Advancing cellulosic ethanol

Exco 60 Workshop (IEA)

Alain Destexhe
Customer Solution Manager

Munich, October 30th, 2007

06/11/2007

The fundamentals

The industrial revolution has been very successful in providing us with incredible amounts of goods

But it has in many places been at great costs to nature and our natural resource base

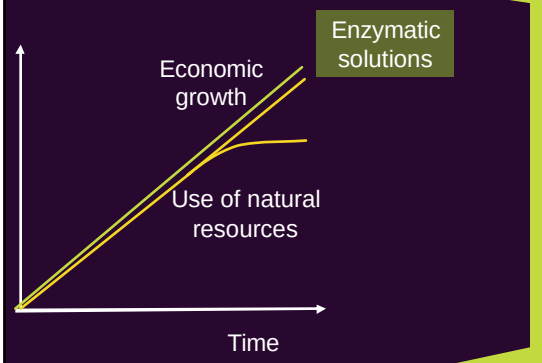
There is a need for accelerated economic growth to meet the needs of a growing world population

– but with less impact on nature

...so we need to find ways to produce more

– with less

Decoupling from economic growth



Enzymes are efficient biological catalysts found in all living organisms

Used in production they can increase the efficiency and yield of a wide range of processes in our society

With enzymes we can "produce more with less" and contribute to the decoupling of economic growth and the use of natural resources

Enzymes are used to produce many of the products we use in our daily lives

Enzymes normally:

- Reduce energy & water consumption
- Reduce the need for harsh chemicals
- Reduce the amount of by-products
- Improve yields

We lead the way in finding sustainable solutions for forward-thinking companies

- Environmental impact comparisons

CO_2 cost producing 1 kg enzyme:

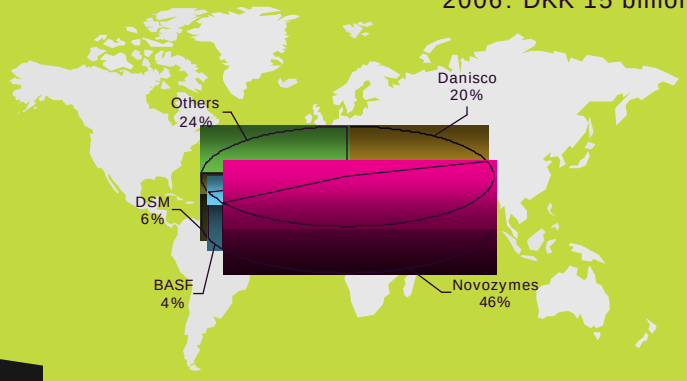
plus 1–10 kg

CO_2 reduction using 1 kg enzyme in different industries:

Minus

Undisputed world leader in industrial enzymes

Total market value 2006: DKK 15 billion



Source: Novozymes' estimate 2006

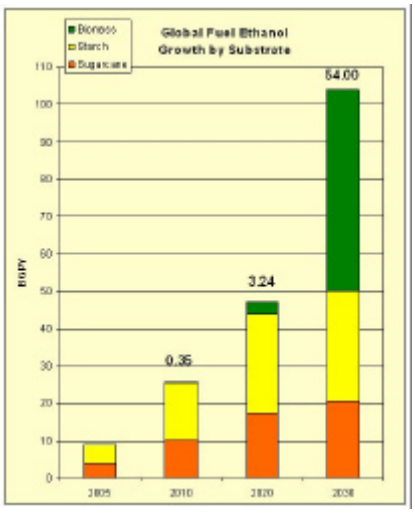
Novozymes - brief introduction

- World leader in industrial enzymes & microorganisms
- Enzymes account for 95% of turnover
- Market leader in all main industries
- More than 600 products sold in 130 countries in 40 different industries
- ~13% of sales invested in R&D
- More than 5,000 granted or pending patents
- Main production in USA, China, and Denmark
- Sales USD ~1.2bn (FY2006)
- Strong profitability (19.7% FY2006) and solid generation of cash flow
- More than 4,500 employees

Novozymes and the biofuels area

- 20–25% growth over next 3–4 years
- Largest supplier of enzymes to the fuel ethanol industry
- Mainly a US business but Europe & Asia nicely growing from lower levels
- RSH-process, reduces energy need, and improves yields from corn-based production
- Collaborations in biomass with industry leaders:
  - POET (formerly Broin) in the US
  - COFCO in China
  - Abengoa in Europe and US
  - CTC in Brazil
- Cellulosic ethanol still 4 years down the road

Growth of Bioethanol: NZ View



Fuel Ethanol growth will be dominated by sugarcane and starch through 2020.

Biomass takes over as starch and sugar become expensive and scarce.

Unless a breakthrough happens…

Agricultural residues
corn stover, bagasse, rice straw, energy crops

Tree residues
mill discard, urban trimming

Cellulosic ethanol

Industrial waste
paper sludge, spent grains

Municipal waste
Newsprint, office paper

Pre-treatment
Physical/chemical disruption, size reduction, hemicellulose, lignin depolymerization

Cellulose	Hemicellulose	Lignin
Enzyme hydrolysis	Enzyme or acid hydrolysis	Chemical feedstock or energy
Glucose	Pentose sugars	
Ethanol, 1,4 diacids, PLA etc.	Ethanol, 1,4 diacids, etc.	

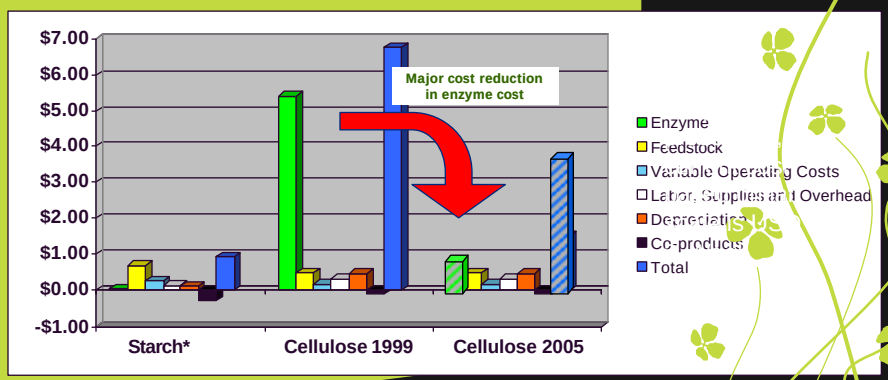
Many challenges remain to be solved – integration!

Feedstock	Pre-treatment	Enzyme hydrolysis	Fermentation	Products co-products
o Selection-collection-storage o Broad spectrum of viable options o Infrastructure required o Ease of pre-treatment Critical cost factors: → Collection cost → (Density)	o Physical disruption o Thermo-chemical o Many candidates-no clear winner o Toxicity of by-products to hydrolysis /fermentation Critical cost factors: → Capital cost → Digestibility → Yield of C5 sugars → Fermentability	~ USD 0.13 0.18/Gal (NREL process economic model/metric) * o Co-location requirement? o Major capital investment required o Hydrolysate tolerance **Critical cost factors:** → **Enzyme loading** → **Enzyme price**	o C6 & C5 conversion o Hydrolysate tolerance Critical cost factors: → Ethanol yield	Critical cost factors: → Concentration → Purity → Value

*** NZ estimates = $0.47-0.93/gal**

Enzyme cost no longer dominates the picture

- Cost comparison after the BioEnergy Project: grain versus biomass in USD/gallon ethanol, April, 2005*



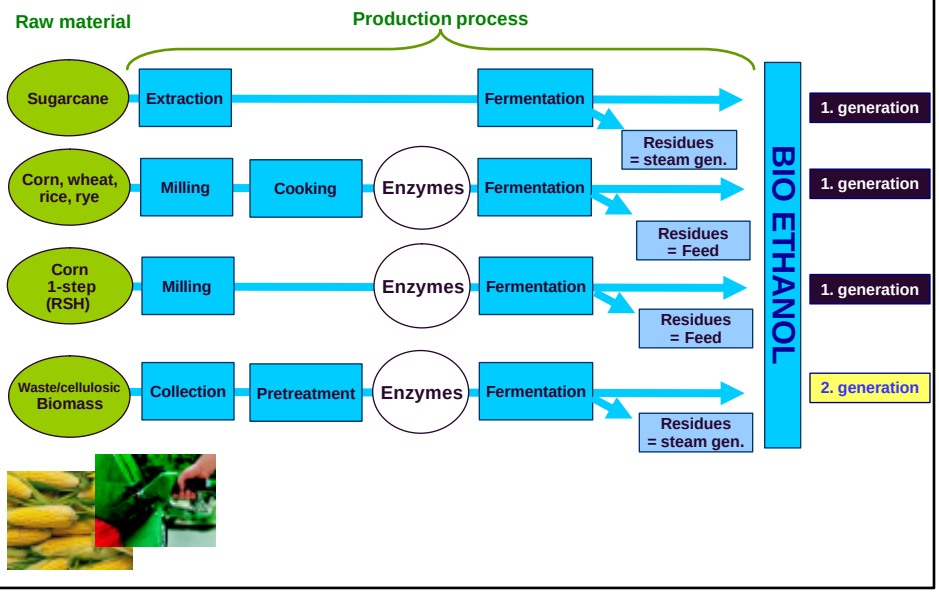
*Modified from "Determining the Cost of Producing Ethanol from Corn Starch and Lignocellulosic Feedstocks", NREL/TP-580-28893 joint USDA, NREL study released in October 2000.

Novozymes' R&D in cellulosic ethanol

DOE/NREL/Novozymes 2001–2004

- Enzyme cost reduction on NREL acid pre-treated stover
- USD 17.8 million grant
- Announced 30-fold cost reduction based on enzyme improvements and process development

Ethanol Production: Technology Evolution

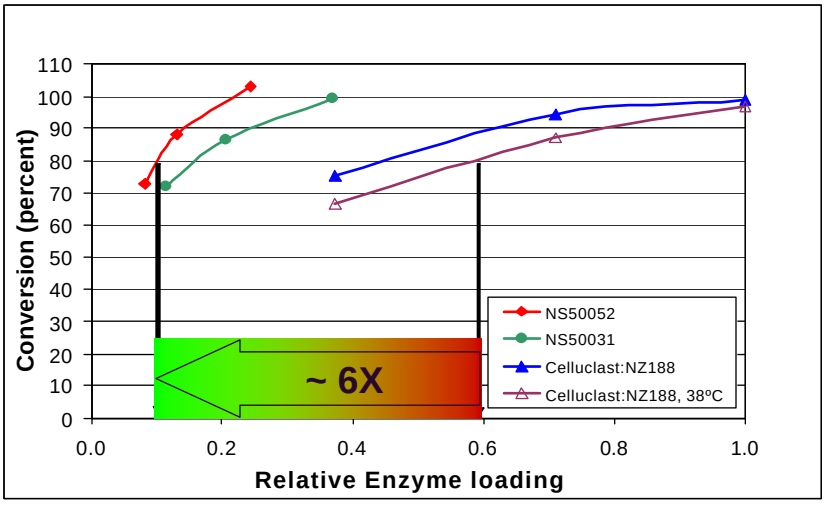


1st generation bioethanol versus 2nd generation bioethanol

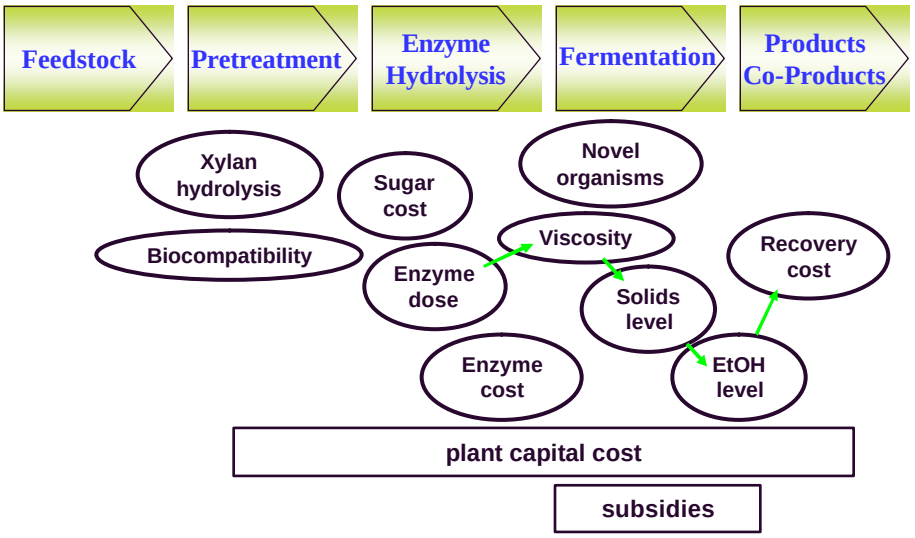
- 2nd generation bioethanol will prove to be a very attractive replacement for gasoline for both economic and environmental reasons*
- The 1st generation bioethanol market must be established in order to facilitate (logistics, filling stations, etc.) the transition towards 2nd generation bioethanol
- Novozymes is committed to be the innovation engine in both 1st and 2nd generation bioethanol production with selected partners

*JRC/Concave/Eucar "Well-to-Wheel"(2005)

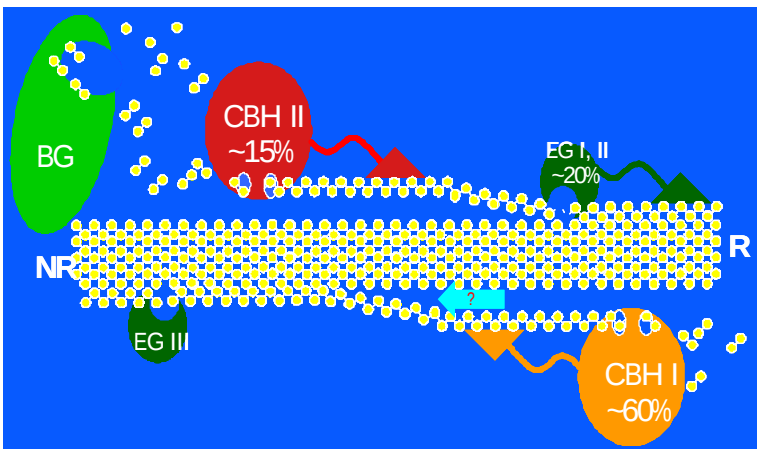
Enzyme improvement



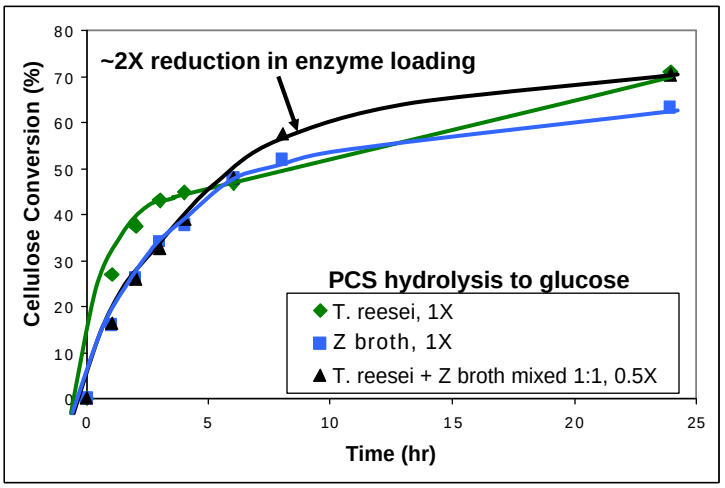
The total process view
-- Developments in one area can impact other areas --



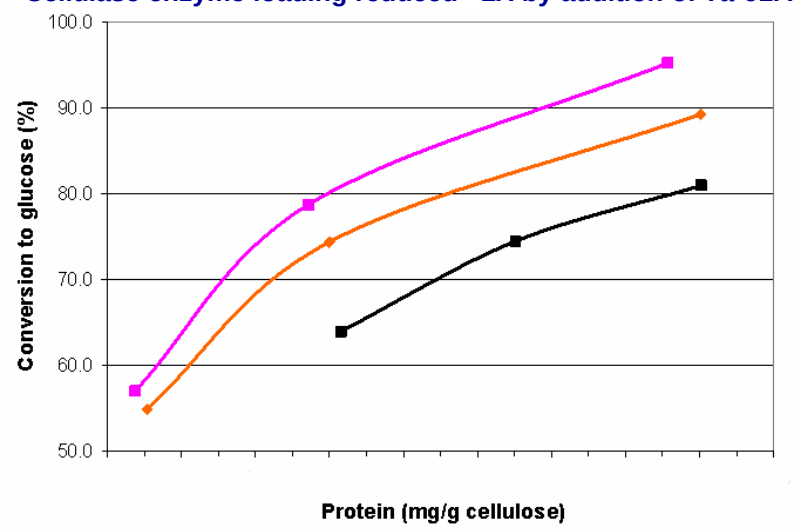
Fungal Cellulase:
A complex, interacting enzyme mix



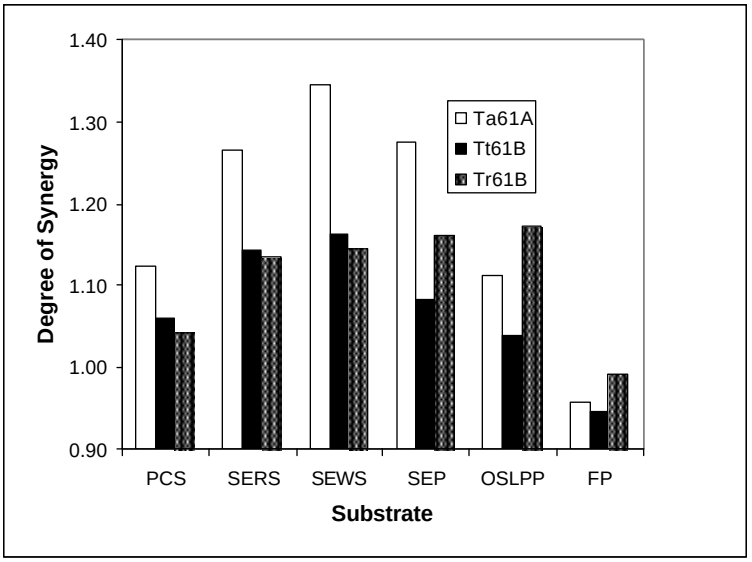
Fungal proteins that work synergistically with *T. reesei* cellulase



Cellulase enzyme loading reduced ~2X by addition of *Ta* 61A



GH61 effect on various substrates



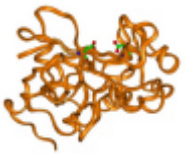
General Challenges for enzyme supply

Technical Challenges of Diversity!

- Variable Feedstocks
- Variable Process scenarios
  - Pretreatments
  - Fermentation organisms

One example:

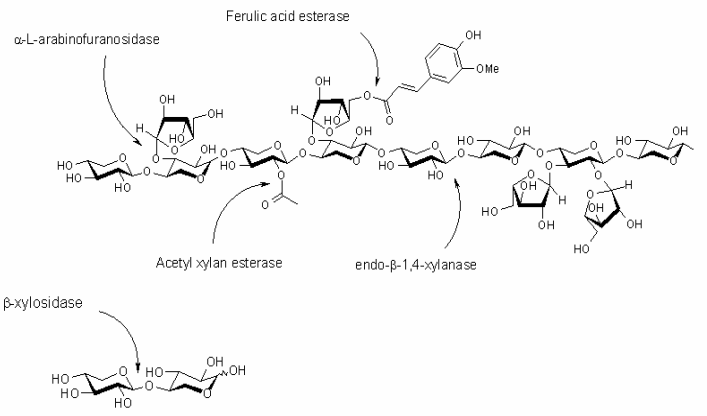
A lower capital cost pretreatment that does not solubilize hemicellulose



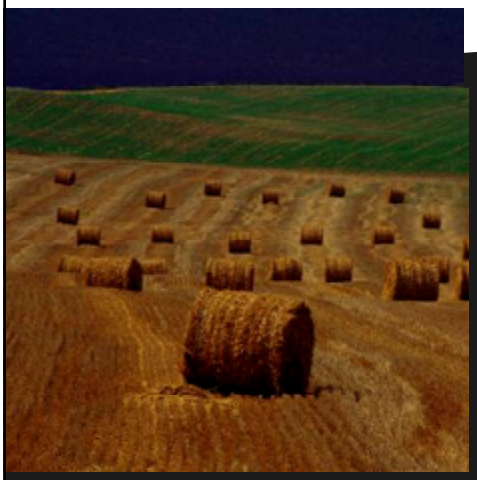
Good progress has been made, but…

- Many pretreatments do not fully solubilize the hemicellulose fraction in biomass
- These pretreatments are attractive as they generally have lower capital cost and are friendlier to fermentations
- Hemicellulose deconstruction requires many more enzyme activities!
- Hemicellulases are generally poorly expressed relative to cellulases, so they cost more!
- Our goal is to devise a hemicellulase mixture that is cost effective

Arabinoxylan degrading enzyme activities



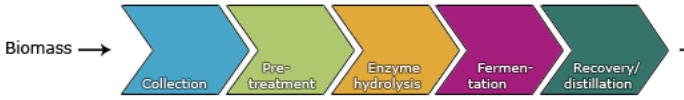
Novozymes and cellulosic ethanol



- Extensive R&D, market, and technical expertise
- Extensive leverage from our manufacturing, R&D, and marketing capabilities in Europe, North America, Latin America, India, and China
- Development of novel cellulases through an unprecedented R&D effort
- Development of several novel hemicellulases as well
- Putting enzymes to work through partnerships

The next steps in cellulosic ethanol

- Four years before commercially viable production process
- Enzymes:
  - Scale-up is to take place
  - Evaluation of enzyme production set-ups
  - Further improvements in enzyme performance



- Business model clarity to be established
- Integration of process steps
- Reduction in capital costs
- More flexible pilot plants using a wide feedstock range
- Continued governmental support

Wrap up

- Enzymes are key to a cost-effective and sustainable development of the fuel ethanol industry and Novozymes is well positioned:
  - Strong track-record
  - Strong R&D platform
  - Strong collaboration partners
  - Strong and unprecedented commitment
- Novozymes is committed to being the innovation engine in both 1st and 2nd generation bioethanol production
- Commercialization of cellulosic ethanol is expected within 4 years from now
- A lot has been achieved already – a lot more still has to happen - and work accelerates
- Learn more at: www.biomass.novozymes.com

Thank you