The Biorefinery approach to production of lignocellulosic ethanol and chemicals from lignocellulosic biomass


Gisle L Johansen
Senior Vice President R&D and NBD

gisle.l.johansen@borregaard.com
www.borregaard.com

Borregaard
The Sustainable Biorefinery
Borregaard is a global leader in bio based chemicals. Strong innovation efforts increase the value added to our customers.
C6 sugars from spruce hemicellulose are fermented in a continuous process to produce 20 million liters ethanol yearly.

Yeast recycled since 1938
Global presence

Borregaard 2012
1200 employees in 20 countries
Borregaard then and now

- Competitive edge in 1889
  - cheap timber
  - cheap energy
  - cheap labor

- Austrian technology
- British capital

- High cost
  - raw materials
  - energy
  - labor

- Competitive edge in 2012
  - technology
  - market
  - innovation pipeline
Borrengaard site in Sarpsborg, Norway

Head office - R&D - Production
700 employees (70 in R&D)
From paper mill to biorefinery

**BIOREFINERY BORREGAARD**

- **Lignin**
  - Wet incineration
  - Bio-Energy
  - Lignosulphonates
  - Oxy lignin sulphonates
  - Vanillin
  - Acetovanillone
  - Veratic Acid
  - Bark beetle pheromones
  - Cellulose octaacetate

- **Cellulose**
  - Fine paper
  - Microfibrillar Cellulose
  - Speciality Cellulose
  - Paper Cellulose
  - Textile fibre
  - Spun textile fibre

- **Hemi-cellulose/sugars**
  - Yeast
  - CO$_2$
  - Bioethanol
  - Acetic Acid / Acetaldehyde / Ethyl Acetate
  - Butanol / 2-Ethylhexanol / DOP
  - Vinyl Acetate
  - PV Ac

**Timeline**
- 1900
- 1950
- 1960
- 1980
- 2000

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Further development of the biorefinery concept

**BioMaterials**
- Polymers
- Composites

**BioChemicals**
- Flavours
- Monomers
- Proteins
- Fine chemicals
- Speciality chemicals

**BioFuel**
- Bioethanol
- Biodiesel
- Biogas

**BioEnergy**
- Electricity/Heat
- Liquid Fuels
- Pellets

Cost/price: Low to High
Creating values: Low to High

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Lignin from biomass - two alternatives

Borregaard BALI process:
- Lignin
- Specialty chemicals

Competing 2G processes:
- Energy – heat and power

Diagram:
- Lignin
- Cellulose
- Hemi Cellulose & Others
BALI™ process in a nutshell - pretreatment

Bagasse

Pretreated and “reactive” pulp

Water soluble lignin
Borregaard LignoTech
World leader in lignin based products

Production
Norway, England, Germany
Spain, Czech Republic, USA,
South Africa, Brazil

Products
A broad range of dispersing and binding agents and other performance chemicals

Applications
• Construction
• Agro chemicals
• Animal feed
• Bricks & tiles
• Lead batteries
• Soil conditioner
• Mining
• Gypsum board
Bagasse mass balance (only C/H/L shown)

Steam explosion

Bagasse

BALI™ acid pretreatment

Solid fraction

Cellulose

Solid fraction

Hemicellulose

Liquid fraction

Lignin

Bagasse mass balance (only C/H/L shown)

Steam explosion

Bagasse

BALI™ neutral pretreatment

Solid fraction

Cellulose

Solid fraction

Hemicellulose

Lignin

Liquid fraction

Pretreated bagasse

Decomposition with enzymes yields high purity sugar in solution

Sugar is transformed to bioethanol or chemicals
Performance evaluation of cellulolytic enzymes

• Many factors affect yields in enzymatic hydrolysis and all need to be taken into account when evaluating and comparing results
  – solids and glucan loading
  – enzyme dosage (on solids or glucan? %w/w or %v/w?)
  – time
  – buffer and concentration of buffer (pH at end of hydrolysis measured?)
  – temperature (mostly at 50 °C, but more stable enzymes are emerging)

• Yields >100% (not uncommon as pretreatment and enzyme technology improves) mainly due to underestimation of glucan in the raw material analysis (main challenge is the 2-step quantitative analytic hydrolysis)

• A performance evaluation of feedstock/pretreatment combinations needs to be done on a case-by-case basis for every enzyme product studied due to differences in product formulation and composition.

• In the end only $/kg sugar counts
DuPont Accellerase® DUET vs TRIO

BALI™ neutral pretreated bagasse
15% substrate/8.5% glucan loading
50 °C, 200 rpm
25 g total reaction mass
sodium citrate buffer
**Novozymes Cellic® CTec2 vs CTec3**

**Graph:**
- **Y-axis:** Glucose yield (%)
- **X-axis:** Enzyme dosage (%w/w glucan)
- **Lines:**
  - Solid line: 48 h CTec3
  - Dashed line: 48 h CTec2

**Details:**
- **BALI™ acid pretreated bagasse**
- 15% substrate/9.7% glucan loading
- 50/53 °C (CTec2/CTec3), 200 rpm
- 28 g total reaction mass
- Sodium citrate buffer
BALI™ produces clean hydrolysates

- BALI™ hydrolysates are easily fermentable to ethanol, indicating the absence of fermentation inhibitors

- Company A (chemical process):
  - "Borregaard hydrolysates were converted very efficiently"

- Company B (fermentation process):
  - "Results for conversion of the acid and neutral hydrolysates are the best we have ever observed"
Demonstration plant for bioethanol and green chemicals - in operation

Biomass

BALI

- Cellulosic ethanol
- Biochemicals
- Lignin Chemicals
Building the first BALI™ demonstration

- Demonstrate lignin grade/quality
- Serve partners
- Reduction of risk (CAPEX est)
- A real “mini plant”, continuous process, scalable equipment (up to 50 m³ scale)
- Includes
  - lignin processing
  - continuous polysaccharide hydrolysis
  - fermentation capabilities
- Feed: 2MTDS/day
- Currently in operation
- Location: Sarpsborg, Norway
- Total cost approx 24 mill USD
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**BALI pilot plant**
10 MUSD for construction of pilot plant received from Innovation Norway

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