Development of High Performance Enzymes

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PROGRESS IS MOST APPARENT IN THE FACT THAT
- A CELLULOSIC ETHANOL INDUSTRY IS EMERGING NOW

World Map: Public info on large scale plants are either built and in the process of scaling up operations or in the currently under construction..."; biochemical conversion (capacity in mio. US gallons per year)
**De-risk Technology: Novozymes Has Been a Key Enabler of the Commercialization**

**Illustrative Example:**

- 10X improvement over 12 years
- From main inhibitor to valuable tool
- Now other cost items hit the steep part of customers' development curves
Drivers of Enzyme Cost Reductions: Enzyme Discovery, Engineering and Production Economy

**Discovery case:**
GH61 is boosting hydrolysis

- + recombinant GH61
- No GH61 added

**Protein engineering case:**
Design of an inhibitor-tolerant BG

**Production economy case:**
*T. reesei* expression

- Recombinant CBH I
- Expressed in *T. reesei* where native CBH I has been deleted

“If it doesn’t express, it doesn’t exist”
Improved hemicellulases in Cellic Ctec3 compared to Cellic Ctec2 increase the xylose yield
Xylan interacts with cellulose and prevents release of glucose

- Optimise cell wall polysaccharide structure and hydrolase specificity
- Reduce the costs and energy of pretreatment and saccharification
- Unlock more fermentable sugars from plant biomass
IMPROVED GLUCOSE YIELD

Improved cellulases in Cellic Ctec3 compared to Cellic Ctec2 increase the glucose yield.
As Industrialized Processes Are Locked into Place, Highly Customized Technologies Are Needed

- Different pretreatment technologies produce different hydrolysates and inhibitors
- Hemicellulose mix (C5 sugar types) also vary. Enzyme components must be tailored to match
Now the Time Has Come to Benefit from Customization for the Individual Process

- Diverging processes are being established at industrial scale
- For every process, there will be an optimal enzyme blend
- Every blend will require further optimization work
- Current CTecX blends contain over 8 separate, unique enzymes

Feedstock pretreatment
- Physical treatment
- Chemical intensity

Cellulosic hydrolysis
- Solids level
- Sugar composition
- Separation and side streams

Further processing
- Yeast
- Fermentation
- Catalysis

Optimization opportunities, many are enzyme related
Adapt and Utilize Strengths to Enable Customers

The game is changing, and Novozymes must stay ahead of the curve
• From demo to commercial
• From breakthrough innovation to process and product optimizations
• From enzyme performance at lab bench to enzyme cost/performance at plant

Leverage premier position
• Use global presence and experience to guarantee enzyme delivery at scale
• Develop individualized delivery models with customers
• Default is hub-and-spoke. Looking to add capacity in Brazil

Customize
• Total production cost will be further reduced through customization
• Enzymes will be developed to fit the needs of specific cellulosic technology, customers, processes and feedstock
A Strong and Optimized Technology Backbone Will Guide Customization

- Enzyme efficacy – a measure of the amount of enzyme needed to achieve a given level of conversion of biomass to sugars – has been dramatically improved.
- Average relative "fold improvement" in enzyme performance over time on a range of industrially relevant pretreated substrates is shown below.
First-wave Commercialization … and Innovation Continues (a Game We Know)

First-wave commercial-scale ethanol plants will initiate the realization of further cost-saving potential in most cost elements through:

- Combined enzyme, yeast and process optimization
- Design experience
- Operating experience

### Enzyme cost-efficiency development
2012 = index 100

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### Total production cost estimate
2012 = index 100

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Illustrative projections of future costs.
THANK YOU FOR YOUR ATTENTION