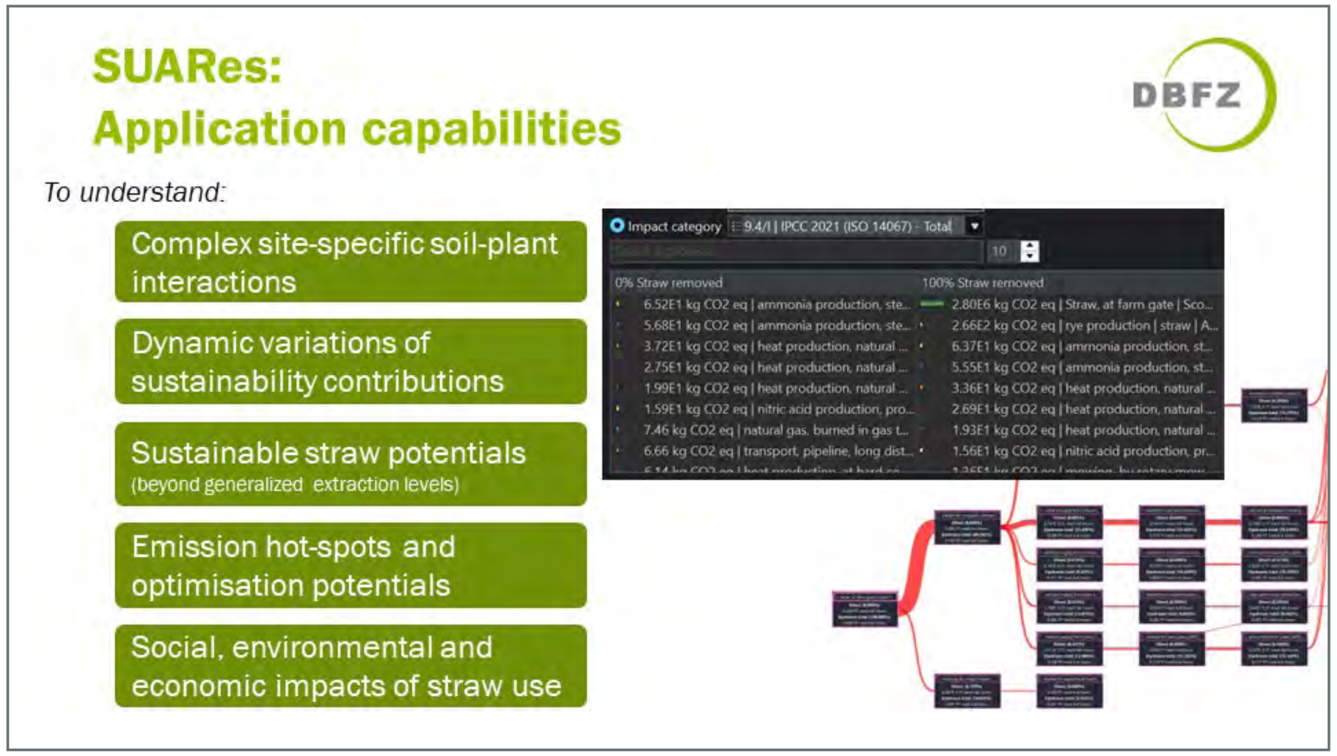


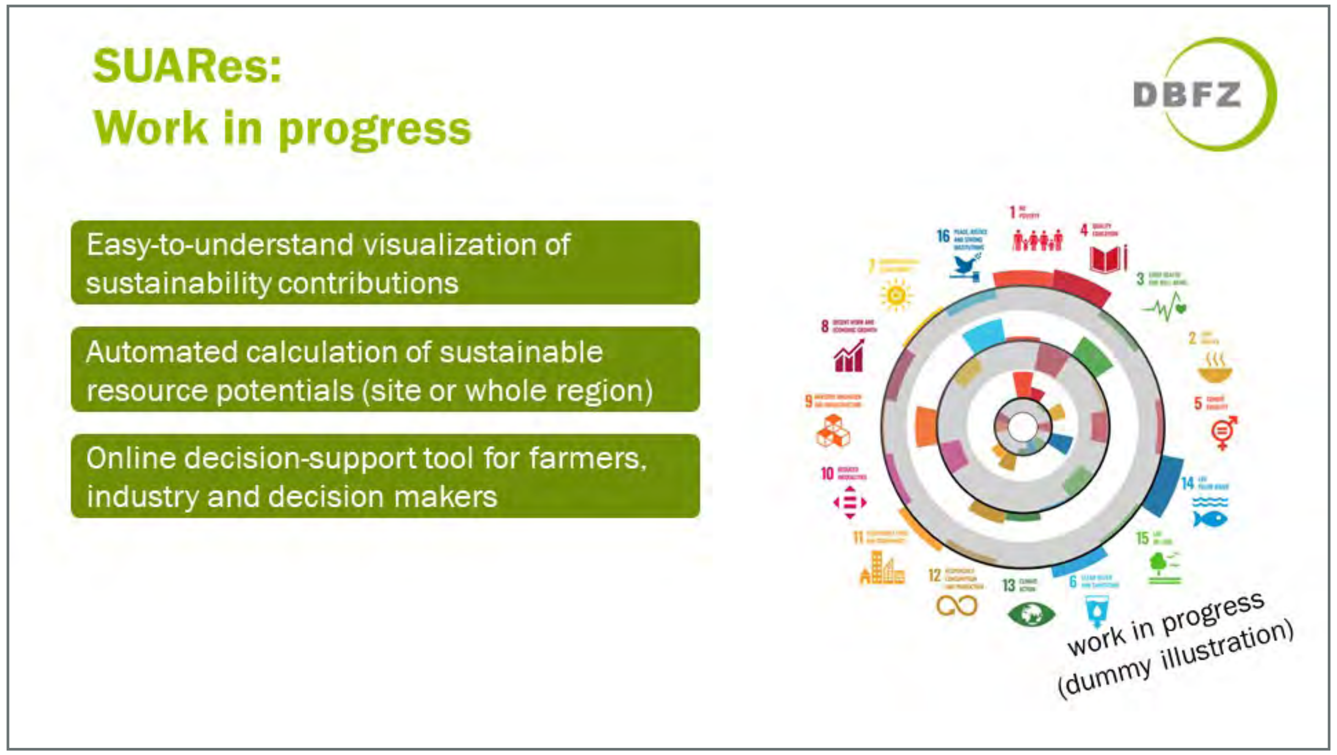


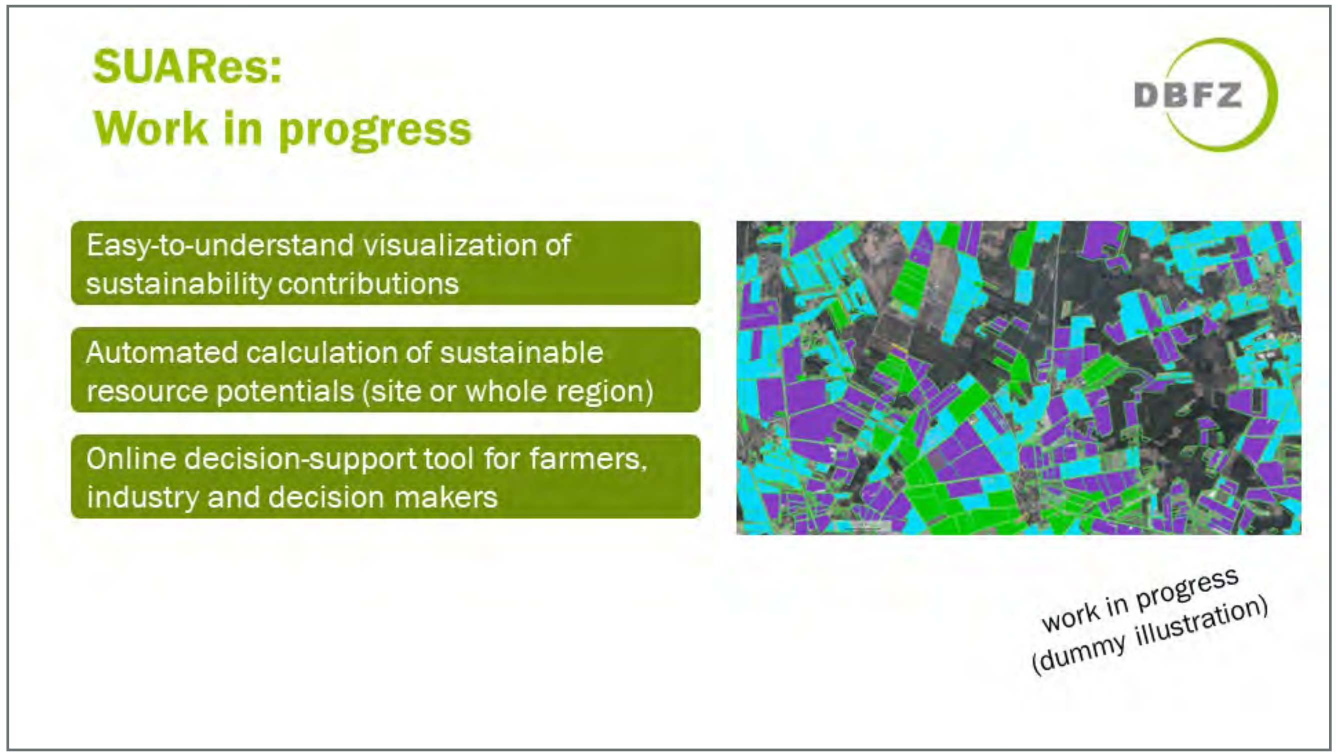
8TH DOCTORAL COLLOQUIUM BIOENERGY AND BIOBASED PRODUCTS

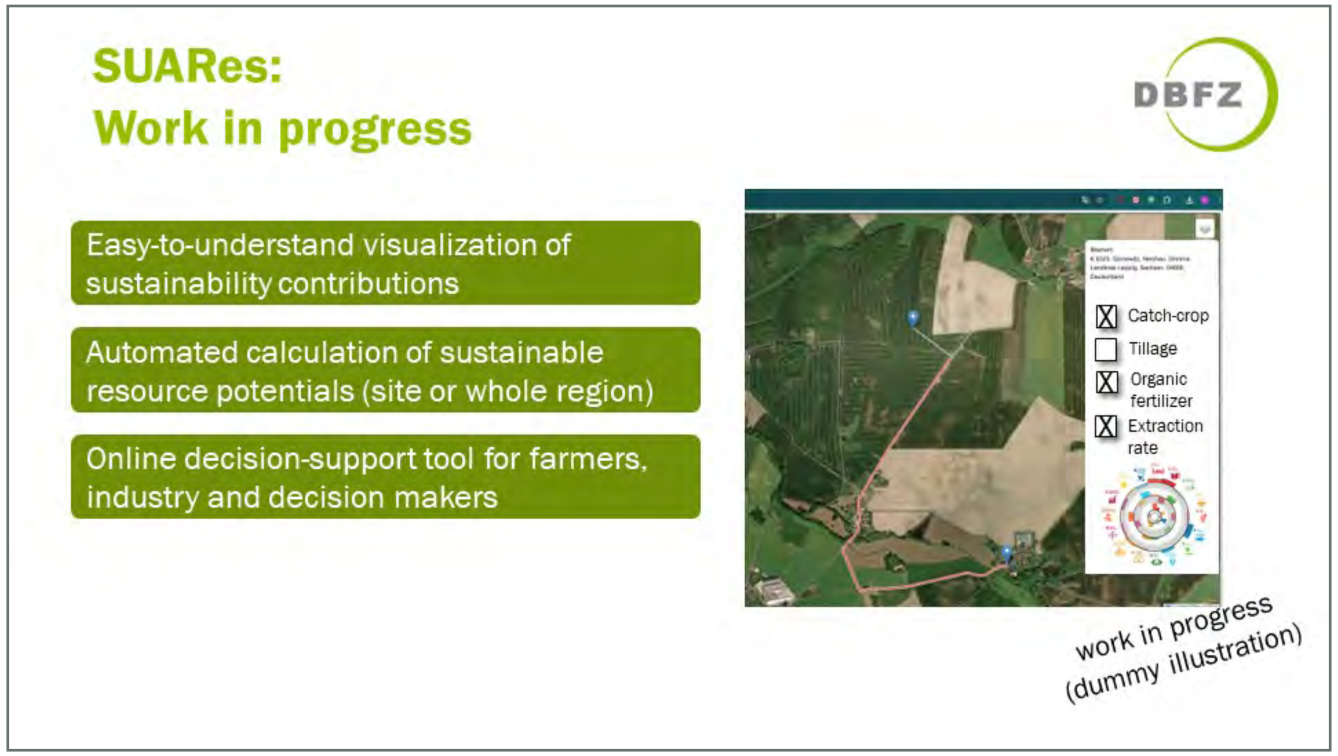

SUARes:
Application examples
DBFZ
To compare sustainability contributions of:
Different straw extraction levels
Alternative cultivation practices
(crop rotations, catch crops, tillage, fertilizers, etc.)
Different locations and fields
Various industrial use cases
(with/without application of biochar and digestate to soil)
digestate
biochar

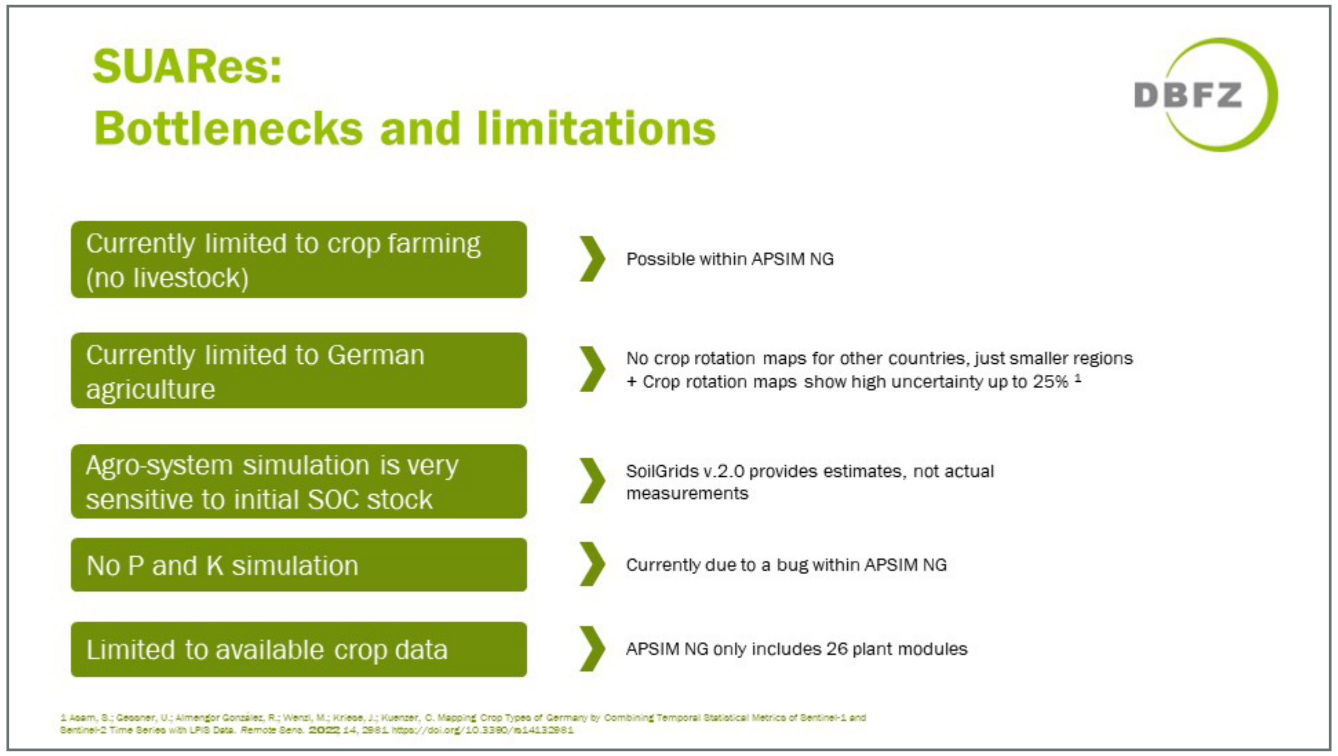

SUARes:
Application capabilities
DBFZ
To understand:
Complex site-specific soil-plant interactions
Dynamic variations of sustainability contributions
Sustainable straw potentials
(beyond generalized extraction levels)
Emission hot-spots and optimisation potentials
Social, environmental and economic impacts of straw use
Total yields
Straw amount
SOC accumulation
Erosion
Fertiliser demand
CO2 emissions


SUARes:
Application capabilities
DBFZ
To understand:
Complex site-specific soil-plant interactions
Dynamic variations of sustainability contributions
Sustainable straw potentials
(beyond generalized extraction levels)
Emission hot-spots and optimisation potentials
Social, environmental and economic impacts of straw use
Impact category
0% Straw removed
100% Straw removed


SUARes:
Work in progress
DBFZ
Easy-to-understand visualization of sustainability contributions
Automated calculation of sustainable resource potentials (site or whole region)
Online decision-support tool for farmers, industry and decision makers
work in progress
(dummy illustration)


SUARes:
Work in progress
DBFZ
Easy-to-understand visualization of sustainability contributions
Automated calculation of sustainable resource potentials (site or whole region)
Online decision-support tool for farmers, industry and decision makers
work in progress
(dummy illustration)


SUARes:
Work in progress
DBFZ
Easy-to-understand visualization of sustainability contributions
Automated calculation of sustainable resource potentials (site or whole region)
Online decision-support tool for farmers, industry and decision makers
Catch-crop
Tillage
Organic fertilizer
Extraction rate
work in progress
(dummy illustration)


SUARes:
Bottlenecks and limitations
DBFZ
Currently limited to crop farming (no livestock)
Possible within APSIM NG
Currently limited to German agriculture
No crop rotation maps for other countries, just smaller regions
+ Crop rotation maps show high uncertainty up to 25% 1
Agro-system simulation is very sensitive to initial SOC stock
SoilGrids v.2.0 provides estimates, not actual measurements
No P and K simulation
Currently due to a bug within APSIM NG
Limited to available crop data
APSIM NG only includes 26 plant modules
1 Asam, S.; Gessner, U.; Almengor González, R.; Wenzl, M.; Kriese, J.; Kuenzer, C. Mapping Crop Types of Germany by Combining Temporal Statistical Metrics of Sentinel-1 and Sentinel-2 Time Series with LPIS Data. Remote Sens. 2022, 14, 2981. https://doi.org/10.3390/rs14132981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SESSION
BIOREFINERIES & BIOFUELS

Samira Reuscher, University of Applied Sciences Darmstadt

Optimization of a microalgae production process for biofuels combined with wastewater treatment

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Keywords: Microalgae, Biofuels, Wastewater Treatment, Repeated-Batch

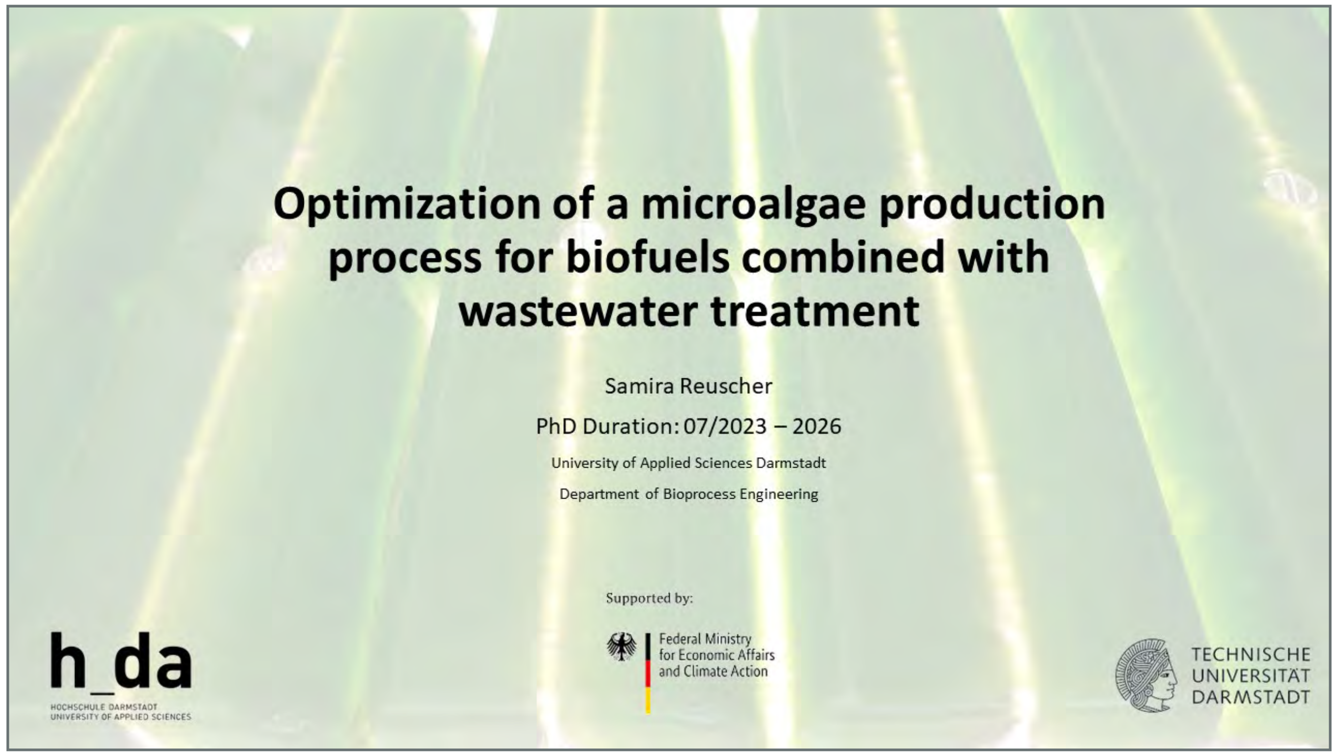
In times of depleting energy sources, renewable feedstocks are explored in current research. Besides wind and solar energy, biomass is an important alternative, but its availability is limited [1]. In this context, microalgae are being investigated as a valuable resource, e.g. in the biofuel sector. The main advantages are independence from cropland area, efficient CO_2-fixation and cultivability in waste streams. Nevertheless, commercialization is not yet realized due to high costs for the up- and downstream process [2].

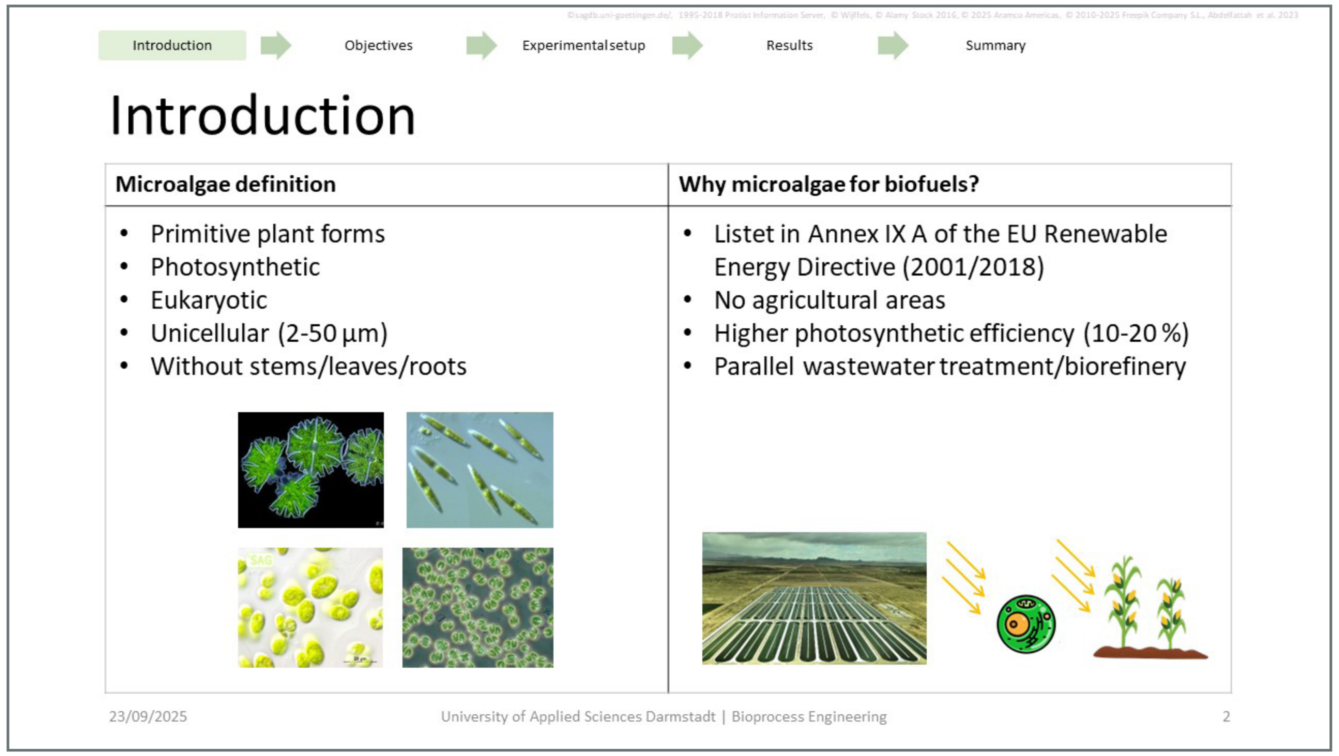
In this study, two optimization aspects were investigated in detail: i) microalgal lipid production in an alternating repeated-batch process and ii) microalgae for advanced wastewater treatment, in particular concerning effluents from the pulp and paper industry. The overall objective is to establish a process for the production of low-cost, lipid-rich biomass by combining algae cultivation with wastewater treatment.

Previous studies have shown that the microalga *Scenedesmus acuminatus* increases lipid formation when subjected to sulfate depletion. However, cell vitality is reduced under these unfavorable conditions, making continuous cultivation processes challenging. In order to investigate the recovery potential of the organisms, a repeated-batch process was developed in which supply and depletion conditions alternated frequently. Regarding the wastewater treatment, algae were incubated in anaerobically treated wastewater from a paper mill. Growth and remediation capacity (chemical oxygen demand COD, micropollutants) were measured over a period of seven days.

The results showed that *S. acuminatus* performs successfully in a repeated-batch process. During sulfate depletion phases, the lipid production increased up to 4.6-fold. Prior to resupply, up to 90 % of lipid-rich biomass could be harvested. The remaining 10 % recovered rapidly within 24 h. During wastewater incubation, biomass productivity was 2 g/L*day. From the initial COD load, 59 % was metabolized within two days. In summary, the results are useful for the development of sustainable microalgae-based processes. In the future, scale-up experiments including Life Cycle Analysis will be performed to evaluate the process feasibility.

[1] BMBF, BMEL (2020): National Bioeconomy Strategy. Available at: https://www.bmel.de/SharedDocs/Downloads/EN/Publications/national-bioeconomy-strategy.pdf?__blob=publicationFile&v=2; assessed 02.04.2025.
[2] Rafa, N. et al. (2021): Strategies to Produce Cost-Effective Third-Generation Biofuel From Microalgae. In: Front. Energy Res. 9, Artikel 749968.

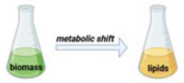




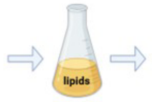
Introduction ➔ Objectives ➔ Experimental setup ➔ Results ➔ Summary

PhD objectives

Strain screening



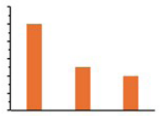
Batch process



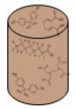
(Semi-) continuous process

- ➢ **Optimizing lipid production in algae**
- ➢ **Wastewater treatment with algae**

Growth in paper mill wastewater



COD reduction
(chemical oxygen demand)



Endocrine substance reduction

23/09/2025 3

Introduction ➔ Objectives ➔ Experimental setup ➔ Results ➔ Summary

Outline

1. **Introduction**
2. **Objectives**
3. **Experimental setup**
4. **Results**
   - 4.1 Lipid production process
   - 4.2 Wastewater treatment
5. **Summary**

23/09/2025 University of Applied Sciences Darmstadt | Bioprocess Engineering 4

Introduction ➔ Objectives ➔ Experimental setup ➔ Results ➔ Summary

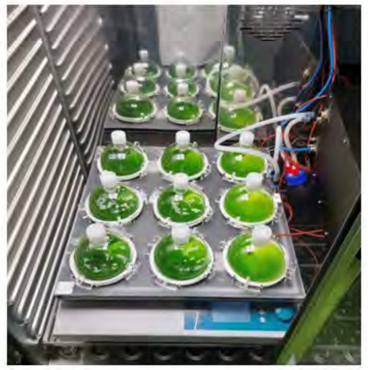
3. Experimental setup

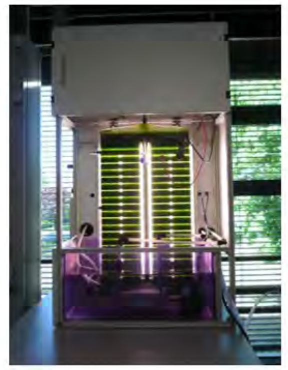
23/09/2025 University of Applied Sciences Darmstadt | Bioprocess Engineering 5

Introduction ➔ Objectives ➔ Experimental setup ➔ Results ➔ Summary

3. Experimental setup

Cultivation requirements *Scenedesmus acuminatus*	
Light	100-1000 µmol/m²s
CO_2-aeration	2-5 %
Nutrients	nitrate, phosphate, sulfate
Mixing	125-250 rpm
Temperature	25-28 °C



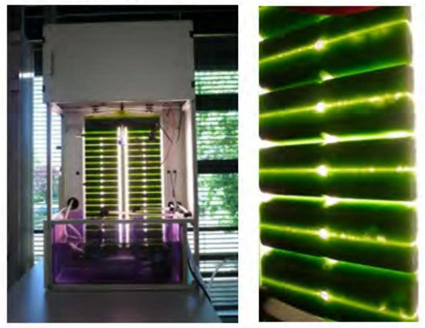


23/09/2025 University of Applied Sciences Darmstadt | Bioprocess Engineering 6

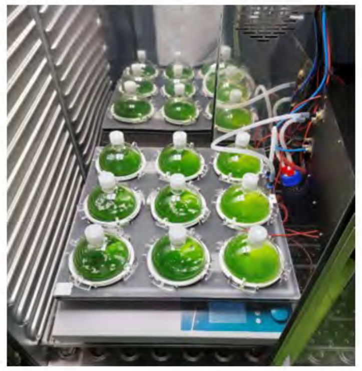
Introduction → Objectives → Experimental setup → Results → Summary

3. Experimental setup

Technical scale (6 – 28 L)



Lab scale (10 – 100 mL)



23/09/2025 University of Applied Sciences Darmstadt | Bioprocess Engineering 7

Introduction → Objectives → Experimental setup → Results → Summary

4. Results

4.1 Lipid production process

4.2 Wastewater treatment

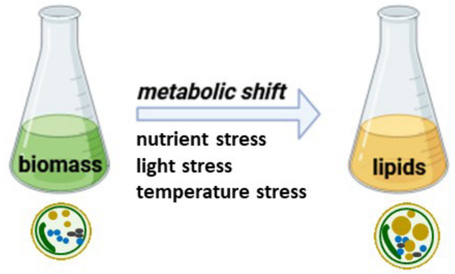
23/09/2025 University of Applied Sciences Darmstadt | Bioprocess Engineering 8

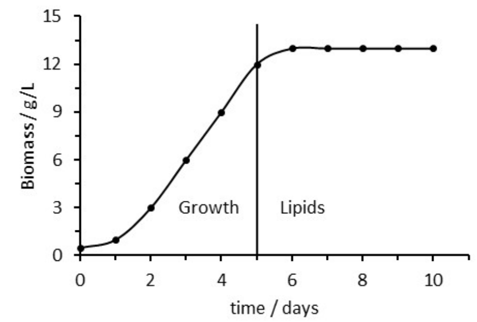
Introduction → Objectives → Experimental setup → Results → Summary

4.1 Lipid production process

Background:

Microalge metabolism shifts to **lipid production** when subjected to **stress**





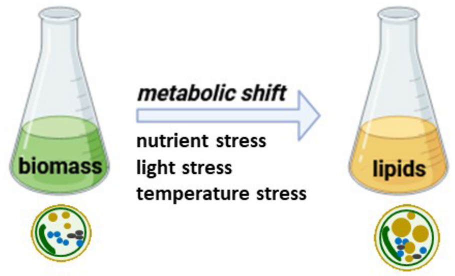
23/09/2025 University of Applied Sciences Darmstadt | Bioprocess Engineering 9

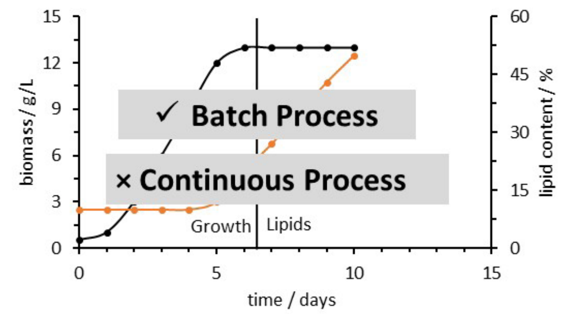
Introduction → Objectives → Experimental setup → Results → Summary

4.1 Lipid production process

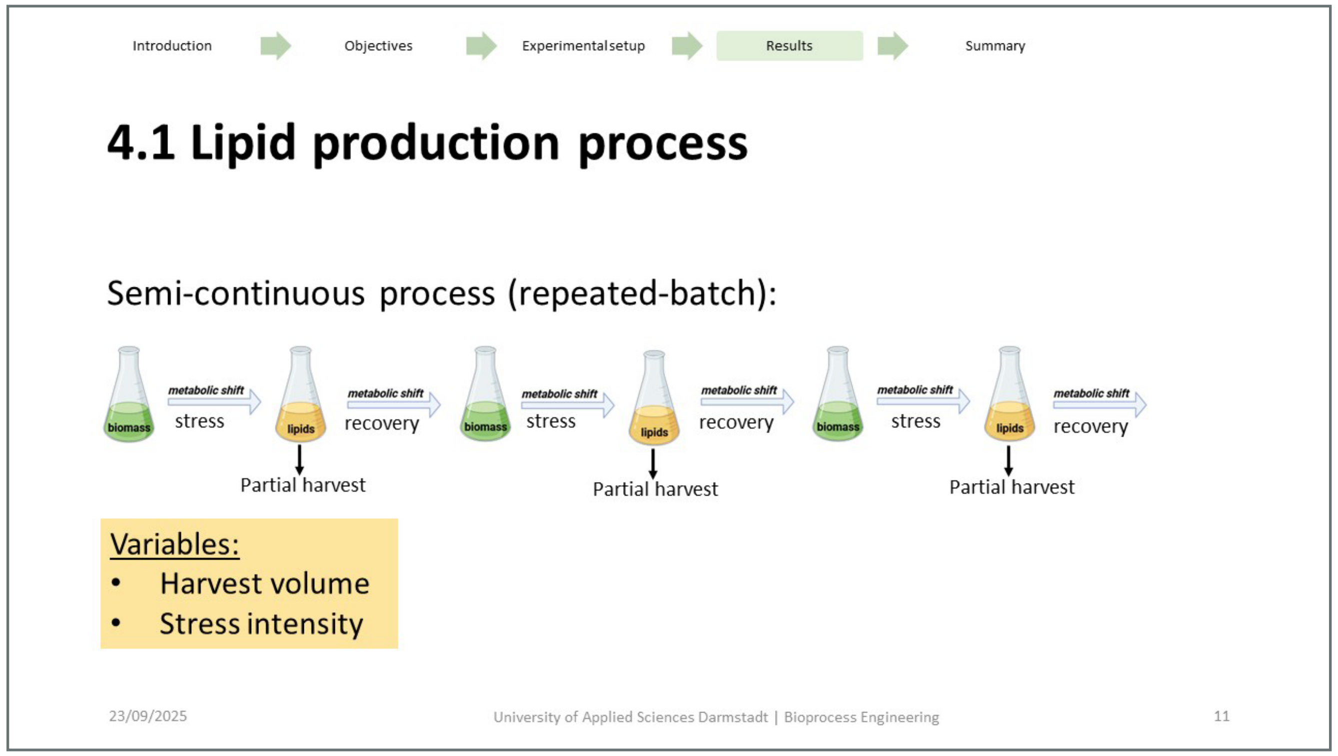
Background:

Microalge metabolism shifts to **lipid production** when subjected to **stress**





23/09/2025 University of Applied Sciences Darmstadt | Bioprocess Engineering 10


Introduction
Objectives
Experimental setup
Results
Summary
4.1 Lipid production process
Semi-continuous process (repeated-batch):
biomass
metabolic shift
stress
lipids
metabolic shift
recovery
Partial harvest
Partial harvest
Partial harvest
Variables:
• Harvest volume
• Stress intensity
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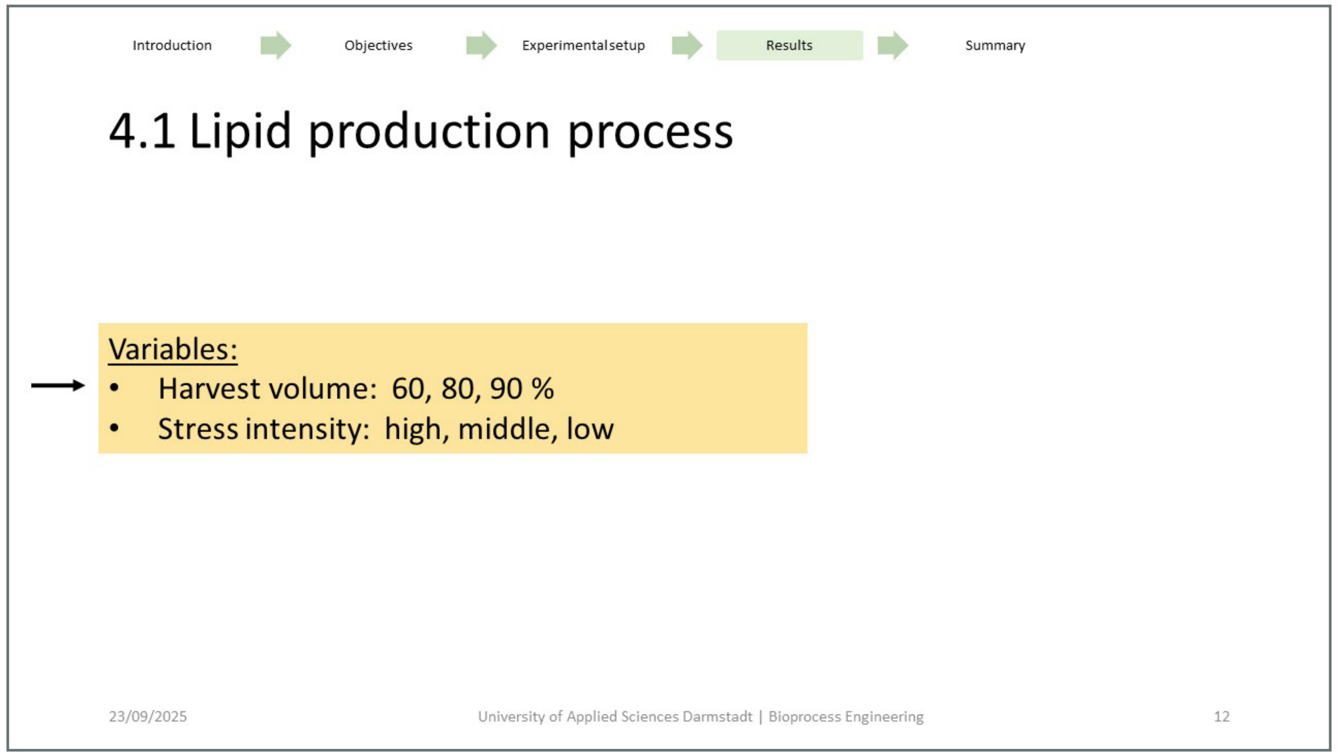
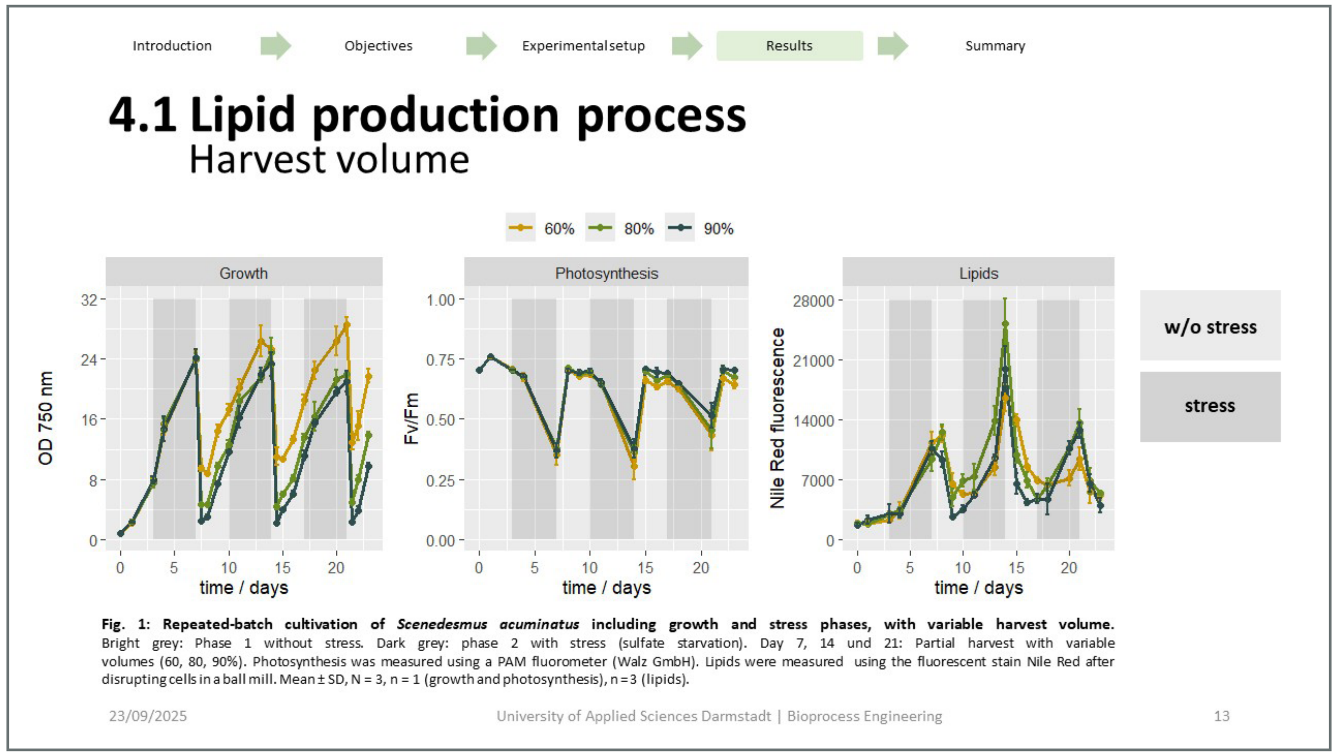
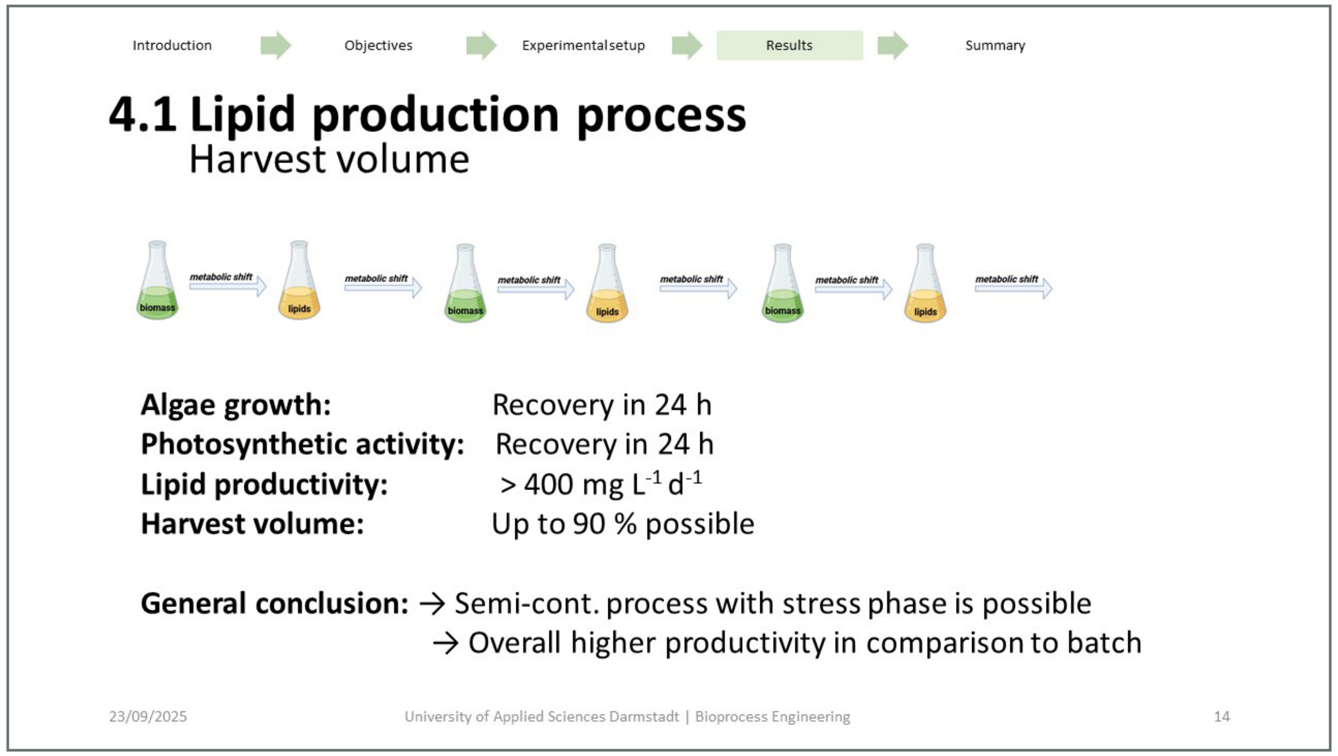
University of Applied Sciences Darmstadt | Bioprocess Engineering
11


Introduction
Objectives
Experimental setup
Results
Summary
4.1 Lipid production process
Variables:
• Harvest volume: 60, 80, 90 %
• Stress intensity: high, middle, low
23/09/2025
University of Applied Sciences Darmstadt | Bioprocess Engineering
12


Introduction
Objectives
Experimental setup
Results
Summary
4.1 Lipid production process
Harvest volume
60%
80%
90%
Growth
Photosynthesis
Lipids
OD 750 nm
Fv/Fm
Nile Red fluorescence
time / days
w/o stress
stress
Fig. 1: Repeated-batch cultivation of Scenedesmus acuminatus including growth and stress phases, with variable harvest volume. Bright grey: Phase 1 without stress. Dark grey: phase 2 with stress (sulfate starvation). Day 7, 14 und 21: Partial harvest with variable volumes (60, 80, 90%). Photosynthesis was measured using a PAM fluorometer (Walz GmbH). Lipids were measured using the fluorescent stain Nile Red after disrupting cells in a ball mill. Mean ± SD, N = 3, n = 1 (growth and photosynthesis), n = 3 (lipids).
23/09/2025
University of Applied Sciences Darmstadt | Bioprocess Engineering
13


Introduction
Objectives
Experimental setup
Results
Summary
4.1 Lipid production process
Harvest volume
metabolic shift
Algae growth: Recovery in 24 h
Photosynthetic activity: Recovery in 24 h
Lipid productivity: > 400 mg L-1 d-1
Harvest volume: Up to 90 % possible
General conclusion: → Semi-cont. process with stress phase is possible
→ Overall higher productivity in comparison to batch
23/09/2025
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14

4.1 Lipid production process
Stress intensity

Variables:
- Harvest volume: 60, 80, 90 %
- → Stress intensity: high, middle, low

4.1 Lipid production process
Stress intensity

Lipid productivity: > 500 mg L^{-1} d^{-1}

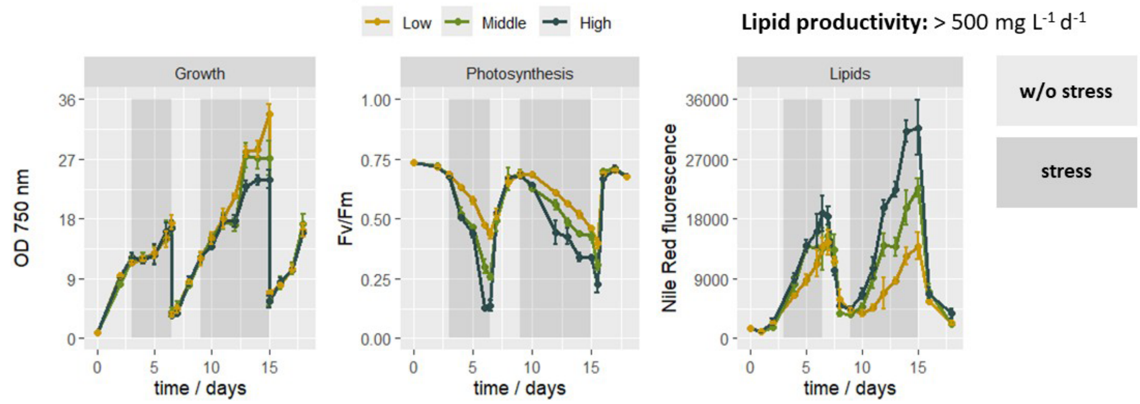


Fig. 2: Repeated-batch with variable stress intensity (low=sulfate depletion, middle=sulfate depletion + high light, high=sulfate depletion + high light + excess phosphorus). Time-evolution of growth (OD 750 nm), photosynthetic activity (maximum photosystem II efficiency Fv/Fm) and lipid production (Nile Red fluorescence). Dark grey areas indicate stress phases. On day 6 and 15, the cultures were partially harvested (80%). Mean ± SD, N = 3, n = 1 (growth and photosynthesis), n = 3 (lipids).

4.1 Lipid production process
Summary

Aim:
- Optimizing microalgae lipid production process

Approach:
- Conversion of classical batch to repeated-batch process with stress phases

Result:
- Inclusion of stress phases are possible due to rapid cell recovery
- Productivities are higher than in classical batch / continuous processes without stress
- Harvest volume: up to 90 %
- Stress intensity: combination of nutrient depletion and high illumination
- Lipid productivity: > 500 mg L^{-1} d^{-1}

4. Results

4.1 Lipid production process

4.2 Wastewater treatment

Introduction → Objectives → Experimental setup → Results → Summary

4.2 Wastewater treatment

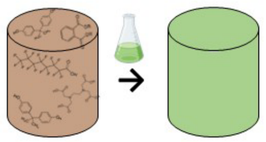
Which wastewater?

- Wastewater from the paper industry (anaerobically treated)

Why?

- Conventional treatment not sufficient (e. g. EDC's remain)

Methodology:



→ Algae growth
→ Reduction of COD (chemical oxygen demand)
→ Reduction of EDC's (endocrine disrupting chemicals)

23/09/2025 University of Applied Sciences Darmstadt | Bioprocess Engineering 19

Introduction → Objectives → Experimental setup → Results → Summary

4.2 Wastewater treatment

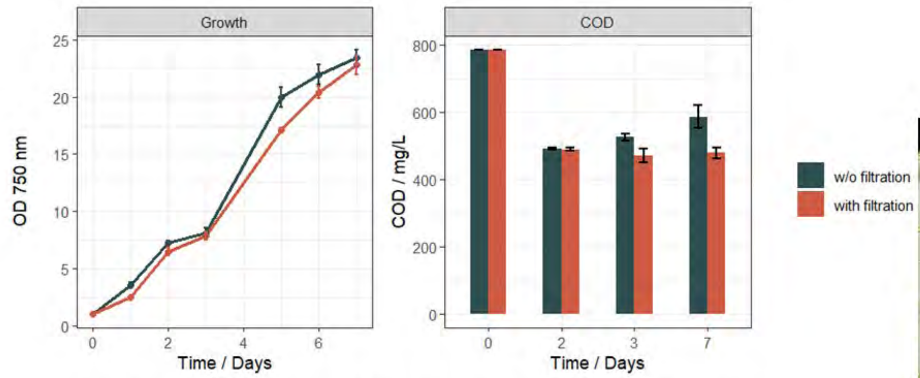


Fig. 3: Microalgae cultures in wastewater of the paper industry. Left: Time-evolution of growth (OD 750 nm). Right: COD load of selected days (chemical oxygen demand). The wastewater was either directly used without filtration (darkgrey) or with additional filtration (5 µm, orange). Mean ± SD, N = 3, n = 1.

Samples without and with filtration

Microalgae grazers

20 University of Applied Sciences Darmstadt | Bioprocess Engineering

Introduction → Objectives → Experimental setup → Results → Summary

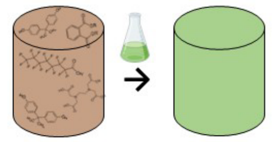
4.2 Wastewater treatment

Aim:

- Simultaneous biofuel production and wastewater treatment

Approach:

- Microalgae cultures in wastewater of the paper industry
- Measurement of growth and treatment efficiency (COD, EDC's)



Results:

- Algae growth: Possible despite of wastewater turbidity and ciliates
- Biomass productivity: 2 g L^{-1} d^{-1}
- COD reduction: 40 %
- EDC's reduction: follows

23/09/2025 University of Applied Sciences Darmstadt | Bioprocess Engineering 21

Introduction → Objectives → Experimental Setup → Results → Summary

5. Summary

Introduction:

- Microalgae biofuels beneficial towards food-crop based fuels, but costly
- Productivity enhancement by optimized processes and simultaneous wastewater treatment

PhD Objectives:

- Development of a semi-continuous lipid production process
- Combination with wastewater treatment

Results:

- Semi-continuous process is possible despite of stress phases
- Lipid productivity increases in comparison to a batch process
- Simultaneous treatment of paper industry wastewater

23/09/2025 University of Applied Sciences Darmstadt | Bioprocess Engineering 22

Leiddi Leal, University of Hohenheim

Biomass valorization and phosphate recovery via hydrothermal carbonization within integrated biorefinery processes

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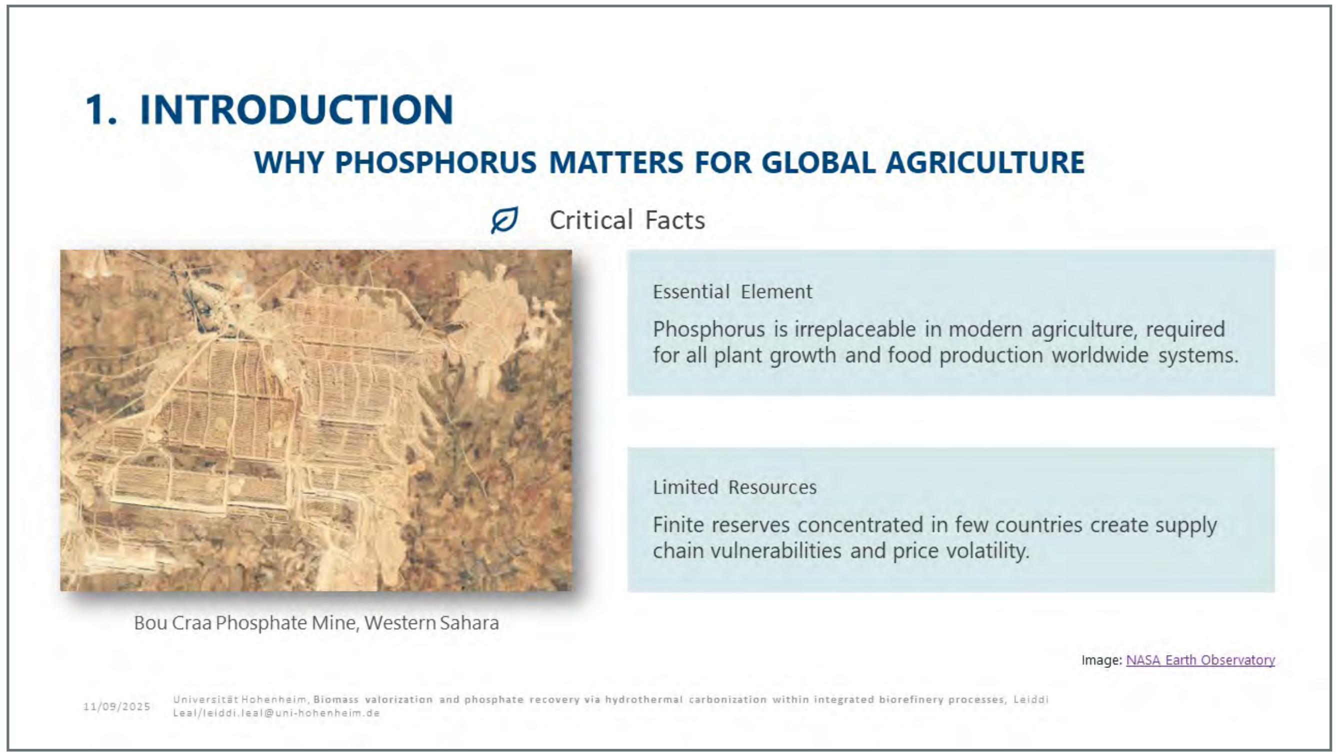
Keywords: Nutrient recycling, Process optimization, Scale-up, Sludge ordinance

Introduction
Sustainable food production requires technologies that valorize biomass and recover critical nutrients like phosphorus [1]. Phosphorus is vital for agriculture, but reserves are limited and unevenly distributed, creating supply risks [2], while poor management causes environmental impacts [3]. Hydrothermal carbonization (HTC) is a promising method to convert biomass into hydrochar while enabling recovery of plant-available phosphate [4]. This work aims to design and optimize an integrated phosphate recovery system to improve yields, cut chemical [5] and energy consumption, enhance sustainability and scalability, and address regulatory challenges.

Approach/Methods
The process uses sewage sludge as feedstock. HTC produces hydrochar, followed by acid leaching to solubilize phosphate and precipitation as struvite fertilizer. Aspen Plus® simulations are applied, supported by experimental data on sludge properties, operating conditions (temperature, time), and acid concentration. Results will be evaluated for process efficiency, optimization potential, and scale-up feasibility.

Results/Outlook
The current Aspen Plus® configuration for an integrated biorefinery process is presented, with energy integration that recovers heat from hot streams and a biogas-fired heater. Defined sludge feed, hydrochar representation and acid choice are outlined. From this flowsheet, operating windows and key verification points are outlined: phosphate in the leach liquor, capture of free ammonia while retaining ammonium for precipitation, and solid-liquid split efficiencies. Emphasis is placed on decision levers relevant to the German sludge ordinance and scale-up.

References
[1] Swarnam, T.P. et al. (2024). Climate smart crop-livestock farming. Int. J. Agric. Sustain., 22(1), 2298189.
[2] Brownlie, W.J. et al. (2023). Phosphorus price spikes: A wake-up call for resilience. Front. Sustain. Food Syst., 7, 1088776.
[3] Lam, K.L. et al. (2022). Life cycle impacts of wastewater-derived P products. Environ. Sci. Technol., 56(14), 10289–10298.
[4] Khoury, O. et al. (2023). Phosphorus recycling from sludge via HTC. Waste Manag., 169, 23–31.
[5] Becker, G.C. et al. (2019). Phosphate recovery as struvite via HTC. J. Environ. Manag., 238, 119–125.



1. INTRODUCTION

GERMANY: SEWAGE SLUDGE ORDINANCE (ABFKLÄRV)

Obligation / Timeline

- WWTPs > 100,000 PE: phosphorus recovery required from 2029
- WWTPs 50,000 –100,000 PE: phosphorus recovery required from 2032

Applicability

- Applies when sludge contains ≥ 2% P (20 g P/kg dry solids)
- Over threshold: land application no longer primary; P-recovery mandatory

Technology-neutral Compliance

- Technology-neutral: recovery from sludge or mono-ash, if compliant
- Operator duty: select, implement, and document a compliant pathway

Source: Ordinance on the Reorganization of Sewage Sludge Utilization of 27 September 2017

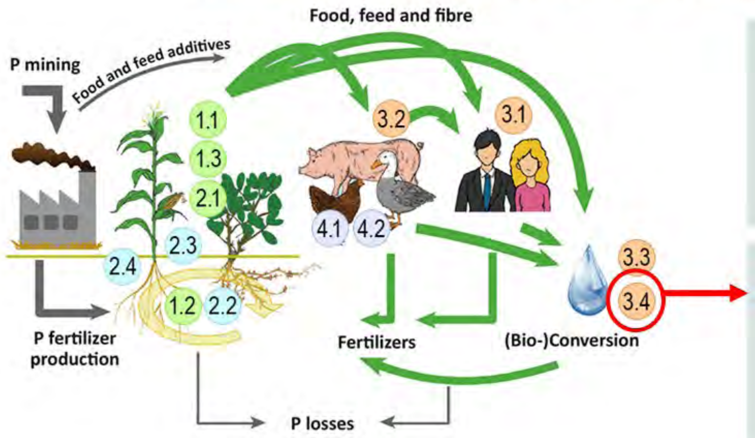
1. INTRODUCTION

RESEARCH QUESTION

How to design and calibrate an HTC-based sludge biorefinery for phosphate recovery that meets AbfKlärV, with defined operating windows for scale-up?

1. INTRODUCTION

AMAIZE-P PROJECT INTEGRATION AND RESEARCH FOCUS



Project Overview

Sino–German International Research Training Group: Thirteen joint research groups work across the phosphorus cycle to adapt maize-based food–feed–energy systems to limited phosphorus.

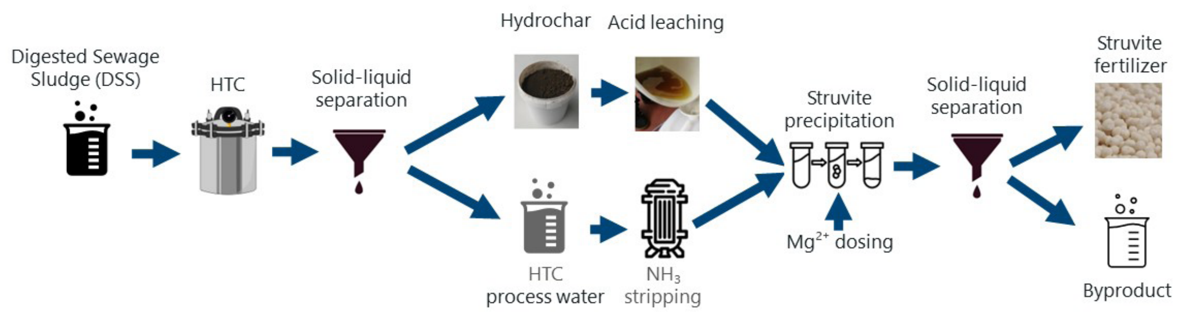
Research Scope

We study Hydrothermal Carbonizaton (HTC) of biomasses, evaluate hydrochar for advanced/activated carbons, and recover phosphate as struvite, examining key equilibria and operating conditions to enable scale-up.

Source: AMAIZE-P website

2. METHODOLOGY

BIOREFINERY CONCEPT APPLIED



Sludge Valorization Approach

- Integration with anaerobic digestion
- Applicability to large wastewater treatment plants

2. METHODOLOGY

PROCESS SIMULATION WITH ASPEN PLUS®

Parameter Optimization

- Find feasible windows (temperature, time, pH, ...)
- Test before piloting

Risk Management

- De-risk decisions with scenarios
- Expose bottlenecks early

Environmental Impacts

- Directional energy and carbon from balances
- Compare alternative routes pre-pilot

Cost Analysis

- Identify cost levers (heating / reagents)
- Support sizing / budgets

3. INTERIM RESULTS

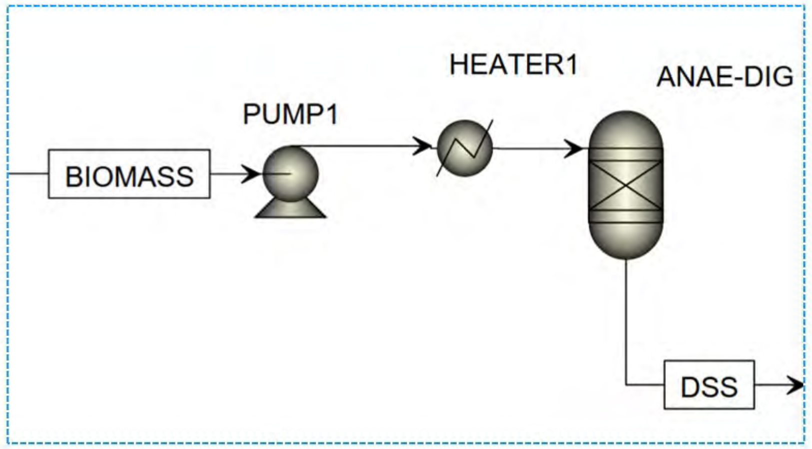
SIMULATION BASE FEED

Group	Component(s)	Role
Moisture	Water	Carrier phase; dissolves salts; enable reactions
Carbon matrix	Glucose, Triolein, Lignin, Cellulose, Glycine (protein proxy)	Drives hydrochar formation in HTC
Nitrogen	Ammonia, Ammonium	$NH_3 \rightleftharpoons NH_4^+$ (acid–base equilibrium)
Phosphate	Dipotassium phosphate (K_2HPO_4, soluble); Calcium phosphate ($Ca_3(PO_4)_2$, solid)	Ensures PO_4 in soluble & insoluble forms
Magnesium	$MgSO_4 \rightarrow Mg^{2+}$	Tracks Mg^{2+} and SO_4^{2-} as co-ions

Basis: composition compiled from municipal sewage-sludge datasets and literature; mapped to Aspen Plus® components.

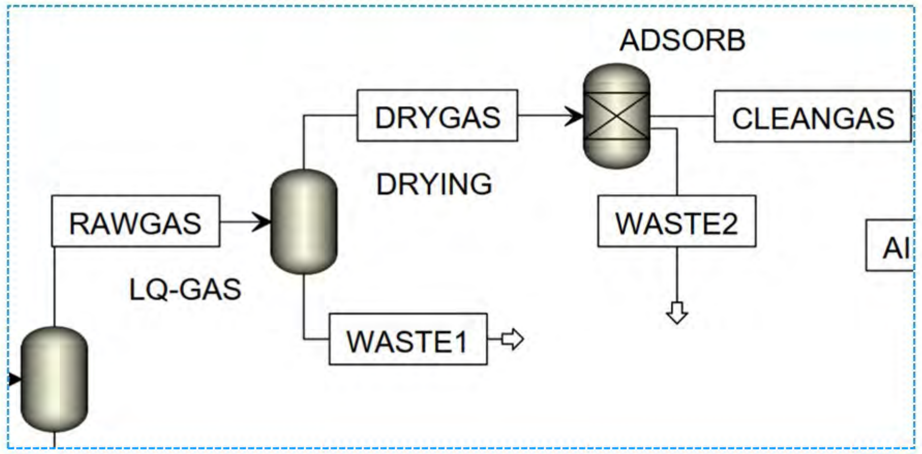
3. INTERIM RESULTS

ASPEN PLUS® FLOWSHEET



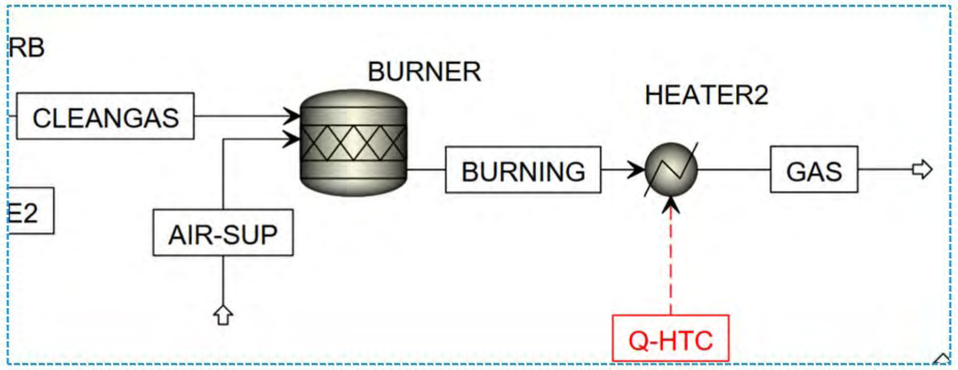
3. INTERIM RESULTS

ASPEN PLUS® FLOWSHEET



3. INTERIM RESULTS

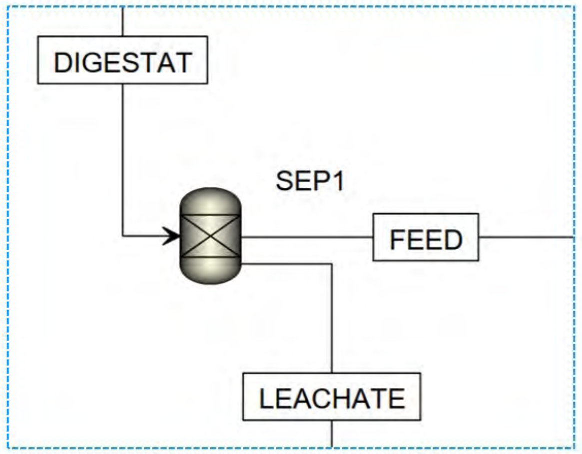
ASPEN PLUS® FLOWSHEET



11/09/2025 Universität Hohenheim, Biomass valorization and phosphate recovery via hydrothermal carbonization within integrated biorefinery processes, Leiddi Leal/leiddi.leal@uni-hohenheim.de

3. INTERIM RESULTS

ASPEN PLUS® FLOWSHEET



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3. INTERIM RESULTS

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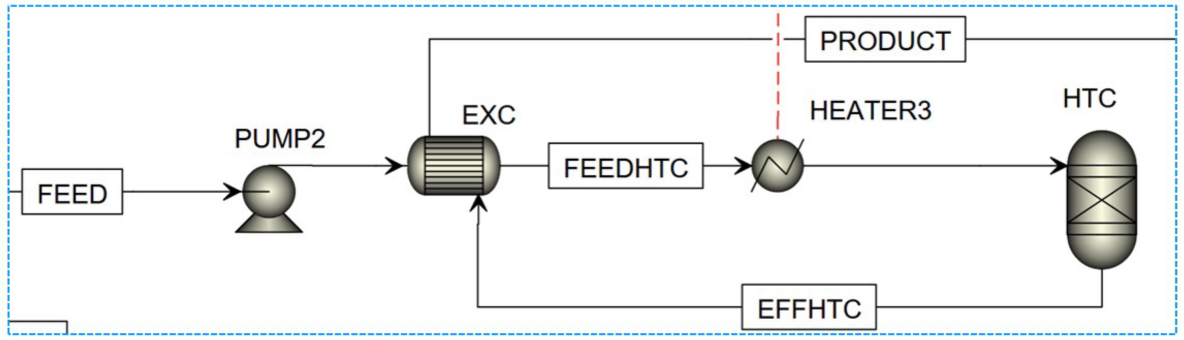

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3. INTERIM RESULTS

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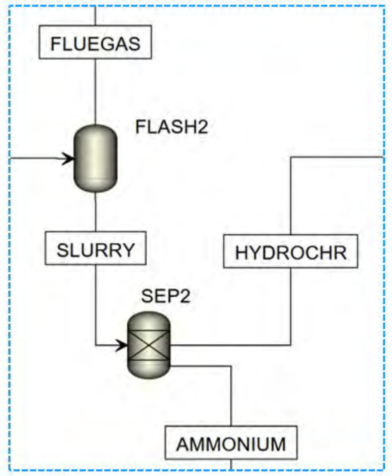

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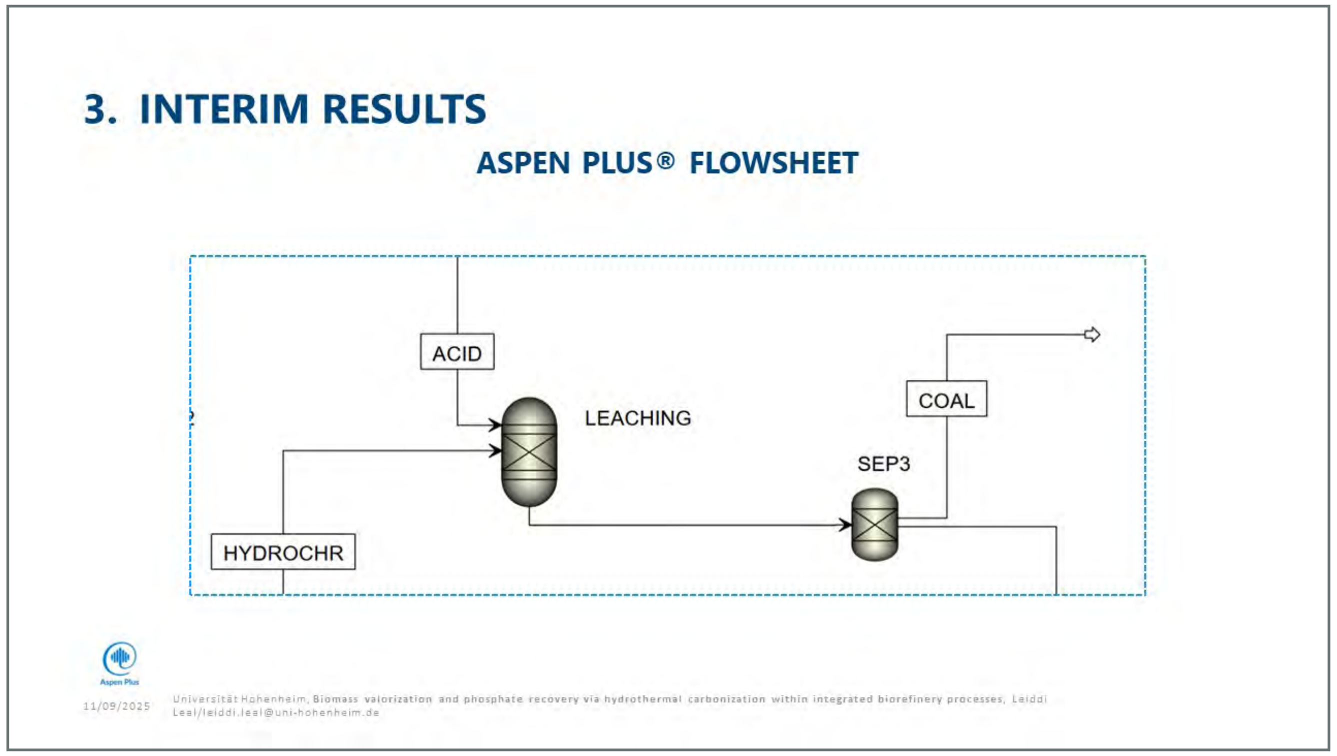
3. INTERIM RESULTS
ASPEN PLUS® FLOWSHEET
ACID
LEACHING
COAL
SEP3
HYDROCHR
Aspen Plus
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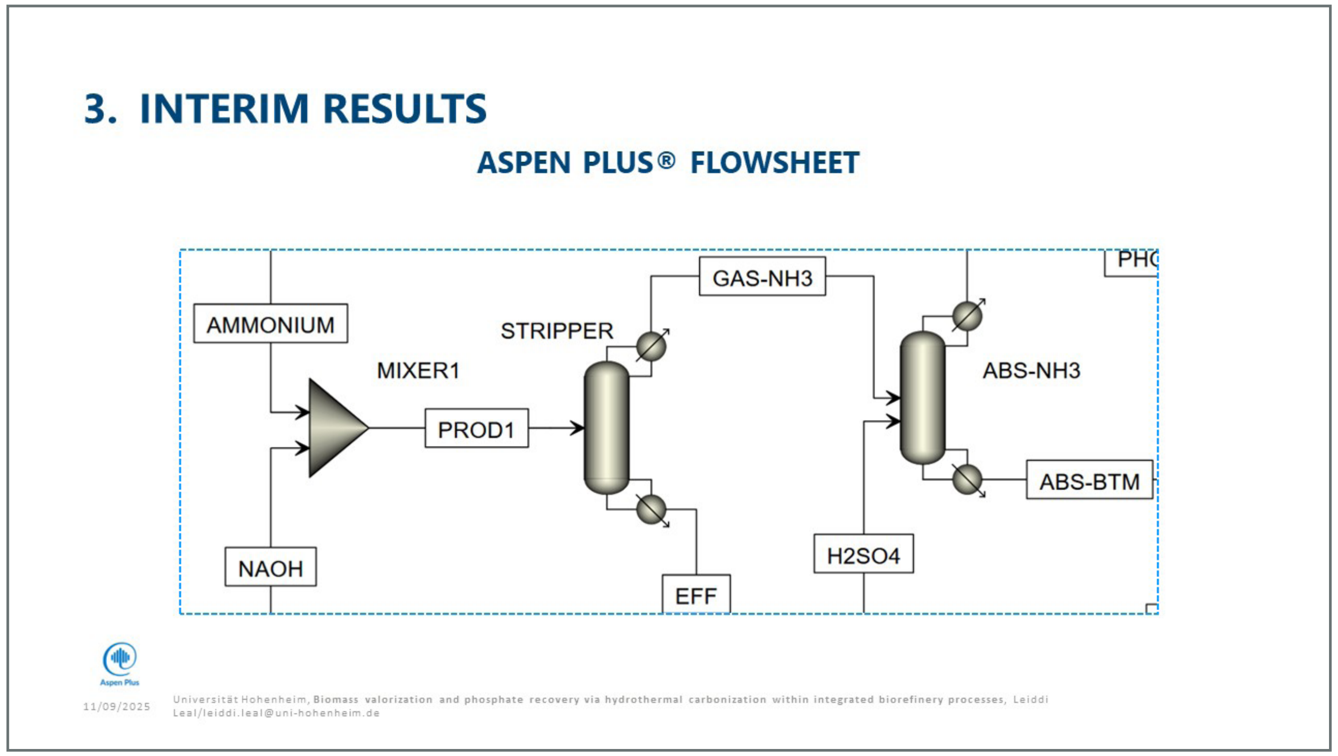
Universität Hohenheim, Biomass valorization and phosphate recovery via hydrothermal carbonization within integrated biorefinery processes, Leiddi Leal/leiddi.leal@uni-hohenheim.de


3. INTERIM RESULTS
ASPEN PLUS® FLOWSHEET
GAS-NH3
AMMONIUM
STRIPPER
MIXER1
PROD1
ABS-NH3
ABS-BTM
NAOH
EFF
H2SO4
Aspen Plus
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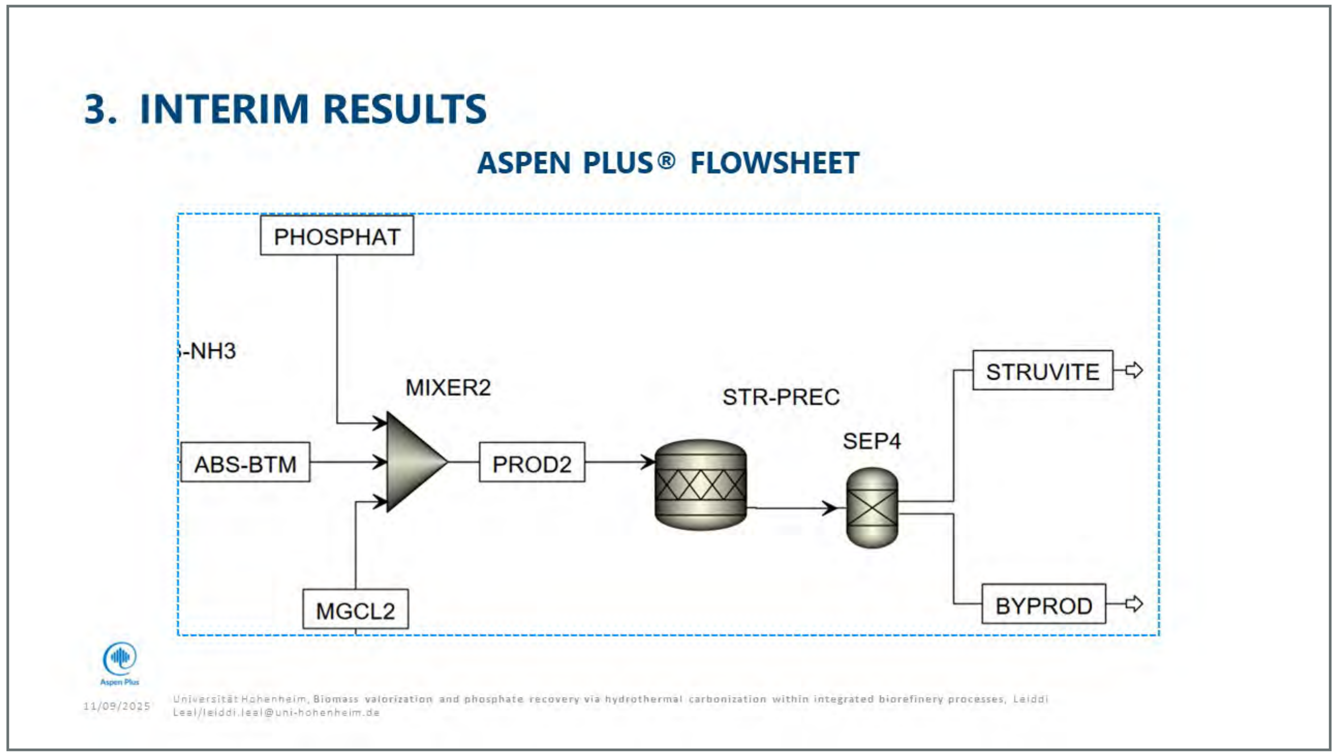
3. INTERIM RESULTS
ASPEN PLUS® FLOWSHEET
PHOSPHAT
MIXER2
STR-PREC
STRUVITE
SEP4
ABS-BTM
PROD2
MGCL2
BYPROD
Aspen Plus
11/09/2025
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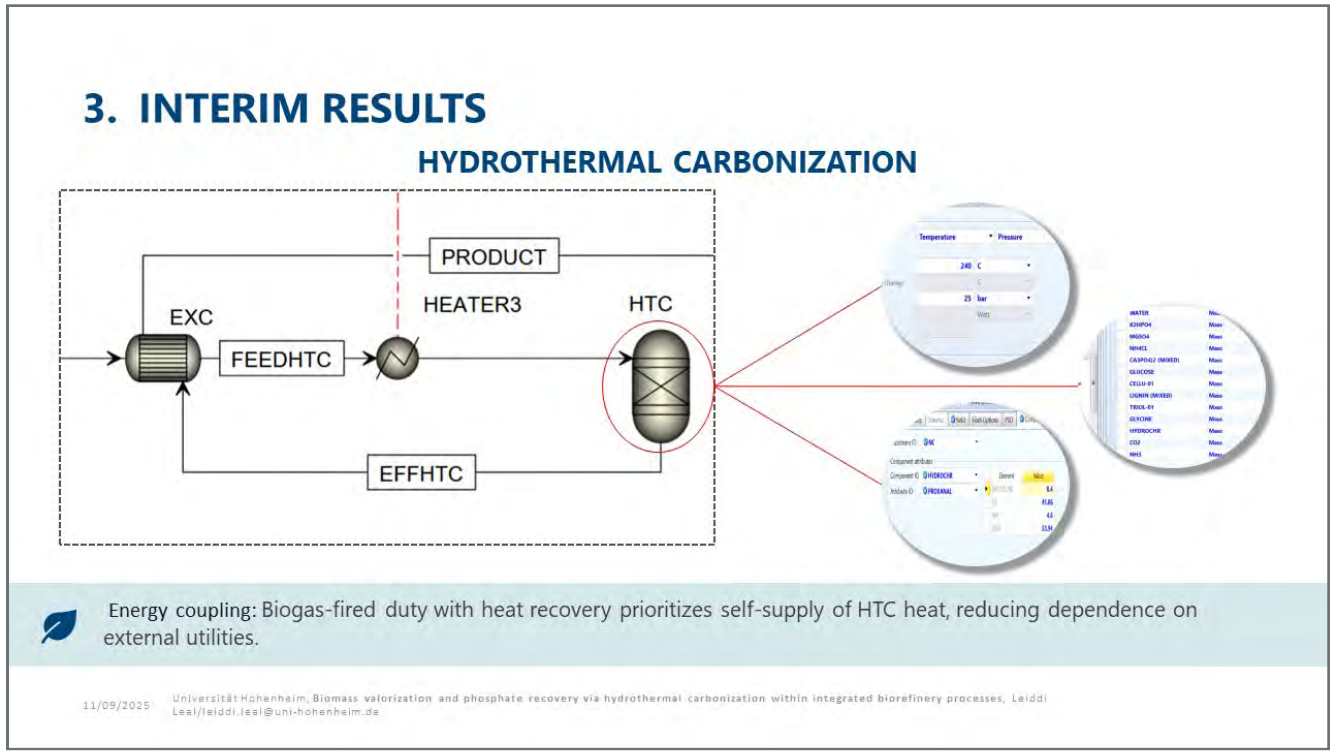
3. INTERIM RESULTS
HYDROTHERMAL CARBONIZATION
PRODUCT
EXC
HEATER3
HTC
FEEDHTC
EFFHTC
Energy coupling: Biogas-fired duty with heat recovery prioritizes self-supply of HTC heat, reducing dependence on external utilities.
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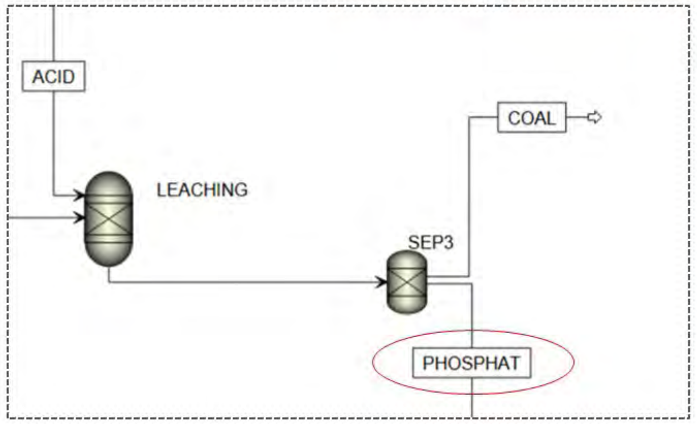
4. IN CALIBRATION

SPECIES / STREAMS WE VERIFY NEXT

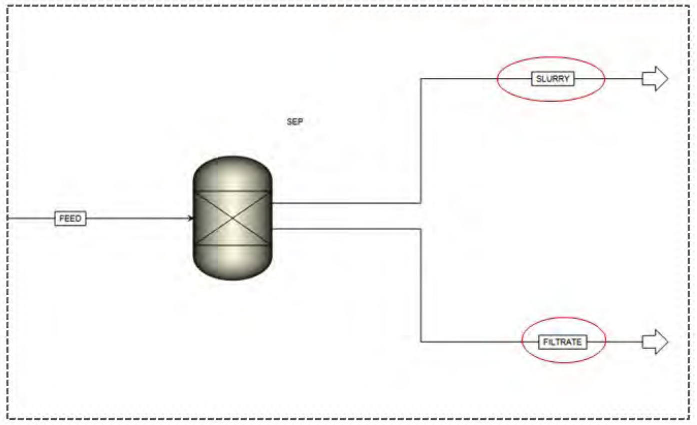


PHOSPHAT

- Confirm phosphate is in the liquid
- Quantify co-ions: Ca^{2+}, Mg^{2+}, SO_4^{2-}, Cl^-
- Set pH and Mg^{2+} dose for struvite

4. IN CALIBRATION

SPECIES / STREAMS WE VERIFY NEXT



SLURRY / FILTRATE

- Calibrate solid–liquid split
- Check dissolved phosphate across separators
- Minimize phosphate losses

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5. OUTLOOK

RESEARCH STATUS

Foundation	Calibration	KPIs / scenarios
• Route / Scope / Base Feed • Thermodynamics • Hydrochar nonconventional solid • Energy outlined	• Acid choice / materials • Solid liquid split efficiency • Total Ammonia Nitrogen / pH	• Phosphate recovery • Energy • Mg^{2+} source / bypass / recirculation • Vendor/controls; comparative routes
	Now	

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6. CONCLUSION

Under the AbfKlärV mandate, our HTC-to-struvite route is defined from lab foundations; with the last plant data, we can report phosphate yields and lock an operating window for an integrated sludge biorefinery.

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8TH DOCTORAL COLLOQUIUM BIOENERGY AND BIOBASED PRODUCTS


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DFG Deutsche Forschungsgemeinschaft
Department of Conversion Technologies of Biobased Resources
Leiddi Leal – 8th Doctoral Colloquium BIOENERGY AND BIOBASED PRODUCTS – 11/09/2025


UNIVERSITÄT HOHENHEIM
THANK YOU FOR LISTENING
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UNIVERSITÄT HOHENHEIM

Simon Krake, Fraunhofer Institute for Interfacial Engineering and Biotechnology IGB

Process optimization of microaerobic hydrogen production by purple bacteria - When waste becomes the fuel of the future

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Keywords: biohydrogen, dark photosynthesis, microaerobic fermentation, process development, purple bacteria

Introduction

One approach to diversifying H_2 production is biotechnological production using bacteria and substrates from the food and chemical industries. This opens up prospects for companies, as they can recover energy instead of disposing waste. Fermentative H_2 can be produced via two pathways: photofermentation, where light energy is used to fix N_2 and produce H_2, and dark fermentation, where H_2 is a product of the pyruvate formate lyase pathway. This approach follows a new form of fermentation, dark photosynthesis by Rhodospirillum rubrum. At microaerobic conditions, metabolism turns partly oxidative and reductive- This increases H_2 yields by enabling H_2 production by dark fermentation as well as photofermentation.

Approach/Methods

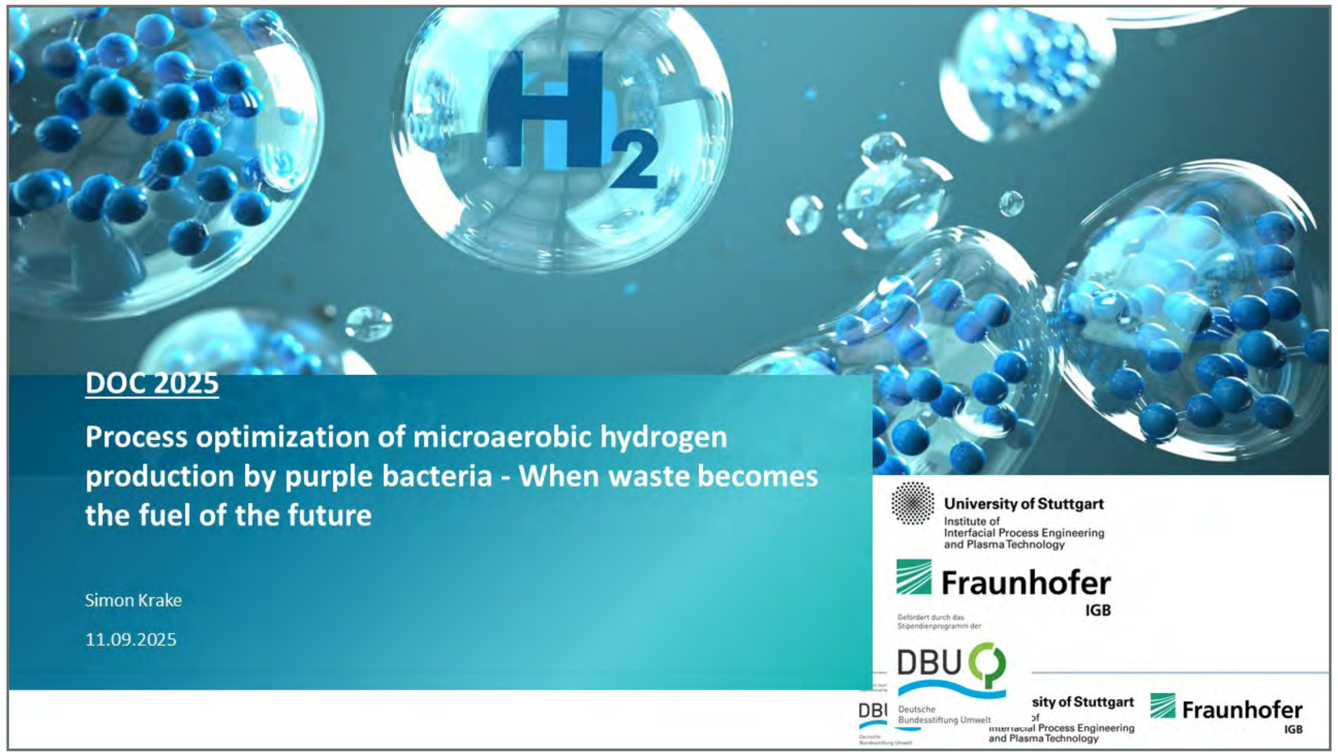
The approach presented here was to use an industrial ethanol containing waste water and adapts the process of microaerobic dark fermentation. Challenges that arose were:

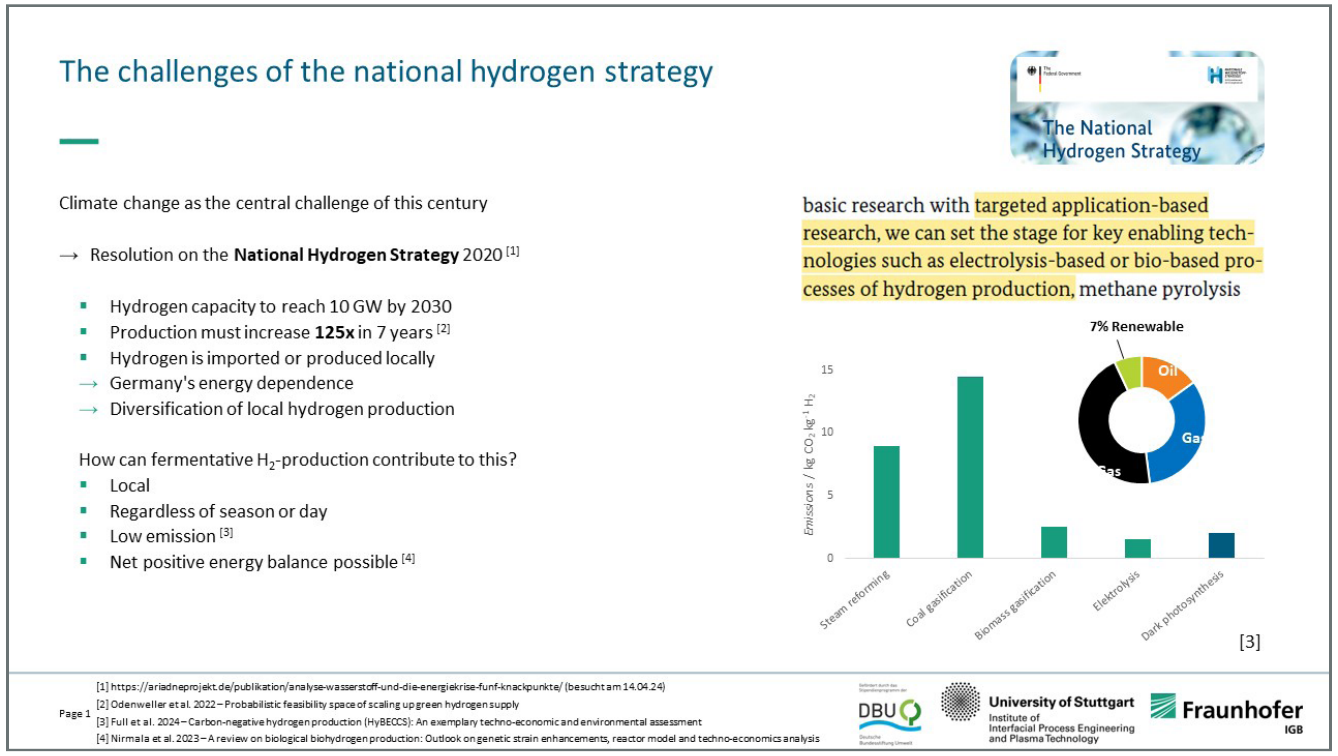
- Evaluation of the toxicity of the rinse water
- Establishment of online offgas analysis by mass spectrometry
- Control of the microaerobic fermentation state
- Development and scale-up of an H_2-producing process with ethanol-containing rinse water

The methods used in this work include the cultivation of bacteria in a microfermenter scale, shaking flasks and controlled bioreactors with a volume ranging from 1 mL to 50 L.

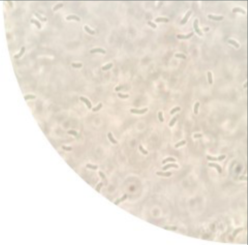
Results/Outlook

The evaluation of the toxicity of the material flow showed that waste water with up to 15 g L-1 ethanol can be used. Optimization of the media composition led to an increase in the consumption of waste water and an increase in growth rate. In a bioreactor setup (1 L) for H_2 production, the microaerobic condition was controlled and a production rate of 0.2 mmol L-1 h-1 was achieved. To enable the assimilation of ethanol as a substrate, a controlled nitrogen dilution of the gassing had to be integrated. Subsequently, the cell density was increased to 33.4 g L-1 by establishing a feeding process. As a result, the H_2 production rate on a demonstrator scale (50 L) was around 5x higher than in the laboratory, with results of 4.7 LH2 h-1 and 0.4 gH2 h-1 respectively. In future, research will be carried out optimizing the process and transferring to a broader substrate portfolio of waste streams.





Biohydrogen through purple bacteria



Purple bacteria as H_2-producers [5]

- *Rhodospirillum rubrum, Rhodobacter sphaeroides* and *Rhodopseudomonas palustris*
- Rod-shaped, gram-negative
- Facultatives
- Purple colouring (bacteriochlorophyll)
- H_2-production through photofermentation or dark fermentation possible under anaerobic conditions

➢ Utilization as an H_2-producer, for bioremediation, bioplastics (PHA) and terpenoids [7–10]

Photofermentation

$$N_2 + 8\,e^- + 8\,H^+ + 16\,ATP \xrightarrow{\text{Nitrogenase}} 2\,NH_3 + H_2 + 16\,ADP + 16\,P_i$$

$$\Delta G^0 = +247\ kJ\ mol^{-1}$$

Dark fermentation

$$C_6H_{12}O_6 + 2\,H_2O \xrightarrow{\text{Formatehydrogen-lyase}} 2\,CH_3COOH + 2\,CO_2 + 4\,H_2$$ [6]

$$\Delta G^0 = -206\ kJ\ mol^{-1}$$

→ Microaerobic dark fermentation?

Page 2

[5] Madigan et al. 2009 – An overview of purple bacteria: systematics, physiology and habitats
[6] Akhlagi & Najafpour-Darzi 2020 – A comprehensive review on biological hydrogen production
[7] Grammel et al. 2003 – Microaerophilic cooperation of reductive and oxidative pathways allows maximal photosynthetic membrane biosynthesis in Rhodospirillum rubrum
[8] Do et al. 2024 – Evaluating the Sulfur Oxidation Capability of a Rhodopseudomonas palustris Strain by Gene and Enzyme Analyses for Potential Applications in Environmental Bioremediation
[9] Kyndt et al. 2022 – Genome Sequence and Characterization of a Xanthorhodopsin-Containing, Aerobic Anoxygenic Phototrophic Rhodobacter Species, Isolated from Mesophilic Conditions at Yellowstone National Park
[10] Licht et al. 2020 – Adaptation to Photooxidative Stress: Common and Special Strategies of the Alphaproteobacteria Rhodobacter sphaeroides and Rhodobacter capsulatus

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Identification of scientific gaps

Search engine: Web of Science

- Bacteria and Hydrogen • 23.030 Hits
- Purple Bacteria and Hydrogen • 651 Hits
- Purple Bacteria and Hydrogen, Category: Energy Fuels • 152 Hits
- + not Algae, Food, Pathways, Gene, Enzyme, Matrix • 96 Hits

Page 5

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Dark photosynthesis
A new perspective on producing hydrogen biologically

The dark photosynthesis [11,12]

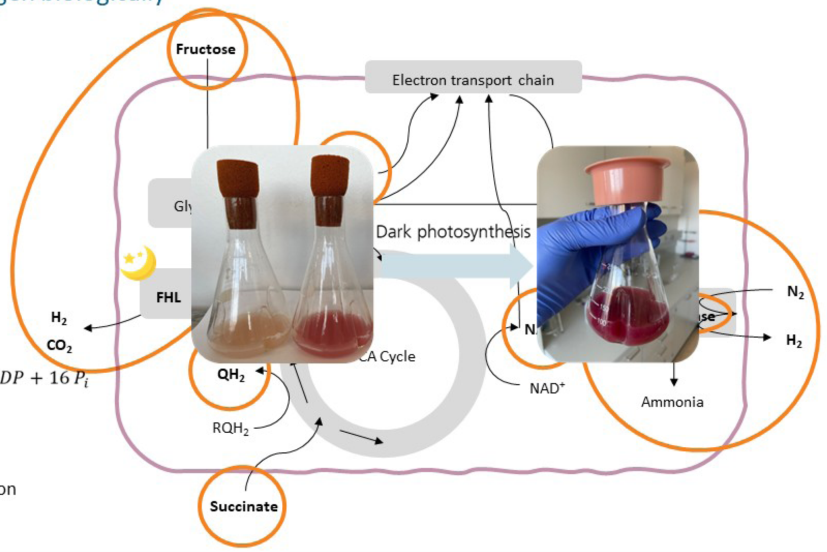
= Dark fermentation + Photofermentation

➢ Due to **dark, microaerobic conditions**
➢ 2-substrate system
➢ Cental inducers: $NADH/NAD^+$ and Q_{H_2}/RQH_2
➢ Formation of photosynthetic membranes including nitrogenase

$$N_2 + 8\,e^- + 8\,H^+ + 16\,ATP \xrightarrow{N_2ase} 2\,NH_3 + H_2 + 16\,ADP + 16\,P_i$$

$$\Delta G^0 = +247\ kJ\ mol^{-1}$$

➢ Energy through ATP at the level of photofermentation



Page 3

[11] Grammel et al. 2003 – Microaerophilic cooperation of reductive and oxidative pathways allows maximal photosynthetic membrane biosynthesis in Rhodospirillum rubrum
[12] Abo-Hashesh et al. 2012 – Microaerobic dark fermentative hydrogen production by the photosynthetic bacterium Rhodobacter capsulatus

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Identification of scientific gaps

Only 7 publications on microaerobic dark fermentation with purple bacteria

Strain	Scale L	Batch?	C-Source	N-Source	μ h^{-1}	$Y_{P/S}$ mol mol^{-1}
R. rubrum [5,6]	0.5	✓	Fructose, Succinate	NH_4^+-Succinate	0.10	**0.2**
	3.5	✓	Fructose, Succinate	NH_4^+-Succinate	0.10	-
R. palustris [7]	0.04	✓	Na-Lactate	Na-Glutamate	-	**1.4**
R. capsulatus [8]	0.1	✓	Succinate, Lactate, Acetate, Malate	Na-Glutamate	-	**0.6**

1 **Comparison of microorganisms and substrates**
→ Substrate spectrum, influence of oxygen/nitrogen
→ Establishing a substrate-strain platform under standardized conditions

2 **Bioreactor scale**
→ Almost exclusively test tubes and shaking flasks
→ Develop microaerobic control and proof of scalability of processes

3 **Space-time yield has to be increased**
→ Higher cell densities
→ Evaluating microaerobic states
→ Extension of production phases
→ Implementing fed-batch or continuous fermentations
• Process optimizations

4 **No complete modeling of microaerobic processes and H_2 formation available**

Page 6

[5] Autenrieth et al. 2021 – New Approach for the concstruction and calibration of gas-tight setups for biohydrogen prodution at the small laboratory scale
[6] Carius et al. 2012 – Stepwise reduction of the culture redox potential allows the analysis of microaerobic metabolism and photosynthetic membrane synthesis
[7] Lazaro et al. 2017 – Optimization of the yield of dark microaerobic production of hydrogen from lactate by Rhodopseudomonas palustris
[8] Abo-Hashesh et al. 2012 – Microaerobic dark fermentative hydrogen production by the photosynthetic bacterium Rhodobacter capsulatus

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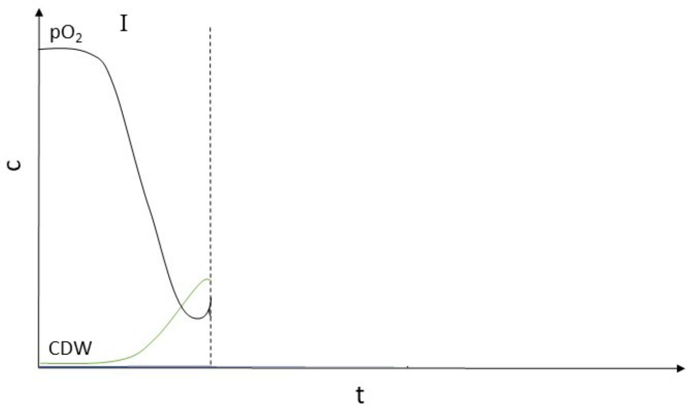
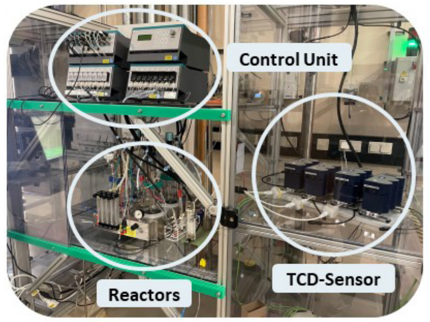
Transfer to controlled bioreactor conditions – process optimization

Establishing a 3-step process





- Adaption to a fructose – ethanol substrate combination
- Using possible waste streams
  - Fructose: Fruit pomace [13]
  - Ethanol: <u>Silan production</u>, tea extraction, distillery wastes [14–16]

[13] Putra et al. 2023 – Waste to Wealth of Apple Pomace: Valorization by Past and Current Extraction Processes: A Review
[14] Kuijai et al. 2022 – Recycling industrial ethanol waste to solid alcohol and improvement of its physical, chemical and fuel properties
[15] Tsuo et al. 1999 – Method of high purity silane preparation. USA patent US6103942A
[16] Seluy et al. 2014 – A Process To Treat High-Strength Brewery Wastewater via Ethanol Recovery and Vinasse Fermentation

Page 4

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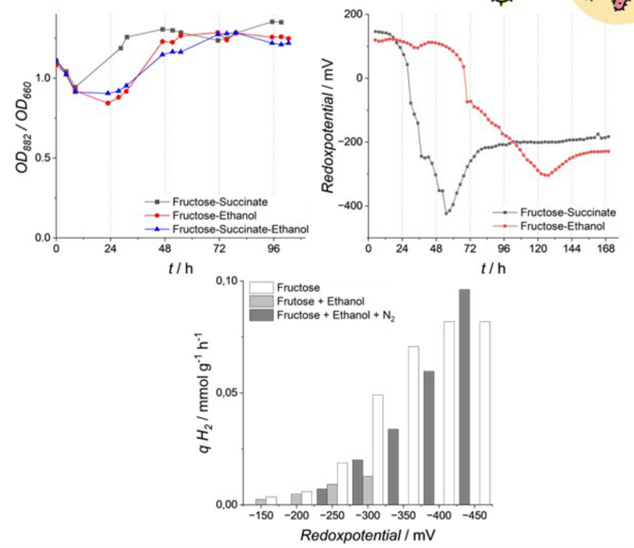
Adapting microaerobic H_2 production to fructose-ethanol

Comparing substrate combinations under microaerobic conditions

- Similar photosynthetic membrane formation
- ➢ <u>Overreduced state reached</u>
- Lower redox potential (Substrate oxidation, oxygen uptake?)
- ➢ <u>No H_2 generation</u>

Regaining H_2 productivity

- Additional N_2 gassing necessary
- ➢ <u>Implement redoxcontrol by stirring and gassing</u>
- Shift in redoxpotential between succinate and ethanol
- ➢ <u>H_2 generation by simultanously fructose and ethanol uptake</u>



Page 6

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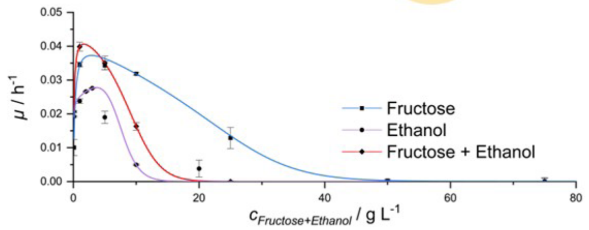
Adapting and optimizing growth on fructose-ethanol

Microfermenter cultivation

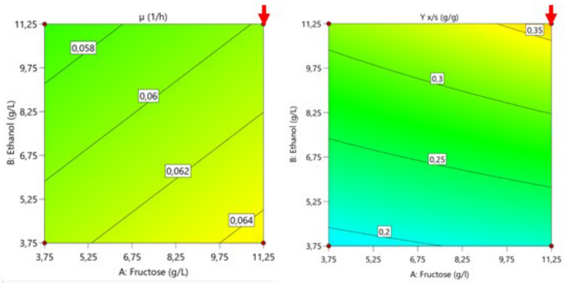
Evaluating dose-response curve for fructose and ethanol

- Fitted by Han Levenspiel kinetics
- <u>Synergistic effects in a 2-substrate system</u>



Media optimization – a DoE

- Central composite design
- Fructose – Ethanol – Ammonium chloride
- Combination of frucose-ethanol for overreduction
- Increase of growth rate by <u>~ 30%</u>



Page 5

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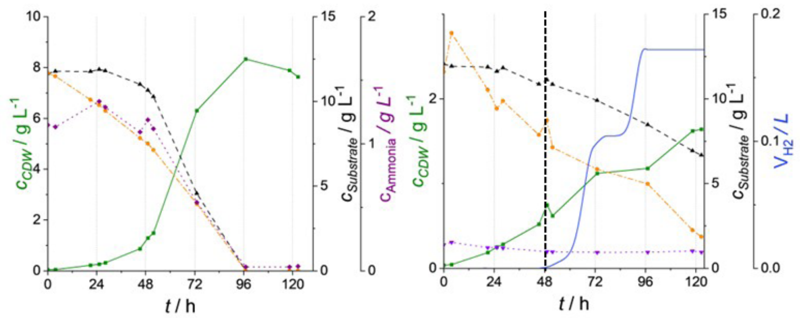
Evaluating process phases

Aerobic and microaerobic growth in batch fermentations

Batch characterization aerobic and microaerobic

- Growth rate under aerobic conditions improved (μ = 0.07 vs. 0.04)
- Sucessfully induced microaerobic dark fermentation after 48 h
- Uptake of TCA-cycle substrate (Ethanol) indicates activity
- Byphasic hydrogen production?
- ➢ Foundation for fed-batch design (k_La, OUR, μ, $Y_{X/S}$, $Y_{X/N}$, q_s, $Y_{P/X}$,…



Aerobic growth **Microaerobic H_2-production**

Page 7

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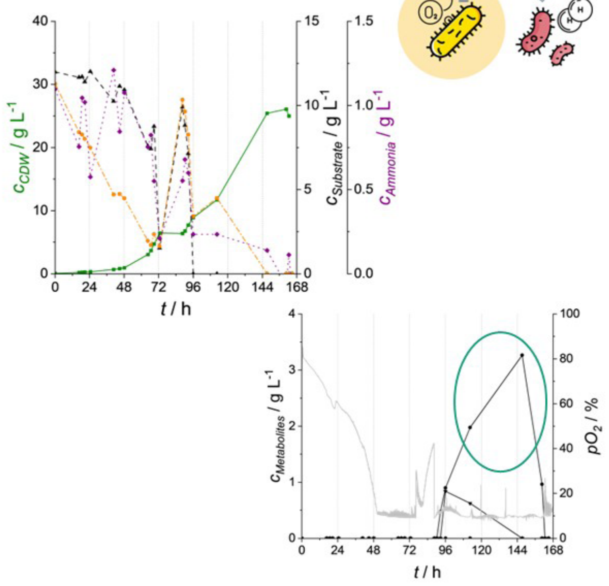
Establishment of a feeding process

pO_2-dependent feed at 1 L scale

Aim: Increasing bacterial biomass to boost hydrogen production

- 15x concentrated medium as feed
- pO_2-dependent feed → When the pO_2 signal rises ("hunger peak"), additional substrate is added at the start of fermentation in accordance with the substrate concentration
- Maximum cell dry weight: **33.4 g L^{-1}**
- μ_{mean} (0–120 h): **0.05 h^{-1}**

➢ Organic acid accumulation – how and when are metabolites produced?



Page 8

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Exploring metabolism under low-oxygen conditions

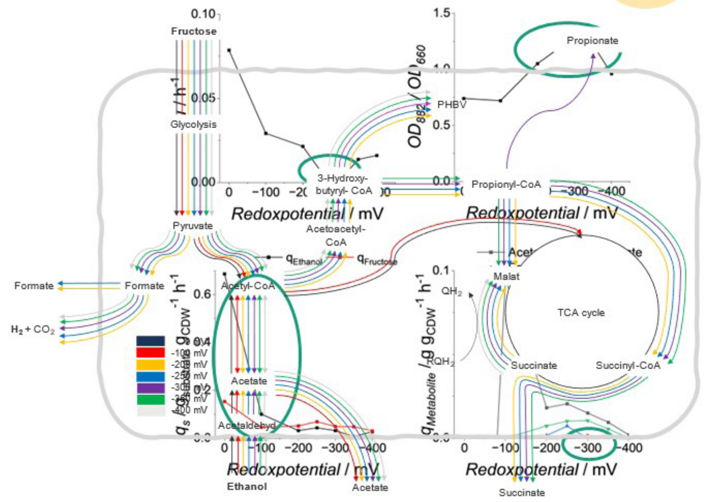
Conclusions based on metabolism

Reached by stepwise reduction of the redox potential by stirring and N_2 gassing

- Microaerobic state between -200 and -400 mV
- Acetate, propionate, formate and succinate as metabolites

Approximate tracking of metabolic pathways:

- Ethylmalonyl pathway as work around for anaplerotic reactions indicated by succinate, propionate and PHBV [17]
- Succinate as product because of bottleneck at succinate dehydrogenase (but enzyme must be active)
- H_2-production at -200 mV



Page 9

[17] Godoy et al. 2023 – Aerobic-anaerobic transition boosts poly(3-hydroxybutyrate-co-3-hydroxyvalerate) synthesis in Rhodospirillum rubrum: the key role of carbon dioxide

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Scaling microaerobic dark fermentation

From 1 L to 50 L

In 50 L pilot scale

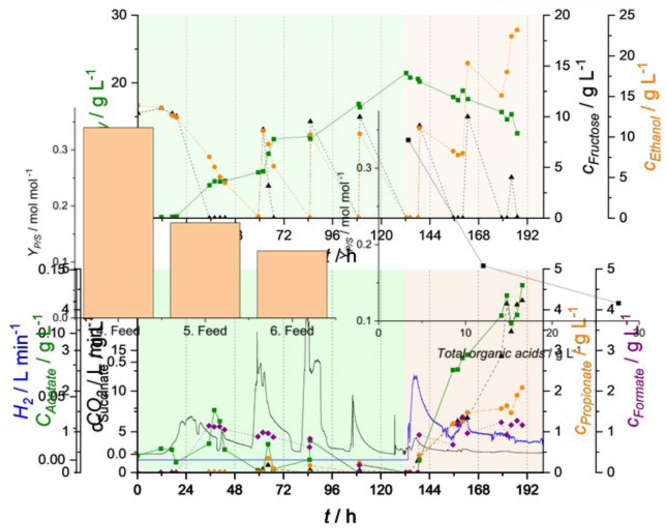
- pO_2-dependent fed-batch:
  - Volume: 30 L → 50 L
  - 6 feeds
    - 3x aerobic growth
    - 3x H_2-production

➢ Maximum CDW: **21.5 g L^{-1}**

➢ Fructose uptake exceeds ethanol uptake

➢ Decline in CDW – substrate or metabolite toxicity?

➢ 3 day production phase not sufficient – evaluation of new concepts



Page 10

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RESULTS & OUTLOOK

Current results of Ph.D.

✓ Adapted microaerobic dark fermentation to a new substrate not described yet in literature

✓ Characterization of the microaerobic state as a function of redox potential

✓ Established a controlled 3-phase bioreactor process with higher cell densities

✓ Scaled to 50 L

What's coming

→ Extension of investigations to new substrate combinations and additional strains

→ Evaluation of new fermentation concepts for extended production phase

→ Process simulation of microaerobic dark fermentation

Page 11

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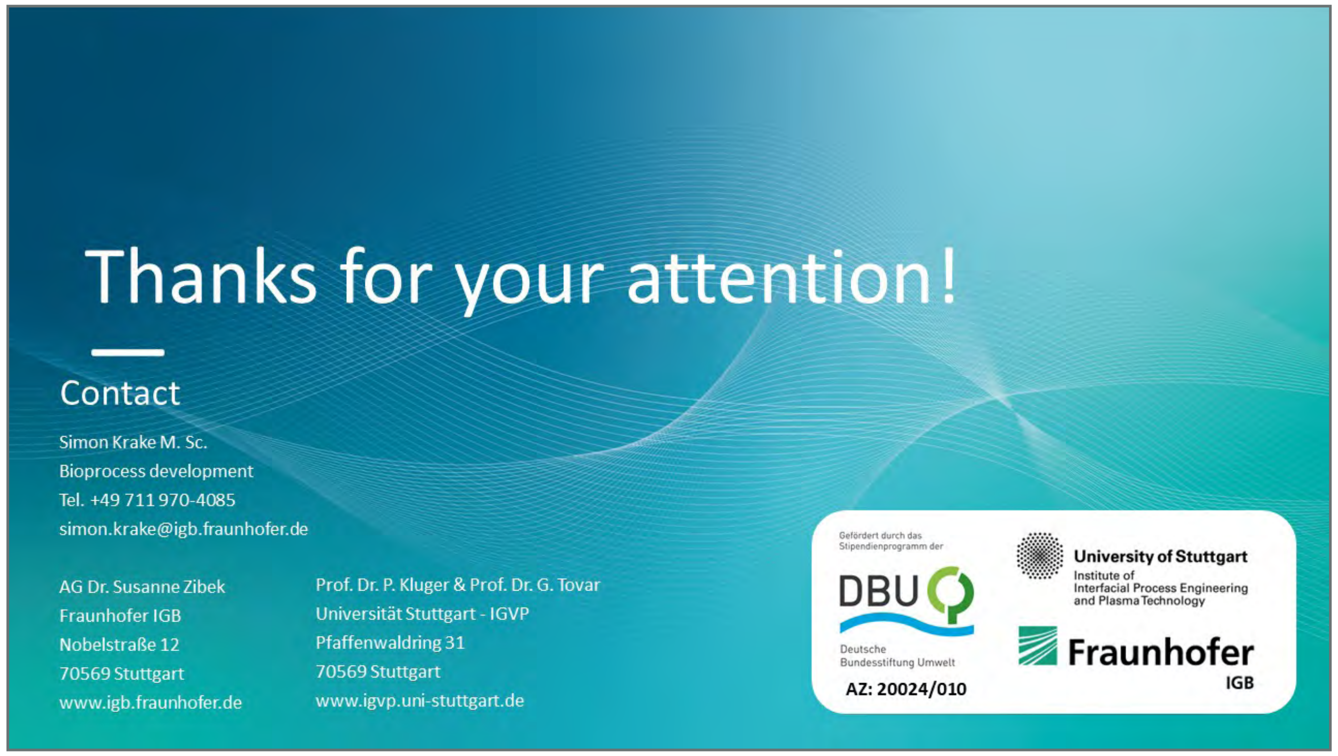
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Ahmed Al-Dubai, AAU Energy / Aalborg University

Effect of Microalgal Nutrient Starvation on Biocrude Upgrading Efficiency during Hydrotreatment

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Keywords: Hydrothermal liquefaction, Microalgae, Biocrude oil, Hydrotreatment

Energy is vital for development, but the continued dependence on fossil fuels contributes significantly to environmental concerns, particularly greenhouse gas emissions. Third generation biofuels derived from microalgae present a promising, sustainable alternative due to their high lipid content, ability to capture CO_2, and lack of competition with food crops. Hydrothermal liquefaction (HTL) enables the efficient conversion of wet microalgae biomass into biocrude oil, eliminating the need for energy intensive drying processes. However, the resulting biocrude requires catalytic hydrotreatment to remove oxygen and nitrogen and to enhance fuel quality. This upgrading step is hydrogen intensive, typically requiring 40-50 g H_2/kg biocrude, largely due to the presence of nitrogen compounds and unsaturated hydrocarbons.

This study investigates nutrient starvation on Parachlorella kessleri, as a strategy to tailor biocrude composition by reducing nitrogen and increasing lipid content, aiming for improved upgrading efficiency and lower hydrogen demand. Unlike previous studies comparing two microalgae with different lipid contents, this work uses a single strain to isolate the effect of nutrient starvation, comparing the hydrotreatment of biocrude from regularly grown (RA) and nutrient-starved (SA) microalgae. Hydrotreating was performed in duplicate using 12 mL Swagelok micro-batch reactors containing 2 g biocrude and 1 g NiMo/γ-Al2O3 catalyst. Reactors were leak-tested, purged with H_2, pressurized to 80 bar, and heated at 325–400 °C for 2–3 h in a fluidized sand bath with agitation. Hydrogen consumption was estimated by pressure changes at room temperature. Products were analyzed by CHN, GC-MS, and SimDis.

Hydrotreatment temperature and hydrogen availability strongly affected heteroatom removal. Hydrotreating at 350°C with a high hydrogen availability (65,6 g H_2/kg biocrude) achieved complete oxygen removal and 30 % nitrogen reduction in both RA and SA. At lower hydrogen availability (32,8 g H_2/kg biocrude) deoxygenation was incomplete (82-92 %) and nitrogen removal was limited (≤6 %). A two stage hydrotreating at higher hydrogen availability (350°C followed by 400° C) increased nitrogen removal to 66 % in RA and 62 % in SA. Notably, Hydrogen consumption during two stage hydrotreating was lower for SA biocrude (29.9 g H_2 /kg biocrude) compared to RA biocrude (48,1 g H_2 /kg biocrude), underscoring the role of nutrient starvation in improving biocrude composition and upgrading efficiency.

This research has received funding from the European Union, under the Horizon Europe project COCPIT (grant no. 101122101)

We are sorry, no slides avalailable

SESSION
BIOCHEMICAL CONVERSION

Alberto Meola, Deutsches Biomasseforschungszentrum

Multi-step modelling of unstable anaerobic digestion processes with hybrid models for process control

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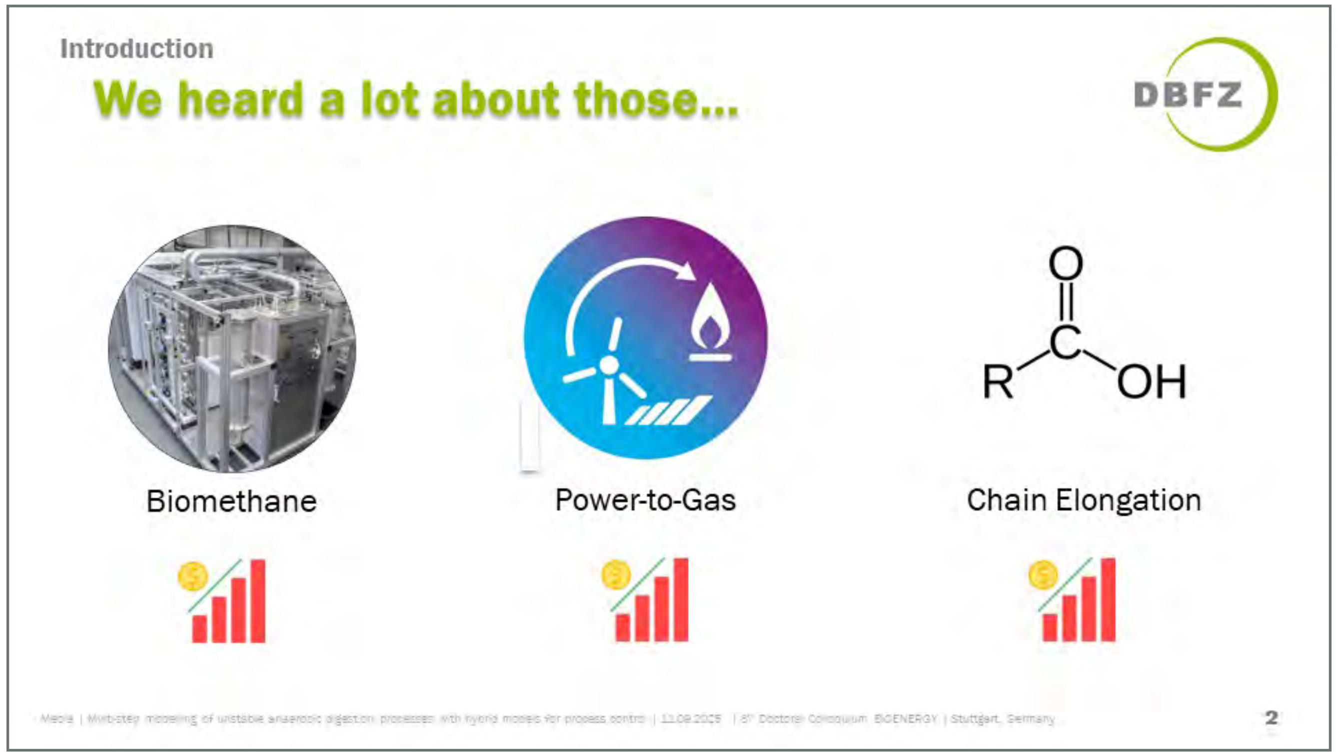
Keywords: Process prediction, biogas production, machine learning, artificial intelligence, transformers

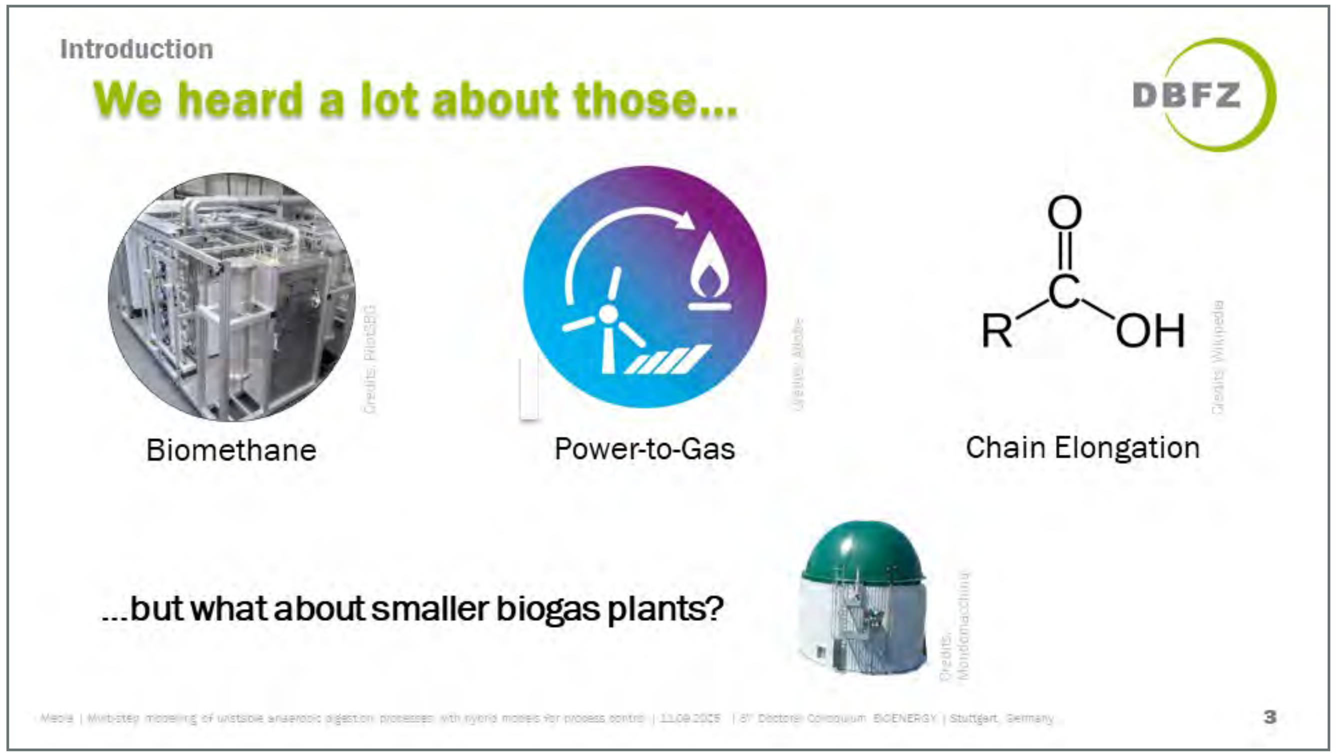
Introduction
Biogas plants support Germany's energy transition by enabling flexible, demand-driven electricity generation. Dynamic operation requires process control strategies, which in turn rely on reliable models. While mechanistic models like ADM1 are accurate, they require extensive measurements and frequent recalibration. ML models offer flexibility but are prone to overfitting, hallucinations, and limited explainability. Hybrid approaches combining mechanistic and ML models are thus explored. This work compares a Transformer-based Informer model, an LSTM NN, and a newly developed Multi-Step Temporal Random Forest (MT-RF). The Informer is hybridized by including outputs from a first-order kinetic model. Models are tested on a full-scale dataset containing sensor faults, suspected inhibition, and out-of-distribution test data. Results show that while complex models improve accuracy, the MT-RF achieves acceptable results with minimal tuning. Hybridization improves generalization and reduces overfitting under variable feeding

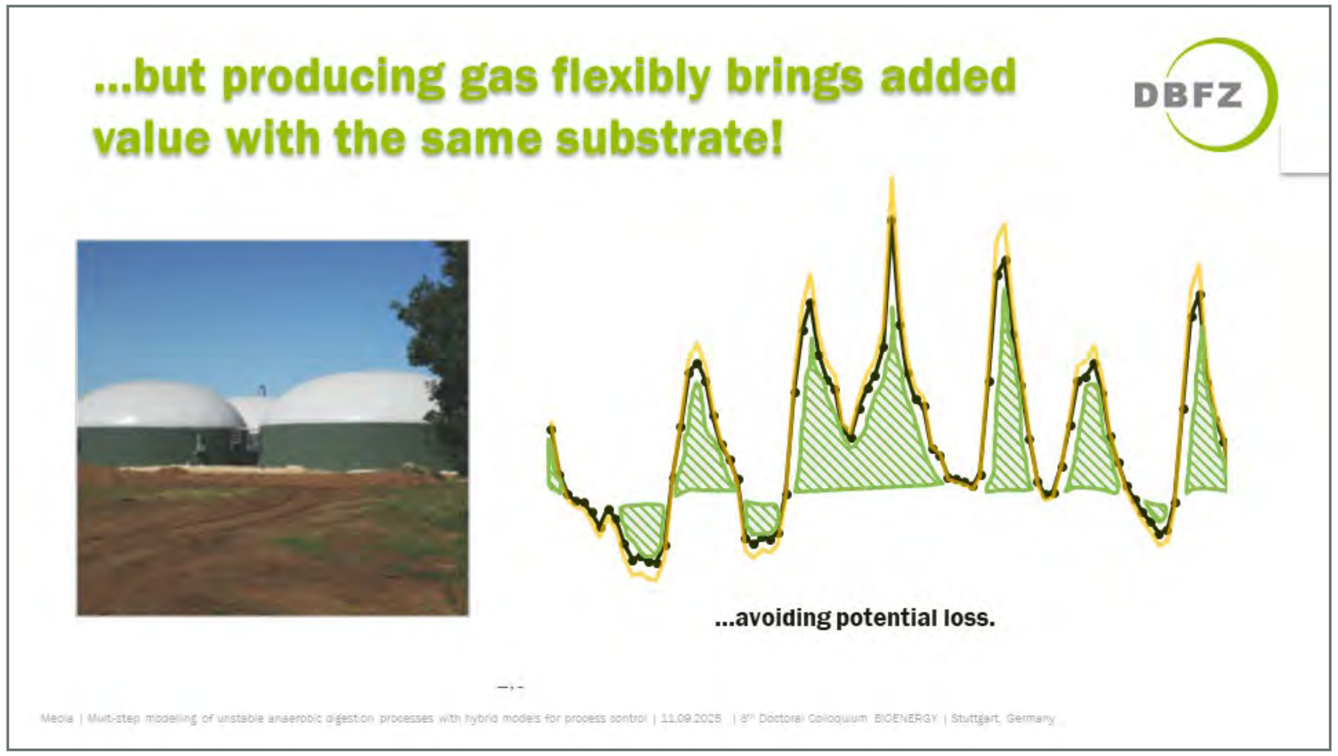
Methods
The dataset covers five months of full-scale data from a 152 m³ biogas reactor at DBFZ (Dataset B in [1]), resampled to 1-hour resolution. At each timestep t, the model receives all measurements up to t+0h and feed quantities up to t+167h, predicting methane production for one week. Models include an LSTM, a hybrid Informer, and the MT-RF. While LSTM and Informer natively model sequences, original RF does not support it. Thus, an autoregressive version of RF that treats past inputs as features was developed as MT-RF.

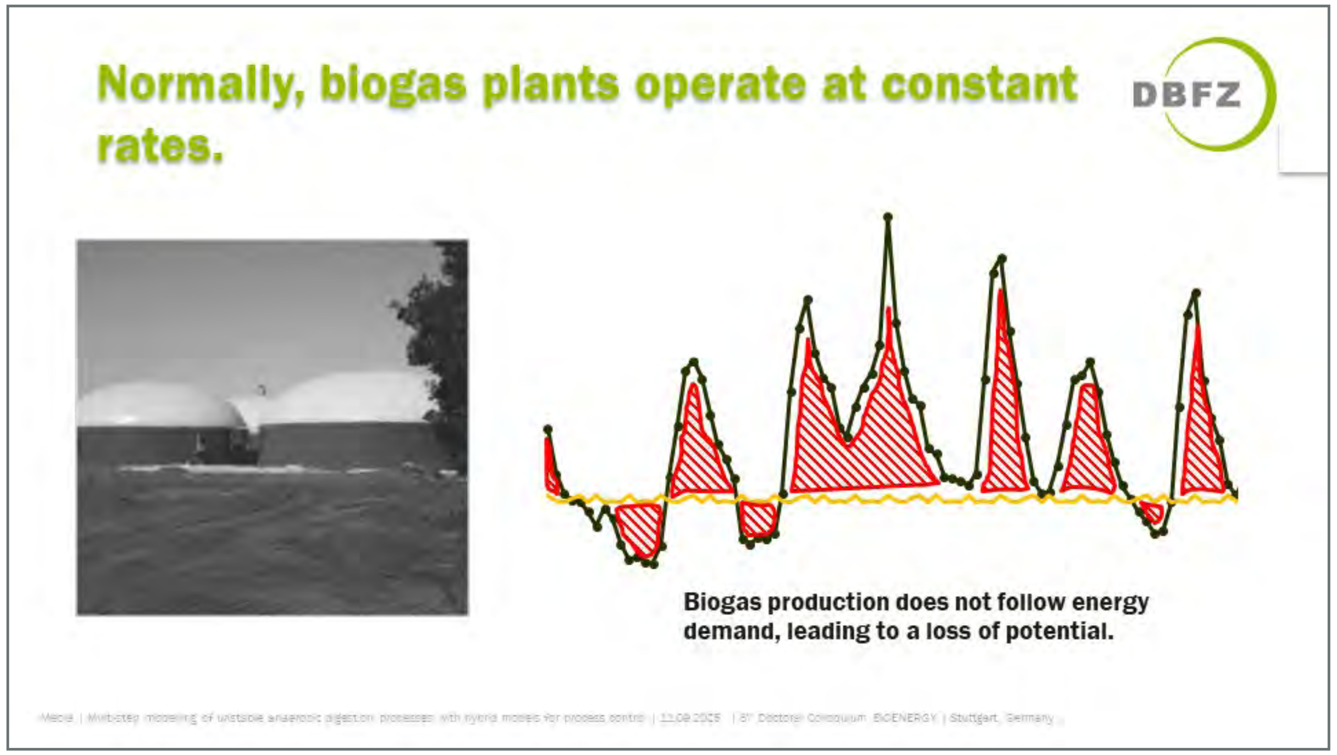
Results
All models perform well for multi-step prediction at industrial scale. Accuracy decreases with forecast horizon, but production peaks are still captured. The hybrid Informer is able to follow the production pattern more closely, even at later timesteps, demonstrating the advantage of incorporating mechanistic models. The best RMSE of 2.46 was achieved by the hybrid Informer. MT-RF, though less accurate, captures key dynamics and requires little tuning. These models are now being tested for feed scheduling based on electricity prices

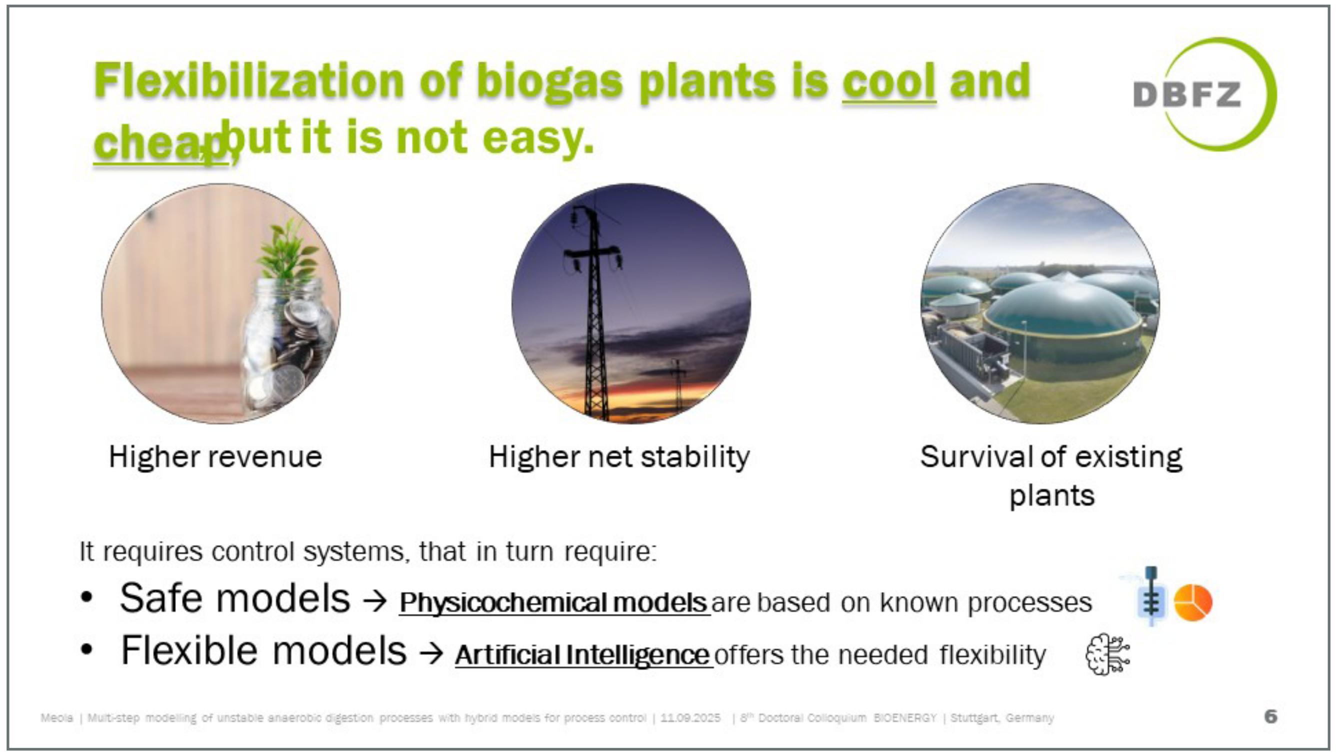
References
[1] Meola, Weinrich, 2025. Full-scale dynamic anaerobic digestion process simulation with machine and deep learning algorithms at intra-day resolution. Ap. En., 390, 125781

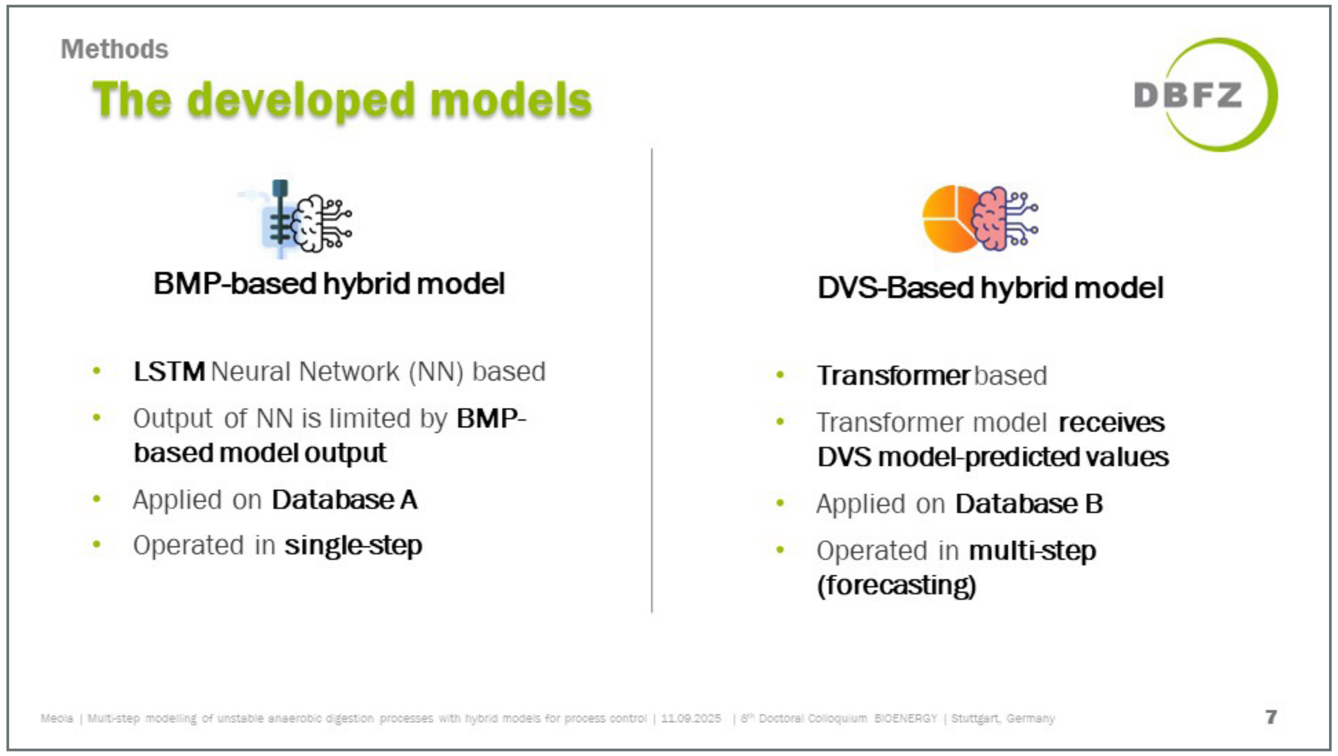


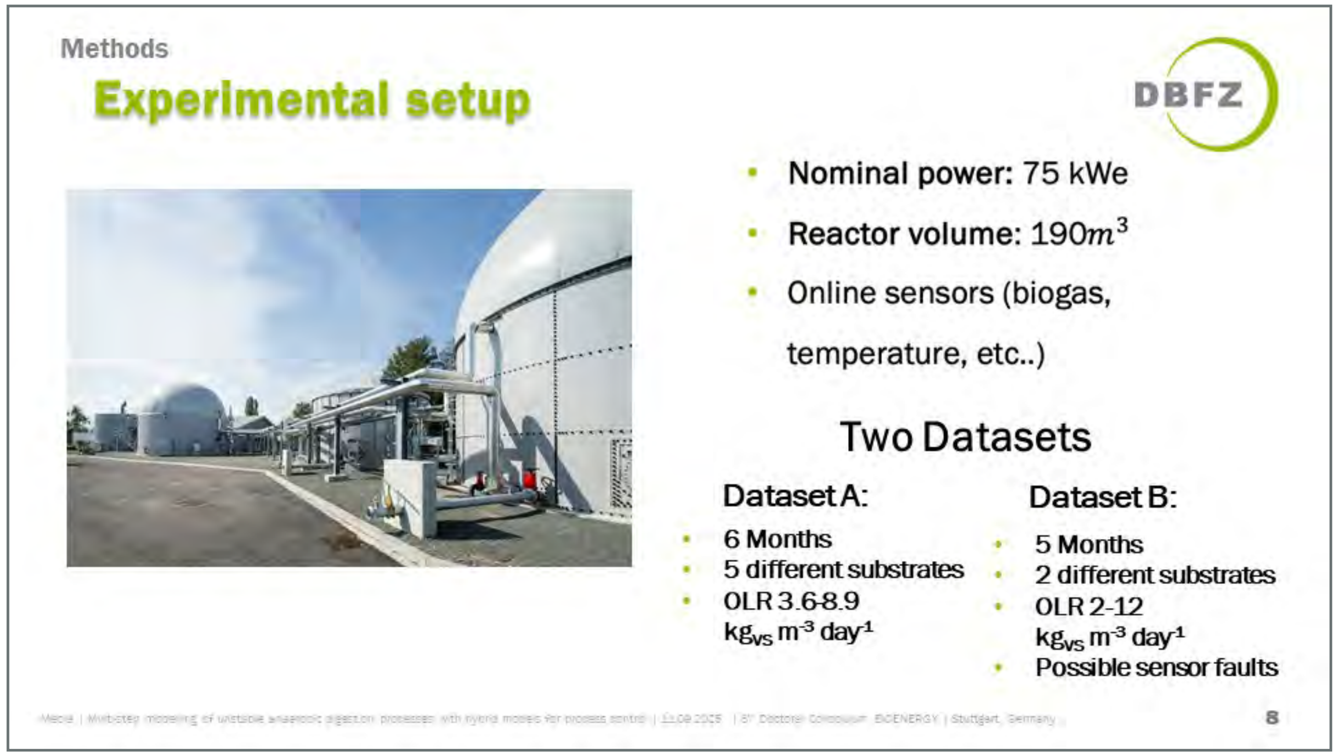

Introduction
We heard a lot about those...
DBFZ
Biomethane
Power-to-Gas
Chain Elongation
R
C
O
OH
...but what about smaller biogas plants?
3

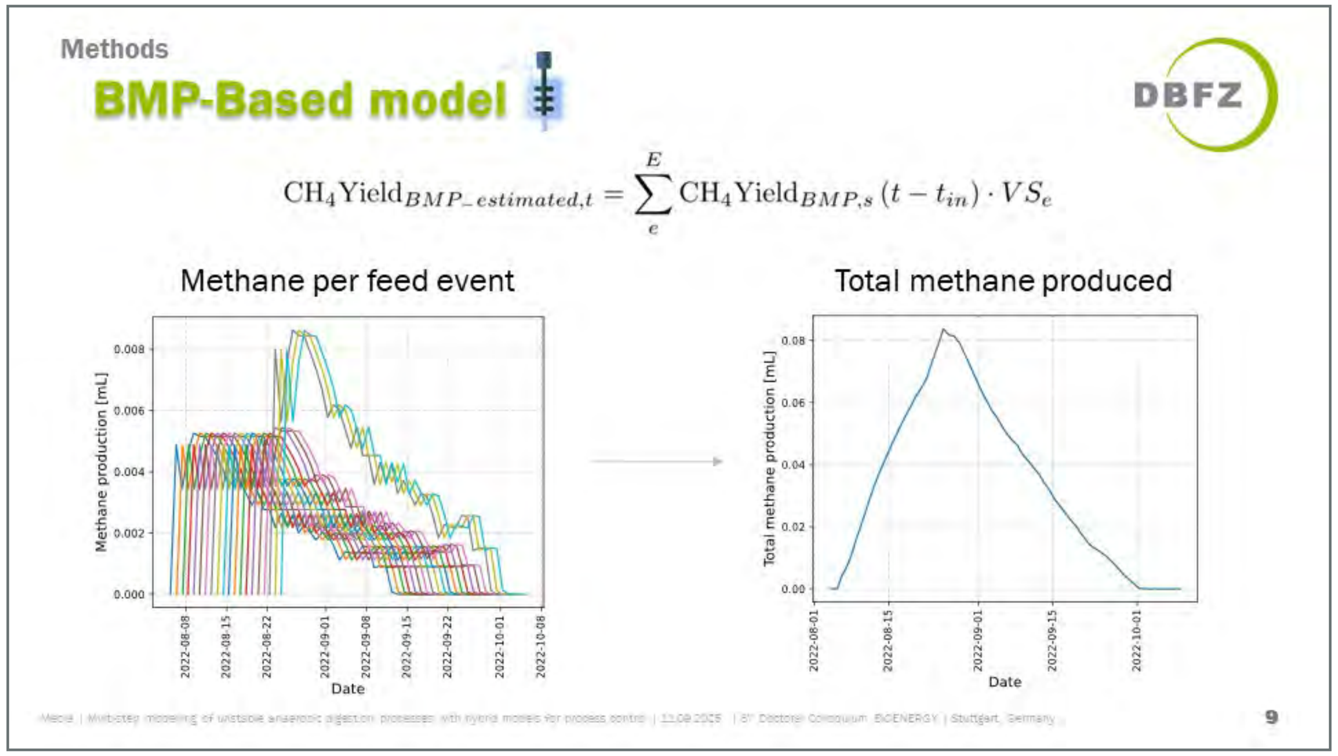

...but producing gas flexibly brings added value with the same substrate!
DBFZ
...avoiding potential loss.

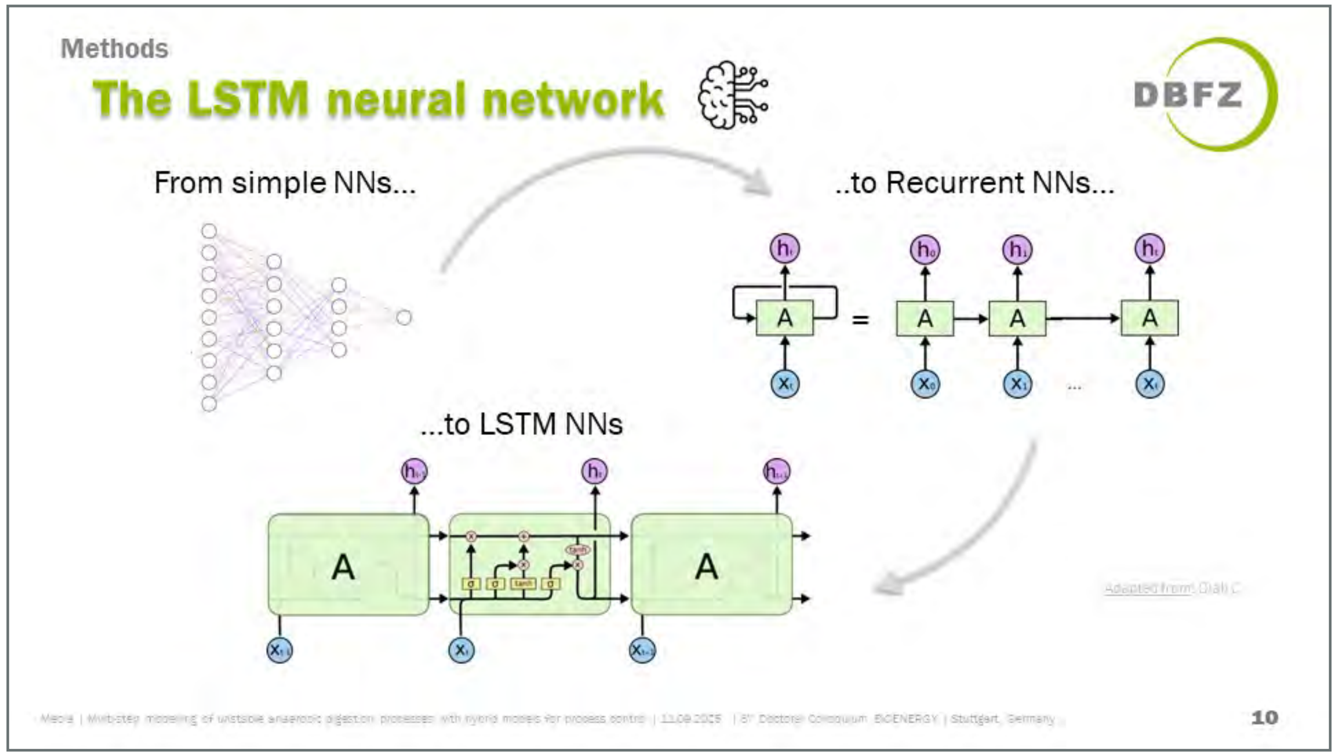

Normally, biogas plants operate at constant rates.
DBFZ
Biogas production does not follow energy demand, leading to a loss of potential.

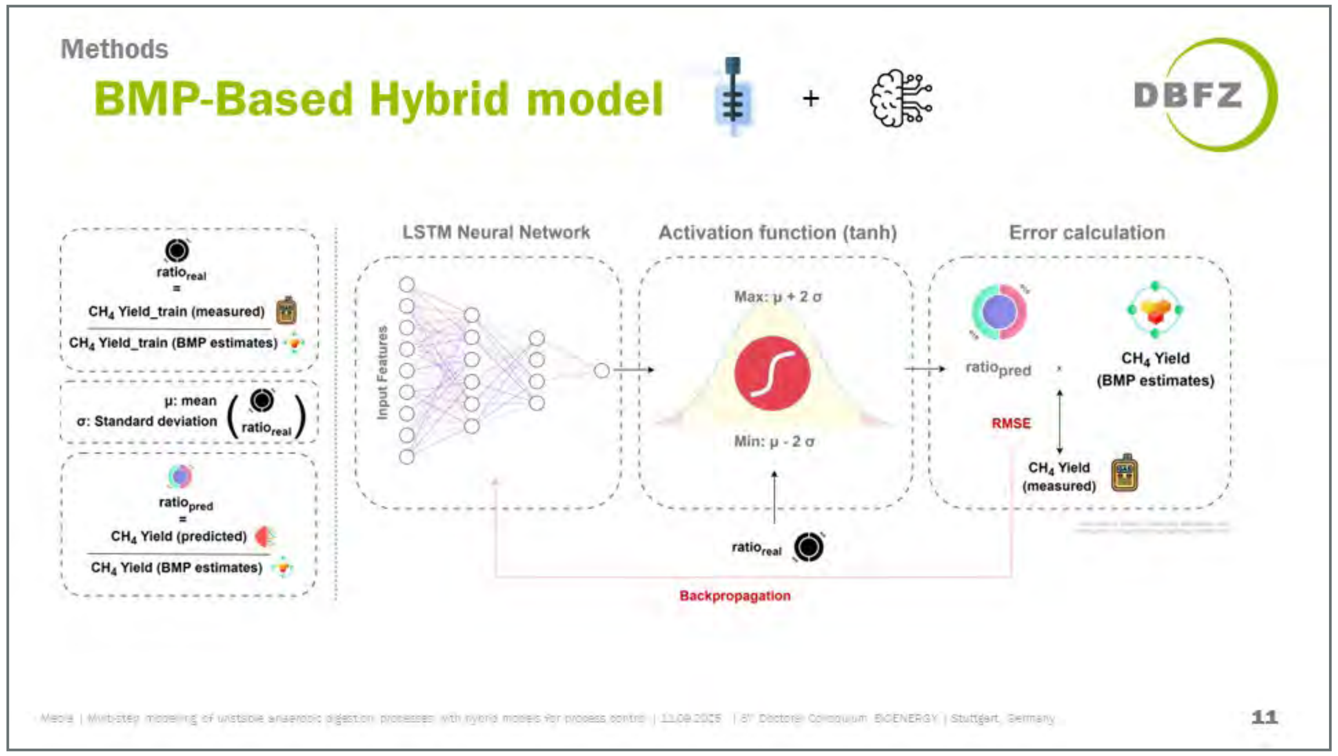

Flexibilization of biogas plants is cool and cheap, but it is not easy.
DBFZ
Higher revenue
Higher net stability
Survival of existing plants
It requires control systems, that in turn require:
• Safe models → Physicochemical models are based on known processes
• Flexible models → Artificial Intelligence offers the needed flexibility
6

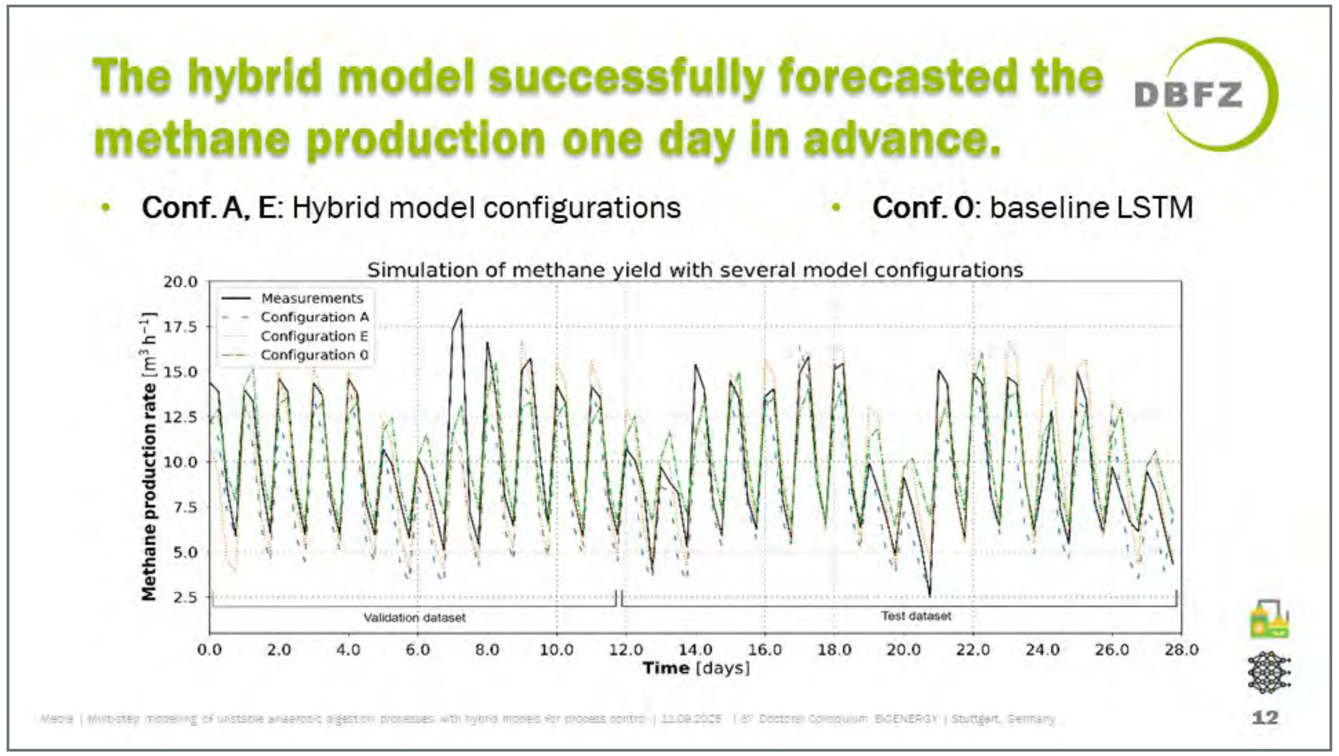

Methods
The developed models
DBFZ
BMP-based hybrid model
LSTM Neural Network (NN) based
Output of NN is limited by BMP-based model output
Applied on Database A
Operated in single-step
DVS-Based hybrid model
Transformer based
Transformer model receives DVS model-predicted values
Applied on Database B
Operated in multi-step (forecasting)
7

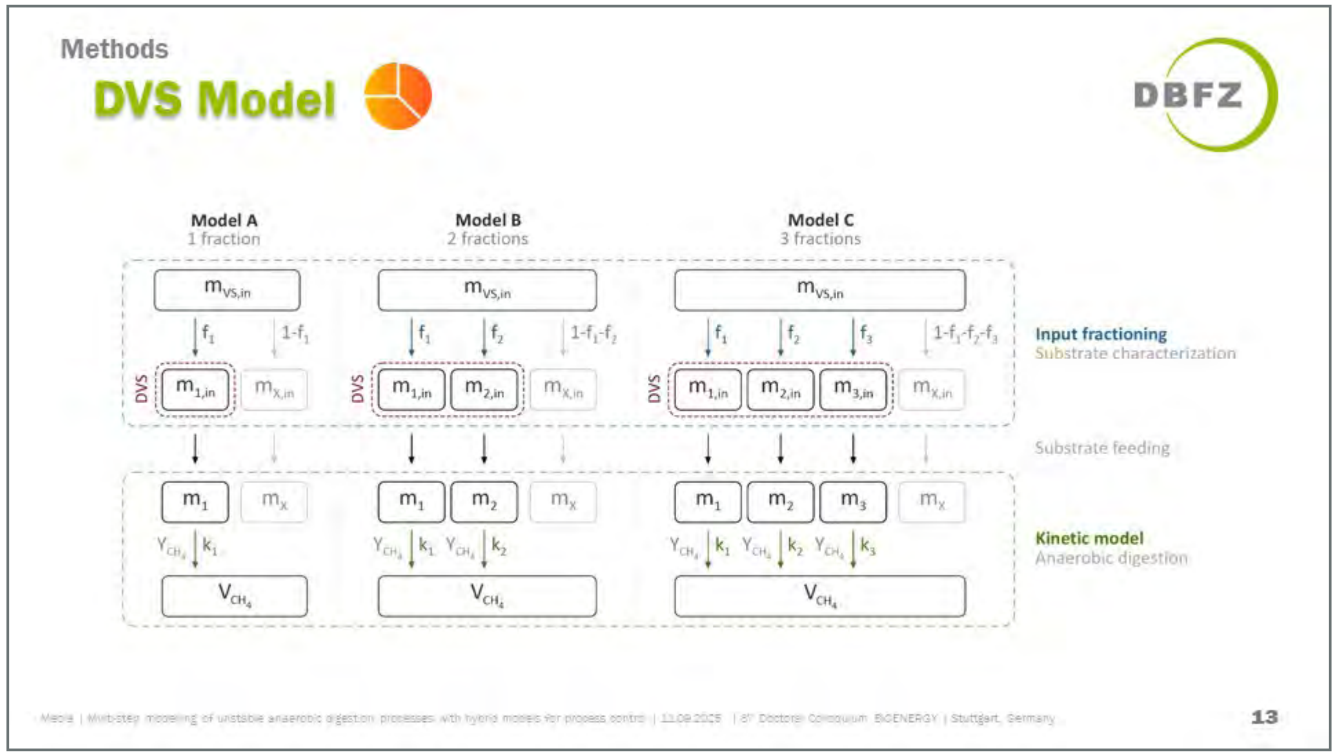

Methods
Experimental setup
DBFZ
Nominal power: 75 kWe
Reactor volume: 190m^3
Online sensors (biogas, temperature, etc..)
Two Datasets
Dataset A:
6 Months
5 different substrates
OLR 3.6-8.9
kg_{VS} m^{-3} day^{-1}
Dataset B:
5 Months
2 different substrates
OLR 2-12
kg_{VS} m^{-3} day^{-1}
Possible sensor faults
8

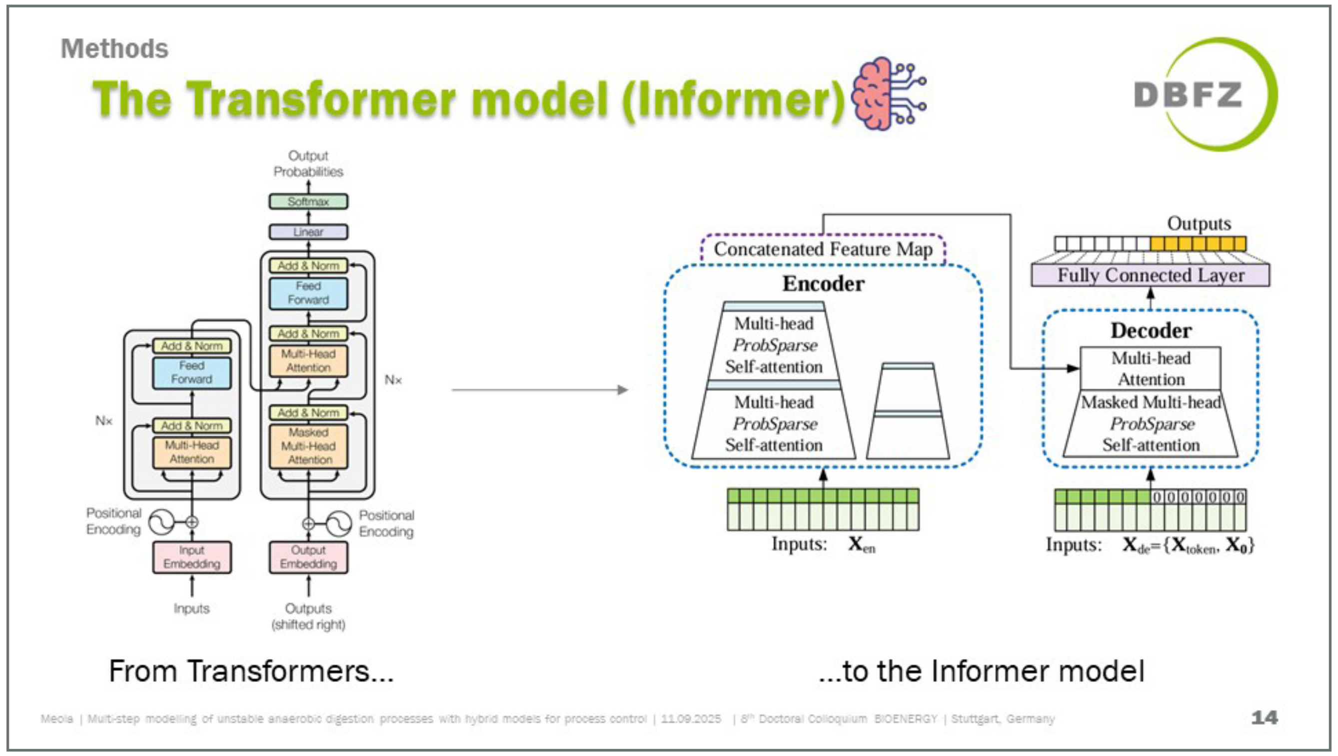

Methods
BMP-Based model
DBFZ
$CH_4Yield_{BMP\_estimated,t} = \sum_{e}^{E} CH_4Yield_{BMP,s}(t - t_{in}) \cdot VS_e$
Methane per feed event
Total methane produced
Methane production [mL]
Total methane production [mL]
Date
Date
9


Methods
The LSTM neural network
DBFZ
From simple NNs...
..to Recurrent NNs...
...to LSTM NNs
A
A
9


Methods
BMP-Based Hybrid model
+
DBFZ
LSTM Neural Network
Activation function (tanh)
Error calculation
ratio$_{real}$ =
CH$_4$ Yield_train (measured)
CH$_4$ Yield_train (BMP estimates)
μ: mean
σ: Standard deviation
ratio$_{pred}$ =
CH$_4$ Yield (predicted)
CH$_4$ Yield (BMP estimates)
Input Features
Max: μ + 2 σ
Min: μ - 2 σ
ratio$_{pred}$
CH$_4$ Yield (BMP estimates)
RMSE
CH$_4$ Yield (measured)
ratio$_{real}$
Backpropagation
11


The hybrid model successfully forecasted the methane production one day in advance.
DBFZ
• Conf. A, E: Hybrid model configurations
• Conf. 0: baseline LSTM
Simulation of methane yield with several model configurations
Measurements
Configuration A
Configuration E
Configuration 0
Methane production rate [m³ h⁻¹]
20.0
17.5
15.0
12.5
10.0
7.5
5.0
2.5
Validation dataset
Test dataset
0.0
2.0
4.0
6.0
8.0
10.0
12.0
14.0
16.0
18.0
20.0
22.0
24.0
26.0
28.0
Time [days]
12


Methods
DVS Model
DBFZ
Model A
1 fraction
Model B
2 fractions
Model C
3 fractions
Input fractioning
Substrate characterization
Substrate feeding
Kinetic model
Anaerobic digestion
13


Methods
The Transformer model (Informer)
DBFZ
Output Probabilities
Softmax
Linear
Add & Norm
Feed Forward
Multi-Head Attention
Masked Multi-Head Attention
Positional Encoding
Input Embedding
Output Embedding
Inputs
Outputs (shifted right)
Nx
Concatenated Feature Map
Encoder
Multi-head ProbSparse Self-attention
Inputs: X$_{en}$
Outputs
Fully Connected Layer
Decoder
Multi-head Attention
Masked Multi-head ProbSparse Self-attention
Inputs: X$_{de}$={X$_{token}$, X$_0$}
From Transformers...
...to the Informer model
14

Methods

DVS-Based Hybrid model

+

DBFZ

Time	Feature 1	Feature 2
00:00	1	10
01:00	0.5	12
02:00	0.4	28
03:00	0.6	14
04:00	0.8	3

Time	DVS Prediction	DVS Prediction + 1
00:00	5	6
01:00	8	9
02:00	10	8
03:00	5	3
04:00	4	7

Time	Feature 1	Feature 2	DVS Prediction	DVS Prediction + 1
00:00	1	10	5	6
01:00	0.5	12	8	9
02:00	0.4	28	10	8
03:00	0.6	14	5	3
04:00	0.8	3	4	7

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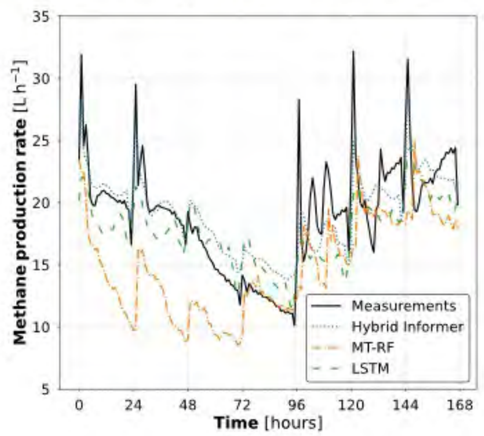
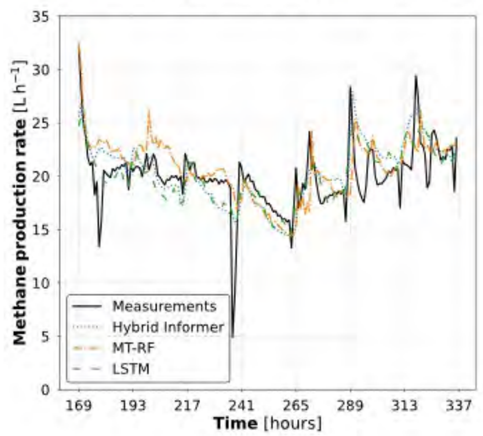
The hybrid model outperformed all other tested models when forecasting one whole week of biogas production in advance.

DBFZ

Sample week n. 1



Sample week n. 2



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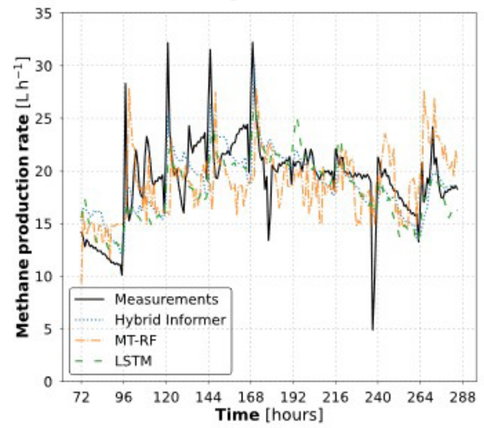
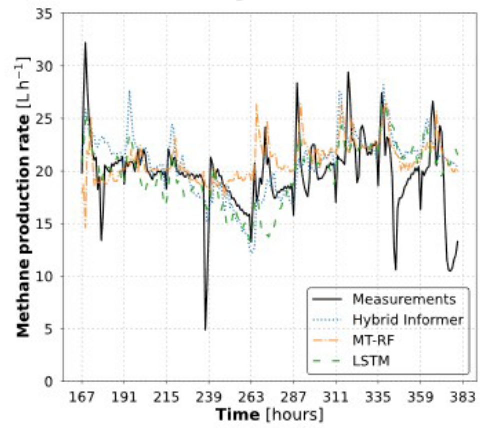
The prediction quality does not strongly decrease with the time.

DBFZ

One-step prediction three days in advance



One-step prediction seven days in advance



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Conclusions

Conclusions

DBFZ

- Hybrid models can succesfully forecast the biogas process
- All tested hybrid models support a high number of substrates
- More complex hybrid models can model datasets with faulty sensors and high variance
- Prediction accuracy does not drammatically decrease with longer prediction horizons

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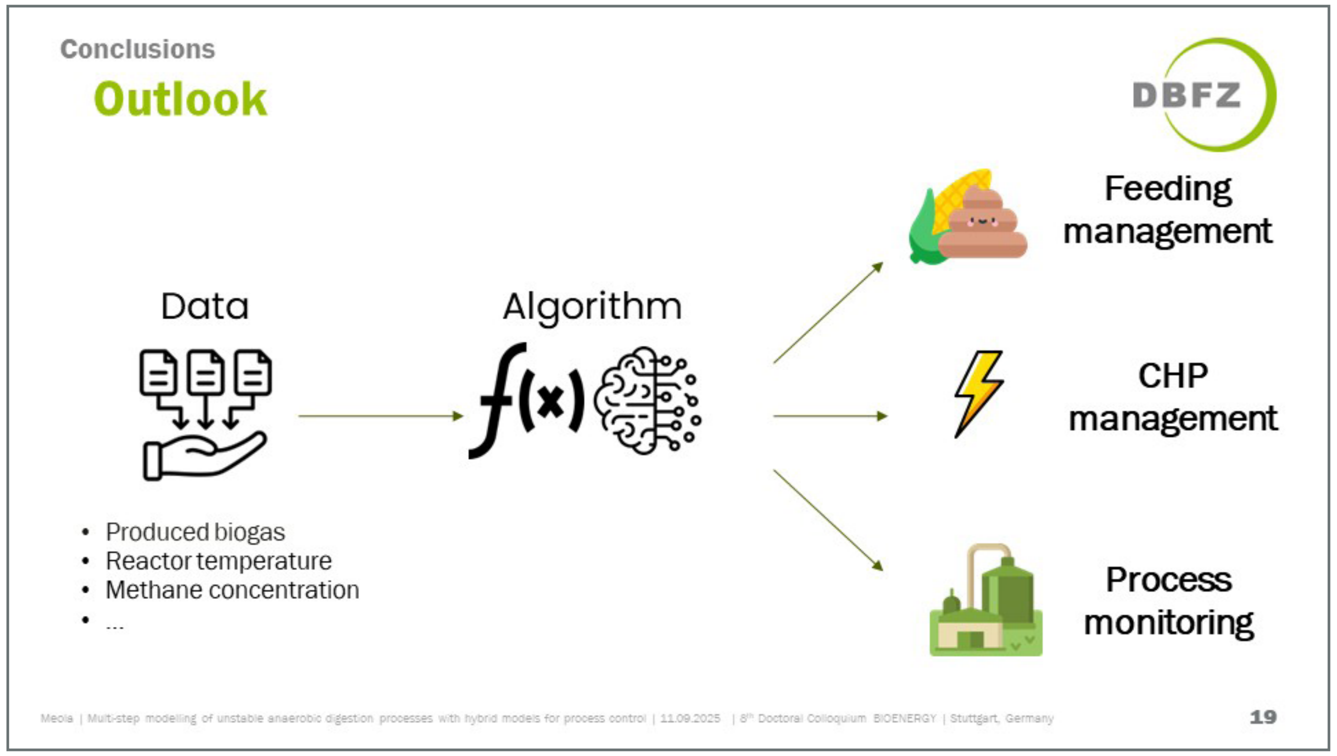
Conclusions
Outlook
DBFZ
Data
Algorithm
Feeding management
CHP management
Process monitoring
• Produced biogas
• Reactor temperature
• Methane concentration
• ...
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19


Thanks to DBFZ, we are working on founding a startup!
DBFZ
DBFZ
clever bioTechnologies
flexible from the bottom up.
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20

Birk Achenbach, University of Stuttgart

Process development for the production of terpolymeric polyhydroxyalkanoate

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Keywords: PHBVV, Levulinic acid, Process optimization, Scale-up, PHA extraction

Introduction

Polyhydroxyalkanoates (PHA) are microbially produced bio-polyesters. They are stored by various microorganisms upon carbon excess paired with a deficiency of nutrients. One of the most promising candidates in this diverse polymer group are copolymer variants such as poly-3-hydroxybutyrate-3-hydroxyvalerate (P(3HB3HV)) and poly-3-hydroxybutyrate-3-hydroxyvalerate-4-hydroxyvalerate (P(3HB3HV4HV)) [1]. As reported by [2], the terpolymer P(3HB3HV4HV), even with small percentages of 4HV can improve the thermal and physical properties in comparison to the well-studied P(3HB3HV) with similar 3HV content. Therefore, our research aims to develop a resilient and stable process to produce a P(3HB3HV4HV) terpolymer with an automated feeding strategy based on the pH and dissolved oxygen (DO).

Approach

The process was developed and scaled up from a 5 L to 23 L and finally to 530 L fermentation volume. The levulinic acid feeding automation was achieved by relying on the dissolved oxygen and the pH as control in the laboratory- and on technical-scale.

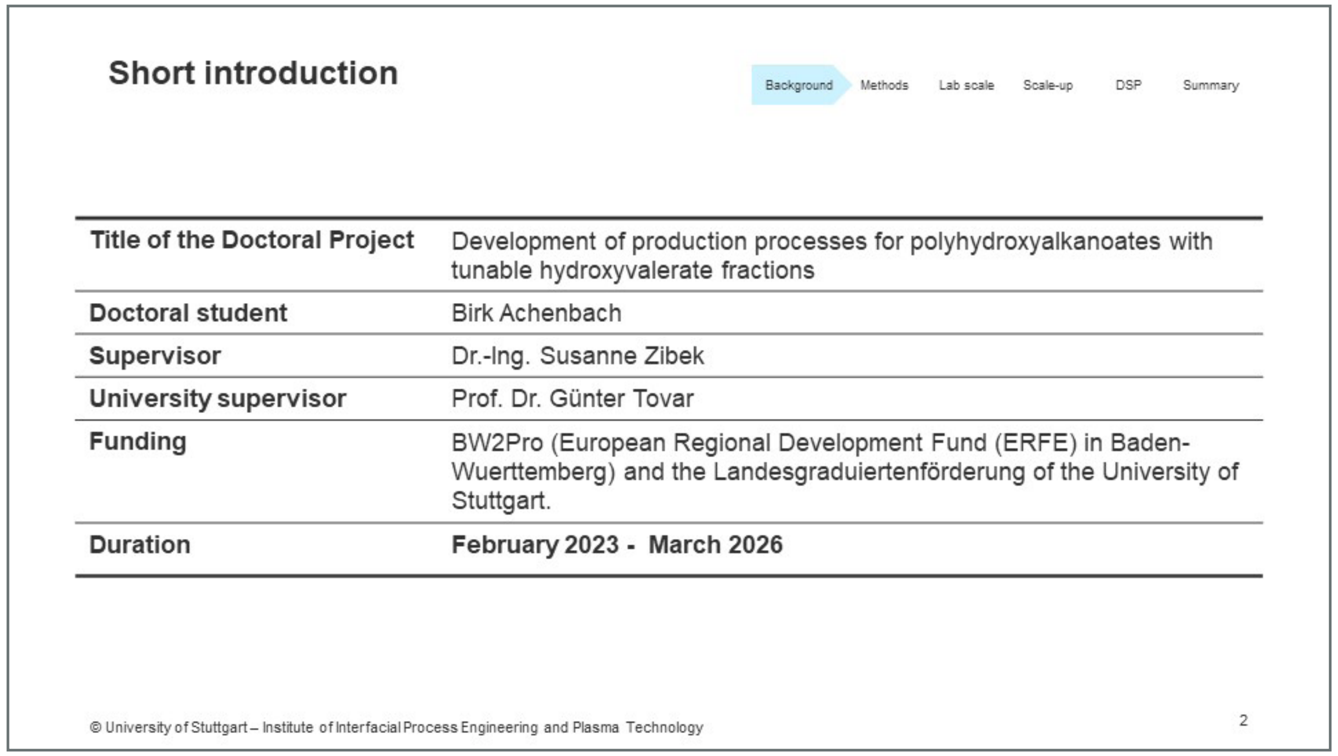
Results

This process resulted in a biomass concentration between 33-41g/L cell dry weight with PHA content higher than 72 % in the laboratory and technical scale. The GC analysis showed that the PHA was composed of terpolymer with 3HB, 3HV, and 4HV in a ratio of 54:46:2 in the technical scale. The produced PHA showed a similar composition and yield (~0.33 gPHA/gLevulinic acid) compared to PHA produced on γ-valerolacton and levulinic acid [1, 2]. During piloting, differences in the growth behavior and product composition were detected. Especially the 3-HV content, which rose in the piloting to 67 %, was significantly linearly correlated with scale-dependent parameters such as mixing times, as well as with increased gas solubility due to increased pressure in the pilot scale. In future research, the scaling effects will be further investigated to fine-tune product composition and improve production rates in large-scale production.

References

[1] Tanadchangsaeng N, Yu J. Miscibility of natural polyhydroxyalkanoate blend with controllable material properties. Journal of Applied Polymer Science. 2013;129(4):2004-16.

[2] Zhila NO, Sapozhnikova KY, Kiselev EG, Nemtsev IV, Lukyanenko AV, Shishatskaya EI, et al. Biosynthesis and Properties of a P(3HB-co-3HV-co-4HV) Produced by Cupriavidus necator B-10646. POLYMERS. 2022;14(19).



Title of the Doctoral Project	Development of production processes for polyhydroxyalkanoates with tunable hydroxyvalerate fractions
Doctoral student	Birk Achenbach
Supervisor	Dr.-Ing. Susanne Zibek
University supervisor	Prof. Dr. Günter Tovar
Funding	BW2Pro (European Regional Development Fund (ERFE) in Baden-Wuerttemberg) and the Landesgraduiertenförderung of the University of Stuttgart.
Duration	**February 2023 - March 2026**

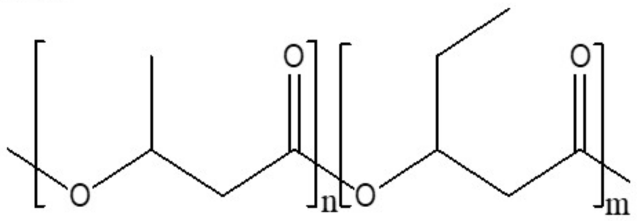
Why do we want to produce PHAs?

Scientific background

Background | Methods | Lab scale | Scale-up | DSP | Summary

3-HB / mol%	3-HV / mol%	4-HV / mol%	T_m / °C	
100	0	0	161 - 178	[1, 2]

- Producers store PHA under nutrient-limiting (N, $PO4^{-3}$, O_2) but carbon-rich conditions
- Polymer properties depend on the monomers and their ratio
- Formed (co-)polymer depends on the microorganism and substrate



3-Hydroxybutyrate (3-HB) 3-Hydroxyvalerate (3-HV)

[1] Tanadchangsaeng, N., Yu, J., Journal of Applied Polymer Science 2015, 132. https://doi.org/10.1002/app.41715
[2] Owen, A.J. et al. (1992). Crystallization and melting behaviour of PHB and PHB/HV copolymer. Polymer. https://doi.org/10.1016/0032-3861(92)90139-n.

 3

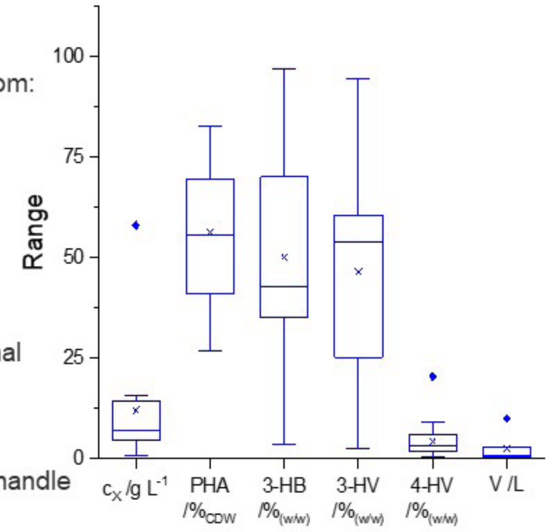
What has already been done?

Literature review

Background | Methods | Lab scale | Scale-up | DSP | Summary

- PHBVV has been produced with *C. necator* from:
  - Levulinic acid
  - 4-Hydroxyvaleric acid
  - γ-Valerolactone
- Production mainly in shake flask, only four publications with fermenter processes
  - Largest vessel (10 L, batch process) with final biomass titer of ~3.2 g_X L^{-1} not suitable for production

→ A scalable fed batch process is needed to handle inhibitory precursor substrates



[1] Valentin, H.E., et al., Applied Microbiology and Biotechnology 1992, 36, 507-514.10.1007/BF00170193
[2] Muzaiyanah, A. R., Amirul, A. A., Applied Biochemistry and Biotechnology 2013, 170, 1194-1215.10.1007/s12010-013-0247-6
[3] Gorenflo, V., et al., BIOMACROMOLECULES 2001, 2, 45-57.10.1021/bm000992
[4] Sheu, D.-S., et al., International Journal of Biological Macromolecules 2018, 118, 1558-1564.https://doi.org/10.1016/j.ijbiomac.2018.06.193
[5] Tanadchangsaeng, N., Yu, J., Journal of Applied Polymer Science 2013, 129, 2004-2016.https://doi.org/10.1002/app.38906
[6] Tanadchangsaeng, N., Yu, J., Journal of Applied Polymer Science 2015, 132.https://doi.org/10.1002/app.41715
[7] Wang, Y., et al., PLOS ONE 2013, 8, e60318.10.1371/journal.pone.0060318
[8] Zhila, N. O., et al., In Polymers, Vol. 14, 2022.10.3390/polym14194226
[9] Valentin, H.E., Steinbüchel, A., Journal of environmental polymer degradation 1995, 3, 169-175.10.1007/BF02068468

 5

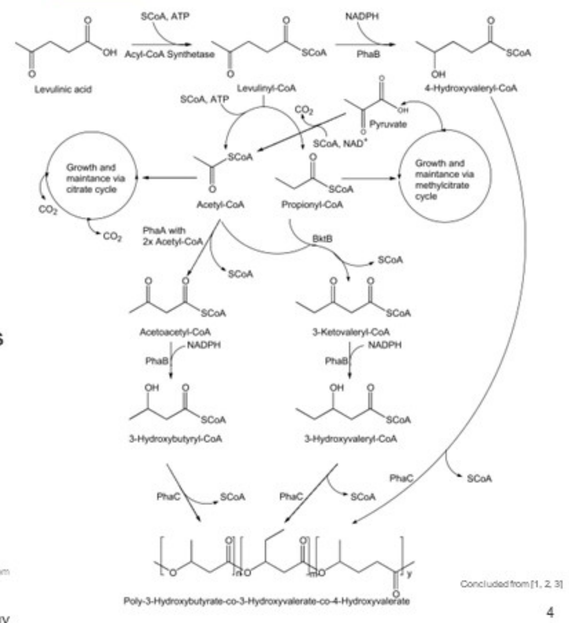
How do we produce PHAs?

Scientific background

Background | Methods | Lab scale | Scale-up | DSP | Summary

- Variety of producers from archaeons to bacteria
- Main organism: *Cupriavidus necator*

  → Wild type is unable to assimilate glucose
- Main substrates of bioeconomy:
  - Sugars → Alternative to the wildtype needed
  - Organic acids → Inhibitory in small concentrations
- Used strain is capable of utilizing glucose and can tolerate levulinic acid concentrations > 10 g L^{-1}



Concluded from [1, 2, 3]

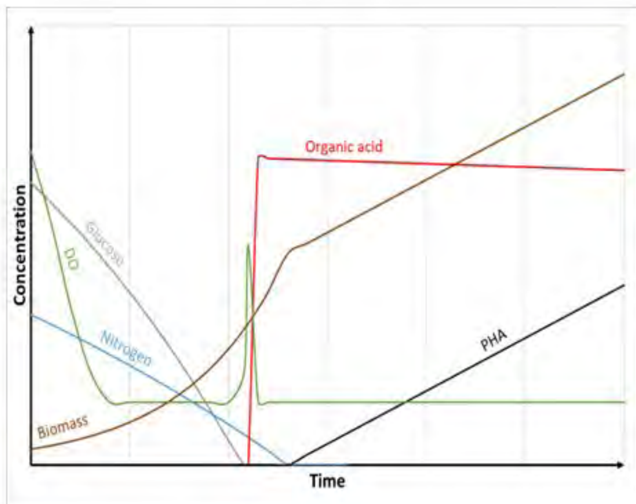
[1] Arenas-López, C. et al. (2019). The genetic basis of 3-hydroxypropanoate metabolism in Cupriavidus necator H16. Biotechnology for Biofuels. https://doi.org/10.1186/s13068-019-1489-5.
[2] Yu, J. et al. (2009). Biopolyester Synthesis and Protein Regulations in <i>Ralstonia eutropha</i> on Levulinic Acid and Its Derivatives from Biomass Refining. Journal of Biobased Materials and Bioenergy. https://doi.org/10.1166/jbmb.2009.1018.
[3] Jaremko, M. and Yu, J. (2011). The initial metabolic conversion of levulinic acid in Cupriavidus necator. Journal of Biotechnology. https://doi.org/10.1016/j.jbiotec.2011.07.027.

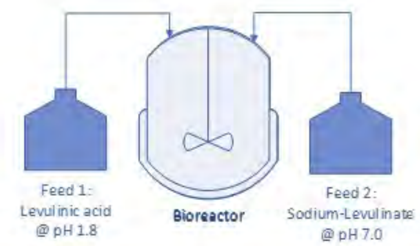
 4

How do we handle inhibitory substrates?

Demand-controlled feeding

Background | Methods | Lab scale | Scale-up | DSP | Summary





Process Automation	1 L – 42 L	1 m³
Feed 1	Full automation	Full automation
Feed 2	Full automation	Automated with manual supervision

[1] Huschner, F. et al. (2015). Development of a feeding strategy for high cell and PHA density fed-batch fermentation of Ralstonia eutropha H16 from organic acids and their salts. Process Biochemistry. https://doi.org/10.1016/j.procbio.2014.12.006.

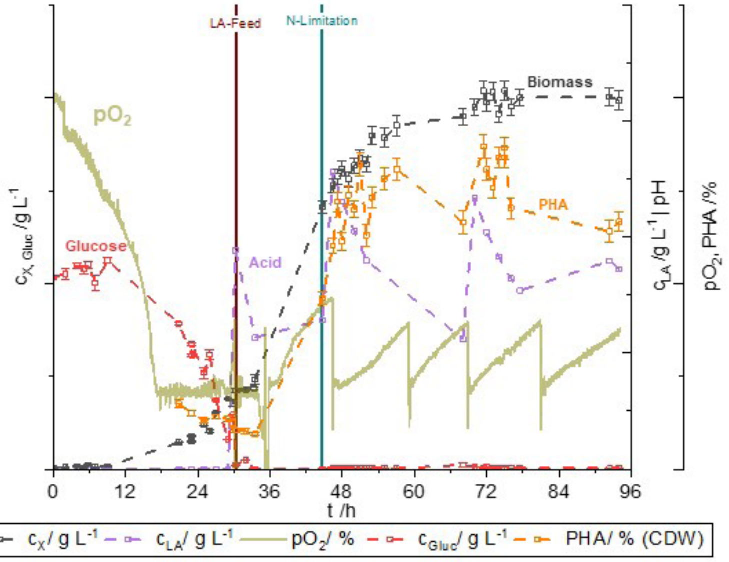
 6

Which phases does the process need?

Background Methods Lab scale Scale-up DSP Summary

Fermentation in the lab-scale

- Specialized stirrer cascade to prevent control delay
- Full automatization of feeding
- Intermediate phase on levulinic acid to prevent "PHB cores"



 7

How to scale up the process?

Background Methods Lab scale Scale-up DSP Summary

Specific power input as scale-up criterion

$$P_S = Ne_0 * \left(0.1\left(\frac{F_G}{n * V_L}\right)^{-0.25} * \left(\frac{n^2 * d_S^4}{g * w_S * V_L^{\frac{2}{3}}}\right)^{-0.20}\right) * \rho_L * n^3 * d_S^5$$

$$P_G = F_G * \rho_L * g * H_L$$

$$t_m = 5.9 * d_T^{\frac{2}{3}}\left(\frac{\rho_L}{P_t}\right)^{\frac{1}{3}} * \left(\frac{d_T}{d_S}\right)^{\frac{1}{3}}$$

$$k_l a = 2.0 * 10^{-3} * P_S^{0.7} * u_G^{0.2}$$

Parameter	Lab-scale (7.5 L)	Technical scale (42 L)	Pilot scale (1 m³)
Power input by gassing P_G / kW m^{-3}	0.07	0.03	0.02
Power input by stirring $P_{S,\,calc}$ / kW m^{-3}	0.09 – 2.80	0.03 – 2.84	0.14 – 2.85
$P_{total,\,calc}$ / kW m^{-3}	0.16 – 2.86	0.16 – 2.86	0.16 – 2.86
k_La / s^{-1}	0.02 – 0.19	0.02 – 0.18	0.02 – 0.15
Mixing time t_m / s	4.3 – 1.6	7.0 – 2.7	12.8 – 4.9

Doran, P. M., Bioprocess Engineering Principles, Academic Press, London, 1995. https://doi.org/10.1016/B978-012220855-3/50009-2
Doran, P. M., Bioprocess Engineering Principles (Second Edition), Academic Press, London, 2013. https://doi.org/10.1016/B978-0-12-220851-5.00008-3
Kraume, M., *Mischen und Rühren: Grundlagen und moderne Verfahren*, John Wiley & Sons, 2006
Storhas, W., *Arbeitsgebiete der Bioverfahrenstechnik* 2ed., Wiley-VCH Verlag GmbH & Co. KGaA, Weinheim, Germany, 2013.

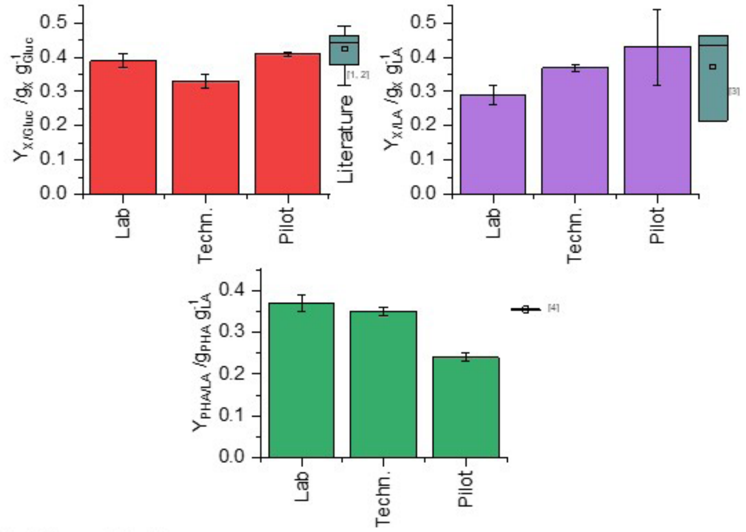
 8

How scalable is the process?

Background Methods Lab scale Scale-up DSP Summary

Multiple Scales in comparison

- Biomass yields stable during scale up
- PHA Yield drop with scale, further research necessary
- Several kilogram of polymer produced and purified



[1] Kim, B.S. et al. (1994). Production of poly(3-hydroxybutyric acid) by fed-batch culture of Alcaligenes eutrophus with glucose concentration control. Biotechnology and Bioengineering.
[2] Ryu, H.W. et al. (1997). Production of poly(3-hydroxybutyrate) by high cell density fed-batch culture of Alcaligenes eutrophus with phospate limitation. Biotechnology and Bioengineering.
[3] Yu, J. et al. (2009). Biopolyester Synthesis and Protein Regulations in <I>Ralstonia eutropha</I> on Levulinic Acid and Its Derivatives from Biomass Refining. Journal of Biobased Materials and Bioenergy.
[4] Sheu, D.-S. et al. (2018). Cultivation temperature modulated the monomer composition and polymer properties of polyhydroxyalkanoate synthesized by Cupriavidus sp. L7L from levulinate as sole carbon source. International Journal of Biological Macromolecules.

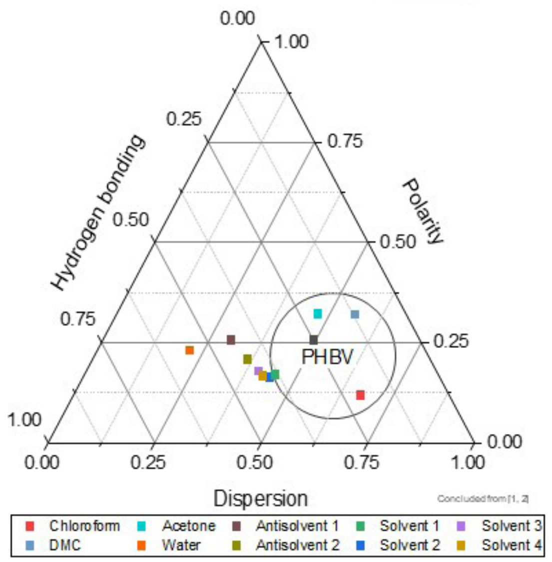
 9

How do we get PHA out of the cells?

Background Methods Lab scale Scale-up DSP Summary

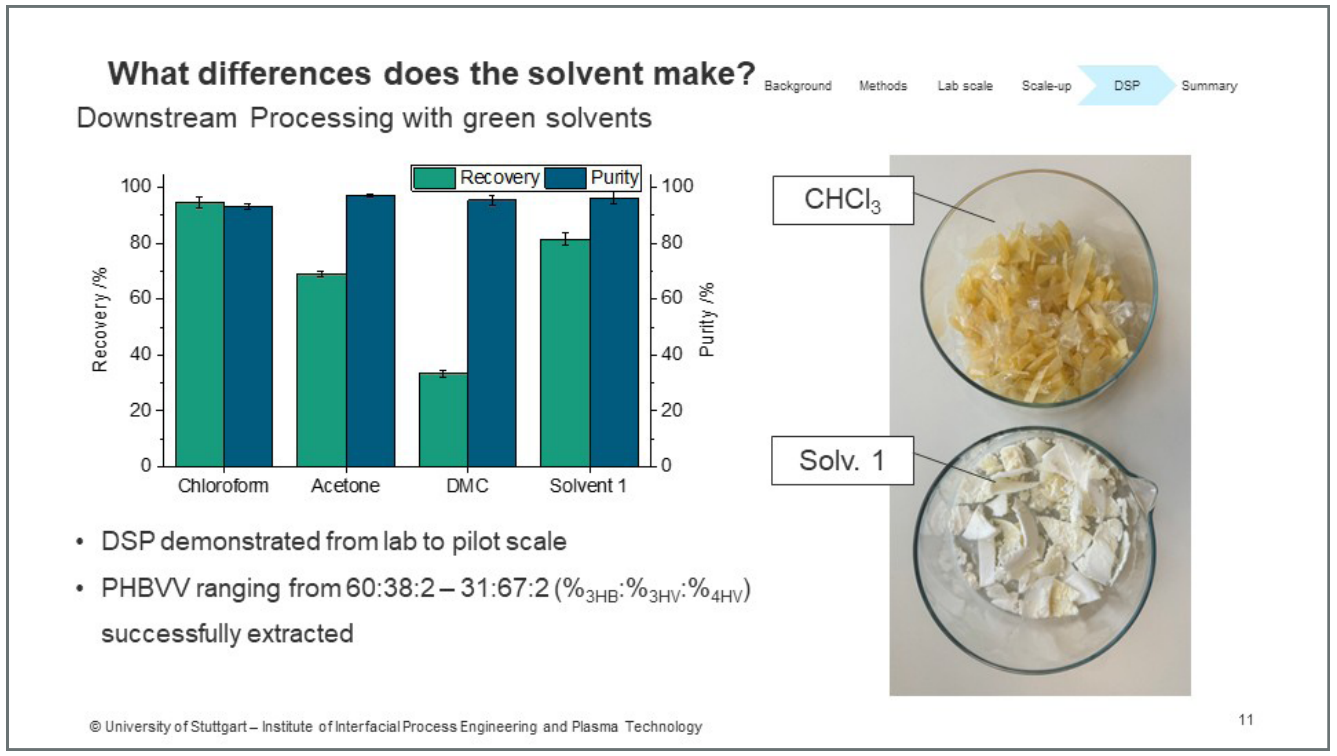
Polymer extraction with different solvents

- State of the Art for PHAs [3]:
  - Extraction with boiling chloroform
  - Precipitation with Antisolvent
- Hansen-Solubility-Parameters (HSP) are used to predict Solvent-Polymer-Interactions
- Green solvents are sustainable alternatives to chlorinated solvents [4]
- Screening of the three closest candidates to P-3HB-co-50%-3HV in the HSP-Space



[1] Terada, M. and Marchessault, R.H. (1999). Determination of solubility parameters for poly(3-hydroxyalkanoates). International Journal of Biological Macromolecules. https://doi.org/10.1016/s0141-8130(99)00036-7
[2] https://hansen-solubility.com/ (accessed 18.04.2024)
[3] Koller, M. et al. (2013). Strategies for recovery and purification of poly[(R)-3-hydroxyalkanoates] (PHA) biopolyesters from surrounding biomass. Engineering in Life Sciences. https://doi.org/10.1002/elsc.201300021
[4] Vermeer, C.M. et al. (2022). Systematic solvent screening and selection for polyhydroxyalkanoates (PHBV) recovery from biomass. Journal of Environmental Chemical Engineering. https://doi.org/10.1016/j.jece.2022.108573

 10


What differences does the solvent make?
Downstream Processing with green solvents
Background
Methods
Lab scale
Scale-up
DSP
Summary
Recovery
Purity
Recovery /%
Purity /%
100
80
60
40
20
0
Chloroform
Acetone
DMC
Solvent 1
CHCl3
Solv. 1
• DSP demonstrated from lab to pilot scale
• PHBVV ranging from 60:38:2 – 31:67:2 (%3HB:%3HV:%4HV) successfully extracted
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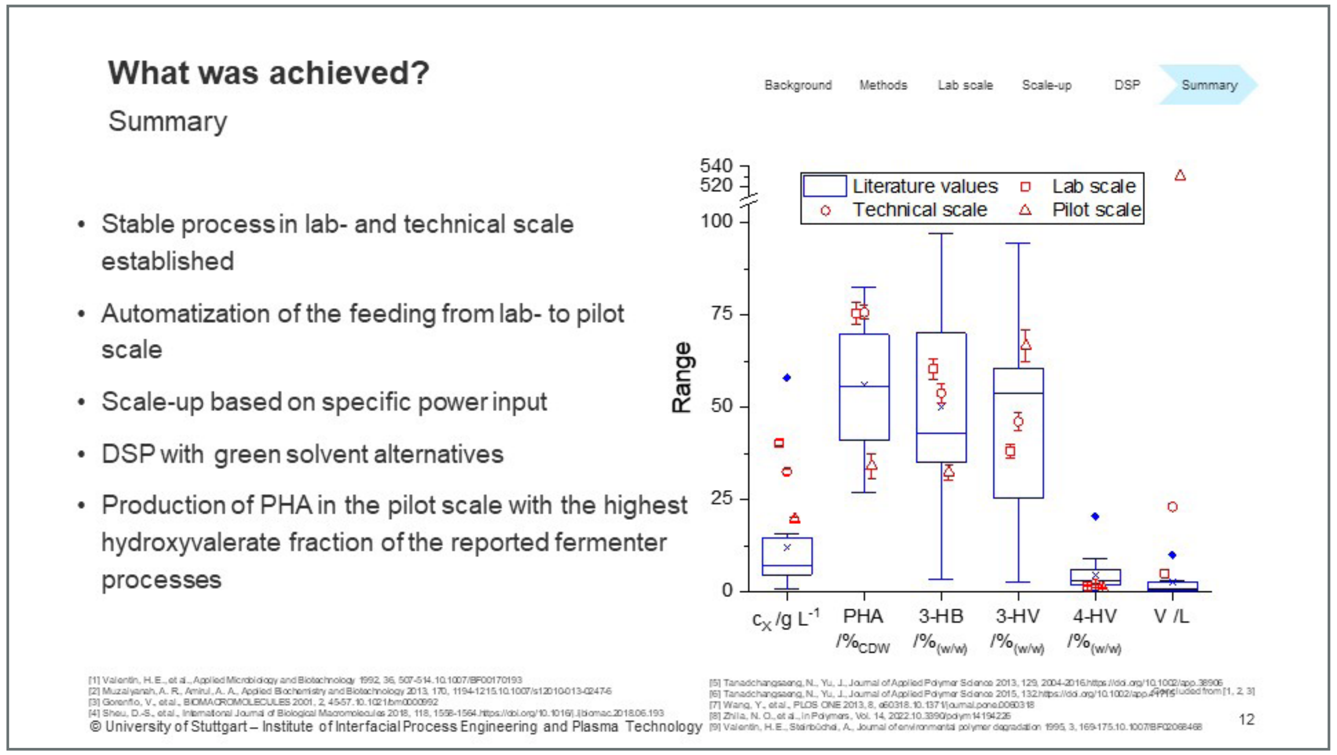
11


What was achieved?
Summary
Background
Methods
Lab scale
Scale-up
DSP
Summary
• Stable process in lab- and technical scale established
• Automatization of the feeding from lab- to pilot scale
• Scale-up based on specific power input
• DSP with green solvent alternatives
• Production of PHA in the pilot scale with the highest hydroxyvalerate fraction of the reported fermenter processes
Literature values
Technical scale
Lab scale
Pilot scale
Range
540
520
100
75
50
25
0
cX /g L-1
PHA /%CDW
3-HB /%(w/w)
3-HV /%(w/w)
4-HV /%(w/w)
V /L
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12


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Benjamin Friedl, Deutsches Biomasseforschungszentrum

Hybrid feature selection for model predictive control based on non-stationary informer

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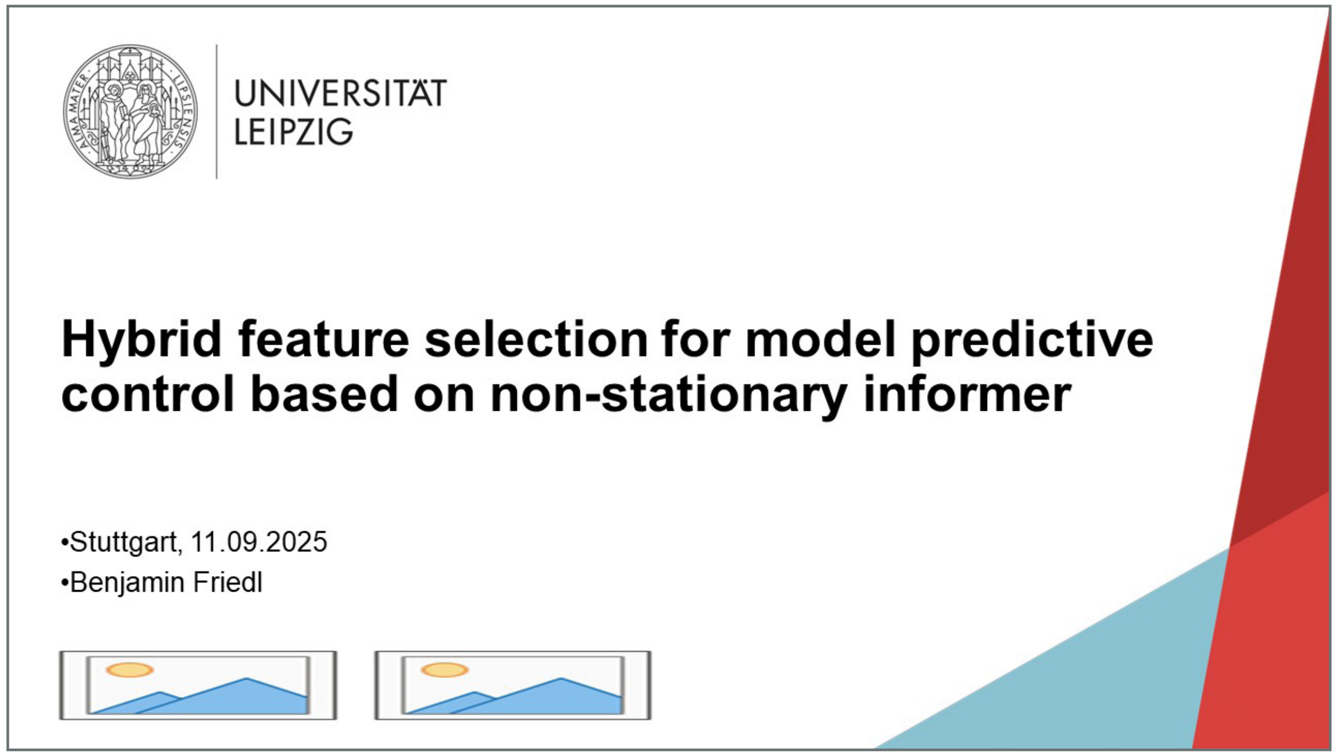
Keywords: biogas technology, anaerobic digestion, process control, artificial intelligence, feature selection

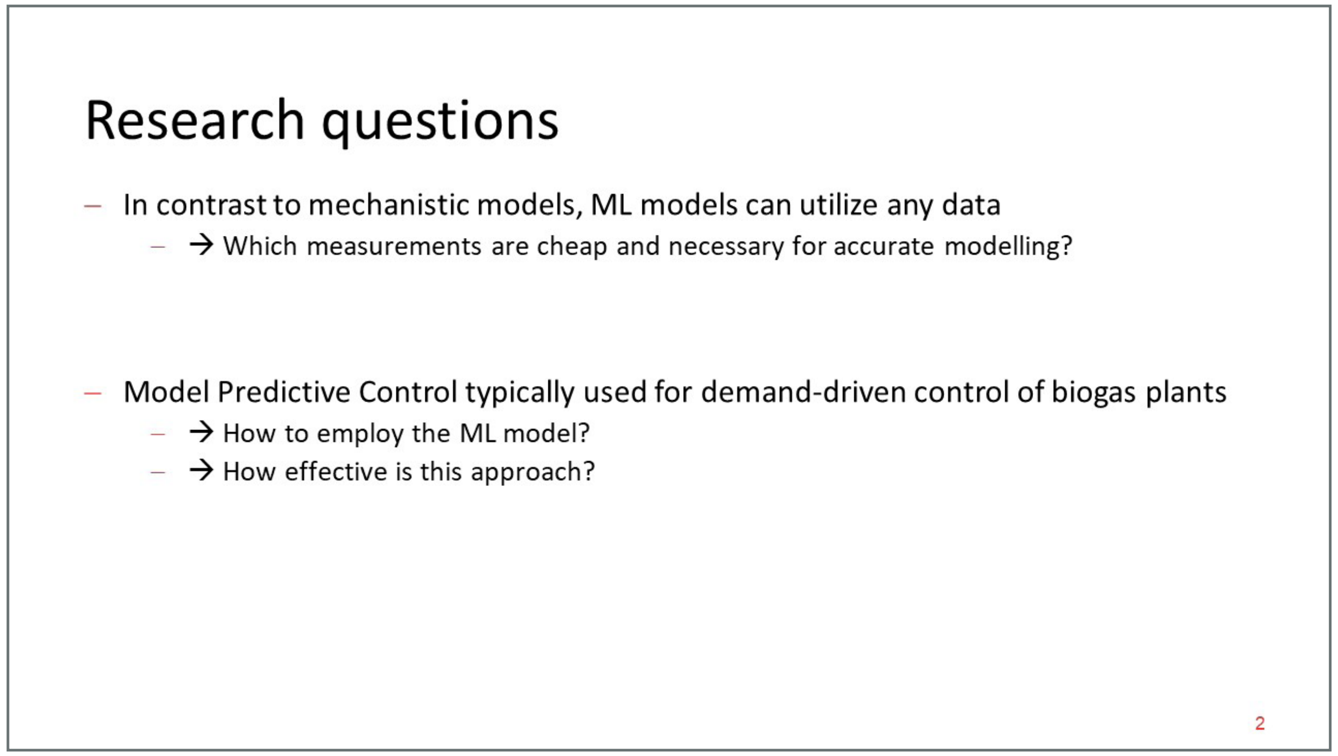
Introduction
Biogas plants are a source of renewable energy that can be used to compensate for the fluctuating energy supply of uncontrollable sources such as wind and solar power. Model Predictive Control (MPC) can be used for demand-driven control strategies but requires an accurate process model of the plant. Previous research on MPC for biogas plants mostly focused on physical models, or on linear models that have limits especially in the presence of inhibition. Thus, more complex machine learning models might have the potential for better control. The Non-Stationary Informer (NSI) as a state-of-the-art forecasting algorithm is chosen as MPC base-model. In this research, the required measurements for such a model to optimally perform are evaluated. Since feature selection for sequential models in multi-step forecasting is an open problem, a novel hybrid feature selection is designed.

Methods
The data applied to model training and feature selection is a combination of three 5-month long full-scale datasets extracted from experiments in a 152 m³ biogas reactor [1]. The hybrid feature selection method combines an mRMR procedure with model-based evaluation of the resulting feature subsets. The mRMR relies on a mutual information computation adapted for time series data. This adaptation includes a strategy for generating independent samples and uses dynamic time warping dissimilarity to incorporate temporal information. In contrast to physical models of biogas plants, the applied NSI is designed to predict the future biogas production directly without modeling future states. It uses an hourly resolution and a prediction horizon of one week. The control objective is to match a given gas demand whilst keeping a stable filling level of an attached gas storage.

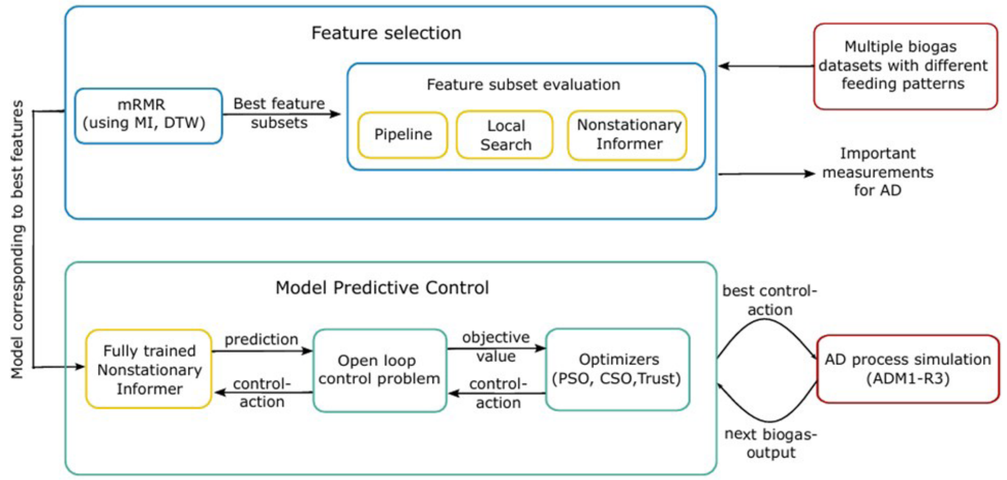
Results and Outlook
According to the mRMR procedure, the most relevant features are previous biogas production, the amounts of solid and liquid feed, followed by system state features such as CO_2 and H_2 content in the biogas, FOS/TAC ratio in the digestate and OLR. The model's performance and its applicability to MPC remain to be evaluated.

References
[1] Meola, Weinrich, 2025. Full-scale dynamic anaerobic digestion process simulation with machine and deep learning algorithms at intra-day resolution. Ap. En., 390, 125781





Overview



3

Contents

- General
  - Data
  - ML model: Nonstationary Informer
- Feature selection
  - Difficulties
  - Mutual Information for timeseries
  - Proposed method: Hybrid mRMR
  - Results

4

Contents

- Model Predictive Control
  - Definition MPC
  - Proposed control problems
  - Optimization algorithm: PSO
  - Control loop
  - Results
- Conclusion

5

General

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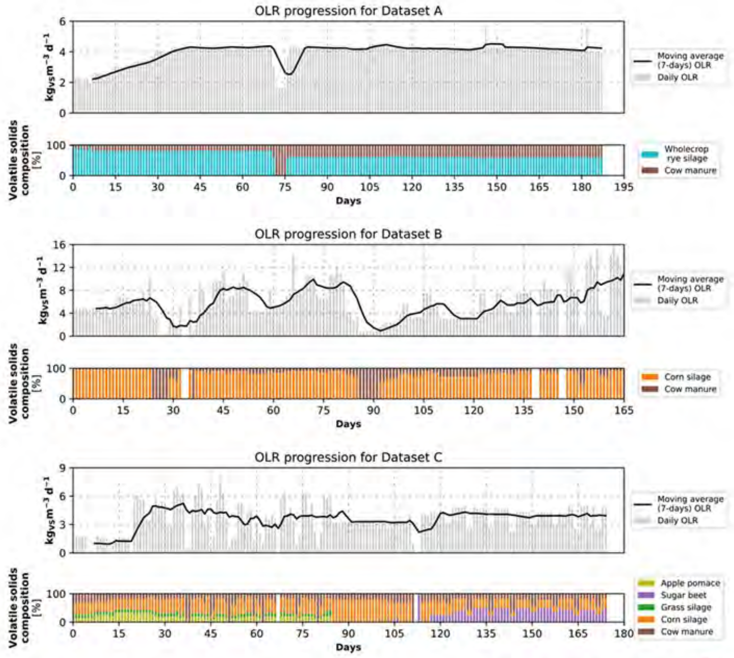
Data - Datasets

- 3 Datasets
- Differ by amounts fed and substrate composition



Source: [1]

7

Data - Features

Type	Resolution	Examples
Operational (gas concentrations)	2 hours	Methane, carbon dioxide
Operational (rest)	1 hour	Temperature, biogas production
Digestate	1-7 days	FOS/TAC, acid concentration
Substrate	instant	Raw ashes, total solids

8

ML model – Nonstationary Informer

- Task: Long sequence time series forecasting
- Transformer-based model: Best for long forecasting tasks due to no vanishing gradients
- Informer: Reduces computational and memory cost of traditional Transformer
- Nonstationary Informer: Extension that helps handling nonstationary data

9

Feature selection

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Feature Selection – Difficulties

- Task: Feature selection for multi-step forecasting
- Problems:
  - Filter methods: Statistical criteria mostly formulated for scalar data, not sequences
  - Wrapper methods: Large training cost of sequential models
- Solution: Utilize Mutual Information computation that is only based on distance between samples
  - → Can be adapted to timeseries
  - → Use within hybrid mRMR method

11

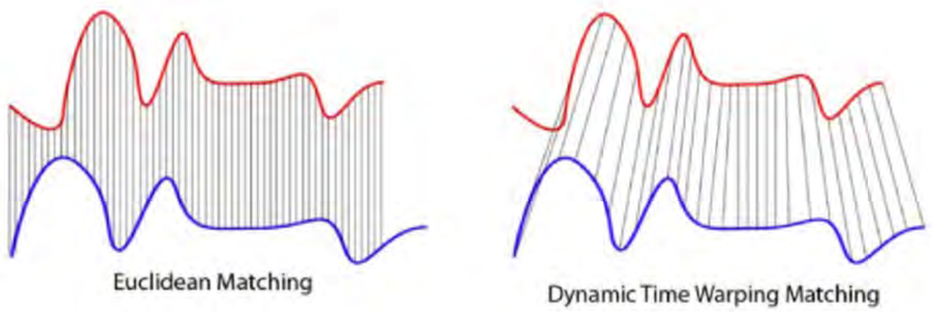
Feature Selection – Mutual Information

- Measures (nonlinear) dependence between two Random Variables
- General Formula: $I(X,Y) = H(X) + H(Y) - H(X,Y)$
- Computation by Kraskov et al. [3]:
  - Requires: Independent samples and some distance measure
  - Approximate probability densities: How many samples in neighbourhood of each sample?
  - Neighbourhood defined by k nearest neighbour

12

Mutual Information - Distance measure

- Dynamic Time Warping: State-of-the-art distance measure for timeseries



Source: [4]

13

Mutual Information – Independent samples

- Task: Extract independent samples from long timeseries
  - → Want to extract sample every T timesteps
- Question: From which time-distance can we consider samples to be independent?
  - Look at auto-correlation → if zero after time-distance, then no dependence
  - Autocorrelation only interpretable for stationary timeseries
- → Process:
  - 1.) Stationarizing timeseries
  - 2.) Computing autocorrelation
  - 3.) Get time-distance
  - 4.) Subsampling

14

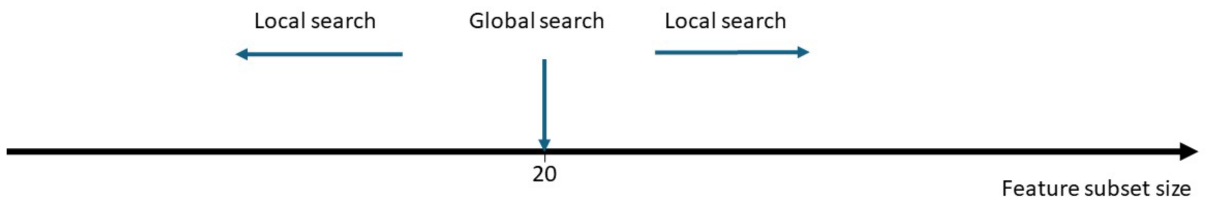
Feature Selection – Hybrid mRMR

- Given: Mutual information computation for pairs of timeseries
  - → Use within mRMR to evaluate informativeness of feature subset S for target
- mRMR [5]: $\Phi(S) = \frac{1}{|S|}\sum_{x_i \in S} I(x_i, t) - \frac{1}{|S|^2}\sum_{i,j \in S} I(x_i, x_j)$
- Will be used in a forward selection procedure
  - → At each step: Select feature for which the subset has the highest mRMR
  - → One feature subset per subset size remains
- Model evaluation: Train model on each filtered feature subset

15

Hybrid mRMR - Problem: Hyperparamter search

- Problem: Large number of hyperparameters
  - → Global hyperparameter search required but not feasible on every feature subset
- Solution: One global search and local search on the other feature subsets



16

Feature Selection – Results mRMR

<u>Chosen features in order</u>:

1.) Biogas production rate

2.) Amount of liquid feed

3.) CO2 (gas)

4.) Amount of solid feed

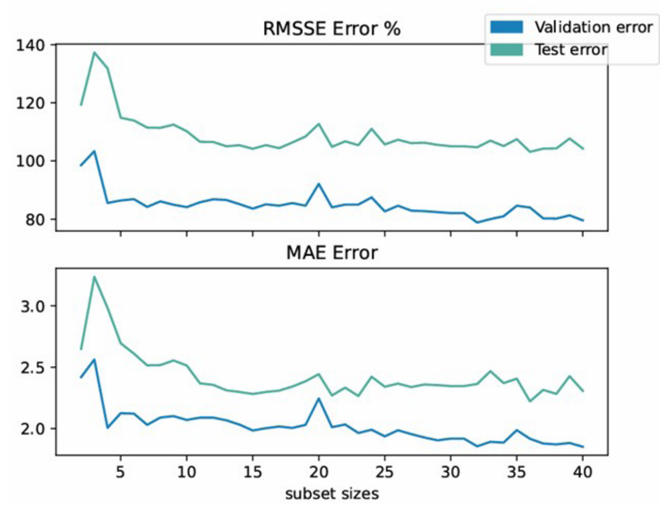
5.) H2 (gas)

6.) FOS/TAC (digestate)

...

17

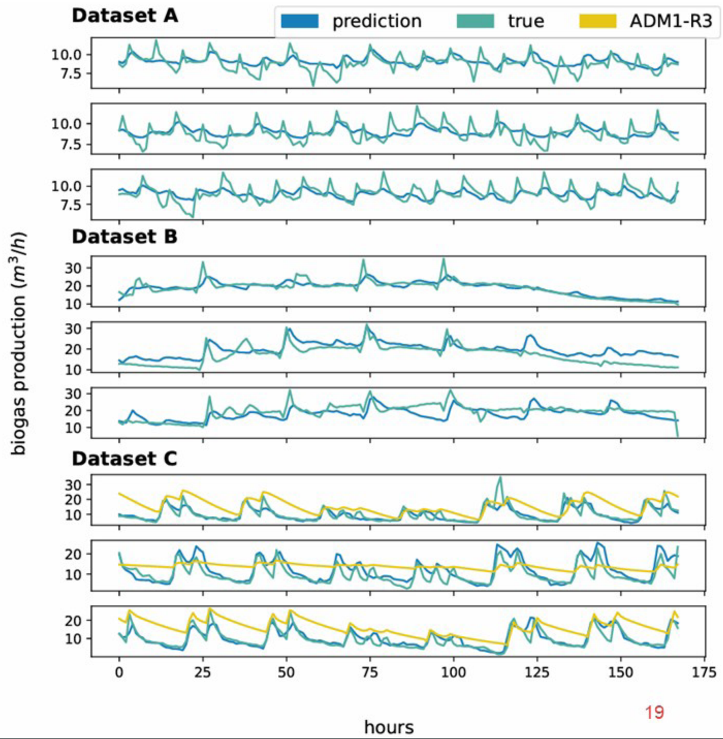
Feature Selection- Results Subset Evaluation



18

Feature selection – Final model performance

– RMSSE: 74.27%



19

Model Predictive Control

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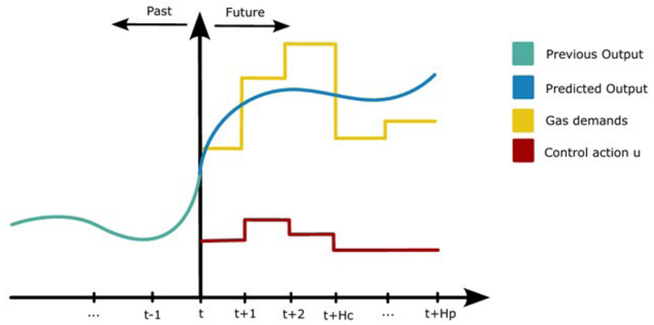
Model Predictive Control - Definition

– Goal: Find next control action u
– Uses: Predictions of a process model
– At each timestep: Solve optimization problem to find u for which predictions are best

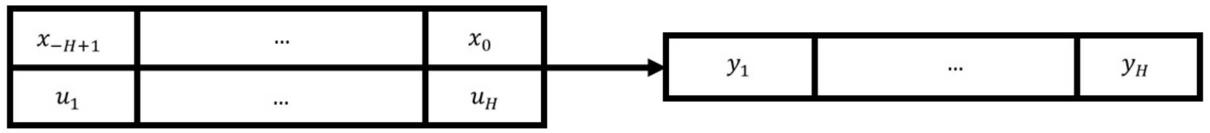


21

Model Predictive Control – Note to process model

– Application to Control: Need to include future control action in input data
  – → Shift features corresponding to control actions

Prediction Length = Sequence Length = H



22

Model Predictive Control – Proposed Control Problem

- Goal: Match a given gas demand timetable whilst keeping a stable filling level of an attached gas storage
- General objective function: $f_{obj}(u) = \sum_{i=t+1}^{t+H_p} w_{e_i} f_w(e_{s_i}) + \lambda \sum_{i=t+1}^{t+H_c} \Delta u_i^2$
- Current storage: $e_{s_i} = pred_i - demand_i + storage_{i-1}$
- Additionally: Upper bound on feeding for every 12h interval and substrate

23

Model Predictive Control – Proposed Control Problem

- Construct two optimization problems:
- 1.) Allow feeding every hour: $$\begin{aligned} \min_u \quad & f_{obj,nonsparse}(u) \\ \text{subject to} \quad & Au \leq b \\ & 0 \leq u \leq q_{max} \end{aligned}$$
- 2.) Allow one feeding every 12h segment: $$\begin{aligned} \min_u \quad & f_{obj,sparse}(u) \\ \text{subject to} \quad & u_{min} \leq u \leq u_{max} \end{aligned}$$

24

Model Predictive Control - Optimization algorithm

- Use PSO: Global evolutionary search universally applied, often in MPC
- Have swarm of solutions: each particle moves according to personal best and global best position
- Constraint handling: Deb's feasibility rule [6]: Always prefer feasible particle
- Add turbulence operator according to Pulido et al. to avoid premature convergence [7]
- Use 20 particles for 50 generations
- Further parameters: $c_1 = c_2 = 2, w = 0.7, V_{max} = 5$

25

Model Predictive Control – Loop

For t = 1,...,end:

- 1.) Optimization of control actions $u_{t+1}, \dots, u_{t+H_c}$ using the process model, optimization problem and optimization algorithm
- 2.) Simulation of next state x_{t+1} and output y_{t+1} using control action u_{t+1}
  - Used: ADM1-R3
- 3.) Updating optimization problem using x_{t+1} and y_{t+1}

26

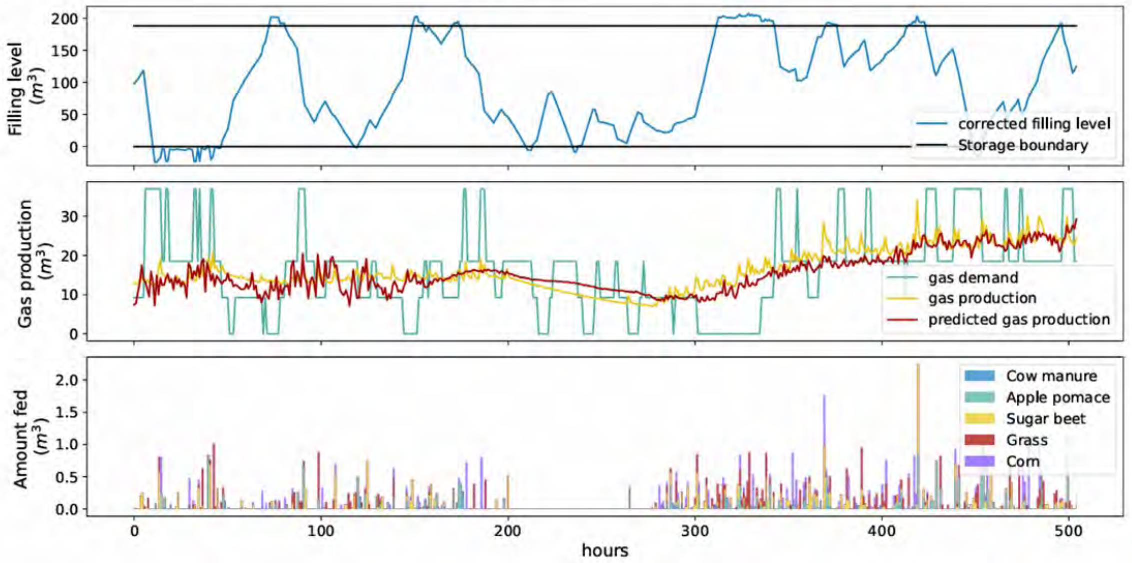
Model Predictive Control – All results

- Gas storage size: $188m^3$, Biogas reactor storage volume: $188m^3$
- Power unit: electrical capacity: $0.085MWh$, efficiency 0.42

Sparse	Control Horizon				
True	24	0.0	102.39	104.73	12.96
		0.2	98.25	101.90	12.14
	48	0.0	88.74	94.38	9.37
		0.2	89.39	95.01	9.94
False	24	0.0	58.00	67.95	1.99
		0.2	60.12	67.26	1.62
	48	0.0	53.017	63.68	2.2
		0.2	60.46	71.49	3.38
			81.33	87.52	5.48

27

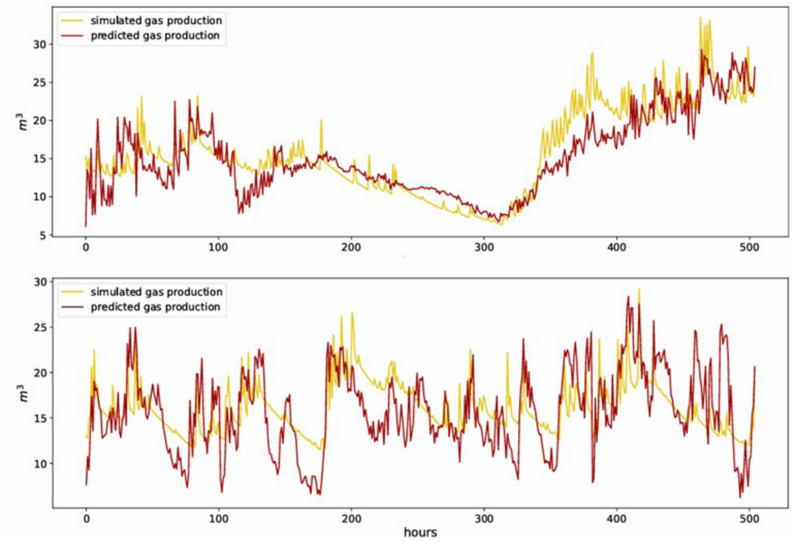
Model Predictive Control – Detailed results



28

Model Predictive Control – Problem

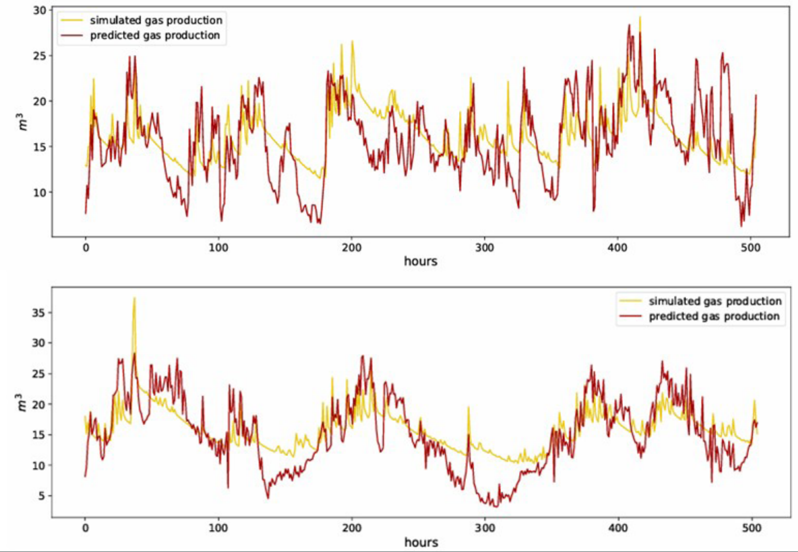
- Cheap:
- Expensive:



29

Model Predictive Control - Problem

-
- Expensive:
- Expensive, smooth: ($\lambda = 0.2$)



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Conclusion

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Conclusion

– Feature Selection: Constructed hybrid mRMR for timeseries data
  – Extracted 10% of original features without loss in performance
  – Corresponding model: Much more accurate than ADM1-R3 on test data

– Model Predictive Control: Try to match gas timetable given gas storage
  – Reduced unsatisfied gas demand by 70% compared to constant production
  – Required global optimization
  – Problem: Increasing resources for optimization resulted in worse results
    – Too dynamic feeding → Can be forced to be smoother

32

Sources

– [1] Alberto Meola and Sören Weinrich. Full-scale dynamic anaerobic diges tion process simulation with machine and deep learning algorithms at intra-day resolution. Applied Energy, 390:125781, 2025.

– [2] Yong Liu, Haixu Wu, Jianmin Wang, and Mingsheng Long. Non stationary transformers: Exploring the stationarity in time series fore casting. Advances in neural information processing systems, 35:9881–9893, 2022.

– [3] Alexander Kraskov, Harald Stögbauer, and Peter Grassberger. Estimating mutual information. Phys. Rev. E, 69:066138, Jun 2004.

– [4] Hamlin, Matthew & Sharma, Mralini & Otten, Colm & Jump, David & Hamilton, Michael. (2022). Pay for Pandemic? Treatment of COVID Effects in Pay-for-Performance Programs.

– [5] Hanchuan Peng, Fuhui Long, and C. Ding. Feature selection based on mutual information criteria of max-dependency, max-relevance, and min redundancy. IEEE Transactions on Pattern Analysis and Machine Intelligence, 27(8):1226–1238, 2005.

– [6] Kalyanmoy Deb. An efficient constraint handling method for genetic algorithms. Computer methods in applied mechanics and engineering, 186(2 4):311–338, 2000.

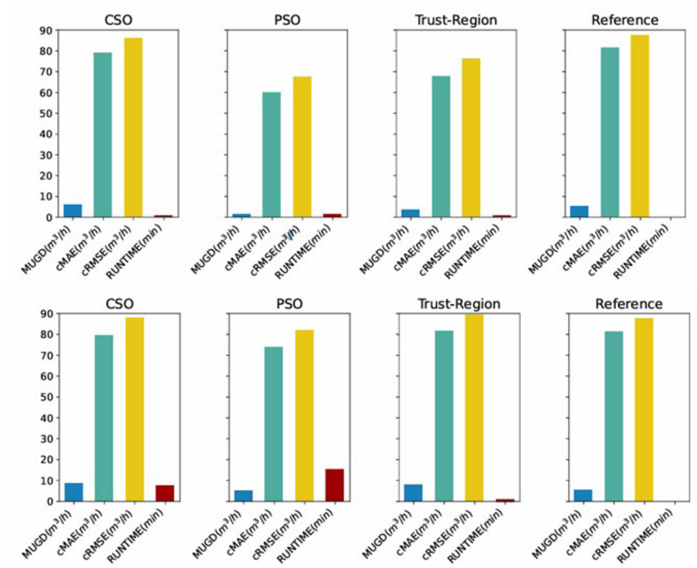
– [7] Gregorio Toscano Pulido and Carlos A Coello Coello. A constraint handling mechanism for particle swarm optimization. In Proceedings of the 2004 Congress on Evolutionary Computation (IEEE Cat. No. 04TH8753), volume 2, pages 1396–1403. Ieee, 2004.

33

Evaluation – Comparison of optimization methods: Expensive optimization

– Cheap:

– Expensive



35

Maria Isabella Lima Garção, University of Hohenheim

Development and Optimization of a Two-Stage Anaerobic Digestion System for Manure-Based Biogas Production

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Keywords: Anaerobic digestion, two-stage digestion, biogas production, liquid manure

Rising energy demand drives the exploration of renewable alternatives. Agricultural waste is vital for bio-based energy, especially in rural areas. This renewable energy, from organic materials like residues, offers a sustainable solution for energy needs. Anaerobic digestion (AD) generates clean energy through biogas, a mix of CH_4 and CO_2. AD can take place in a single reactor or multiple reactors. In the latter, hydrolysis and acidogenesis occur in one reactor, while acetogenesis and methanogenesis happen in separate reactors, optimizing each stage independently.

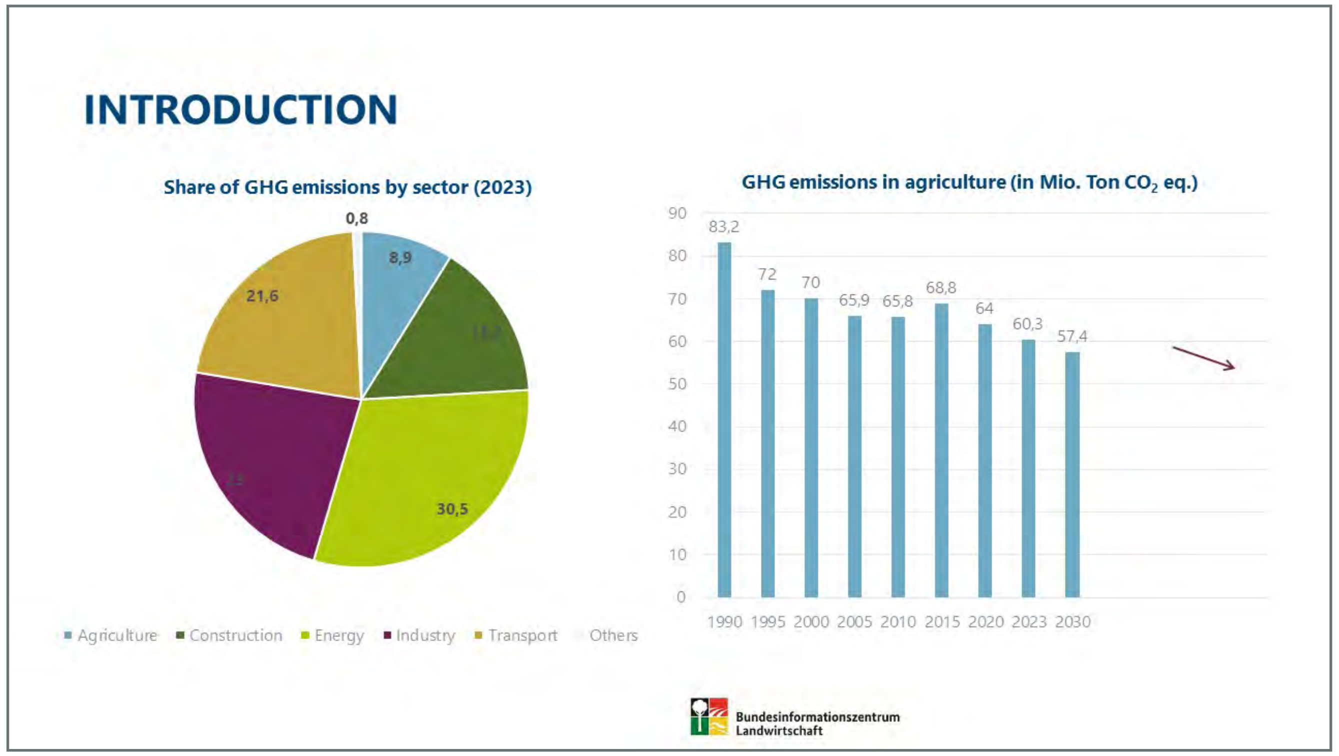
This research aims to develop and optimize a new process for producing biogas from manure dedicated to the two-stage system with a dual focus on energy production and GHG mitigation in agriculture. The primary goal is first to compare two-stage digestion with one-stage on a laboratory scale, then scale up to a two-stage pilot plant that is 100 times larger.

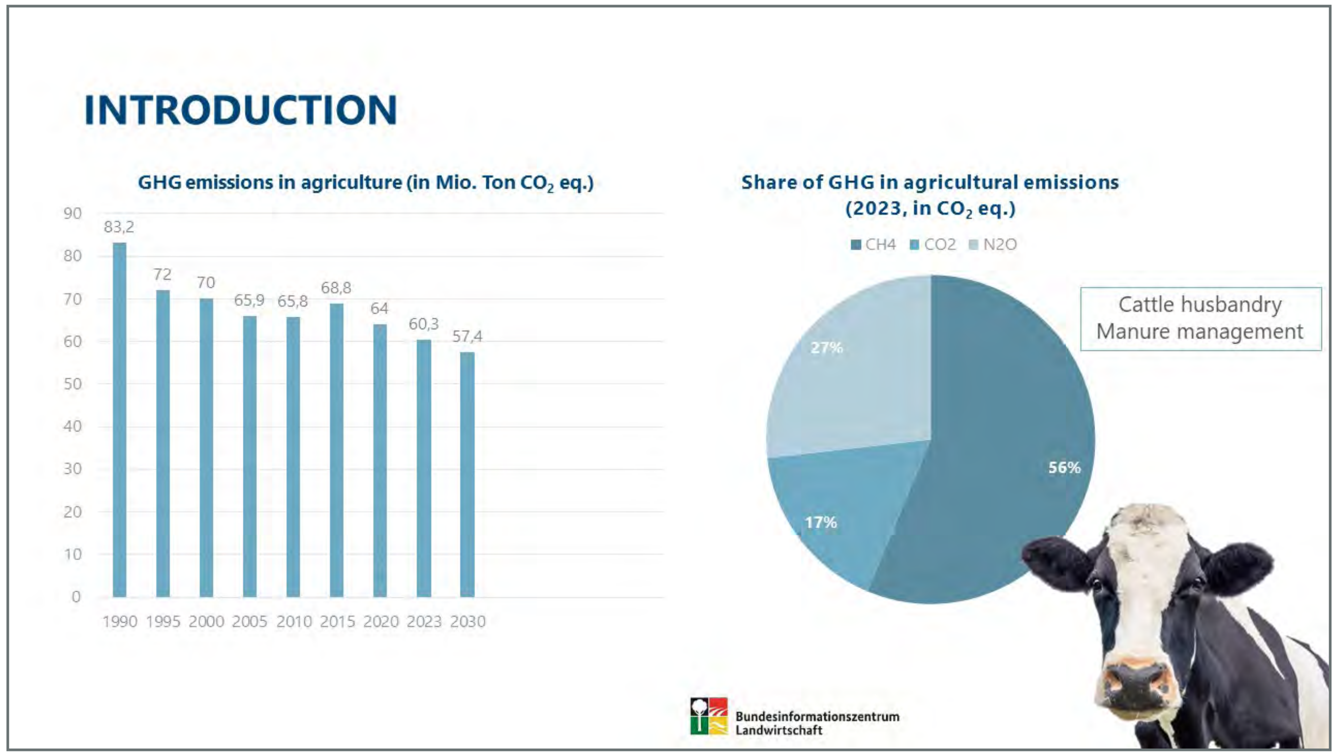
Experiments are being carried out in the lab and on a pilot scale, using a continuous stirred acidification reactor (AR) and a packed bed anaerobic filter (AF).

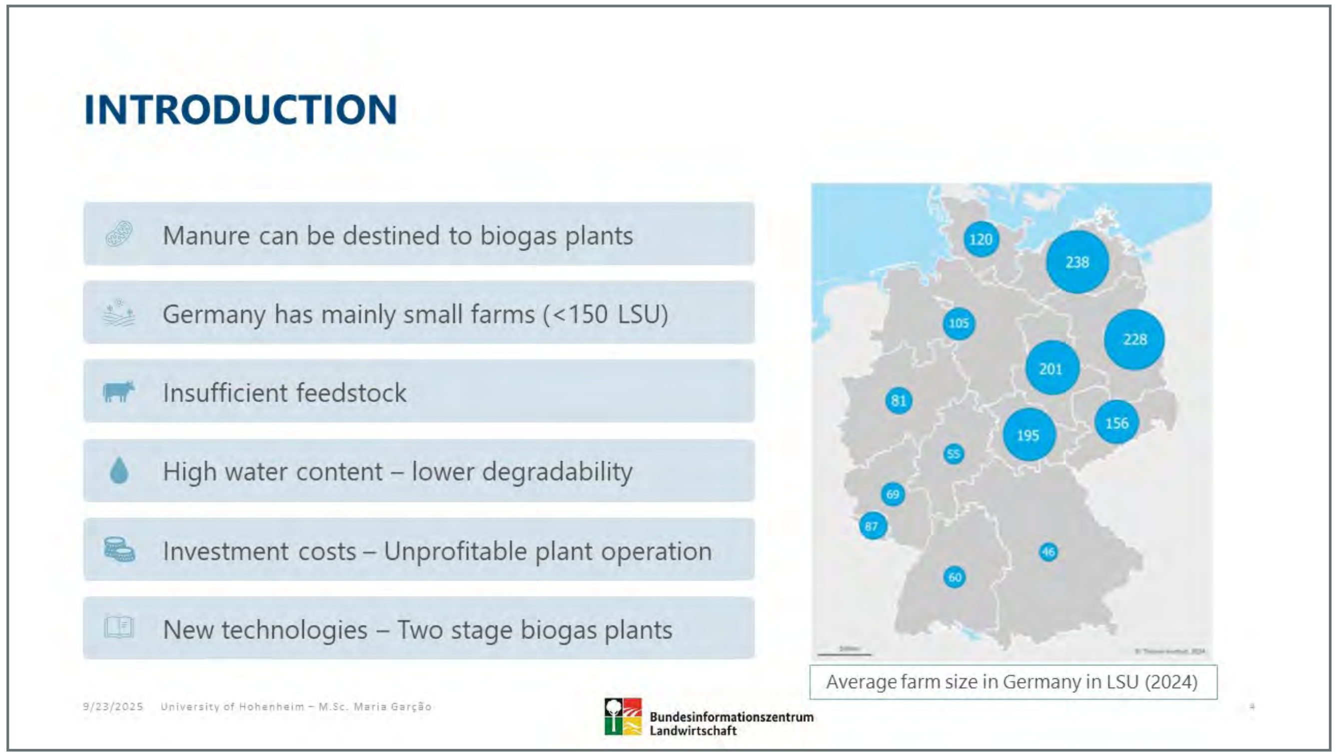
In the one-stage configuration, the substrate is fed directly into the AR, where all anaerobic digestion phases occur. In the two-stage setup, a sieve is integrated within the AR to separate the solid and liquid fractions of the digestate. In the pilot scale, an edge gap filter is integrated into the system to filter the digestate. The solid fraction remains in the AR for further degradation, while the liquid fraction is pumped to the AF.

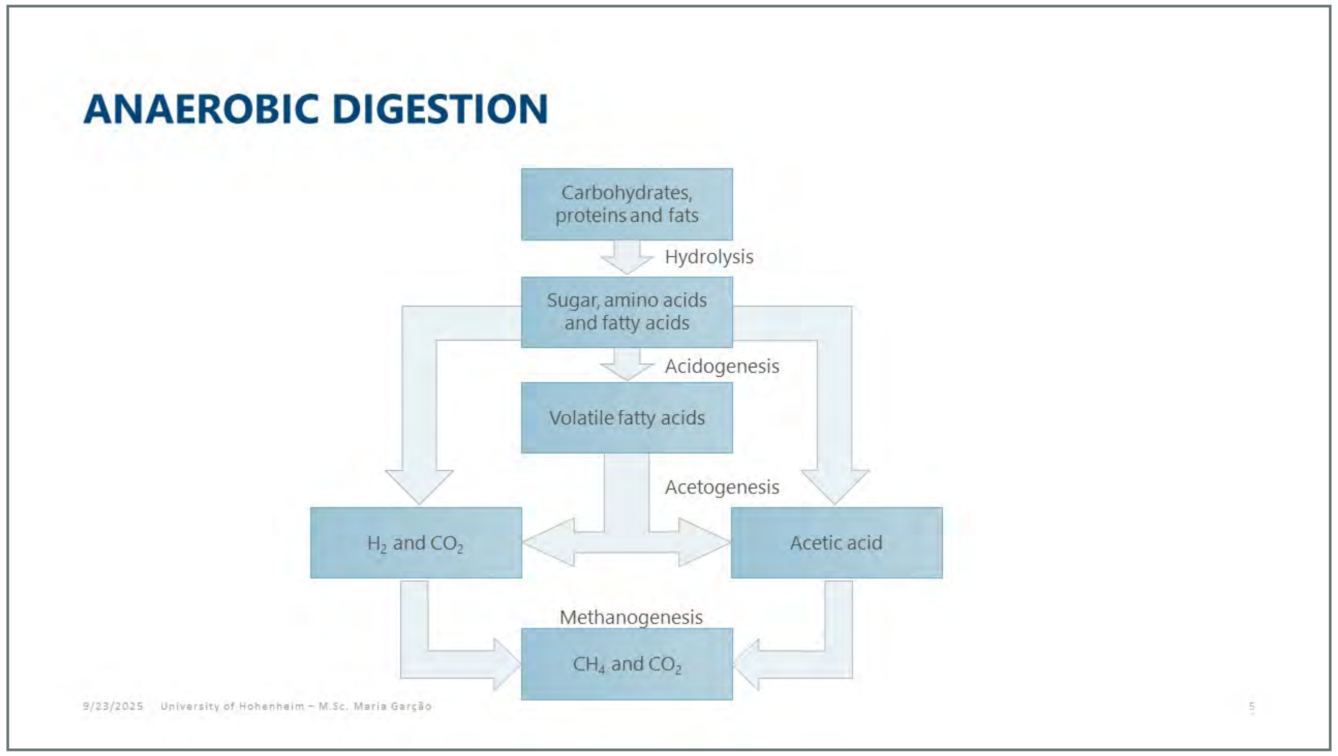
Preliminary lab results show improved specific methane yield (SMY) with the two-stage system, increasing by 16 % and 52 % under mesophilic and thermophilic conditions, respectively. Both reactors maintained stable pH levels around 7.8 in one stage, indicating balanced digestion. The two-stage system showed slightly lower pH in the CSTRs due to acid formation, while the AFs reached higher pH values, reflecting efficient methanogenic activity and VFA's consumption.

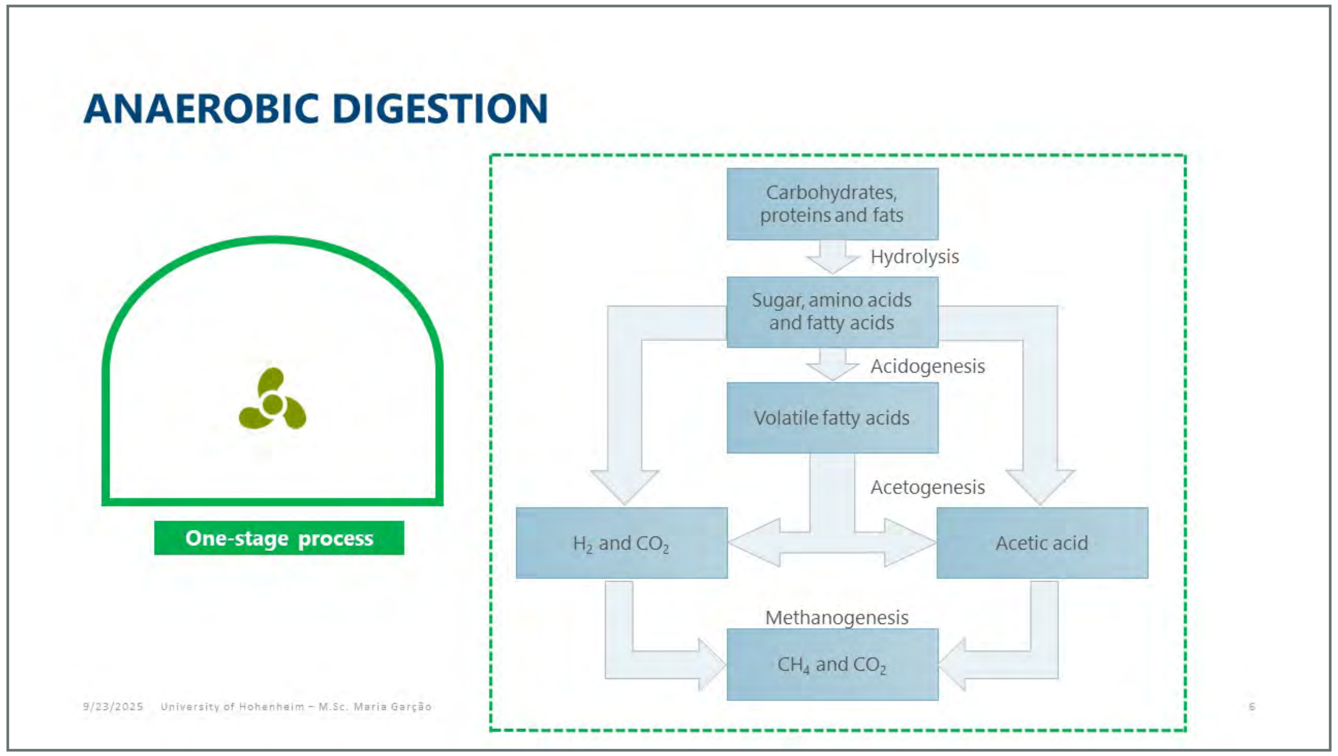
These results suggest the two-stage fermentation process outperforms the one-stage setup in methane production and process stability. Separating the stages allows optimal conditions for each part, leading to better performance.




INTRODUCTION
GHG emissions in agriculture (in Mio. Ton CO_2 eq.)
90
80
70
60
50
40
30
20
10
0
83,2
72
70
65,9
65,8
68,8
64
60,3
57,4
1990 1995 2000 2005 2010 2015 2020 2023 2030
Share of GHG in agricultural emissions (2023, in CO_2 eq.)
CH4 CO2 N2O
27%
17%
56%
Cattle husbandry
Manure management
Bundesinformationszentrum Landwirtschaft


INTRODUCTION
Manure can be destined to biogas plants
Germany has mainly small farms (<150 LSU)
Insufficient feedstock
High water content – lower degradability
Investment costs – Unprofitable plant operation
New technologies – Two stage biogas plants
120
238
105
228
201
81
156
195
55
69
87
46
60
Average farm size in Germany in LSU (2024)
Bundesinformationszentrum Landwirtschaft


ANAEROBIC DIGESTION
Carbohydrates, proteins and fats
Hydrolysis
Sugar, amino acids and fatty acids
Acidogenesis
Volatile fatty acids
Acetogenesis
H_2 and CO_2
Acetic acid
Methanogenesis
CH_4 and CO_2


ANAEROBIC DIGESTION
One-stage process
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Sugar, amino acids and fatty acids
Acidogenesis
Volatile fatty acids
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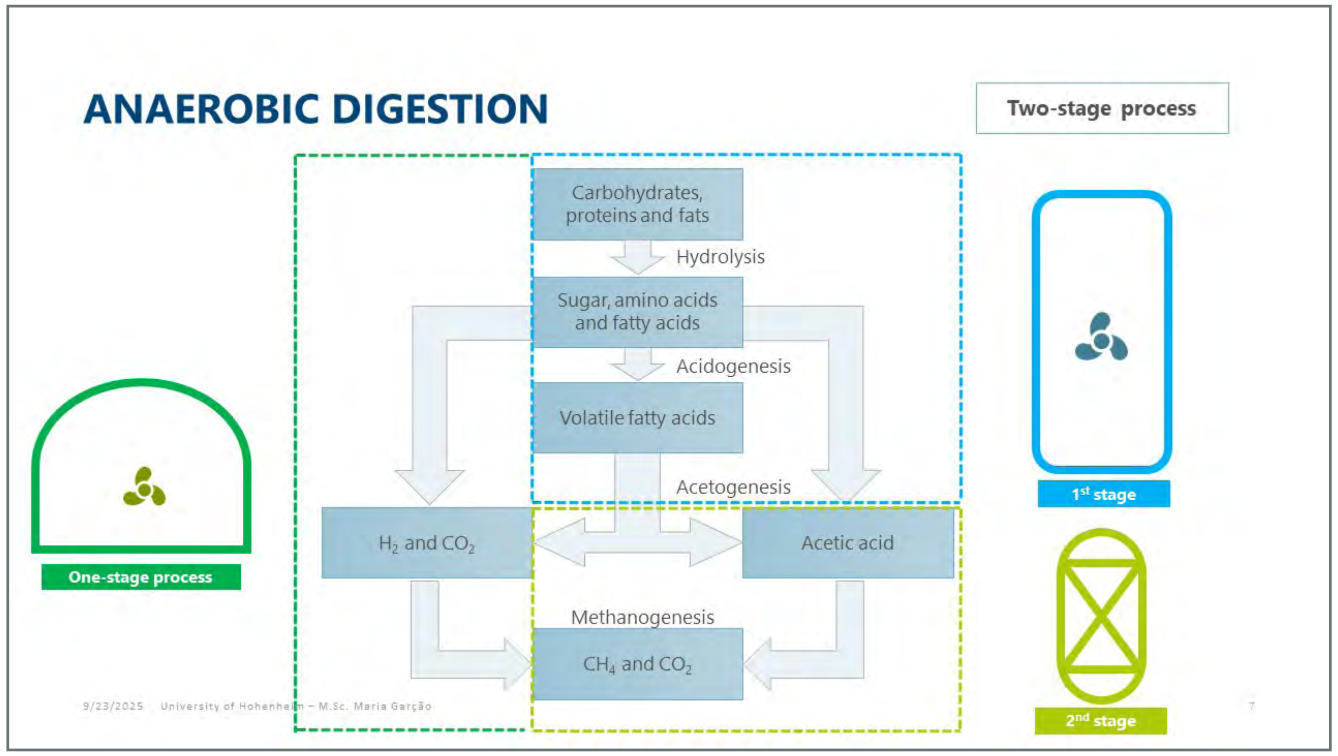
H_2 and CO_2
Acetic acid
Methanogenesis
CH_4 and CO_2


ANAEROBIC DIGESTION
Two-stage process
Carbohydrates, proteins and fats
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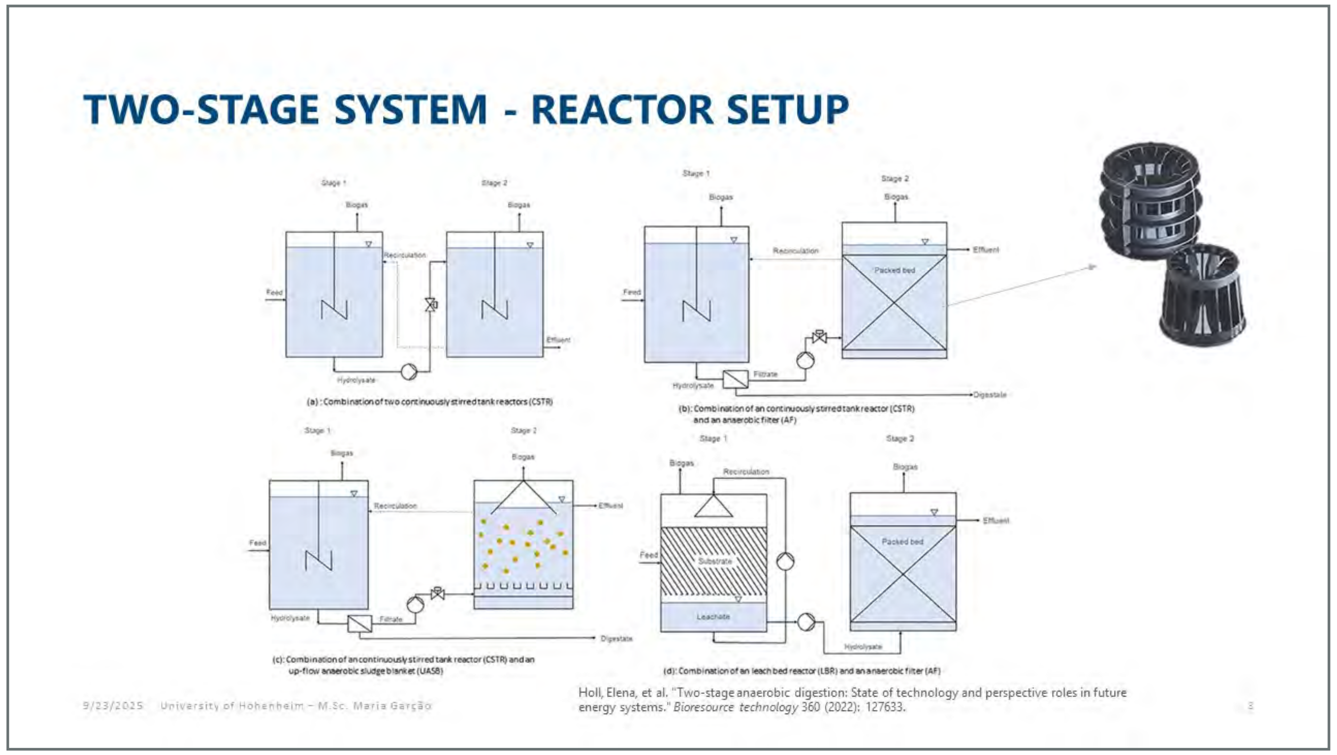
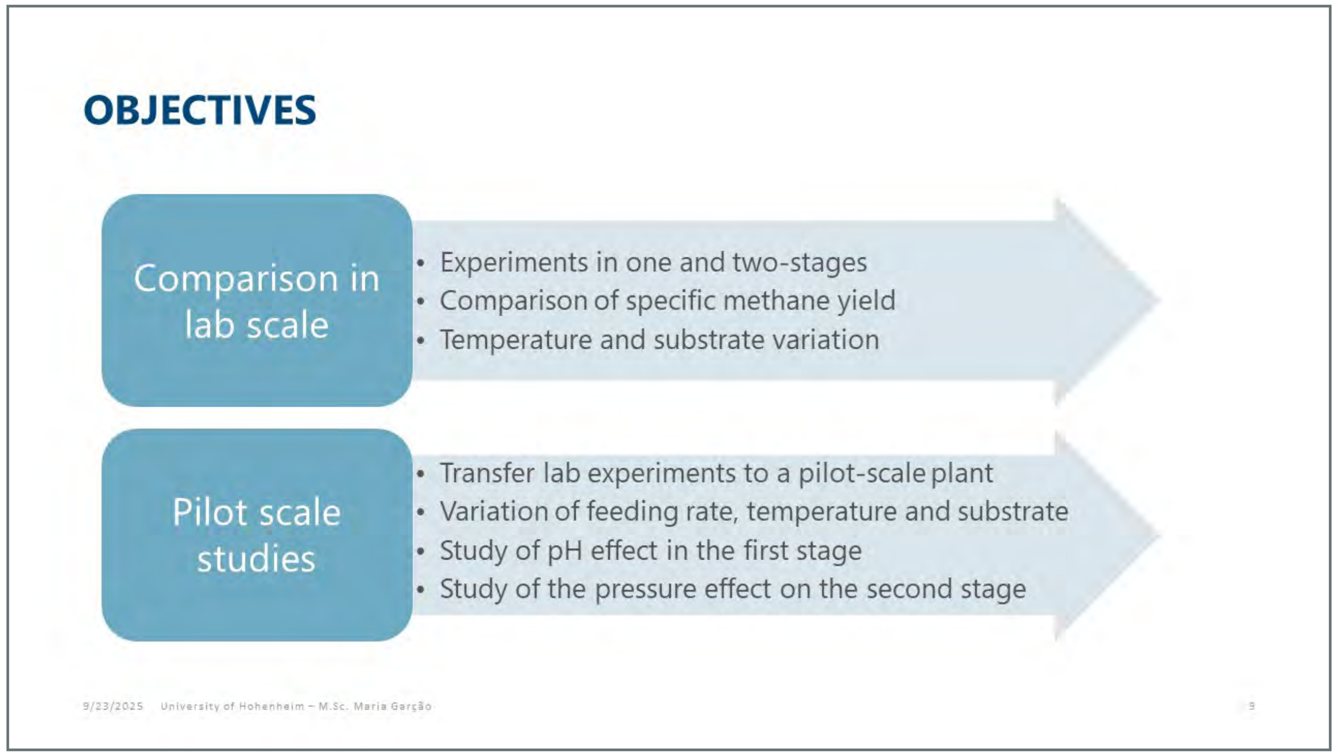
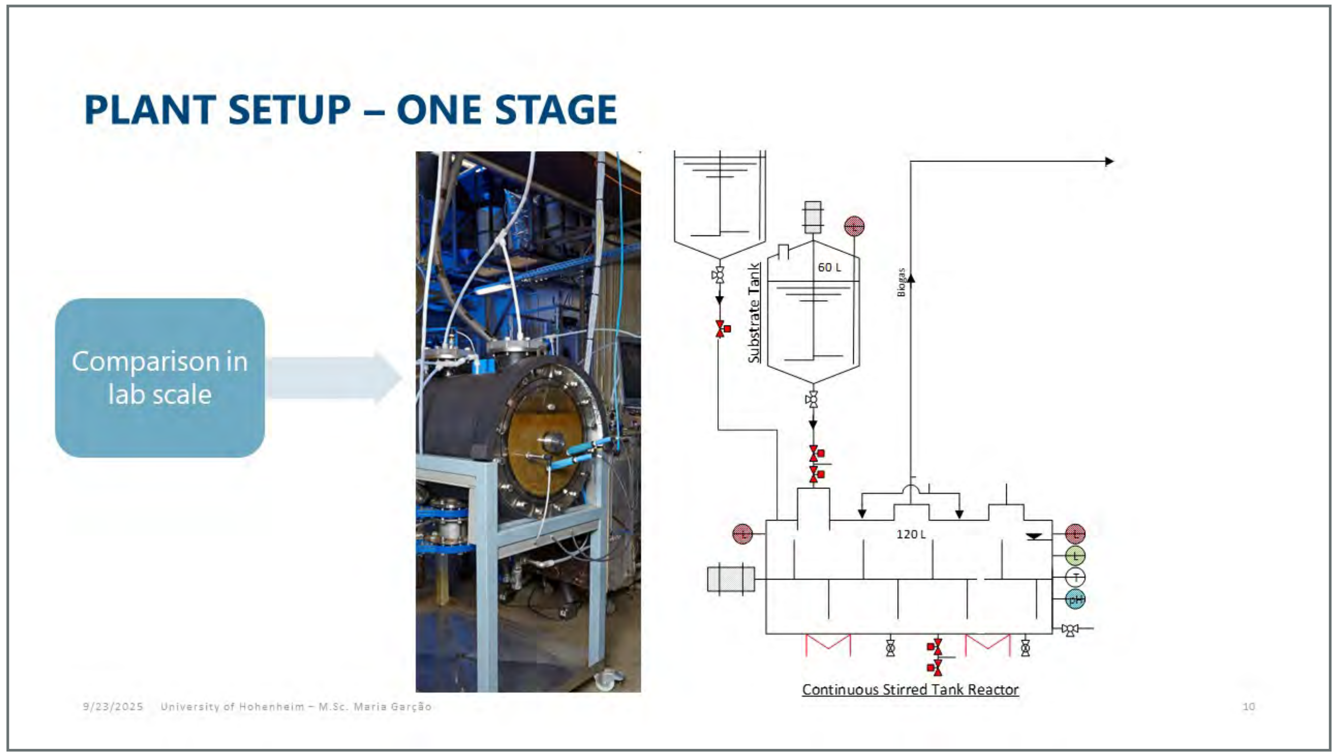
Acetogenesis
H_2 and CO_2
Acetic acid
Methanogenesis
CH_4 and CO_2
One-stage process
1st stage
2nd stage

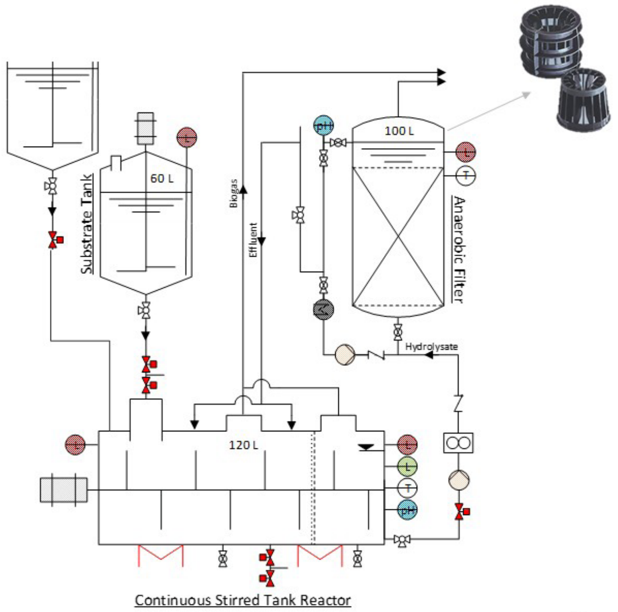

TWO-STAGE SYSTEM - REACTOR SETUP
Holl, Elena, et al. "Two-stage anaerobic digestion: State of technology and perspective roles in future energy systems." Bioresource technology 360 (2022): 127633.


OBJECTIVES
Comparison in lab scale
Experiments in one and two-stages
Comparison of specific methane yield
Temperature and substrate variation
Pilot scale studies
Transfer lab experiments to a pilot-scale plant
Variation of feeding rate, temperature and substrate
Study of pH effect in the first stage
Study of the pressure effect on the second stage


PLANT SETUP – ONE STAGE
Comparison in lab scale
Substrate Tank
60 L
120 L
Continuous Stirred Tank Reactor

PLANT SETUP – TWO STAGES

Comparison in lab scale



Continuous Stirred Tank Reactor

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WORK PLAN

Setup	Substrate	Temperature (°C)	OLR (g_{VS}/L.d)	HRT (days)
One stage	100% manure	38	1.5	25
		55		
Two stages		38		
		55		
One stage	75% manure + 25% sugar beet seepage	38	2.0	
		55		
Two stages		38		
		55		

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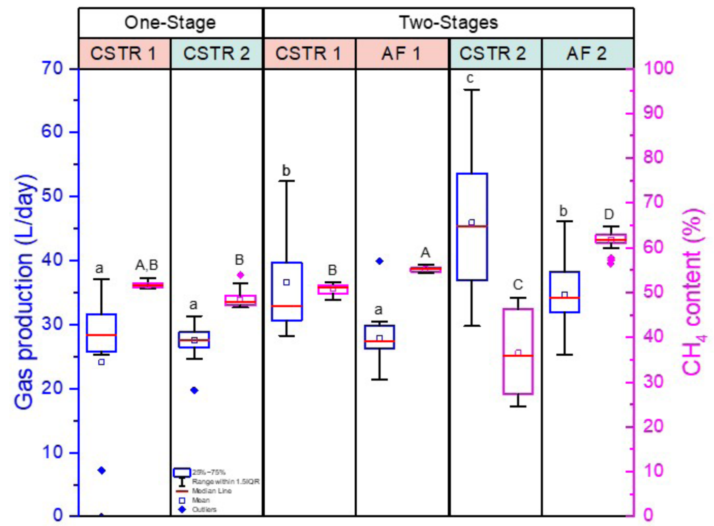
EXPERIMENT 1: 100% MANURE

100% MANURE – GAS PRODUCTION AND QUALITY

CSTR 1 and AF 1 Mesophilic (38 °C)

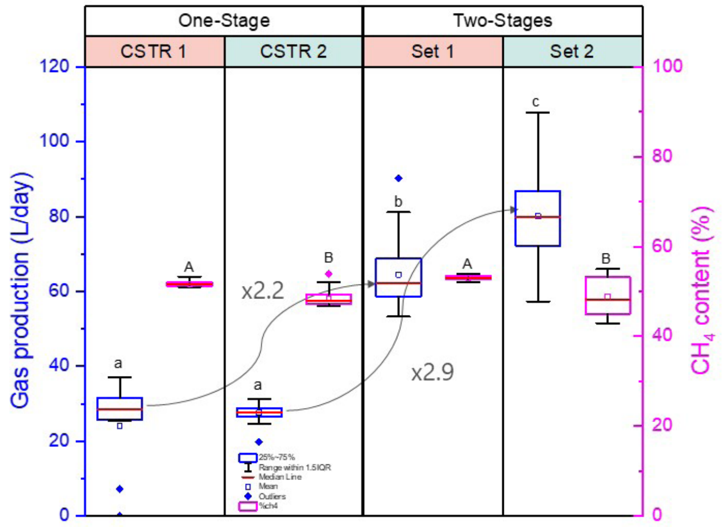
CSTR 2 and AF 2 Thermophilic (55 °C)



100% MANURE – GAS PRODUCTION AND QUALITY

CSTR 1 and AF 1
Mesophilic (38 °C)

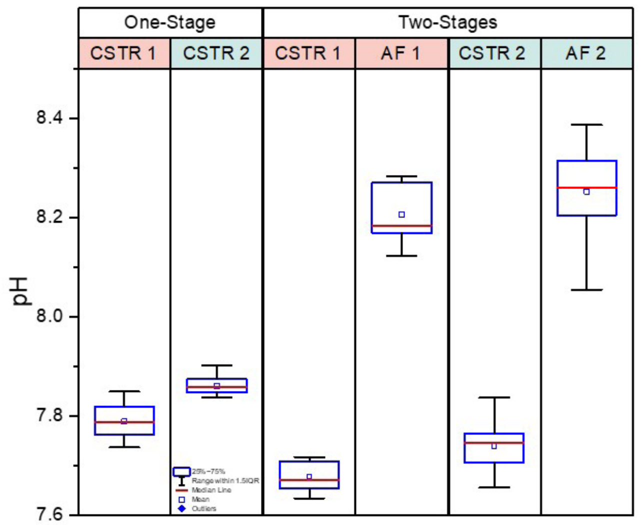
CSTR 2 and AF 2
Thermophilic (55 °C)



100% MANURE – pH

CSTR 1 and AF 1
Mesophilic (38 °C)

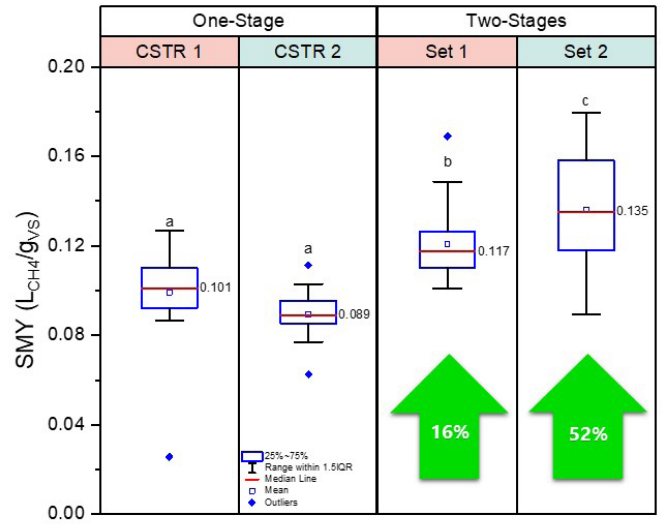
CSTR 2 and AF 2
Thermophilic (55 °C)

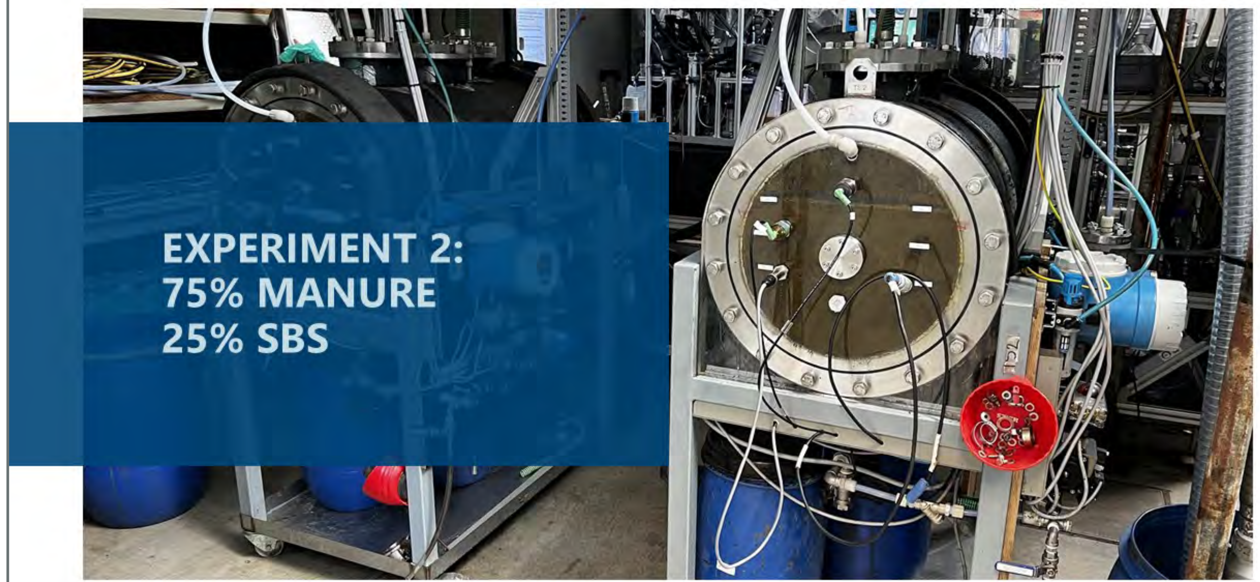


100% MANURE – SPECIFIC METHANE YIELD

CSTR 1 and AF 1
Mesophilic (38 °C)

CSTR 2 and AF 2
Thermophilic (55 °C)

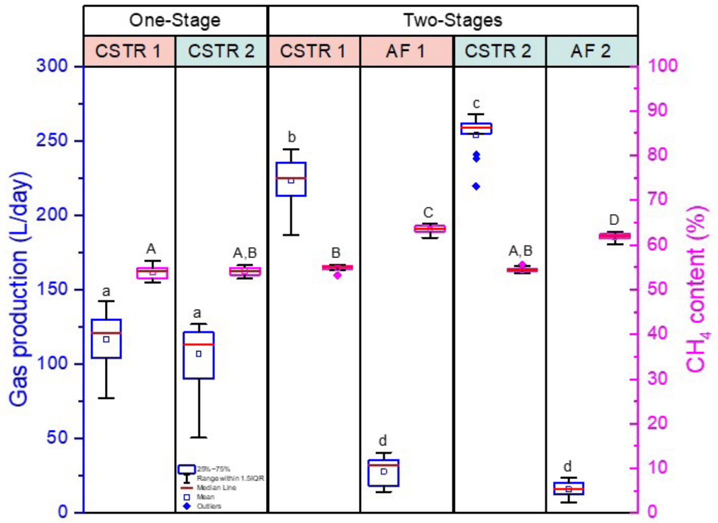




75% MANURE + 25% SBS – GAS PRODUCTION AND QUALITY

CSTR 1 and AF 1
Mesophilic (38 °C)

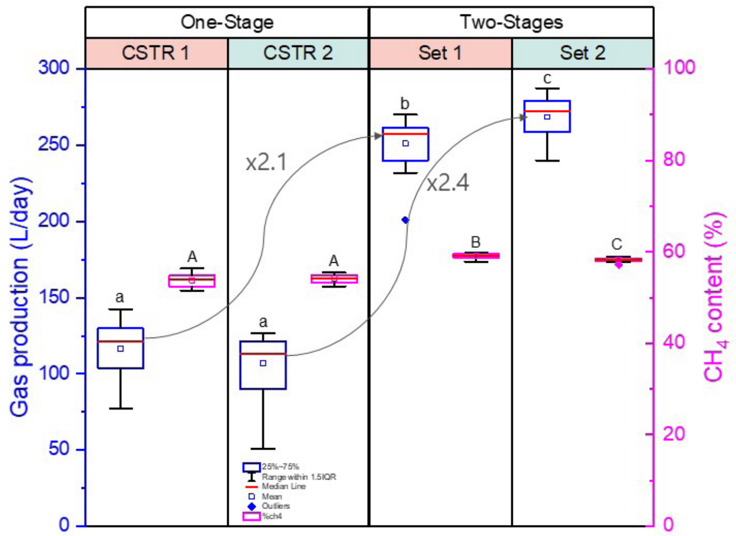
CSTR 2 and AF 2
Thermophilic (55 °C)



75% MANURE + 25% SBS – GAS PRODUCTION AND QUALITY

CSTR 1 and AF 1
Mesophilic (38 °C)

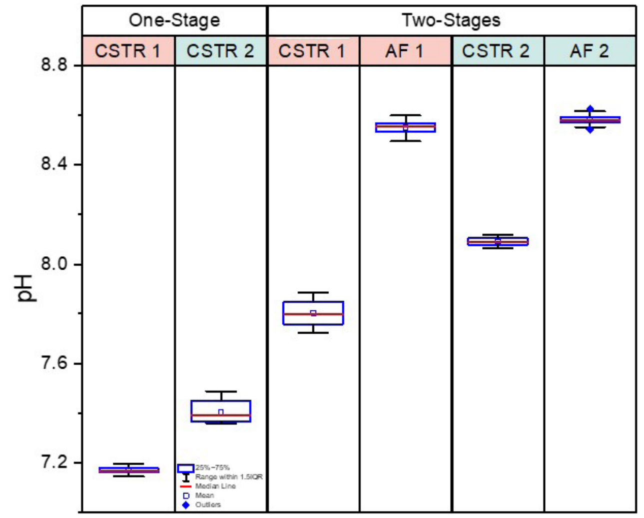
CSTR 2 and AF 2
Thermophilic (55 °C)



75% MANURE + 25% SBS – pH

CSTR 1 and AF 1
Mesophilic (38 °C)

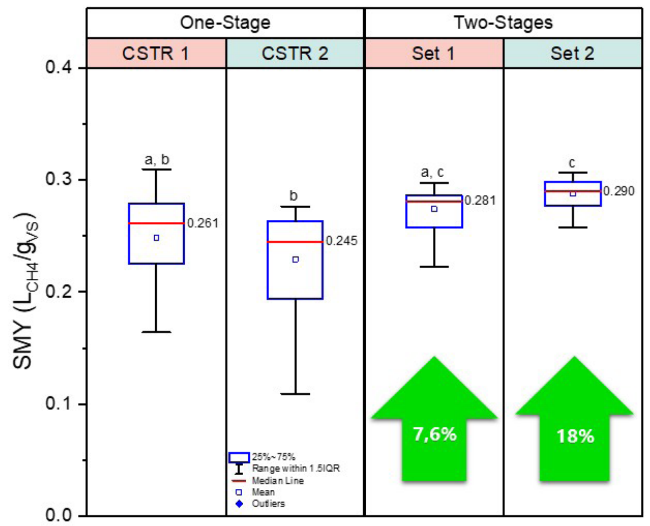
CSTR 2 and AF 2
Thermophilic (55 °C)

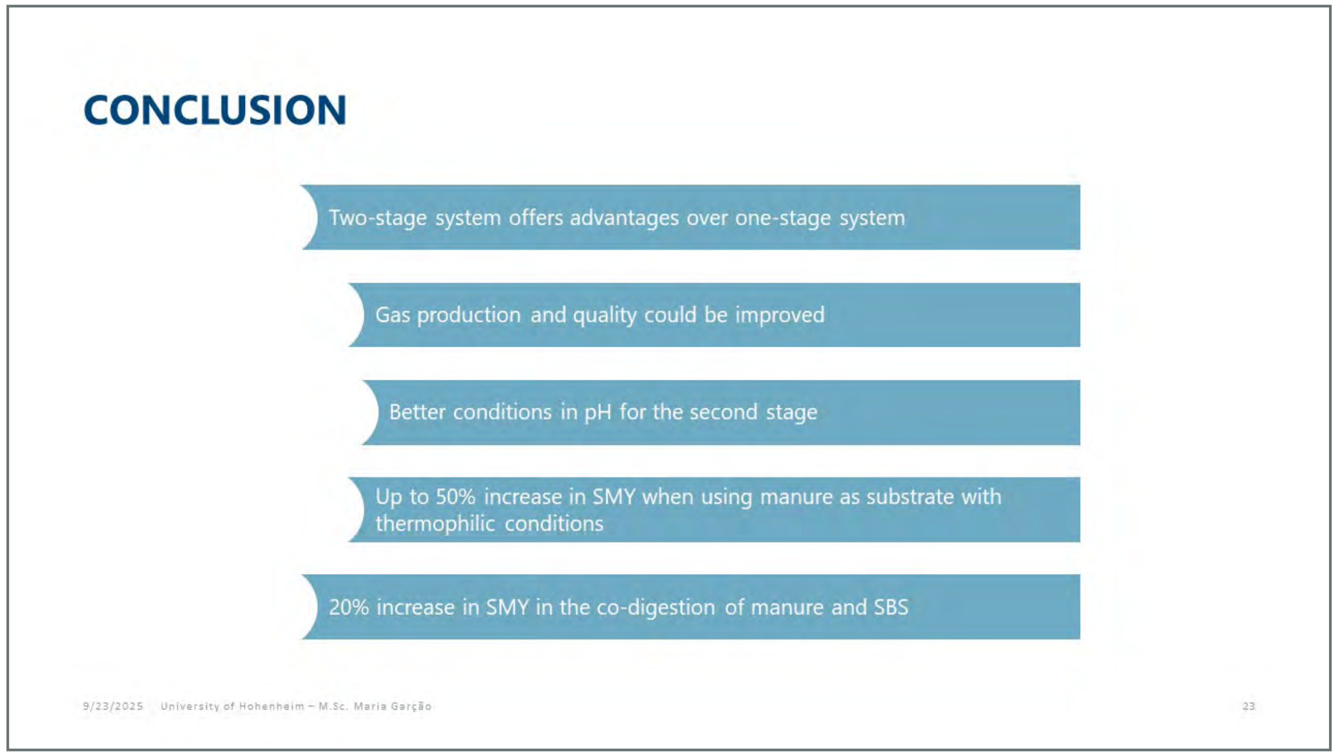


75% MANURE + 25% SBS – SPECIFIC METHANE YIELD

CSTR 1 and AF 1
Mesophilic (38 °C)

CSTR 2 and AF 2
Thermophilic (55 °C)




CONCLUSION
Two-stage system offers advantages over one-stage system
Gas production and quality could be improved
Better conditions in pH for the second stage
Up to 50% increase in SMY when using manure as substrate with thermophilic conditions
20% increase in SMY in the co-digestion of manure and SBS
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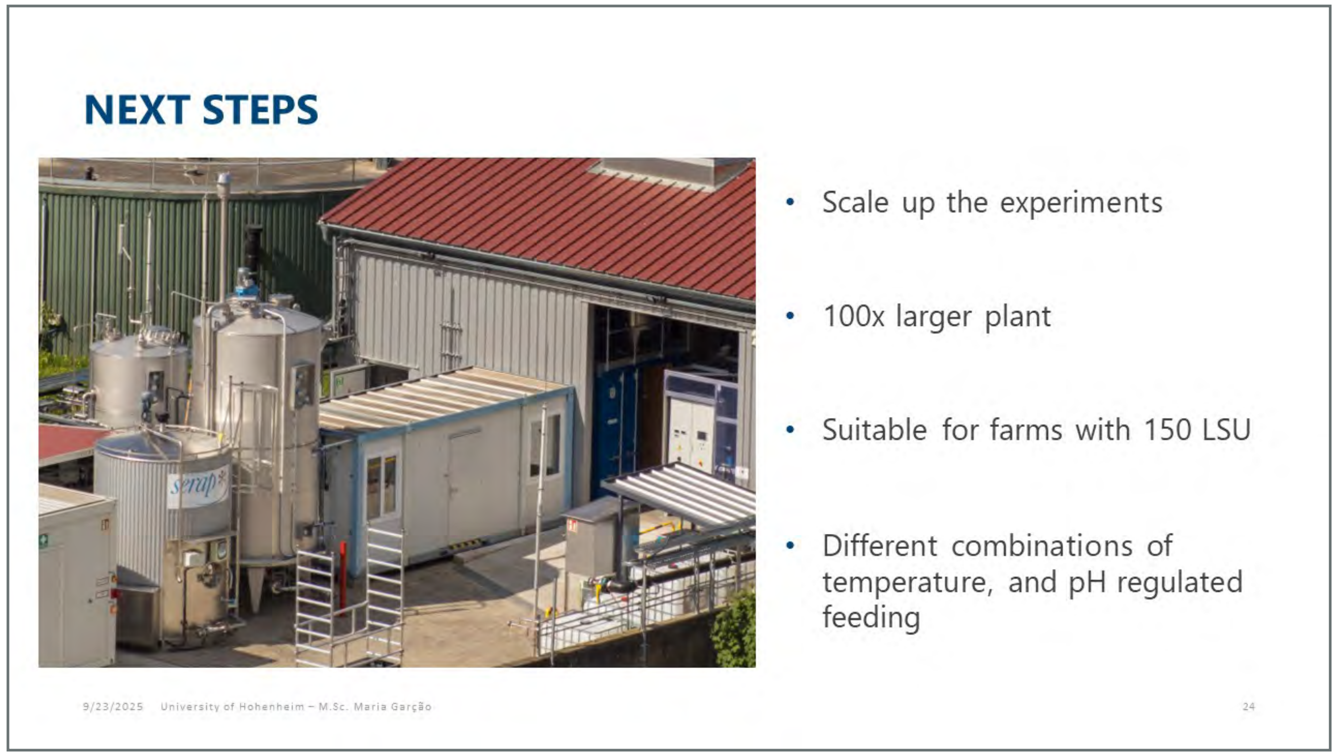
NEXT STEPS
Scale up the experiments
100x larger plant
Suitable for farms with 150 LSU
Different combinations of temperature, and pH regulated feeding
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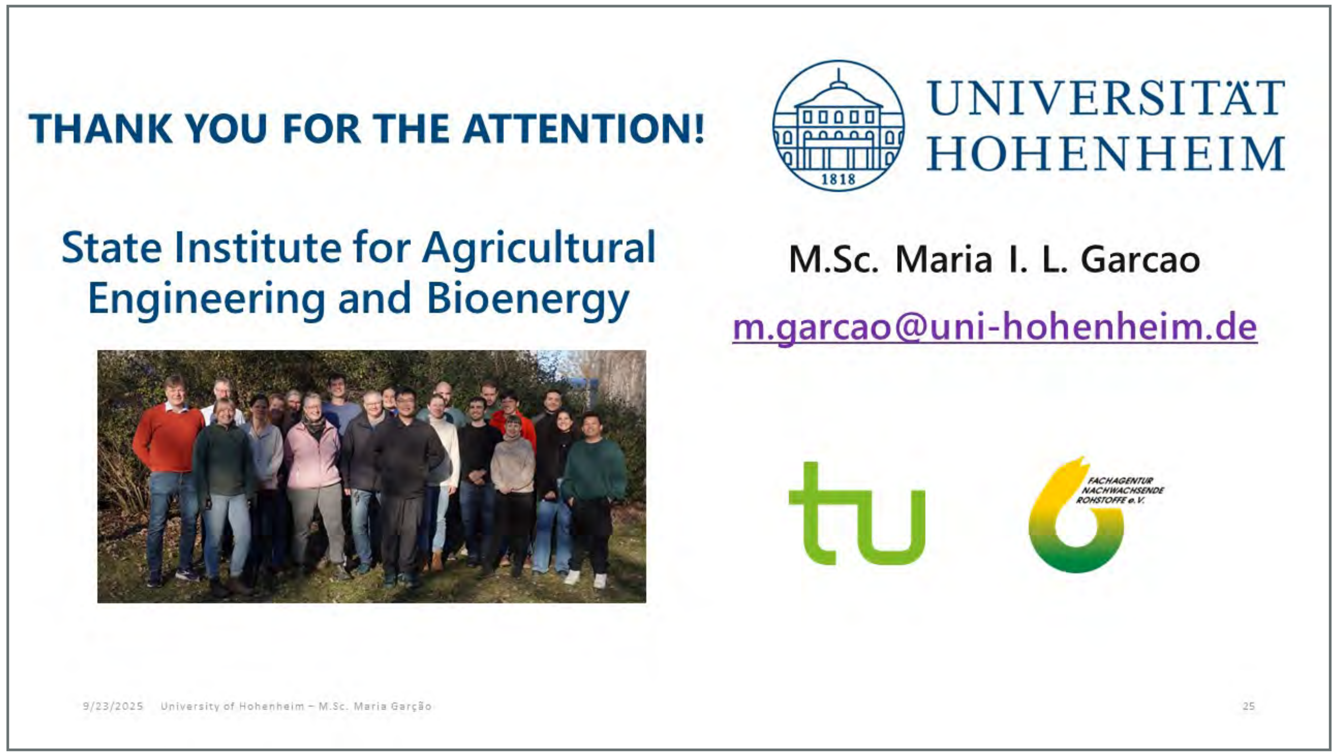
THANK YOU FOR THE ATTENTION!
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1818
State Institute for Agricultural Engineering and Bioenergy
M.Sc. Maria I. L. Garcao
m.garcao@uni-hohenheim.de
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25

SESSION
CIRCULAR BIOECONOMY IN INDUSTRY

8TH DOCTORAL COLLOQUIUM BIOENERGY AND BIOBASED PRODUCTS

Henri Steinweg, Karlsruhe Institute of Technology

Bringing up industrial capacities on gas fermentation - Where is the niche?

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Keywords: Gas-Fermentation, Autotrophic metabolism, Techno-economic analysis, Levelized costs of products

Introduction

Anthropogenic carbon use currently follows a linear path from lithospheric sources to atmospheric release, extending the biospheric carbon balance. To reduce this dependency, industrial processes must increasingly draw carbon from atmospheric reservoirs. Biomass—via photosynthetic fixation—remains the dominant source, with boreal and tropical zones contributing ~1/3 and ~2/3 of global biologic carbon assimilation, respectively. My presentation explores fermentative CO_2 conversion from: (1) boreal forestry biomass, (2) tropical agricultural biomass, and (3) small- scale CO_2 point sources. Fermentative gas processes offer decentralized, low-threshold solutions for CO_2 valorisation into chemicals like ethanol, acids, and ketones, especially using thermophilic strains like Moorella thermoacetica.

Approach

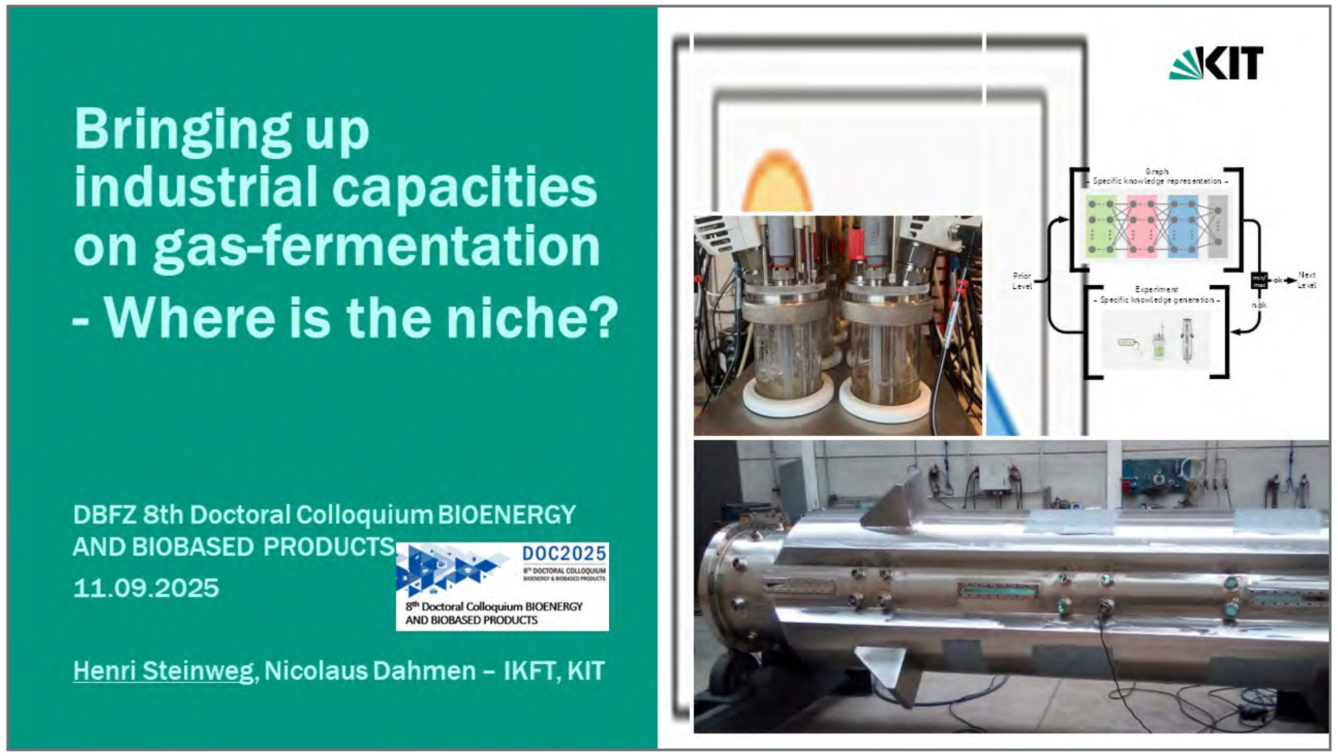
[1] Boreal Forestry Biomass: At sites like Metsä Kemi - Europe's largest biogenic CO_2 point source - most carbon ends as emissions from unutilized wood fractions. This case compares levelized costs of on-site gas-fermentation (e.g., ethanol) vs. CO_2 capture and transport.

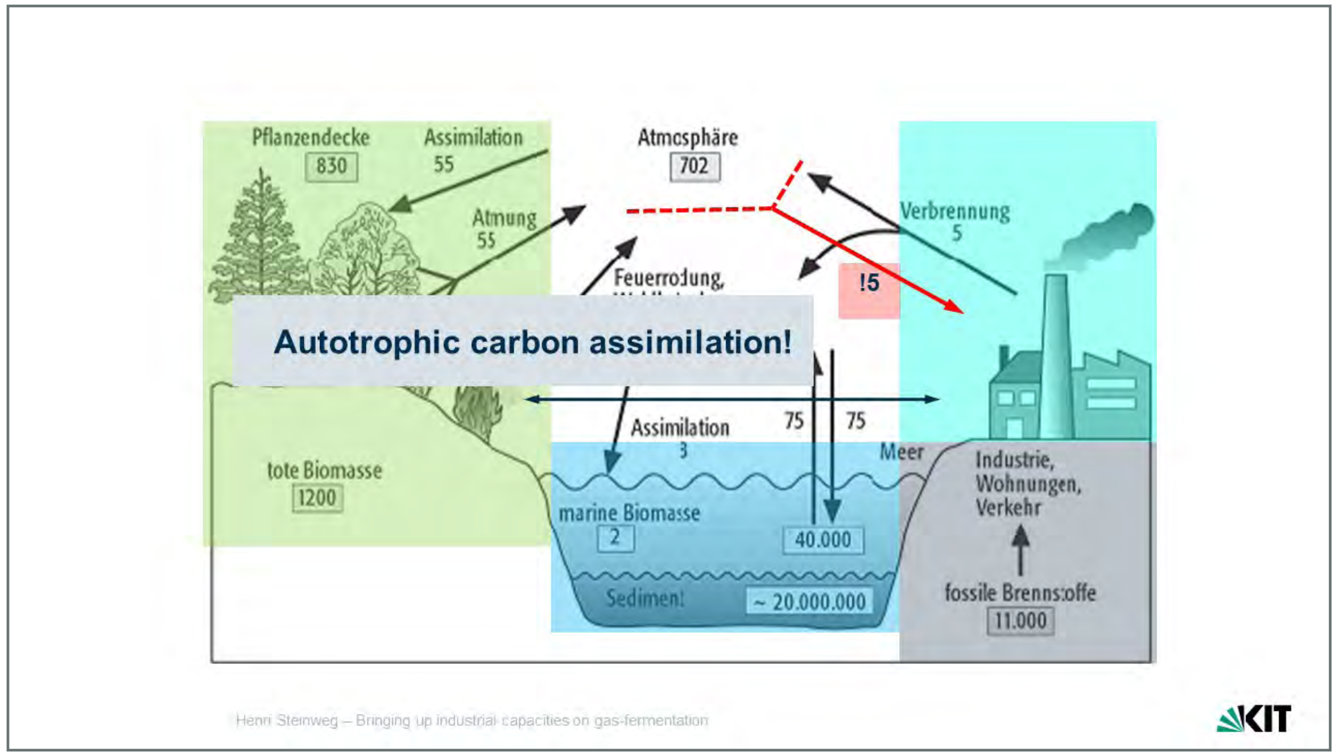
[2] Tropical Agricultural Biomass: Using a sugarcane biorefinery in São Paulo as a model, this case assesses retrofitting fast pyrolysis with gas-fermentation of off-gas to ethanol, maintaining energy self- sufficiency.

[3] Small-scale CO_2 Sources: Small emitters (e.g., cement, metallurgy) lack scale for centralized CO_2 use. A case study explores decentralized gas-fermentation for producing high-value products like acetone at EU-ETS-covered sites.

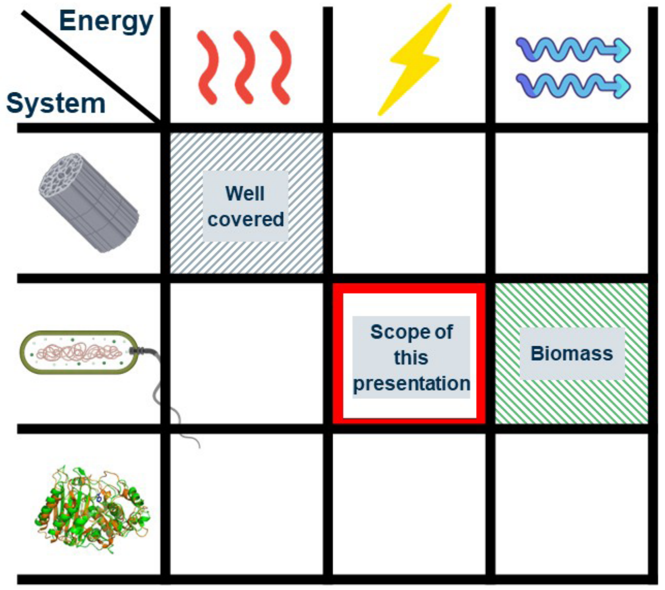
Outlook

In boreal forestry, local gas-fermentation may offer cost advantages over CO_2 capture and provision (~120–150 €/t CO_2) due to moderate conditions and self-regenerating catalysts. In tropical agriculture, energy-self-sufficient processing of residues could yield FPBO (100- 200 €/t) and ethanol (240–400 €/t) while delivering carbon dioxide removal (CDR) products. For small-scale emitters, e.g., EU- ETS-covered mineral sources, on-site fermentation targets niche markets like non- petrochemical cosmetic-grade acetone (1500–2400 €/t). Demonstrating gas-fermentation across diverse contexts supports a circular carbon economy linking atmospheric carbon to industrial use.





Intro – Route to routes?



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Intro – Gas fermentation

Wood-Ljungdahl pathway + Acetogenesis

- Trade-off CO / CO2 for energy
- Trade-off Acetate / Ethanol for pH (acid triggers stress, redoxpotential)

Reaction equations

- Acetate higher yields than ethanol:

$$2\,CO_2 + 4\,H_2 \longrightarrow CH_3COOH + 2\,H_2O$$

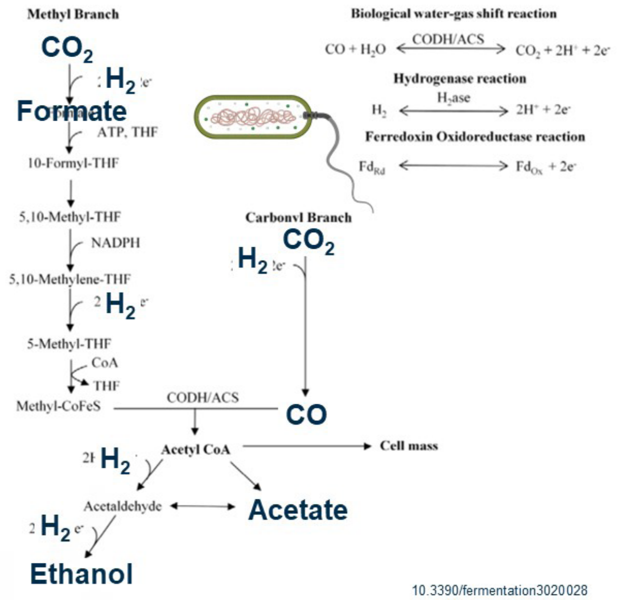
– **Product C:O 1:1**

$$2\,CO_2 + 6\,H_2 \longrightarrow CH_3CH_2OH + 3\,H_2O$$

– **Product C:O 2:1**

-> Evolving strains to reaction conditions:

- Need to evolve to higher H_2-partial pressures



10.3390/fermentation3020028

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Intro – Carbon handling

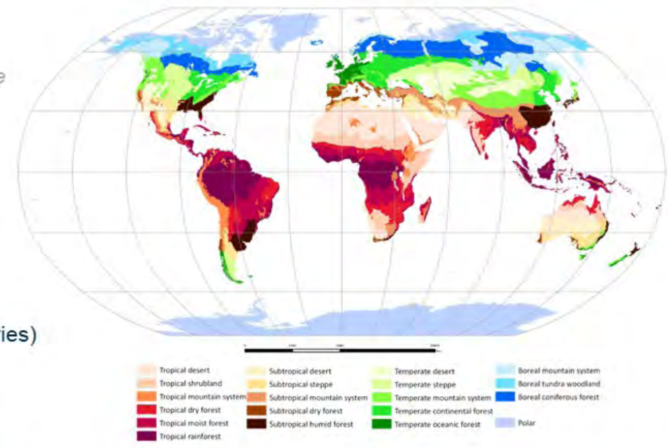
Where do we find „handled carbon"?

Gro **Turnover** production (GPP) *Carbon from atmosphere*

- Total ~130-169 Gt 'C'/a [1]

Net **Fixation** production (NPP) *Carbon in biomass*

- **Borreal Forests *1/3 'C'***
  - 1135 Mha (Scandinavia, Russia, Alaska, Canada)
  - NPP ~**2.6-4.6** Gt 'C'/a [2]
- **Tropical agriculture** (~23.5°N-23.5°S) **2/3 'C'**
  - 456 Mha – 640 Mha (FAOstat; 127 "tropical" countries)
  - NPP ~**4.1-8.0** Gt 'C'/a [3]
- Antropogenic **point** sources
  1. Power, Industry (~2/3 of foss. C) -> 6.67 Gt 'C'/a [4]
  2. Cement 0.5 Gt 'C'/a -> **total 7.2 Gt 'C'/a** [5]



https://foris.fao.org/static/data/fra2010/ecozones2010.jpg

[1] 10.1002/2015... [3] 10.1371/journal.pone.0051759 [5] ...
[2] 10.1126/science.1201609 [4] 10.1038/s41558-020-0797-x

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Intro – Summary

1. Fermentative processes are based on living organisms
2. They reproduce themselves in habitable environmental conditions
3. They are adaptive and evolving, as every organism
4. Organisms are highly selevtive: This biologic autotrophic neiche allows the conversion of non-pure streams into non-pure (aqueous) streams
5. Hydrogen supply is limiting high volumetric yields, getting worse at high salinity and higher temprature
6. Acetate requires less hydrogen than ethanol, but cannot be separated easily
7. Microbial activity increases with higher temprature
8. Reactor design has to provide sufficient interphase at elevated pressure

-> Optimal biotechnological and processtechnological development is not trivial

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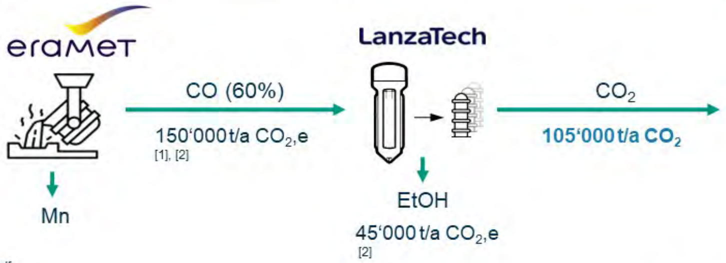
State of the art

Industrialisation: LanzaTech

- Picture: Steelanol in Ghent, BE
- Focus on CO-rich off-gases
- EtOH as only full-commercial product

- ~35-50% of CO to EtOH

Which could be a nieche of (full) CO_2-utilisation of CO-free gas-steams?



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[1] https://www.norskeutslipp.no/en/Miscellaneous/Company/?CompanyID=6261
[2] https://www.eramet.com/wp-content/uploads/2024/10/2024-10-31-PR-Eramet-LanzaTech.pdf

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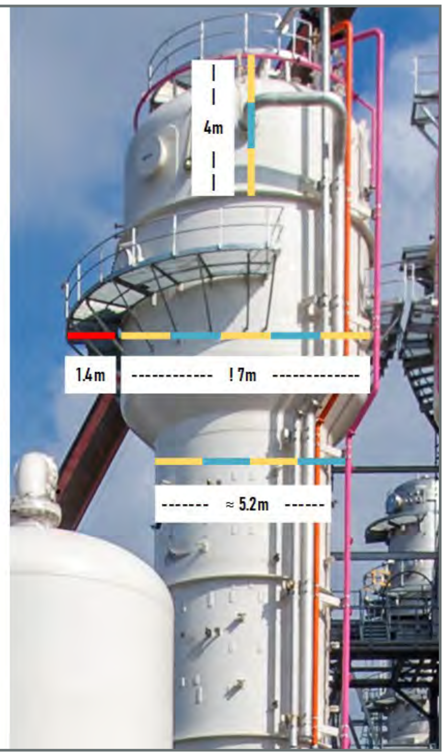
State of the art

LT Steelanol Ghent

- Investment **165 M€** (2021)
  - Convert 125'000 t CO_2/a
  - *CapEx: **1320** [€$_{2021}$/t CO_2 a] or **2000** [€$_{2021}$/t EtOH a]*
- Reactor sizing
  - Height: 35m (4m headspace, wide part total 9.5m)
  - Diameter 7m
  - Volume 210 m³ (upper) + 500 m³ (lower) ≈ **700 m³ liquid** / reactor
  - Fixation 1,509 [kg $CO_{2,e}$/L EtOH]
    -> Volumetric productivity of **~4 kgEtOH/m³h – on CO+H_2!**
  - ~20'750 t/a EtOH per reactor / 83'000 t/a EtOH (4 reactors)
- **Currently EtOH price down, thus LT struggeling**
- **So, different location? Different product?**



https://www.veolia.be/nl/business-cases/steelanol-groene-warmte-duurzame-bio-ethanol
https://corporate.arcelormittal.com/media/cases-studies/arcelormittal-belgium-marks-milestone-by-lifting-bioreactors-into-place-at-its-industrial-scale-demonstration-plant-for-carbon-neutral-steelmaking

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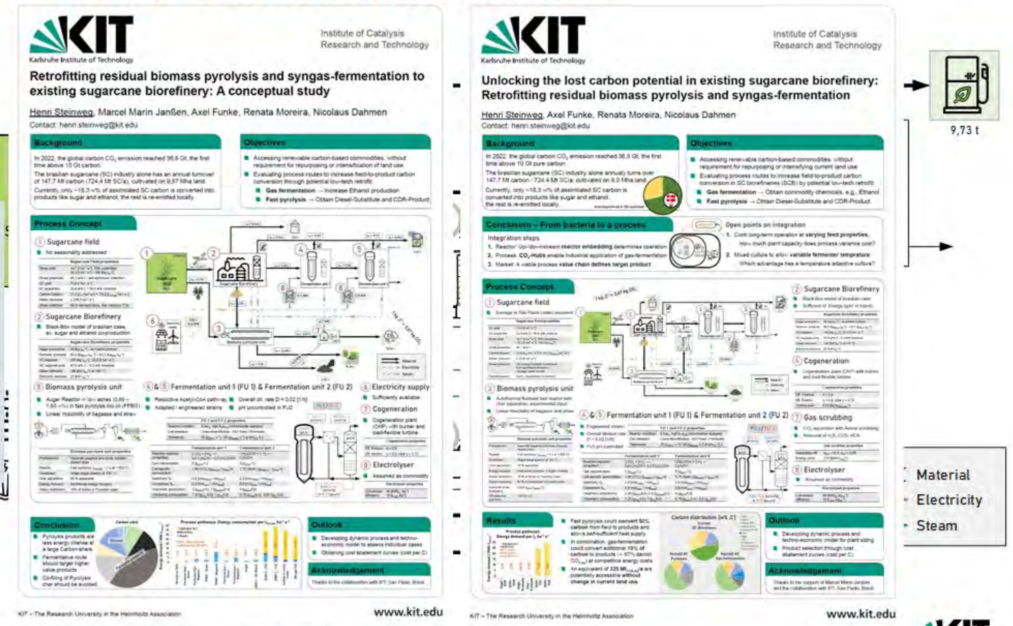
Tropical arable and permanent cropland

Brasilian SC-Biorefinery

2-stage retrofit:

1. Combatting seasonality with **fast pyrolysis**
2. Bringing up carbon yield with **gas fermentation**

-> From 20 to 85% 'C' field-to-products



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Case 1 – Cement plant Mergelstetten

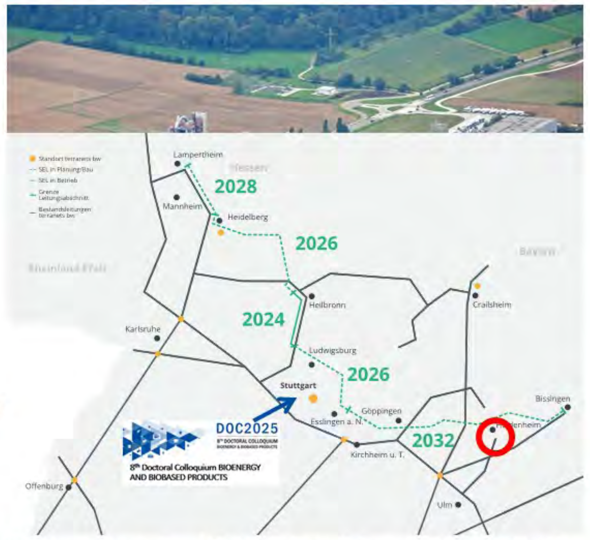
Point source

Cement plant has to deal with CO_2 emissions

- ~393'000 [t CO_2 / a] emission by 2023
- CCS might be one option
- CCU maybe good alternative?

Currently in research project for high purity CO_2-off-gas

=> 320'000 [t CO_2 / a] available (x0.8) assumed



https://www.dehst.de/SharedDocs/downloads/DE/publikationen/VET-Bericht-2023.html

https://www.stuttgarter-zeitung.de/inhalt.klimaschutz-in-baden-wuerttemberg-grossanlage-fuer-klimafreundliches-kerosin-verzoegert-sich.bd47aa6c-d0d8-42ae-9b5f-25153b961fd5.html
https://www.terranets-sel.de/unser-auftrag-ihre-energieversorgung

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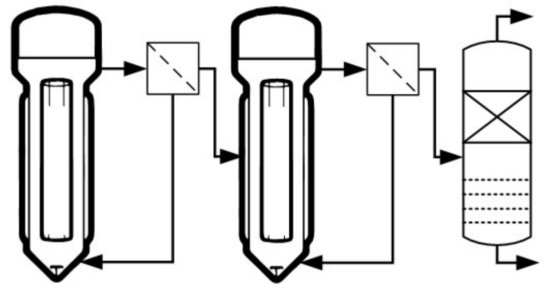
Case 1 – Point source

- **Acetate as intermediate**
  - Higher conversion (H_2 limiting!)
  - But 2-step required
- Valorisation in second fermenter
  - engineered pathway to target molecule
  - Acetone as target:
    - Current market fossil
    - Easy to separate from aqueous broth



Both broths linked, no intermittend purification!

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Case 1 – Point source

- Full continuous
- Buffer tank capacity 48h operation
- Acetate to Acetone STY early-stage as engineered

Parameter	Fermenter 1 (F1:F2 1:0.5 m³Liq) Values per F1 m^3_{Liquid}	Fermenter 2 Value per F1 m^3_{Liquid}	Distillation Value
STY	7.23 [k 6.9 [kg CO_2/h] with 1.01 [kg H_2/h]	4 [kg Acetone/m^3_{F2}h]	-/-
Titer	20 [kg]	5.2 [kg/m^3_{F2}]	874 [kg/$m^3_{Distillate}$] Acetone + Nitric acid
Design	Gas-Lift reactor	Gas-Lift reactor	Flash distillation
Gas, in	14.6 [kg CO_2/h], 1.3 [kg H	Overall ~0.5 kg CO_2 /CO_2 inlet	-/-
Gas, out	3.5 [kg/h]	4.5 [kg/h]	0.34 [kg/h]
Liq.,in	344 [kg Media/h]	356 [kg Broth/h]	359 [kg Broth/h]
Liq.,out	356 [kg Broth/h]	359 [kg Broth/h]	354 [kg Waste water/h]
Product out	7.23 [kg Acetate/h]	1.9 [kg Acetone/h]	4.9 [kg Distillate/h]
Effluent	Gas	Gas	Water
Conversion / Separation eff.	78 [% CO_2] 80 [% H_2]	80 [% Acetate]	97 [% Acetone]

Overall 12.8% CO_2 to Acetone

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Case 1 – Point source

- Formic acid included as side-product
- Cell retention 0.95 / 0.05
- BM = $C_1H_{1.4}O_{0.9}$

Parameter	Fermenter 1 Value	Fermenter 2 Value
Reaction equation	2.1 CO_2 + 4.2 H_2 -> 1 Acetate + 0,03 BM + 2 H_2O	3 Acetate + 2 O_2 -> 1 Acetone + 3 H_2O + 3 CO_2 + 0,013 BM
Conversion	0.8 (H_2)	0.8 (Acetate)
Overstociometric	1.05 CO_2 dosage	1.1 O_2 dosage
Pathway	Wood-Ljungdahl, Acetogenic	Modified ABE
pH	5.5	6.0
pH Control	Sodium Hydroxide	Nitric Acid
Temprature	60 [°C]	37 [°C]
Pressure	10 [bar_g]	0 [bar_g] = atm
Product tolerance	20 [g/L Acetate], 15 [g/L Acetone]	25 [g/L Acetone]

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Case 1 – Point source CAPEX

Cost estimation
- Fermenter: Turton
- Pressure vessel: Towler & Sinnot

Only main equipment ISBL-Costs:
- Fermenter 1
  - Gas-Lift fermenter
- Fermenter 2
  - Gas-Lift fermenter
- Flash-Distillation
  - Flash-Tank
  - Clean & Dirty distillation (Sieve Trays)

General assumptions
- Clean and dirty column equipment are identical
- All equipment in SS316
- 8 stages per column, reflux ratio of 2
- VLE with AspenPlus / UNIQUAC-HOC
- No storage vessels, pumps, HEX, auxilliaries, …
- OPEX only material streams

Equipment	Dimensioning Parameter	Dimensioning	Installed equipment costs (€$_{2024}$)
Fermenter 1	10 barg	4 units 2919 m^3_{Liq} total	63.2 M€ (22t€ / m³)
Fermenter 2	0 barg = atm	2 units 1403 m^3_{Liq} total	7.4 M€ (5.3 t€ / m³)
Flash tank	1.5 bara, H/D 3 τ >4.5 min	1 unit H 13.4 D 4.5 m	1.4 M€
Clean	8.1 w% V feed	1 unit H 6.55 D 1.7 m	0.5 M€
Dirty	91.9 w% L feed	1 unit H 5.95 D 4.8 m	1.4 M€

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165 M€

125t t/a CO_2

1st stage

3.65 kg CO_2/kg Acetone

320‘000 t/a CO_2
=> 151‘950 t/a CO_2
=> 40‘805 t/a Acetone

x3 vs. 74 M€ est.

2nd stage

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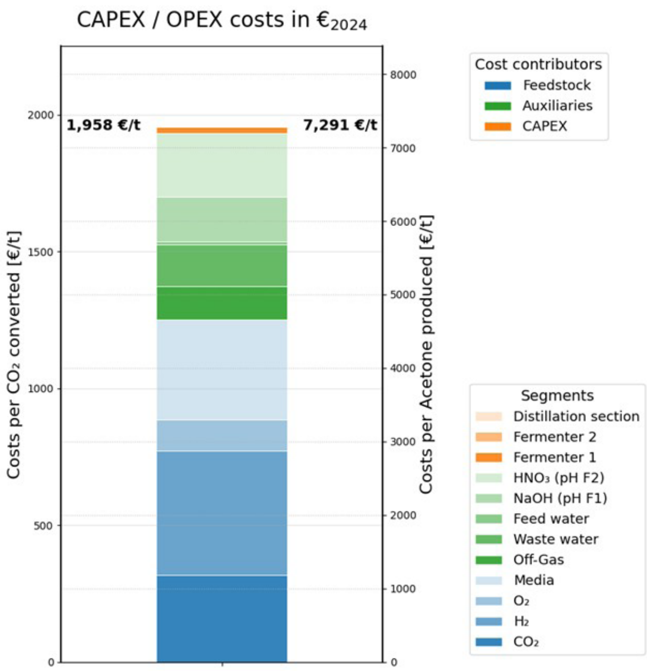
Case 1 – Point source OPEX

Component	Price per unit [€/t]	Cost m³F1 [€/h]
CO_2	150	2.19
H_2	2500	3.16
O_2	350	0.79
Media	7.5	2.55
Gas treatment	100	0.84
Waste water	3	1.06
Feed water	0.2	0.07
NaOH	280	1.15
HNO_3	260 (at 86%)	1.62

H_2-costs: Global H_2 cost tool
Brändle, Gregor; Schönfisch, Max; Schulte, Simon (2020), Estimating Long-Term Global Supply Costs for Low-Carbon Hydrogen, EWI Working Paper No. 20/04.



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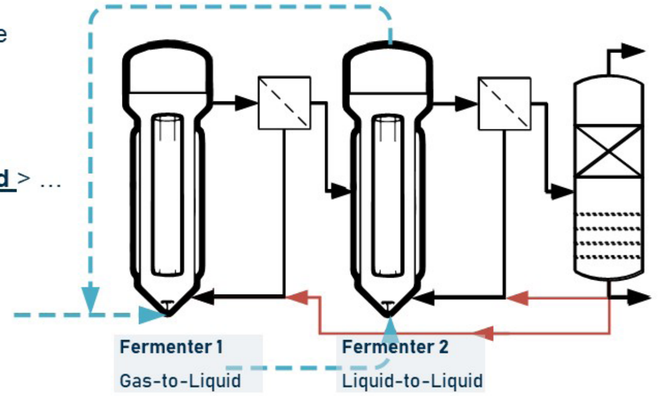
Case 1 – Point source Summary

- F2 productivity as bottleneck due to early-stage biotech
- pH Control:
  - Inorganic acid for Acetic acid consumption
  - Nitric acid > Sulforic acid > **Phosphoric acid** > …
- CO_2 utilisation:
  - High (~50%) CO_2 re-emission as partial conversion and oxidative 2nd step
- Waste Water:
  - High (~190L WW/kg Acetone) waste water emission and thus high media demand

=> Stream integration



Process integration
- Gas recirculation
- Liquid recirculation
- Reduced pH control demand

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Case 1b – Point source

- Full continuous
- Buffer tank capacity 48h operation
- Acetate to Acetone STY early-stage as engineered

Parameter	Fermenter 1 (F1:F2 1:0.6 m³Liq) Values per F1 m^3_{Liquid}	Fermenter 2 Value per F1 m^3_{Liquid}	Distillation Value
STY	7.23 [k 9.9 [kg CO_2/h] with 1.01 [kg H_2/h]	4 [kg Acetone/m^3_{F2}h]	-/-
Titer	51 [kg]	25 [kg/m^3_{F2}]	949 [kg/$m^3_{Distillate}$] Acetone ~~+ Nitric acid~~
Design	Gas-Lift reactor	Gas-Lift reactor	Flash distillation
Gas, in	7.3 [kg CO_2/h], 1.1 [kg H_2 [illegible]	[illegible]	-/-
Gas, out	3.1 [kg CO_2/h]	[illegible] (recycle)	0.3 [kg/h] *(recycle)*
Liq.,in	20 [kg Media/h]	140 [kg Broth/h]	149 [kg Broth/h]
Liq.,out	140 [kg Broth/h]	149 [kg Broth/h]	17.5 [kg Waste water/h]
Product out	7.23 [kg Acetate/h]	2.3 [kg Acetone/h]	2.3 [kg Distillate/h]
Effluent	Gas	-/-	Water
Conversion / Separation eff.	80 [% CO_2] 90 [% H_2]	99 [% Acetate]	93 [% Acetone]

Overall ~0.2 kg CO_2 /CO_2 inlet

Overall 30.6% CO_2 to Acetone

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Case 1b – Point source CAPEX

Cost estimation
- Fermenter: Turton
- Pressure vessel: Towler & Sinnot

Only main equipment ISBL-Costs:
- Fermenter 1
  - Gas-Lift fermenter
- Fermenter 2
  - Gas-Lift fermenter
- Flash-Distillation
  - Flash-Tank
  - Clean & Dirty distillation (Sieve Trays)

General assumptions
- Clean and dirty column equipment are identical
- All equipment in SS316
- 8 stages per column, reflux ratio of 2
- VLE with AspenPlus / UNIQUAC-HOC
- No storage vessels, pumps, HEX, …
- OPEX only material streams

Equipment	Dimensioning Parameter	Dimensioning	Installed equipment costs (€$_{2024}$)
Fermenter 1	10 barg	5 units 3459 m^3_{Liq} total	76.7 M€ (22t€ / m³)
Fermenter 2	6 barg	3 units 2066 m^3_{Liq} total	27.9 M€ (13.5t€ / m³)
Flash tank	1.5 bara, H/D 3 τ >4.5 min	1 unit H 14.9 D 5 m	1.7 M€
Clean	8.7 w% V feed	1 unit H 6.55 D 1.3 m	0.4 M€
Dirty	91.3 w% L feed	1 unit H 5.95 D 1.4 m	0.4 M€

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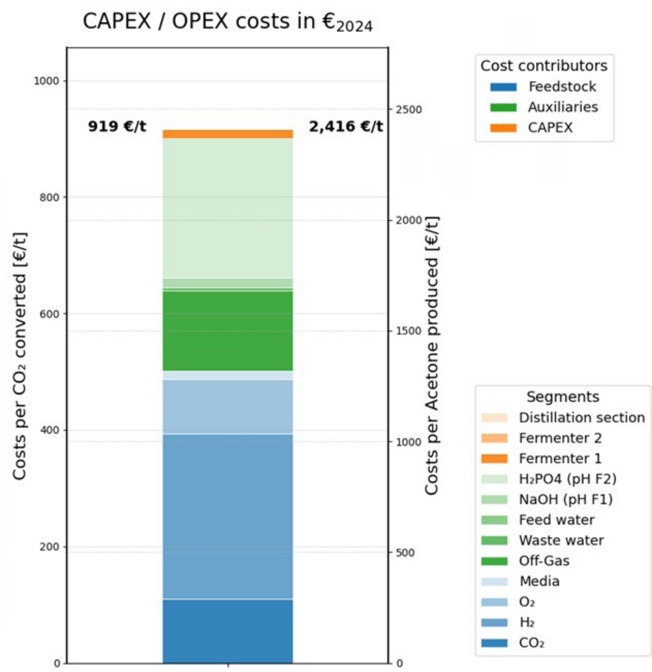
Case 1b – Point source OPEX

Component	Price per unit [€/t]	Cost m³F1 [€/h]
CO_2	150	*2.19* -> 1.09
H_2	2500	*3.16* -> 2.81
O_2	350	*0.79* -> 0.93
Media	7.5	*2.55* -> 0.15
Gas treatment	100	*0.84* -> 1.36
Waste water	3	*1.06* -> 0.05
Feed water	0.2	*0.07* -> 0.00
NaOH	280	*1.15* -> 0.17
H_3PO_4	1280	*1.62* -> 2.38

H_2-costs: Global H_2 cost tool
Brändle, Gregor; Schönfisch, Max; Schulte, Simon (2020), Estimating Long-Term Global Supply Costs for Low-Carbon Hydrogen, EWI Working Paper No. 20/04.



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Case 1b – Point source Summary

- F2 productivity as bottleneck due to early-stage biotech
  - Still, through recycle high conversion
- pH Control:
  - Nitric acid > Sulforic acid > **Phosphoric acid** > …
  - Phosphoric acid seems suitable, still expansive and with impact in WW
- CO_2 utilisation:
  - Lowered (~20%) CO_2 re-emission, more converted
- Waste Water:
  - Very low (~9L WW/kg Acetone) waste water emission

=> Stream integration successful: 2400 €/t Acetone *almost* viable
- Better utilisation of CAPEX, less OPEX per m³ -> more product per „effort“
  - Phosphoric acid recovery! -> ~1800 €/t Acetone

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Case 2 – Borealic forest biorefinery Metsä Kemi

Size – (one of the) largest biogenic CO_2-point sources in EU

Scale:

- >4.2 Mt CO_2/a at Kemi site
- Central biomass handling
- Good location, potential for synergies

Est. 150 €/t CO_2 provision cost (clean, compressed, at gate)

=> 3‘360‘000 [t CO_2 / a] available (x0.8) assumed

https://yle.fi/a/3-10689743

https://www.andritz.com/newsroom-en/environmental-solutions/2024-06-13-metsae-carbon-capture-group

https://archive.nordregio.se/en/Publications/Publications-2016/GREEN-GROWTH-IN-NORDIC-REGIONS-50-ways-to-make-/Circular-economy-/An-ecosystem-of-arcti/index.html

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Case 2 – Borealic forest biorefinery CAPEX

Cost estimation
- Fermenter: Turton
- Pressure vessel: Towler & Sinnot

Only main equipment ISBL-Costs:

- Fermenter 1
  - 5000m³ micro-sparged fermenter
- Fermenter 2
  - Gas-Lift fermenter
- Flash-Distillation
  - Flash-Tank
  - Clean & Dirty distillation (Sieve Trays)

General assumptions
- Clean and dirty column equipment are identical
- All equipment in SS316
- 8 stages per column, reflux ratio of 2
- VLE with AspenPlus / UNIQUAC-HOC
- No storage vessels, pumps, HEX, …
- OPEX only material streams

Equipment	Dimensioning Parameter	Dimensioning	Installed equipment costs (€$_{2024}$)
Fermenter 1	0 barg = atm	34 units 175‘000 m^3_{Liq}	361 M€ (2t€ / m³)
Fermenter 2	0 barg = atm	28 units 21‘700 m^3_{Liq}	109 M€ (5t€ / m³)
Flash tank	1.5 bara, H/D 3 τ >4.5 min	2 units H 14.9 D 5 m	3.4 M€
Clean	8.7 w% V feed	1 unit H 6.55 D 4.2 m	1.3 M€
Dirty	91.3 w% L feed	1 unit H 5.95 D 4.6 m	1.3 M€

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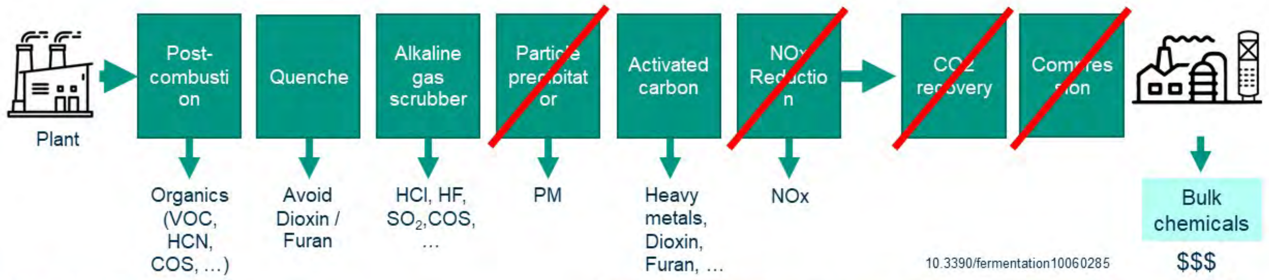
Case 2 – Borealic forest biorefinery Metsä Kemi



10.3390/fermentation10060285

Assumptions:

- **Ambient pressure fermentation (as large scale)**
- **5000 m³ Micro-sparged fermenters**
- Cost advantage ~150 €/t CO2
- Free Oxygen as on-site Electrolyseurs
- Phosphoric acid recycle (x0.1 costs)

https://puring.de/en/biogas-plant-friesoythe-reference-project/

https://rundblick-niedersachsen.de/kein-termin-die-mega-biogas-anlage-infriesoythe-wird-von-zeitverzug-geplagt

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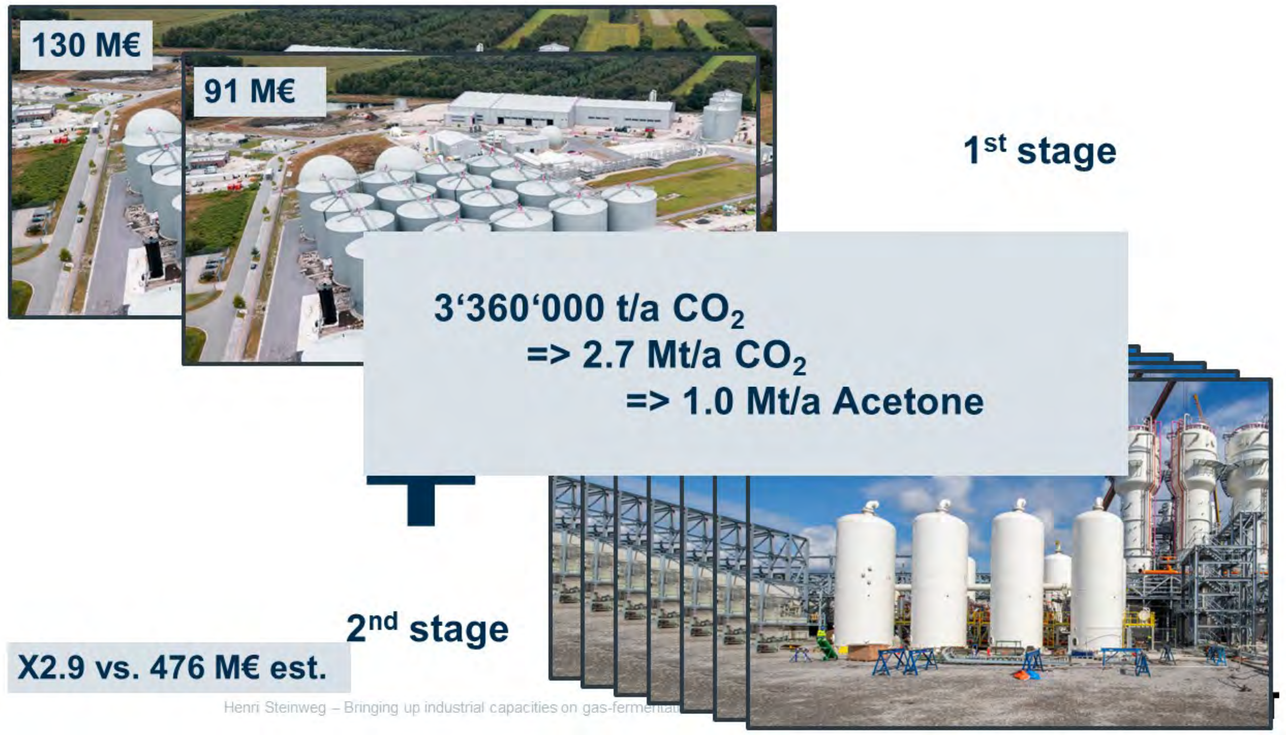

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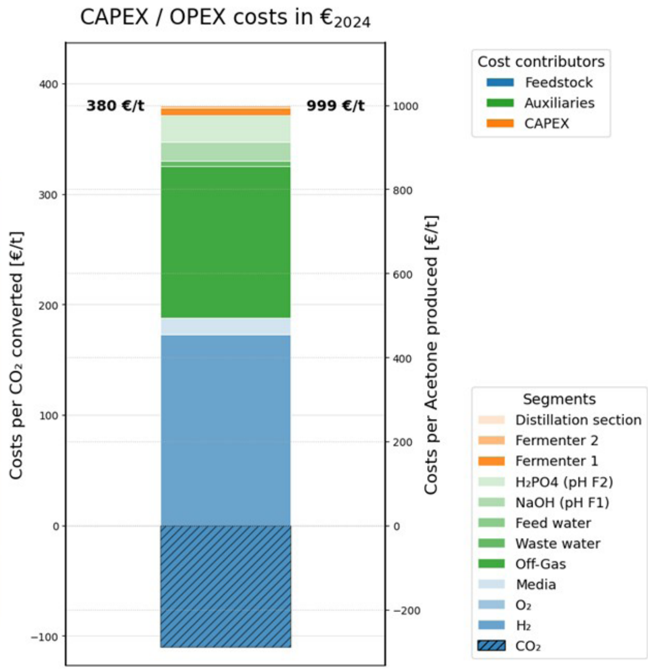
Case 2 – Biorefinery OPEX

Component	Price per unit [€/t]	Cost m³F1 [€/h]
CO_2	– 150 (cost adv.)	– 0.23
H_2	2500	0.58
O_2	0 (on-site H_2-el.)	0.00
Media	7.5	0.03
Gas treatment	100	0.28
Waste water	3	0.01
Feed water	0.2	0.00
NaOH	280	0.03
H_3PO_4	128 (x0.1 rec.)	0.05

H_2-costs: Global H_2 cost tool
Brändle, Gregor; Schönfisch, Max; Schulte, Simon (2020), Estimating Long-Term Global Supply Costs for Low-Carbon Hydrogen, EWI Working Paper No. 20/04.



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Case 2 – Borealic forest biorefinery Summary

- Direct utilisation of off-gas (uncleaned, uncompressed)
  - only ambient pressure reactors to keep low gas-handling adv.
- Large-scale micro-sparging for H_2-supply to be tested
- Phosphoric acid recovery to be tested
- On-site integration might bring (further) advantages

With approx. 1000 €/t Acetone viable

– even without CO_2-related saving ~1250 €/t Acetone ~*viable*
=> maybe further cost reduction through less off-gas?
=> life-time of 5000 m³ micro-sparged reactors to be tested

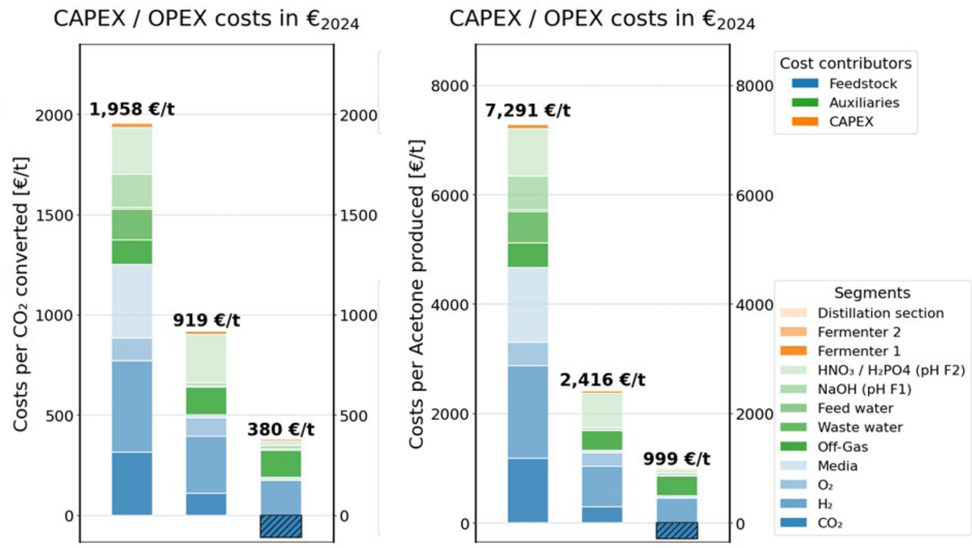
Henri Steinweg – Bringing up industrial capacities on gas-fermentation

Summary

Costs decrease:

- Stream integration:
- CO_2 / Acetate conversion
- Media / Waste water
- pH control
- Pressure:
- Productivity increase
- *Large* scale: Not worth it?
- Raw off-gases only atm
- Pure gases pressurised
- Site integration:
- Cost advantages

- Cost underestimation x3 at CAPEX (main EQ)



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Outlook

Research issues:

- Strain development
  - Ammonia tolerance
  - Free acid tolerance
  - Strain adaptation & evolution
  - Robustness of engineered strains
- Process design
  - Design reactors for H_2-Mass transfer
  - Volumetric productivity in pressurised environment
  - 2-step processes: Gas & Media recirculation / pH control
- Experimental:
  - Validation of operational envelopes
  - Real-world process integration, even bench-top
  - Long-term operation

-> Routes to access biogenic carbon reservoirs in economic feasible way

Focus on what is handled anyways

Case 1:
Clean-gas fermentation
- **Standalone plant**
- **64'000 t/a CO_2 for full-size reactor**

Case 2:
Raw-gas fermentation
- **Integrated plant**
- **100'000 t/a CO_2 (in off-gas) for full-size reactor**

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END
Please feel free to ask questions!
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PYROCO2
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LinkedIn
KIT

Natalia Toriello España, University of Hohenheim

Circular Economy Approach to Construction: Investigating Hydrochar as a Pore-forming Agent in Fired Clay Bricks

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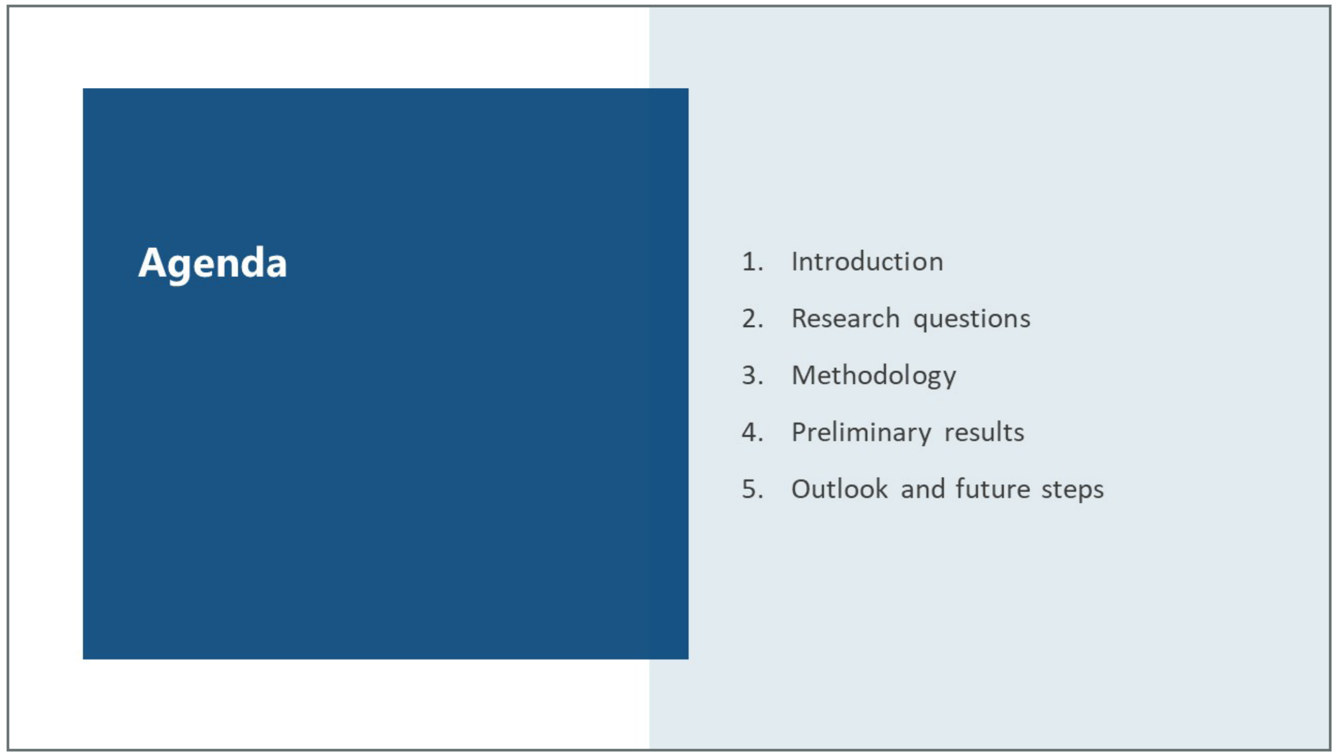
Keywords: Hydrochar, Circular Economy, Phosphorus Recovery, Fired Clay bricks

Introduction
Fired clay bricks are used worldwide in construction. Their porosity improves thermal insulation, enhancing energy effiency in buildings. Conventional pore-formers like sawdust, polystyrene, and paper pulp, increase CO_2 emissions during firing. A sustainable alternative, hydrochar-produced through hydrothermal carbonization (HTC) of sewage sludge - poses a potential for waste valorization and phosporus recovery, supporting circular economy goals and upcoming regulations. However, its application in construction remains underexplored. This study addresses hydrochar's potential for valorization as a pore-forming agent in fired clay bricks, considering material properties and its environmental impacts after phosphorus recovery.

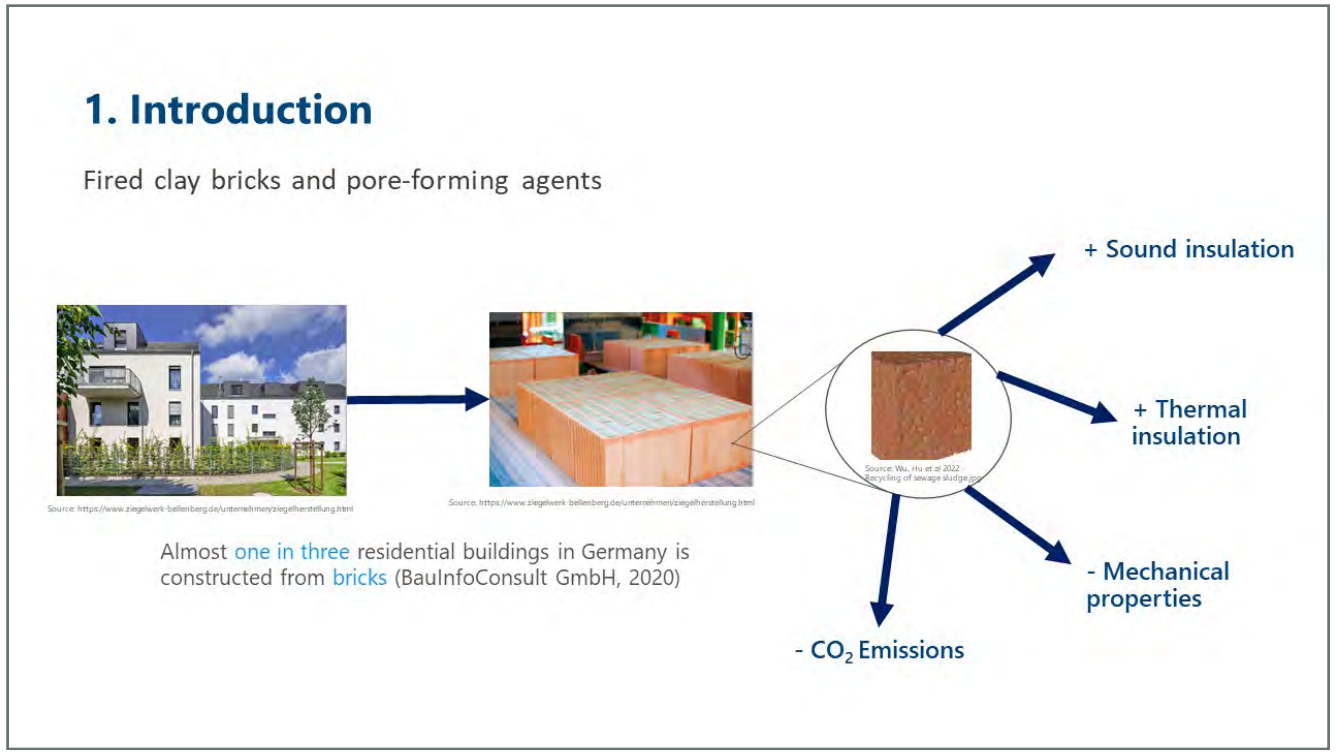
Approach/Methods
Hydrochar will be produced from sewage sludge via HTC and phosphorus will be recovered from it through acid leaching. The resulting material will be integrated into clay mixtures to manufacture fired bricks which performance will be evaluated. A thorough characterization pre and post leaching will be carried out to assess changes in the composition and identify optimization opportunities. The enviromental impact will be assessed by heavy metal leaching and energy analysis based on the hydrochar's calorific value.

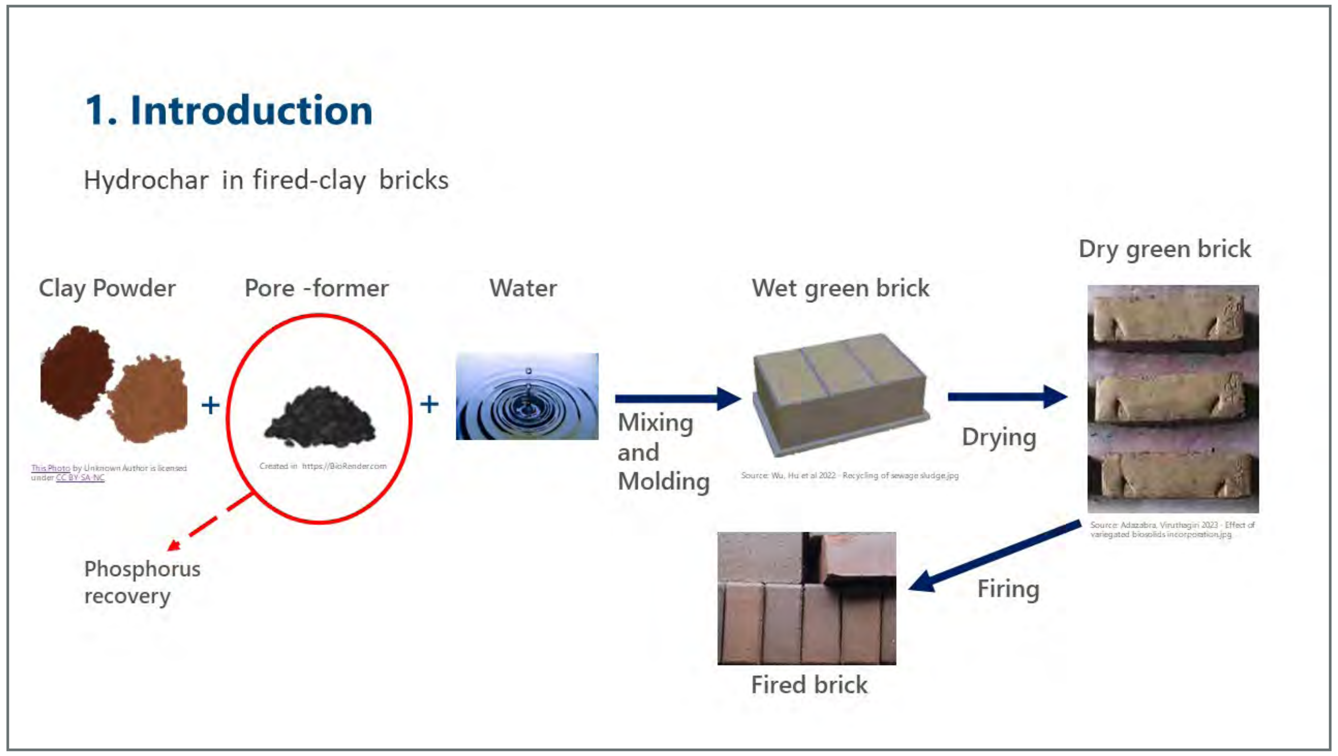
Results/Outlook
Various hydrochar samples will be produced from digested sludge out of different regions at five different temperatures within the HTC range (180°C-260°C). Yield, proximate and ultimate composition, phosphorus and heavy metal content and thermogravimetric analysis will be determined out of the samples before and after leaching.

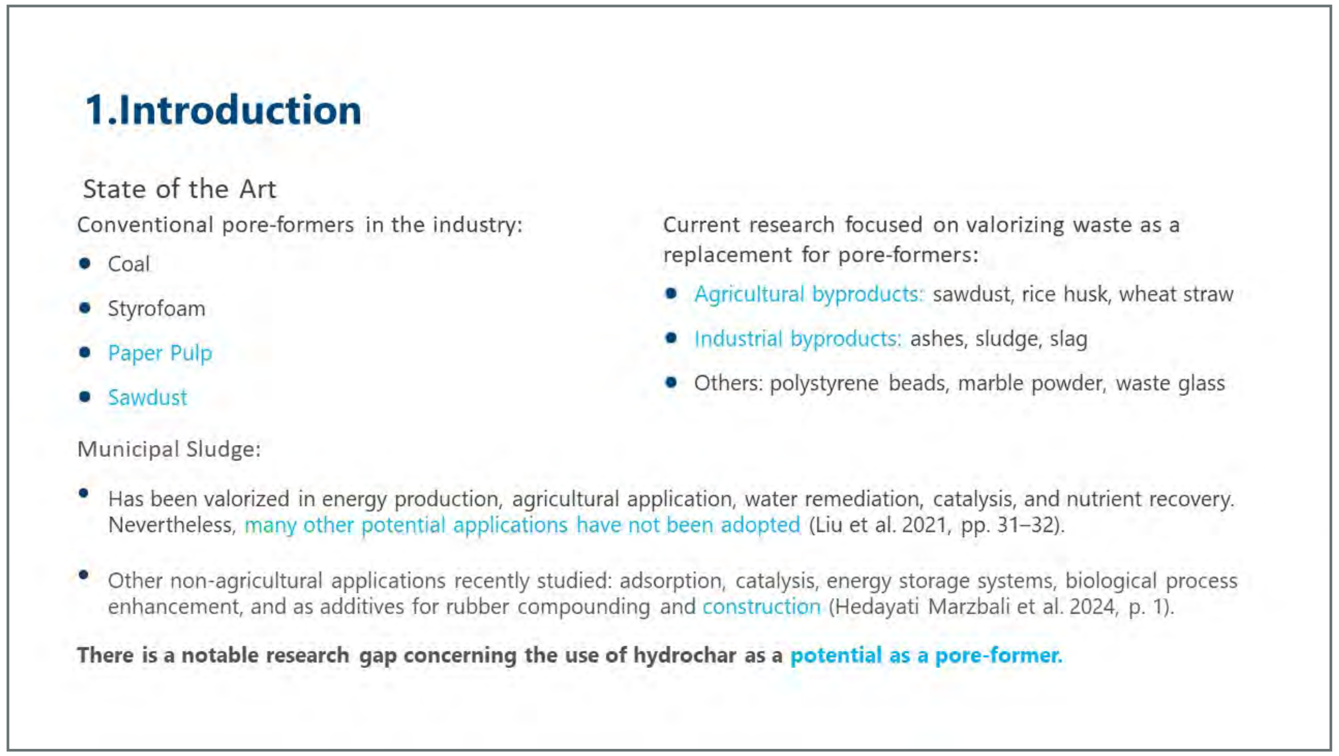
After thorough comparison the best performing hydrochar will be selected to develop a reproducible method, enabling as next step the scale-up to pilot scale. The final outcome expected is to validate hydrochar as a sustainable pore-former, while incorporating phosporus recovery without compromising the fired-clay brick's properties, supporting the decarbonization of the building sector. This study will bring insights into phoshorus recovery processs optimization and utilization of hydrochar in construction.




1. Introduction
Valorization of sludge and Sewage Sludge Ordinance
In 2023 Germany produced 1,6 tonnes dm of municipal sewage sludge (Statistisches Bundesamt, 2025)
Starting 2029 the Sewage Sludge Ordinance states that wastewater treatment plants must recover phosphorus
Hydrothermal carbonization (HTC) can process feedstock with high moisture content at a relatively low temperatures (180°C-260°C) resulting in a carbonaceous product: hydrochar

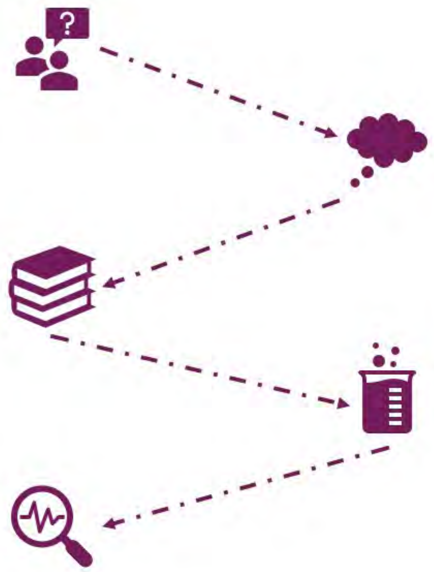

1. Introduction
Fired clay bricks and pore-forming agents
Almost one in three residential buildings in Germany is constructed from bricks (BauInfoConsult GmbH, 2020)
+ Sound insulation
+ Thermal insulation
- Mechanical properties
- CO_2 Emissions


1. Introduction
Hydrochar in fired-clay bricks
Clay Powder
Pore -former
Water
Wet green brick
Dry green brick
Mixing and Molding
Drying
Firing
Fired brick
Phosphorus recovery


1.Introduction
State of the Art
Conventional pore-formers in the industry:
Coal
Styrofoam
Paper Pulp
Sawdust
Current research focused on valorizing waste as a replacement for pore-formers:
Agricultural byproducts: sawdust, rice husk, wheat straw
Industrial byproducts: ashes, sludge, slag
Others: polystyrene beads, marble powder, waste glass
Municipal Sludge:
Has been valorized in energy production, agricultural application, water remediation, catalysis, and nutrient recovery. Nevertheless, many other potential applications have not been adopted (Liu et al. 2021, pp. 31–32).
Other non-agricultural applications recently studied: adsorption, catalysis, energy storage systems, biological process enhancement, and as additives for rubber compounding and construction (Hedayati Marzbali et al. 2024, p. 1).
There is a notable research gap concerning the use of hydrochar as a potential as a pore-former.

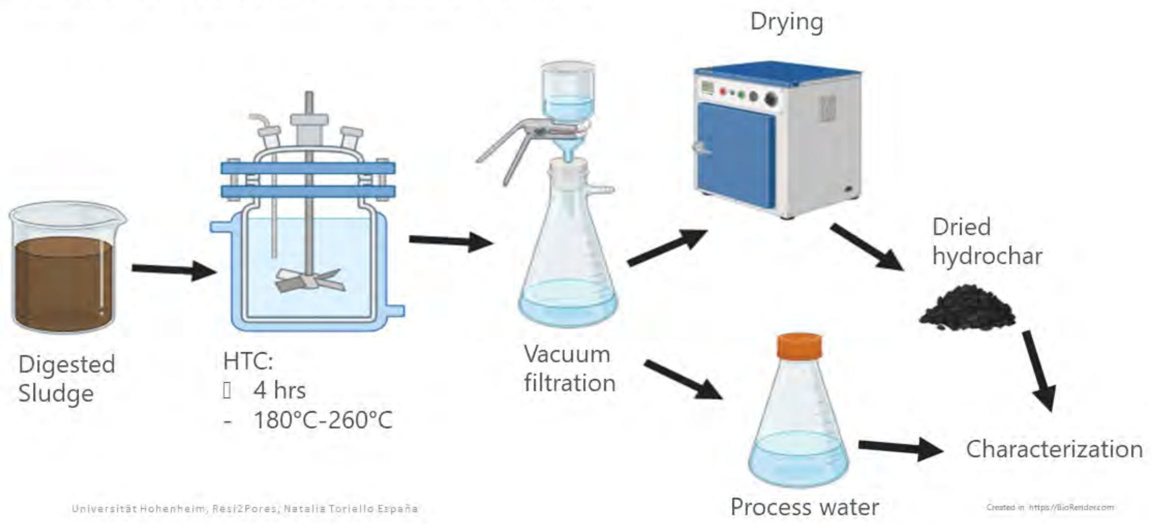
2. Research Questions

- How does the composition of hydrochar influences key fired clay brick parameters?
- How does the phosphorus recovery process alter hydrochar's composition and its potential to be recycled?
- What are the environmental implications of incorporating hydrochar as a pore-forming agent in fired clay bricks, particularly energy efficiency and leaching of contaminants?



3. Methodology

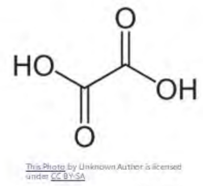
Production of Hydrochar from different sludges



3. Methodology

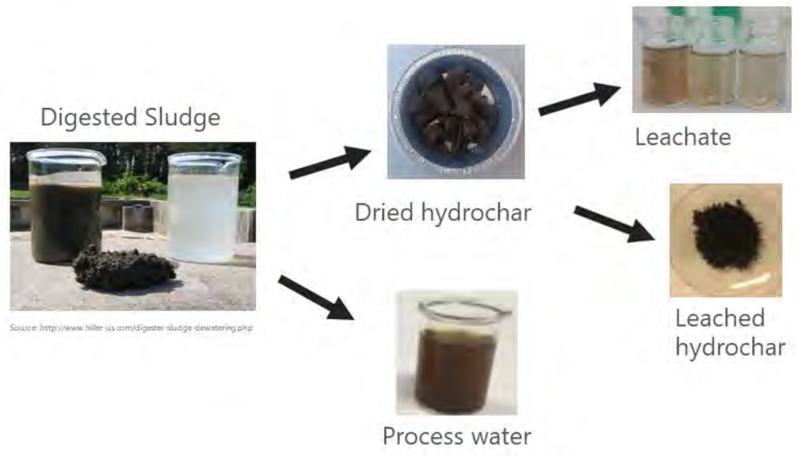
Phosphorus recovery through acid leaching

- Oxalic acid
- 1:10 ratio
- Constant stirring
- Samples taken at different times



3. Methodology

End-to-end characterization: From feedstock to final product



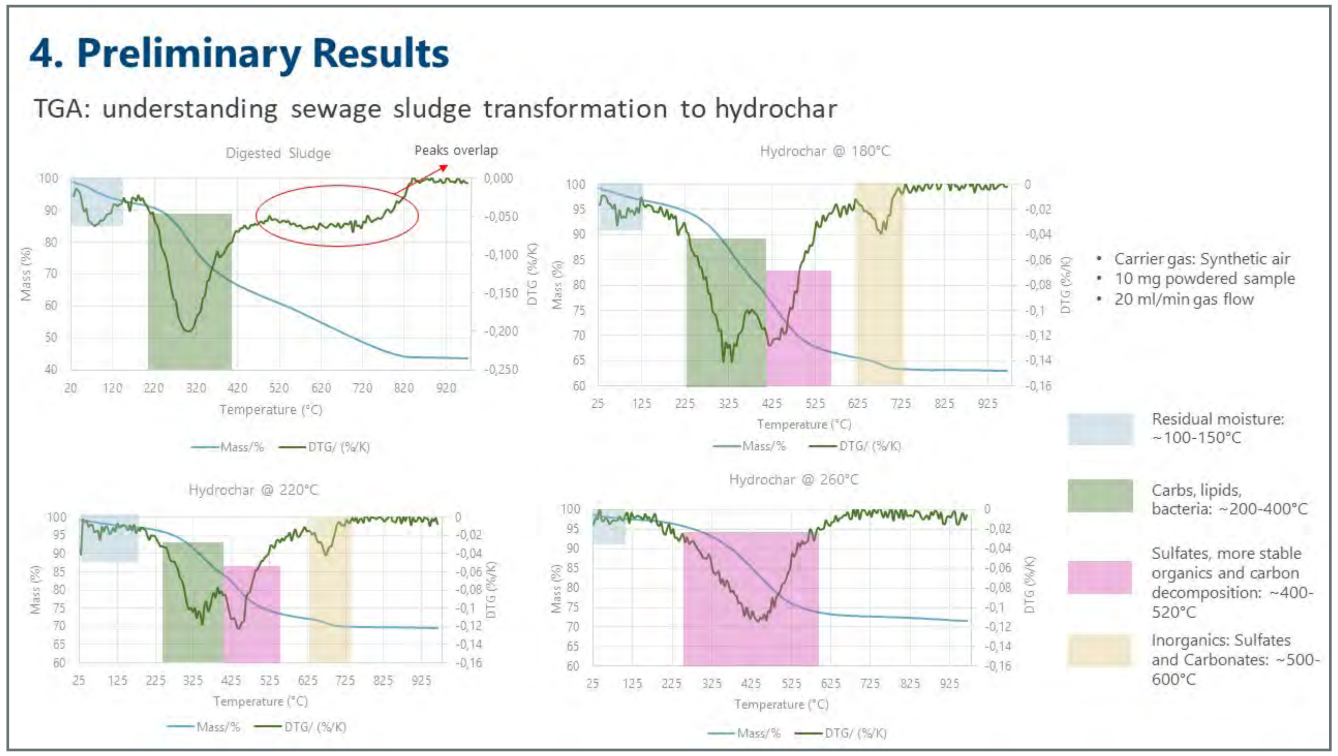
Analyses:

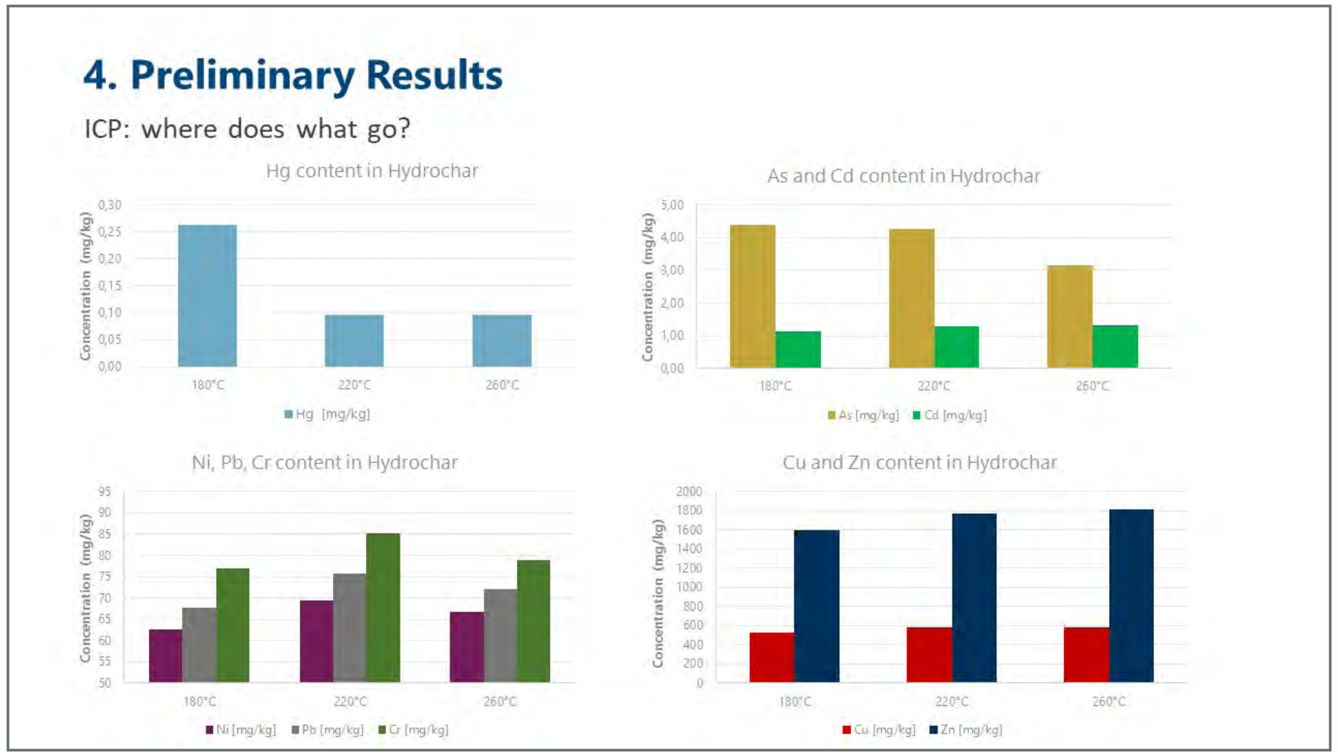
Solids:

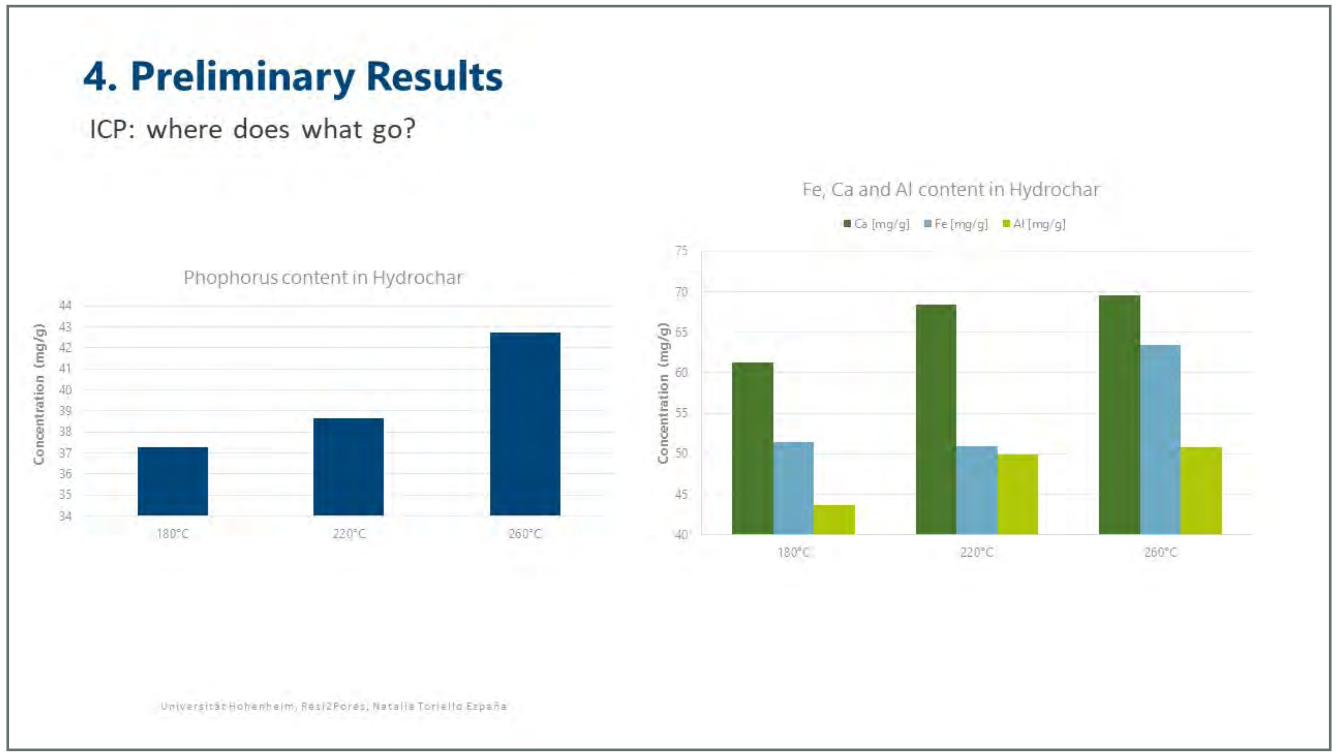
- Thermogravimetric analysis (TGA)
- Proxymate and elemental analysis
- Element content through ICP-OES

Liquids

- Ammonium
- Total carbon
- Orthophosphate
- Element content through ICP-OES







5. Outlook and future steps

Changes in hydrochar induced by acid leaching

Incorporating leached hydrochar in clay mixture and evaluate its performance

What properties does the mixture clay-hydrochar has?

Brick's performance: compressive strength, thermal conductivity, water absorption

Environmental impact of hydrochar use in fired clay bricks

Hydrochar's high heating value: Potential energy savings?

Heavy metal leaching assessment

Our Research Group

Konversions Technologien

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UNIVERSITÄT HOHENHEIM

THANK YOU FOR YOUR ATTENTION! QUESTIONS?

REFERENCES

Adazabra, Aaron N.; Viruthagiri, G. (2023): Effect of variegated biosolids incorporation on the technological properties of fired clay bricks using Taguchi method. In *Case Studies in Construction Materials* 19, e02314. DOI: 10.1016/j.cscm.2023.e02314.

Hedayati Marzbali, Mojtaba; Hakeem, Ibrahim Gbolahan; Ngo, Tien; Balu, Rajkamal; Jena, Manoj Kumar; Vuppaladadiyam, Arun et al. (2024): A critical review on emerging industrial applications of chars from thermal treatment of biosolids. In *Journal of environmental management* 369, p. 122341. DOI: 10.1016/j.jenvman.2024.122341.

Liu, Huan; Basar, Ibrahim Alper; Nzihou, Ange; Eskicioglu, Cigdem (2021): Hydrochar derived from municipal sludge through hydrothermal processing: A critical review on its formation, characterization, and valorization. In *Water research* 199, p. 117186. DOI: 10.1016/j.watres.2021.117186.

Wu, Kai; Hu, Yuan; Xu, Linglin; Zhang, Lintao; Zhang, Xiong; Su, Yufeng; Yang, Zhenghong (2022): Recycling of sewage sludge in clay-free thermal insulation brick: assessment of microstructure, performance, and environment impact. In *Environmental science and pollution research international* 29 (59), pp. 89184–89197. DOI: 10.1007/s11356-022-22003-1

Universität Hohenheim, Resi2Pores. Natalia Toriello España

Valerie Flaig, TH Köln – University of Applied Sciences

The need for sustainable biomass utilisation and CCU applications in a future defossilised carbon circular economy in Germany

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Keywords: biomass utilisation, CCU, EU-ETS, point sources, defossilisation

Introduction

With the intention to accomplish climate neutrality in Germany, a complete energy transformation is necessary to replace fossil fuels. However, scientists agree that a complete substitution of carbon-based energy sources and feedstocks is unfeasible. Therefore, as motivation for the research activities, the carbon requirements for a German climate-neutral scenario are depicted and compared to the carbon sources that are generally available here. In addition, the share of usable carbon sources in the future and the possible products of carbon capture and utilisation (CCU) will be discussed.

Approach

To evaluate the carbon required in a German climate-neutral scenario, different reports are considered. Hence, a middle, worst and best case for the carbon demand are derived. In respect of possible future carbon sources, political requirements and the sustainability and competition for the use of biomass are considered. Based on the estimated necessary carbon demand and the availability of regenerative carbon sources, an overall mass balance for a future defossilised carbon circular economy is devised, incorporating CCU for biogenic CO_2. Thus, potential CCU products and associated market demands are also examined.

Results and Outlook

The carbon mass balance indicates that defossilisation cannot rely solely on an enhanced biomass use. While maximising biogenic residues utilisation is crucial, expanded CCU processes from biogenic point sources are essential too. Here, it is favourable that some CCU products exhibit substantial demand. Unfortunately, a carbon gap remains bridgeable only by the energy-intensive Direct Air Capture (DAC) process.

The preliminary work shows the necessity of comprehensive implementation of CCU process chains linked to the energetic or material utilisation of biomass from point sources. However, industrial companies currently see no economic advantage in CCU processes for biogenic CO2 and political requirements do not incentivise such processes, impeding Germany's 2045 climate-neutrality goal. Therefore, further research activities will develop and compare CCU system solutions to identify economically and ecologically favourable scenarios, to promote the implementation of CCU for biogenic CO_2.

We are sorry, no slides avalailable

Nikolaus Manolikakes, Deutsches Biomasseforschungszentrum

Decarbonization of steel industry - Sustainable binders for iron ore agglomeration

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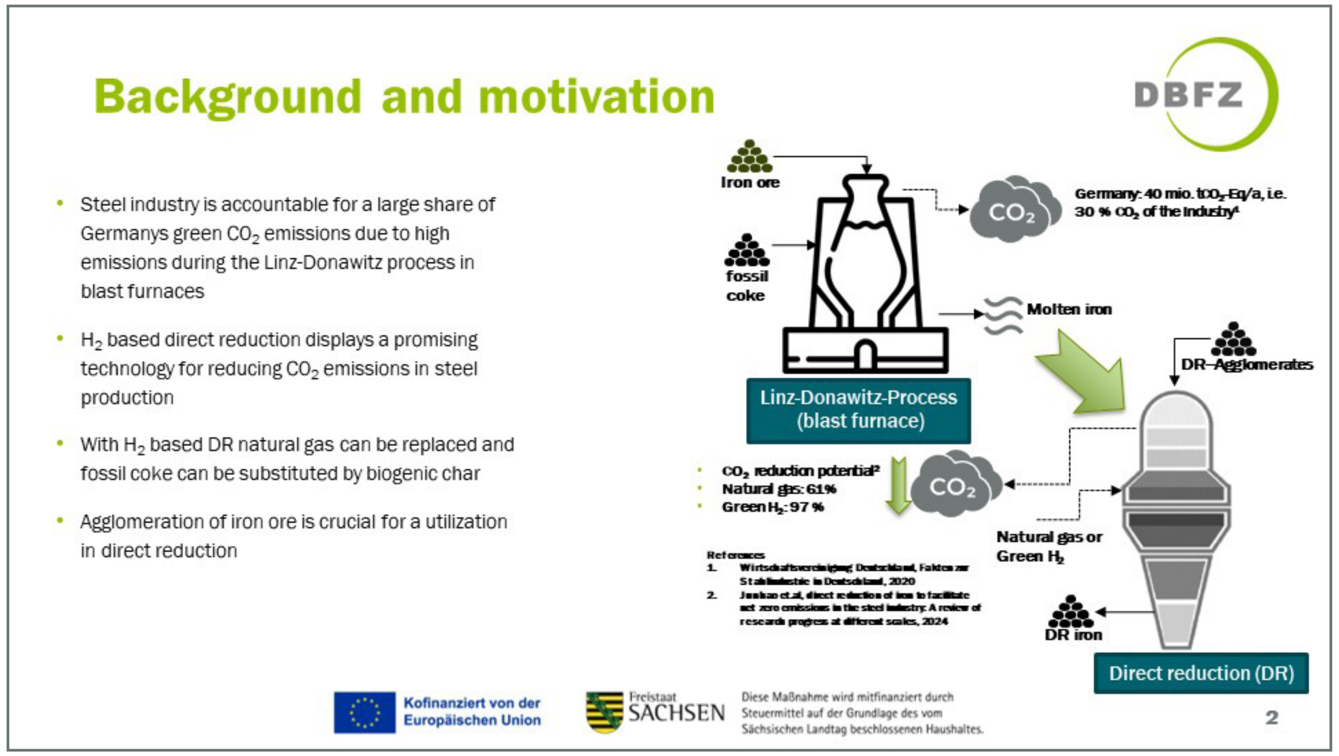
Keywords: Iron ore, Agglomeration, Organic binders

Introduction
Direct reduction (DR) of iron ore is a promising approach for decarbonization of the steel industry. To be suitable for the DR process iron ore has to be agglomerated. The most common method for agglomeration is in balling discs with the help of a wetting agent and binder. In these devices green agglomerates with minor mechanical properties are produced which are hardened afterwards for better handling. In iron ore agglomeration there are different ways of agglomerate growth and bonding mechanisms, highly dependent on the particle size and structure, wettability of the iron ore and on the machine settings and binders. The most common binder is bentonite, which has the downside of decreasing the yield of steel and increasing the amount of slag and CO_2 emissions. Organic binders have shown promising results in recent studies and could be a key factor in future iron ore agglomeration.

Approach
For investigating the suitability of organic binders, agglomeration experiments on a lab scale shall be conducted with the use of organic binders and bentonite as reference material. The results shall be assessed with established norms for iron ore agglomeration. For optimization of agglomeration behavior and green agglomerate strength, a special focus is on the pretreatment of materials to improve their wettability and moisture capacity. These two properties have a significant influence on promoting capillary forces and liquid bridges, which are the most important bonding mechanisms in balling agglomeration. To improve these properties there is the option of mechanical treatment by grinding and physical treatment with radiation. For better wettability the wetting agent can be modified with additives.

Outlook
Based on existing studies it is expected, that with increased wettability the strength of agglomerates will increase. At the same time, this improved wettability will cause the iron ore to absorb a larger amount of liquids, thus increasing the required amount of wetting agent. Hence the aim should be, to achieve a wettability which is sufficient for agglomeration, but prevents the iron ore from adsorbing too much wetting agent to ensure an efficient drying of agglomerates.



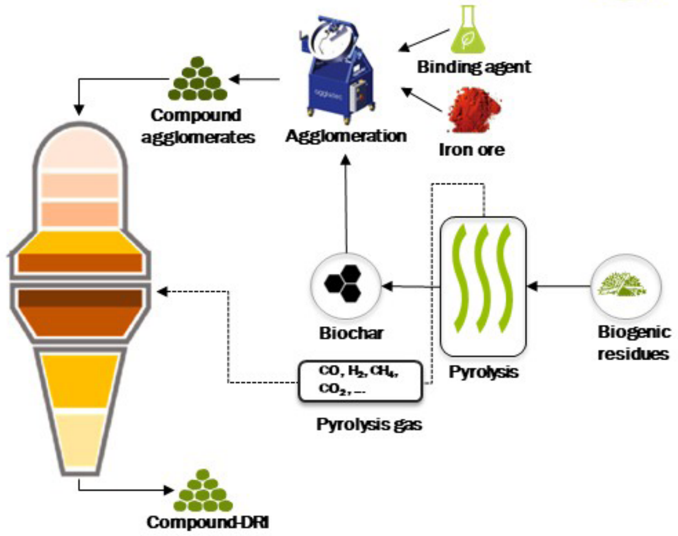
Background and motivation

DBFZ

Research focus project BioFe

- Investigation on suitability of biogenic residues for steel production
- Experiments for the production of iron ore / biochar compound agglomerates
- Experiments and modelling of the reduction process with pyrolysis gas and hydrogen
- Evaluation of the integration between pyrolysis and iron direct reduction process through process simulation
- Economical and ecological assessment

https://www.dbfz.de/biofe



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3

Theoretical background

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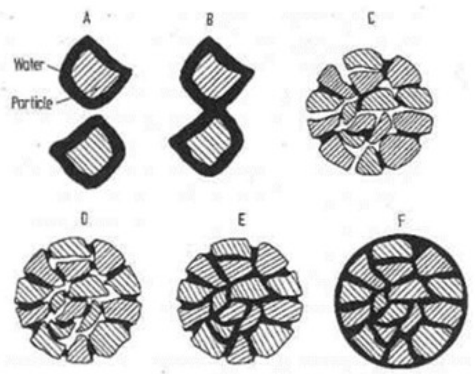
Agglomeration of iron ore

- Iron ore agglomeration is mostly done in balling discs
- A mixture of fine grained iron ore, biochar and binder is injected into these discs
- By rotation of the disc, contact between the particles is established and with the addition of wetting agent the particles start to stick together and to agglomerate
- When the agglomerates achieve a certain size they fall out of the disc and proceed to the next step
- Important properties and parameters in iron ore agglomeration are:
  - Wettability / moisture capacity
  - Particle size (distribution) and shape
  - Disc angle and rotation speed
  - Type and amount of binder



Meyer K. Pelletizing of iron ores. Berlin: Springer 1980

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4

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4

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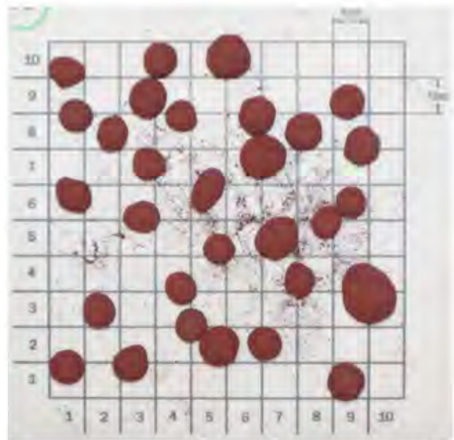

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4

Theoretical background

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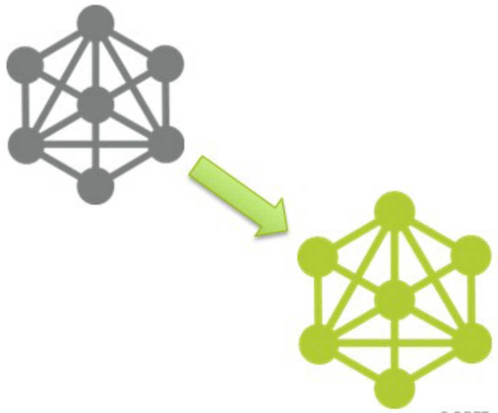
Binders in iron ore agglomeration

- Bentonite
  - Most commonly used binder in iron ore agglomeration (3.2 Mt/a)
  - Claystone, which swells when in comes in contact with water
  - Causes a lot of slag in steel production, thus consuming more energy and decreasing the yield of steel
- Organic binders
  - Examples: Starch, carboxy methyl cellulose, lignosulfonates, dextrin
  - Burn during induration, leaving no residues → Yield of steel is higher
  - In general weaker mechanical properties than bentonite



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5

Theoretical background

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Parameters in iron ore agglomeration

- Moisture content after agglomeration
- Drop number
  - Simulates agglomerates dropping from conveyor belts
  - No established norms
  - Agglomerates are dropped from cca. 0.5 m till they break or max. 10 times
  - Industry standard is ≥ 4
- Compressive strength
  - Simulates load on agglomerates during transport or in a reactor
  - Established norm (ISO 4700)
  - Measured with a UTM
  - Industry standard is ≥ 30 N for dry and ≥ 2 kN for indurated agglomerates
- Abrasion and tumble index
  - Gives information about the friability and estimated fines of agglomerates
  - Industry standard for tumble index 93 – 96 w.-% > 6.3 mm
  - Industry standard for abrasion index 5 w.-% < 0.5 mm

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6

Screening experiments

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Materials and Methods

- Different types of binders
  - Cold swelling starch (**CSS**)
  - Powdery lignosulfonate (**LS**)
  - Bentonite as reference material
- Different concentration of biochar
  - Grinded to a grain size <1mm
  - Added in concentrations of 10, 15 and 20 w.-%
- Machine settings
  - Constant rotation speed
  - Constant disc angle
  - Variation of spray and feed zone
- Drying at 105°C for 2h
- Indurating at 850°C for 1h dwell time + heating and cooling phase
- Assessing the drop numbers (wet, dry and indurated) and dried and indurated compressive strength

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Screening experiments

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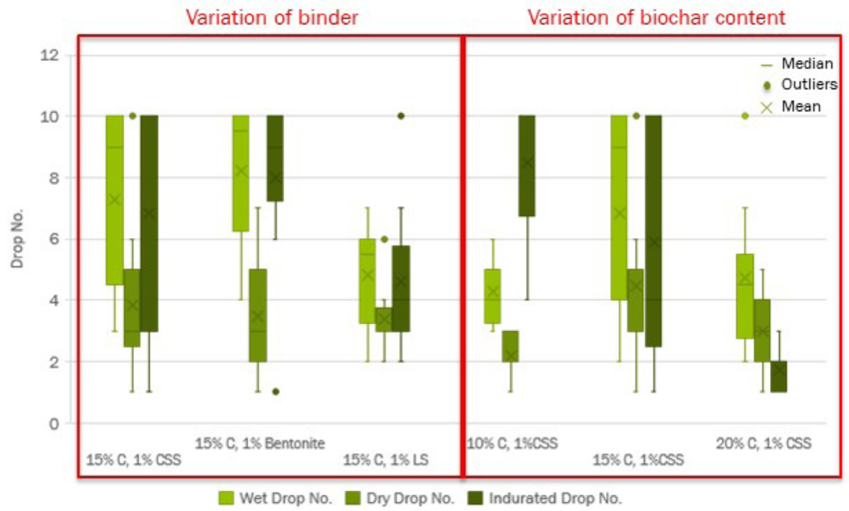
Results

- Moisture contents
  - Mixture before agglomeration ~10 w.-%
  - Wet moisture content 33 – 38 w.-%
- Drop numbers
  - Mostly sufficient in wet state, but insufficient in dried state
  - Increase with induration
  - Drop number decreases with increasing biochar content



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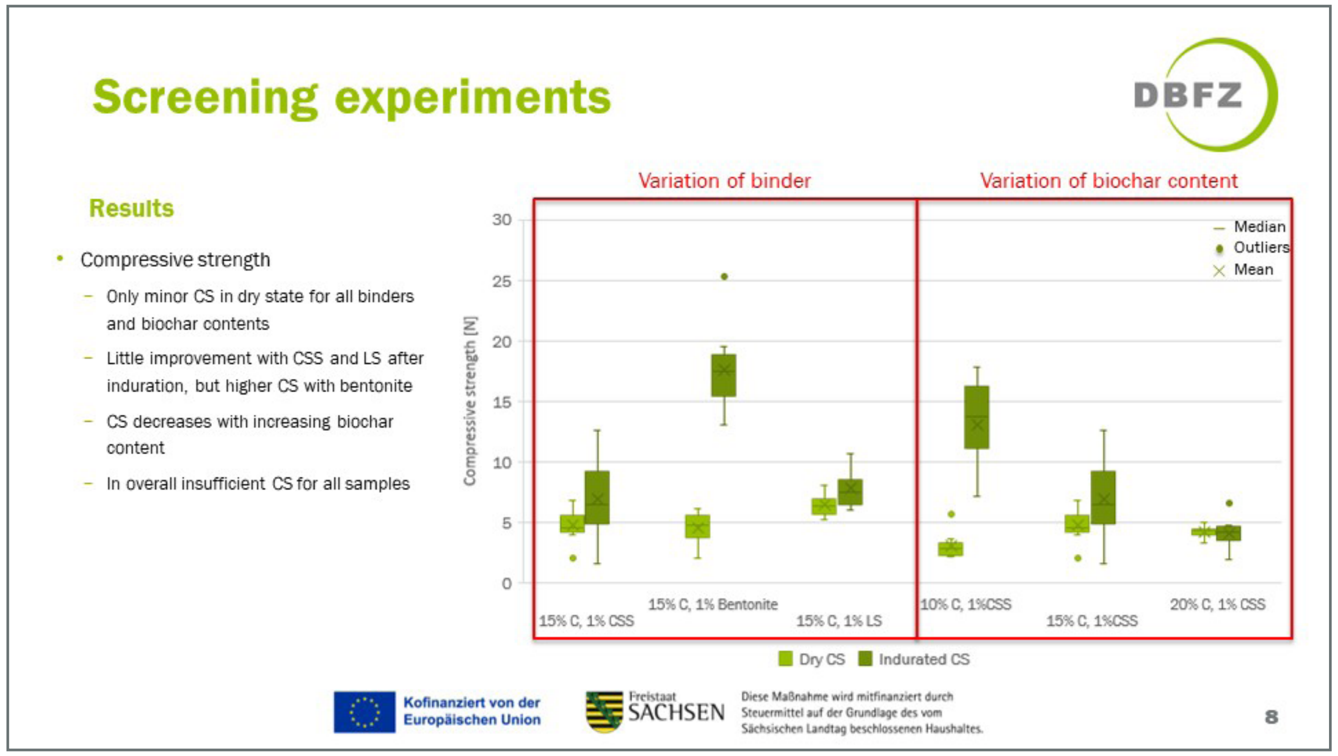
Screening experiments
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Results
Compressive strength
Only minor CS in dry state for all binders and biochar contents
Little improvement with CSS and LS after induration, but higher CS with bentonite
CS decreases with increasing biochar content
In overall insufficient CS for all samples
Variation of binder
Variation of biochar content
Compressive strength [N]
30
25
20
15
10
5
0
Median
Outliers
Mean
15% C, 1% CSS
15% C, 1% Bentonite
15% C, 1% LS
10% C, 1%CSS
15% C, 1%CSS
20% C, 1% CSS
Dry CS
Indurated CS
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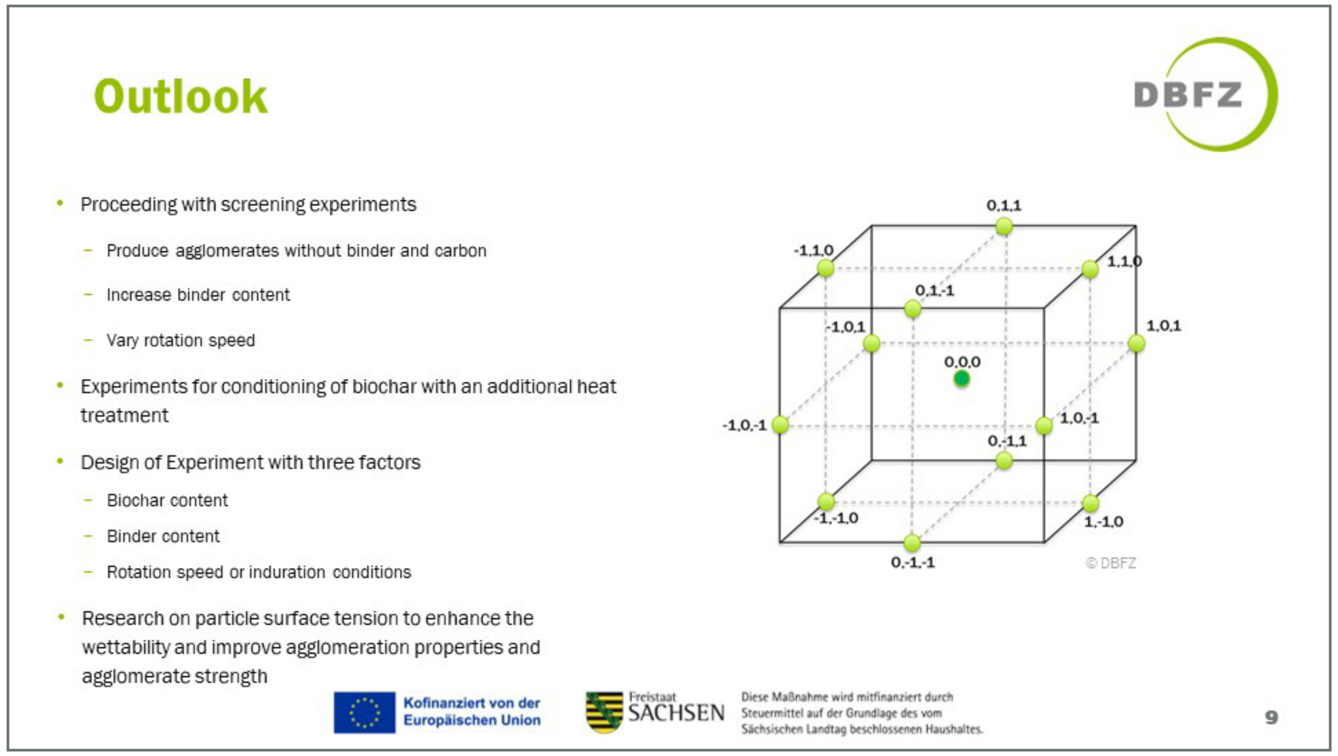
Outlook
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Proceeding with screening experiments
Produce agglomerates without binder and carbon
Increase binder content
Vary rotation speed
Experiments for conditioning of biochar with an additional heat treatment
Design of Experiment with three factors
Biochar content
Binder content
Rotation speed or induration conditions
Research on particle surface tension to enhance the wettability and improve agglomeration properties and agglomerate strength
0,1,1
-1,1,0
1,1,0
0,1,-1
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-1,0,-1
1,0,-1
0,-1,1
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1,-1,0
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9


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