


***Industrial Biocatalysts for the bio-based  
economy***  
***Biorefinery development & Biocatalysis***

**Pauline Teunissen**

**Renewable Resources and Biorefineries**  
**September, 19-21, 2005**

# Defining a Biobased Economy

A Danisco Company



An economy based on biotechnology that uses renewable raw materials to produce products and energy.

# Benefits of the Biobased Economy

A Danisco Company

## Economic

- Reduce cost, better control of product properties
- New product & market opportunities
- Improved balance of trade & energy independence

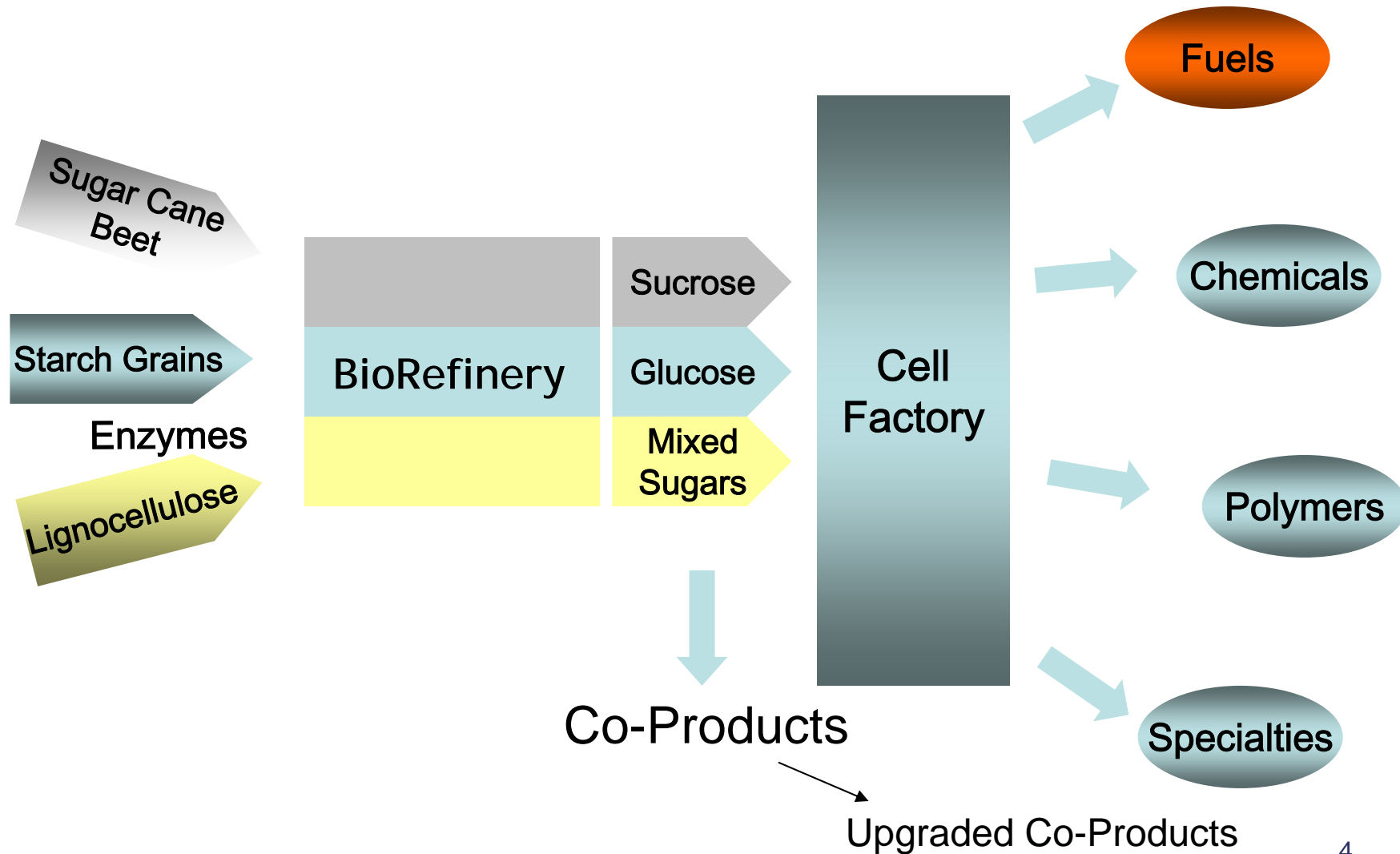
## Environmental

- Pollution prevention, reduced emissions of GHG and toxics
- 'Green' fuels, chemicals & materials
- Reusable & recyclable products

## Social

- Rural economic diversification & growth
- Developing countries can access the biobased economy
- Improvements in human/environmental health & quality of life

# The BioRefinery



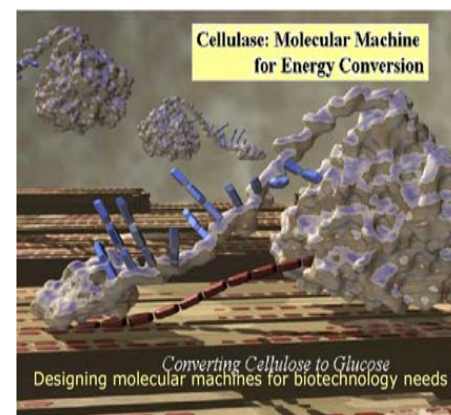
# Why Increased Attention in Biorefineries?

A Danisco Company

- Growth in World Economy driving demand for goods which is in turn putting demand on Petroleum supplies.
  - Price of Petroleum is Rising
- Fuel ethanol industry continues to grow at double digit rates
- New technologies [GSHE] may allow for significant improvements in conventional process by :
  - Reduction in energy usage
  - Removal of unit operations
  - Reduced plant capital
- Technology continues to advance in cellulosic biomass conversion and in Pathway Engineering

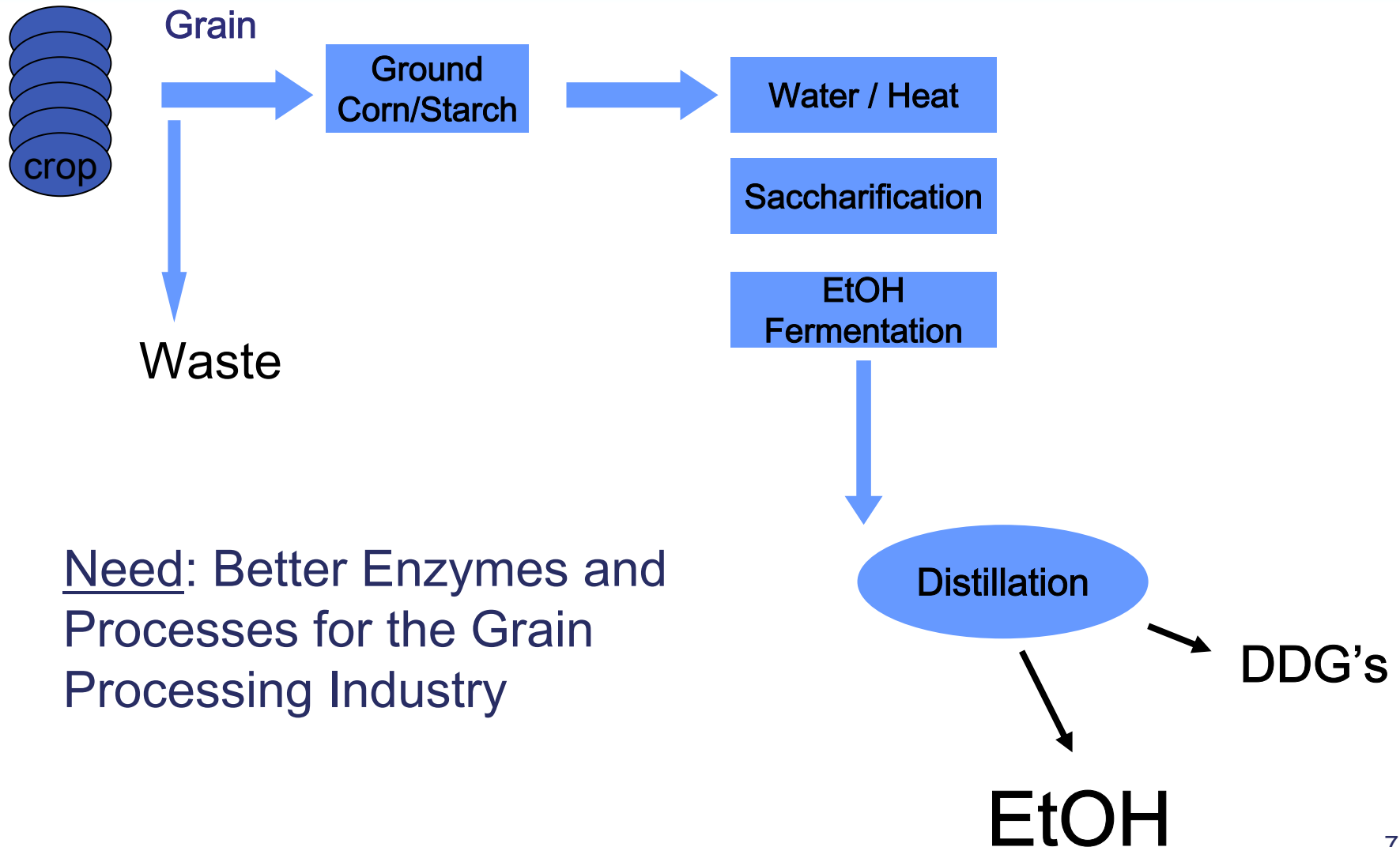
# Technology is being brought to bear on the issues

- Low Energy Milling of Bio-feedstocks to sugars and other components for further processing
- Efficient Bioconversion of Mixed Sugars to Products
- Efficient Utilization of Byproducts
  - Optimized extraction of value
  - Cost Allocation
  - Bioprocess integration

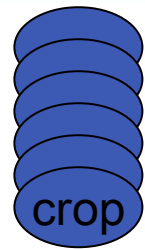


# The Grain Milling Process

A Danisco Company



# The DOE Cellulosic Biomass Sub-Contract



Grain



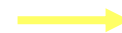
Waste

Pre-Treatment

Saccharification

EtOH  
Fermentation

Distillation



**EtOH**

## Why Cellulosic Biomass:

- Plentiful, and Potentially Low Cost
- Could be Financially Competitive
- Potential Synergies with Conventional Processing Technologies

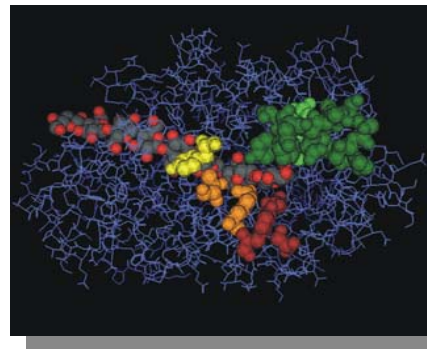
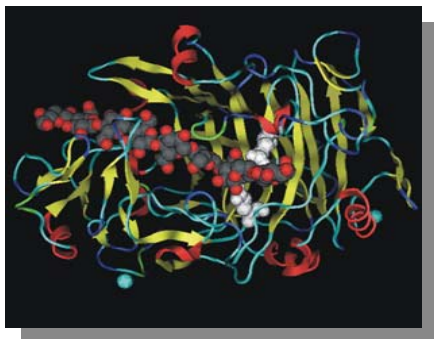
## The Challenge:

1 billion bushel/yr Corn production yields 25 million dry tons of Corn stover which could potentially produce >2.5 billion gal EtOH per year

Co-Product  
Unknown Value



- Improved Low Cost Cellulase for Biomass Conversion to Ethanol
  - Project Elements
  - Status of Biomass Conversion Effort



- Cellulase cost reduction goal can only be achieved by BOTH:
  - Improved production economics (reduced \$/gm enzyme)
  - Improved cellulase performance (reduced gm enzyme/gal EtOH)

$$\text{Effective cellulase cost} \left( \frac{\$}{\text{gal EtOH}} \right) = \left( \frac{\$}{\text{gm enzyme}} \right) \cdot \left( \frac{\text{gm enzyme}}{\text{gal EtOH}} \right)$$

Engineer & recruit limiting cellulase components that have enhanced thermostability / specific activity

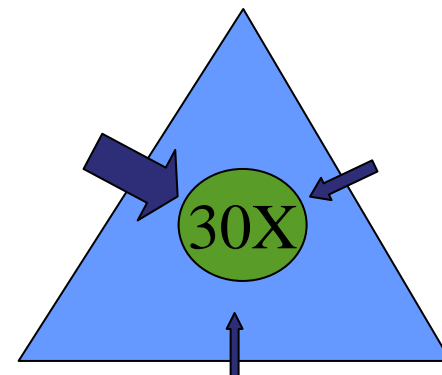
**Protein Engineering, Novel Cellulolytic Activities, Assays and Screens**

Develop an enhanced *T. reesei* production organism (Platform organism) to produce all the key activities in one host

Regulation, induction, derepression, genomics

Improve the manufacturing Process to minimize production cost

Breakthrough economics required



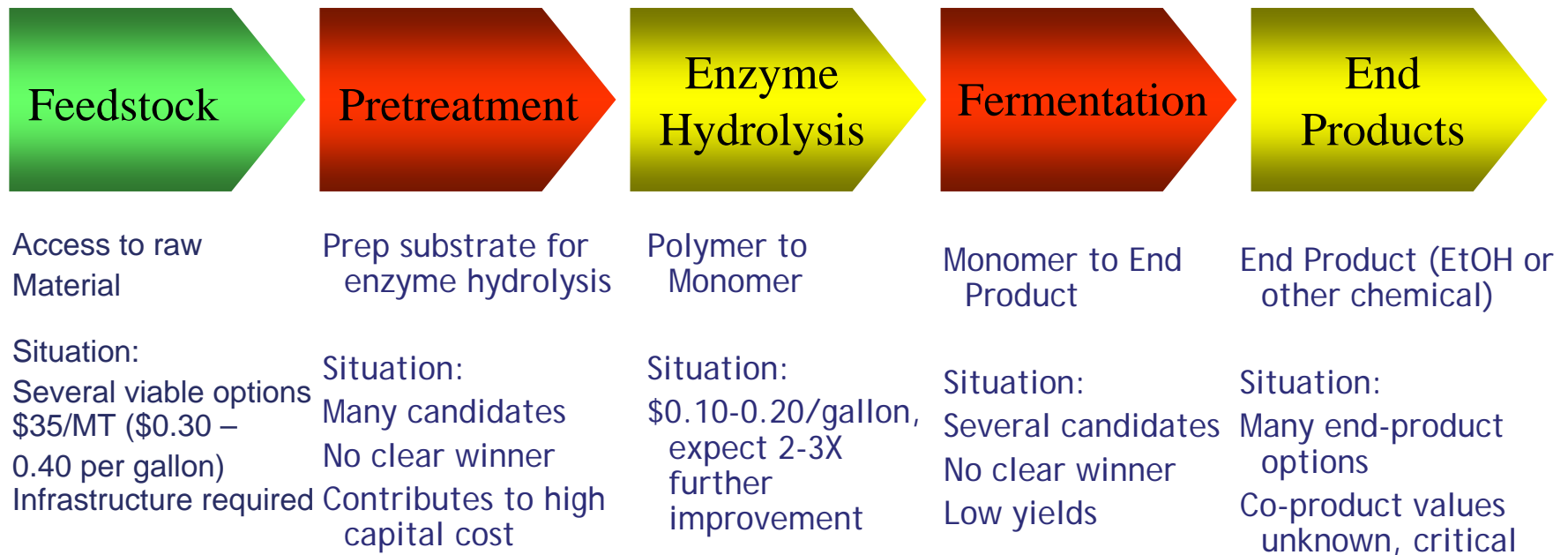
# NREL Program Results

- Put in place the tools required
- Built a Suite of Enzymes with enhanced thermostability & improved specific performance at elevated temperatures
- Developed an improved production strain carrying the enhanced cellulase components
- Built an enhanced production process
- Plans are in place to provide a developmental product(s) in support of continued industry development

# Biomass Biorefinery Analysis

A Danisco Company

## Biorefinery Value Chain

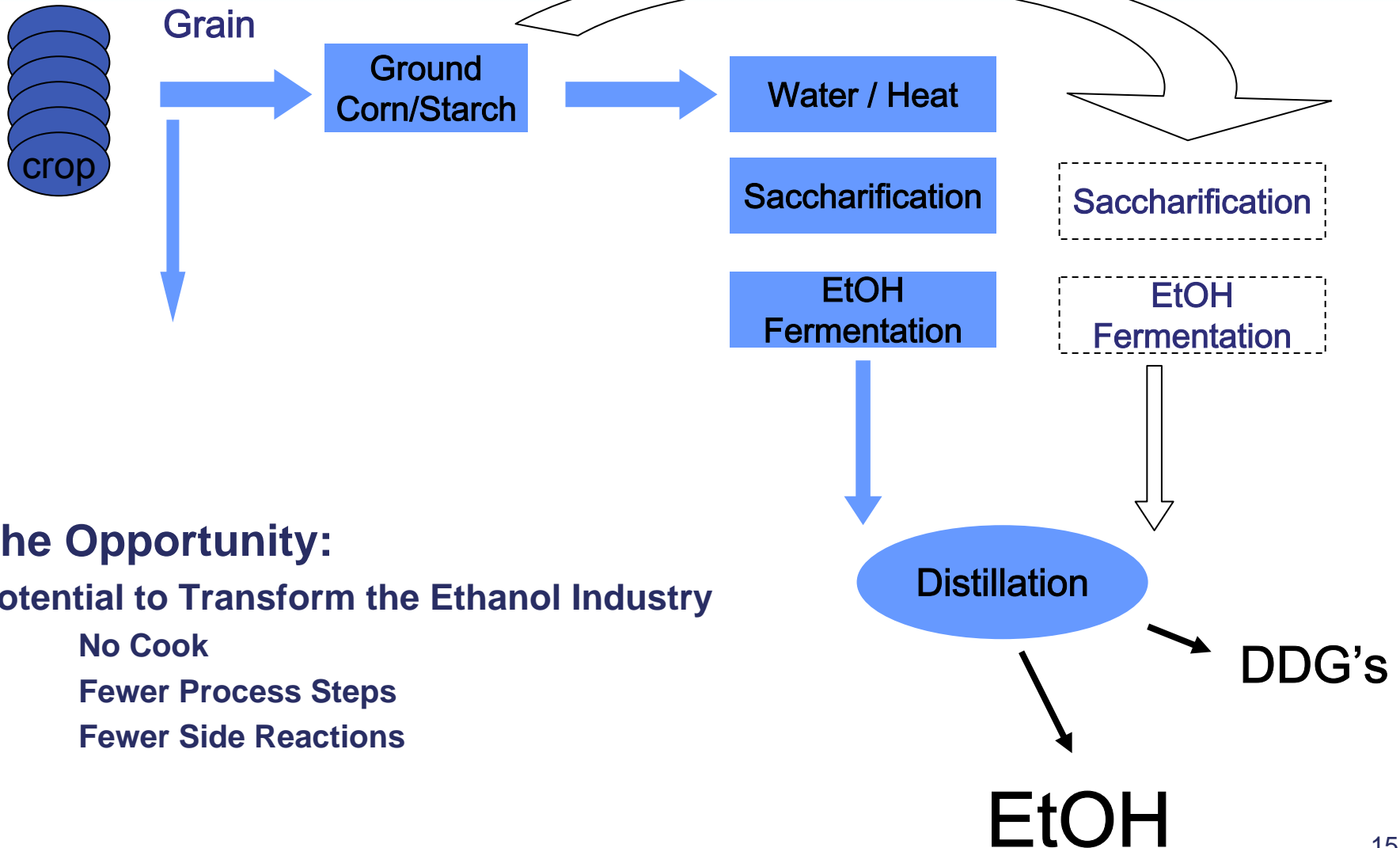


# Other Challenges

- Raw Material Price
- Ethanol Pricing
- Capital Intensity
- Co-Products

# Granular Starch Hydrolysis

A Danisco Company

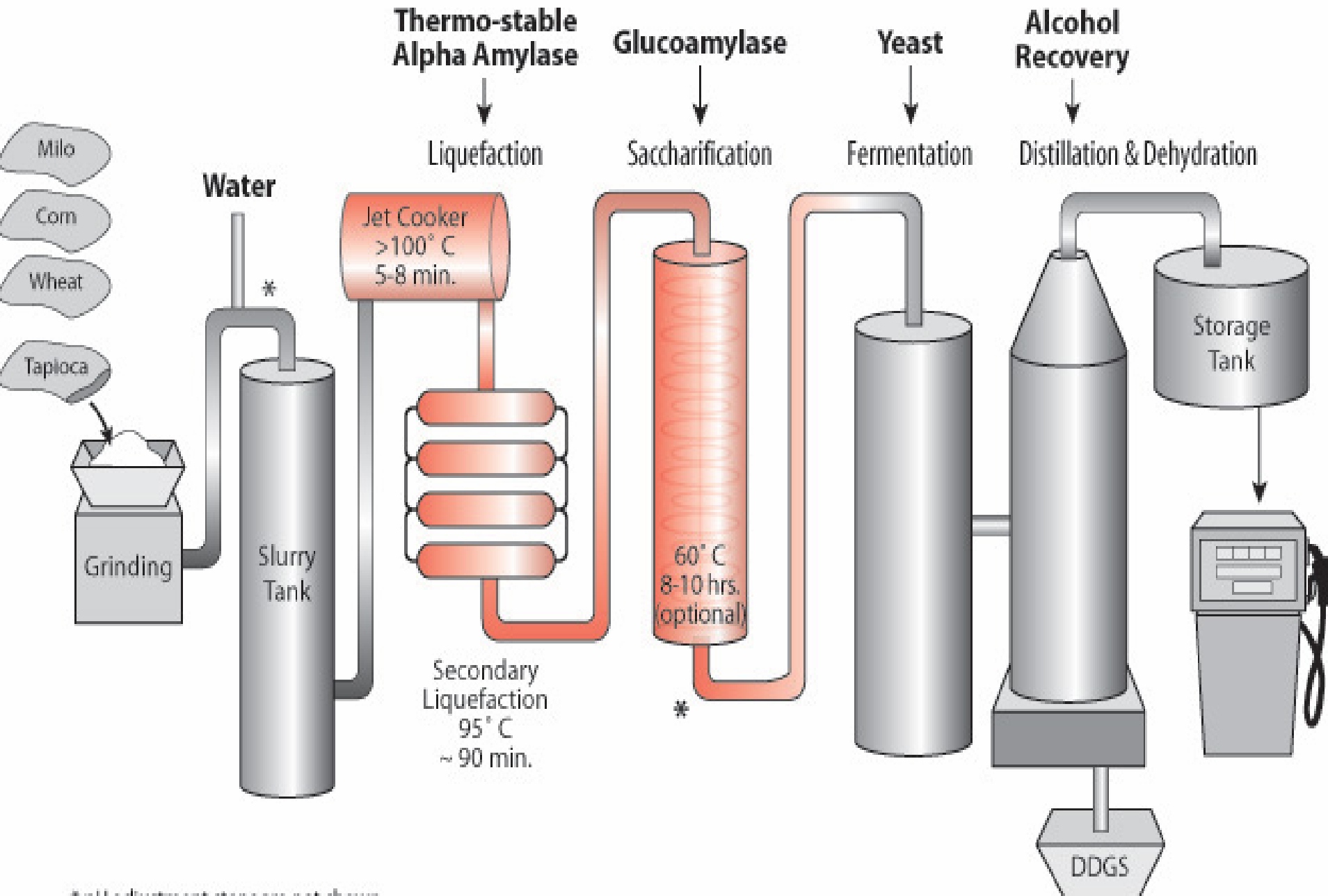


## The Opportunity:

### Potential to Transform the Ethanol Industry

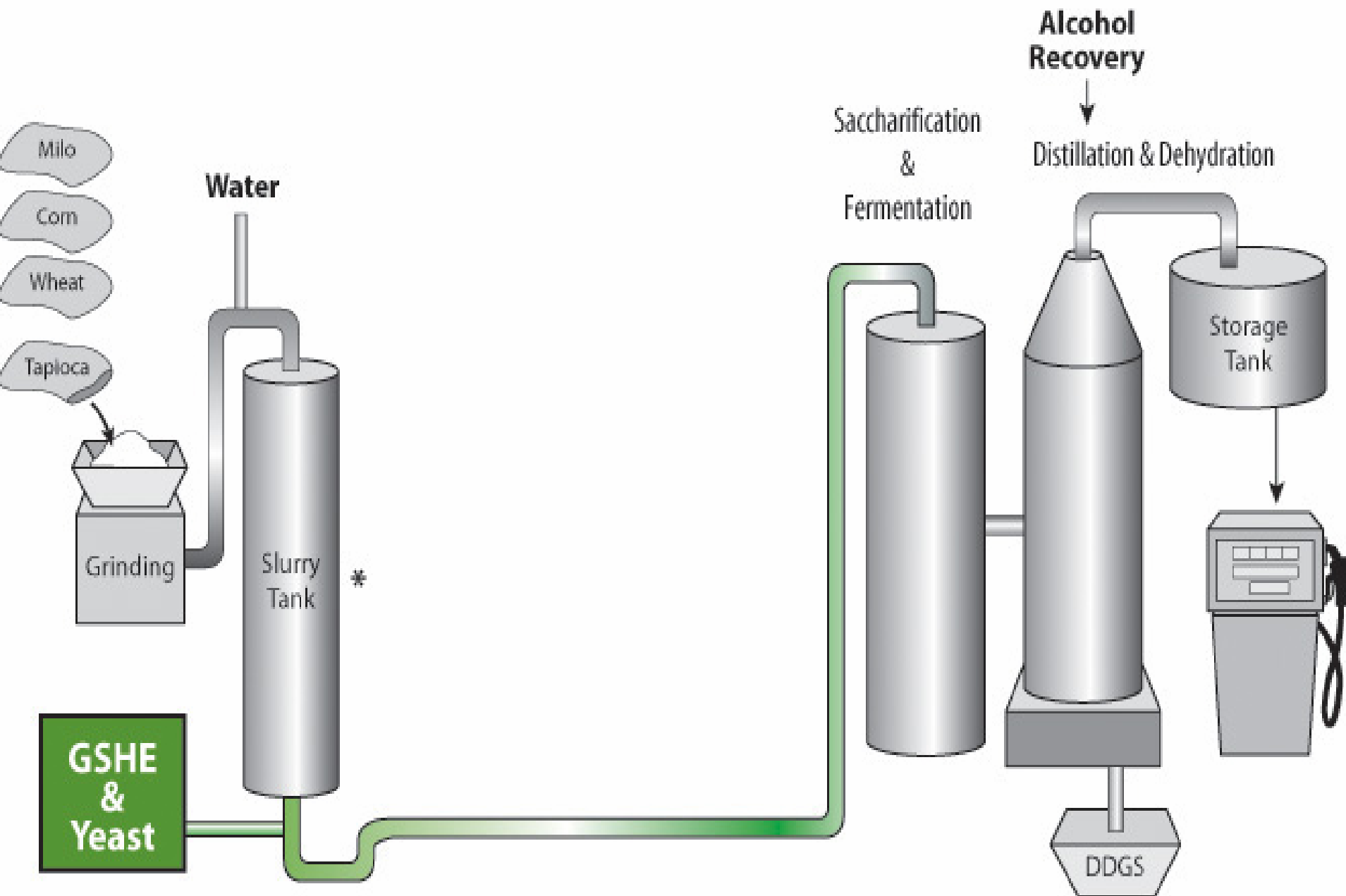
- No Cook
- Fewer Process Steps
- Fewer Side Reactions

# Conventional Ethanol Production Process





# Low Energy Ethanol Production Process



# What are the potential benefits of GSHE to the Ethanol Industry ?



A Danisco Company

**Energy saving - Elimination of jet cooking**

**Capacity increase - High density fermentation - higher alcohol yield**

**Carbon conversion efficiency - Higher yield**

**Reduction of yeast growth inhibitors - High glucose, Maillard products, etc.**

**Reduction in by-products formation**

**(Reduction in osmotic stress) - Glycerol, organic acids, etc.**

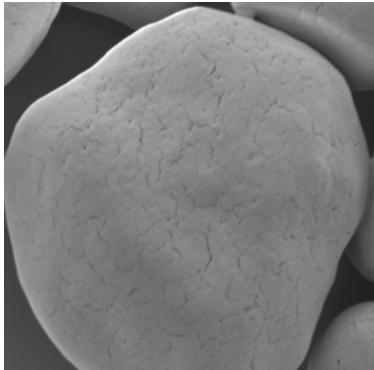
**Value added byproduct (DDGS) - Higher protein content**

**Process Simplification - Reductions in unit operations**

**Saving on the operational cost - Labor, time, chemicals**

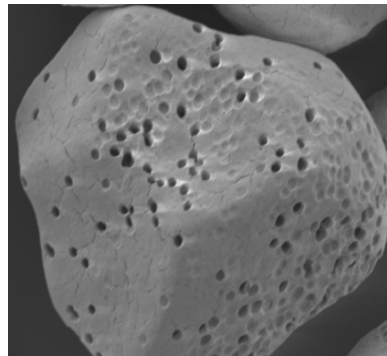
**Saving on the capital cost - Capacity increase/new plant**

# Enzymatic Drilling of Granular Starch

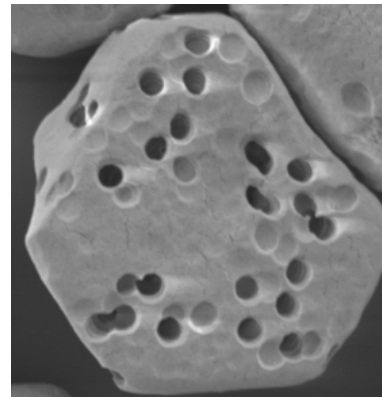


Granular Starch

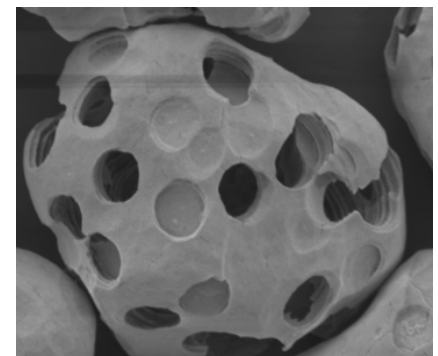
Granular Starch +GSHE, 2hr



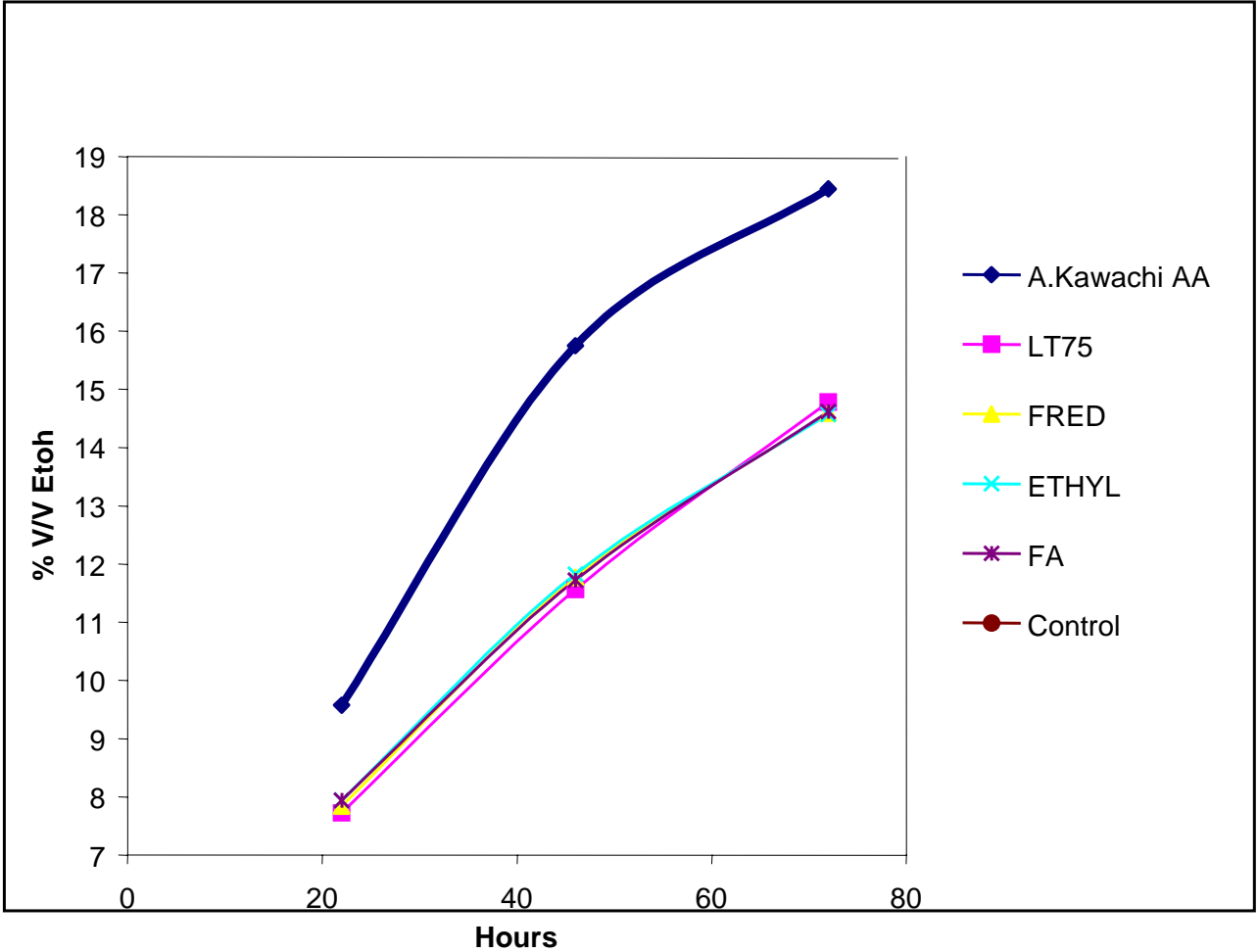
Granular Starch +GSHE , 4 hr



Granular Starch  
+GSHE, 8hr

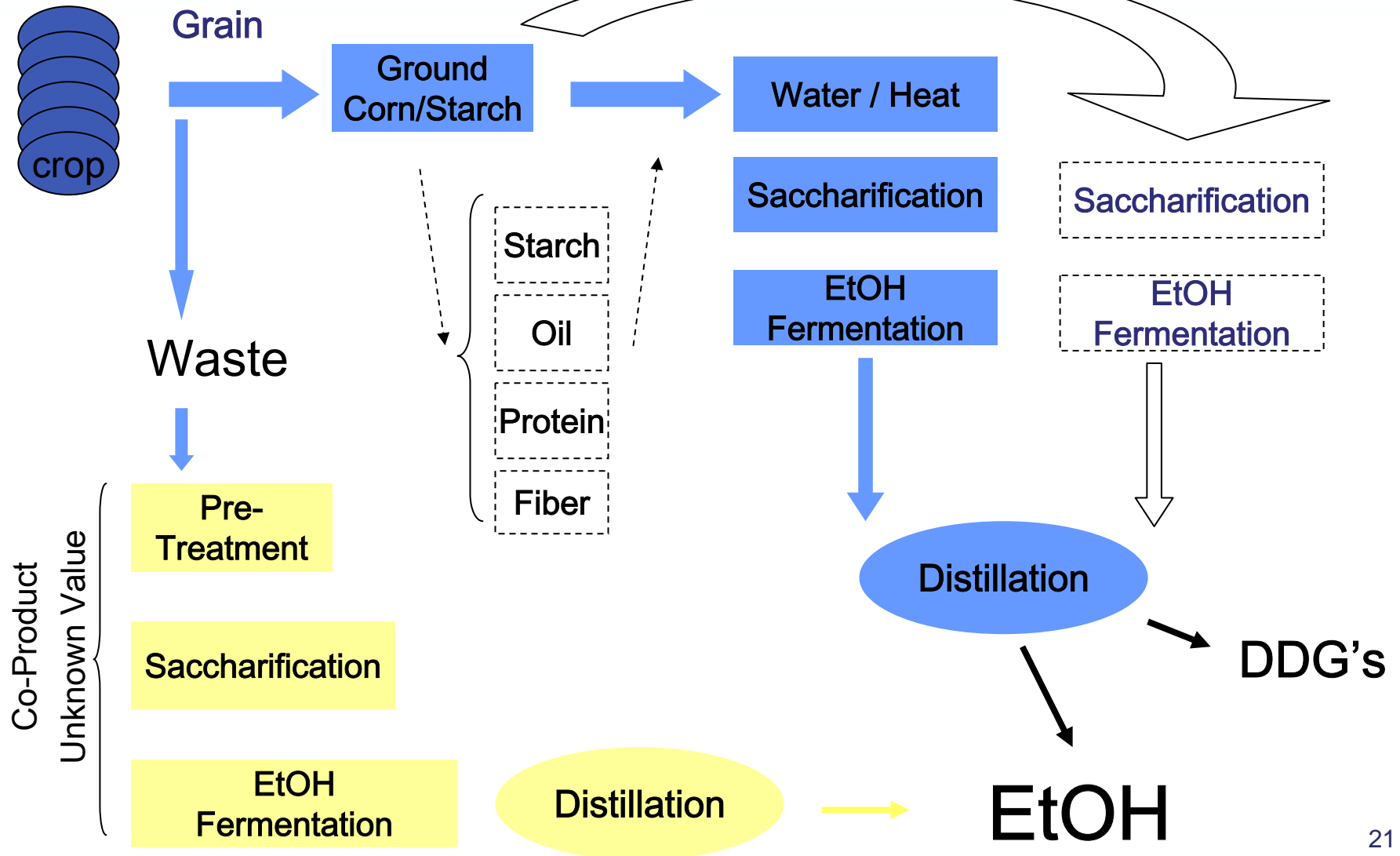


# Comparison of different alpha amylases with glucoamylase under yeast fermentation for Ethanol

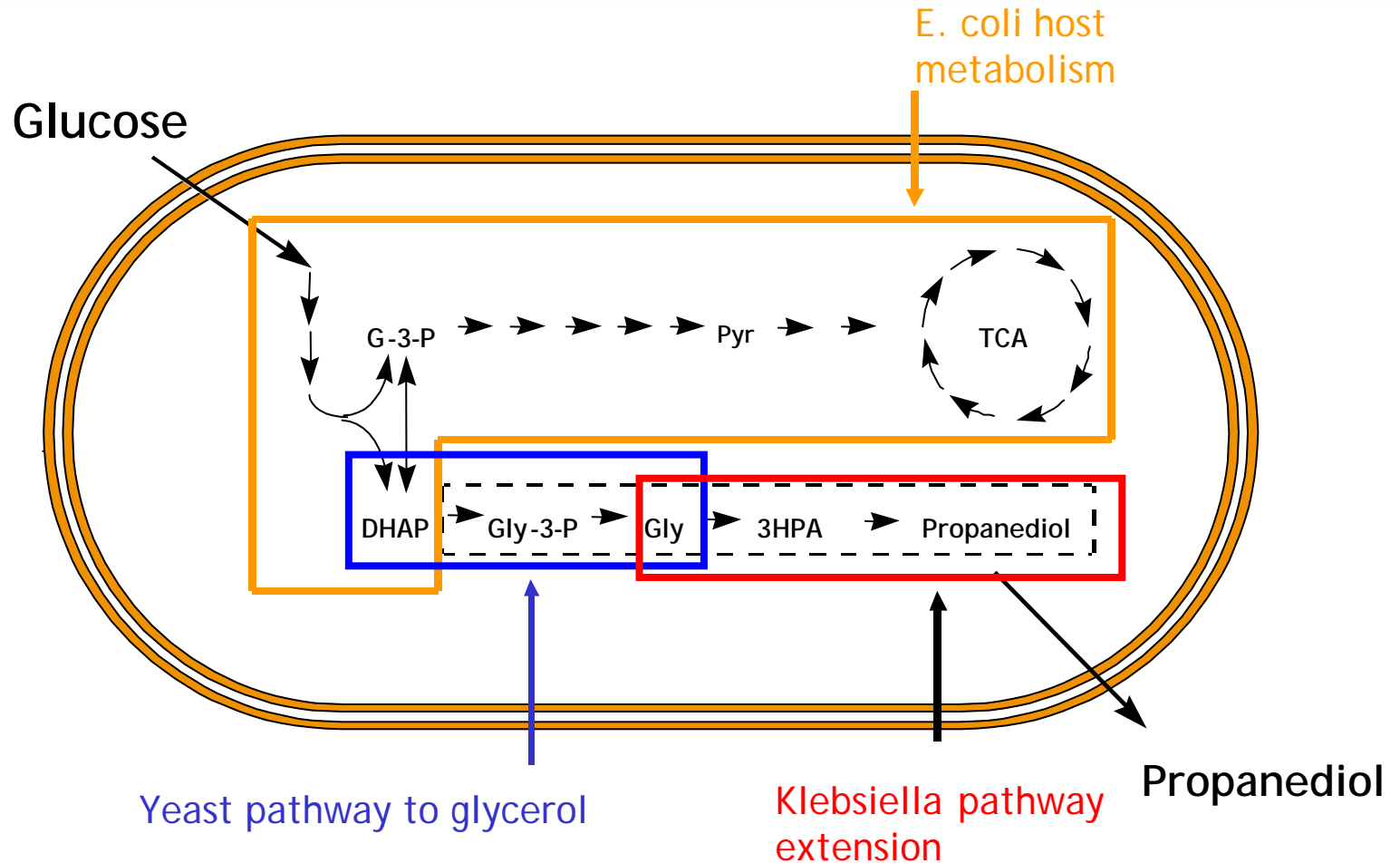


# The BioRefinery Front-End

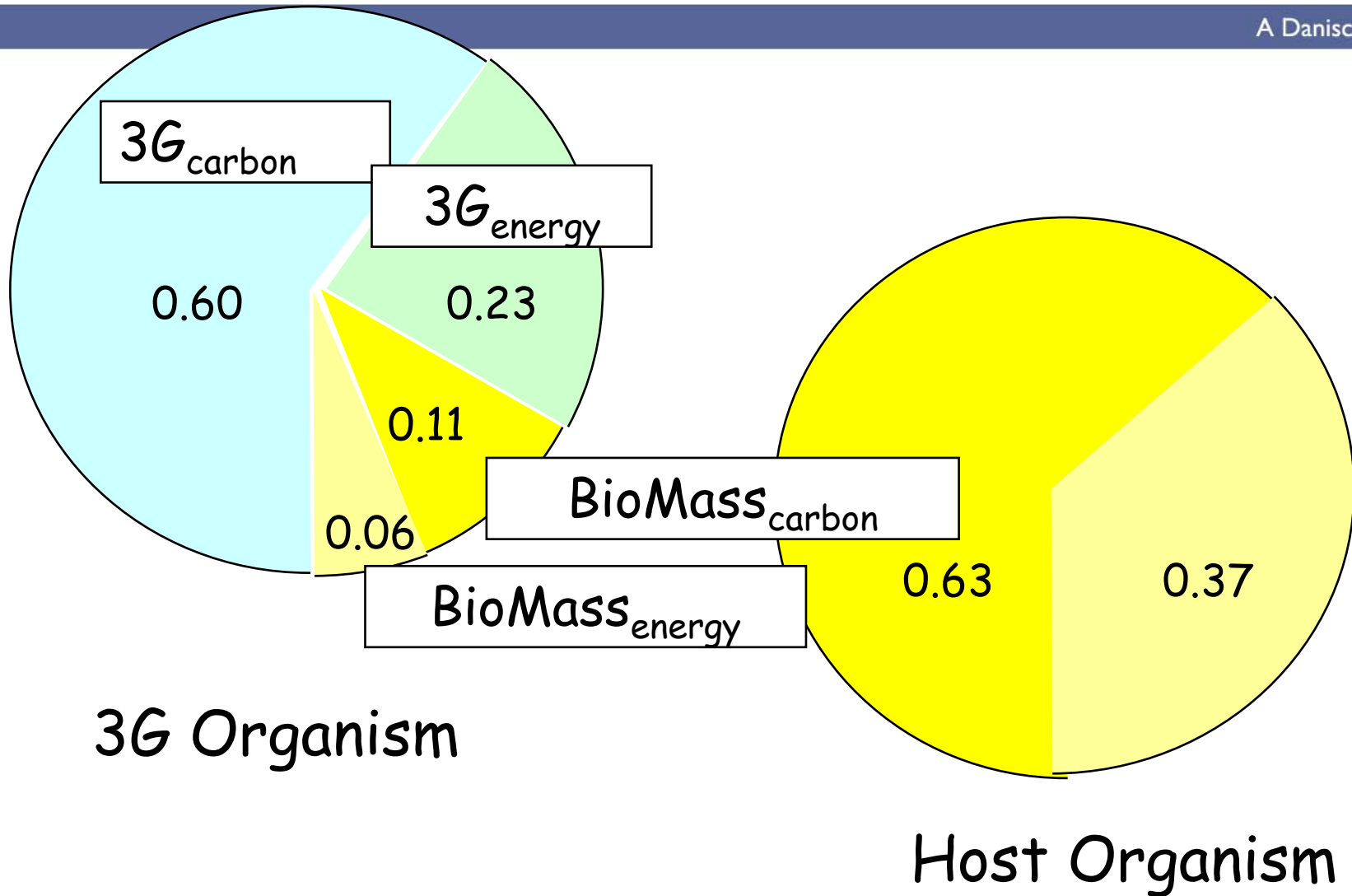
A Danisco Company



# The BioRefinery Back-End



# Fraction of Glucose Utilization for Engineered 3G Organism



# Conclusions

A Danisco Company

- Technologies are rapidly advancing.
- Biomass conversion technology continues to progress. Significant *challenges remain*.
- Starch processing technology is rapidly evolving.
- Cellulosic & starch technologies & processes could very well merge in synergistic ways.

