BIO XX: Biofuels and Bioproducts

Instructor: Aaron Socha, PhD (aaron.socha@bcc.cuny.edu)
Course Homepage: http://www.csebcc.org/Courses/Biofuels_GreenChem/BIOXX.html

Course Meeting Times: TBD
Office Hours: TBD
Office Location: Snow Hall
Lecture Location: TBD
Lab Location: TBD

Prerequisites: CHM11/12, BIO11/12
Co-requisites: CHM 31, PHY 31, CSI 31

Course Format: Lectures = Lectures and discussion following reading assignments from the previous week. Lab = Instruction/demonstration and Experiments. Lab will be open for student projects most weekdays from 9am-5pm.

Reading Materials:

1. **RORM** = *The Art of Writing Reasonable Organic Reaction Mechanisms 2nd Ed*. R.B. Grossman (2003). http://jpkc.huanghuai.edu.cn/include/htmleditor/uploadfile/20130309151535265001.pdf
2. **IAB** = *Industrialization of Biology: A Roadmap to Accelerate the Advanced Manufacturing of Chemicals* (National Academies of Science, 2015). https://www.nap.edu/catalog/19001/industrialization-of-biology-a-roadmap-to-accelerate-the-advanced-manufacturing
3. **MNP** = *Medicinal Natural Products – A biosynthetic approach, Third Edition* by Paul M. Dewick, (2009). Available on-line through Research Gate
4. **NREL** = *NREL Procedure for Determining Structural Carbohydrates and Lignin in Biomass (*2012): http://www.nrel.gov/docs/gen/fy13/42618.pdf
5. **LLP**: Steve Blank's Lean Launchpad Harvard Business Review article and You Tube videos: https://hbr.org/2013/05/why-the-lean-start-up-changes-everything https://www.youtube.com/watch?v=VZvgj6B2JZs&list=PLAwxTw4SYaPnxzSuovATBMrNowGaaEBmW
6. **SJA**: Selected Journal Articles (provided by instructor before specific class meetings)

**NOTE* Page numbers in Course Schedule below refer to the page numbers on the page of the Book's PDF, not the page numbers in Adobe Reader.*

Course Description:

This sophomore-level course covers biomass pretreatment, biorefining and mechanisms of secondary metabolism through chemical and biological investigations. Specific attention will be paid to plant cell wall architecture, cellulosic biofuel production, natural product pathways (fatty acid/polyketide, shikimic acid, terpene) biodiesel, biorefining by-products (extractives, lignin and glycerol). A hands-on lab component of the course will reinforce chemical and engineering analyses (HPLC, GC-MS) and techniques (separations, distillations) and introduce students to chemical and biological reactors. The course final project requires students to research the markets and perform customer interviews towards a sustainable business model for a chosen bioproduct.

Course Objectives:

1. Students will develop a deeper understanding of the connections between chemistry and biology with a uniting theme of bio-based chemical production.
2. Emphasis of this course is placed on the understanding of small molecule biosynthesis and hands-on, technical skills required to operate a chemical (Parr) reactor and a bio-reactor.
3. Additional emphasis is places on the societal and economic value of bio-based fuel and chemical manufacturing.
4. Students attending this course should gain insight into how a formal training in chemistry/biology can be leveraged into a scientific career and/or a career focused on sustainable chemical manufacturing/business.

At the end of this course students should be able to:

1. Identify the pathway(s) used to biosynthesize a given natural product/molecule.
2. Follow Safety and Risk Management protocol not limited to: signage and nomenclature, acid/base spill protocol, hazardous waste disposal/chemical hygiene/personal protective equipment.
3. Work in a chemical safety hood and a laminar flow hood.
4. Operate and troubleshoot a chemical reactor by understanding the principals governing heat exchange, digital control systems, and pressurized gasses.
5. Operate and troubleshoot a bio-reactor by understanding the principals governing digital control systems, sterile culture technique, media preparation.
6. Understand the underlining costs associated with a bio-based process.
7. Calculate the actual and theoretical yield of a biomolecule from pretreatment or fermentation.
8. Perform “Fermi-type” calculations on all aspects of lab work and lecture topics.
9. Enhance the purity of product mixtures by understanding and implementing the principals of chromatography, evaporation/distillation, filtration, centrifugation.
10. Quantify the actual yields of several biomolecules using HPLC and GC-MS by understanding the principals governing sample preparation and instrument calibration (pipetting, pH, filtration, serial dilutions).
11. Write a Standard Operating Procedure (SOP) for the production of a biomolecule.
12. Maintain an accurate written and digital lab notebook. Be able to select appropriate data, and think creatively to convert selected data to appropriate charts, graphs, diagrams, tables, etc. for a report.
13. Gather information from external sources (journal articles, accredited websites, etc.)
14. Demonstrate presentation skills.

Course Schedule:

All Lecture Notes and Reading Assignments are available on the Course Homepage.
Please complete Reading Assignment and review Lecture Notes before class.

Date	Week	Topic	Reading Assignment
	1 Lec	Review of Organic Chemistry Concepts and Reaction Mechanisms	**RORM** pp. 1-43
	1 Lab	Introduction to Parr Reactor – Orientation to SpecView Software and Chemical/Pressure Safety Considerations	Parr Safety Lab
	2 Lec	Introduction to Biosynthesis: Building Blocks and Common Reaction Mechanisms	**MNP** pp. 1-18
	2 Lab	Introduction to BioReactor – Orientation to Sartorius Software, Media Preparation, Sterile Techniques/Autoclaving, Probes, and Safety Considerations	Bioreactor Orientation Lab
	3 Lec	Plant Primary Metabolism and Enzyme Thermodynamics	**SJA**
	3 Lab	Soxlet Extraction of Biomass and Soda Pulping in the Parr Reactor: Oxidative vs. Inert Conditions	Soda Pulping Lab
	4 Lec	**Fermi Type Exam 1 (Lectures 1-3)** Industrial Biotechnology Part 1: Overview, History and Societal Benefits	 **IAB** pp. 1-34
	4 Lab	Separation of Cellulose Pulp and Enzymatic Hydrolysis to Glucose	Cellulase Lab
	5 Lec	The Plant Cell Wall: “Architecture and Artifacts”	**SJA**
	5 Lab	Glucose Derivitization and GC-MS Quantification	Glucose Derivitization Lab
	6 Lec	Biomass Pretreatment for Cellulosic Biofuels	**SJA**
	6 Lab	Lignin Lab: Size Exclusion HPLC of Oxidized “Condensed” vs. “Native” Lignin and Hydrophobic (HP-20) Separation of Oxidized Lignin and GC-MS Analysis of Benzaldehydes and Benzoic Acids	Lignin Lab
	7 Lec	Secondary Metabolism Part 1: Fatty Acids and Polyketides	**MNP** pp. 39-71
	7 Lab	Preparation of Sodium Glyceroxide Catalyst	Glyceroxide Lab
	8 Lec	**Fermi Type Exam 2 (Lectures 4-7)**	

	Biodiesel and Glycerol	**SJA**
8 Lab	Biodiesel Synthesis with Sodium Glyceroxide	Biodiesel Lab
9 Lec	Secondary Metabolism Part 2: The Shikimic Acid Pathway	**MNP** pp. 137-152
9 Lab	*E.coli* in the Bioreactor – Isopentenol Production with EZ Media	Isopentenol EZ
10 Lec	Secondary Metabolism Part 3: Terpenes and Steroids	**MNP** pp. 187-195
10 Lab	*E.coli* in the Bioreactor – Isopentenol Production with "not-so" EZ Media	Isopentenol Lignocellulosic
11 Lec	Ionic Liquids in the Biorefinery	**SJA**
11 Lab	Reductive Amination of Vanillin	Reductive Amination Lab
12 Lec	Industrialization of Biology Part 2 – Chemical Targets and The Business of Biology	**IAB** pp. 35-65 **LLP** videos
12 Lab	Synthesis of a Renewable, Platform Ionic Liquid	Carbonate IL Lab
13 Lec	**Fermi Type Exam 3 (Lectures 8-12)**	
13 Lab	Reading Week	
14 Lec	Reading Week	
14 Lab	***Final Presentations: Student Bio-Business Models***	

Grading Policy:

Lecture and Lab Attendance & 'Mindful' Participation		25%
Fermi-type Exams (3)		25%
Lab Reports (3)		25%
Final Project Presentation		25%
	Total	100%

Assessment:

Attendance and "Mindful" Participation

The course Attendance and Participation assessment will consist of in class discussions where students are expected to answer questions based on the assigned reading. Excessive tardiness, absence or lack of engagement will not be tolerated. During laboratory experiments a technique or calculation (e.g. calibration curves, dilutions, mass balance calculations) will be demonstrated once or twice and afterwards students will expected to be able to demonstrate the technique in variety of situation.

Exams and Description of Fermi-Type Questions:

Exams will consist of chemistry problems, short answers and Fermi-type calculations applied to the themes of biofuel and biomass. A Fermi problem is one often used in engineering education whereby dimensional analysis and approximation are used to solve the problem to a reasonable degree of accuracy. These "back of the envelope" type calculations are used routinely and often performed with little or no data. They are extremely useful in laboratory settings where the scientist is often required to use very small amounts of substances (e.g. 100 uL of liquid) containing many, many things (e.g. 3×10^{17} molecules). As such, Fermi estimates can used to inform where to invest (and save) time during the course of an experiment.

Lab Report:

It is likely that not all of the course's laboratory experiments (described in the Course Schedule) will be completed, and is it also likely that several labs will last more than one week. A total of 3 Lab Reports will be due by the end of the semester. An example of a lab report format can be found on the Course Homepage.

Description of Final Project:

During the semester you will learn about the chemistry, biology and introductory engineering of several biofuel and bioproduct platforms. In particular we will focus on the sugar platform (e.g. fermentation of glucose), thermochemical and enzymatic reactions, and spend a significant time discussing feedstocks. Your final project will fuse these ideas to Fermi-estimated *capital* and *operational* costs for a biomanufacturing process. You will work in two teams of 3-4 and designate roles (such as Quality Control Specialist, Chief Technology Officer, Chief Financial Officer, Marketing Manager, etc.) to each group member.

At the beginning of the semester, think how you will form and brand a startup company that will:

- Using a comprehensive literature search, select a feedstock/microbe/process that could be used to manufacture a consumer product. Determine if you will produce a *commodity* or *specialty* chemical. Design a process to manufacture, purify, analyze and package your product. You must be cognizant of potential pitfalls such as:

    - What is the rate, titer and yield of your product?
    - What are the separation steps and costs? Are there valuable by-products?

- What are the feedstock and product transport costs?
- How do you perform QC on feedstock and product?
- What capital equipment will you need in your manufacturing facility?
- What are the estimated associated energy and waste disposal costs to make 10 kg of your product? Can you benefit from an "economy of scale"?
- **Who are your customers?**

- To answer the last question, conduct a series of short interviews with potential customers to see if there is a market for your product. Present the combined results of your interviews using Steve Blank's Business Model Canvas format. If necessary, make adjustments to your value proposition using the results of your Customer Discovery process. Present a Customer Archetype for your product.

Your final project will be a 3-5 min Promotional You-Tube Video for your team, process and product's brand. You should not spend much time making animated graphics, rather you should address the above items using diagrams/schematics/chemical structures and images from the lab and scripted testimonials (from yourself and your potential customer archetypes).

Here are two examples of a New York based companies that produce renewable chemical starting materials from plants:

https://www.youtube.com/watch?v=MdDgNYyS1h0
http://www.cedarck.com/technologies.html

Several Slides Describing Final Project are Available on the Course Homepage