Conversion routes to cellulosic alcohol
Proving second generation processes in practical demonstration

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Biocommodities = white biotechnology
| We make biotechnology work.

- Since 1921 independent
- Located in Vienna, Austria, Hong-Kong and Huston, TX
- Bioprocess plants for the sugar, starch and food industries
- From raw material preparation to final product
- Proprietary technology
  - alcohol | bioethanol
  - vinegar
  - yeast
  - organic acids
  - starch sugars

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36 bioethanol plants since 1981 in North America, China, Europe with a total annual capacity of 5 million tons

First with largest bioethanol plants on three continents

Technology supplier to major producers, e.g.

- Jilin Fuel Ethanol
- Abengoa Bioenergy
- Cargill
- Südzucker (CropEnergies)

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Complementing client’s 2G process with proven bioethanol technology
► Process design for pilot and demonstration plants
► Assist in developing fermentation and separation strategies
► Equipment supply for separation, distillation and dehydration

Examples:
► demo plant of INBICON | DK
► demo plant of IOGEN | CD
► pilot plant ABENGOA BIOENERGY | US
► pilot plant of MITSUI/SIME DARBY | MY
► commercial plant INEOS Bio | US
Biorefineries

Feedstock\(^1\)
- Oil crops (rape, sunflower, etc.), waste oils, animal fats
- Sugar and starch crops
- Lignocellulosic biomass (wood, straw, energy crop, MSW, etc.)
- Biodegradable MSW, sewage sludge, manure, wet wastes (farm and food wastes), macro-algae
- Photosynthetic micro-organisms, e.g. microalgae and bacteria

Conversion routes\(^2\)
- (Biomass upgrading\(^3\)) + Combustion
- Transesterification or hydrogenation
- (Hydrolysis) + Fermentation
- Gasification (+ secondary process)
- Pyrolysis (+ secondary process)
- AD\(^4\) (+ biogas upgrading)
- Other biological / chemical routes
- Bio-photochemical routes

Heat and/or Power
- Liquid fuels
  - Biodiesel
  - Bioethanol
  - Syndiesel / Renewable diesel
  - Methanol, DME
  - Other fuels and fuel additives
- Gaseous fuels
  - Biomethane
  - Hydrogen

\(^1\) Parts of each feedstock, e.g. crop residues, could also be used in other routes

\(^2\) Each route also gives co-products

\(^3\) Biomass upgrading includes any one of the densification processes (pelletisation, pyrolysis, torrefaction, etc.)

\(^4\) AD = Anaerobic Digestion

Source: Executive Summary Bioenergy – a Sustainable and Reliable Energy Source, IEA, 2009

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SHOWCASE PROJECT: INBI CON | Kalundborg | Denmark

Second generation demonstration plant

Input: 30 000 t/y wheat straw
Output: 5.4 million liters ethanol
13,100 t lignin pellets
11,250 t C5-molasses
SHOWCASE PROJECT: INBICON | Kalundborg | Denmark
Combination of technology

Straw Handling | Hydro-thermal Pretreatment | Liquefaction | Fermentation | Destillation

DONG 20 years experience | INBICON core technology | VOGELBUSCH downstream technology

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SHOWCASE PROJECT: INBI CON | Kalundborg | Denmark

Status Quo

- Proven technology for integral process on industrial scale – design capacity reached
- Steam explosion pretreatment – no chemicals required
- 2G Bioethanol produced at spec
- Distribution of BIO95 2G fuel in Denmark by STATOIL
- Highly pure lignin pellets delivered to power plant
- C5 molasses delivered to biogas plant
- Design available for industrial scale plants

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SHOWCASE PROJECT: INEOS Bio | Vero Beach, FL | USA

Second generation commercial plant

Input: vegetative waste
       yard waste
       municipal solid waste

Output: 30 million liters ethanol per year
        6 MW gross electric power generation
SHOWCASE PROJECT: INEOS Bio | Vero Beach, FL | USA

gasification

power generation

fermentation

distillation
SHOWCASE PROJECT: INEOS Bio | Vero Beach, FL | USA

Process Overview: Bioethanol from waste combined with CHP

**Waste heat and offgas recovery** for renewable power generation for use in the bioethanol process and for export

**Feedstock versatility** allows a range of biomass feedstocks to be used including waste

**Two stage gasification** to produce syngas without significant by-products

**Syngas converted into bioethanol** via fermentation using proprietary biocatalyst then distillation

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SHOWCASE PROJECT: INEOS Bio | Vero Beach, FL | USA

Status quo

► Strong US government partnership
  ▸ DOE grant & USDA loan guarantee
► EPC awarded to AMEC in November 2010
► Ground broken in February 2011
► Currently under commissioning
Syngas fermentation
General facts

► Fermentation of syngas into ethanol based on the following reactions:
  ► 6CO + 3H_2O \rightarrow C_2H_5OH + 4CO_2
  ► 2CO_2 + 6H_2 \rightarrow C_2H_5OH + 3H_2O
► Also other side reactions e.g. into acetic acid
► Microorganisms:
  ► High productivity of ethanol
  ► Low by-product formation
  ► High tolerance against inhibiting substances in the syngas
  ► e.g. Clostridium ljungdahlii

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Syngas fermentation
General facts

► Feedstock for gas fermentation can be derived from a broad range of sources:
  ► Syngas of biomass (e.g. vegetative waste, yard waste)
  ► Syngas of municipal wastes
  ► Industrial waste gases (e.g. steel production)
  ► Combination of several sources
  ► Waste streams converted directly on site into thermal or electric power

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## Comparison of different technologies

<table>
<thead>
<tr>
<th></th>
<th>Starch based</th>
<th>Cellulosic based</th>
<th>Syngas fermentation</th>
</tr>
</thead>
<tbody>
<tr>
<td>Raw material</td>
<td>wheat / corn</td>
<td>wheat straw</td>
<td>biomass</td>
</tr>
<tr>
<td>Yield l alcohol / t raw material</td>
<td>390</td>
<td>180 (C6) 250 (C6 + C5)</td>
<td>200 - 260</td>
</tr>
<tr>
<td>Fermentation time hours</td>
<td>60 – 70</td>
<td>120 – 150</td>
<td>&lt; 1</td>
</tr>
<tr>
<td>Alcohol content %vol in mash</td>
<td>11 – 16</td>
<td>5.0 – 10.0</td>
<td>3.0 – 5.0</td>
</tr>
<tr>
<td>Viscosity cP</td>
<td>30 – 50</td>
<td>200 - 400</td>
<td>5 – 10</td>
</tr>
<tr>
<td>Steam consumption t /1000 l alc</td>
<td>0.3 – 0.4</td>
<td>2.0 – 4.0</td>
<td>-</td>
</tr>
<tr>
<td>Upstream (Hydrolysis)</td>
<td></td>
<td></td>
<td>3.0 – 5.0</td>
</tr>
<tr>
<td>Distillation / Dehydration</td>
<td>1.2 – 2.0</td>
<td>1.7 – 2.5</td>
<td></td>
</tr>
<tr>
<td>Evaporation / Drying</td>
<td>1.8 – 2.0</td>
<td>2.5 – 4.0</td>
<td></td>
</tr>
<tr>
<td>By products</td>
<td>DDGS</td>
<td>Lignin C5 fraction</td>
<td>Thermal / electrical power</td>
</tr>
</tbody>
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Cellulosic ethanol – Status quo

Achieved

- Stable, proven processes
- Plant in industrial design available
- Industrial product quality requirements

Unresolved

- Insufficient legal framework to support cellulosic ethanol
- High investment costs compared to G1 plants
- Still higher production costs compared to G1 product
- Raw material availability and costs
- „First of its kind“ Issues

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Special downstream processing solutions
| For first and second generation bioethanol

GIVEN CONTEXT
Cutting process energy consumption improves the plant feasibility.

Technological measures to improve energy efficiency of cellulosic ethanol plant:

1. VB Multipressure distillation
   ➔ minimizing energy demand for distillation
2. VB Zero steam evaporator heated by dryer’s vapor
   ➔ minimizing energy demand for stillage treatment

Saving energy = Saving costs!

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Vogelbusch Multipressure distillation I

| Influence of alcohol content in mash on steam demand |

- Conventional double column distillation and dehydration system
- VOGELBUSCH Triple Column distillation and dehydration system

Specific steam consumption [kg / 1000 l alcohol]

vol% alcohol in mash

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### Vogelbusch Multi-pressure distillation II

| For first and second generation bioethanol |

<table>
<thead>
<tr>
<th>Feature</th>
<th>Pressure Stages</th>
</tr>
</thead>
<tbody>
<tr>
<td>3 pressure stages for threefold usage of life steam</td>
<td>vacuum, atmospheric, overpressure</td>
</tr>
<tr>
<td>Distillation in split mash columns</td>
<td>vacuum, atmospheric</td>
</tr>
<tr>
<td>Rectification in split rectifiers</td>
<td>atmospheric, overpressure</td>
</tr>
<tr>
<td>Hydrous alcohol vapors fed directly to molecular sieve unit</td>
<td></td>
</tr>
<tr>
<td>Split mash columns can be used for separate feed streams (hybrid plants)</td>
<td></td>
</tr>
</tbody>
</table>
Vogelbusch Multi-pressure distillation III

Overpressure

Atmospheric

Vacuum

Alcoholic Vapour

Mole Sieve

Singlings

Steam

Pre-concentrated Stillage

Evaporation

Decanted Stillage

Decantation

Mash

Vapour
Vogelbusch zero steam evaporator
| For first and second generation bioethanol

- Evaporators are used for concentration of decanted residues from distillation
- Dryers are used for
  - DDGS in first generation plants
  - Lignin in second generation plants
- Dryer’s vents are a valuable heating source for evaporation
- State-of-the-art indirect heated dryers produce vapors with a wet bulb temperature of 90 – 98 °C
- Depending on wet bulb temperature 50 – 80 % of total dryer’s vapors can be utilized as heating source in evaporators
- 1G Plants: multi-effect evaporators are heated completely by dryer’s vapors without any additional live steam
- 2G Plants: considerable reduction of life steam for evaporation of effluents

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Conclusions

Energy efficiency

• Thermal integration by special downstream solutions can save up to 40% of live steam

Additional income

• It’s not enough to be thermally selfsufficient!!
• Additional income by selling (more) surplus energy

CO₂ reduction

• Considerable reduction of carbon footprint of the plant

ROI

• ROI for thermal integration in downstream typically within 2 – 3 years
Thank you for your attention.

For questions please contact
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