BIOREFINERY CONCEPT OF THE ZITTAU/GÖRLITZ UNIVERSITY OF APPLIED SCIENCES

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Abstract

This article presents the circular-economy-based biorefinery concept developed by the "Biorefinery" research group at the Zittau/Görlitz University of Applied Sciences. The biorefinery concept aims the holistic utilization of plant raw materials and residues, in orders to exploit their entire value creation potential. The material or energetic utilization of all parts of the plants or plant residues results in significant economic and ecological advantages compared to conventional recycling methods and commonly accepted utilization concepts. The biorefinery process of our research group also envisages feeding products made of or containing natural fibers after their use to a novel recycling process using saprobionthic fungi. As a result of fungal recycling mycelium-based biocomposites are produced and provided for further applications, e.g. in the construction industry or as packaging material. In this way, carbon can be sequestered in the long term and CO_2 emissions can be avoided.

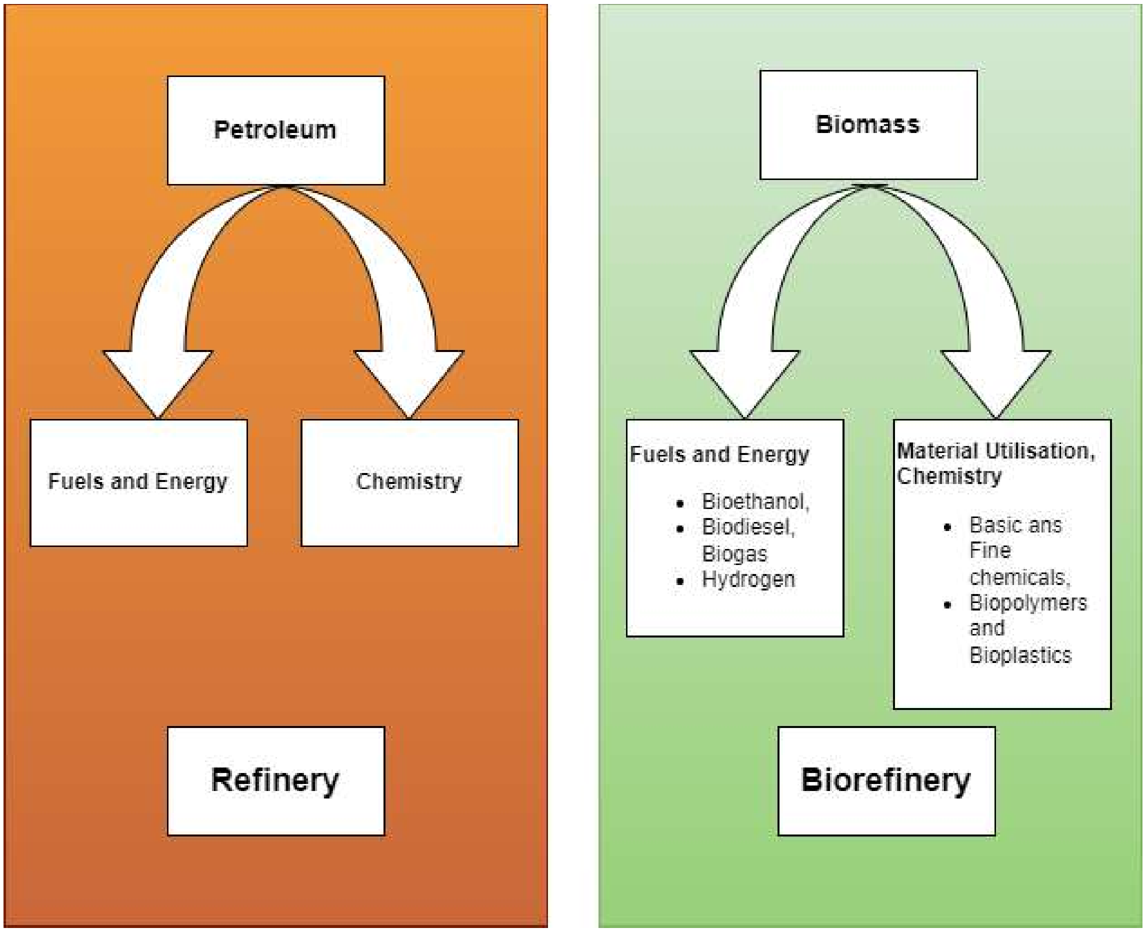
Keywords

Circular economy; Biorefinery; Emission reduction; Plant biomass; Value-added products.

Introduction

There is no single definition for biorefinery that is commonly accepted by scientists or other experts. In general, the term biorefinery stands for producing systems that combine different technologies and processes in order to convert biological raw materials into a range of different valuable intermediates and end products.

Some of the numerous definitions available in scientific (or non-scientific) publications are as follows: "Green biorefineries represent complex (to fully integrated) systems of sustainable, environmentally and resource-friendly technologies for the comprehensive (holistic) material and energetic utilization as well as exploitation of biological raw materials in form of green and residue biomass from a targeted sustainable regional and utilization." The American National Renewable Energy Laboratory published the following definition: "A biorefinery is a facility that integrates biomass conversion processes and equipment to produce fuels, power and chemicals from biomass. The biorefinery concept is analogues to today's petroleum refineries (Fig. 1) which produce multiple fuels and products from petroleum." [1]



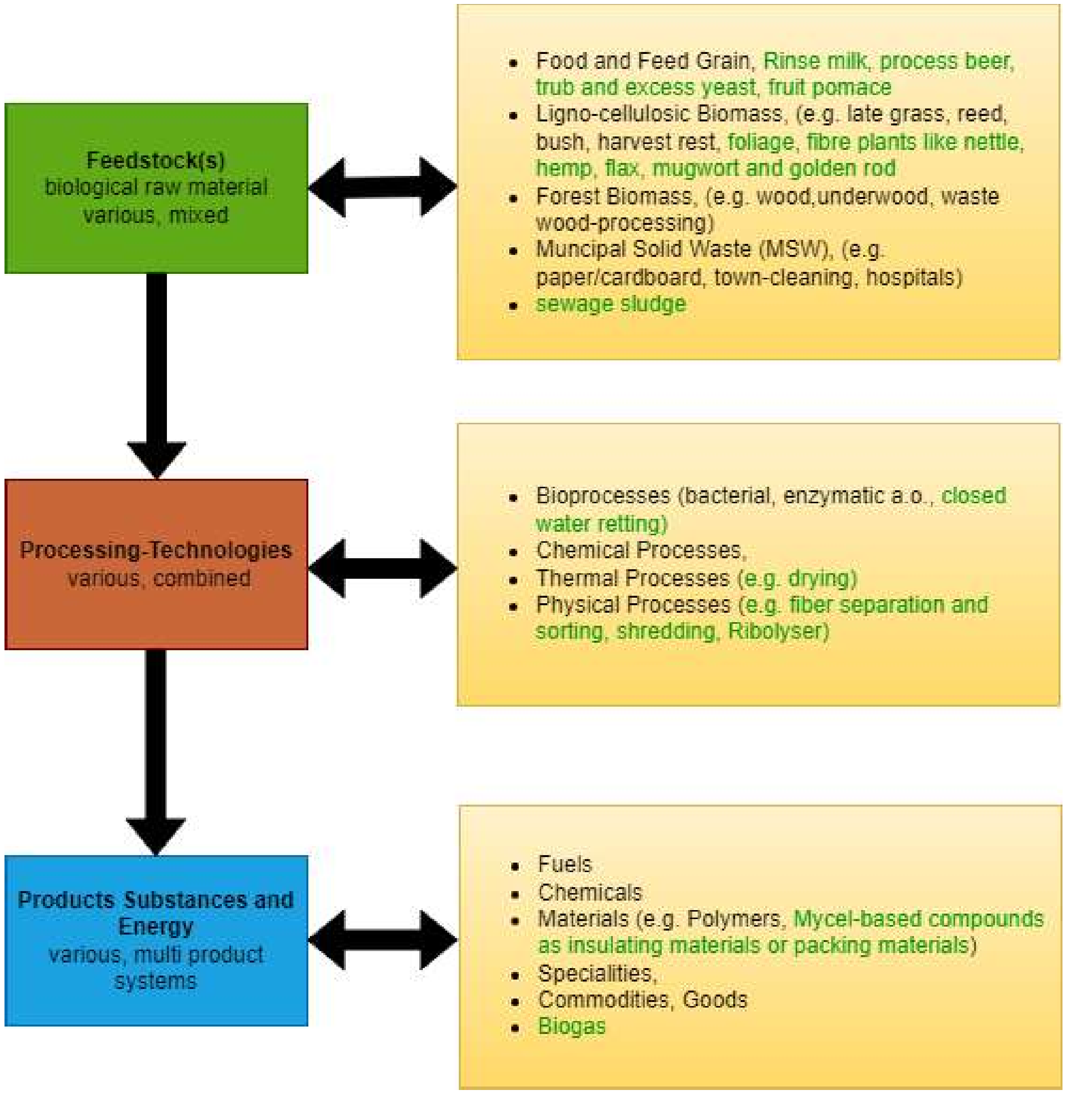
Source: [1]

Fig. 1: *Comparison of the basic-principles of the petroleum refinery and the biorefinery*

1 Research Subject

One thing that all definitions have in common is: "biorefineries start with a biomass-feedstock-mix to produce a multiplicity of most various products by a technologies-mix." [1] (Fig. 2)

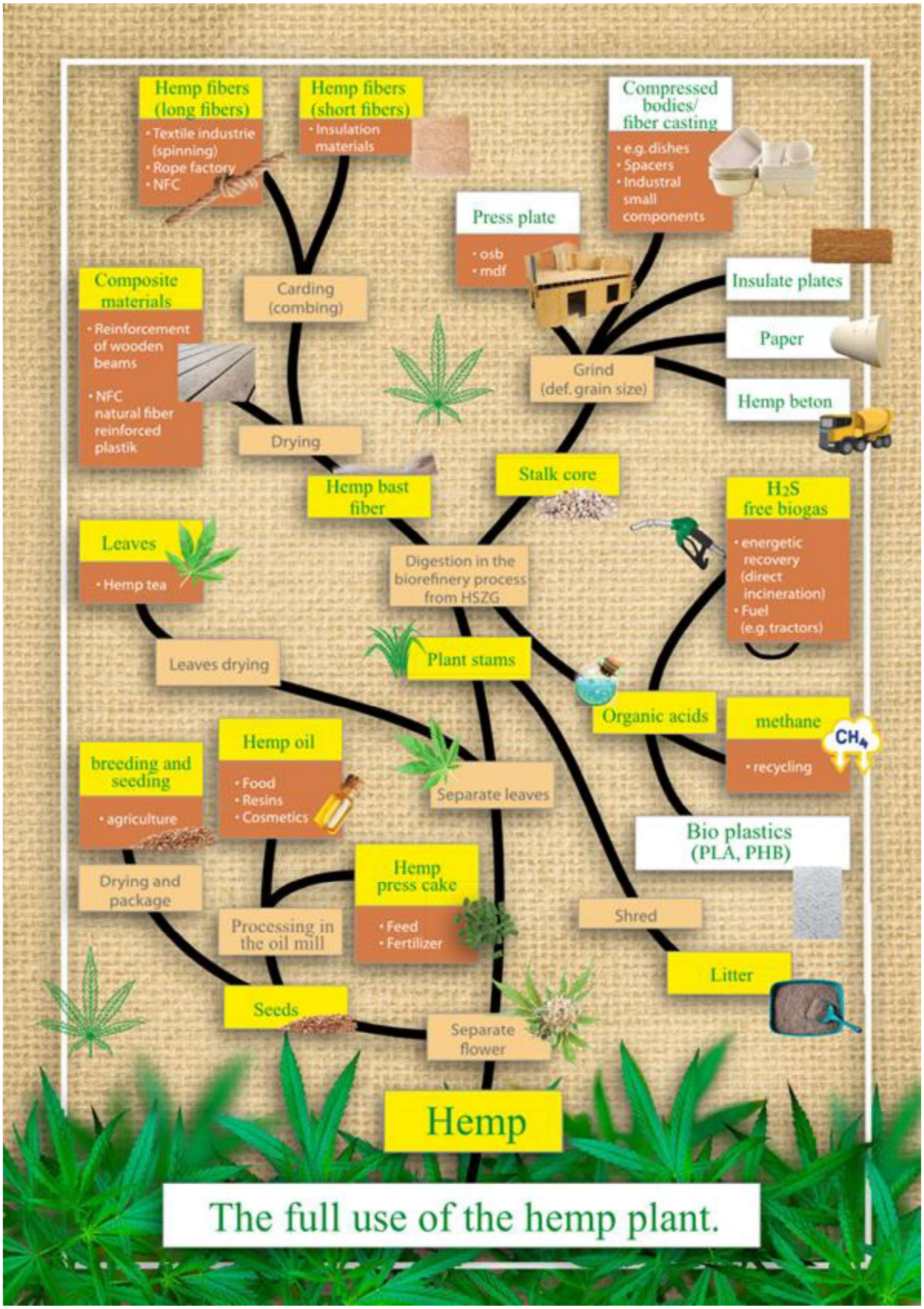
The idea of biorefineries serves as an essential basis for the work of our research group. We therefore deal with the development and implementation of sustainable concepts for the utilization of plant raw materials and plant-based residues under the premise that all components of the feedstock are used either materially or energetically. In this way, resources can be used efficiently and the value-added potential of the raw materials can be fully exploited. Our research activity has the focus on bringing value chains together to create economic cycles. (This is the basic idea behind circular economy through sector coupling.) Value chains can be assigned to completely different industrial sectors (agriculture, biotechnology, transport system, construction industry, food and non-food industry (Fig. 3)), though they are strongly depending on each other and are therefore tightly interconnected. In addition to closing value chains to economic cycles is one of our fundamental goals to open up new value creation paths (value chains) and to integrate them into existing economic cycles.



Source: Adopted from [1] and supplemented

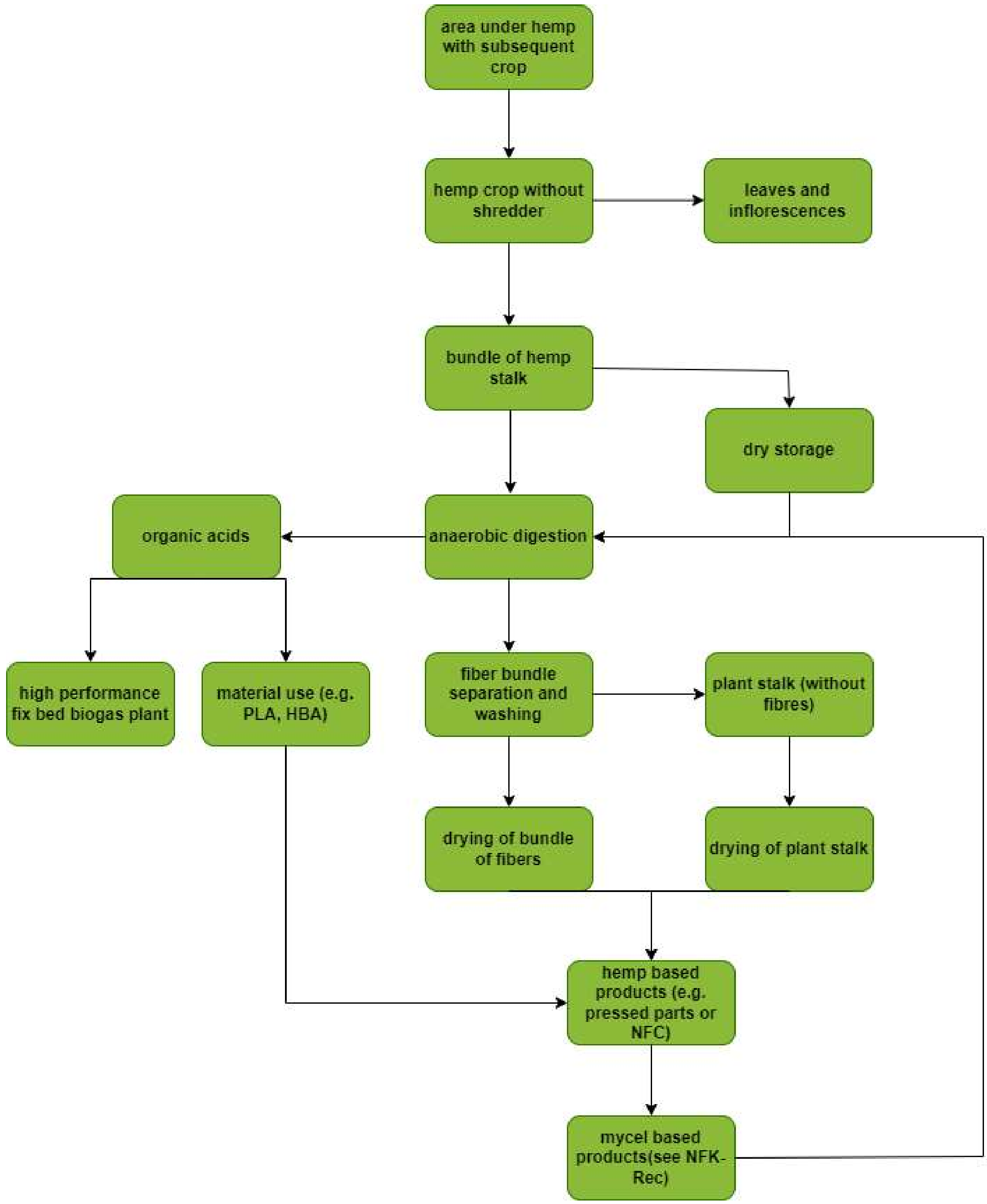
Fig. 2: *Basic principles of a biorefinery from biological feedstocks to substance and energy products, supplements with our substrates, processes and products from our process*

In order to cover/consider the entire life cycle of products made of or containing natural fibers, we also focus on recycling and the possibilities of subsequent uses. In this context, special attention is paid to extending the useful life (time for use and subsequent uses) of the products so that carbon can be sequestered for as long as possible. In this way, the recycling concepts we develop contribute significantly to sustainability and emission reduction.



Source: Adopted from Dr. H. Geilert and supplemented by Matthias Tirsch

Fig. 3: *Hemp plant and their use in various industries*



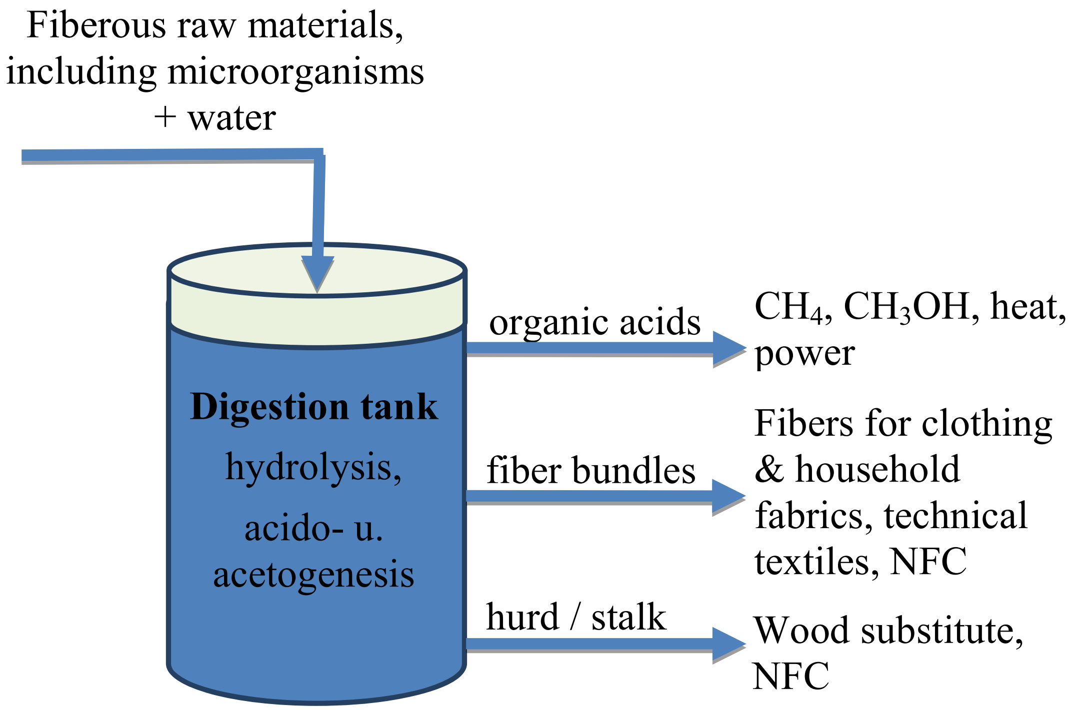
Source: Biorefinery team

Fig. 4: *Flow diagram of Biorefinery process at the Zittau/Görlitz University of Applied Sciences on an example of hemp*

In addition to the ecological aspect, our recycling concepts also offer economic advantages, which result partially from the fact that we work with regionally available raw materials that do not have to be transported over long distances. Especially in the field of natural fibers, cotton fibers – but meanwhile also hemp or flax fibers (or semi-finished natural-fiber-based products) – are imported from abroad, which is of course associated with considerable harmful impacts on the environment [2]. A further significant economic advantage of holistic utilization concepts results from the fact that a wide range of intermediate and end-products can be produced and provided for further processing while keeping the amount of waste (the fraction of raw materials that can be used neither materially nor energetically) at a level near to zero. Nothing is lost, nothing is thrown away – right in line with the principle of biorefineries!

Taking hemp as an example, the holistic utilization concept / biorefinery concept for plant raw materials/biomass can be presented in Fig. 4.

One of the key technologies for the processing of plant-based raw materials is the so called "water retting" which takes place under anaerobic conditions in a tightly closed tank (Fig. 5).



Source: Judit Harsányi.

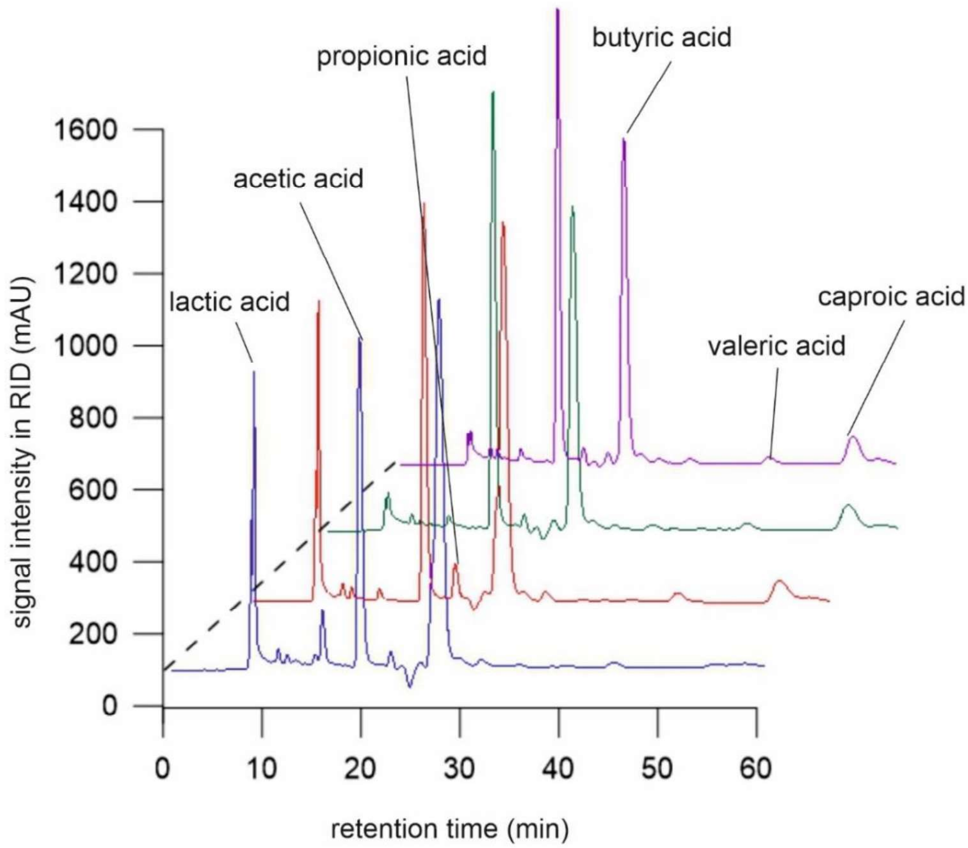
Fig. 5: *Water retting process optimized by the Biorefinery research group with the key product groups*

It is based on the metabolic activity of microorganisms (bacteria) and enables to clearly separate fibers from the woody core (hurd) of the stem of plants. The retting process was developed by our research group on the basis of the technique of traditional water retting (i.e. soaking the plants in either stagnant or moving water to release fibers due to the microbial degradation of glue-like substances like pectin) [3]. Conventional methods for fiber extraction at industry scale involve techniques where fibers (fiber bundles) are subjected to considerable mechanical stress, which consequently leads to reduced stability (tensile strength) and/or severe shortening of the fibers. In addition, fibers may contain shives and dust after mechanical extraction, that have to be removed in subsequent energy-consuming process steps to allow further processing of fibers [4]. In comparison with conventional extraction methods, the advanced technology of water retting developed by our research group provides fibers having no surface adhesions or other contamination due to dust and/or shives (Fig. 6).

Source: Erik Lautzus

Fig. 6: *Examples of hemp products after anaerobic digestion. As a result of water retting clearly separated fiber bundles without surface contamination and clean stalks (hurds) are obtained for further processing.*

Harmful impacts on environment – as they occur especially when applying traditional water retting – can be avoided, too. Water retting in a closed system like a tank allows controlling the retting process at all times. In contrast to this, the traditional retting technology that took place either on the field (field/dew retting) or in water bodies (water retting) is time-consuming and in addition to this, the effects of unpredictable environmental influences can neither be controlled nor avoided, which in turn can lead to reduced fiber qualities. Another particular advantage of water retting in a closed system is the fact that organic acids generated during degradation of organic material (pectin) by microorganisms – can be collected and used for further material or energetic recovery (Fig. 7). This considerably increases the overall economy of plant processing.



Source: Marzena Poraj-Kobielska

Fig. 7: *Example of chromatogram demonstrating composition of acids during anaerobic digestion of biomass (here in example of pineapple leaves) on day 3 (dark blue), day 5 (brown), day 8 (green) and day 9 (purple). At first are build lactic and acetic acid, then butyric acid and valeric and caproic acid in the second week of hydrolysis by elongation of chain from simple acids. [5].*

If required, mechanical techniques are also used for processing the raw materials, either alone or in combination with water retting as described previously. The aim of mechanical processing is either to pretreat raw materials for subsequent water retting or to extract fibers directly. Mechanical pretreatment techniques used in the processing of plant biomass include, for example, pressing between two rollers or carving the plant tissue. The aim of these techniques is to create a larger surface area for microorganisms to attack by opening up the harder tissue layers in which the fibers are embedded. In this way, the retting process can be intensified and a higher fiber yield can be achieved. The so-called ribolyser, see Fig. 8, is used to extract fibers mainly from grass stalks consisting of fine, soft and comparatively short fibers. During pretreatment with the ribolyser the plant tissue is destroyed by friction forces resulting from the sliding of grass stalks against each other. As a result of pretreatment with the ribolyser fibers are released from the plant tissue and are ready for further processing.

Source: Erik Lautzus

Fig. 8: *Ribolyser*

Ribolyser is applied exclusively when processing grass, i.e. plants with short, soft fibers. In the case of plants containing long fibers (e.g. flax or hemp) the ribolyser is not applied, since the fibers could be considerably damaged and/or shortened during mechanical disintegration with the machine. In addition to this, long fibers are likely to tangle more than short fibers, which can lead to damages on the machine or can make subsequent processing of fibers more difficult or even impossible.

The utilization concept presented in Fig. 6 can be transferred or adapted to other plants or plant derived biomass (e.g. residues from beer production) depending on the quality raw material. Thus, we are dealing with the utilization of many regionally growing plants such as flax, nettle, mugwort, palm lily and amaranth. In addition to indigenous plants, we develop concepts also for the holistic utilization of more exotic plants such as banana and pineapple. In the case of these plants, it is not the fruits but the leaf sheaths (banana) or the leaves (pineapple) that are suitable for versatile uses, e.g. as sources of fibers and energy. Both raw materials cause significant environmental and hygienic problems in the corresponding tropical growing regions due to insufficient disposal or utilization.

In order to develop an adequate utilization concept, raw materials are investigated in individual projects. Doing so, our research group is able also to address specific requests and R&D-ideas of regional enterprises. Due to the intensive cooperation with regional – but also with some national – companies, the work of our research group can be highly adapted to the needs and preferences of SME. Due to cooperations with SME we also have better chances to transfer innovations from the laboratory scale into practice.

Some selected biorefinery-projects are presented in the following sections.

2 Industrial Projects

2.1 Project Flachsgarn

Funded by the SME program ZIM of the AiF.

Duration: 1. 6. 2022 – 31. 5. 2024.

The main objective of the project Flachsgarn (= Flax Yarn) is the development of technologies for the emission-free production of goods/items on the basis of flax fibers with high gravimetric fineness. The results of the project will be available for the entire German textile industry.

Within the scope of the project, a novel technology for the gentile extraction of fibers from flax is developed, see Fig. 9. The technology is mainly based on water retting, that takes place in an airtight tank. The advanced technology of water retting and its application for fiber extraction was recently developed by the "Biorefinery" research group at Zittau/Görlitz University of Applied Sciences. Applying the novel water retting technology the fibers can be gently detached from the stalk and they are free of shives and surface-contaminants. Consequently, the fiber bundles obtained in this way are almost white and have an exceptionally fine structure. In contrast to conventional mechanical extraction techniques, no low-quality fibers are produced. The fiber bundles produced can be prepared for subsequent processing, e.g. by drying and cutting them to the desired length. Then, fibers can be processed to a yarn, which in turn can be used for the production of scrims or fabrics with a very high fineness. High degrees of fiber fineness are particularly interesting for textile applications.

Source: Erik Lautzus

Fig. 9: *Flax after anaerobic digestion. Flax stalk (left), flax fibers (in the middle), and flax yarn (right).*

In order to completely exploit the added value creation potential of flax, not only the fibers, but also the by-products generated during fiber processing are subject to investigations within the frame of the project. Thus, the following by-products are assumed to be suitable for further utilization: Stalks for the application as wood substitute (e.g. in paper production or as construction material), organic acids generated during the water retting process for material or energetic use, and seeds that can be used to produce linseed oil.

Participating project partners: Zittau/Görlitz University of Applied Sciences and Netzfabrik Kremmin GmbH.

2.2 Project Biostring

Funded by the SME program ZIM of the AiF.

Duration: 1. 6. 2022 – 31. 5. 2024.

The aim of the project "BioString" is the development of innovative biodegradable natural fiber containing granules for the production of natural fiber-reinforced composites (NFC) using injection molding.

Within the scope of the project fibers from goldenrod are used for the first time as reinforcement in polymer composites, see Fig. 10. 100-120 species belong to the genus goldenrod (*Solidago* sp.), most of which originate from North America. As being an extremely invasive species, Canadian Goldenrod (*Solidago canadiensis*) impacts biodiversity and native species in Europe seriously. Landscape management measures are necessary to stop uncontrolled spread of goldenrod. On the other hand, the plant is cultivated for versatile medicinal purposes.

Source: Photo on the left side: https://www.seven-morning.com/de/kanadische-goldrute.html; on the right side: Erik Lautzus

Fig. 10: *Picture of goldenrod (left), tensile test bars with goldenrod (right)*

Both landscape management measures and medicinal application allow no entire use of the plant. However, residual material can be used for fiber production. Thus, the aim of this project is the development of a technology – in accordance with industrial requirements – for the extraction and processing of fibers from goldenrod. In order to determine the optimal fiber-polymer-ratio, various biobased and biodegradable fiber-plastic-composites are produced and investigated regarding mechanical properties. Here it is of particular importance that the plastic content of NFC-granules (and NFC-products) is reduced to a minimum without affecting product quality. In this way – replacing synthetic plastic with natural fibers – sustainability of NFC production can be significantly enhanced. The fiber-polymer granules are foreseen to be processed with an innovative injection molding system that is to be equipped with a new type of metering unit to provide granules with optimum fiber-polymer-ratio.

Besides NFC-production the project considers also the end-of-life recycling of fiber containing composites. Thus, not only basic investigations on the biodegradability of NFC will be conducted, but also a specific marker will be developed. In contrast to state-of-the-art technologies the marker will allow waste sorting machines to detect and to separate NFC from other waste fractions effectively.

The overall objectives of the project BioString include enhanced sustainability, significant reduction of CO_2 emission and economic viability in the production of natural fiber reinforced composites by using injection molding technology. The efficient use of goldenrod as a valuable natural resource, e.g. by using its fibers for the production of NFC, is another key aspect of the project.

Participating project partners: Zittau/Görlitz University of Applied Sciences and Peiler & Klein Kunststofftechnik GmbH.

2.3 Project Green Fibers

Funded by the SME program ZIM of the AiF.

Duration: 1. 6. 2022 – 31. 5. 2024.

The aim of the project Green Fibers is the development of a new type of natural fiber composite (NFC) on the basis of fibers extracted from hemp by suing a specific and gentle fiber extraction technology (advanced water retting). Due to this novel extraction technology fibers with optimal fineness, length and good mechanical properties can be provided for the subsequent production of yarn, fabrics and NFC, see Fig. 11. The resulting natural fiber polymer composites are characterized by significantly higher tensile and tear strength and twice the bending stiffness of conventional natural fiber-reinforced plastics.

The innovations achieved in the project Green Fibers should contribute to the establishment of new applications for hemp and hemp-based composites, including the application as reinforcement fibers in cladding or structural elements. Thus, a large market may benefit from the results of this research project.

Source: Erik Lautzus

Fig. 11: *Exposed mesh structure of fibers*

Participating project partners: Zittau/Görlitz University of Applied Sciences, PRK GmbH Kunststoffverarbeitung, the German Institute for Textile and Fiber Research Denkendorf and Digel Sticktech GmbH und Co. KG.

2.4 Project NFK Rec

Funded by the SME program ZIM of the AiF.

Duration: 1. 5. 2022 – 30. 4. 2024.

Natural fiber composites are widely used in various industrial sectors. As a consequence of this, the amount of NFC-waste is steadily increasing. Thus, the recycling industry faces the challenge of finding environmentally friendly methods for the recycling of those materials.

The aim of the project NFK-Rec is the development of an ecologically viable technological concept – including the construction of necessary equipment – for the processing and recycling of NFC waste. The technology is based on the application of selected fungi. In a plant, which is similar to a trickle bed reactor, the previously shredded and sterilized NFC-parts undergo a fungal treatment. During that treatment the natural fiber content of NFCs is destroyed. The degradation of natural fibers is supported by a subsequent post-maturing process, where the decomposition of the natural fibers can be completed, see Fig. 12.

In addition to mycelium some of the fungi (e.g., shiitake, oyster mushroom, or king trumpet mushroom) that are foreseen for the application in NFC-recycling, can develop also edible fruiting bodies during the post-maturing process. These can be harvested and sold after appropriate testing for food safety.

Source: Erik Lautzus

Fig. 12: *Fungi growing on shreds of NFC parts. Pleurotus eryngii, Pycnoporus cinebareus and Letinus edodes (left picture), Irpex lacteus in mycoreactor developed and produced in this project (right picture)*

After a while, NFCs, are completely interwoven by the fungal mycelium and are ready for the next process step, i.e. anaerobic digestion in which the biologically degradable part of pretreated NFC is converted into organic acids by microorganisms (bacteria). The organic acids (e.g. acetic acid, lactic acid, etc.) can then be utilized either materially (e.g. for the production of bio-based plastics) or energetically (e.g. for the production of biogas). The plastic fraction left over from the fermentation process can be separated and used as additive in the construction industry, or alternatively it can be re-used for the production of plastic/NFC.

Participating project partners: Zittau/Görlitz University of Applied Sciences, TU Dresden, Weima GmbH and Schmidtberger Maschinenbau GmbH.

2.5 Project Mobile High-Performance Biogas Plant

Funded by the European Regional Development Fund (ERDF).

Duration: 1. 1. 2022 – 31. 12. 2022.

The aim of the project is the development of a compact high-performance biogas plant which – by means of novel fixed-bed fermenters – enables the decentralized and flexible production of biogas from different feedstocks. The biogas with a methane content of at least 70% can be produced in a significantly shorter process compared to conventional large scale biogas plants. Furthermore, investigations with regard to the biochemical conversion of combustion gas (exhausted by a combined heat and power plant) and electrochemically produced hydrogen (from renewable energy electricity surpluses) to methane. The synthesis of methane takes place in an innovatively designed high-performance fixed-bed gas digester in order to minimize the CO_2 emissions of the downstream CHP plant. In addition to the environmentally friendly production of high-quality biogas, also process wastewater is to be treated, e.g. by the recovery of minerals like phosphate. After recovery phosphate can be used for the production of natural fertilizers. The "salt-free" process wastewater thus achieves a quality that allows to discharge wastewater without any concerns into the public sewage system.

The measures presented here – the utilization of exhaust gas from incineration processes as well as the treatment of the process waste water – serve the environmentally viable completion/creation of material and energy cycles.

Participating project partners: Zittau/Görlitz University of Applied Sciences, Haase Tank GmbH, Gedes e.V., Covac GmbH, Rublic & Canzler GmbH.

Conclusion

The implementation of biorefineries, i.e. the basic idea for the generation of a mixture of products from natural resources, in economy is essential, in order to establish a sustainable life. Therefore, it is of fundamental importance to increasingly replace fossil-based products with biodegradable, nature-based products. This should be done wherever the technical requirements of the application can be fulfilled by the natural materials. Moreover, it is essential to use natural resources efficiently. On the one hand, this means that the raw materials (+ residues from agriculture and industry) must be completely utilized – either materially or energetically. On the other hand, the "useful" life of bio-based products should be significantly extended by processing and using them in subsequent applications. In this way, carbon can be sequestered in the long term and CO_2 emissions can be avoided. In order to put all this into practice as efficient as possible, cooperation with industrial partners is of particular importance.

The current and future projects of the research group "Biorefinery" are dedicated to exactly these goals.

Acknowledgements

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KONCEPT BIORAFINÉRIE OD VYSOKÉ ŠKOLY APLIKOVANÝCH VĚD V ŽITAVĚ/GÖRLITZ

Tento článek představuje koncept biorafinérie založený na cirkulárním hospodářství, který vyvinula výzkumná skupina „Biorafinérie“ na Vysoké škole aplikovaných věd v Žitavě/Görlitz. Cílem koncepce biorafinérií je komplexní využití rostlinných surovin a zbytků, aby se využil celý jejich potenciál pro tvorbu nových produktů. Materiálové nebo energetické využití všech částí rostlin nebo rostlinných zbytků vede k významným ekonomickým a ekologickým výhodám ve srovnání s běžnými metodami recyklace a běžně přijímanými koncepcemi využití. Proces biorafinace naší výzkumné skupiny rovněž předpokládá, že produkty vyrobené z přírodních vláken nebo obsahující přírodní vlákna budou po jejich použití podrobeny novému recyklačnímu procesu využívajícímu saprobiontní houby. Výsledkem houbové recyklace je výroba biokompozitů na bázi mycelia, které jsou určeny pro další použití, např. ve stavebnictví nebo jako obalový materiál. Tímto způsobem lze dlouhodobě zachycovat uhlík a zamezit emisím CO_2.

BIORAFFINATIONSKONZEPT ENTWICKELT AN DER HOCHSCHULE ZITTAU/GÖRLITZ

In diesem Artikel wird das von der Forschungsgruppe „Bioraffinerie“ der Hochschule Zittau/Görlitz entwickelte kreislauforientierte Bioraffineriekonzept vorgestellt. Das Bioraffineriekonzept sieht vor, pflanzliche Roh- und Reststoffe möglichst vollständig zu verwerten, sodass ihr gesamtes Wertschöpfungspotential ausgenutzt werden kann. Durch die stoffliche oder energetische Verwertung sämtlicher Komponenten der Pflanzen bzw. pflanzlicher Reststoffe werden ökonomische und ökologische Vorteile im Vergleich zu herkömmlichen Verwertungswegen erzielt. Das Bioraffinationsverfahren unserer Forschungsgruppe sieht weiterhin vor, naturbasierte Produkte nach ihrer Nutzung einem neuartigen Recyclingprozess mithilfe von saprobionthischen Pilzen zuzuführen, in dem myzel-basierte Biokomposite hergestellt und weiteren Verwendungen z.B. in der Bauindustrie oder als Verpackungsmaterial zugeführt werden. Auf diese Weise kann der Kohlenstoff langfristig gebunden und somit CO_2-Emission vermieden werden.

KONCEPCJA BIORAFINERII Z UNIWERSYTETU NAUK STOSOWANYCH W ZITTAU/GÖRLITZ

Niniejszy artykuł przedstawia koncepcję biorafinerii opartej na gospodarce o obiegu zamkniętym, opracowaną przez grupę badawczą „Biorafineria” na Uniwersytecie Nauk Stosowanych w Zittau/Görlitz. Celem koncepcji biorafinerii jest kompleksowe wykorzystanie surowców i resztek roślinnych w celu wykorzystania ich pełnego potencjału do tworzenia nowych produktów. Odzysk materiałów lub energii ze wszystkich części roślin lub resztek roślinnych prowadzi do znacznych korzyści ekonomicznych i ekologicznych w porównaniu z konwencjonalnymi metodami recyklingu i powszechnie akceptowanymi koncepcjami odzysku. Opracowany przez naszą grupę badawczą proces biorafinacji przewiduje również, że produkty wykonane z włókien naturalnych lub je zawierające będą po zużyciu poddawane nowemu procesowi recyklingu z wykorzystaniem grzybów saprobiontowych. Efektem recyklingu grzybów jest produkcja biokompozytów na bazie grzybni, które są przeznaczone do dalszego wykorzystania, np. w budownictwie lub jako materiał opakowaniowy. W ten sposób długoterminowo można wychwytywać węgiel i ograniczyć emisje CO_2.