Green biorefinery and biotechnological work at Wood KPLUS

(Biorefinery linking agriculture/forestry and chemical industry)

BIRGIT KAMM

Wood Kplus, Area Wood Chemistry and Biotechnology, Linz, Österreich and BTU Cottbus-Senftenberg, Deutschland
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2.1 Biotechnology
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* RR- Renewable resources
1. Objectives
1.1 Use of biomass (RR=renewable resources)

- 13% or 2.7 million tons RR used in German chemical industry, mostly for the production of specialty chemicals.

- Until 2030, German chemical companies will use 50% more renewable resources for their processes.

- In Europe, a 10.4 billion EUR specialty chemicals market volume is expected (until 2030).

- Activities in the field of biomass use in Austria on various industrial areas like Upper Austria, Lower Austria, Steiermark, Kärnten

The Chemical Industry 2030
[https://www.vci.de/vci/downloads-vci/2012-12-10-vci-prognos-study-chemistry-2030-short-version.pdf]
1.2 Specialty chemicals

Specialty chemicals are the base for the production of relatively high priced derivatives, like
(1) Engineering Polymers (specialty plastics)
(2) Consumer chemicals (washing, cleaning and personal care products, fragrances etc.)
(3) Paints and coatings
(4) Plant production agents (insecticides, fungicides, nematicides, acaricides, etc.)
(5) Fuel additives

Example: German chemical industry, year 2011
• 43% of the chemicals production
• Market volume 67 bn. Euro
• 12% of the world volume of 567 bn. Euro

The Chemical Industry 2030
[https://www.vci.de/vci/downloads-vci/2012-12-10-vci-prognos-study-chemistry-2030-short-version.pdf]
1. Biorefinery principles

**LCF-BIOREFINERY**

- **Lignocellulosic Feedstock (LCF)**
  - Sugar Raw material
  - Cogeneration (CHP) Heat and Power
- **Cellulose**
  - 'biotech./chemical'
- **Hemicellulose**
  - 'biotech./chemical'
- **Lignin**
  - 'chemical'
- **Fuels, Chemicals, Polymers and Materials**
- **Residues**

**WHOLE CROP-BIOREFINERY**

- **Whole Crop Cereals - Dry Mill -**
  - Flour (Meal)
    - 'physical/chemical'
- **Grain**
  - 'biotechn./chemical'
- **Starch line, Sugar Raw material**
- **Residues**
- **Cogeneration (CHP) Heat and Power**

**GREEN BIOREFINERY**

- **Green Biomass**
  - Techn. Press
- **Press Juice**
  - 'biochemical'
  - 'biotechnol./physical'
- **Proteins, Soluble Sugars**
- **Residues**
- **Biogas, Cogeneration (CHP) Heat and Power**
- **Feed, Fuels, Chemicals, Polymers and Materials**

**TWO-PLATFORM-CONCEPT**

- **Biomass**
  - Cogeneration (CHP) Heat and Power
- **Clean Gas**
- **SynGas Platform**
  - 'gasification'
  - 'thermal chemical'
- **Fuels, Chemicals, Polymers and Materials**
- **Sugar Raw material**
- **Residues**
- **conditioning Gas**
1.4 Biobased platform chemicals and derived specialty chemicals

Biobased specialty chemicals 1.5 Market assessment (selection)

<table>
<thead>
<tr>
<th>Nr.</th>
<th>DOE’s TOP 15</th>
<th>Source</th>
<th>Derivatives</th>
<th>Use and products</th>
<th>Marketable bio-based products</th>
<th>Note*</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>1</td>
<td>Succinic acid</td>
<td>Fermentation from glucose</td>
<td>1,4-Butanediol, tetrahydrofuran, γ-butyrolactone, maleic acid anhydride, pyrrolidone</td>
<td>Solvents, polyester, polyurethane, nylon, paints, food additives</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>2</td>
<td>Fumaric acid</td>
<td>Fermentation from glucose</td>
<td>Same as succinic acid</td>
<td>Same as succinic acid</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>3</td>
<td>Malic acid</td>
<td>Enzymatic hydroxylation of fumaric acid by fumarate hydratase</td>
<td>Same as succinic acid</td>
<td>Same as succinic acid</td>
<td>Yes</td>
<td>Yes</td>
</tr>
<tr>
<td>4</td>
<td>2,5-Furan dicarboxylic acid</td>
<td>Oxidation of 5-hydroxymethylfurfural</td>
<td>2,5-Bishydroxymethylfuran, 2,5-Bis(aminomethyl)-Tetrahydrofuran</td>
<td>Polyamide, Polyester z.B. Substitution der Terephthalsäure im PET</td>
<td>Demonstration is planned</td>
<td>Yes</td>
</tr>
</tbody>
</table>

*A – Beginning of commercialization, B - significant activities [CEN. ACS. Org. 10, 2014]
### Biobased specialty chemicals – 1.5 Market assessment (selection)

<table>
<thead>
<tr>
<th></th>
<th>Product</th>
<th>Production Method</th>
<th>End Uses</th>
<th>Available in Europe</th>
<th>Available in US</th>
<th>Literature</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>3-Hydroxy propionic acid</td>
<td>Fermentation from glucose or glycerin</td>
<td>1,3-propanediol, acrylic acid, acrylamide, methyl acrylate, Polytrimethylene terephthalate, highly resistant carpet fibers, contact lenses</td>
<td>No</td>
<td>Yes</td>
<td>[CEN. ACS. Org. 10, 2014]</td>
</tr>
<tr>
<td>6</td>
<td>Glycerin</td>
<td>Chemical or enzymatic transesterification of vegetable oils</td>
<td>Propylene glycol, ethylene glycol, 1,3-propanediol, lactic acid, epichlorohydrin, acrolein, Polyester, soaps and cosmetics, antifreeze agents</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
</tr>
<tr>
<td>7</td>
<td>Sorbitol</td>
<td>Hydrogenation of glucose</td>
<td>Isosorbide, Flame protection agents, pharmaceuticals, biobased softeners (Polysorb® ID 37), polymers</td>
<td>Yes</td>
<td>Yes</td>
<td></td>
</tr>
</tbody>
</table>

Biobased specialty chemicals

Starting position in different regions like Germany, Austria
Alignment of the value added chain

- Agriculture
- Forestry
- Paper industry
- Food industry

Biomass and organic wastes as raw materials

Precursor 1
Precursor 2
Precursor 3

Specialty chemical A
Specialty chemical B
Specialty chemical Y
Specialty chemical Z

Specialty chemicals

Customer
Customer
Customer

[Based on BASF-lecture in the frame Masterplan, cluster pastics, chemicals HF specialty chemicals]
Biobased specialty chemicals

Current processing potential of bio-based raw materials

[Fig. from BASF-lecture in the frame Masterplan, cluster pastics, chemicals HF specialty chemicals]
Biobased specialty chemicals by biorefining

Raw material

Pretreatment/conditioning & component separation

Platform

Conversion/finishing

Conversion/finishing

Product – energy

Product – materials

Sideproduct Food/Feed

Raw material

Platform

Product

Primary refining

Secondary refining

[Roadmap Biorefineries, 2012, FNR e.V.]
New biobased specialty chemicals by biorefining

Example: Potential Analysis State of Brandenburg (Germany), 2015
2. From Fundamentals to Implementations

Lab Space: 2.500 m² / Office Space: 1400m² / 115 Employees / > 200 Projects
Wood Chemistry & Biotechnology

Alternative feedstocks & decomposition processes

Chemical Process technology for biomass utilisation

Value added Products from Biomass

Bioprocess Technology
Wood Kplus can contribute along the whole process chain (some examples)

- Steam Explosion, Refiner, Thermal etc.
- Inhibitor Screening and Detoxification
- Biomass decomposition (Hydrolysis)
- Strain selection, fermentation and optimisation
- Polymer formulation………..
2.1. Extremophiles as New Process Building Block

• Industrially relevant properties
• Combinations possible (e.g. alkalihalophile)

<table>
<thead>
<tr>
<th>Type</th>
<th>Range</th>
</tr>
</thead>
<tbody>
<tr>
<td>Thermophile</td>
<td>T = 60-80°C (max. 113 °C)</td>
</tr>
<tr>
<td>Psychrophile</td>
<td>T &lt; 15°C (min. -18°C)</td>
</tr>
<tr>
<td>Acidophile</td>
<td>pH&lt; 5 (min. pH=0)</td>
</tr>
<tr>
<td>Alkaliphile</td>
<td>pH&gt;9 (max. pH=11)</td>
</tr>
<tr>
<td>Halophile</td>
<td>Salt &gt;3,5% (max. 35%)</td>
</tr>
</tbody>
</table>
Product fermentation with extremophiles
Example – PHA fermentation

• PHA an intracellular biopolymer

• Benefits using Halophiles:
  – Non sterile process
  – Easy cell lysis (osmotic pressure)
  – Conversion of C5 and C6
  – Conversion of polysaccharides possible
Lactic acid and its industrial applications

Food
- Preservative
- Flavour
- Acidulant
- Acid mineral fortification

Pharmacy
- Chiral intermediates
- Pharmaceuticals
- Dialysis solutions
- Parenteral solutions

Chemistry
- Agro-chemicals
- Green solvents
- Cleaning agents
- Bioplastic

2-hydroxypropionic acid

Polymerisation

Polylactic acid
Biochemical conversion of lignocellulose to D-Lactic acid

Lignocellulosic raw material

Waste products from paper industry

Sulfite spent liquor

D-Lactic acid

- GMO E.coli
- GMO Yeasts
- LAB
- Natural
- GMO

Cellulose

Hemicellulose (Xylan)

Enzyme production

Microbe enrichment

Pretreatment

Saccharification

Fermentation

- Biological
- Physico-chemical
  - Steamexplosion
- Chemical
  - LX-Process

- Cellulase mixture
  - Celluclast
  - Cellic CTEc2
2.2 The Pulp Mill Biorefinery

Lignocellulosic feedstock

SSL (organic load) → Processing → Cellulose → value-adding products

Refining → By-products

→ Biofuels, Organic acids, High value products

SSL = spent sulphite liquor

→ Energy generation
→ Back into process
→ Clarification plant
Example: A Medium-Sized Pulp Mill Converting 800,000t Beech Wood

Composition of beech wood
H. Sixta (1986) Lenzinger Berichte 61, 5-11

Theoretical yield
- 200,000t lignin
- 304,000t cellulose
- 274,000t hemicell.
- 18,400t extractives
Biorefinery Potential

→ **cellulose** sells as pulp, paper, fibres or derivatives

→ **lignin** sufficient to provide energy for pulping process

→ **hemicellulose** needs to sell at a higher price than 0.104€/kg

(based on today’s oil price - not including CAPEX/OPEX)

<table>
<thead>
<tr>
<th>Target Product</th>
<th>Selling Price Estimate €/kg</th>
<th>dated from</th>
</tr>
</thead>
<tbody>
<tr>
<td>EtOH</td>
<td>0.50</td>
<td>2015</td>
</tr>
<tr>
<td>BuOH</td>
<td>1.89</td>
<td>2015</td>
</tr>
<tr>
<td>PHB</td>
<td>6.50</td>
<td>2015</td>
</tr>
</tbody>
</table>

**Ex. EtOH:**
Fermentable hemis in SSL: 120,000 tons
yield factor estd. 0.32g/g

→ earnings minus heating value: **6.5 Mio €**

Selection of possible value chains to be realized at wood KPLUS

- Development of Wood-PLA compounds (or other biobased polymers) with improved thermo-mechanical properties and of related high performance products (e.g. 3D-printing)
- **Production of high value lignins → product development** (e.g. lignin based carbon fibers, respective composites, aerogels, carbogels)
- Development of fully biobased fiber composite materials
- Development of system solutions (e.g. compostable dishes or insecticide releasing carriers for forestry and agriculture)
2.3 Novel Materials from Byproducts: e.g. Lignin Aerogels

SEM-Pictures of the pore structure of different aerogels. (A) 8 %, (B) 13.4 % and (C) 20.7% Lignin-Formaldehyd [wt% in H$_2$O].
(Zoom 10.000-times)…..(B) BET specific surface: 200 qm/g
Reputation, Biorefinery activities

- Editor of the „biorefinery“ book series
  Biorefineries – Industrial Processes and Products
  (Wiley-VCH)

- Author in Ullmann’s Encyclopaedia Industrial Chemistry (Wiley-VCH)

- Member of the Advisory Board
  CLEAN-Soil, Air, Water (Wiley-VCH)
  CHEMSUSCHEM (WILEY-VCH)
  Biofuels, Bioproducts and Biorefining
  (Wiley & Sons, Society of Chemical Industry)
Topics covered include: new metabolic pathways of microbes living on green plants and in silage; using lignocellulosic hydrolysates for the production of polyhydroxyalkanoates; fungi such as Penicillium as host for the production of heterologous proteins and enzymes; bioconversion of sugar hydrolysates into lipids; production of succinic acid, lactones, lactic acid and organic lactates using different bacteria species; cellulose hydrolyzing bacteria in the production of biogas from plant biomass; and isoprenoid compounds in engineered microbes.
Invitation

Student Camp Biorefineries and Biobased Industrial Products
25. - 28. February 2019

Venue: Linz and Lenzing (Austria)
THANK YOU FOR INVITATION.
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