Creating value from wood – The Borregaard biorefinery

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Materials
- Borregaard
- Speciality materials (600 M€)
- Ingredients and pharma (180 M€)
- Energy (22 M€)

Elkem
- Aluminum extrusion
- Branded consumer goods
- Associated companies
- Financial investments

Biorefinery in context

Orkla
- Specialty materials (600 M€)
- Ingredients and pharma (180 M€)
- Energy (22 M€)

SAPA

Branded consumer goods

REC, Jotun

Turnover
- Orkla: NOK 74 billion (35,000 employees)
- Borregaard: NOK 5 billion (1,400 employees)

120 years of innovation

20% of revenue from products launched in the last 5 years
**Sulfite pulping**

- Variation of parameters allows for great specialization
  - raw material (moisture, aging)
  - impregnation time
  - temperature profile
  - ratio free/bound \( \text{SO}_2 \)

- Cellulose as a chemical, not as a fiber

- Raw material for cellulose acetate
  - very low lignin content
  - good brightness
  - high reactivity

- Raw material for cellulose ethers
  - high viscosity

**Fermentation to ethanol**

Lignocellulosic ethanol produced since 1938

20 million liters yearly

Raw material is monosaccharides from spruce hemicellulose

**Feedstocks**

- 1G ("food crops")
  - sugar, starch, vegetable oil, animal fats

- 2G ("non-food crops")
  - lignocellulosic biomass

- 3G, 4G
  - algae, designed crops

\[
\text{C}_{6} \text{H}_{12} \text{O}_{6} \xrightarrow{\text{yeast}} 2\text{C}_2\text{H}_5\text{OH} + 2\text{CO}_2
\]

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\]
Oxidation of lignosulfonate to vanillin

Copper catalyst is recycled due to strict limitations on copper in effluent.

Properties of Lignosulfonates

- MW: 20,000 – 80,000 Da
- Polydispersity: 6-8
- Sulfonate groups: 0.6-1.2 per monomer
- Organic sulfur: 4-8%
- Solubility: soluble in water at all pH, insoluble in most organic solvents
- Color: very light to very dark brown
- Sold in powder or liquid form
- Non-toxic, LD₅₀ > 5 g/kg

Several hundred applications:
- Flow modifier in cement and concrete
- Crystal growth modifiers in lead batteries
- Dispersing agent/emulsion stabilizer
- Corrosion inhibitor for organic acids
- Soil conditioning

What is a biorefinery?

IEA definition of biorefinery:

“Biorefinery is the sustainable processing of biomass into a spectrum of marketable products”

- Biorefinery: concepts; facilities; plants; processes; cluster(s) of industries.
- Sustainable: maximising economics, and minimizing environmental aspects; fossil fuel and feedstock replacement.
- Processing: upstream processing; transformation; fractionation; thermo-chemical and/or biochemical conversion; extraction; separation; downstream processing.
- Biomass: crops; organic/forest residues; aquatic biomass.
- Spectrum: more than one marketable product.
- Marketable products: both intermediates and final products (i.e. fuels; power; heat; food; feed; chemicals; materials).

Spectrum of marketable products

~ 90% of incoming biomass converted to marketable products.
Sustainable processing

Biomass
- Natural
- Renewable
- Non-toxic

Processing
- Reduced emissions
- Energy saving
- Raw material utilization
- Risk management

Products
- Good performance
- Replace oil based chemicals

Reducing the CO₂ footprint
~84% of energy renewable within 2010

Key figures from LCA analysis

<table>
<thead>
<tr>
<th>Environmental impact</th>
<th>Ethanol (96%)</th>
<th>Lignin (powder)</th>
<th>Lignin (liquid)</th>
<th>Vanillin</th>
</tr>
</thead>
<tbody>
<tr>
<td>Global warming potential</td>
<td>1211</td>
<td>335</td>
<td>704</td>
<td>1227</td>
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<tr>
<td>Acidification potential</td>
<td>11.3</td>
<td>3.8</td>
<td>7.1</td>
<td>10.4</td>
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<tr>
<td>Eutrophication potential</td>
<td>3.26</td>
<td>0.95</td>
<td>1.64</td>
<td>2.75</td>
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<tr>
<td>Photocatalytic ozone creation potential</td>
<td>0.7</td>
<td>0.24</td>
<td>0.42</td>
<td>0.69</td>
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<tr>
<td>Ozone depletion potential</td>
<td>8.90E-05</td>
<td>2.60E-05</td>
<td>4.30E-05</td>
<td>1.10E-04</td>
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<tr>
<td>Cumulative energy demand</td>
<td>MUHV</td>
<td>33000</td>
<td>8700</td>
<td>19200</td>
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<tr>
<td>Waste</td>
<td>57.8</td>
<td>26.8</td>
<td>37.8</td>
<td>59.6</td>
</tr>
</tbody>
</table>

Biorefinery technologies

<table>
<thead>
<tr>
<th>technology</th>
<th>temperature</th>
<th>output</th>
<th>opportunities</th>
</tr>
</thead>
<tbody>
<tr>
<td>pretreatment</td>
<td>&lt; 200 °C</td>
<td>polymers (glucan, xylan,</td>
<td>biomaterials</td>
</tr>
<tr>
<td>hydrosis</td>
<td></td>
<td>lignin)</td>
<td></td>
</tr>
<tr>
<td>fermentation</td>
<td></td>
<td>monomers (monosaccharides)</td>
<td></td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
</tr>
<tr>
<td>pyrolysis extraction</td>
<td>&gt; 200 °C</td>
<td>monomers (biooil: phenols,</td>
<td>pyrolysis platform</td>
</tr>
<tr>
<td></td>
<td></td>
<td>acids, aldehydes, alcohols</td>
<td>(energy, chemicals)</td>
</tr>
<tr>
<td>gasification</td>
<td>&gt; 700 °C</td>
<td>synthesis gas (CO/H2)</td>
<td>FT diesel</td>
</tr>
</tbody>
</table>

Comparable fossil based products give 200-1500% higher GHG emissions

Application for swanlabelling of ethanol for fuel is in progress
**Sugar platform pathways**

**Hydrolysis process**
Dissolving cellulose and hemicellulose leaving hydrolysis lignins undissolved

- Strong acid
- Weak acid
- Enzymatic
- Microbial

**Pulping process**
Dissolving lignin and (hemicellulose) leaving cellulose undissolved

- Kraft
- Soda
- Sulfite
- Solvent
- Extrusion

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**Challenges for 2nd generation bioethanol**

**Technical**

- Low % of feedstock useful
  - Only approx. 40%-45% of biomass can be converted to product
- Low yield in several process steps
  - Theoretically maximum 51% yield of ethanol from C6 sugars
  - No industrial solution for fermenting C5 sugars to ethanol (will take long)
  - Several process steps with 80%-95% yield create loss and sidestreams
  - Lignocellulosic biomass is recalcitrant to degradation – tough demands on pre-treatment and liquefaction/hydrolysis steps
- Sidestreams impure – challenge to convert into valuable products

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**Solutions**

- Integrated biorefinery
  - Make value-added products from sidestreams
  - Plan for pre-treatment & separation processes that facilitate manufacture of products from all streams
  - Increase yields in each process step
  - Place manufacturing where cheap feedstock and energy is readily available and surplus energy could be utilized

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**Biomass2Products**

- Patent applied in 2008
  - Flexible feedstock
  - Good fractionation of cellulose, hemicellulose and lignin
  - Easy access to C5/C6 sugar platform via enzymatic hydrolysis
  - Lignin applications identified
  - Process ready for scale up in pilot plant

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Borregaard funding position

EU projects
- EuroBioRef (U. of Lille: 2010 - 2013) - FP7 Joint Biorefinery call, BRG grant 3.0M€
- Suprabio (U. of Oxford: 2010 - 2013) - FP7 Joint Biorefinery call, BRG grant 1.1M€
- Sustaincomp (Innventia: 2009 - 2012) – FP7, BRG grant 0.85M€

Norwegian/Nordic grants
- XIXU (BIP BRG: 2008 – 2011) – NFR BIA – total max grant 6 MNOK
- Biomass2Products (BIP BRG: 2009 – 2014) – NFR BIA – total max grant 19 MNOK
- LignoRef (KMB PFI: 2009 – 2012) – NFR Renergi – total max grant 24 MNOK

(NFR = Norwegian research council, NIC = Nordic innovation centre, NER = Nordic energy research)

The incentives paradox

- Cost/price
- Creating values

BioMaterials
- Polymers
- Composites
BioChemicals
- Flavours
- Monomers
- Proteins
- Fine chemicals
- Speciality chemicals
BioFuel
- Bioethanol
- Biodiesel
- Biogas
BioEnergy
- Electricity/Heat
- Liquid Fuels
- Pellets

Green house gases are accumulating, the arctic is melting, the weather is crazy, chemicals break down the ozone layer and we're fried alive by UV radiation from the sun – and did I mention peak oil?

What a business opportunity!!!