Novozymes’ recent development in HMF/FDCA:
A top value-added biobased chemical building block

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Novozymes: A world leader in Bio-innovation

- Global leader in industrial enzymes and microorganisms
- 47% global market share within industrial enzymes
- Market leader in all main industries
- 2012 global sales DKK 11.23B
- Aggressive pursuit of new biotechnology
  - 14% of sales invested in R&D (~1150 employees at 10 R&D sites globally)
  - >50 new products introduced in the last 5 years
- Over 6,000 pending and issued patents
  - 165 new patent families in 2011
  - The fifth most patent active company globally in Biotech and Health care (2002-2006) - the only European company on the top 40 list
Leveraging our capabilities

Continuous development of Novozymes’ biotechnology platform for enzymes...

...creates opportunities for new business areas

### Molecular biology
- Strain development using protein engineering, genetic modification, DNA sequencing, etc.

### Bioinformatics & systems biology
- Application of computer algorithms in discovery of enzymes in DNA databases

### Screening systems
- Application of high-throughput robotics to find the best biosolution

### Industrial scale fermentation
- Continuously optimizing and improving yields for 60 years

### Microorganisms

### BioAgriculture

### Biopolymers

### Biochemicals
USING BIOTECHNOLOGY TO PRODUCE BIOCHEMICALS

Petro-based feedstock → Enzyme technology → Chemicals (bulk, fine, specialty)

Bio feedstock such as sugars, oils, fats → Fermentation → Bio-ethanol

Sugar → Enzyme technology → Chemical catalysis → Bio-chemicals

Other bio feedstock (e.g. oils) → Advanced fermentation → Bio-chemicals

Starch → Enzyme technology → Chemical catalysis → Bio-chemicals

Cellulose → Enzyme technology → Chemical catalysis → Bio-chemicals

Pre-treatment → Enzyme technology → Chemical catalysis → Bio-chemicals

Chemicals (bulk, fine, specialty)

Bio-ethanol

Bio-chemicals
Our business model — providing win-win-win solutions

- Novozymes provides the biotechnology to enable production of biochemicals
- Novozymes partners with established agricultural players and chemical players
- Novozymes engages in connecting these players, thus creating new value chains

Grain processors: New markets
Novozymes: License payments and royalties
Chemical companies: Sustainable supply
NOVOZYMES’ BIOCHEMICALS
PROJECTS AND PARTNERS

Our biosolutions for biochemicals

C3
- 3-Hydroxyl Propionic acid
  - Acrylic acid
    - Other applications
      - Outlicensing
        - BASF
  - Propylene
  - Propanol
    - Outlicensing
      - Braskem

C4
- L-Malic acid
  - Outlicensing

C6
- HMF/FDCA
  - Outlicensing
  - Biocatalyst
  - Other opportunities
    - Partnering
HMF/FDCA
HMF/FDCA have a strong potential to be future building blocks in the chemical industry

- Unique molecules with many new application opportunities
- HMF/FDCA can replace aromatic compounds that are challenging to produce from renewable feedstock
- Favourable production costs, no “CO₂ lost” in production process

Extract from “DOE Top 12 Report”

<table>
<thead>
<tr>
<th>Building Blocks</th>
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<tbody>
<tr>
<td>1,4 succinic, fumaric and malic acids</td>
</tr>
<tr>
<td>2,5 furan dicarboxylic acid</td>
</tr>
<tr>
<td>3 hydroxy propionic acid</td>
</tr>
<tr>
<td>aspartic acid</td>
</tr>
<tr>
<td>glucaric acid</td>
</tr>
<tr>
<td>glutamic acid</td>
</tr>
<tr>
<td>itaconic acid</td>
</tr>
<tr>
<td>levulinic acid</td>
</tr>
<tr>
<td>3-hydroxybutyrolactone</td>
</tr>
<tr>
<td>glycerol</td>
</tr>
<tr>
<td>sorbitol</td>
</tr>
<tr>
<td>xylitol/arabinitol</td>
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</tbody>
</table>

HMF

5-hydroxymethyl furfural

FDCA

Furan-2,5-dicarboxylic acid
HMF/FDCA
— From specialty chemicals to fuel markets

- Bisphenol A replacement in polycarbonate and epoxy resins
- FDCA as phthalate replacer in plasticizers
- Etc.
- FDCA as partial PTA replacer in PET and PBT
- Etc.
- HMF conversion to “green” diesel and jet fuel
The “Novozymes HMF Technology” focuses on utilising cheap glucose as feedstock

The technology focuses on using both glucose and fructose without separation, converting into HMF at milder process conditions and recycling unused glucose with GI.

Key goal
Integrated process that combines biocatalysis and chemical catalysis; enabling cost-effective production of HMF.
“Novozymes HMF Technology” can use both glucose and fructose and recycle unused glucose.

Published IPs:
- WO 2011/124639 (Oct 12, 2011)
- WO 2013/053816 (April 18, 2013)
High efficient biocatalyst to convert HMF to FDCA

Step 1: Saccharification
- Enzymatic saccharification: from starch to glucose

Step 2: Chemical and enzymatic catalysis
- Enzymatic production of HMF via conversion of glucose to fructose

Step 3: Chemical oxidation
- Chemical oxidation of HMF to FDCA tested in lab/pilot scale

Glucose $\rightarrow$ Fructose $\rightarrow$ 5-hydroxymethyl furfural $\rightarrow$ Furan-2,5-dicarboxylic acid

NEW: Enzymatic oxidation
Proprietary enzyme technology for producing DFF or FDCA

Experimental enzymes and testing made in mM lab scale
- Full conversion of HMF to DFF >30min. Reaction time
- Full conversion of DFF achieved > 1h reaction time
  - Yielding a mixture of FFCA and FDCA
Novozymes has worked on technology for production of HMF in the past 4 years

**Phase I** (2008-2010): Academic/Industrial collaboration
- Project between Novozymes and the Technical University of Denmark
- Initially, very broad investigation of technology to produce HMF
- Proof-of-concept for new and innovative HMF production process
- First patent application filed

**Phase II** (2011-2012): Optimisation phase
- Successfully realized the proof-of-concept for technology
- Demonstration of recycling approach
- Second patent application filed and published

**Phase III** (2012-): Open to partner development in pilot scale and industrialization
Business model: Novozymes is a committed technology provider for HMF/FDCA production

Development phase

- Novozymes is a well established biotech player that actively work on assembling the value chain with our partners
- Novozymes can provide access to
  - Enabling technology (process IPR) and process know-how for making renewable HMF for new materials
  - Enzymes for production of renewable HMF from glucose and/or starch
  - HMF samples (timing and quantity to be discussed)
- Collaboration structure is flexible: Novozymes recognise that partners and customers have different competences

Commercialisation phase

- Novozymes is a biotechnology provider that enables our partners and customers to produce HMF/FDCA
- Novozymes is a committed player in the biobased society that appreciate business models with incentives to improve technology over time
- Remuneration
  - Sales of optimised enzymes
  - Licensing of technology
By varying polymerization conditions (catalyst amount, 2^{-\text{nd}} stage reaction time and 2^{-\text{nd}} stage reaction temperature), different $M_W$ PBFs were synthesized. Preferred second stage reaction conditions for higher $M_W$ PBF is polymerization at 200°C for 8 hours under vacuum using 200 ppm catalyst; The highest PBF $M_W$ values reached was $M_W$ 61,000 and PDI 4.3.
PBF is comparable to PBT with better elongation at break

- When $M_w \geq 37,000$ the elongation at break is comparable to PBT.
- The different crystallinity of PBF leads to slight increases in material strength but decreased ductility;
- Crystal structure of high molecular weight PBF is very similar to the PBT crystal structure.
- Similar thermal stabilities based on TGA traces.

<table>
<thead>
<tr>
<th>Sample No.</th>
<th>Melting enthalpy $^b$ (J/g)</th>
<th>Crystallinity, % from X-ray</th>
<th>Young’s Modulus (MPa)</th>
<th>Elongation at break, %</th>
<th>Stress at break $^c$ (MPa)</th>
</tr>
</thead>
<tbody>
<tr>
<td>6-1 $^a$</td>
<td>6.3</td>
<td>8.1</td>
<td>959±58</td>
<td>1055±56</td>
<td>31.8±2.9</td>
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<tr>
<td>6-2 $^a$</td>
<td>9.2</td>
<td>25</td>
<td>1054±60</td>
<td>445±32</td>
<td>27.5±0.4</td>
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<tr>
<td>6-3 $^a$</td>
<td>39.5</td>
<td>38</td>
<td>1091±117</td>
<td>284±93</td>
<td>35.5±1.9</td>
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<tr>
<td>6-4 $^a$</td>
<td>47.2</td>
<td>44</td>
<td>1112±45</td>
<td>7.4±1.9</td>
<td>43.2±8.5</td>
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<tr>
<td>PBT</td>
<td>48.0</td>
<td></td>
<td>950±104</td>
<td>272±71</td>
<td>37.6±2.5</td>
</tr>
</tbody>
</table>

$^a$ Sample 6 differing in crystallinity.

$^b$ Measured via DSC.

$^c$ Measured via tensile test.
Summary

- **Novozymes** is dedicated to commercialise and continuously optimise the HMF/FDCA production processes and stay in the biochemical’s business as technology provider
  - Successfully realized the proof-of-concept for technology
  - Demonstration of recycling approach
  - Covered by 2 patents
- **Novozymes is developing technology for production of HMF** and can also provide the possibility to transfer HMF to FDCA via enzymatic catalyst
  - The Novozymes enzymatic conversion of glucose to fructose enables further conversion into stable HMF at milder process conditions
  - HMF technology under development is compatible with existing high fructose corn syrup production
  - HMF samples (timing and quantity to be discussed)

- **What is Novozymes looking for? A company...**
  - With strong engineering and scale up expertise
  - With expertise and interest in FDCA and other HMF derived products
  - That has an interest in a business model where Novozymes is remunerated in the form of sales of optimised enzymes and technology licensing
Contact information regarding HMF/FDCA

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