LOW-COST FERMENTATION GRADE GLUCOSE FROM (CORN-BASED) BIOREFINERIES

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BASF at a Glance

BASF – The Chemical Company

- The world’s leading chemical company
- Offers intelligent system solutions and high-value products for almost all industries
- Sales 2008: € 62.3 billion
- Income from operations (EBIT) 2008: € 6.46 billion
- Employees (December 31, 2008): ca. 97,000
The Verbund Site Ludwigshafen
The world’s largest integrated chemical complex
“Verbund” – a Management Philosophy

“They pump in natural gas, oil and salt at one end, make everything and the by-products are recycled. There is very little actual waste.”
(The Times, Nov. 1998)

- Manufactures high-value products in a dense network of plants
- est. 1865
- size: 10 km² ~ 2500 acres
- > 30,000 employees on-site
- > 200 plants
- > 8.5 mil. tons of products per year
- > 2000 km over ground pipes
- 115 km roads; 211 km rail
Motivation for development of a biorefinery

Access to low-cost sugar is a **prerequisite** for chemicals from renewables.

BASF‘s current situation is characterized by:

- Access to sugar at market price only
- Regions of low cost sugar production are distant from
  - chemical markets
  - BASF production sites
- Current technologies for sugar production are
  - capital-intensive
  - exceed BASF‘s demand for sugar

**Develop own access to sugar at producer economics, even at moderate scale.**

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# Fermentation sugar sources

Comparison of existing technologies

<table>
<thead>
<tr>
<th>Process</th>
<th>Sugar mill</th>
<th>Wet-milling</th>
<th>Dry-milling (BioEtOH)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw material</td>
<td>Sugar cane</td>
<td>Corn</td>
<td>Corn</td>
</tr>
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<td>Fermentation sugar purity</td>
<td>&gt; 98 %</td>
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<td>~ 70%</td>
</tr>
<tr>
<td></td>
<td></td>
<td>(food-grade)</td>
<td></td>
</tr>
<tr>
<td>Autonomy of sugar production</td>
<td>Low</td>
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<td>High</td>
</tr>
<tr>
<td>Raw material costs</td>
<td>World market</td>
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<tr>
<td>Investment costs</td>
<td>Low</td>
<td>High¹</td>
<td>Low</td>
</tr>
<tr>
<td>Production costs</td>
<td>Low</td>
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¹ World-scale plants (>1.5 Mio tons/a crushing capacity)
Process idea and overview
Basic flow scheme of bioethanol production

- Corn
  - Milling
  - Liquefaction
    - α-Amylase
  - Saccharification
    - β-Glucoamylase
  - Fermentation
  - Destillation
    - Whole stillage
    - Thin stillage
    - Biomass & Solids
  - Solid-/Liquid-Sep.
    - Concentration
      - DDGS
      - Drying
        - Syrup
  - Ethanol
Process idea and overview
Adaption for fine chemical fermentation processes

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- Corn
  - Milling
  - Liquefaction
    - $\alpha$-Amylase
  - Saccharification
    - $\beta$-Glucosamylase
  - Fermentation
  - Solid-/Liquid-Sep.
  - Downstreaming
    - Thin stillage
    - Biomass & solids
    - Fine chemicals (e.g. amino acids, vitamins, enzymes, ...)
  - Concentration
  - Syrup
  - Drying
    - DDGS-equivalent co-product
Process idea and overview
Pilot-scale development

Overall view pilot plant
Process idea and overview
Liquefaction & saccharification

Detailed view pilot plant
Mashing
2nd liquefaction
Saccharification

1st liquefaction
Process idea and overview

Fermentation

Fermentation 300 L

Fermentation 2400 L
Process idea and overview
Solid/liquid separation

Centrifugal separation
Process idea and overview
Drying

Drying equipment

Dry co-product
Glucose production cost structure

- Raw materials incl. corn
- Net-raw material costs
- Co-products of corn-processing (and fermentation)
- Variable costs
- Fixed costs
- Glucose production costs
# Fermentation sugar sources
Comparison of existing technologies & BASF process

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<tr>
<td>Investment costs</td>
<td>Low</td>
<td>High&lt;sup&gt;1&lt;/sup&gt;</td>
<td>Low</td>
<td>Medium</td>
</tr>
<tr>
<td>Production costs</td>
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<td>Low&lt;sup&gt;1&lt;/sup&gt;</td>
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<sup>1</sup> World-scale plants (>1.5 Mio tons/a crushing capacity)
Conclusion corn-based biorefinery

Successful development of a process for the production of glucose.

- A high performing fermentation sugar source
- Medium investment costs
- Low glucose costs, even at moderate production scale
- Backward-integration to cheap sugar at production sites worldwide

Short-term realization of the process is possible worldwide.
2nd generation biorefinery concept
biofuel / chemicals production via fractionation

biomass

fractionation

monomerisation

conversion

biobased product

why fractionation?
tailor-made conversion conditions for each stream
- space time yield
- capital investment
- flexibility

Source cartoon: Faix & Lehnen
Example: biomass pretreatment
ionic liquids

- liquid below 100 °C
- non flammable
- immiscible with many organic solvents
- BASF know-how & production
- various emerging applications
- dissolution of (ligno-)cellulose
- exclusive license from the University of Alabama (patents of Prof. Rogers)
Example: biomass pretreatment
biorefinery with ionic liquids

- screening of >50 ILs
- screening of parameters:
  - temperature
  - precipitating agent
  - water content of the IL
  - precipitation protocol
- series of experiments in closed process cycles
- two patents filed:
  WO 2008090155
  WO 2008090156
Example: biomass pretreatment
digestion of switchgrass by cellulases

- disintegration of the lignocellulose structure (hydrolysis rate x7)
- challenges:
  - >99% IL-recycling
  - high investment costs
  - energy costs
Thank you for your attention!

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