Biological innovations fuel a growing bioresource economy

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California Bioresources Summit
Finding biological answers
Biotechnology innovation – what is it?

Sometimes the greatest answers in life are found in its smallest components.

Enzymes
- Catalyzing processes and building up or breaking down molecules

Microorganisms

We also work with other proteins, biopolymers and related technologies.

Cleaner clothes with less consumption of energy
Better nutrition with less food waste
Green fuel to reduce our dependence on oil
Higher yields and fewer pesticides
Novozymes is the bioinnovation leader-in a broad range of industries

- Household Care
- Agriculture
- Bioenergy
- Animal Health & Nutrition
- Food & Beverages
- Textile
- Pulp & Paper
- Leather
- Wastewater Solutions
Across the agricultural value chain

More yield and crop protection

Healthier animals and fewer additives

Renewable fuel and materials
Biorefineries - transforming bioresources to diverse products

- Wheat
- Wheat straw
- Corn
- Corn stover
- Sugar cane
- Bagasse
- Cassava
- Energy crops
- Sugar beet
- MSW

Starch/sugar-based
Cellulosic-based

- Renewable energy
  - Ethanol
  - Electricity
  - Biogas
  - District heating

- Animal feed
  - Chicken
  - Cow
  - Swine

- Food and beverage
  - Sweetener
  - Modified starch

- Renewable chemicals and materials
  - Chemicals
  - Textiles
  - Plastics
  - Detergents
Enzymes enable the release of sugars from complex plant structures (lignocellulose)

- Enzymes are key to effective and cost efficient ethanol production, releasing C5 and C6 sugars from the biomass.
- During the fermentation process, yeasts or other microorganisms convert the sugars into products.
- Lignin is typically used for generating steam and power.
Example of an integrated cellulosic biorefinery

Sustainable bio-feedstock

Straw → Ethanol production

Ethanol production → Combined heat and power (CHP)

Combined heat and power (CHP) → Biogas production and upgrade

Biogas production and upgrade → Sustainable bio-feedstock

Ethanol 0.30 l/kg straw*

Excess electricity 0.27 kWh/kg straw*

CO₂ 0.7 kg/kg straw*

Biomethane 58 l/kg straw*

Biofertilizer

*Lignin

Electricity & stream

Electricity

*Dry matter
The vision of a fossil-free energy and transport system

- Wind
- Solarpower
- Sustainable bio-feedstock

- Windpower
- Combustibles and/or biogas
- Carbon storage
- Biorefinery
- Materials and feed

- The grid
- E-fuel synthesis
- Liquid and gaseous fuels

- Windpower
- Solarpower
- Sustainable bio-feedstock
- CHP
- Combustibles and/or biogas
- Carbon storage
- Biorefinery
- Materials and feed

- Liquid and gaseous fuels
- Materials and feed
Heavy-duty transportation is not as easily electrified, and will emit more than light-duty

60-70% of transport CO₂ emissions in 2050
Decentralized approach to bio-innovation

14 major R&D sites  
~1400 employees
Raizen’s Costa Pinto Plant in Piracicaba (SP, Brazil)

- Capacity 11 mGal/yr
- Sugarcane bagasse
- “Bolt on” at existing sugarcane biorefinery
- In operation since late 2015

* Source: novoCana.com 22 Mar 2017
st1 Cellunolix® Kajaani plant in Finland

Ethanol Capacity 2.6 mGal/yr
• Additional side products: lignin, biogas, turpentine, furfural, vinasse,

First of a kind process optimized for softwood
• Sawdust (80 % pine & 20 % spruce)

Plant in operation since 2017
Renescience- Household waste to green energy

Northwich plant in UK-operational since 2017

First full-scale bio plant in the world capable of handling household waste by means of enzymes.

Unsorted MSW waste to power, sorted glass/metal/plastics, solids (for incineration) generate around 5 MW of electricity which is enough to power around 9,500 typical households.

Current commercial biomass conversion plants using biochemical pathways

“Steel in the ground”
... ~ USD 2 BN Total Investment Cost...
...with an EtOH production capacity of ~130 M gal/yr
...on 3 continents
Conclusions

• Novozymes brings diverse technology options relevant for expanding sustainable use of bioresources

• Path to decarbonization relies on biorefineries, along with electrification – Green carbon and Green electrons

• Continue expansion of products in biorefineries, while learning from global “first movers”
Questions
18 years of continuous development has enabled a new industry

- **2001**: One of largest R&D investments in Novozymes’ history was initiated.
- **2005**: Biomass conversion pilot plants worldwide testing Novozymes enzymes.
- **2009**: Launch of Cellic® CTec for the first cellulosic ethanol demonstration plants.
- **2013**: The first commercial cellulosic ethanol plant: Crescentino, using Cellic® enzymes.
- **2014**: Exclusive partnership with Brazil’s largest sugar-based ethanol producer.
- **2015**: Launch of first Cellic® customized products- significant cost reductions for key customers.
- **2017+**: Expansion and diversification of commercial processes.

**Biomass conversion pilot plants**

- **2009**: Launch of Cellic® CTec for the first cellulosic ethanol demonstration plants.
- **2013**: The first commercial cellulosic ethanol plant: Crescentino, using Cellic® enzymes.

**Customized Cellic® enzyme technology**: customization of enzymes to match specific process and feedstock.

- **Enzyme use costs (indexed)**
  - **2007**: 100
  - **2008**: 80
  - **2009**: 60
  - **2010**: 40
  - **2012**: 20
  - **2015**: 10
  - **2018**: 0

**Years**

- **2007**: Cellic® CTec
- **2009**: Cellic® CTec2
- **2012**: Cellic® CTec3
- **2015**: Customized Cellic®
Novozymes Yeast - Cellerity®
With Cellic®, providing full biotechnology package to cellulosic ethanol producers

- **Stable**
  - Stable diploid industrial yeast strain able to ferment C5/C6 biomass slurries at 15-20% TS.
  - Propagates on industry standard substrates without costly supplemental nutrients

- **Robust**
  - Typical yeast pitch of 0.5 to 1 gDCW/L
  - Rapid xylose conversion even at high acetate levels.
  - Temperature tolerant to temporary excursions above 35°C

- **Substrate utilization**
  - >85% total sugar utilization (>90% glucose, >80% xylose)

- **Speed**
  - Fast fermentation (complete within 48-72 hours depending on %TS and pitch)
  - Fast xylose consumption throughout fermentation, specific uptake rates of 1.2 g/L/h have been observed.

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**NREL Acid Pretreated Corn Stover**
20% TS, 1 g DCW/L, pH 5.5, 2 g/L urea, 35°C

![Graph showing sugar and alcohol concentrations over time](image-url)
Bridging the gap to a sustainable future

- Is a call to define an effective pathway to mitigate climate change
- Is Novozymes contribution based on what we know works
- Is intended to start a conversation and an invitation to work together
- Is a living document (not final) for all to access and use without restrictions

Find the report on Novozymes.com
Biorefining is a platform that will develop and adapt over time.

Production cost of standard fuel equivalent vs. Time

- Fuels
- Electricity
- Feed / food / chemicals / materials
- Carbon capture and storage
Typical enzymes used in industrial processes

<table>
<thead>
<tr>
<th>Class</th>
<th>Industrial enzymes</th>
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| **Oxidoreductases**    | Peroxidases (Catalases)  
                       | Glucose oxidases  
                       | Laccases                                                      |
| **Transferases**       | Fructosyltransferases  
                       | Glucosyltransferases                                        |
| **Hydrolases**         | Amylases  
                       | Cellulases  
                       | Lipases  
                       | Pectinases  
                       | Proteases  
                       | Pullulanases  
                       | Phytases                                                      |
| **Lyases**             | Pectate lyases  
                       | Acetolactate decarboxylases                                  |
| **Isomerases**         | Glucose isomerases                                                               |
| **Ligases**            | No products at the moment                                                        |

**Transferase**

\[ A + B + X \rightarrow A + X + B \]

**Ligase**

\[ A + B \rightarrow A + B \]

**Oxidoreductase**

\[ A + B \rightarrow A + B + \cdot \]