The role of biorefineries in making the transition towards the bioeconomy

presented by:

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The role of biorefineries in making the transition towards the bioeconomy

Biorefining is the transfer of the efficiency and logic of fossil-based chemistry and substantial converting industry as well as the production of energy onto the biomass industry.

It is absolutely necessary to develop solutions in three sustainable and biobased sectors:

- Biopower/Bioenergy (electricity and heat)
- Biofuels (transportation fuels)
- Biobased Products (chemicals/materials) in context of a biobased economy.

3-pillar model of a future biobased economy

European Commission (2012), Innovating for Sustainable Growth: A Bioeconomy for Europe, SWD 11 final, Brussels

Biobased industrial products can only compete with petro-chemically based products if the raw materials are optimally exploited and a variety of value-creating chains are developed and established.
→ development of substance-converting basic product systems and multi product systems, especially biorefineries.
Biorefineries combine necessary technologies between biological raw materials and the industrial intermediates and final products.

After providing code-defined basic substances (via fractionation) it is necessary to develop industrially relevant Product Family Trees.

Currently four Biorefinery Systems are forced within research, development and practice:

- **The Whole Crop Biorefinery (WC-BR)**
  raw material: cereals, maize etc..

- **The Green Biorefinery (G-BR)**
  raw material: ‘nature-wet’ biomasses, green grass, lucerne, clover, immature cereals a.o..

- **The Lignocellulose Feedstock Biorefinery (LCF-BR)**
  raw material: ‘nature-dry’ biomasses, wood, straw, corn stover, cellulose-containing biomass and waste.

- **The Two-Platform Concept**
  production of syngas and/or sugar as platforms for biobased products and fuels.
Sugar Platform
'SynGas Platform'
'gasification'
'thermal chemical'
Fuels,
Chemicals,
Polymers and
Materials
conditioning 
Gas
Cogeneration
( CHP )
Heat and Power
Residues
Clean Gas
Sugar 
Raw material
Biomass

Grain
'biotechn./chemical'
'physical/chemical'
Fuels,
Chemicals,
Polymers and 
Materials
Lignocellulosic
Raw material

Hemicellulose
'biotech./chemical'
Fuels, 
Chemicals,
Polymers and
Materials

Cellulose
'biotech./chemical'
Fuels,
Chemicals,
Polymers and 
Materials

Press Juice
'biochemical'
'biotechnol./physical'

Feed, Fuels, 
Chemicals,
Polymers and 
Materials

Press Cake
'hydrothermal'
'enzymatic'
' thermal chemical'

Proteins, 
Soluble  Sugars

Cellulose
'biotech./chemical'
Fuels,
Chemicals,
Polymers and
Materials

Lignin
'chemical'
Fuels, 
Chemicals,
Polymers and
Materials

Lignocellulosic Feedstock 
(LCF)

Biomass

The Two-Platform Concept

Integrated Biorefinery - Technical Objectives & Future Solicitations

Existing Starch Based Biorefineries: Wet & Dry Mills

- 2000
  - Increase ethanol production by access to residual starch & increased protein in co-products

- 2005
  - Fractionation of the feedstock to access the high value products prior to ethanol production

- 2010
  - Fractionation of residues in Dry Mills for new co-products from lignin

- 2020
  - Integrated Industrial Biorefinery: multiple feedstocks fractionated to high value products for economics and fuel production drive scale

Planed solicitation

Completed solicitation

Fractionation of grain and residues, introduction of energy crops in dry mills

Existing biorefineries, Phase I, (Selection)

<table>
<thead>
<tr>
<th>Plants</th>
<th>Raw material</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Sugar and Ethanol production</td>
<td>Sugar cane</td>
<td>Brazilia</td>
</tr>
<tr>
<td></td>
<td></td>
<td>27 billion litre/a</td>
</tr>
<tr>
<td>Corn hydrolysis and Ethanol</td>
<td>Maize corn</td>
<td>U.S.A.</td>
</tr>
<tr>
<td>Production</td>
<td></td>
<td>54 billion litre/a</td>
</tr>
<tr>
<td>Corn hydrolysis/ Sugar and</td>
<td>Cereal Corn</td>
<td>EU</td>
</tr>
<tr>
<td>Ethanol production</td>
<td>Sugar beet</td>
<td>4 billion litre/a</td>
</tr>
</tbody>
</table>
## Existing biorefineries, Phase II, (Selection)

<table>
<thead>
<tr>
<th>Kind of BR</th>
<th>Raw material</th>
<th>Country</th>
</tr>
</thead>
<tbody>
<tr>
<td>Corn hydrolysis &amp; Lactic acid fermentation &amp; PLA production</td>
<td>Corn (maize)</td>
<td>U.S.A.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>200 kt LA/a</td>
</tr>
<tr>
<td></td>
<td></td>
<td>140 kt PLA/a</td>
</tr>
<tr>
<td>Corn hydrolysis &amp; 1,3-Propandiol Fermentation</td>
<td>Corn</td>
<td>U.S. A.</td>
</tr>
<tr>
<td></td>
<td></td>
<td>45 kt PDO/a</td>
</tr>
<tr>
<td>Ethanol-Fermentation &amp; Dehydration &amp; PE Production</td>
<td>Sugarcane</td>
<td>Brazil</td>
</tr>
<tr>
<td></td>
<td></td>
<td>200 kt PE/a</td>
</tr>
<tr>
<td>LCF biorefinery Ethanol &amp; Lignin for energy</td>
<td>Wheat straw</td>
<td>Spain</td>
</tr>
<tr>
<td></td>
<td></td>
<td>5,000 litre/a</td>
</tr>
<tr>
<td></td>
<td></td>
<td>Germany</td>
</tr>
<tr>
<td></td>
<td></td>
<td>1,000 tons/a</td>
</tr>
</tbody>
</table>
Biorefineries in construction in Europe, Phase II (Selection)

<table>
<thead>
<tr>
<th>Kind of BR, Country</th>
<th>Raw material</th>
<th>Main-Products</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cellulosic Ethanol, U.S.</td>
<td>Corn waste</td>
<td>Ethanol</td>
</tr>
<tr>
<td></td>
<td>Switch Gras</td>
<td>*500 million gal</td>
</tr>
<tr>
<td>LCF biorefinery</td>
<td>Beech wood</td>
<td>Prod: 20.000 gal</td>
</tr>
<tr>
<td>Research Consortium</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Germany</td>
<td>Wood</td>
<td>Sugars, Lignin</td>
</tr>
<tr>
<td></td>
<td>(180kg/d)</td>
<td></td>
</tr>
<tr>
<td>Booregard, Norway</td>
<td></td>
<td>Sugars, Lignin</td>
</tr>
<tr>
<td></td>
<td>Wood</td>
<td></td>
</tr>
<tr>
<td></td>
<td>(1 t/d)</td>
<td></td>
</tr>
<tr>
<td>Green biorefinery</td>
<td>Grass</td>
<td>Lactic acid,</td>
</tr>
<tr>
<td>Industrial Consortium</td>
<td></td>
<td>amino acid,</td>
</tr>
<tr>
<td>Austria</td>
<td></td>
<td>Fibres, biogas</td>
</tr>
<tr>
<td></td>
<td>(5t/h)</td>
<td></td>
</tr>
<tr>
<td>Green biorefinery</td>
<td>Alfalfa/ wild</td>
<td>Proteins, Lactic</td>
</tr>
<tr>
<td>Industrial Consortium</td>
<td>mix grass</td>
<td>acid, Animal</td>
</tr>
<tr>
<td>Germany</td>
<td>(30kt/a)</td>
<td>feeds, Biogas</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
</tr>
</tbody>
</table>
Integrated Biorefinery Options

**Hydrolysis**
Acids, enzymes

**Sugars and Lignin**

**Gasification**
High heat, low oxygen

**Synthesis Gas**

**Digestion**
Bacteria

**Bio-Gas**

**Pyrolysis**
Catalysis, Heat, Pressure

**Bio-Oil**

**Extraction**
Mechanical, Chemical

**Carbon-Rich Chains**

**Separation**
Mechanical, Chemical

**Plant Products**

**Use:**
- Fuels
- Ethanol
- Biodiesel
- Hydrogen
- Power
- Electricity
- Heat
- Chemicals
- Plastics
- Solvents
- Chemical Intermediates
- Phenolics
- Adhesives
- Furfural
- Fatty acids
- Acetic Acid
- Carbon black
- Paints, Dyes, Pigments, Ink, Detergents etc.
- Food & Feed

Model of biobased Flow-chart for Biomass Feedstock

- **Biomass**
- **Precursors**
- **Platforms**
- **Building Blocks**
- **Secondary Chemicals**
- **Intermediates**
- **Products/Uses**

**Carbohydrates**
- Starch
- Hemicellulose
- Cellulose

**Lignin**
- Lipids, Oil
- Protein

**Sugar**
- Glucose
- Fructose
- Xylose

**SynGas**
- Methanol
- Ethanol
- Glycerol
- Lactic acid
- Propionic acid
- Levulinic acid
- Furfural
- Lysine
- Gallic acid
- Carnitine
- Phenolics
- Caprolactam
- Furfural
- Levaninic acid
- Lactic acid
- 1,3-PDO
- Acrylic
- THF
- Glycerol
- Lactic acid
- Polyactic acid
- Polyurethanes
- Polyesters
- Polysaccharides
- Polysaccharides
- Resins
- Polyurethanes

**Primary Products**
- Ethanol
- Methanol
- Ether
- Olefins
- Olefins
- Acrylic
- Diacids, Esters
- Dilactide
- PLA
- Polyacrylic
- Polylactide
- PLA
- Polyethyleneoxide
- Polyurethanes
- Polysaccharides
- Polysaccharides
- Resins
- Polyurethanes

**Use Categories**
- Industrial
- Transportation
- Textiles
- Safe Food Supply
- Environment
- Communication
- Housing
- Recreation
- Health and Hygiene

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One fundamental task in the biorefinery topic is the development of biorefinery demonstration plants, close to industry, agro-industry, and forest-industry.

Biorefineries present:

- Complex and integrated systems of sustainable technologies based on biological raw materials.
- Economically self-consisting enterprises and economic entities.
- Bearing pillars of the future biobased economics.
- Motors of research and development in the 21st century.

Two examples will be presented.
By primary production of photosynthesis in green crops more than 20 tons of dry matter as well as 3 tons of proteins per hectare in temperate climates can be obtained per year.
Start of construction 20014, Primary Biorefinery Selbelang'
Tier 1: 8.000 t DM (8 mo/y); Primary products: pellet, chlorophyll, Prenacell® fibre, Lactic acid, Proteins, biogas-energy; Construction cost: 6,2 Mio EURO (Basic engineering)
Example:
Selected and simplified processes of a green biorefinery

**Fields, grasslands**
alfalfa, grass, clover
Harvest and cutting
40,000 t/y (DM: 20%)

Wet fractionation by press → Press cake

Press juice → Filtrate

Protein coagulation
Membrane separation

Separation

Lactic acid / Lysine fermentation

Silage fodder

Steam

Decanter separation
Protein purification

Purification

Drying processes by electricity

Fodder protein
Cosmetic protein
Single cell biomass
Lactic acid / Lysine

Filtrate

Biogas plant
Green Biorefinery

**scenario 1: Lactic acid**

<table>
<thead>
<tr>
<th>input:</th>
<th>quantity</th>
<th>unit</th>
</tr>
</thead>
<tbody>
<tr>
<td>Cut green biomass (Lucerne, Clover, Grass)</td>
<td>40.000</td>
<td>t</td>
</tr>
<tr>
<td>Heat</td>
<td>2.200</td>
<td>GJ</td>
</tr>
<tr>
<td>Electricity</td>
<td>1005</td>
<td>MWh</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>output:</th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>Silage fodder</td>
<td>DM: 40 %</td>
<td>13.000</td>
</tr>
<tr>
<td>Fodder-Protein 80 %</td>
<td>DM: 90 %</td>
<td>400</td>
</tr>
<tr>
<td>Cosmetic-Protein 90 %</td>
<td>DM: 90 %</td>
<td>29</td>
</tr>
<tr>
<td>Lactic acid 90 %</td>
<td>DM: 90 %</td>
<td>660</td>
</tr>
<tr>
<td>Residue to Biogas plant TS: 2 %</td>
<td></td>
<td>17.690</td>
</tr>
<tr>
<td>Single cell-Biomass</td>
<td>DM: 90 %</td>
<td>33</td>
</tr>
</tbody>
</table>

(as Fodder-Protein 60 %)

Schönicke, Kamm, CLEAN 2009, 37 (1)
Green Biorefinery scenario 2: **Lysine**

**input:**

<table>
<thead>
<tr>
<th>cut</th>
<th>Green Biomass (Lucerne, Clover, Grass)</th>
<th>quantity</th>
<th>unit</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>DM: 20 %</td>
<td>40.000</td>
<td>t</td>
</tr>
<tr>
<td>Heat</td>
<td></td>
<td>2200</td>
<td>GJ</td>
</tr>
<tr>
<td>Electricity</td>
<td></td>
<td>500</td>
<td>MWh</td>
</tr>
</tbody>
</table>

**output:**

| Silage fodder            | DM: 40 %                              | 13.000   | t    |
| Fodder-Protein 80 %      | DM: 90 %                              | 400      | t    |
| Cosmetic-Protein 90 %    | DM: 90 %                              | 30       | t    |
| Lysine–HCl, 50%          | DM: 90 %                              | 620      | t    |
| Residue to Biogas plant 2% | DM: 90 %                              | 17.770   | t    |
| Single cell-Biomass      | DM: 90 %                              | 31       | t    |

(as Fodder-Protein 60 %)
The Icelandic ethanol-oriented biorefinery based on lignocellulloses Model project – Demonstration Plant – 20,000 tons lignocelluloses/year
General Scheme of a Lignocellulose Feedstock Biorefinery
### Tab. : Sources of lignocelluloses

<table>
<thead>
<tr>
<th>No.</th>
<th>Source Groups</th>
<th>Examples</th>
</tr>
</thead>
<tbody>
<tr>
<td>group 1</td>
<td>existing landscape species</td>
<td>softwood, hardwood, reed (Schilf), reed grass, switch grass, dry grasses etc.</td>
</tr>
<tr>
<td>group 2</td>
<td>fast-growing plantations</td>
<td>poplar (Pappel), willow (Weide), locust (Robinie), wood grass, eucalyptus, sudan grass</td>
</tr>
<tr>
<td>group 3</td>
<td>landscape conservation</td>
<td>old forest, residual wood and under-wood from forestry, switch grass, dry grasses, hay, straw</td>
</tr>
<tr>
<td>group 4</td>
<td>process lignocelluloses</td>
<td>straw, corn stover, press cake from crop drying plant, ethanol plants and oil mills, by-products from cereal mills, whole crop refineries, paper mill and pulp industry</td>
</tr>
<tr>
<td>group 5</td>
<td>used materials and waste</td>
<td>timber (Bauholz), used wood, recovered paper, cellulosic municipal solid waste</td>
</tr>
</tbody>
</table>
Model of the Icelandic ethanol-oriented biorefinery based on lignocelluloses

- **Regional Farmers**
  - Biomass Producer
    - Barley, Hey, Lupine
  - Vegetables Producer
    - Salad, Tomato, a.o.
  - Animal husbandry
    - Sheep, Cattle

- **Inhabitants**
  - Regional Jobs

- **Biomass**

- **Energy**
  - Regional Sources
    - Geothermal Heat

- **Icelandic Biorefinery**
  - Biomass Conversion Mill
  - Biobased Products Factory
    - Chemical/Enzymatic Hydrolysis
    - Conversion, Fermentation, Distillation
    - Separation, Packaging, Storage

- **Tourism**
  - Educational Leave
  - Hotel Sector

- **Fuel Industry**

- **Chemical and Producing Industry**
  - Ethanol
  - Lignin

- **Carbon dioxide**
  - Proteins
  - Yeast
  - Fertilizer

Green SeePark Mývatn
Modern Life, Working and Recovery with Nature in Northern Iceland
<table>
<thead>
<tr>
<th><strong>The Icelandic ethanol-oriented biorefinery (demonstration plant) - corner data</strong></th>
</tr>
</thead>
<tbody>
<tr>
<td><strong>Raw Material</strong></td>
</tr>
<tr>
<td>Lignocellulosic biomass (mix)</td>
</tr>
<tr>
<td><strong>Main Technologies</strong></td>
</tr>
<tr>
<td>Acid hydrolysis, Sugar fermentation</td>
</tr>
<tr>
<td><strong>Main Process Energy</strong></td>
</tr>
<tr>
<td>Geothermic steam</td>
</tr>
<tr>
<td><strong>Plant basis/Location</strong></td>
</tr>
<tr>
<td>LC-Feedstocks</td>
</tr>
<tr>
<td><strong>Main Product (Phase I)</strong></td>
</tr>
<tr>
<td>Ethanol for E10 Fuel</td>
</tr>
<tr>
<td><strong>Operating Company</strong></td>
</tr>
<tr>
<td>Icelandic Biomass Company</td>
</tr>
<tr>
<td><strong>Total costs</strong></td>
</tr>
</tbody>
</table>
The Icelandic ethanol-oriented biorefinery – Main process modules
Advantages of the production of Ethanol

Ethanol is not only a fuel, but also a basic chemical for a lot of solvents, products and materials

- Diethyl ether
- Ether formation
- Acetone
- Keton synthesis
- Esterification
- Ethyl lactate
- Ethyl levulinate
- other

- Lebedew Process
- Butadiene
- Other
- Acetaldehyde
- Acetic acid
- Acetic anhydride
- Rubber
- Polymers
- Ethene
- Vinyl acetate
- Ethene
- Propylene
- C4-cut
- Benzine
- Crack gas
- Aromatics

- Oxidation
- Dehydrating
- Mobile Process
- Steam cracker
- Synthetic Naphtha
- Fuels
- Fuel additive
- Solvents
Regional Biorefineries are also in other regions - without geothermic energy- profitable.

For process energy it’s possible to use:

• The Lignin fraction, approx. 30% in lignocellulose
  the heating value (calorific value) of Lignin lies between 13 MJ/kg and 19 MJ/kg (DM) (wood: 18 MJ/kg, heating oil: 30-35 MJ/kg).

• Biogas Cogeneration: Heat and Power (Electricity).
The Icelandic Ethanol-oriented biorefinery – Summary

The Icelandic Ethanol-oriented Biorefinery (demonstration plant) can produce **7 Mio litres Ethanol/year.**

The Icelandic Ethanol-oriented LCF-Biorefinery is profitable!

**7 Mio l Ethanol (pure) is equivalent to 70 Mio E10 petrol.**

E10 petrol is normal petrol with 10% Ethanol.

Each Icelandic Inhabitant could to refuel approx. **233 Litres E10 petrol** per year.
Why is such (small scale) Ethanol-oriented LCF-Biorefinery profitable?

- Research and development supported by European Commission (BESUB project) and the Icelandic Government.
- Iceland has a very efficient and low price non-fossil energy market (geothermic energy). Hence, energy-intensive processes (e.g. acid recovery) are so economically and environmentally friendly.
- Private Operating Companies, Finance and Government to act in concert.
- Economical biomass and product markets could be organized (without subsidy).
Several requirements to enter the phase of development of Industrial Biorefinery Technologies and Biobased Products:

- To increase the production of substances on the base of biogenic raw materials in the ordinary plants of production of cellulose, starch, protein, sugar and oil.
- To get the commitment of the chemistry, particularly the organic and technical chemistry, for the concept of biobased products and biorefinery systems.
- To force the combination of biological and chemical conversion of substances.
- To introduce and establish biorefinery demonstration plants.
Contact

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Web: www.biorefinery.de, www.biorefinica.de

Potsdam and Teltow in the Greater Berlin, Germany
Thank you for the invitation and your attention

City of Potsdam - Market Square
State of Brandenburg, Greater Berlin, Germany