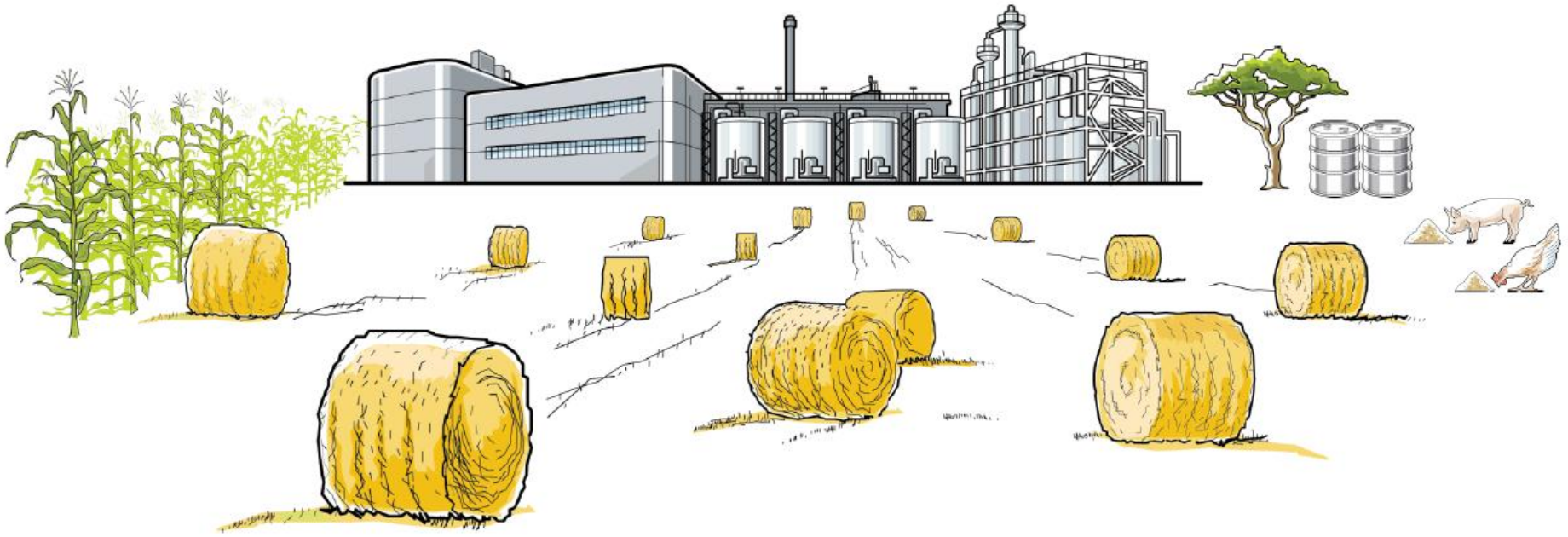
Alessandro Fazio, PhD
Fermentation Optimization Scientist, Kalundborg (Denmark)

28th November 2013, CNR Milan

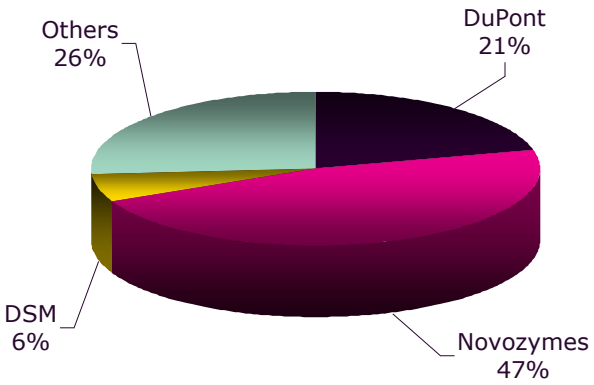
Agenda

- Introduction: Novozymes and Enzymes
- The Enzymatic Route from Lignocellulose to Ethanol
- The Enzyme Industry



Novozymes in brief

- World leader in Industrial Enzymes
- More than 700 products used in 130 countries in more than 30 different industries
- More than 6,500 granted patents
- Main production in USA, China, Brazil and Denmark
- More than 6,000 employees



Food and Beverages

Household care

Bioenergy

Agriculture

Wastewater Solutions

BioPharma

Textiles

Leather

Pulp and Paper

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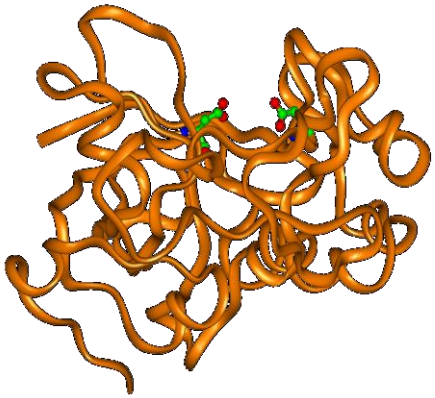
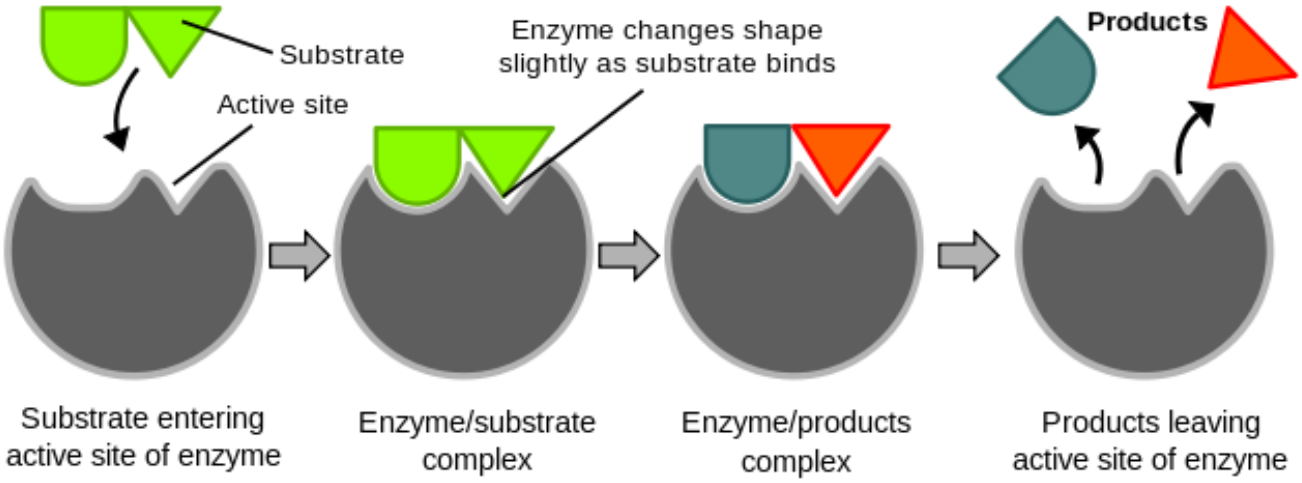
Enzymes are proteic catalysts

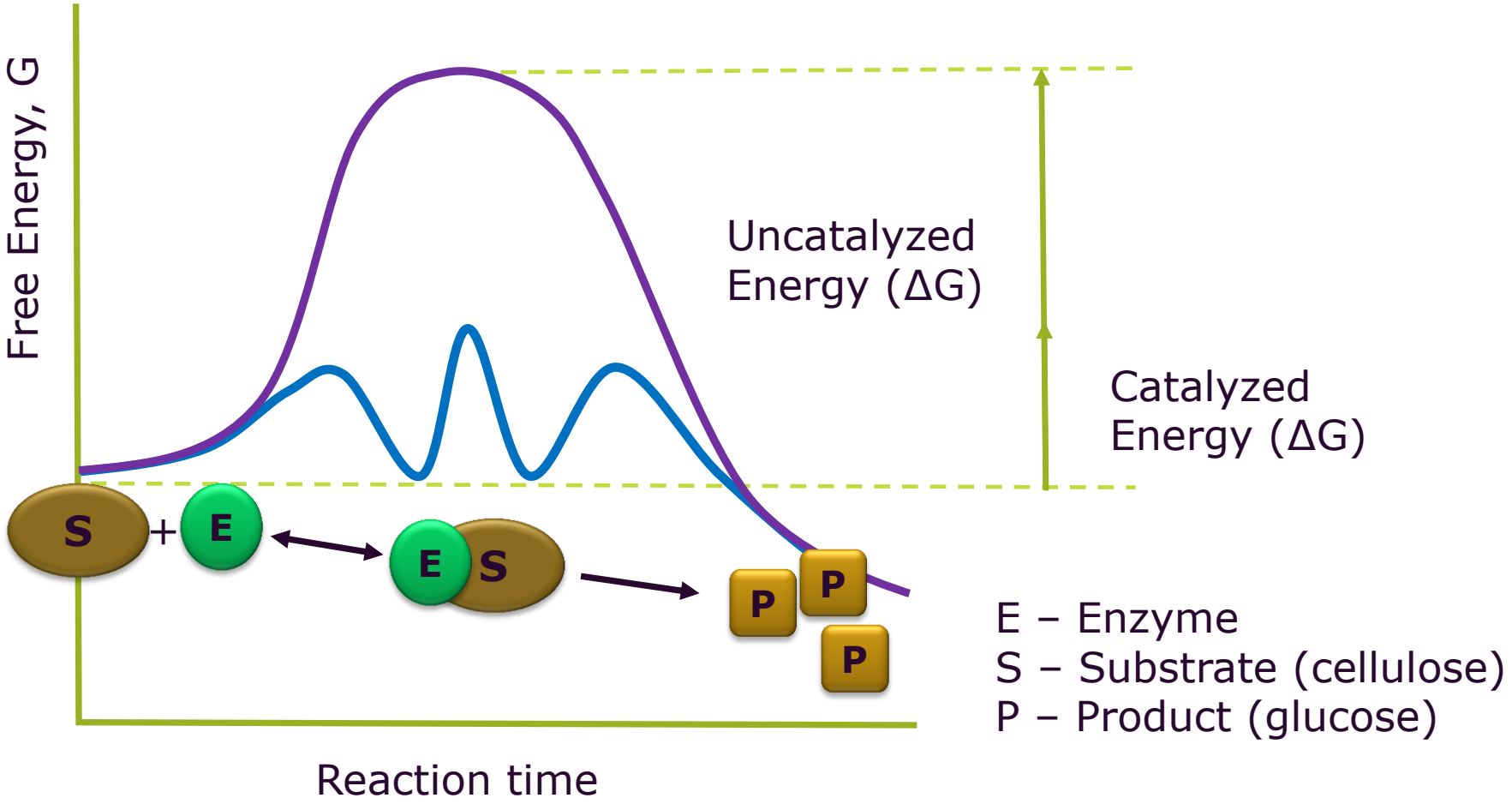
- Not living organisms
- Highly specific action
- Regulated
- Kinetics





Source: Wikipedia

Enzymes catalyse reactions by lowering the activation energy necessary for a reaction to occur



The role of enzymes:
From lignocellulosic biomass…

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The enzymatic route from biomass to ethanol

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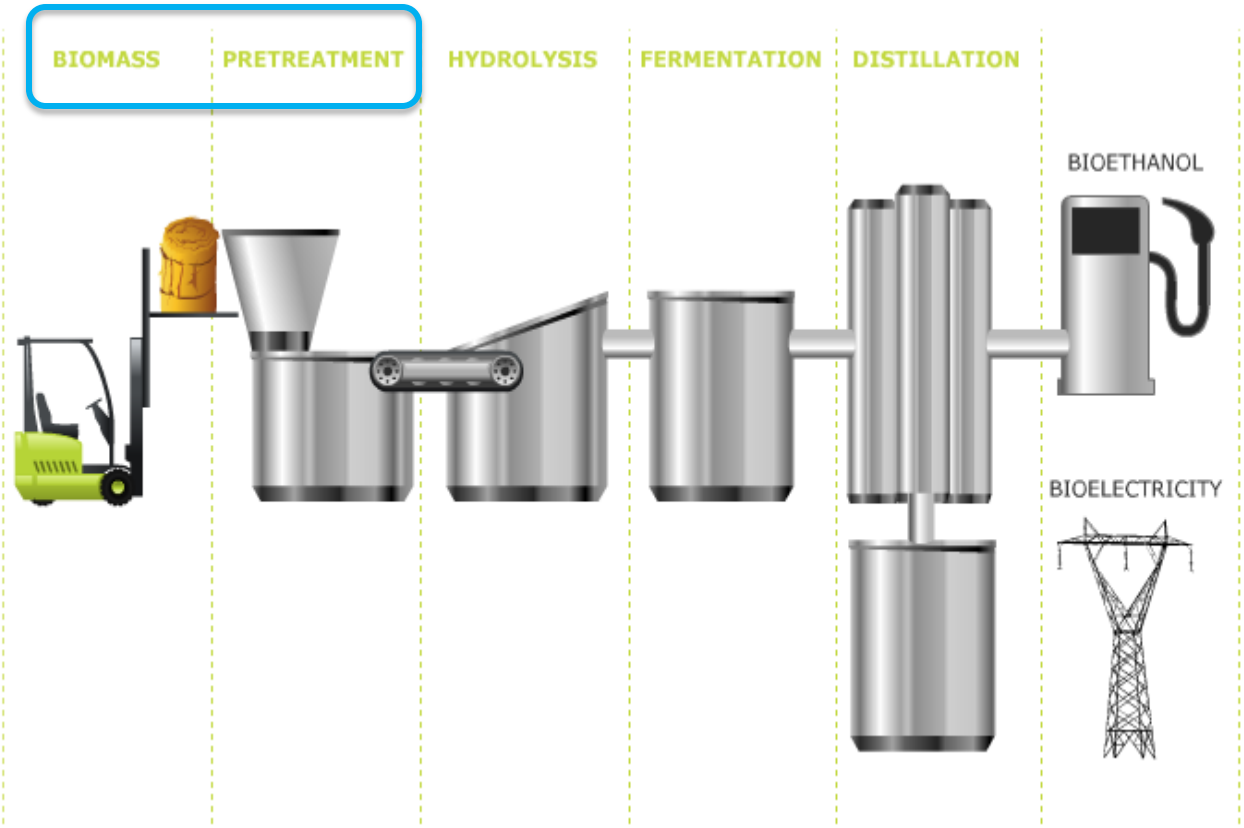

Lignocellulosic biomass

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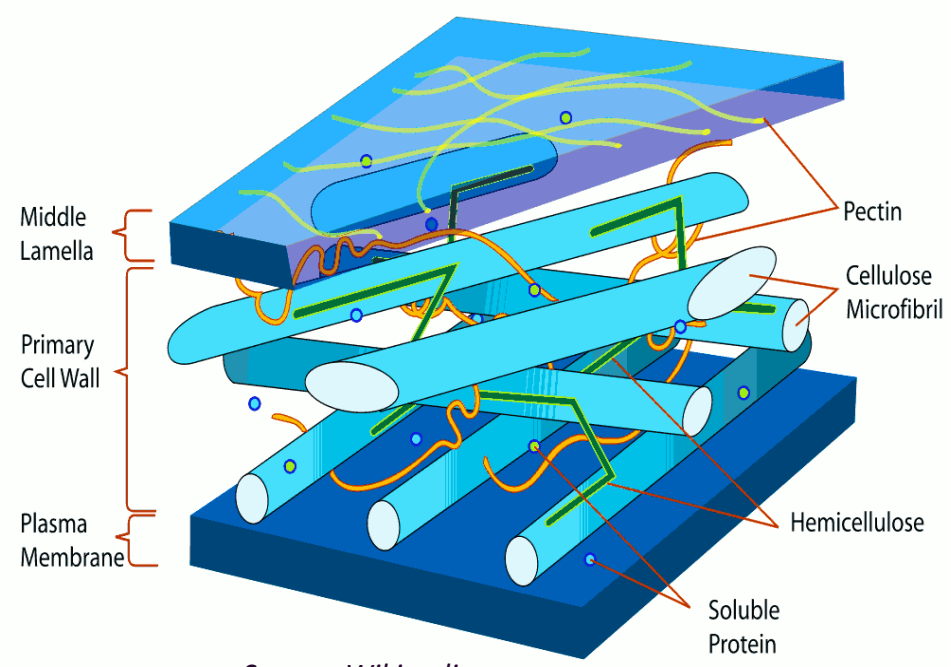
Sources

- Agricultural products/waste
- Forest products
- Energy crops
- On-site feedstocks
- Municipal wastes
- Seaweed
- Yard waste
- Sewage sludge
- Etc…

Constituents

- Cellulose (20-50%)
- Hemicellulose (10-40%)
- Lignin (10-30%)

Plant cell wall: Hetero-matrix of interlinked polymers



Source: Wikipedia

Pretreatment

Making the cellulose accessible to enzymes

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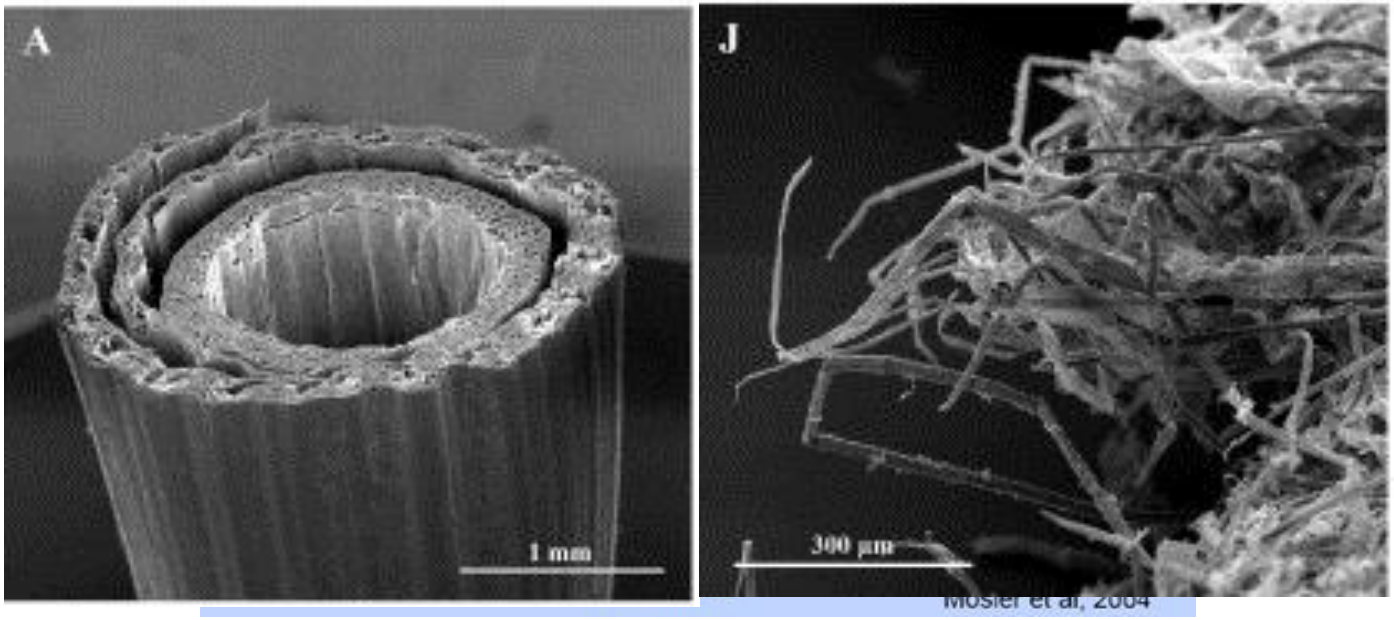
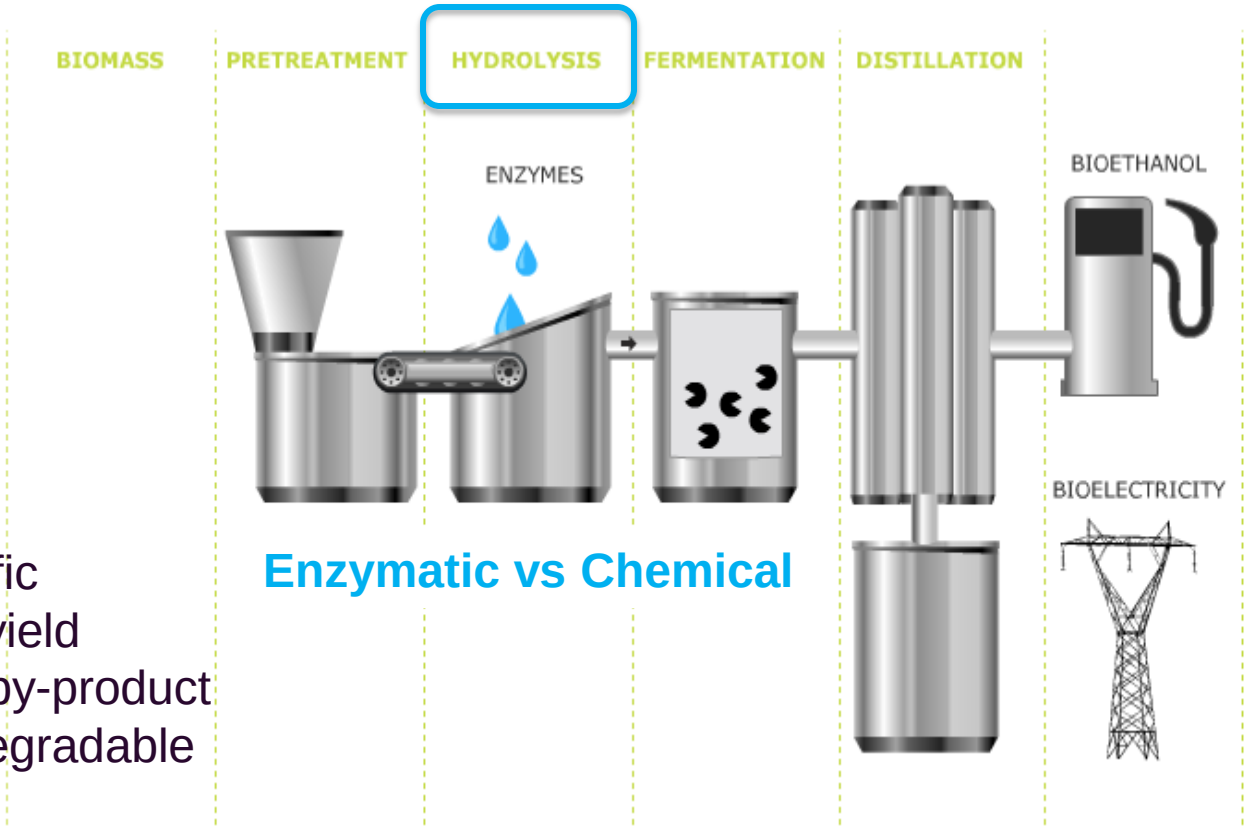
1. Size reduction
2. Liquefaction (pre-hydrolysis)
3. Structure break-down
   - Physical
   - Chemical



Kristensen *et al. Biotechnology for Biofuels* 2008 1:5

The enzymatic route from biomass to ethanol

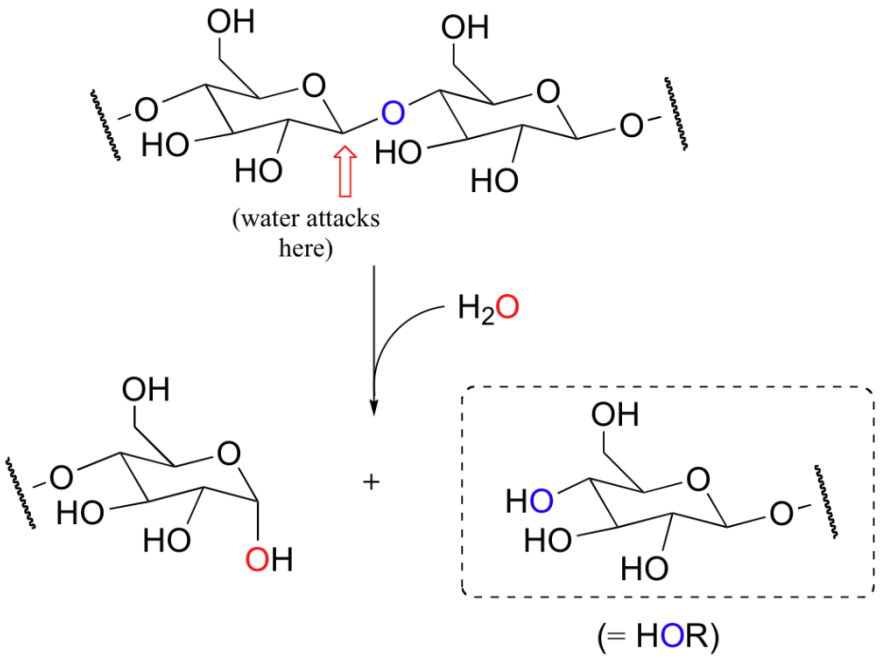


- Specific
- High yield
- Less by-product
- Bio-degradable

Enzymatic vs Chemical

CELLULOSE HYDROLYSIS = SACCHARIFICATION

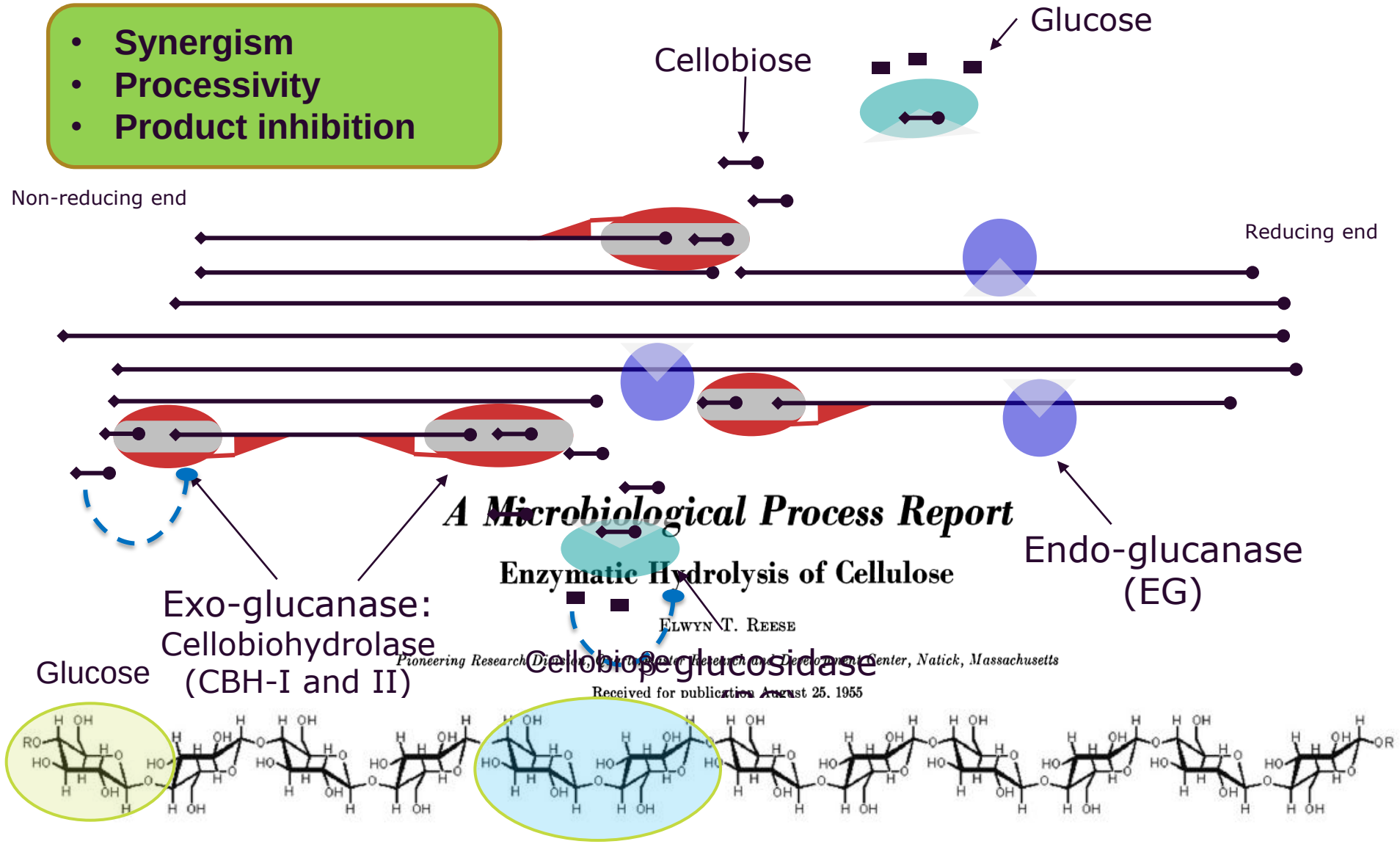
Hydrolases



CELLULOSE SACCHARIFICATION

The endo-exo model of *Trichoderma reesei*

- **Synergism**
- **Processivity**
- **Product inhibition**



A Microbiological Process Report

Enzymatic Hydrolysis of Cellulose

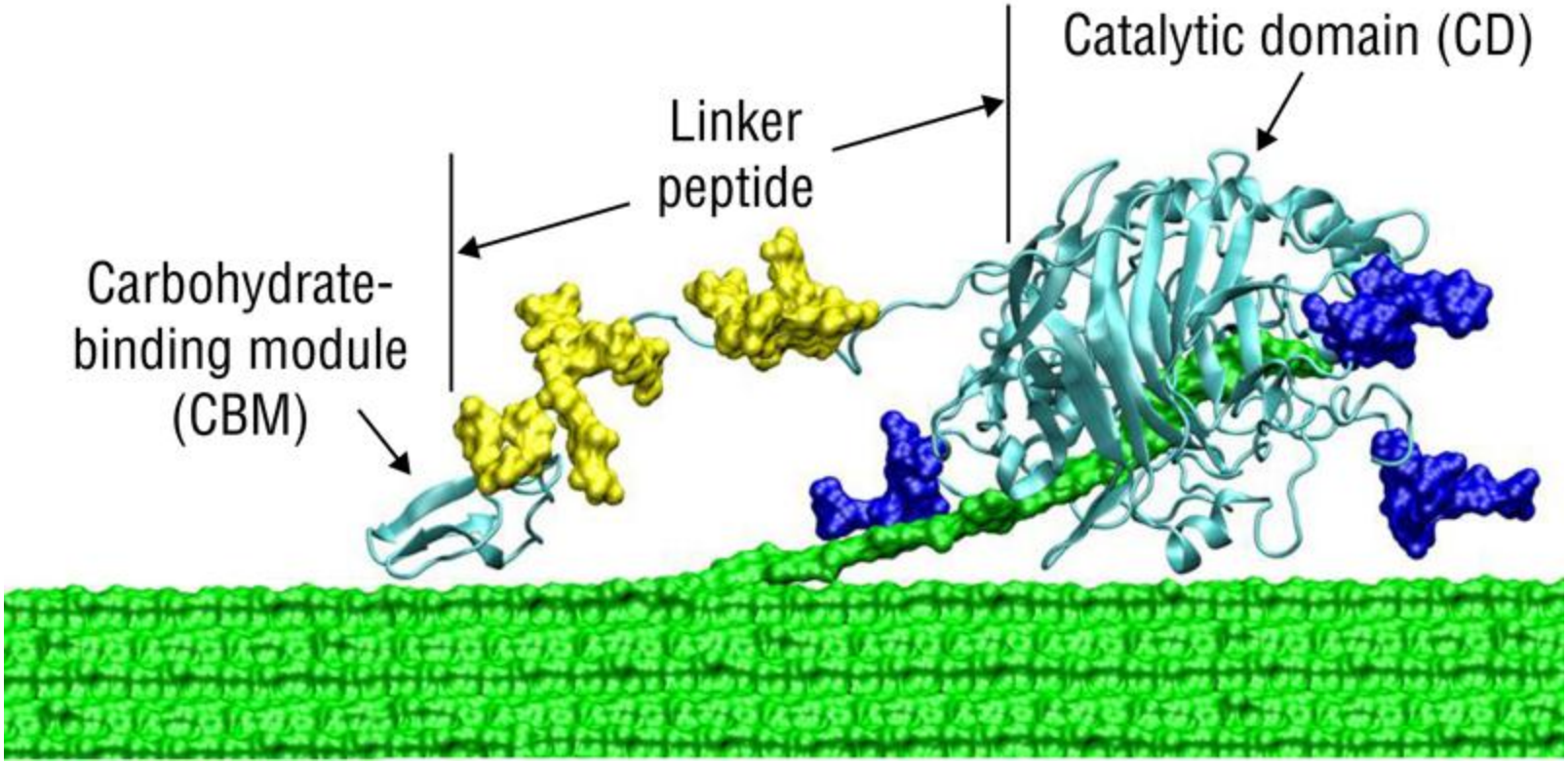
Elwyn T. Reese

Pioneering Research Division, Quartermaster Research and Development Center, Natick, Massachusetts

Received for publication August 25, 1955

CELLULOSE SACCHARIFICATION

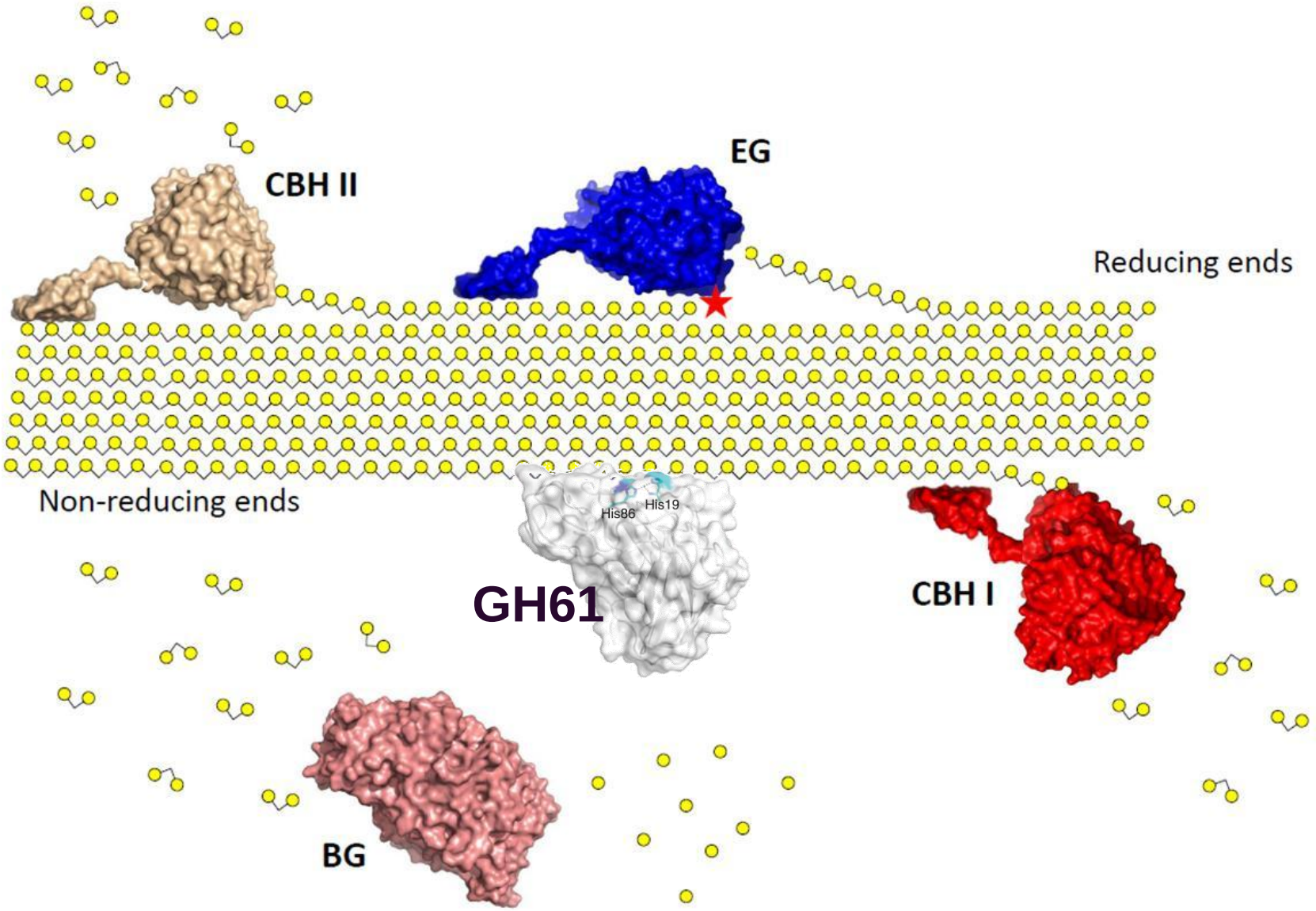
Cellobiohydrolase



Source: NREL Continuum

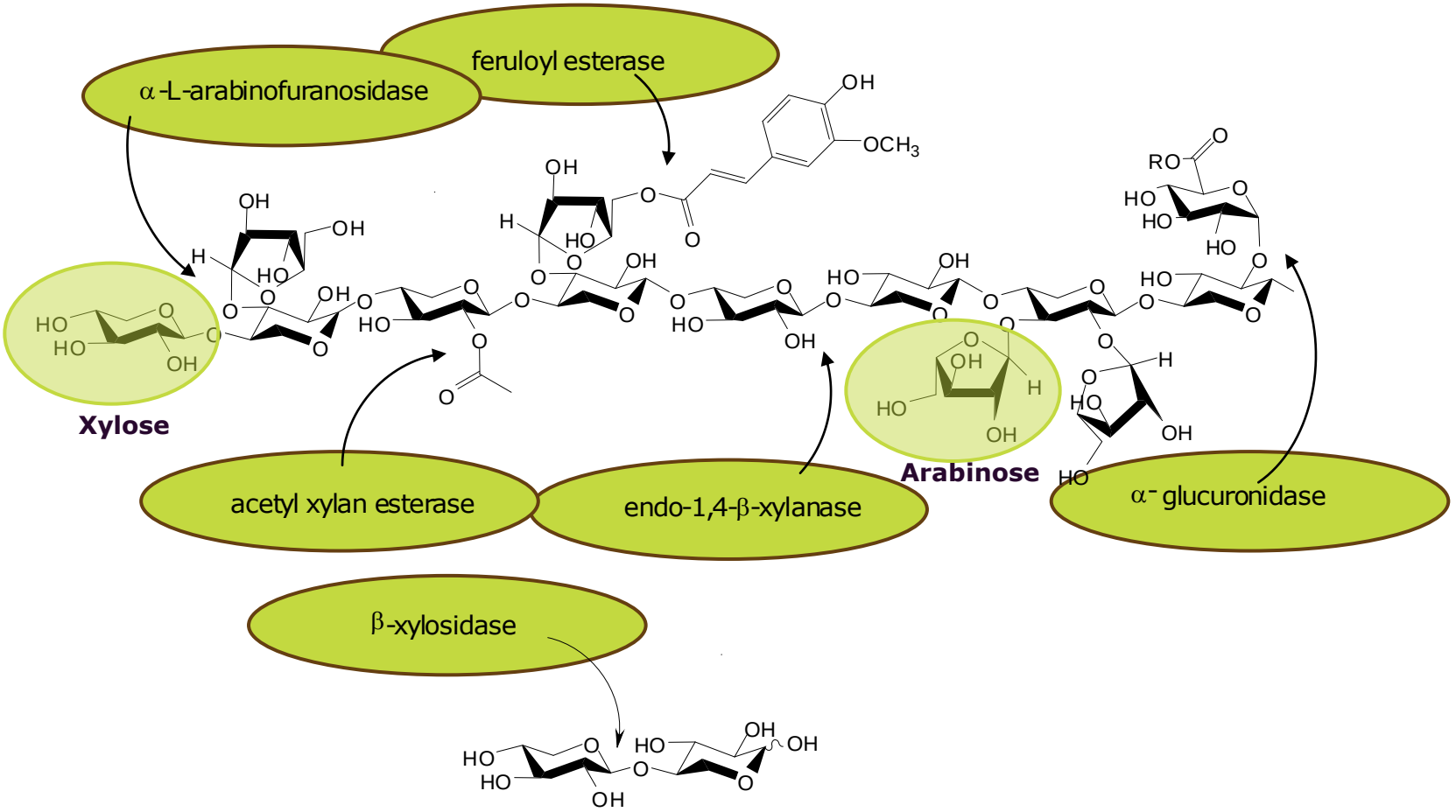
CELLULOSE SACCHARIFICATION

Cellulase enhancing factor

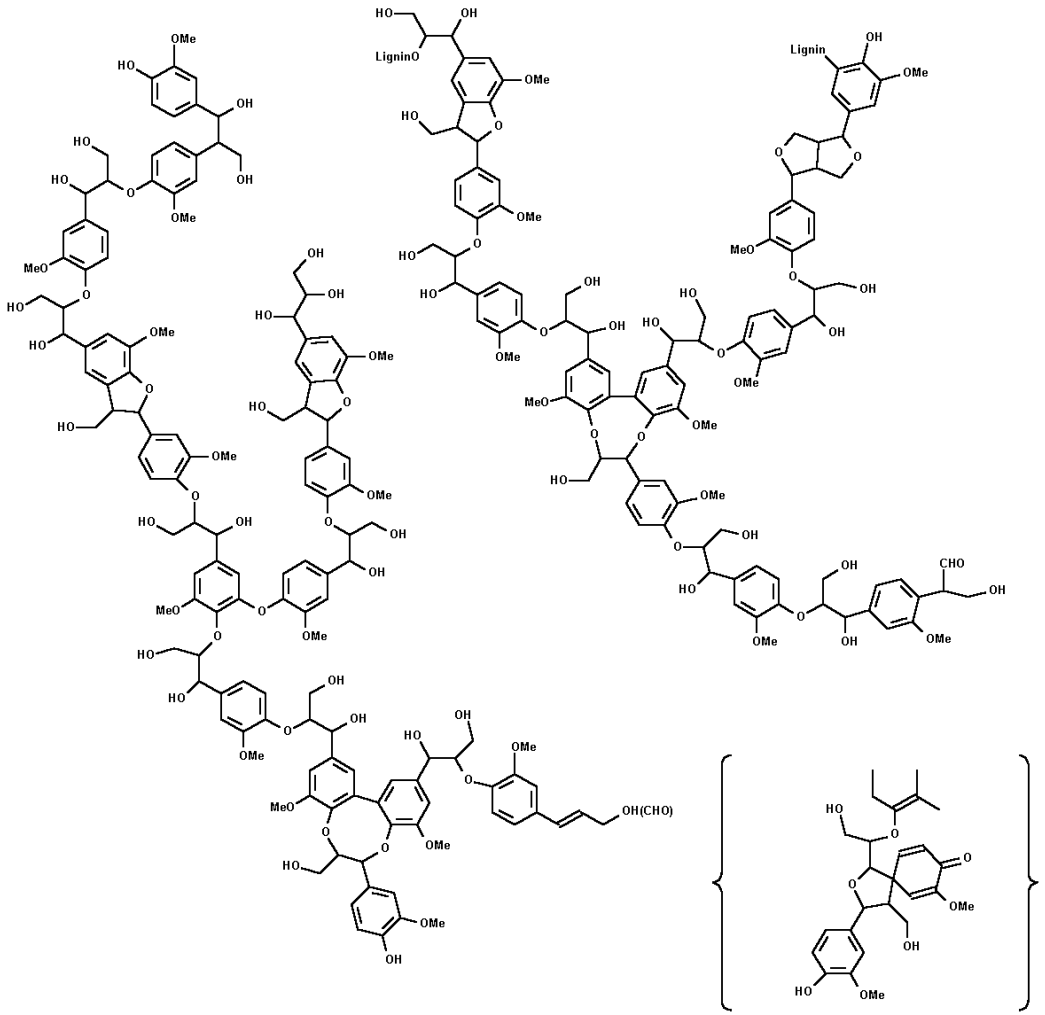


Hemicellulases

Extraction of pentose sugars



And the lignin?



- Cannot be turned into sugar!
- Barrier to cellulase
- Lignin-based energy

The enzymatic route from biomass to ethanol

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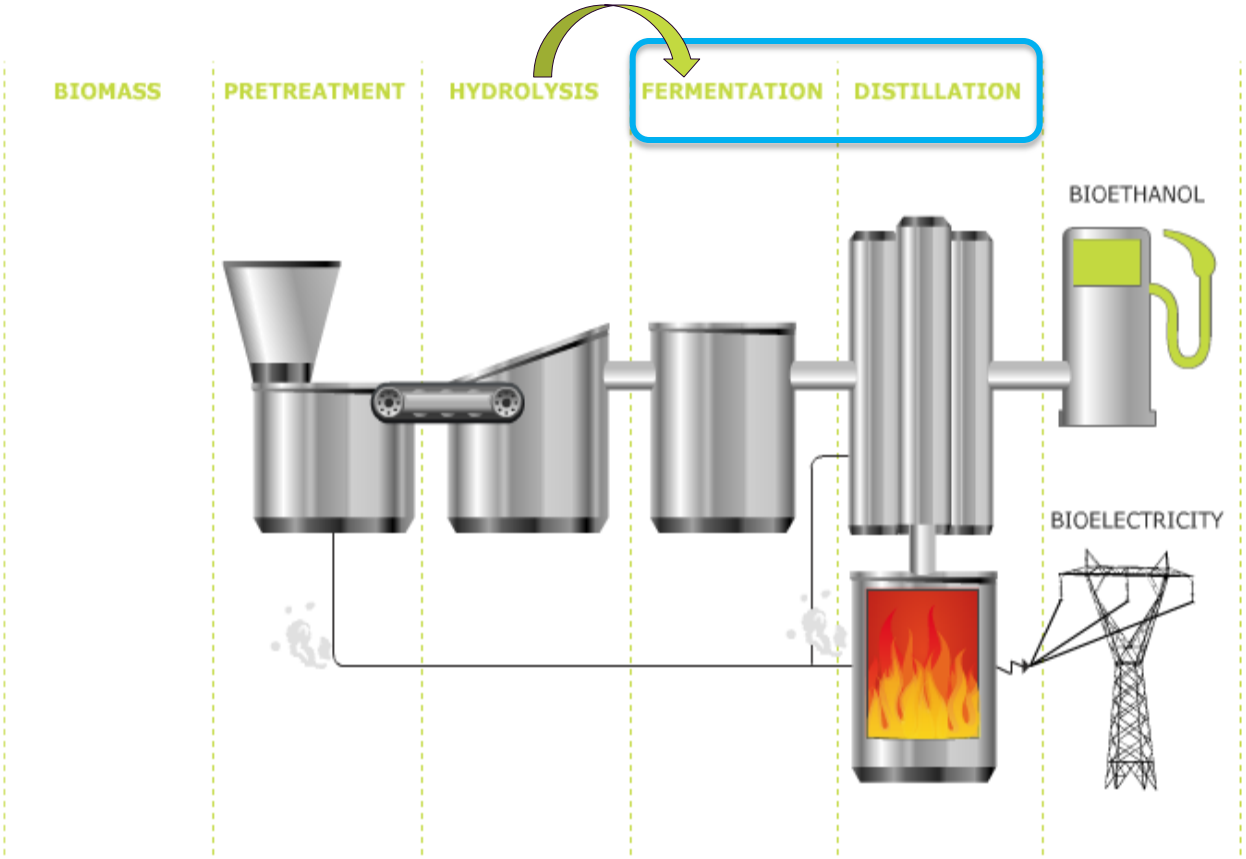
SHF: Separate Hydrolysis and Fermentation



Process configuration

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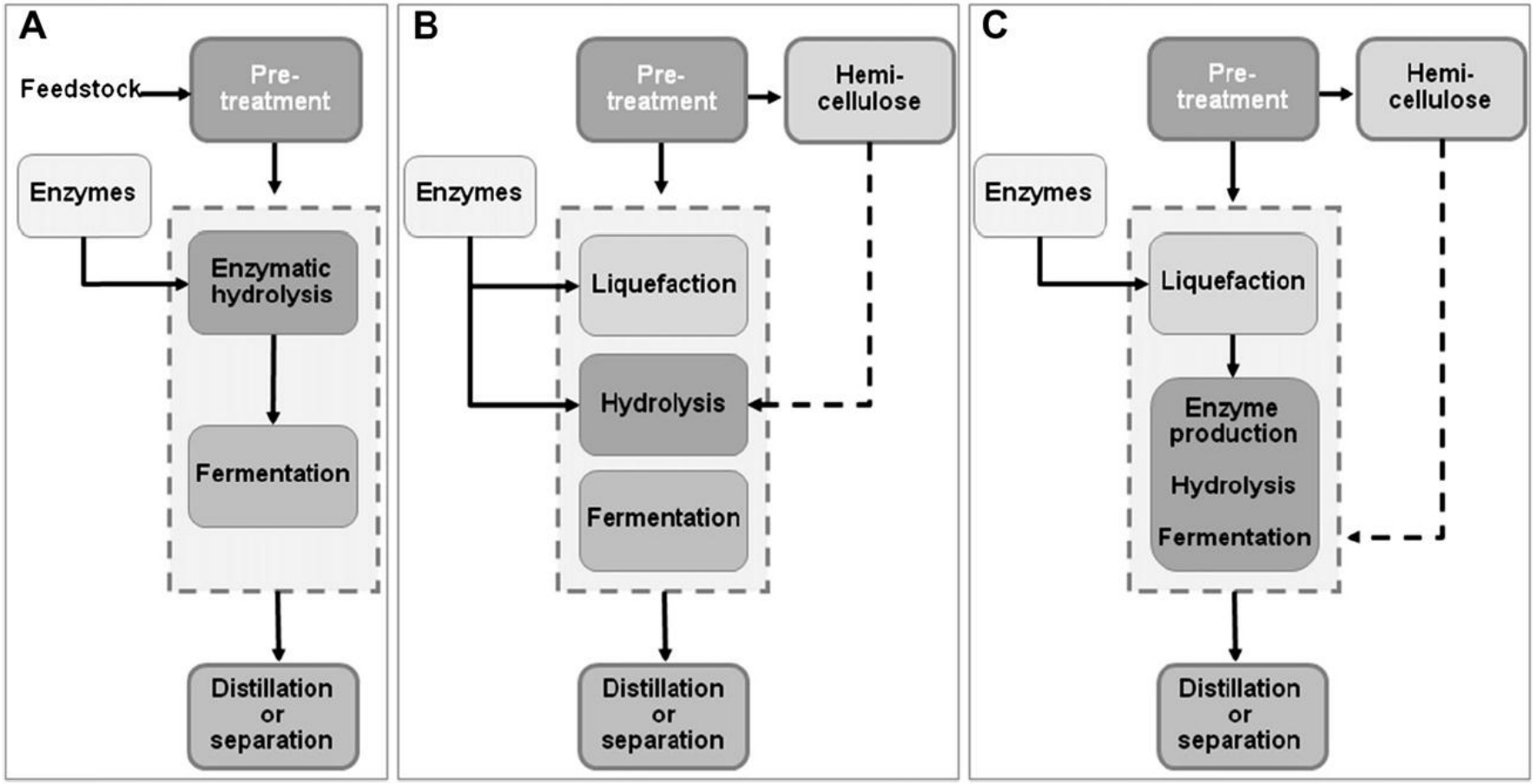
SSF: Simultaneous Saccharification and Fermentation + liquefaction

CBP: Consolidated BioProcessing



Viikari *et al. Biomass and Bioenergy* 2012; 46, 13-24

The industrial production of enzymes

Kalundborg

Costs and Optimization

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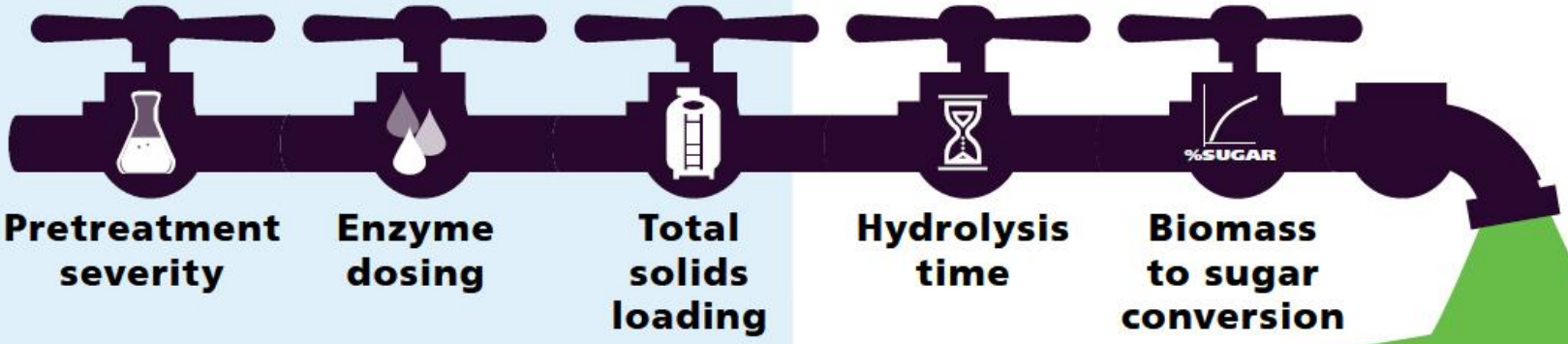
Parameters affecting the reduction of enzyme and ethanol production costs.

Reduction as per unit of enzyme	Reduction as per unit sugar	Reduction as per unit ethanol
Optimal domain structures	Pretreatment and accessibility of raw material	Yield from raw material
High specific activity	Synergistic (and new) cellulases	Productivity
Low end-product inhibition	Accessory enzymes	Final concentration
High thermal stability	Reduction of the amount of externally added enzymes	New process concepts
Optimal binding (cel vs. lignin)		
Enhanced volumetric production of enzymes		

Viikari *et al. Biomass and Bioenergy* 2012; 46, 13-24



Your plant's sweet spot

Novozymes commitment

Novozymes commitment

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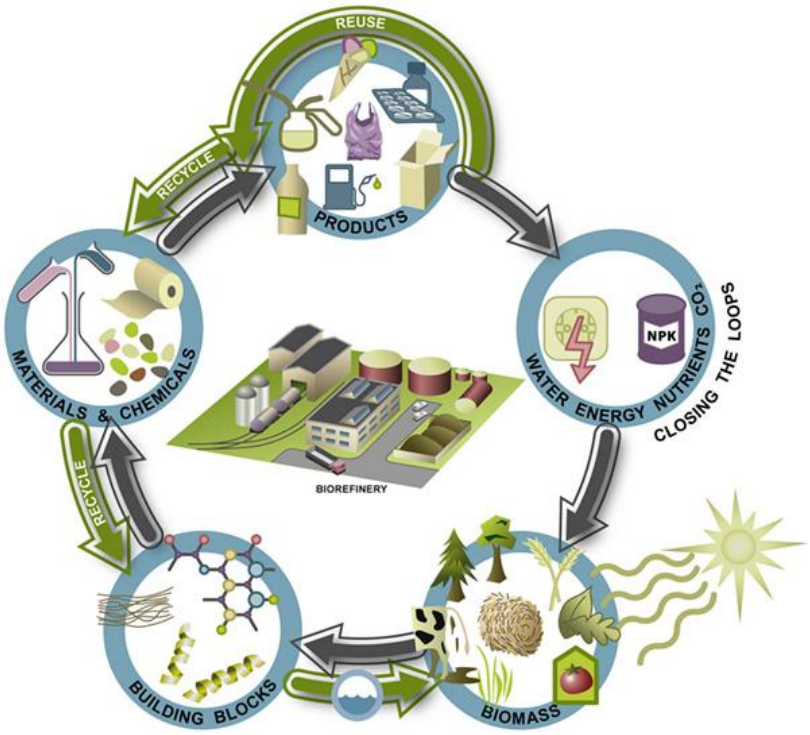
bridge 2020



Municipal Solid Waste (MSW) is becoming an attractive industry

Region	MSW Generated (Mn. T/yr)	Tipping fees* (USD/T)	Disposal market (USD Bn./yr)	Regional MSW Trends
European Union	251.2 → 266.5 (6.0%)	70.0 → 70.0	17.6 → 18.6 (5.6%)	• Driven by population growth • Number of incineration plants under construction (UK biogas) • Landfilled: 45% • Recycled: 37% • Incinerated: 18% • WtE: 4.4%
United States	228.0 → 256.1 (12.3%)	50.0 → 50.0	11.4 → 12.8 (12.2%)	• Driven by population growth • Incineration losing traction • Landfilled: 62% • Recycled: 24% • Incinerated: 14% • WtE: 0.3% (86 plants)
China	190.0 → 510.2 (168%)	8.0 → 8.0	1.5 → 4.0 (166%)	• Driven by urbanization, population growth, economic improvement and energy needs • Waste recovery thru incineration and **biogas** gaining speed • Landfilled: 82% • Recycled: 3% • Incinerated: 15% (44 plants) • WtE: No official data available
Canada	18.1 → 25.2 (39%)	63.0 → 63.0	1.1 → 1.5 (36.3%)	• Driven by population growth • Landfills are widely used • Landfilled: 75% • Recycled: 25% • Incinerated: No official data available • WtE: No official data available
India	40.0 → 137.5 (243%)	8.0 → 8.0	0.3 → 1.1 (266%)	• Driven by population growth, urbanization, energy needs and economic upliftment • Incineration plants preferred due to electricity generation • Landfilled: 91% • Recycled: No official data • Incinerated: No official data • WtE: No official data
Brazil	54.4 → 120.8 (122%)	2.0 → 2.0	0.1 → 0.2 (100%)	• Driven by population growth, urbanization, energy needs and economic upliftment • Highly subsidized waste to energy market supplementing incineration • Landfilled: 98% • Recycled: < 2% • Incinerated: No industry • WtE: No industry

From 781 mill. ton 1.3 bn ton

From $ 32.3 bn to $38.2 bn

% growth

2012

2025

*Average tipping fees collected from municipalities and trade sources.
Source: World Bank 2012, Publicly Available Information

Biofuel from MSW

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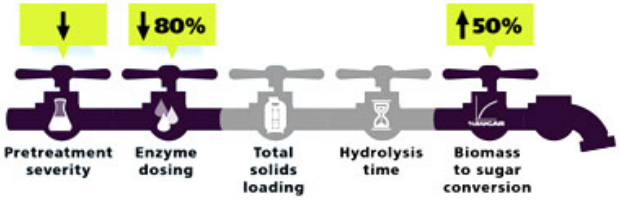
Cellulosic ethanol > Our partners paths > **Fiberight**

Fiberight's path to success

Transforming municipal solids waste to valuable advanced biofuels with Cellic® CTec3 and Novozymes.

While partnering with Novozymes and using Cellic CTec3, Fiberight reduced enzyme dosing by 80% and at the same time increased cellulose to glucose conversion by 50% with a mild, cost-effective pretreatment.

Fiberight has achieved their lowest total cost and is commercializing.



Fiberight

KEY FACTS	
Current feedstock	Municipal solid waste
Pretreatment	Mild cook
Capacity	6 MGY
Production start-up	2013
Novozymes' partner since	2009

Wastes as resources at Novozymes

Waste biomass

NovoGro® - 120,000 tons/year – fertiliser

Waste water - 3,100,000 m^3/year

Biogas

Symbiosis with municipal waste water treatment plant

Biomass-to-Value

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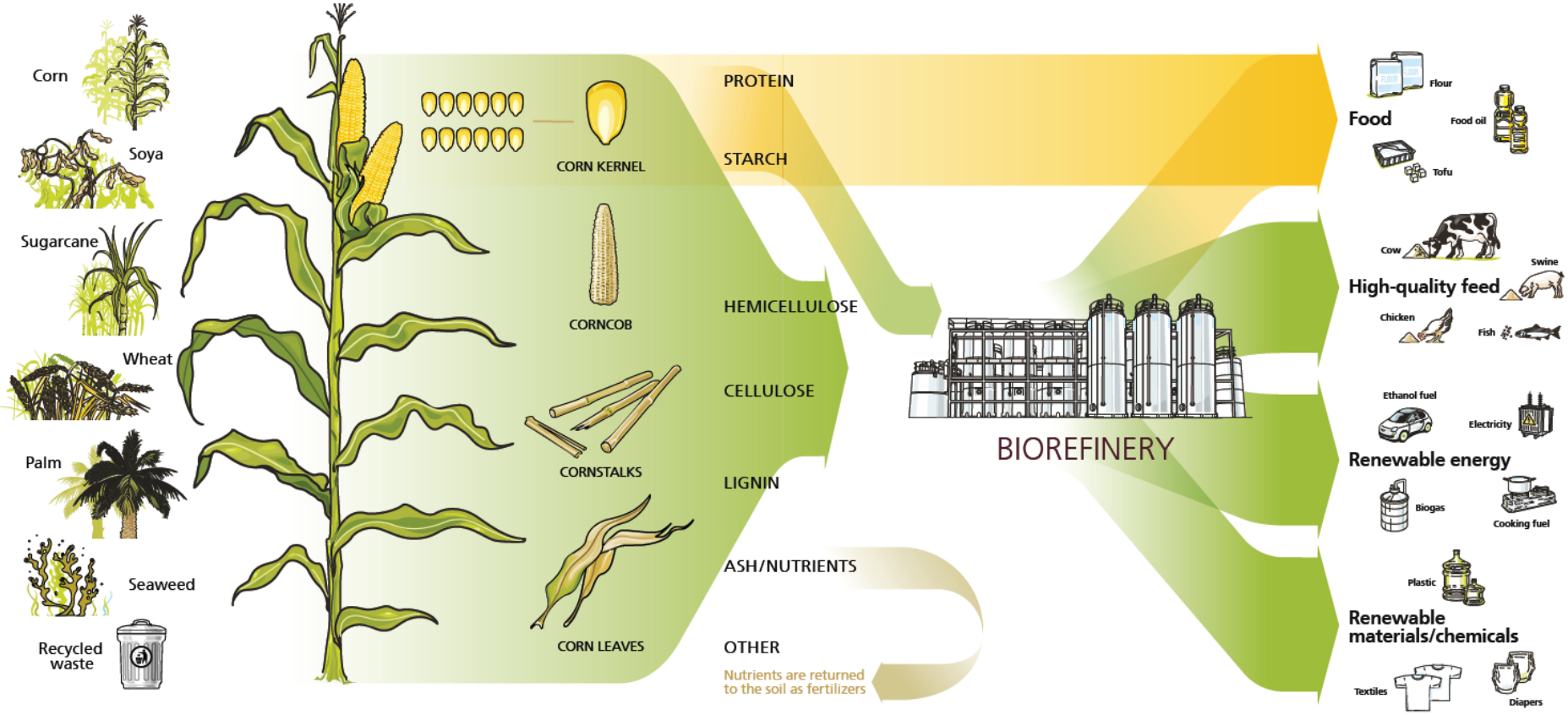

Mange Tak!

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