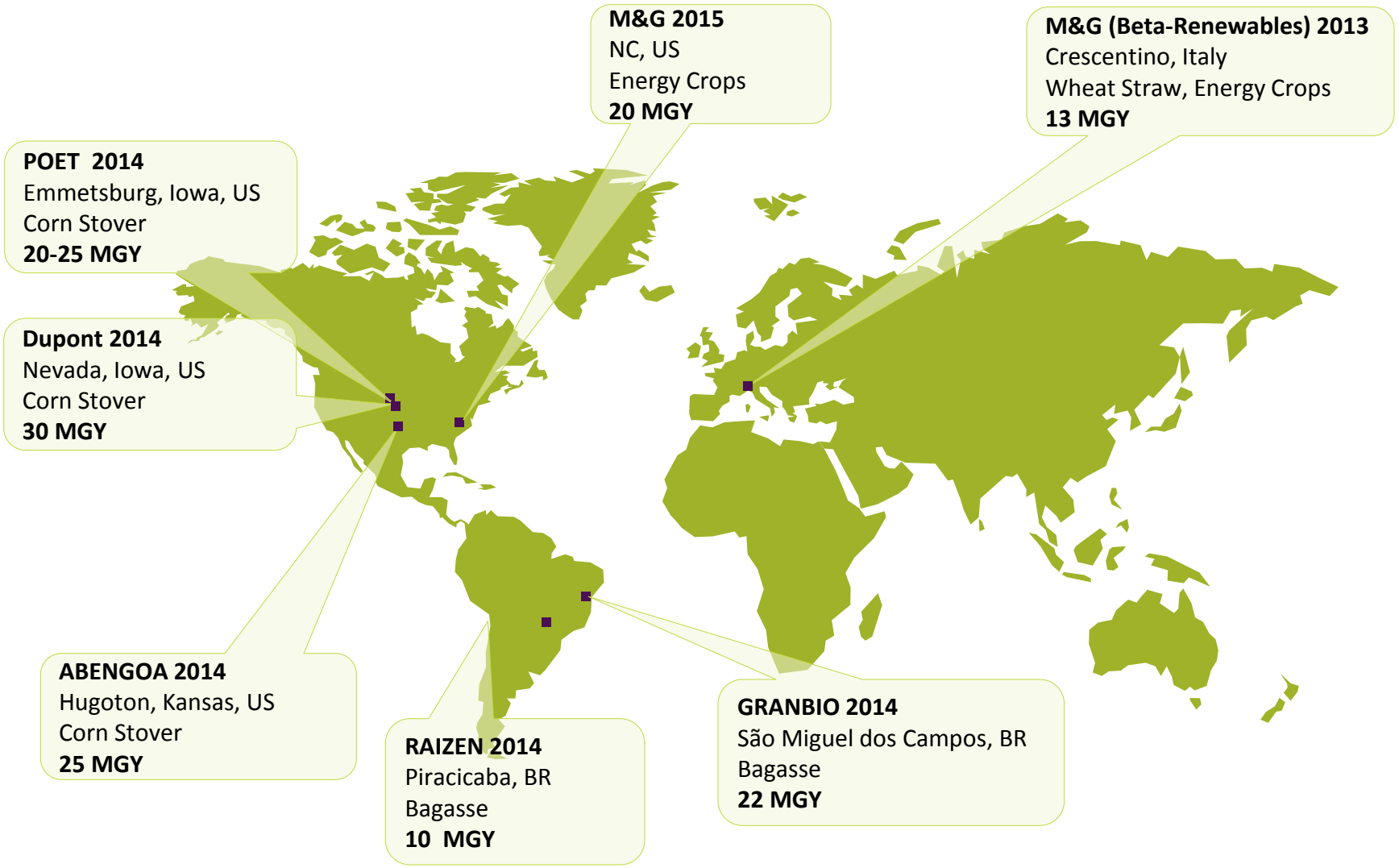



Development of High Performance Enzymes

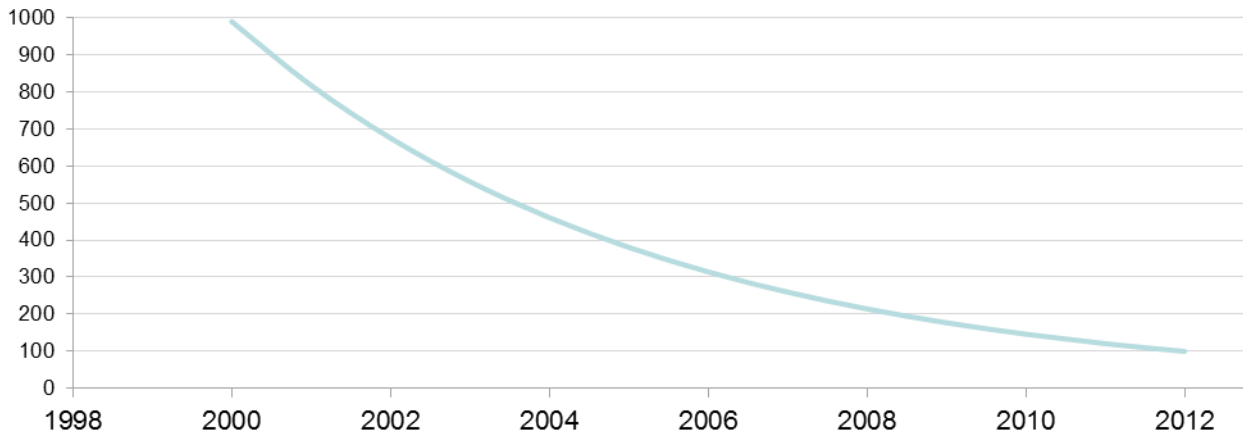
Johan Mogensen, Novozymes R&D

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



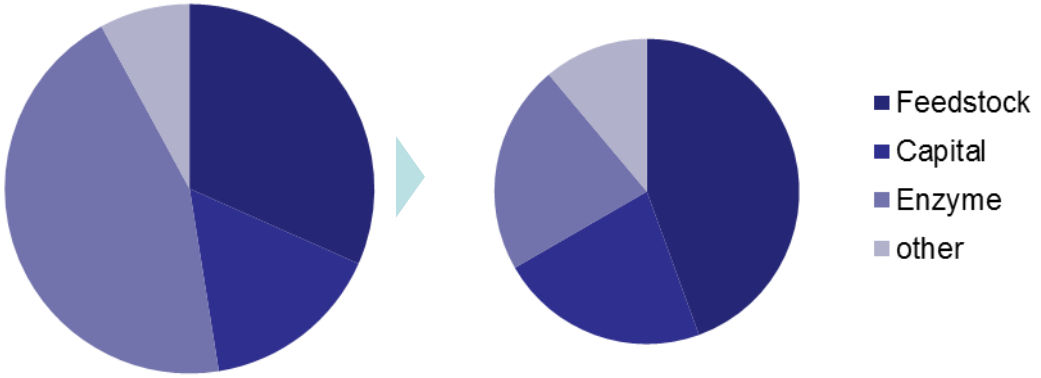
World Map: ***Public info on large scale plants are either built and in the process of scaling up operations or in the currently under construction…"; biochemical conversion (capacity in mio. US gallons per year)***

De-risk Technology: Novozymes Has Been a Key Enabler of the Commercialization



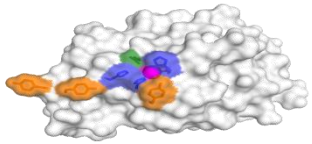
- 10X improvement over 12 years
- From main inhibitor to valuable tool
- Now other cost items hit the steep part of customers' development curves

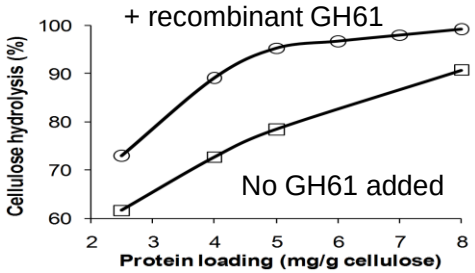
Illustrative Example:



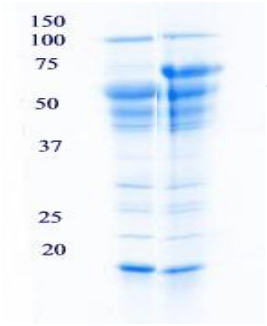
Drivers of Enzyme Cost Reductions: Enzyme Discovery, Engineering and Production Economy

Discovery case:
GH61 is boosting hydrolysis





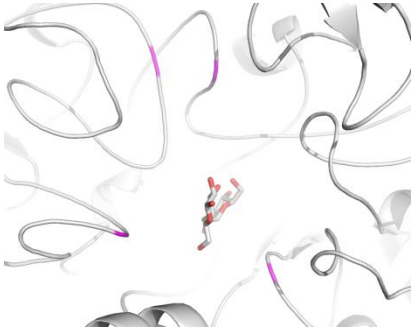
Production economy case:
T. reesei expression

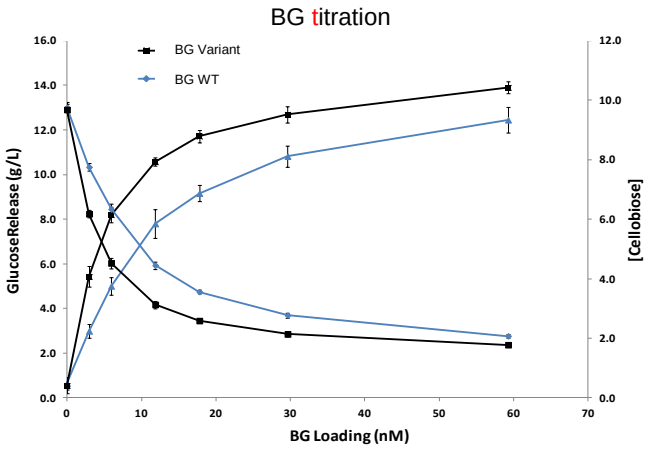


Recombinant CBH I
Expressed in *T. reesei* where native CBH I has been deleted

"If it doesn't express, it doesn't exist"

Protein engineering case:
Design of an inhibitor-tolerant BG

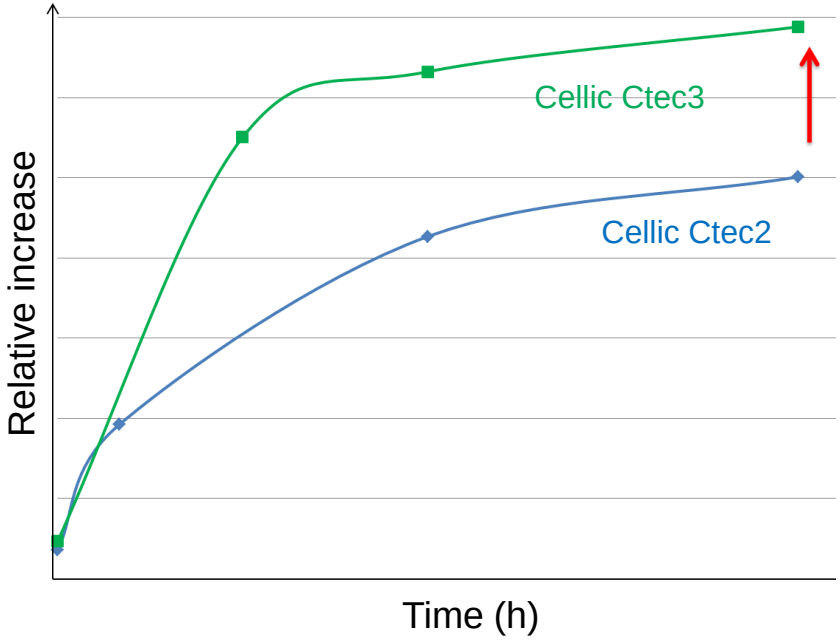




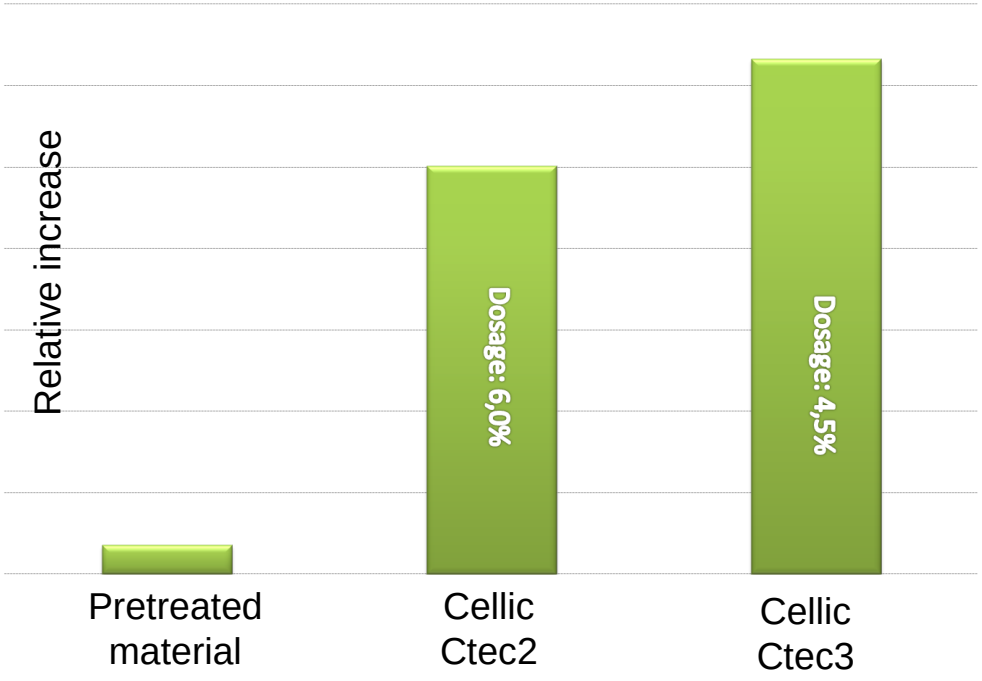
CELLIC CTEC2 VERSUS CELLIC CTEC3 - IMPROVED XYLOSE YIELD

Improved hemicellulases in Cellic Ctec3 compared to Cellic Ctec2 increase the xylose yield

Improvement in xylose yield at iso-dosage

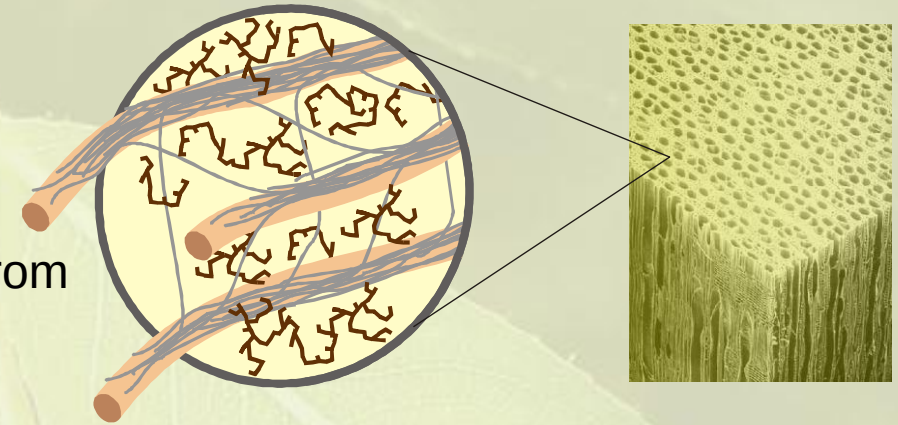


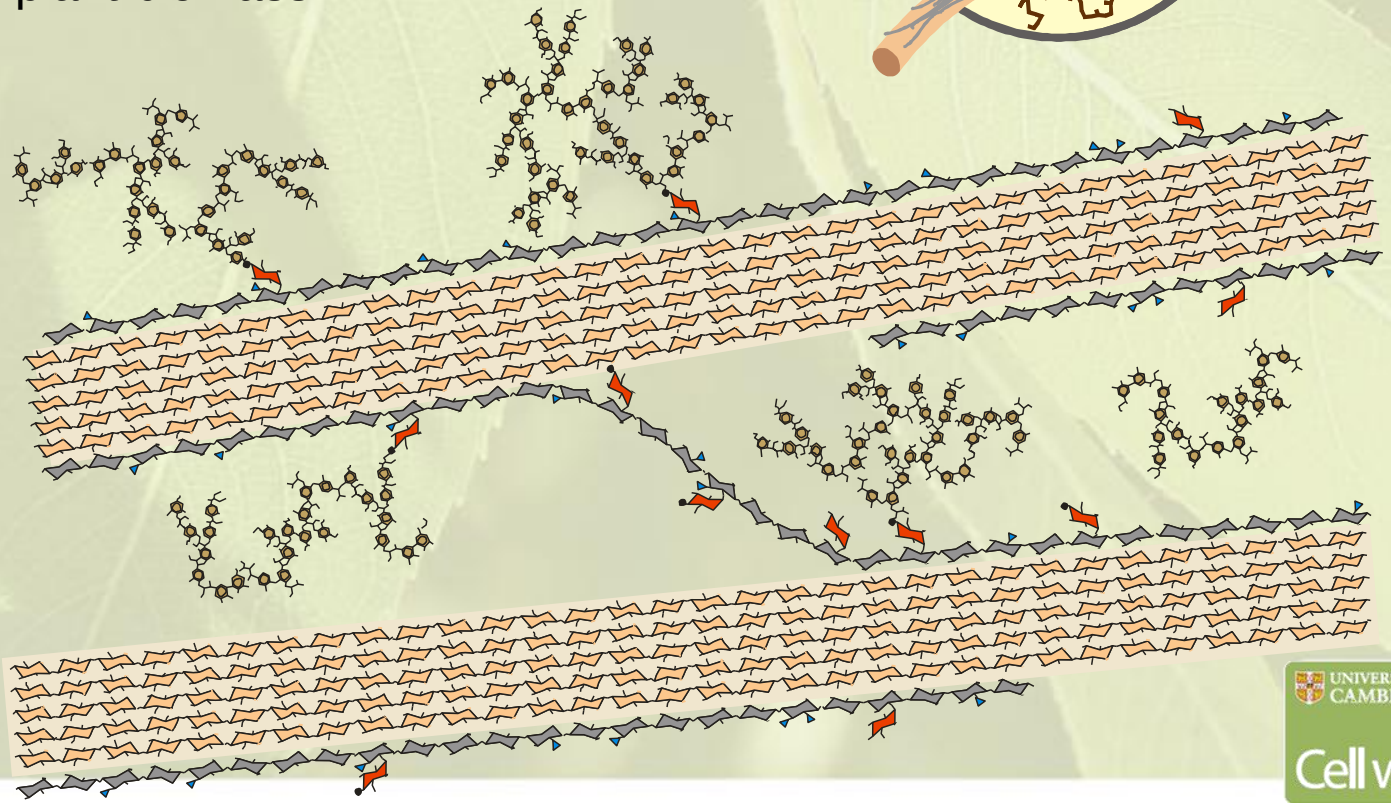
Xylose released - dosed at iso-activity



Xylan interacts with cellulose and prevents release of glucose

•Optimise cell wall polysaccharide structure and hydrolase specificity
• Reduce the costs and energy of pretreament and saccharification
• Unlock more fermentable sugars from plant biomass



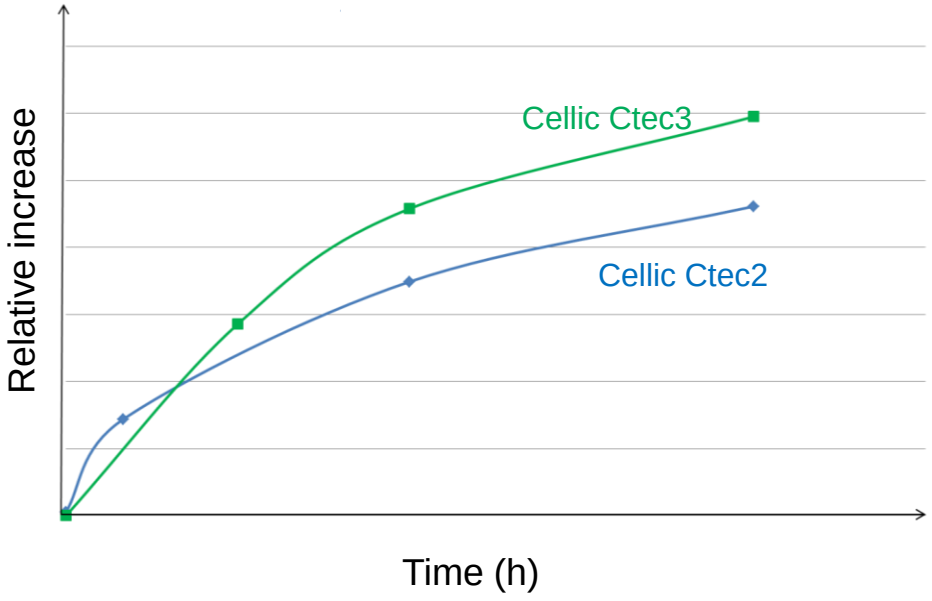


UNIVERSITY OF CAMBRIDGE
Cell wall sugars

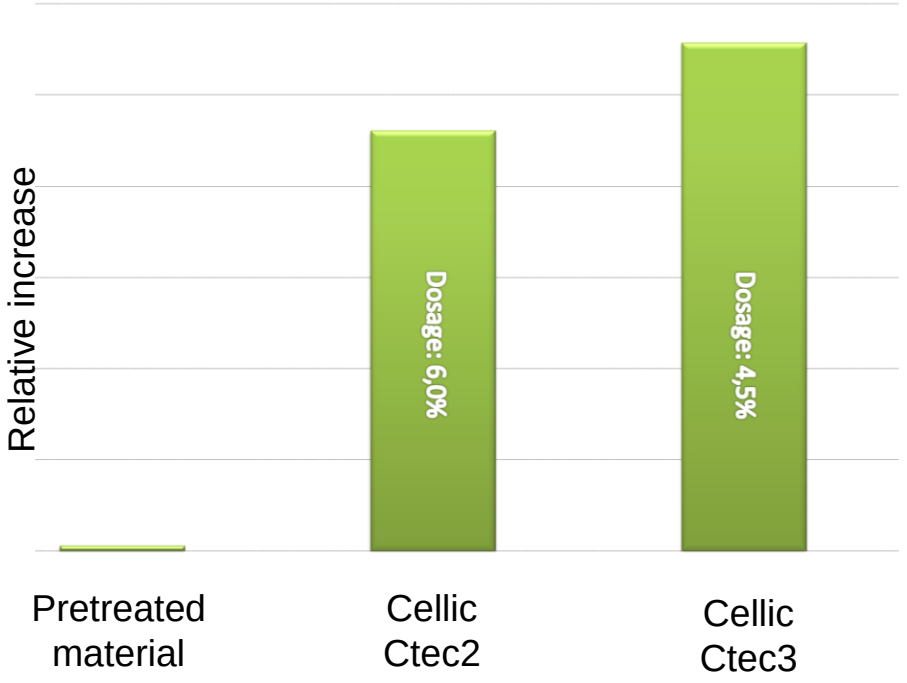
CELLIC CTEC2 VERSUS CELLIC CTEC3 - IMPROVED GLUCOSE YIELD

Improved cellulases in Cellic Ctec3 compared to Cellic Ctec2 increase the glucose yield

Improvement in glucose yield - at iso-dosage

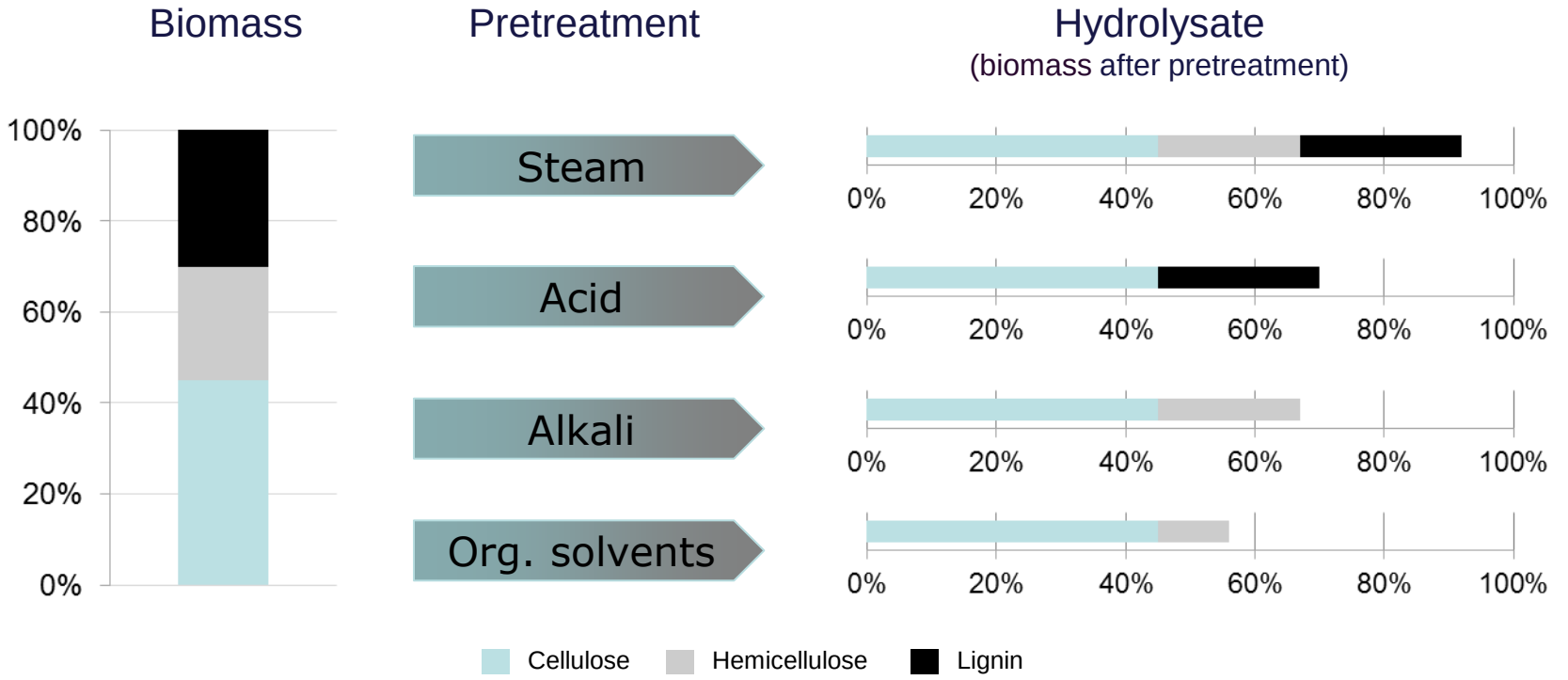


Glucose released - dosed at iso-activity



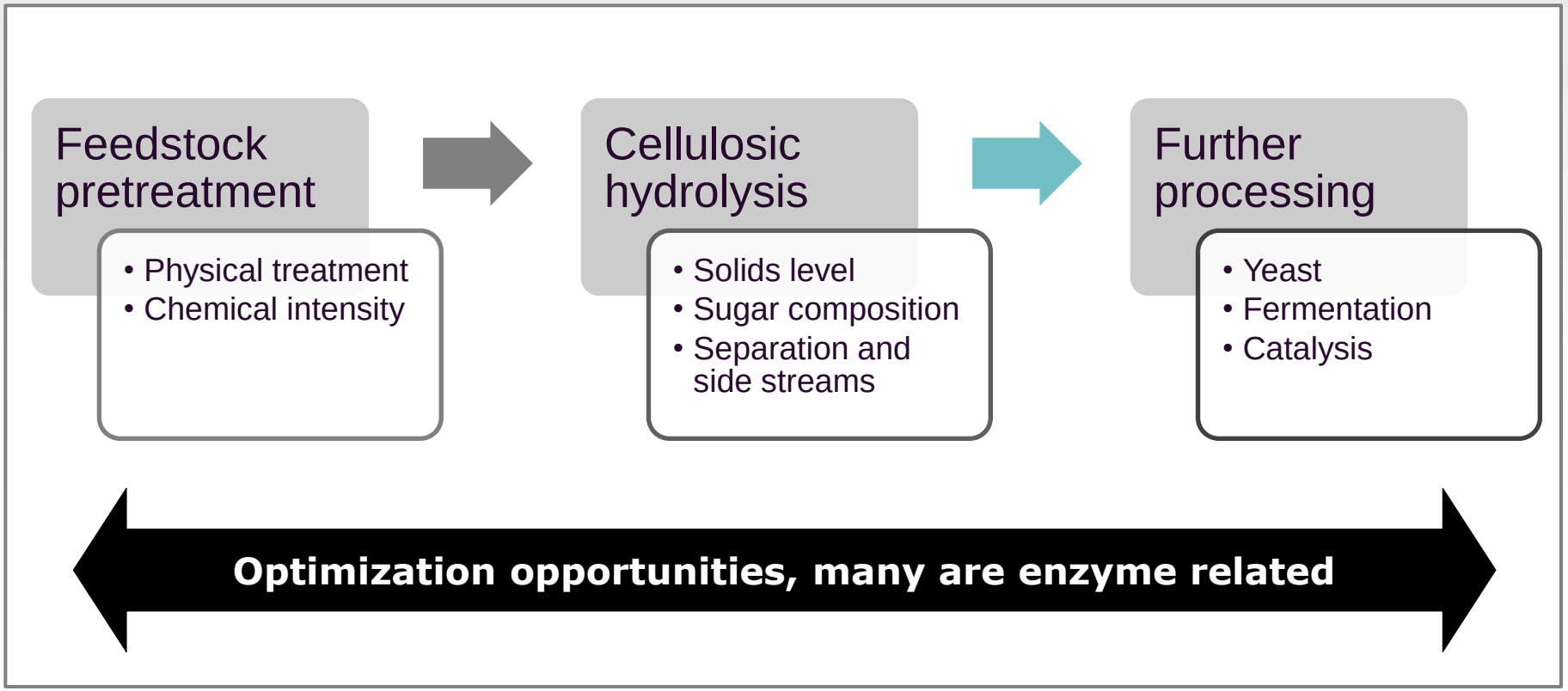
As Industrialized Processes Are Locked into Place, Highly Customized Technologies Are Needed

- 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



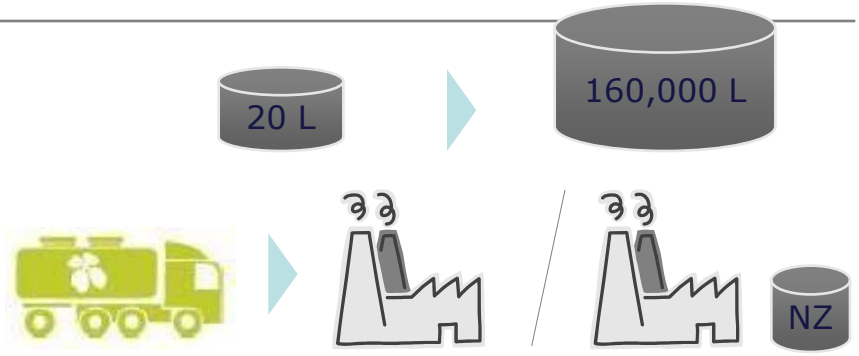
Adapt and Utilize Strengths to Enable Customers

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

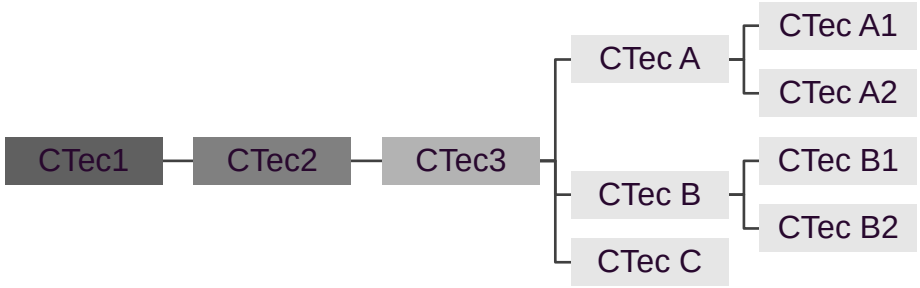
Leverage premier position

- 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



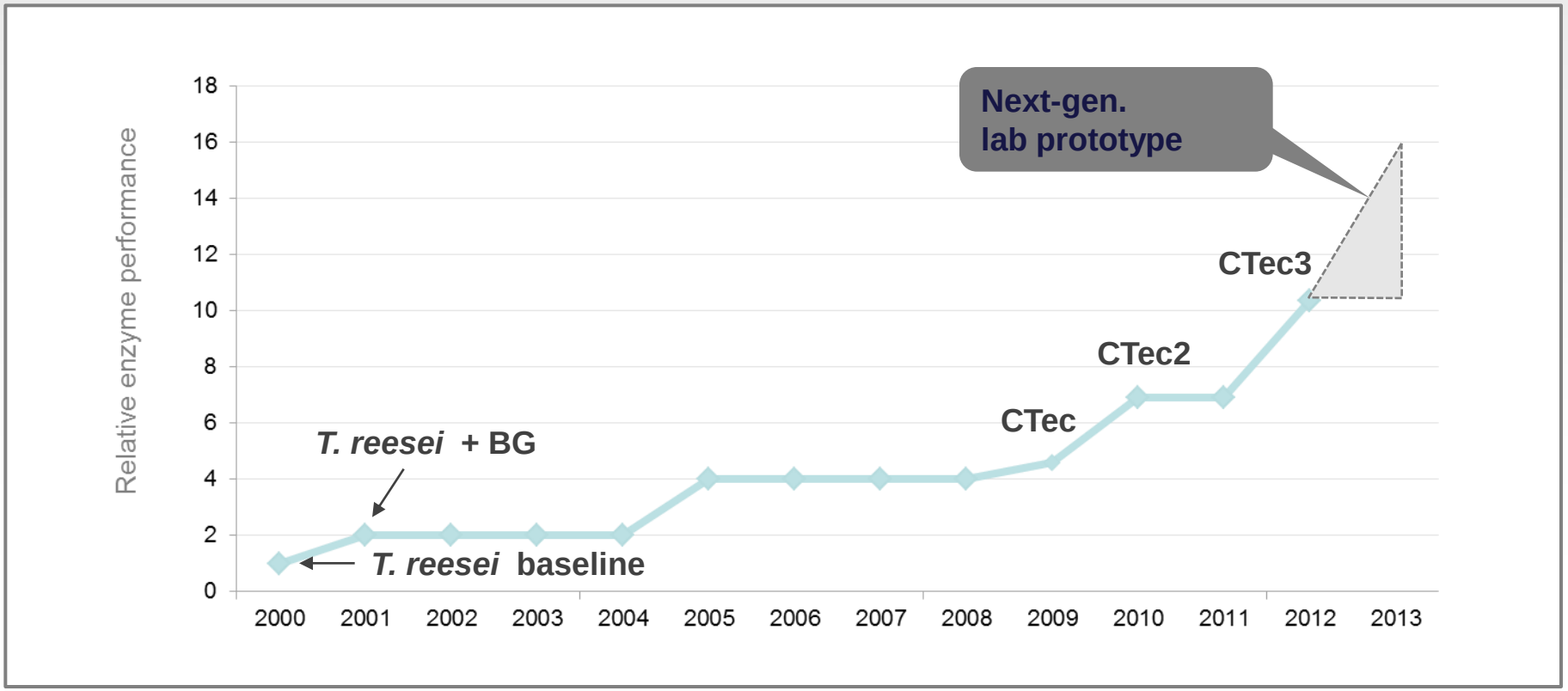
Customize

- 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



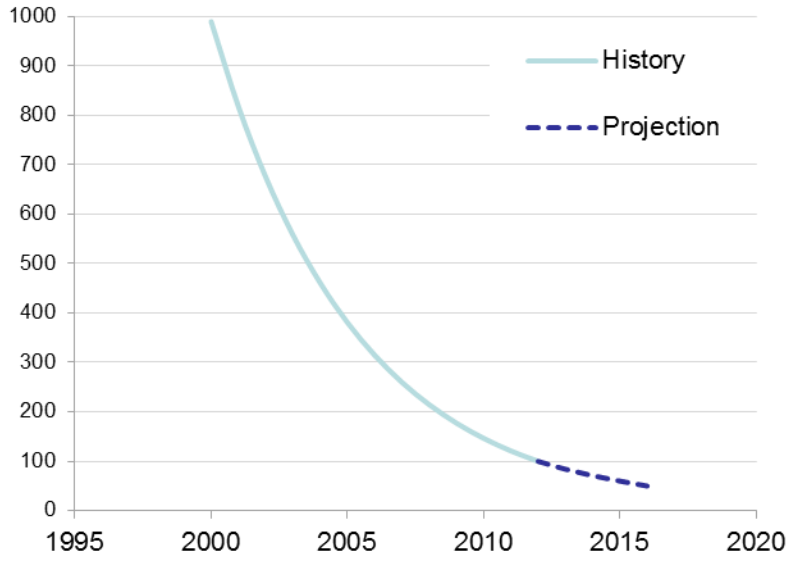
First-wave Commercialization
… and Innovation Continues (a Game We Know)

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

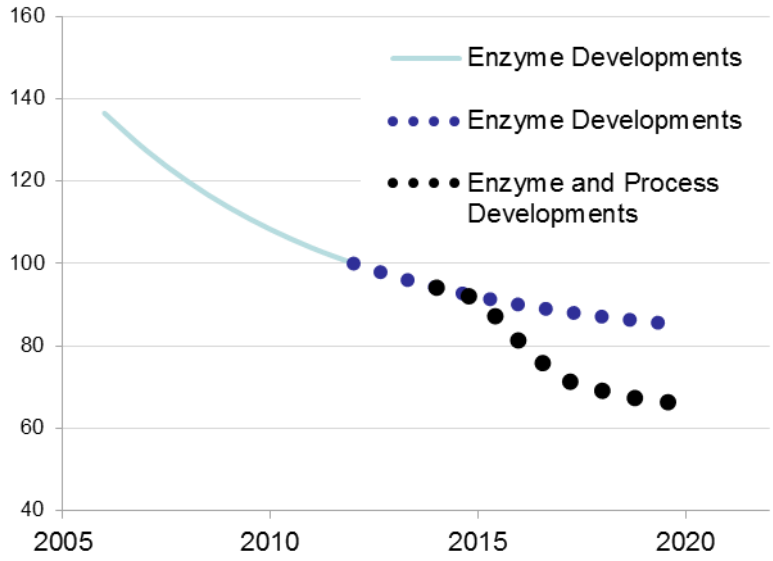
- Combined enzyme, yeast and process optimization
- Design experience
- Operating experience

Illustrative projections of future costs

Enzyme cost-efficiency development
2012 = index 100



Total production cost estimate
2012 = index 100



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THANK YOU FOR YOUR ATTENTION