Discover Chemical & Biochemical Engineering at Rutgers

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Glycans, Glycoconjugates, and Glycan Active Enzymes Engineering Lab,
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Groups for today’s activity

<table>
<thead>
<tr>
<th>Group</th>
<th>Samples</th>
<th>Substrate</th>
<th>Enzyme Loading</th>
<th>Enzyme solution</th>
</tr>
</thead>
<tbody>
<tr>
<td>Group 1</td>
<td>C1</td>
<td>50mg</td>
<td>5mg/g</td>
<td>A</td>
</tr>
<tr>
<td>Group 2</td>
<td>C1</td>
<td>50mg</td>
<td>5mg/g</td>
<td>A</td>
</tr>
<tr>
<td>Group 3</td>
<td>C1</td>
<td>50mg</td>
<td>50mg/g</td>
<td>C</td>
</tr>
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<td>Group 4</td>
<td>C1</td>
<td>50mg</td>
<td>50mg/g</td>
<td>C</td>
</tr>
<tr>
<td>Group 5</td>
<td>C1</td>
<td>200mg</td>
<td>5mg/g</td>
<td>B</td>
</tr>
<tr>
<td>Group 6</td>
<td>C1</td>
<td>200mg</td>
<td>5mg/g</td>
<td>B</td>
</tr>
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<td>50mg/g</td>
<td>D</td>
</tr>
<tr>
<td>Group 8</td>
<td>C1</td>
<td>200mg</td>
<td>50mg/g</td>
<td>D</td>
</tr>
<tr>
<td>Group 9</td>
<td>C3</td>
<td>50mg</td>
<td>5mg/g</td>
<td>A</td>
</tr>
<tr>
<td>Group 10</td>
<td>C3</td>
<td>50mg</td>
<td>5mg/g</td>
<td>A</td>
</tr>
<tr>
<td>Group 11</td>
<td>C3</td>
<td>50mg</td>
<td>50mg/g</td>
<td>C</td>
</tr>
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<td>50mg/g</td>
<td>C</td>
</tr>
<tr>
<td>Group 13</td>
<td>C3</td>
<td>200mg</td>
<td>5mg/g</td>
<td>B</td>
</tr>
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<td>Group 14</td>
<td>C3</td>
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<td>5mg/g</td>
<td>B</td>
</tr>
<tr>
<td>Group 15</td>
<td>C3</td>
<td>200mg</td>
<td>50mg/g</td>
<td>D</td>
</tr>
<tr>
<td>Group 16</td>
<td>C3</td>
<td>200mg</td>
<td>50mg/g</td>
<td>D</td>
</tr>
</tbody>
</table>

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

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)!
What do you think can feed mushrooms and cars?
Plants are abundant in sugar polymers...

Can you name the most abundant organic polymer?
...but polymers are trapped inside cell walls

Lignin-Carbohydrate Complexes

Walls are like reinforced concrete!
Carbohydrate polymers are all around you!

Starch

Oligosaccharides

Raffinose

Galactose

Glucose

Fructose

Sugars

Glucose (a monosaccharide)

Sucrose (a disaccharide)

Sugar Alcohols (Polyols)

Sorbitol

Xylitol

Glucose

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!
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...
Cellulosic biomass can be ‘refined’ like crude oil.

**Platforms/pathways**

- **Cellulosic sugar platform**
  - Enzymatic hydrolysis → Sugars → Fermentation

- **Pyrolysis oil platform**
  - Fast pyrolysis → Liquid bio-oil → Upgrading

- **Syngas platform**
  - Gasification → Raw syngas → Filtration and clean-up

- **Lipid (oil) platform**
  - Algal and other bio-oils → Transesterification/Catalytic upgrading

**Products**

- By-products
- Power

- Ethanol
- Methanol
- Butanol
- Alkenes
- Aromatics
- Petrol
- Diesel
- Jet fuel
- Dimethyl ether
- Heat and power

**Feedstock production and logistics**
- Energy crops
- Agricultural by-products
- Waste streams
- Algae
- Coal
- Natural gas
Cellulosic sugar platform based *bio*-refinery

1. **Biomass** is harvested and delivered to the biorefinery.
2. **Biomass** is cut into shreds and pretreated with heat and chemicals to make cellulose accessible to enzymes.
3. Enzymes break down cellulose chains into sugars.
4. **Microbes** ferment sugars into ethanol.
5. **Ethanol** is purified through distillation and prepared for distribution.
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!
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\(^{\text{th}}\) century)

- Complicated chemistry demanded new concepts and innovations by 19\(^{\text{th}}\) century

*BASF Indigo Plant*
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

Research & Testing
Design & Construction
Pulp & Paper
Biotech/Pharmaaceuticals
Chemicals
Business Services
Environmental Engineering
Other Industry
Rubber
Plastics
Textiles
Metals
Minerals
Agricultural
Cosmetics
3a. Overview to Rutgers CBE Program

3b. Industrial Opportunities

3c. Rutgers Undergraduate Experiences
Undergraduate Program

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

Graduate Program

- ~200 students
  - 140 masters students
  - 60 PhD students
22 Faculty
6 Women (#1 in SOE)
5 joint with Biomedical Engineering
1 joint with Chemistry & Chemical Biology
Highly Diverse and Interdisciplinary Research
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)
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
For students interested in graduate, professional school or industrial research...

CBE Honors Academy:

1 year as Aresty Research Assistant (e.g., end of freshman year)
+ 2 years of research
+ professional and scientific skills development
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
ChemE Car Competition
“Sir Winski” car took 1st place at regionals, 4th place at nationals in 2014!
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

http://www.aiche.org/

https://www.youtube.com/watch?v=_UXwbxM8Yfl
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
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Q1. What is the impact of pretreatment on hydrolysis?

Lignin Removal Improves Cellulose Access

Pretreatment Effect 1

Crystalline Cellulose Fibers (before pretreatment)

Disintegrated Amorphous Cellulose (after pretreatment)

Modified from Mosier 2005
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

Why is it useful?
Depending on situation, can use Arrhenius equation to solve for:
• activation energy
• rate constant at given temperature
Q3. What is impact of enzyme-cellulose concentrations?

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

MM Equation to Model Enzyme Kinetics

\[ V_{\text{max}} = [k]x[\text{Enzyme}] \]

Where;

\( k = \text{Reaction Rate Constant} \)
Expected results from experiments

Results for Untreated C1 Samples

Results for Pretreated C1 Samples

Varying enzyme & cellulose conditions depicted in legend

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)
Slide courtesy of Sonia Brady (Vanderbilt University)