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THE STATE UNIVERSITY OF NEW JERSEY

# Discover Chemical & Biochemical Engineering at Rutgers

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# Groups for today's activity

| | Samples | Substrate | Enzyme Loading | Enzyme solution |
|---|---|---|---|---|
| Group 1 | C1 | 50mg | **5mg/g** | A |
| Group 2 | C1 | 50mg | **5mg/g** | A |
| Group 3 | C1 | 50mg | 50mg/g | C |
| Group 4 | C1 | 50mg | 50mg/g | C |
| Group 5 | C1 | 200mg | **5mg/g** | B |
| Group 6 | C1 | 200mg | **5mg/g** | B |
| Group 7 | C1 | 200mg | 50mg/g | D |
| Group 8 | C1 | 200mg | 50mg/g | D |
| | | | | |
| Group 9 | C3 | 50mg | **5mg/g** | A |
| Group 10 | C3 | 50mg | **5mg/g** | A |
| Group 11 | C3 | 50mg | 50mg/g | C |
| Group 12 | C3 | 50mg | 50mg/g | C |
| Group 13 | C3 | 200mg | **5mg/g** | B |
| Group 14 | C3 | 200mg | **5mg/g** | B |
| Group 15 | C3 | 200mg | 50mg/g | D |
| Group 16 | C3 | 200mg | 50mg/g | D |

Tubes with C3 samples are labeled 'C3' on the cap
Each tube is labeled with either '50' or '200' to indicate the amount of cellulose

Tubes that would be put at 25C are labeled with green tape
Tubes that would be put at 50C are labeled with yellow tape

In each group, 1 student's tube put at 50C, 1 at 25C

Enzyme solution:(4 colors of tape
A. 0.025mg/ml (Pink tape)
B. 0.1mg/ml (Red tape)
C. 0.25mg/ml (Orange tape)
D. 1mg/ml (Blue tape)

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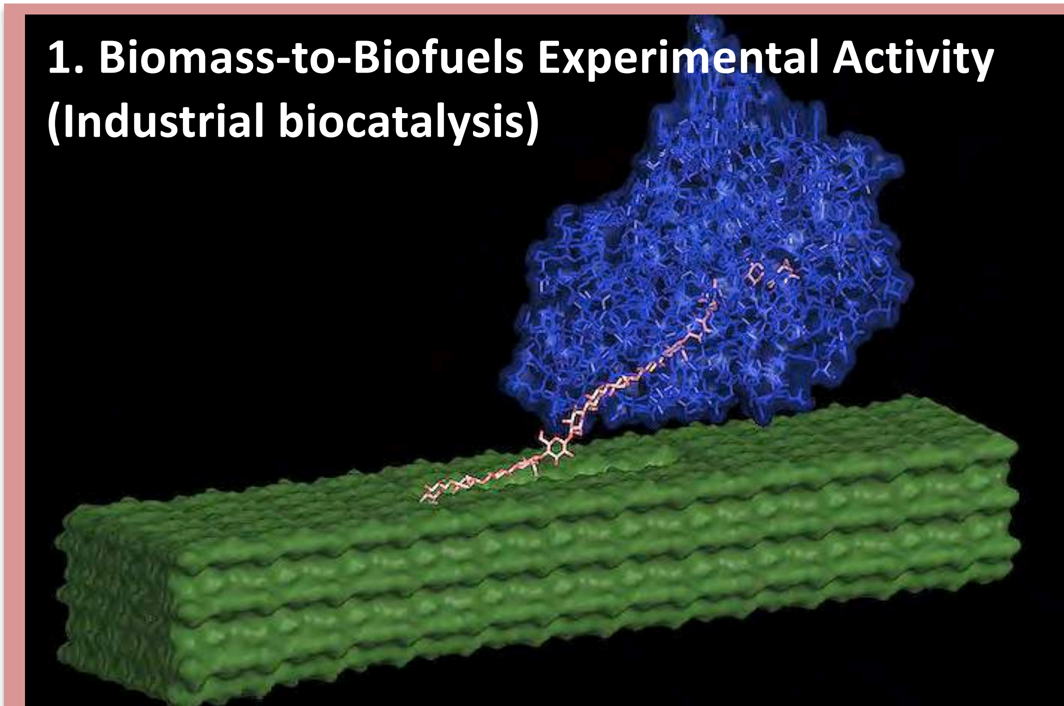
# Discover CBE @ Rutgers

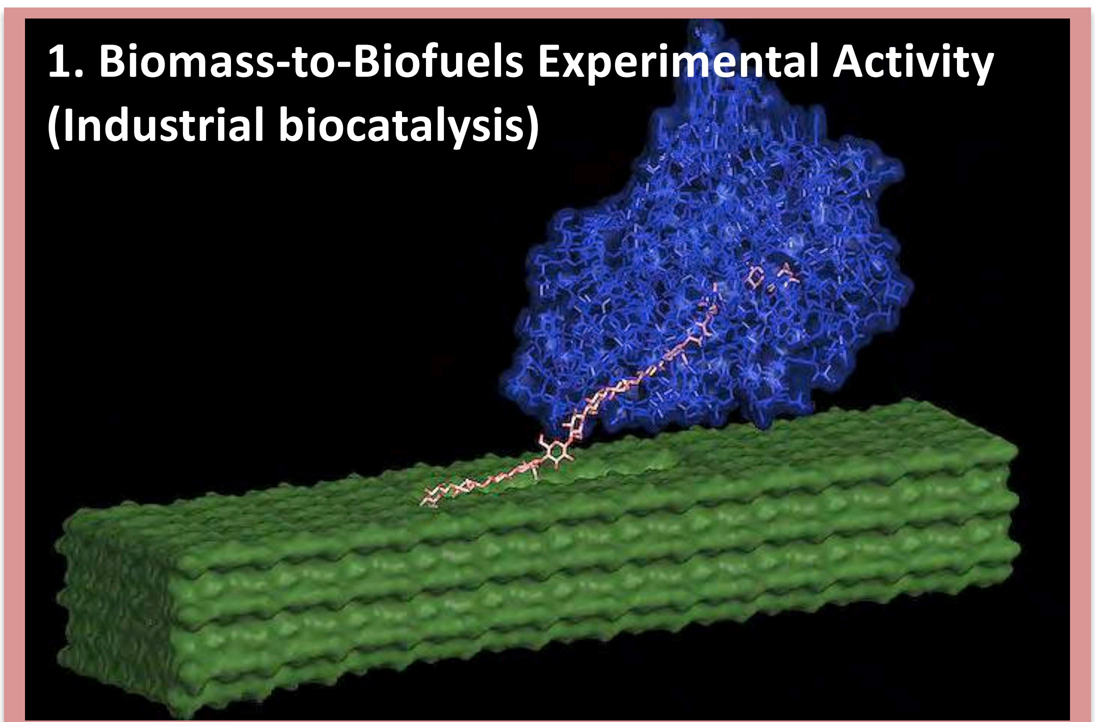

2. What is Chemical and Biochemical Engineering (CBE)?

3a. Overview to Rutgers CBE Program

3b. Industrial Opportunities




3c. Rutgers Undergraduate Experiences


1. Biomass-to-Biofuels Experimental Activity
(Industrial biocatalysis)


**Why is it challenging to convert biomass to bioenergy?**

**…cows seemed to have figured out how to do this**

**…and so do you (probably not eating as much salad)!**


Sugar

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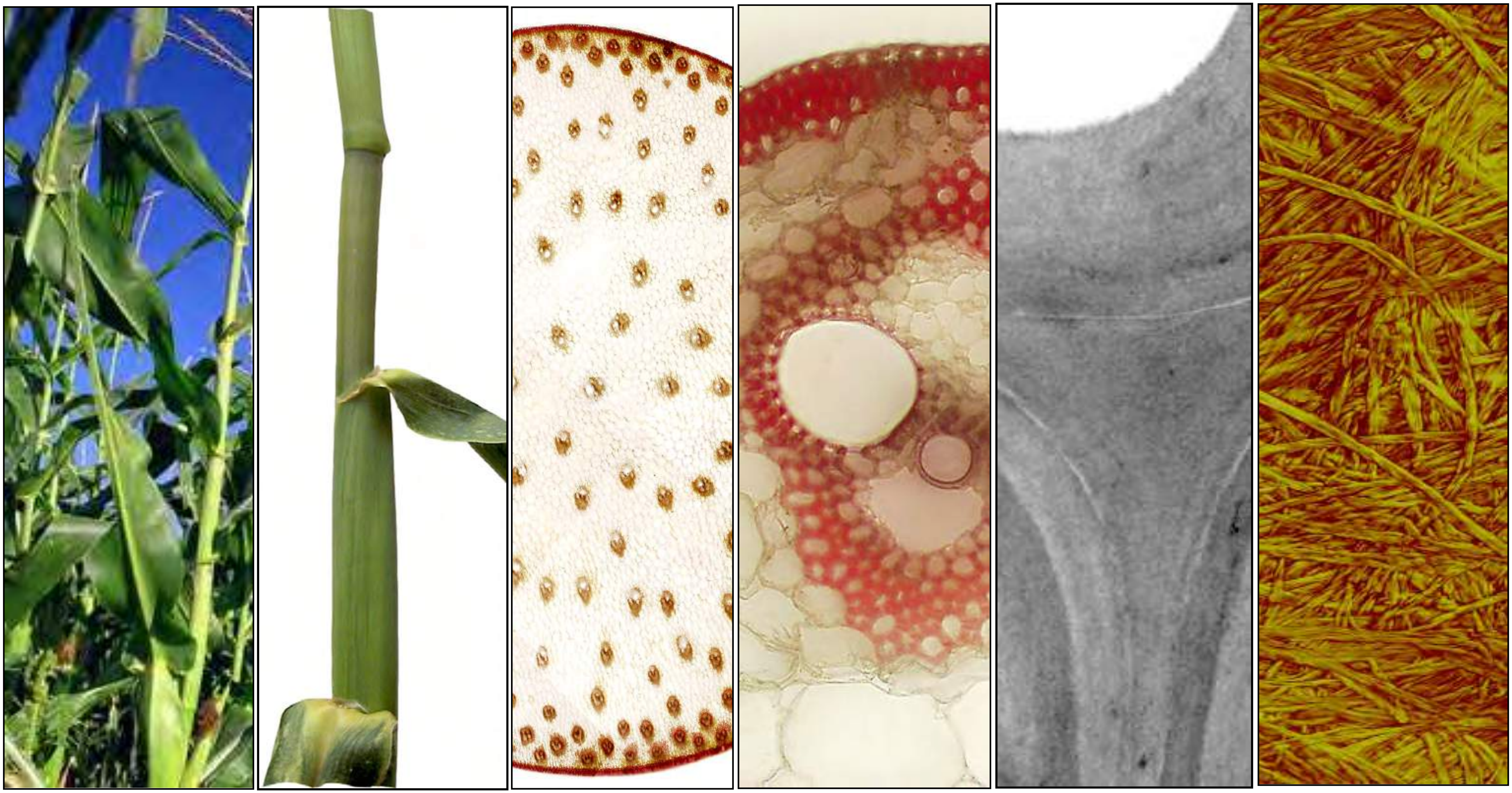
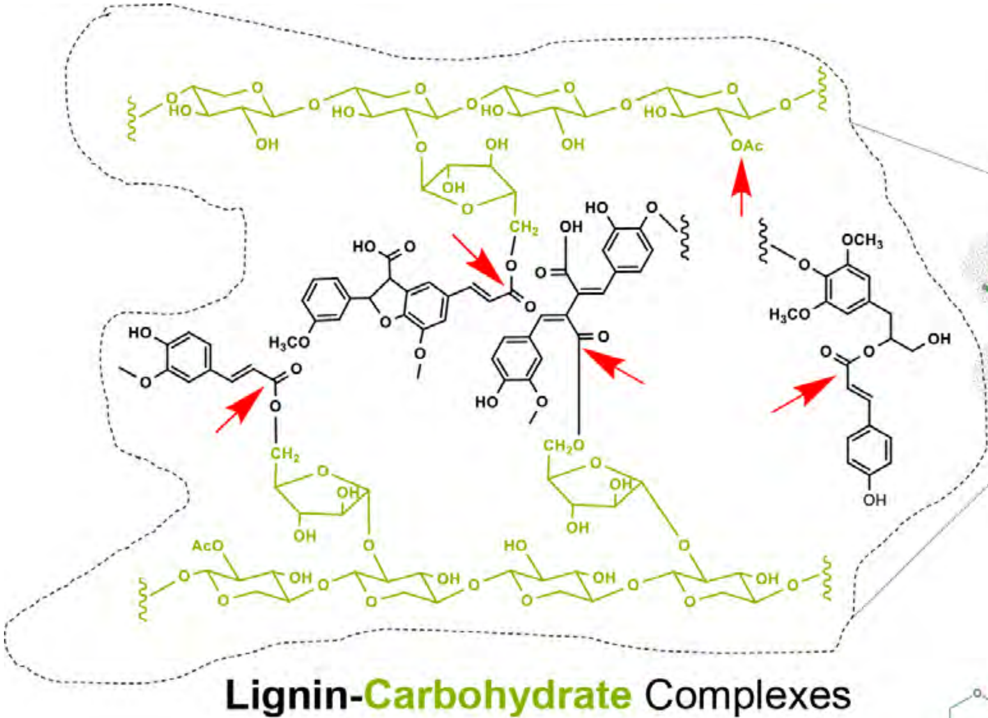
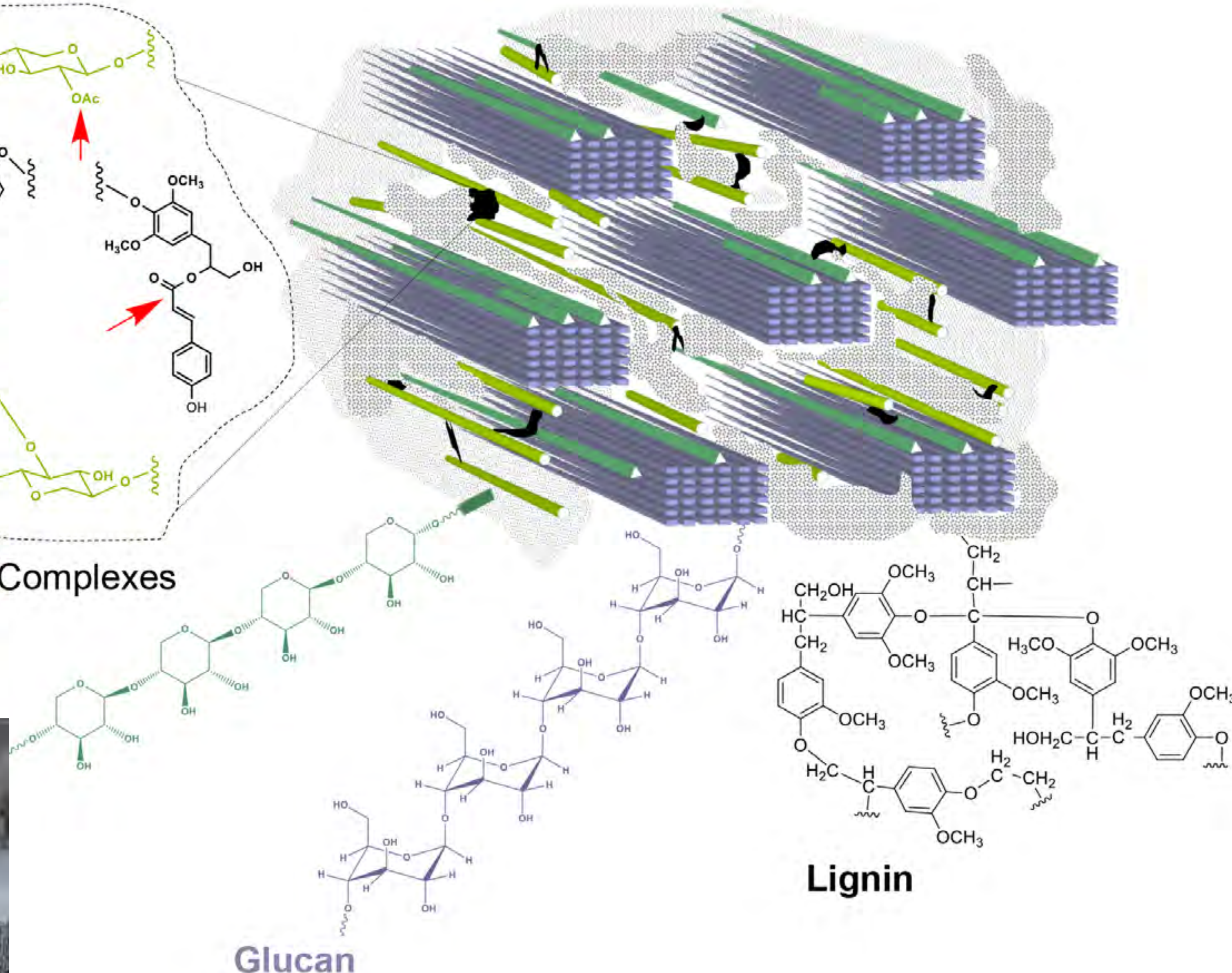
# Plants are abundant in sugar polymers…



**Can you name the most abundant organic polymer?**

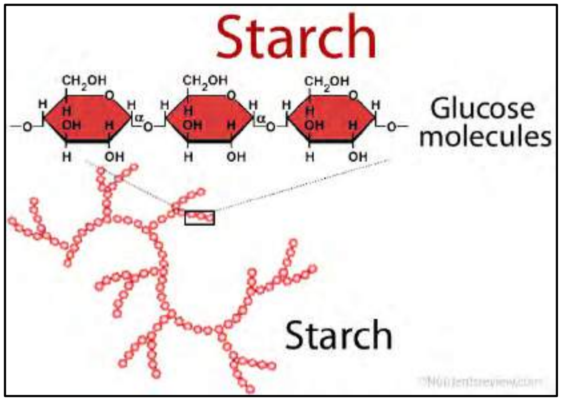
# …but polymers are trapped inside cell walls

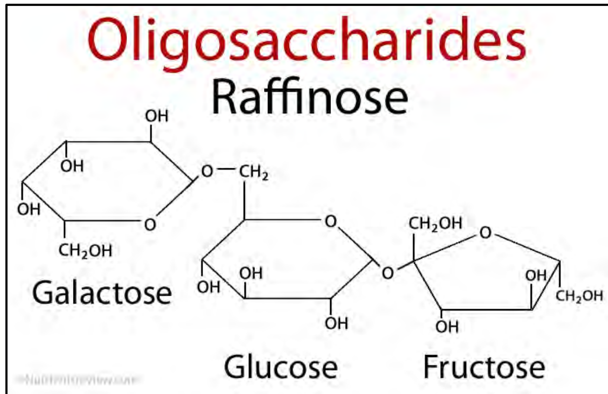


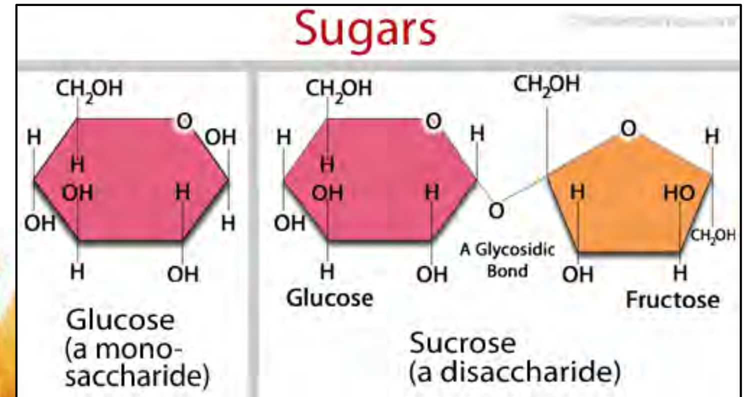



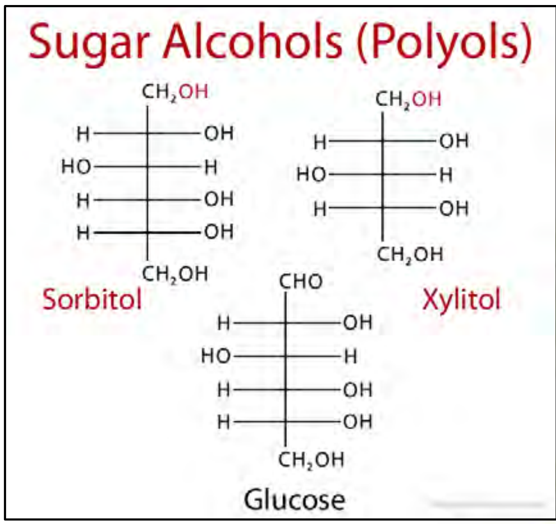

## Walls are like reinforced concrete!

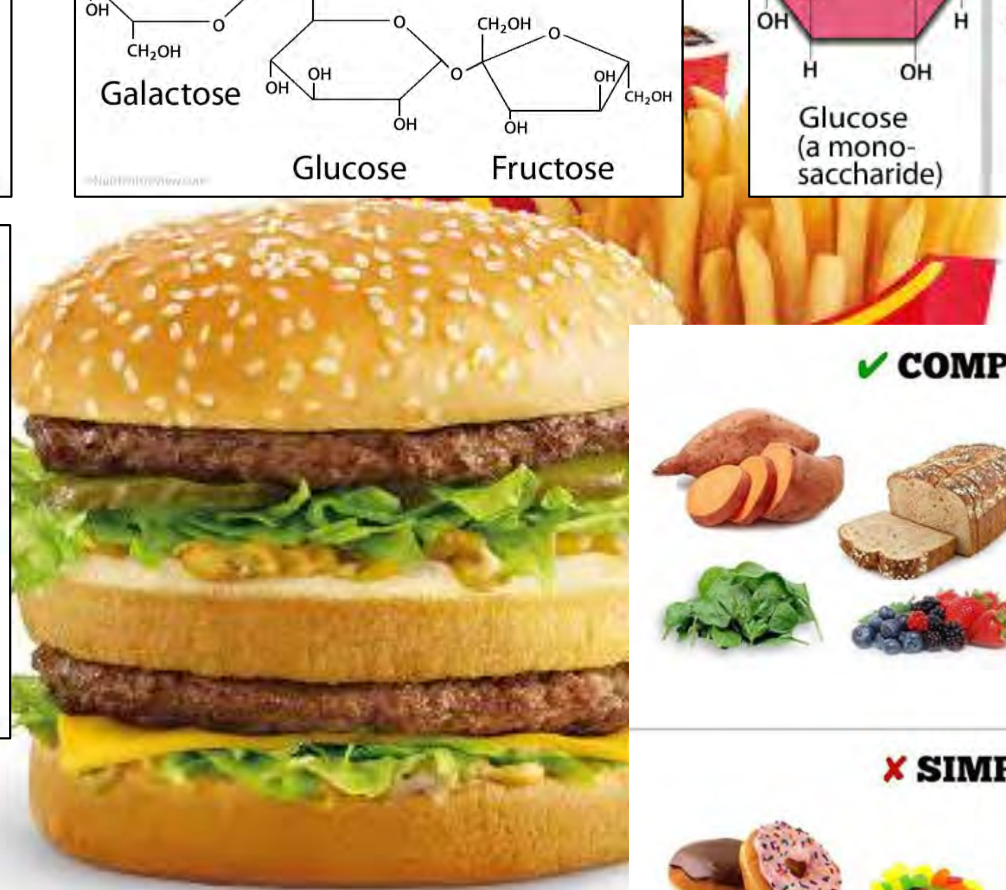
# Carbohydrate polymers are all around you!



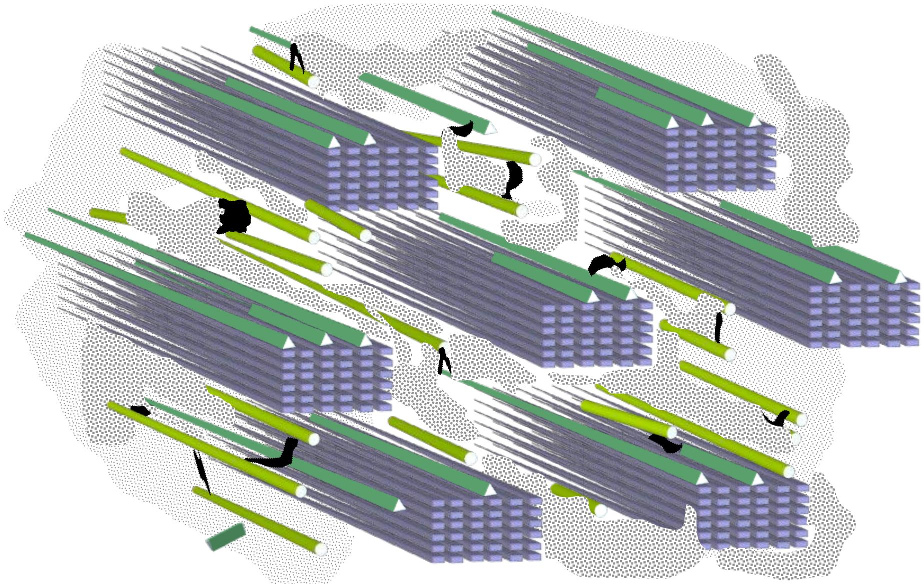



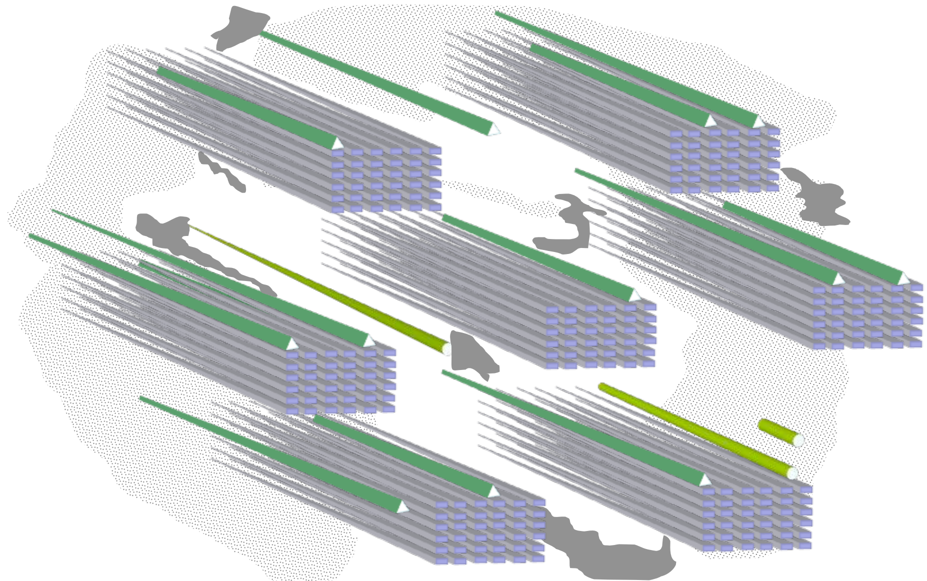




http://www.nutrientsreview.com, MacDonald's

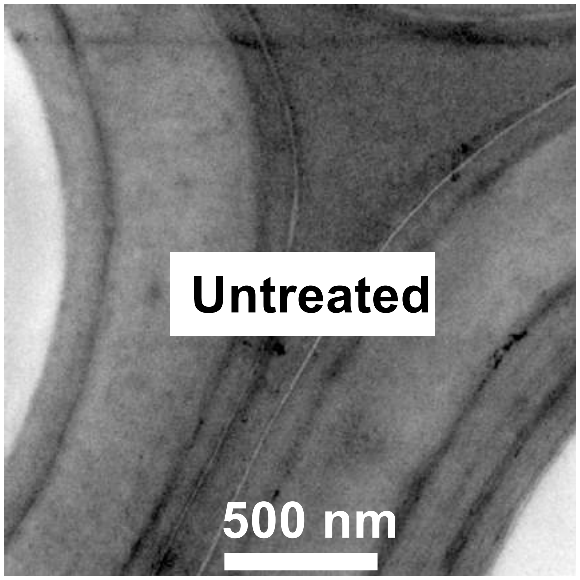
# Chemical pretreatments can breakup walls

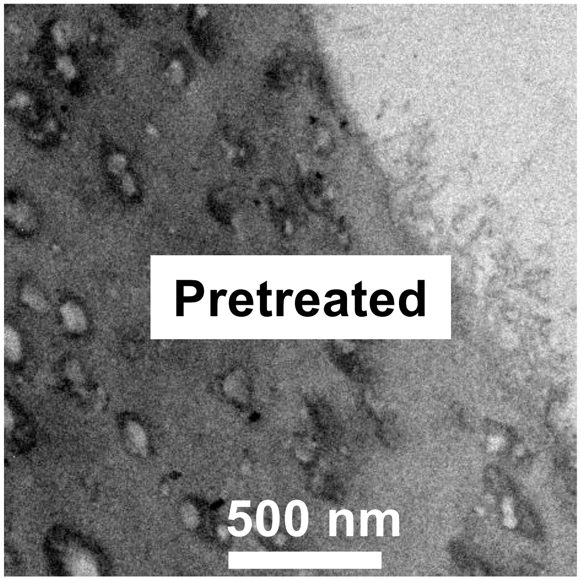


Untreated Biomass



Ammonia-treated Biomass

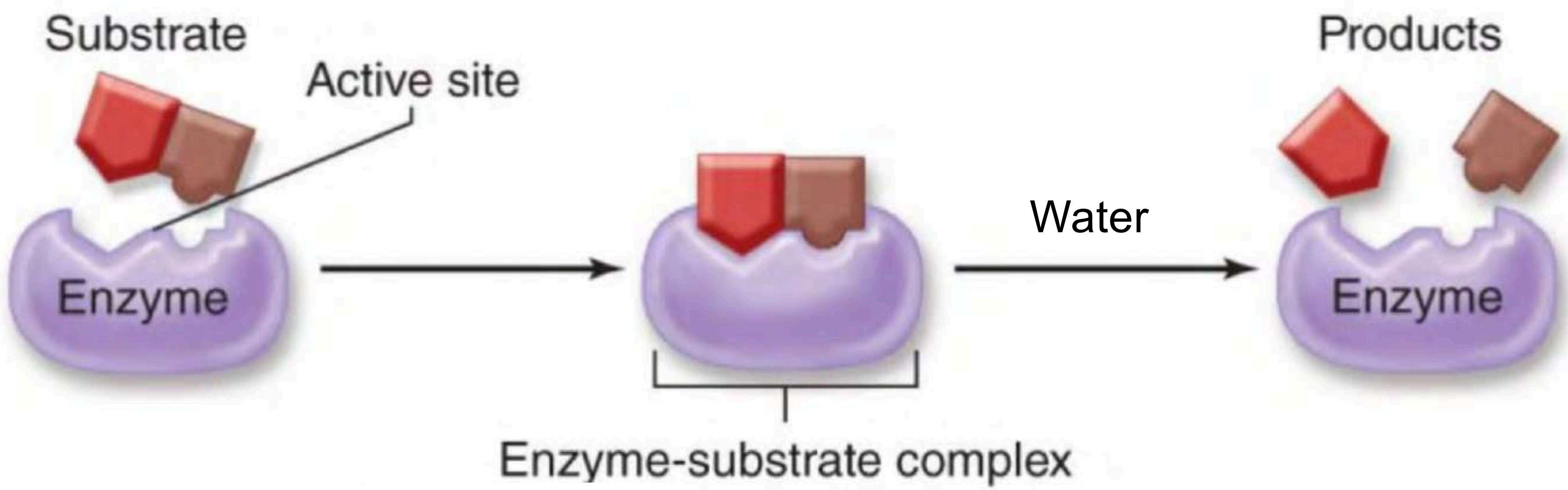


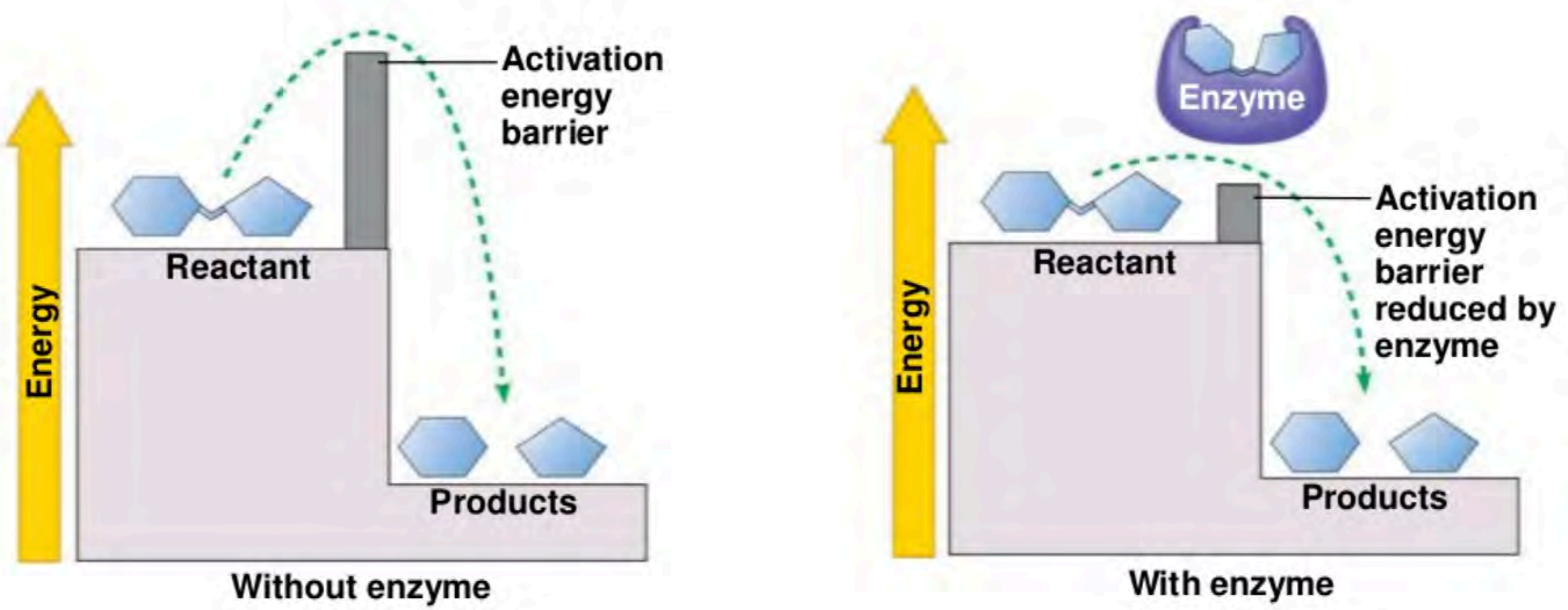




**Need to remove the concrete!**

# How do living systems breakdown polymers?

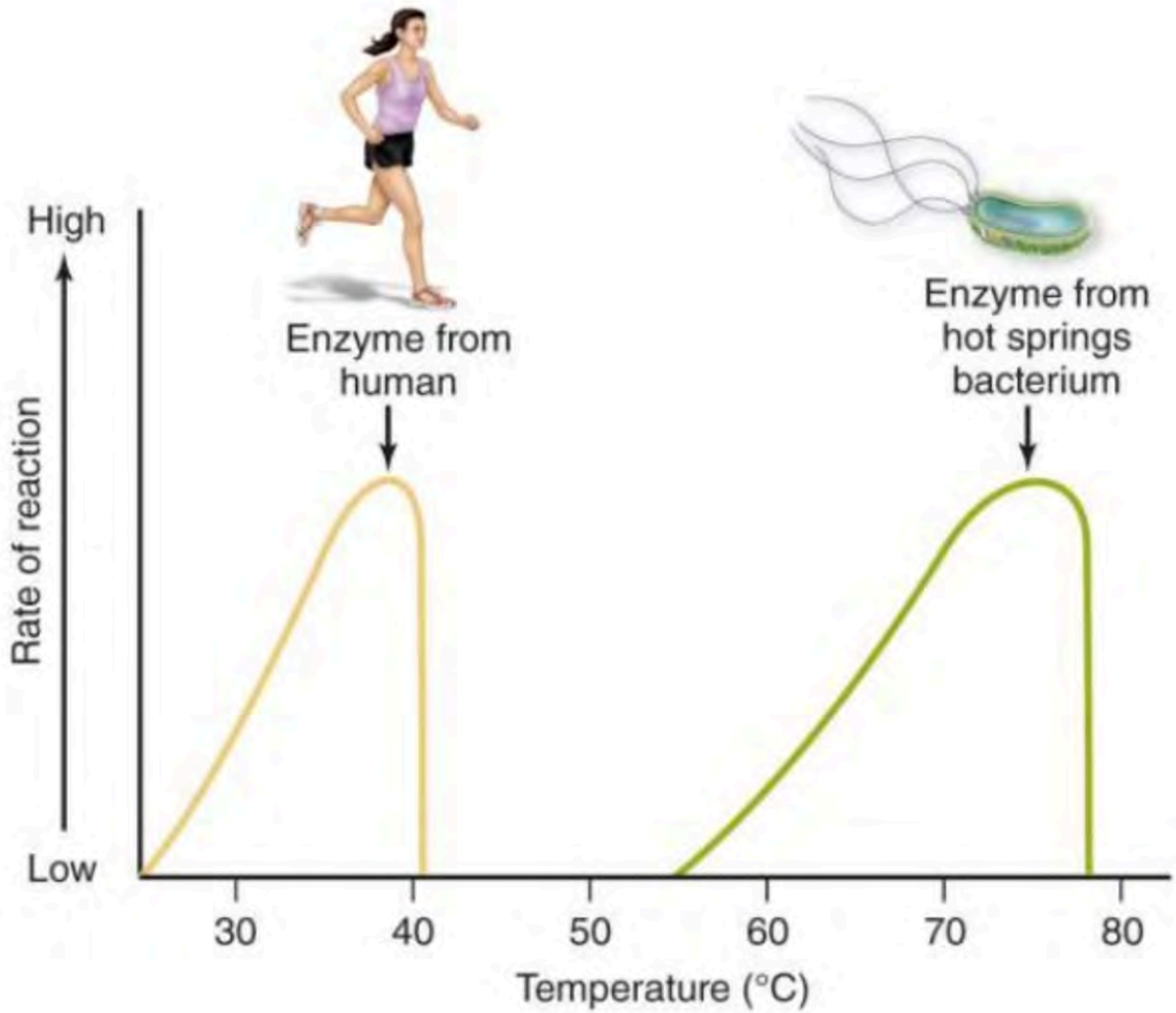
# Enzymes are biocatalysts that break polymers




## How fast do enzymes speed up hydrolysis reactions by?

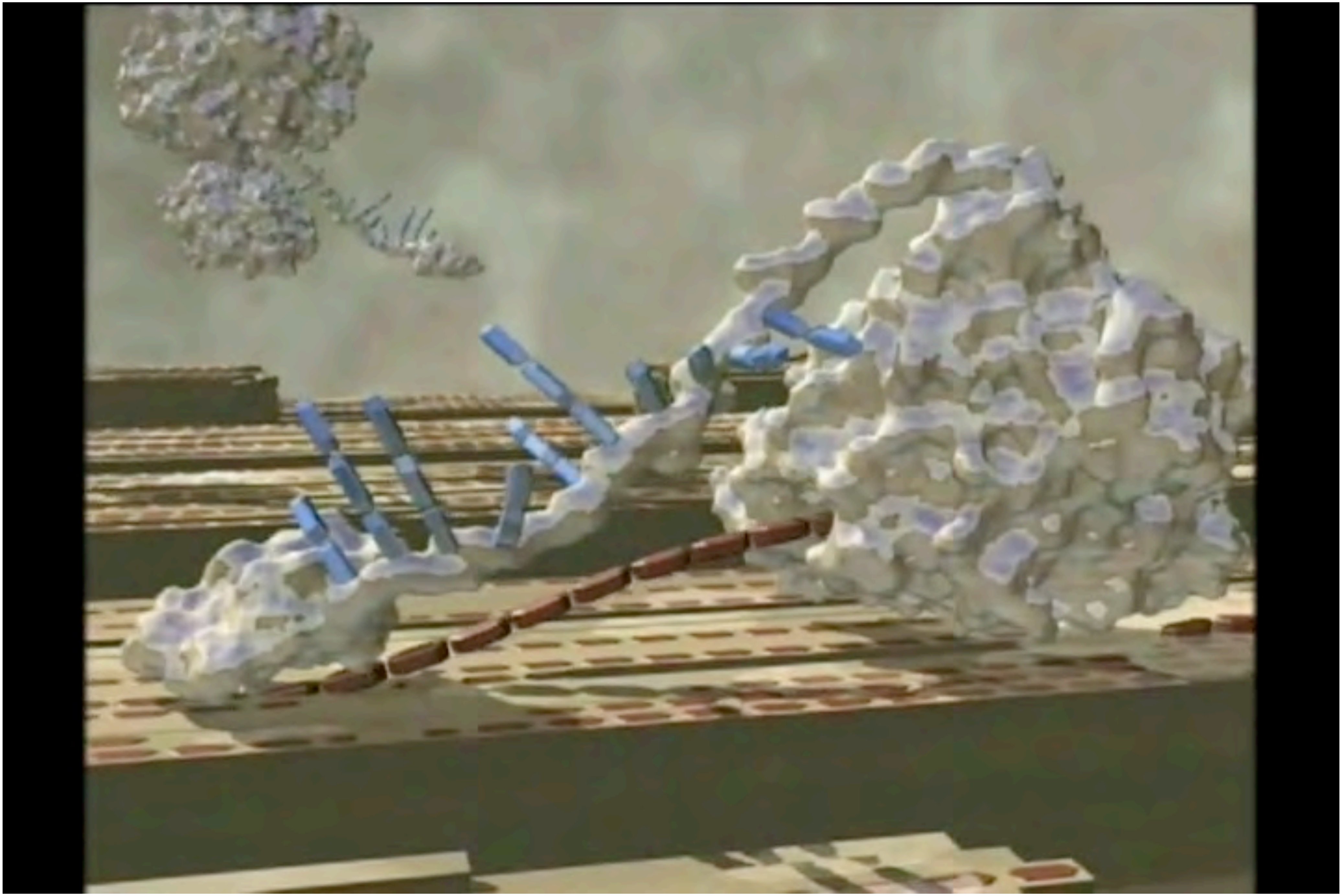
# Enzymes are temperature sensitive



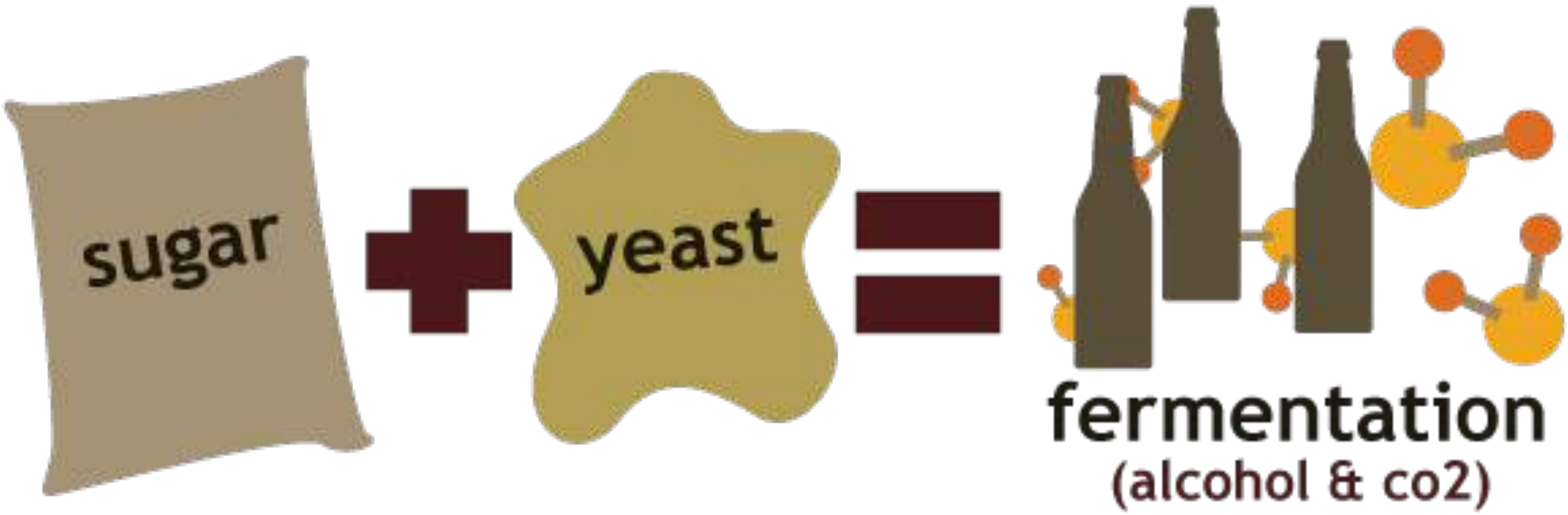

**Why are enzymes temperature sensitive?**

# Shrinking and exploring plant cell walls…

# 'Watching' cellulase enzymes at work (or play)…



# How to convert glucose sugar into biofuel?




**Yeast can 'ferment' glucose into ethanol!**

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# Making 'biofuel' or 'beer' from biomass

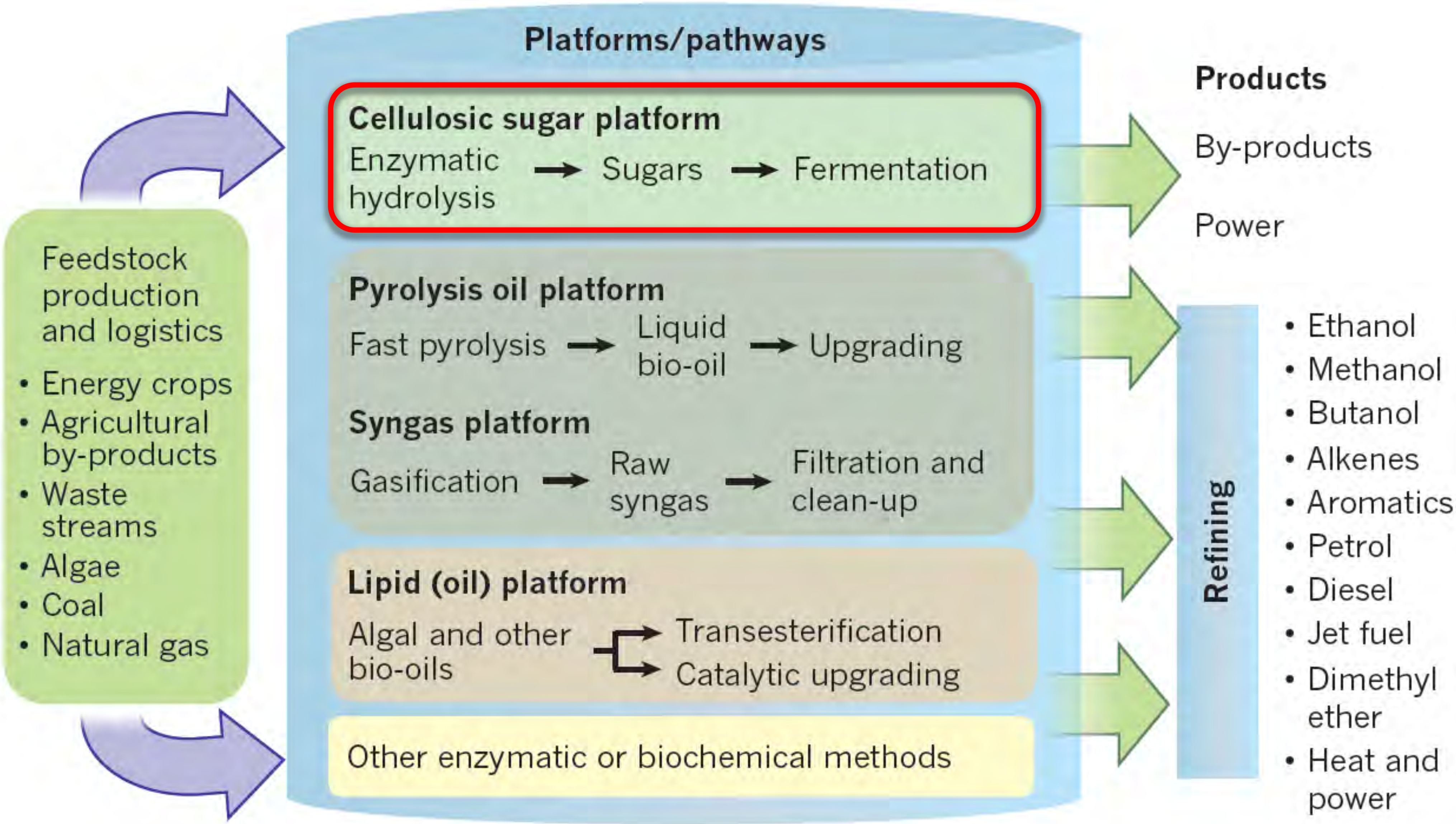
Aerial view of POET-DSM's Project Liberty cellulosic ethanol plant in Emmetsburg, Iowa

**25 million gallons cellulosic ethanol produced annually…**

20★17

AIChE®
BEER BREWING
COMPETITION

# Cellulosic biomass can be '*refined*' like crude oil



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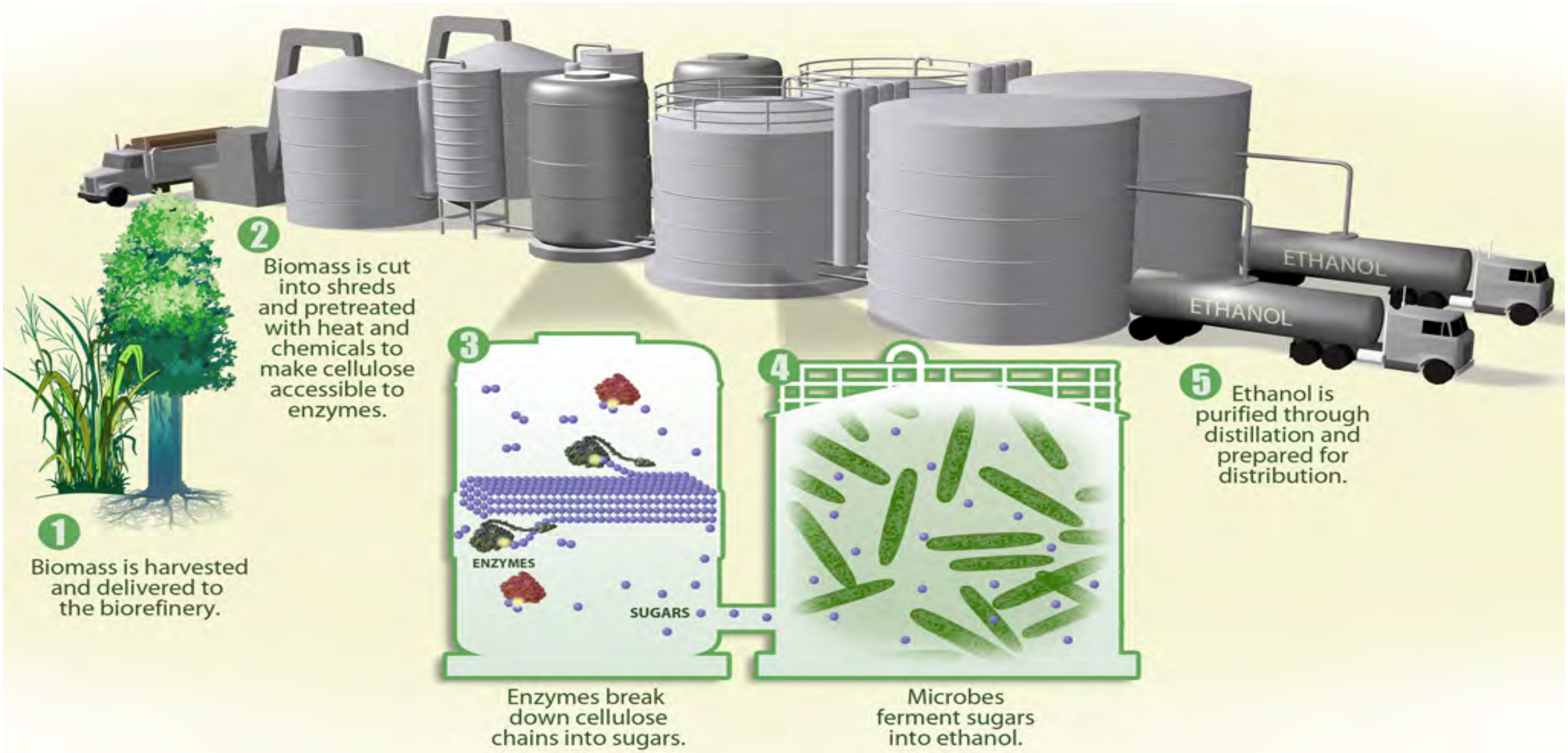
# Cellulosic sugar platform based *bio*-refinery

*Harvest & Transport* ➜ *Biomass Pretreatment* ➜ *Enzymatic Hydrolysis* ➜ *Sugar Fermentation* ➜ *Product Recovery* ➜ *Biofuel Distribution*




Department of Energy

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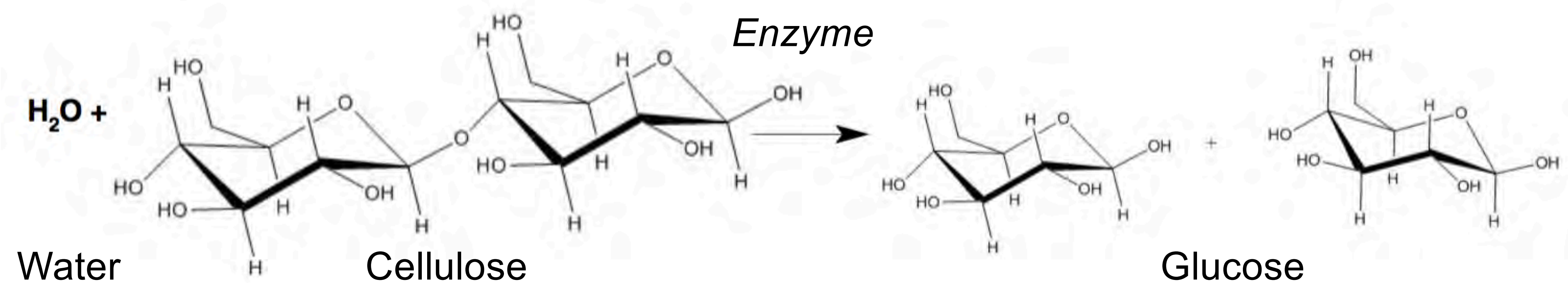
# "Grass-to-Gas" Hands-on Experimental Activity

**Enzymatic hydrolysis** is a key step for converting cellulosic biomass into sugars in a bio-refinery…and is focus of activity!

Through this hands-on activity we will explore;

- What is the impact of pretreatment on hydrolysis?
- What is the impact of enzyme concentrations?
- What is the impact of cellulose concentrations?
- What is the impact of temperature on reaction rate?




**Focus to ask questions like biochemical engineers do!**

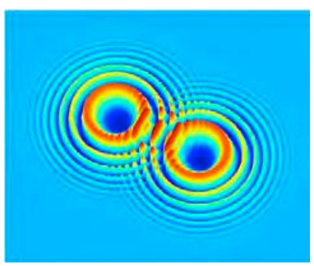

**2. What is Chemical and Biochemical Engineering (CBE)?**

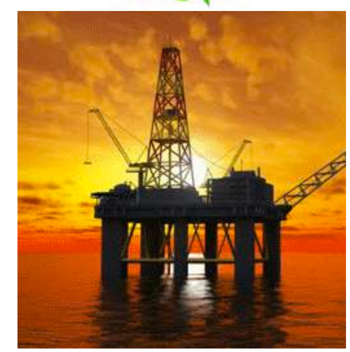
# What is Chemical Engineering?

- No universal definition…

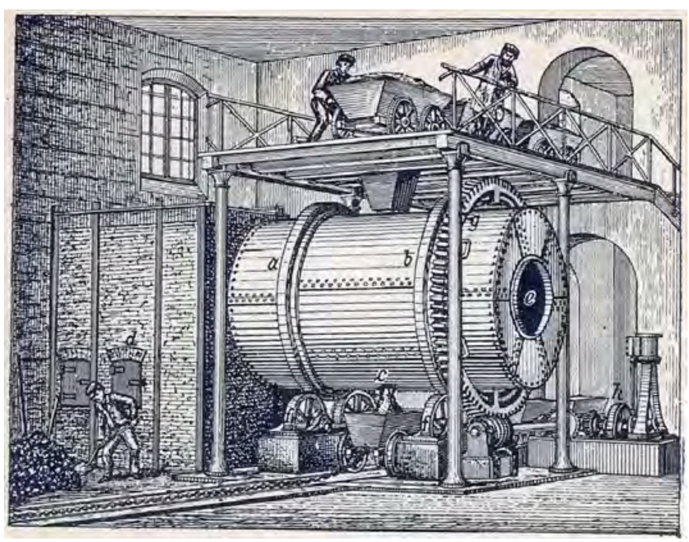
- ChE's apply basic sciences – math, chemistry, physics & biology – and engineering principles to understand, develop, design, operate & maintain processes that: **convert raw materials to desired products, and improve quality of life in a sustainable manner!**

$$\int f(x)\,dx$$

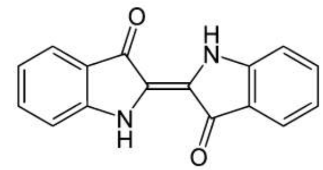



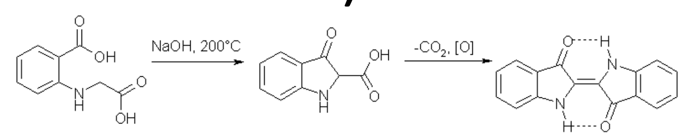

# Historical Origins of Chemical Engineering



- **Scale-up** of chemical processes during industrial revolution



- Principles of operation of simple chemical reactions as batch processes (or **unit operations** like distillation)



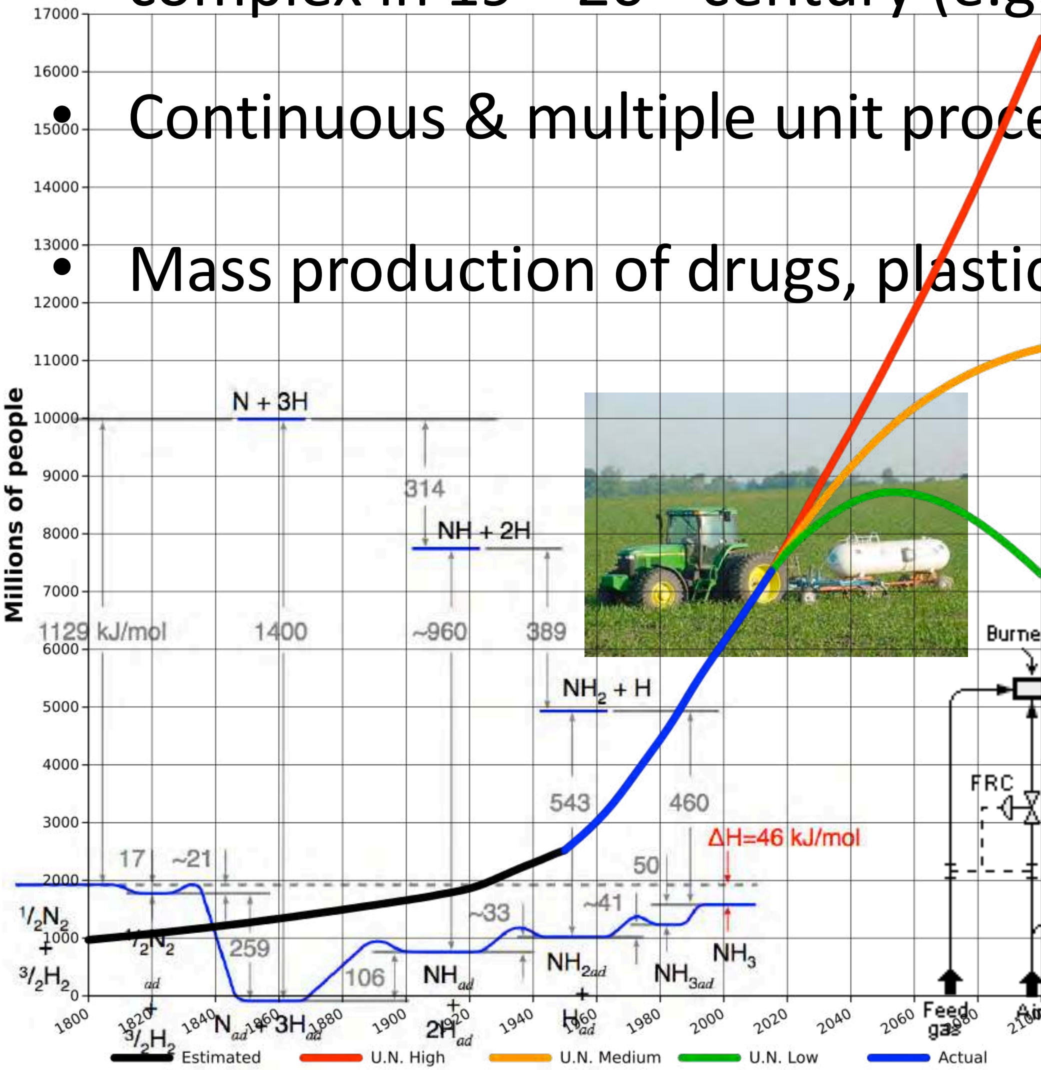

- Initially, chemists & mechanical engineers worked together ($18^{th}$ century)

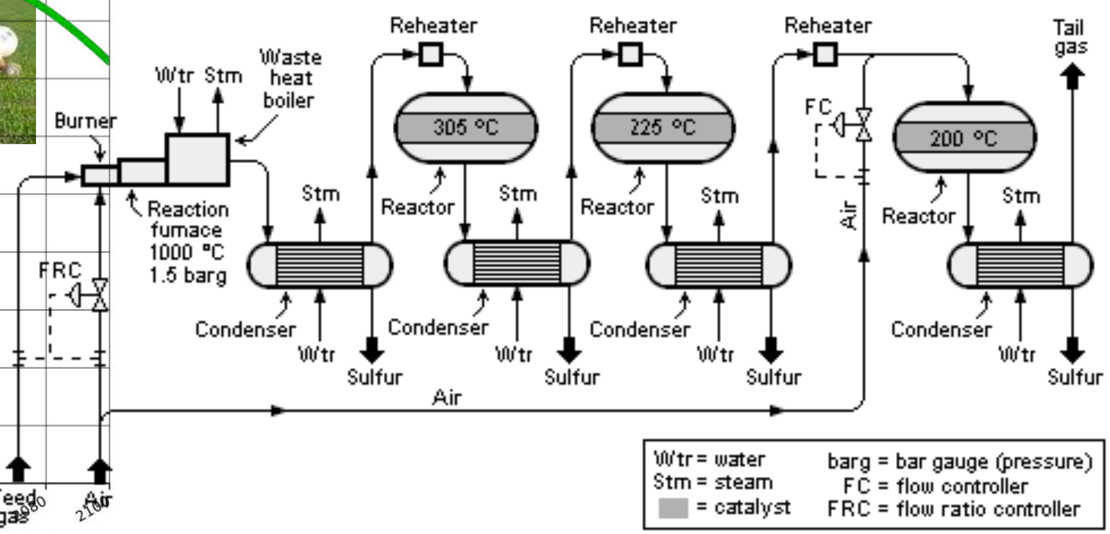
*BASF Indigo Plant*

- Complicated chemistry demanded new concepts and innovations by $19^{th}$ century

# Petro-Agrochemical Revolution

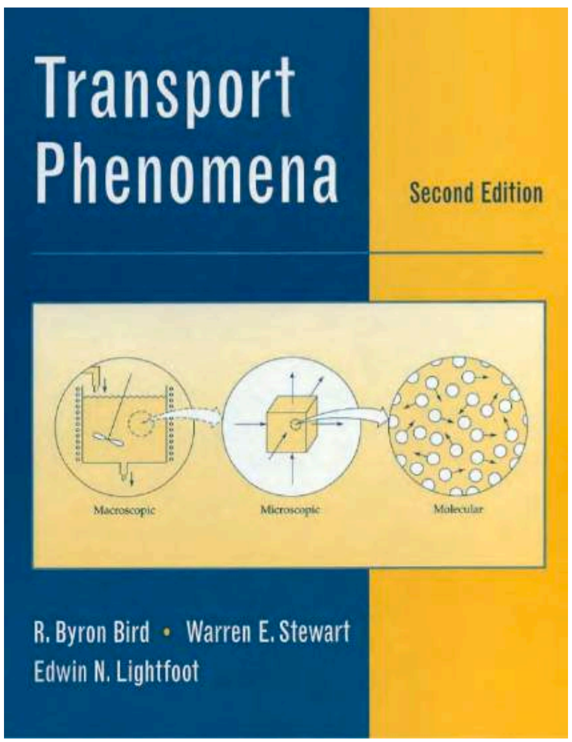
- Chemical engineering developed as processes became more complex in 19th-20th century (e.g., Haber-Bosch Process)
- Continuous & multiple unit processes, control and safety designs
- Mass production of drugs, plastics…and eventually computers

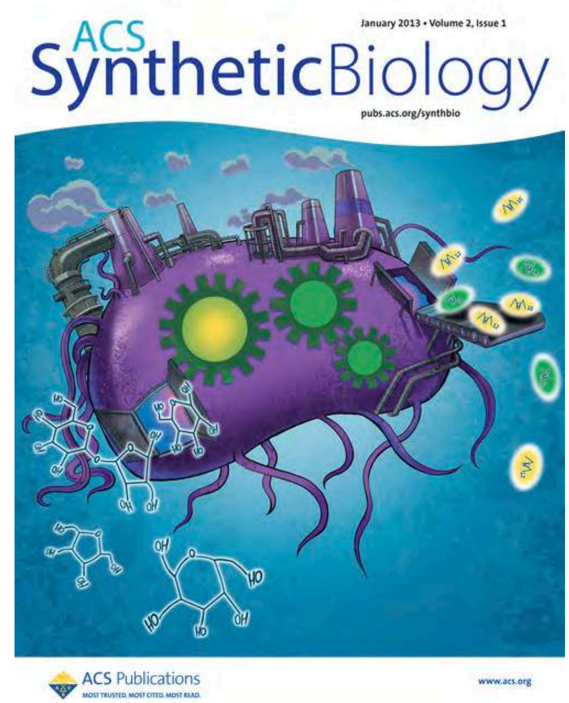


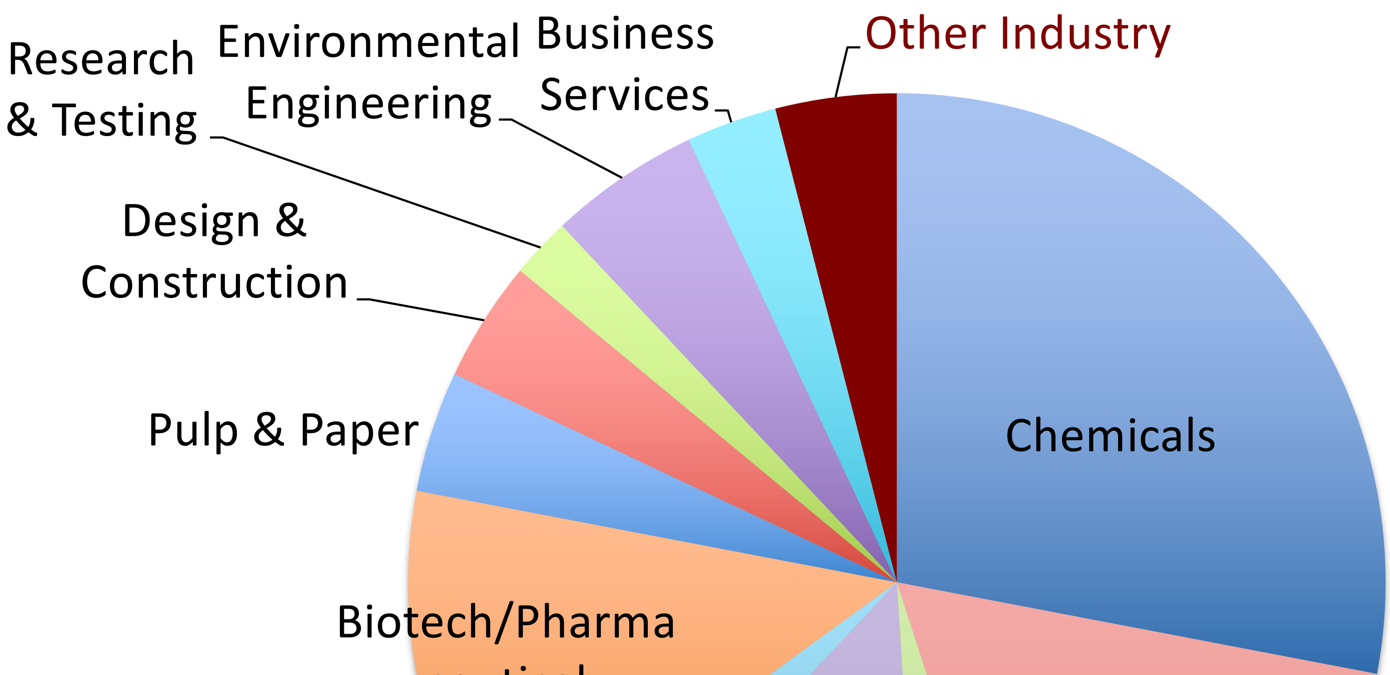
# Evolution over last 60 yrs…

- 1960s – advanced mathematical methods
- 1970s – biochemical & biomedical applications
- 1980s – advanced computational methods
- Present day – highly interdisciplinary (e.g., nanotechnology, biotechnology, genetic engineering, materials engineering)



# Professional Opportunities





Rubber

Plastics

Textiles

Metals

Minerals

Agricultural

Cosmetics

3a. Overview to Rutgers CBE Program

3b. Industrial Opportunities

3c. Rutgers Undergraduate Experiences

# Rutgers CBE Students

## Undergraduate Program

- ~350 students (Soph, Jr, Sr)
- 4th largest program in SOE
- 33% women

## Graduate Program

~200 students

- 140 masters students
- 60 PhD students

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# Chemical & Biochemical Faculty

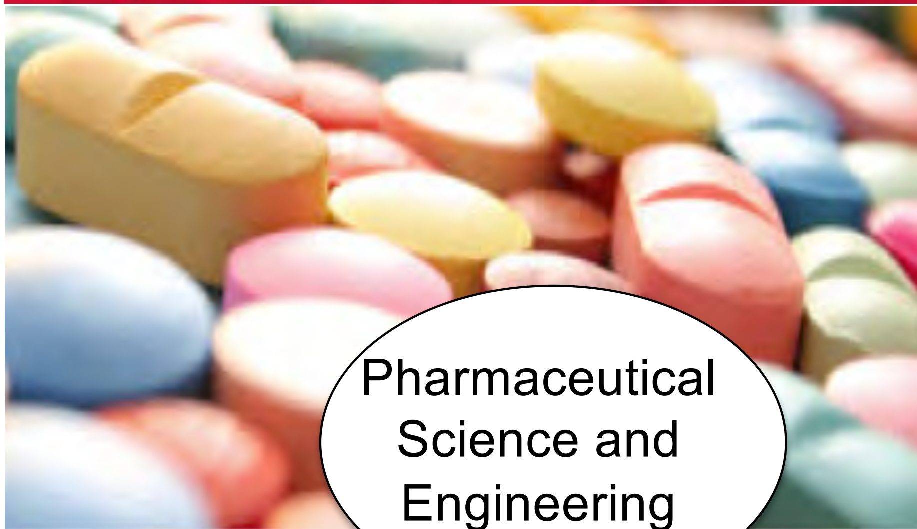
Undergraduate Director

CBE Chair

Graduate Director

- 22 Faculty
- 6 Women (#1 in SOE)
- 5 joint with Biomedical Engineering
- 1 joint with Chemistry & Chemical Biology
- Highly Diverse and Interdisciplinary Research

# RUTGERS CBE Faculty Core Research Areas



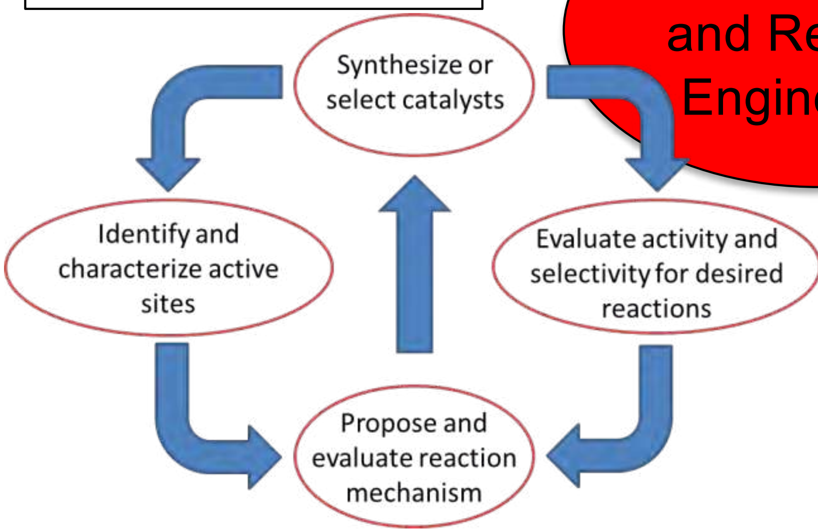
## Pharmaceutical Science and Engineering

Glasser,
Ierapetritou,
Muzzio,
Ramachandran,
Tomassone

## Biotechnology & Bioengineering

Androulakis, Buettner,
Chundawat, Moghe,
Pedersen, Roth, Zhang, Sofou

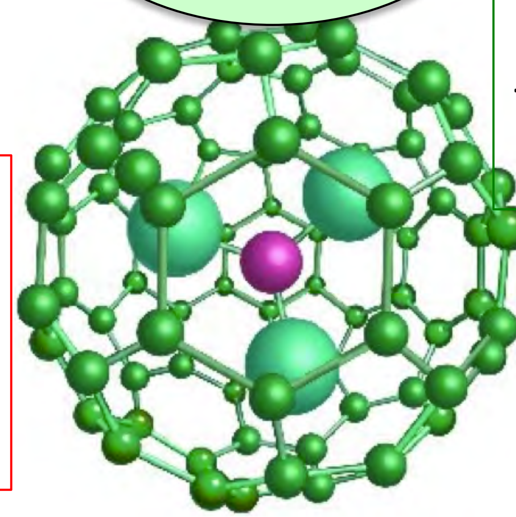
## Process Systems and Reaction Engineering

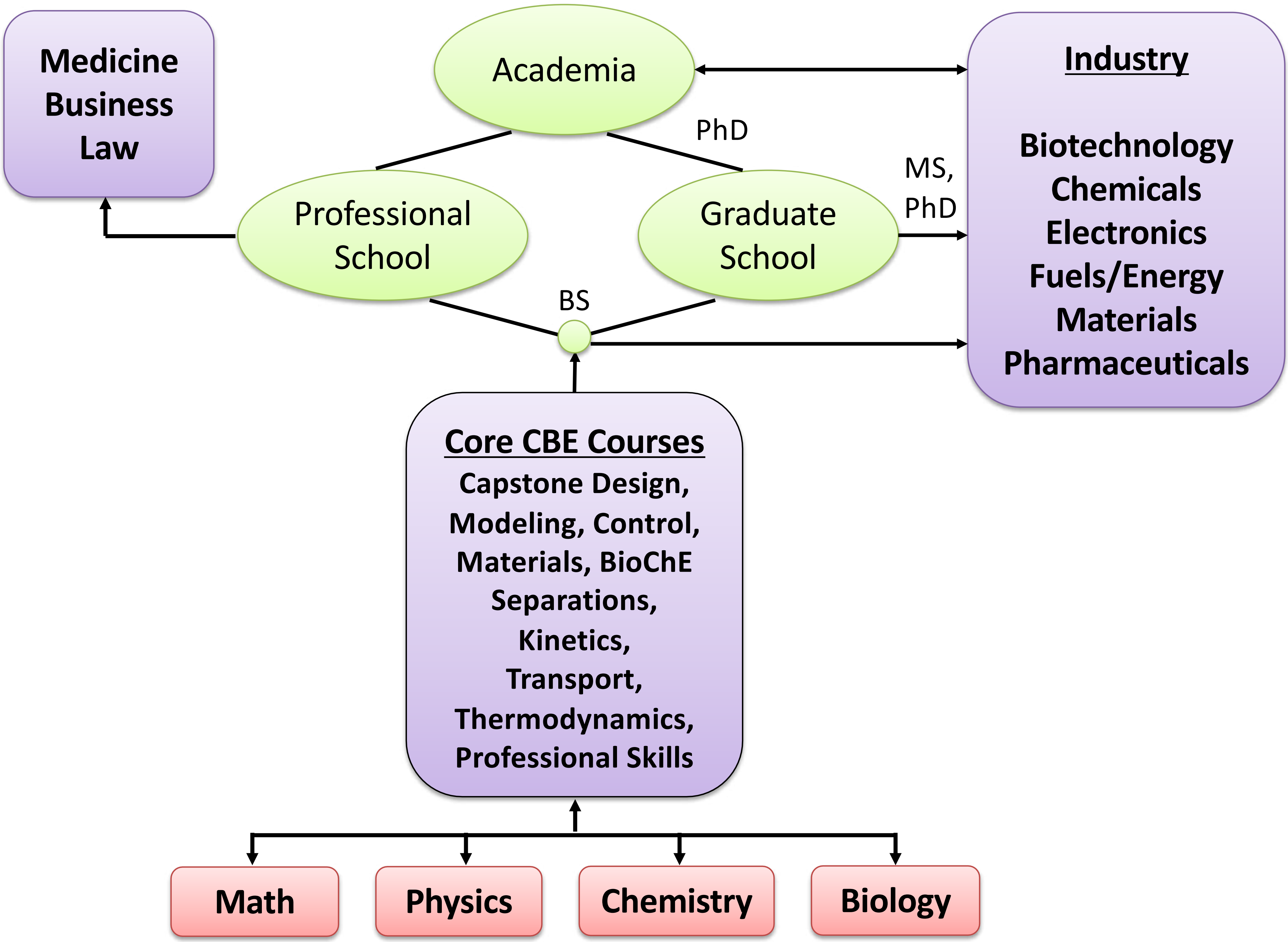



Ierapetritou,
Ramachandran,
Celik,
Chundawat,
Tsilomelekis

## Advanced Materials & Modeling

Asefa, Chiew,
Dutt,
Neimark,
Scheinbeim,
Shapley,
Hara,
Tomassone




Medicine
Business
Law
Academia
PhD
Industry
Biotechnology
Chemicals
Electronics
Fuels/Energy
Materials
Pharmaceuticals
Professional School
Graduate School
MS, PhD
BS
Core CBE Courses
Capstone Design, Modeling, Control, Materials, BioChE Separations, Kinetics, Transport, Thermodynamics, Professional Skills
Math
Physics
Chemistry
Biology

# CBE Undergraduate Curriculum

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Chemical engineering major courses begin fall of sophomore year…

In junior year, can choose technical elective options in several areas;

- Biochemical
- Pharmaceutical
- Environmental
- Pre-Medical
- Energy etc…

Or choose electives to match interests (e.g. Bioinformatics)

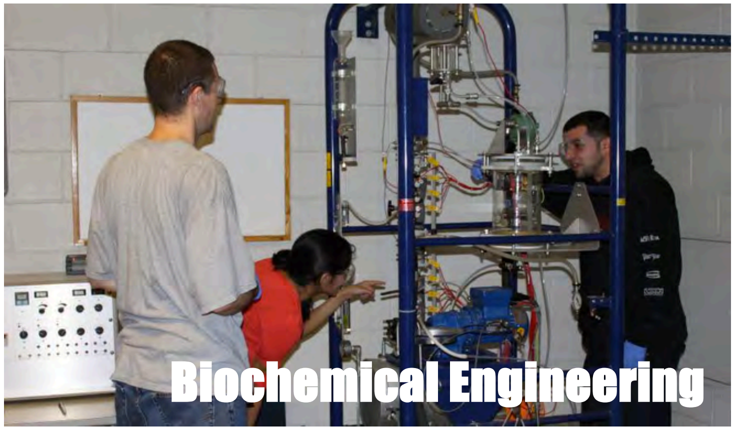
| FALL | | | SPRING | | | |
|---|---|---|---|---|---|---|
| **Freshman Year** | | | | | | |
| 01:160:159 | Gen. Chemistry for Eng. | 3.0 | 01:160:160 | Gen. Chemistry for Eng. | 3.0 | |
| 01:355:101 | Expository Writing | 3.0 | 01:160:171 | Intro. Experimentation | 1.0 | |
| 14:440:100 | Eng. Orientation Lectures | 1.0 | 14:440:127 | Intro. Computers for Eng. | 3.0 | |
| 01:640:151 | Calculus I | 4.0 | 01:640:152 | Calculus II | 4.0 | |
| 01:750:123 | Analytical Physics I | 2.0 | 01:750:124 | Analytical Physics I | 2.0 | |
| __:__:__ | Hum./Soc. Science Elective | 3.0 | 14:440:221 | Eng. Mechanics Statics | 3.0 | |
| | | 16.0 | __:__:__ | Hum./Soc. Science Elective | 3.0 | |
| | | | | | 19.0 | |
| **Sophomore Year** | | | | | | |
| 14:155:201 | **Analysis I** | **M3.0** | 14:155:208 | **Thermodynamics I** | **M3.0** | |
| 14:155:298 | **Professional Skills Devel** | **M1.0** # | **14:155:210** | **Biological Foundations of ChE** | **M3.0** | (≥'18) |
| 01:160:307 | Organic Chemistry I* | 4.0 | 01:160:308 | Organic Chemistry II | 4.0 | |
| 01:640:251 | Multivariable Calculus | 4.0 | 01:640:244 | Diff. Eqns. Engineering & Physics | 4.0 | |
| 01:750:227 | Analytical Physics II | 3.0 | 01:220:102 | Microeconomics | 3.0 | |
| 01:750:229 | Analytical Physics II Lab | 1.0 | | | 17.0 | |
| | | 16.0 | | | | |
| **Junior Year** | | | | | | |
| 14:155:303 | **Transport Phenomena I** | **M3.0** | 14:155:304 | **Transport Phenomena II** | **M3.0** | |
| 14:155:307 | **Analysis II** | **M3.0** | 14:155:324 | **Separations Processes** | **M3.0** | |
| 14:155:309 | **Thermodynamics II** | **M3.0** | 14:155:441 | **Kinetics** | **M3.0** | (≥'17) |
| 01:160:311 | Organic Chemistry Lab^ | 2.0 | 14:155:407 | **Processing & Prop. Mats.** | **M3.0** | (≥'17)Δ |
| 01:640:421 | Advanced Calc. for Eng. | 3.0 | 01:160:328 | Physical Chemistry II | 4.0 | (≤'17)+ |
| __:__:__ | Hum./Soc Science Elective | 3.0 | __:__:__ | Hum./Soc. Science Elective | 3.0 | |
| | | 17.0 | | | 19.0 | |
| **Senior Year** | | | | | | |
| | | | 14:155:416 | **Process Engineering II** | **M4.0** | |
| 14:155:411 | **Intro Biochem. Eng.** | **M3.0** | 14:155:428 | **Design & Econ. II** | **M4.0** | |
| 14:155:415 | **Process Engineering I** | **M4.0** | __:__:__ | Technical Elective | 3.0 | |
| 14:155:422 | **Process Simul. & Control** | **M3.0** (≥'17) | __:__:__ | General Elective | 3.0 | |
| 14:155:427 | **Design & Econ. I** | **M3.0** | | | 14.0 | |
| __:__:__ | General Elective | 3.0 | | | | |
| | | 16.0 | | | | |

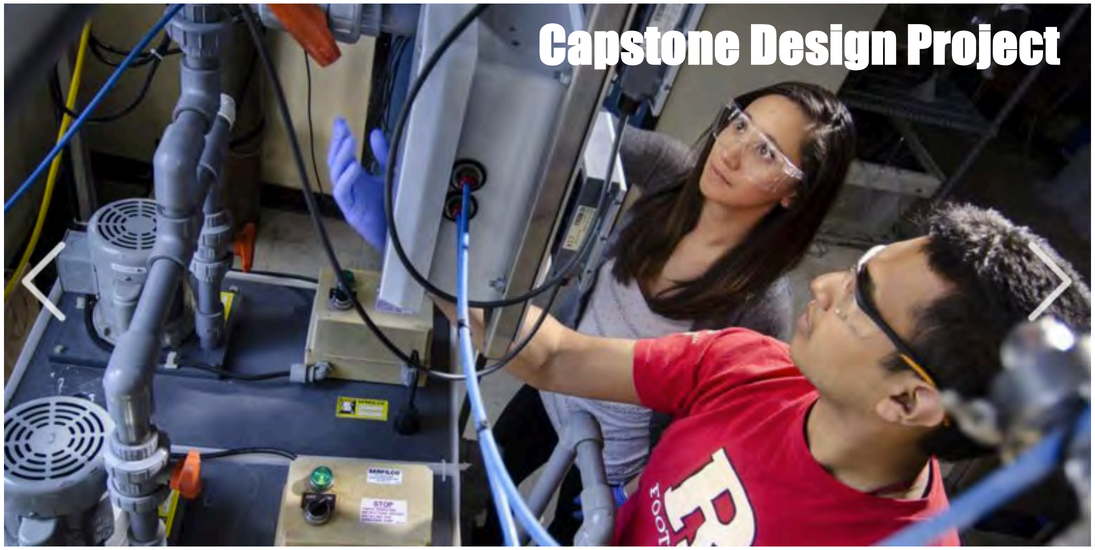
**TOTAL: 130.0 (131.0 '17)**

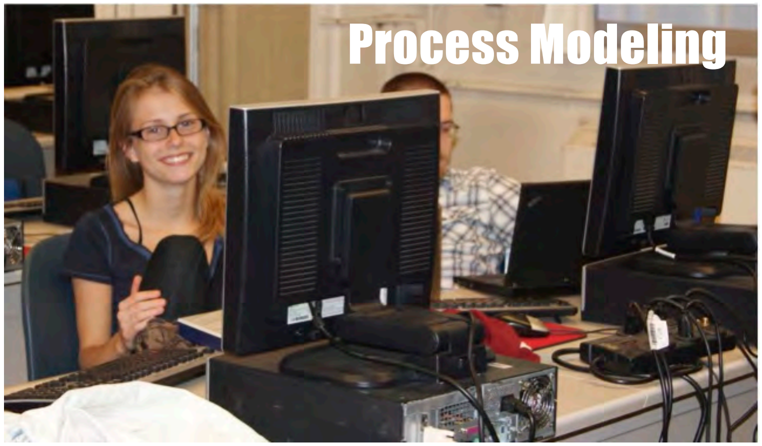
# CBE Undergraduate Curriculum

Senior year…

- Process Engineering Lab
- Capstone Design Course

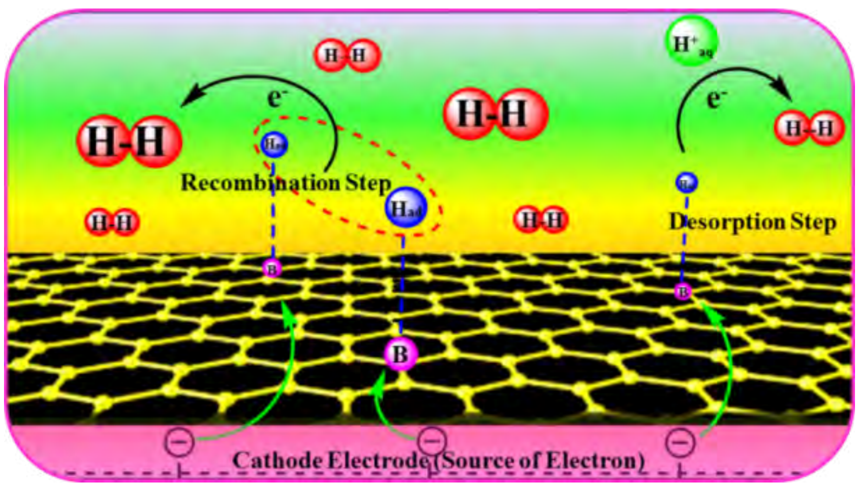



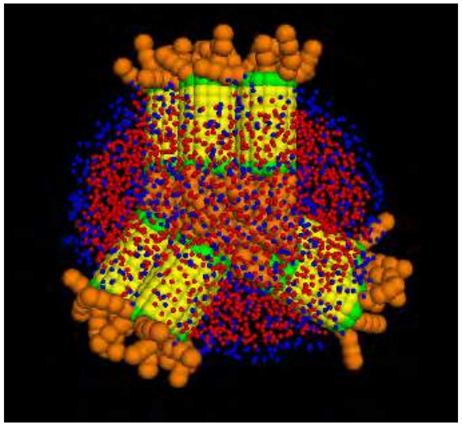



# Advanced Degree Programs

- MS in Chemical Engineering (also BS/MS)
- ME in Pharmaceutical Engineering (also BS/ME)
- Masters of Business and Science (MBS) (also BS/MBS)
- PhD in Chemical Engineering
- Interdisciplinary MD/PhD program



# Career Development

- Co-ops
  - 6 months full-time in industry – summer + 1 semester
  - Recommend during/after junior year
  - Work out arrangements with Undergraduate Director
- Internships
- Research
  - department,
  - other engineering departments
  - other universities
- Assistance with resumes, interviewing skills
- Guidance in preparing for graduate school

# CBE Industry Partners

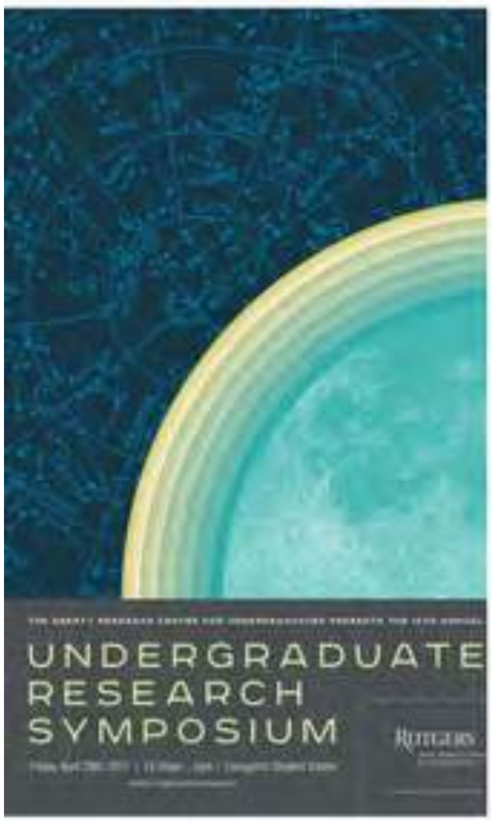
TR-N K
schenck AccuRate
Gericke
Glatt
SIEMENS
EMERSON Process Management
gsk GlaxoSmithKline
Johnson & Johnson
Pfizer
Bristol-Myers Squibb
MERCK
DEM Solutions
ITASCA
NATOLI
O'HARA TECHNOLOGIES
Resodyn ACOUSTIC MIXERS
IBS Caribe, Inc.
Lilly
Boehringer Ingelheim
SUNOVION
VERTEX
ThermoFisher SCIENTIFIC
ATS
MCC
AstraZeneca INTERNATIONAL
PSE
Specim
middleton research
Catalent
PHARMA LASER
VTT
Automated Ingredient Systems
Abbott Laboratories
ALBEMARLE
Tunnell Consulting
HALDOR TOPSØE
Chevron
FDA U.S. Food and Drug Administration Protecting and Promoting Your Health
ExxonMobil
EVONIK INDUSTRIES
BASF The Chemical Company
UOP A Honeywell Company
JM Johnson Matthey
CRI DELIVERING INNOVATION
Malvern
GRACE Enriching Lives, Everywhere.
innopharmalabs

# RUTGERS Aresty Research & Honors Program

**<u>For students interested in graduate, professional school or industrial research…</u>**

CBE Honors Academy:

1 year as Aresty Research Assistant (e.g., end of freshman year)
+ 2 years of research
+ professional and scientific skills development

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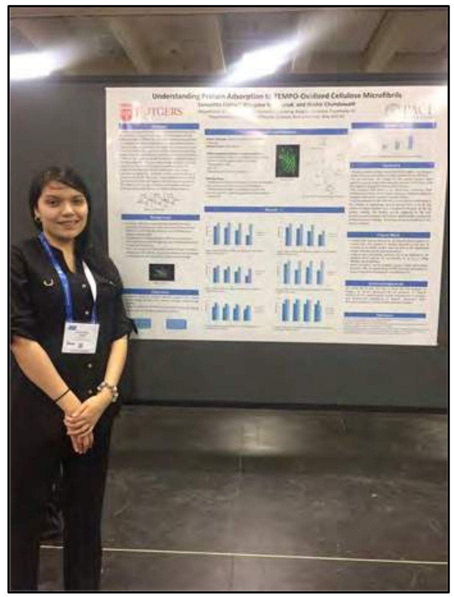
# CBE Graduates in Grad School

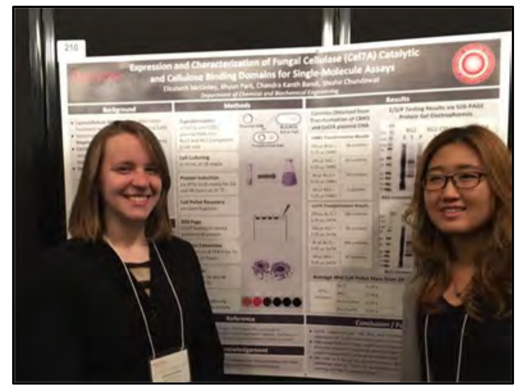
## Grad School/Research

- Berkeley
- Carnegie Mellon
- Cornell
- Drexel
- Georgia Tech
- MIT
- NJIT
- Penn State
- Princeton
- Purdue
- Stanford
- Illinois
- Rutgers
- U. Minnesota
- U. Massachusetts
- U. Wisconsin
- U. Delaware

MS and PhD Students
in Chundawat Lab



Samantha from
Pace University (NYC)



Liz (Merck) and Jihyun (U. California)
from Chundawat Lab

Undergraduate and Graduate Students
at Chundawat Lab Annual Lunch

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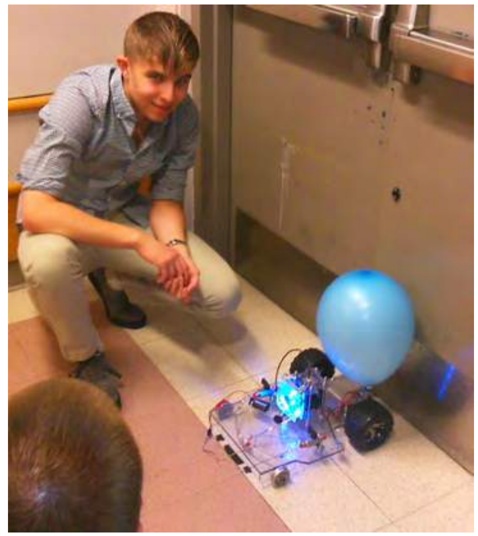
# CBE Student Organizations

RUTGERS AIChE

**AIChE Student Chapter**
http://aiche.rutgers.edu



**Annual AIChE College Bowl**
**1st Place since 2011 against Princeton, NJIT and Stevens**

**ChemE Car Competition**
**"Sir Winski" car took 1st place at regionals, 4th place at nationals in 2014!**

## Omega Chi Epsilon

Home About Us

**The Beta Sigma Chapter of Rutgers University**

*In This Society, Professionalism Is Engraved In*

ISPE
Connecting a World of Pharmaceutical Knowledge

## Rutgers ISPE

*International Society for Pharmaceutical Engineering*

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# More information on CBE

http://www.careercornerstone.org/chemeng/chemeng.htm

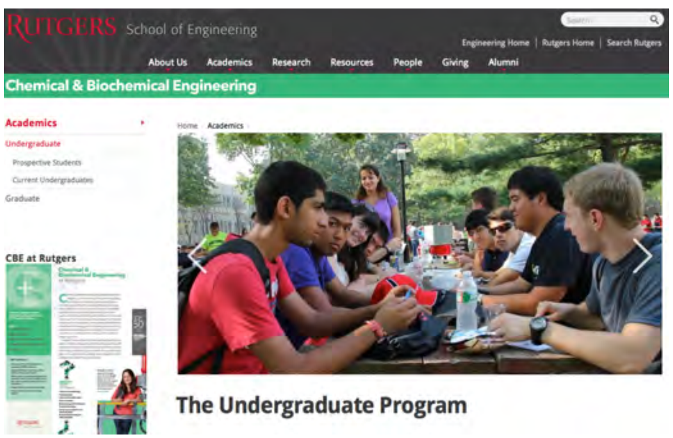
**Overview - Preparation - Day in the Life - Earnings - Employment - Industries - Professional Development - Career Path Forecast - Professional Organizations - Profiles of Chemical Engineers - PowerPoint - Podcast**

AIChE The Global Home of Chemical Engineers

http://www.aiche.org/

YouTube

https://www.youtube.com/watch?v=_UXwbxM8YfI
https://www.youtube.com/watch?v=RJeWKvQD90Y




For More Info:

cbe.rutgers.edu

**Employment Outlook**

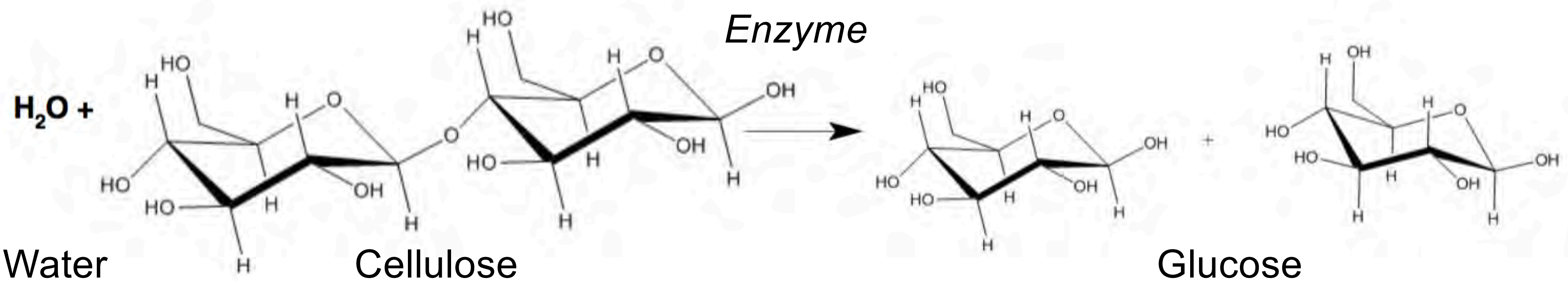
http://stats.bls.gov/ooh/architecture-and-engineering/chemical-engineers.htm

# RUTGERS “Grass-to-Gas” Hands-on Experimental Activity

**Enzymatic hydrolysis** is a key step for converting cellulosic biomass into sugars in a bio-refinery…and is focus of activity!

Through this hands-on activity we will explore;

- What is the impact of pretreatment on hydrolysis?
- What is the impact of enzyme concentrations?
- What is the impact of cellulose concentrations?
- What is the impact of temperature on reaction rate?




Water Cellulose Glucose

**Focus to ask questions like biochemical engineers do!**

# Q1. What is the impact of pretreatment on hydrolysis?

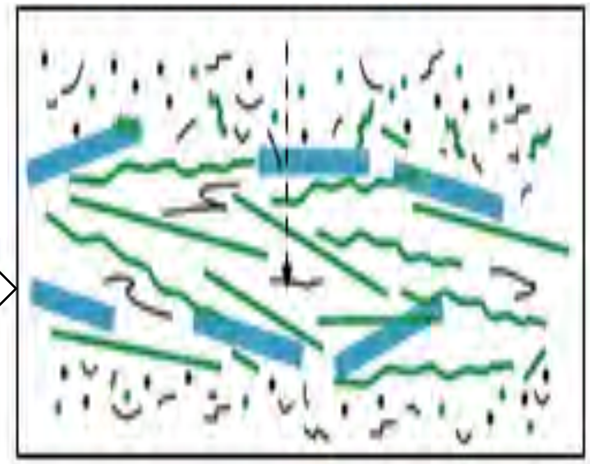
**Hemicellulose (in black)**

**Lignin (in blue)**

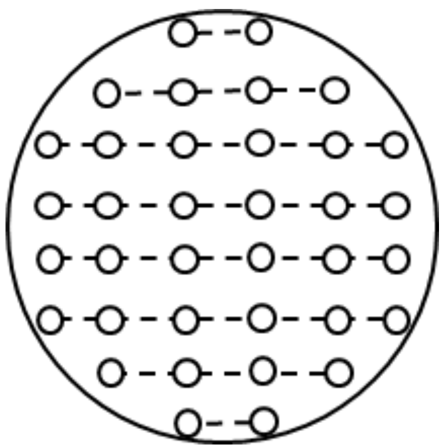
**Cellulose (in green)**

Pretreat Effect 1

**Lignin Removal Improves Cellulose Access**

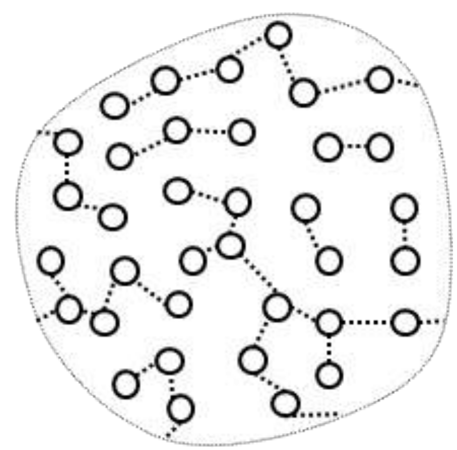


*Modified from Mosier 2005*



**Crystalline Cellulose Fibers (before pretreatment)**

Pretreat Effect 2



**Disintegrated Amorphous Cellulose (after pretreatment)**

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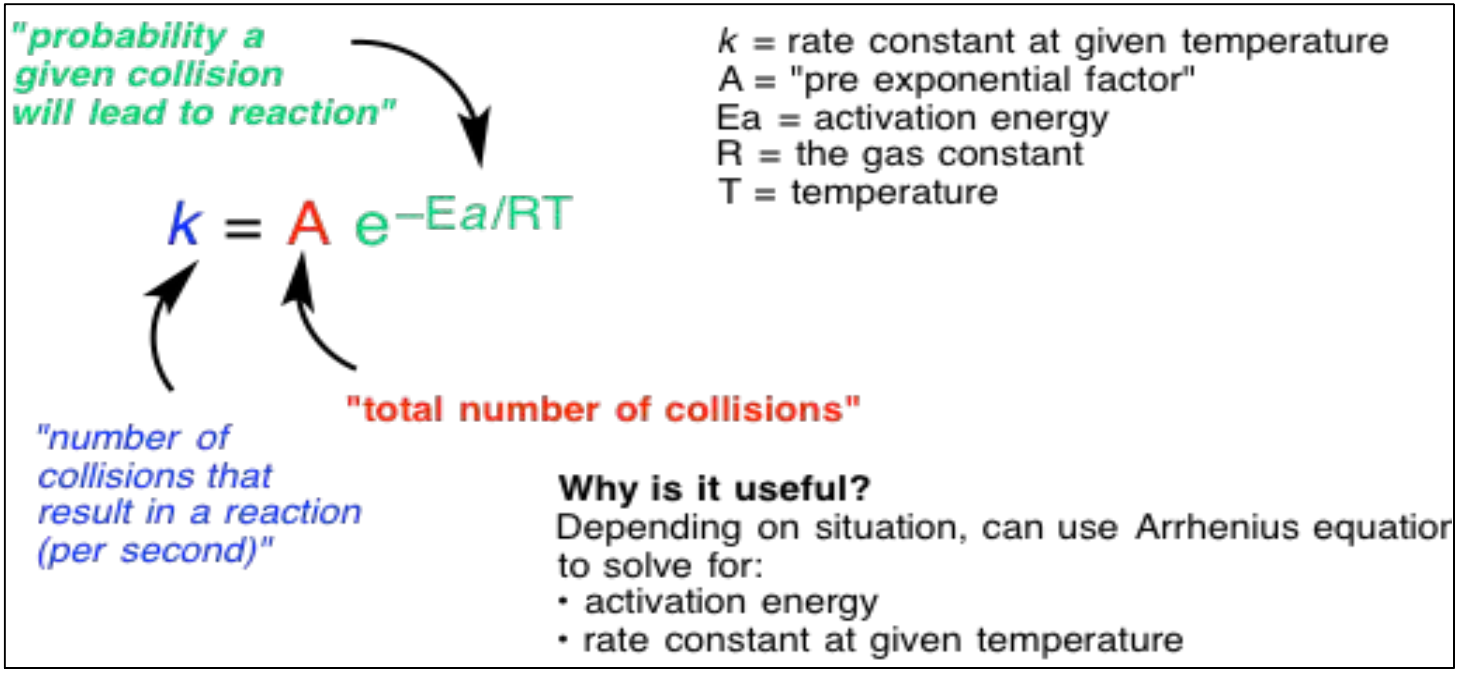
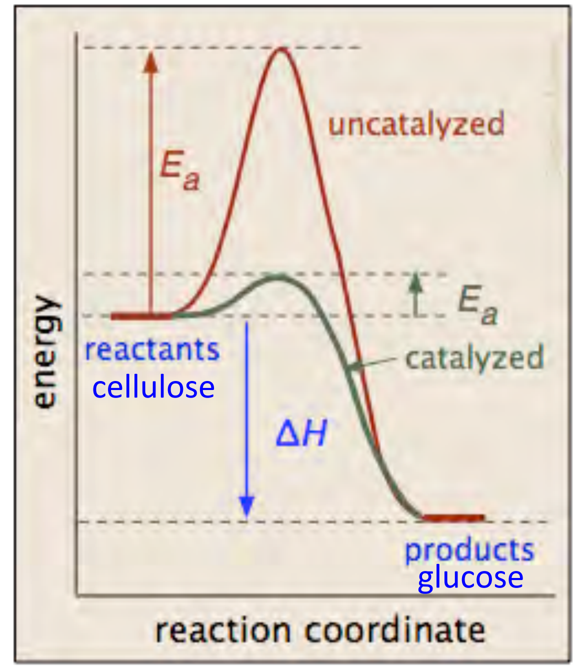
# Q2. What is the impact of temperature on hydrolysis?




**Arrhenius Rate Law Equation Used to Model Reaction Rate Constants**




**Free Energy Map for Reaction Path**

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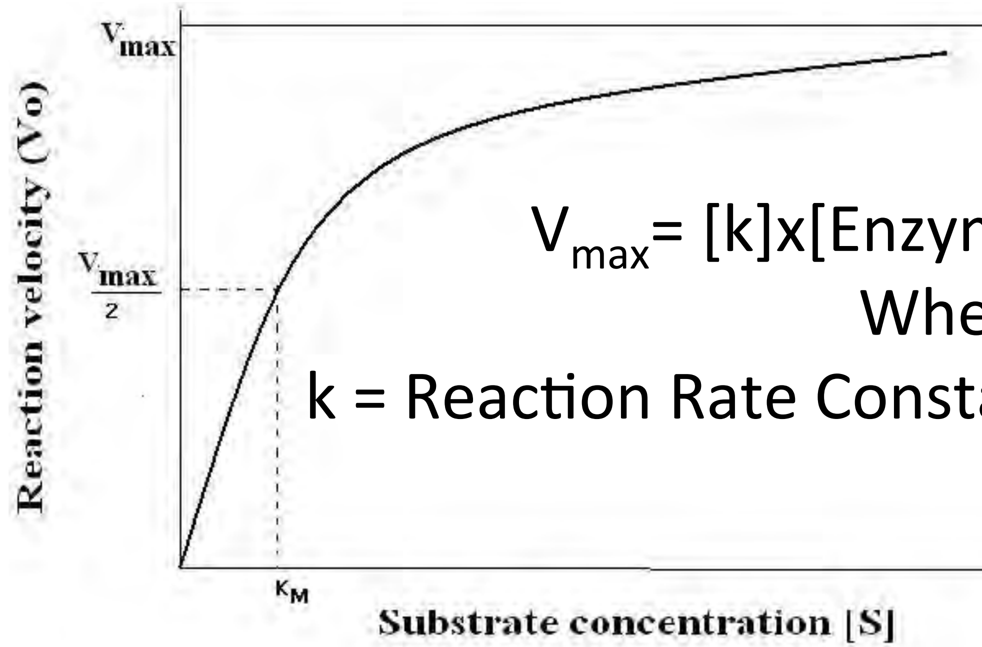
# Q3. What is impact of enzyme-cellulose concentrations?

$$V_0 = V_{max}\left(\frac{[Substrate]}{[Substrate] + K_m}\right)$$

**MM Equation to Model Enzyme Kinetics**




$V_{max}$= [k]x[Enzyme]

Where;

k = Reaction Rate Constant

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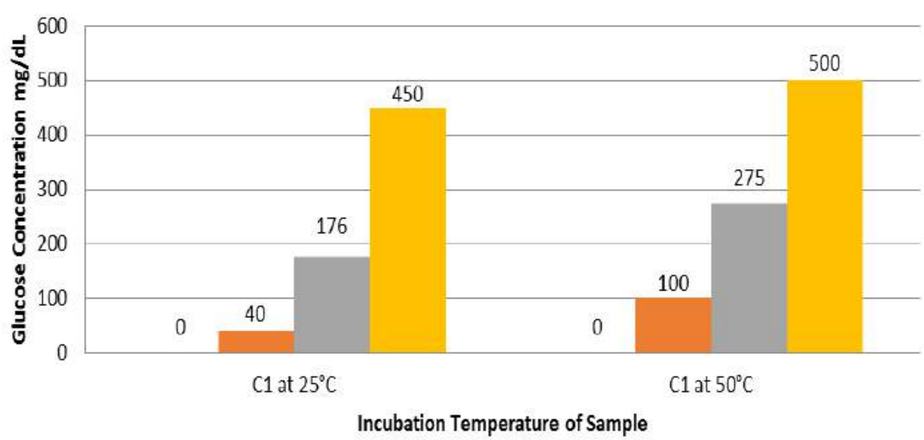
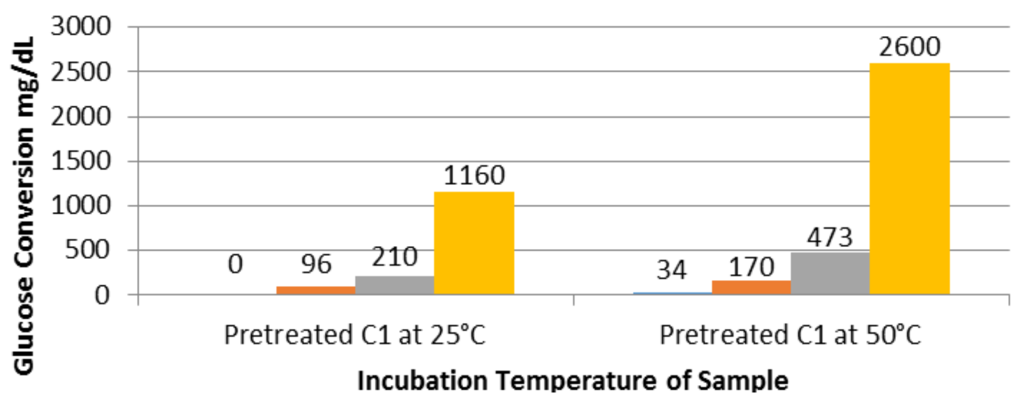
# Expected results from experiments

## Results for Untreated C1 Samples




*Varying enzyme & cellulose conditions depicted in legend*

## Results for Pretreated C1 Samples

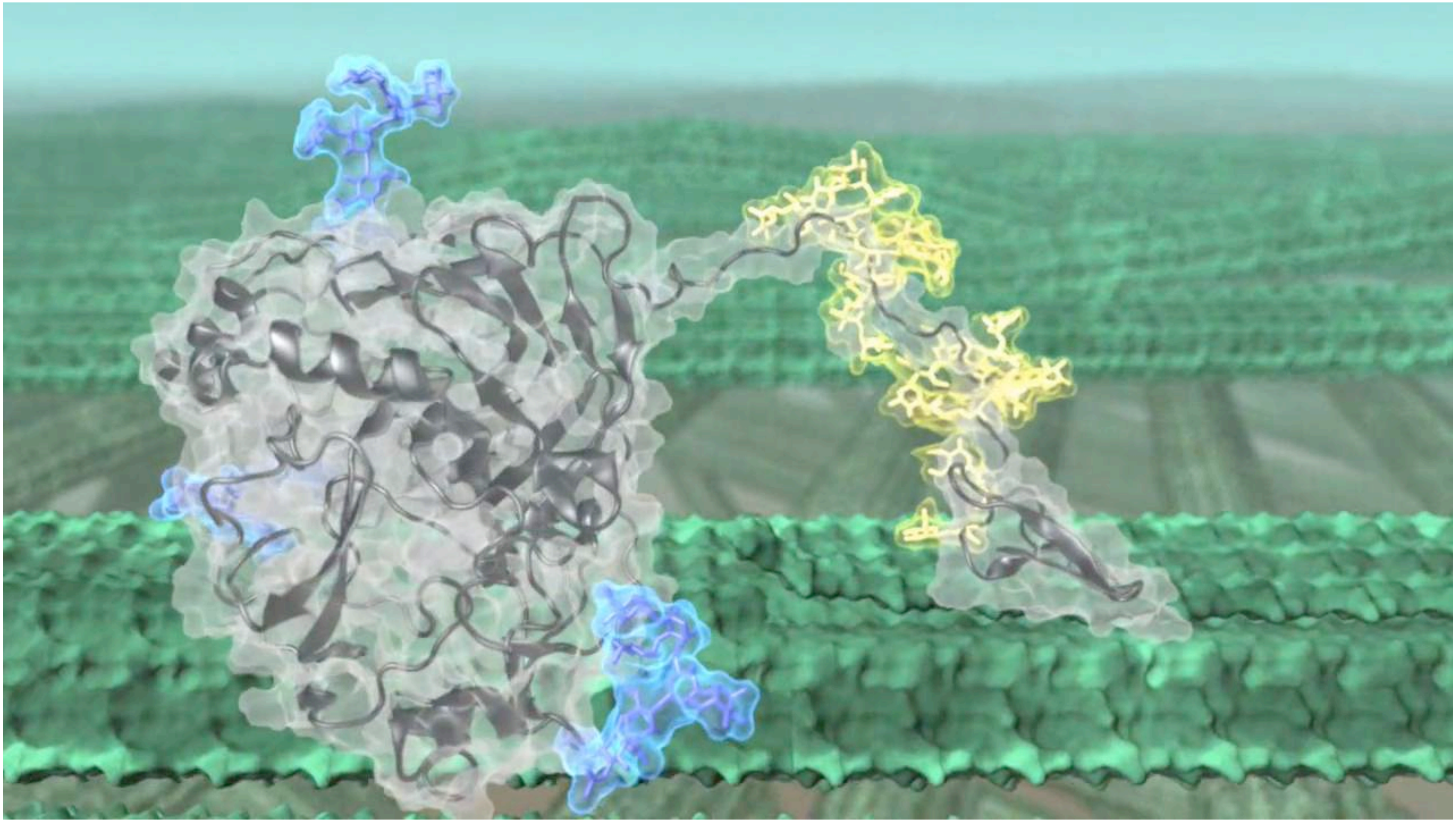



Low Enzyme Concentration (5 mg/g), Low Substrate Concentration (25 mg)
Low Enzyme Concentration (5 mg/g), High Substrate Concentration (250 mg)
High Enzyme Concentration (50 mg/g), Low Substrate Concentration (25 mg)
High Enzyme Concentration (50 mg/g), High Substrate Concentration (250 mg)

**Your results may deviate slightly from these ones…**

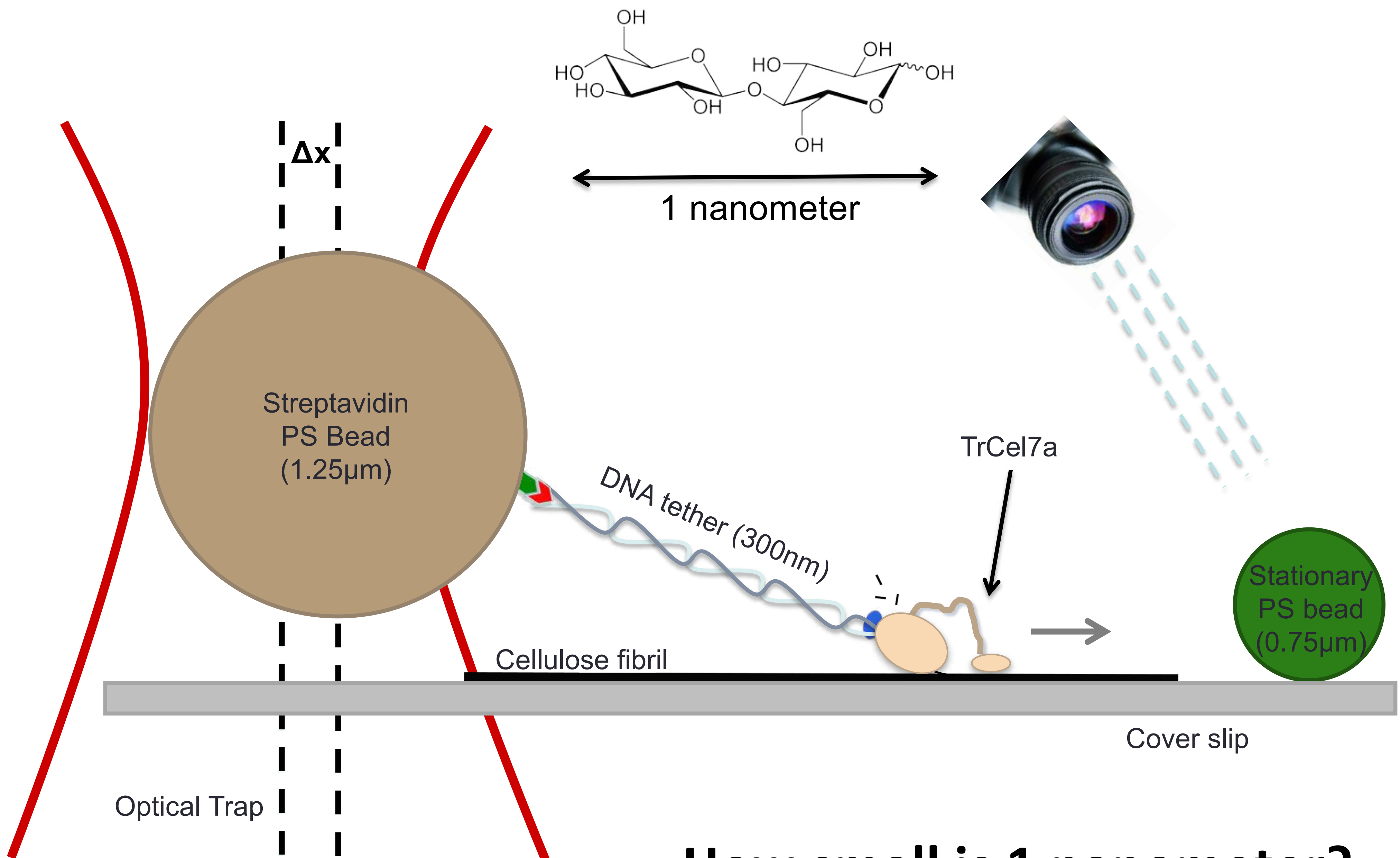

So, what do we know about how these enzymes work currently?

# Molecular simulation of cellulase breaking cellulose



Cel7A-cellulose animation courtesy of collaborators at NREL (Beckham, Payne)

# Single-molecule cellulase assay




## How small is 1 nanometer?

Slide courtesy of Sonia Brady (Vanderbilt University)