BEE 4870
Sustainable Bioenergy Systems
FALL 2010

Instructor of record. Lars Angenent, Ph. D.
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Course Webpage. http://angenent.bee.cornell.edu/BEE4870.html
Credits. 3

Time of Class.	Lectures: Tuesdays and Thursdays from 9:05 - 9:55 am Lab: Wednesday from 1:25 - 4:25 pm
Location of Class.	Lectures: Room B15, Riley-Robb Hall Lab: Room B15 with group activity in room 400 Riley-Robb Hall

Instructors.

- Lars Angenent (214 RR, 5-2480, la249 [at] cornell.edu)
- Norm Scott (216 RR, 5-4473, nrs5 [at] cornell.edu)
- Miriam Rosenbaum (mr625 [at] cornell.edu)

Teaching Assistant. Elliot Friedman (esf59 [at] cornell.edu), contact Elliot by e-mail to make an appointment.

Office Hours. Wednesdays: 1:25 – 4:25 pm during our design period, please let me know at 1:25pm that you want to meet.

Pre-requisite. BEE2220 or equivalent thermodynamics course.

Prerequisites by topic. Engineering Thermodynamics.

Course Description. Capstone design course for upper-level undergraduate and graduate students to understand energy systems that include a bioprocessing step (i.e., an engineered bioreactor). Offers a system approach to understanding renewable bioenergy systems (biomass) and their conversion processes, from various aspects of biology, engineering, environmental impacts, economics, and sustainable development. A large part of the course will deepen your understanding of bioprocessing with undefined mixed cultures.

Overview. This course, intended for upper level undergraduates and graduate students, will offer a systems approach to understand energy systems that include a bioprocessing step, such as anaerobic digestion, anaerobic fermentation, and microbial fuel cells. In general, this course focuses on biomass-to-bioenergy conversion, including introduction to major treatment steps, such as pretreatment steps, fermentation steps, and product separation steps. The course integrates physics, engineering, environmental impacts, economics, and sustainable development. Different energy generation technologies will be compared to gain an understanding of the advantages and limitations of these technologies. Students are expected to be interested in and appreciate the need for quantitative aspects of energy systems. In addition to theoretical knowledge, students gain empirical knowledge through a group design project and field trips to existing renewable energy systems (biomass systems) in New York State. An emphasis of this course is technical and economic analysis of large-scale energy systems and their conceptual design.

Goals and Outcomes. This course is intended to give upper-level undergraduate and graduate students the capabilities to:

1. Use a systems approach to design renewable bioenergy systems.
2. Understand the energy conversion processes for biomass systems.
3. Understand the advantages and limitations of renewable bioenergy systems
4. Use nontechnical factors in system design based on assessment of environmental impacts, economics, and sustainable development.
5. Excel in a team-oriented design experience, focused on the application of renewable bioenergy technologies.
6. Design a "real life" renewable bioenergy system.

Required Text. No required text. Course powerpoint presentations and handouts **[H]** will be given to you as hard copies and/or posted on our course web site as password-protected pdf files (password will be given to you during the first lecture).

Class Design Project. The primary effort is a comprehensive design project of a sustainable bioenergy system that includes a bioprocessing step. The team can choose between several ideas given by the instructor, but if a student group is committed to a specific system of choice we can negotiate the project. Periodic presentations and reports on progress of the design project are required during the course of the semester. These three presentations/reports are scheduled on September 22, October 20, and November 10. On these dates the student groups will make an oral and written report to the class during the Lab/Discussion session (Wednesday afternoon). The comprehensive design group projects will be due December 1 with a written report and oral presentation.

<u>Proposal report (Sept. 22)</u>: 2-page, single-spaced report with introduction and small literature review (~0.5 pages), propose what you will design, and show questions that you have and that you will ask during your site visit.

<u>Progress report I and site visit (Oct. 20)</u>: 5-page, single-spaced report with design progress and site visit outcomes. Note which changes were made to the design and show pictures of the site visit in the appendix. An initial flow diagram for your design should be shown and presented. Initial calculations on the feasibility are requested.

<u>Progress report II and feasibility study (Nov. 10)</u>: 10-page, single-spaced report that shows the feasibility of the project. Final design decisions should be reported with the economic analysis and life cycle assessment. Figures should show the flow diagram of the design. Calculations may be presented in an appendix.

<u>Final report (Dec. 2)</u>: 25-page, single-spaced report. According to guidelines shown below with calculation and other information in the appendix. Structure of report: 1. Executive summary; 2.

Description of the problem; 3. Potential designs that you have considered; 4. Actual design – in detail; 5. Benefits/costs of the design; Appendices with details.

Each summer, the American Society of Agricultural and Biological Engineers holds a conference called the Northeast Agricultural/Biological Engineering Conference (NABEC). There is a student design competition. Attached are the rules and guidelines for each competition. When you are preparing your final reports, please keep in mind the format guidelines (see below) as I will be choosing the best final reports and submitting them (with your permission) to NABEC in the spring. If you would like further information on this program, please go to http://www.abe.psu.edu/nabec/

The ***guidelines*** for the final report are:

The design projects must include: 1) A written report (see **format** for entries). 2) Drawings and/or specifications that describe the design and 3) Extensive or substantial test or performance data obtained from a) a prototype or physical model of the machine or critical component, and or b) a computer simulated test of the system or process.

FORMAT FOR NABEC STUDENT DESIGN COMPETITION ENTIRES
1. Title Page
The cover page of the entry shall state:
a. Title of the paper b. Full Name(s) of the contestant(s) c. Name of the department and school d. Name(s) of the adviser(s) for the paper e. Expected date(s) of graduation f. Date on which the paper is submitted for the regional contest g. Signatures of contestant(s), adviser(s), and the student branch Faculty Adviser (department head if no student branch exists) h. The date of signing
In the case of multi-authored papers, all correspondence will be directed to the first author unless otherwise requested as a footnote on the cover page.
2. Second Page; The second page shall contain the following:
a. A statement of how the subject was chosen b. An abstract of the paper c. Acknowledgements
3. Third Page; The third page shall contain the Table of Contents.
4. Organization; Each paper shall be organized under appropriate headings. The presentation shall follow a logical pattern and conform to good technical writing standards. Drawings and/or specifications and test data should be entered as appropriate.

Site Visit. We are planning to visits one location in Ithaca with the entire group: 1. The Ithaca Wastewater Treatment Facility, where digesters generate methane for combined heat and power (CHP); Depending on which project you will be involved with, individual groups will also visit this latter facility again; and in addition you may visit: 2. The Anheuser-Busch Inbev, Inc. wastewater treatment plant; 3. A corn-to-ethanol plant; 4. A biodiesel plant; 5. A farm-based anaerobic digester; or 6. A composting facility. For the latter visit the group will present their visit to the rest of the class. These visits are required and will most likely occur during the Wednesday afternoon lab section, more information will be given during the course.

Individual Review Paper. Students are required to write (individually) a review paper on an engineering system that is needed for their group project. This can be a small aspect of the overall renewable bioenergy system that the group is designing. The students are encouraged to find their own topic and to keep the scope limited in order to go into depth. The instructor may be consulted to find a possible topic. The students should be critical and point out possible advantages and disadvantages. At least 15 references from peer-reviewed publications are necessary for such a review. Web pages on the innovative process are allowed but do not count towards the 15 references. Make sure that you include a minimum of three references that were published during the first energy crises (1970s-1980s). Individual reports are due on November 16. Writing assignments are required to be typed with 1.0 line spacing, 1" margins, and font 12 points Times or Times New Roman with a total of 5 pages (references not included, but figures are and they should be nicely embedded in the text). Writing assignments are primarily evaluated for content, but writing effectiveness is also important (e.g., organization, style, grammar, punctuation, spelling, and neatness). Examples of text that can be consulted for writing effectiveness are:

- W. Strunk Jr. and E. B. White. 1979. The Elements of Style. 3rd Ed. MacMillan Publishing Co., Inc., New York.
- J. G. Smith and P. A. Vesilind. 1996. Report Writing for Environmental Engineers and Scientists. Lakeshore Press, Woodsville, NH.

Figures are encouraged!

Quizzes. The quizzes are designed to evaluate the knowledge that you have gained during reading and lecture periods (Tuesdays and Thursdays). These quizzes are scheduled during three changes in topics and the dates are September 23, October 19, and November 23.

Grading.	Announced quizzes (3)	15%
	Individual Review Paper	20%
	Team-based Design Project	65%

Tentative Course Outline: [Read these handouts before coming to lecture]

Date	**Reading, quizzes etc**	**Topic** (amount of lectures)
We., Aug. 25 Th., Aug. 26 **2 hours**	Introduction **[H1]** Angenent Lab **[H2]**	**Introduction** 1. Objectives of the course 2. Individual Review Papers 3. Design projects and cooperative learning 4. Groups and seating 5. Getting to know Angenent and Friedman (TA)
Tu., Aug. 31 We., Sept. 1 Th., Sept. 2 Tu., Sept. 7 We., Sept. 8 Th., Sep. 9 Tu., Sept. 14 We., Sept. 15 Th., Sept. 16 Tu., Sept. 21 We., Sept. 22 Th., Sept. 23 Tu., Sept. 28 We., Sept. 29 **24 hours**	Introduction **[H3]** Angenent Lab **[H2]** Group-based projects, interview sheet, student intro Fundamentals **[H3]** Microbiology (Mol) Site visit to Ithaca WWTP Fundamentals **[H4]** Fundamentals **[H4]** Choosing groups and projects – **Germany** **Experience (Scott)** Reactors **[H3&5]** Alkalinity Calculation Engineering Design & Proposal presentations and report Quiz 1 & Alkalinity Equipment/Safety Active learning & site visit	**Anaerobic Digestion** 1. Introduction (1) 2. Fundamentals (3) 3. Microbiology (1) 4. Reactor Designs (1) 5. Alkalinity calculations (1.5) 6. Equipment and safety (1)
Th., Sept. 30 Tu., Oct. 5 We., Oct. 6 Th., Oct. 7 Tu., Oct. 12 We., Oct. 13 Th., Oct. 14 **10 hours**	Introduction & Eng. Electron flow **[H6]** Active learning & site visit Substrate **[H6]** Fall Break Active learning & site visit Growth	**Fundamentals, stoichiometry, and kinetics of biochemical operations** 1. Introduction 2. Engineering Approach to Incorporate Microorganisms in Mass Balances 2.1 Major Types of Microorganisms (1) 2.2 Engineering Approach (0.5) 3. Stoichiometry of Biochemical Operations 3.1 Equations for Microbial Growth (1.5) 4. Kinetics 4.1 Biomass Growth and Substrate Utilization (0.5) 4.2 Maintenance, Endogenous Metabolism, Decay, Lysis, and Death (0.5)

Tu., Oct. 19 We., Oct. 20 Th., Oct. 21 Tu., Oct. 26 We., Oct. 27 Th., Oct. 28 **10 hours**	Quiz 2 & Life cycle **[H7]** Presentations site visits and proposal Life cycle **[H8]** Economics **[H9]** **Wayne McFarland, Stearns & WhelerGHD design** Economics **[H10]**	**Economic analysis & Life cycle assessment** 1. Life cycle assessment (1.5) – Dr. Norm Scott 2. Economic analysis (2)
Tu., Nov. 2 We., Nov. 3 Th., Nov. 4 **5 hours**	MFC **[H15]** Active learning MEC **[H15]**	**Bioelectrochemical systems (BES)** 1. Microbial Fuel Cells (MFCs) (1) – Dr. Rosenbaum 2. Microbial Electrolysis Cells (MECs) (1) Rosenbaum

Date	**Exams, etc.**	**Topic**
Tu., Nov. 9 We., Nov. 10 Th., Nov. 11 Tu., Nov. 16 We., Nov. 17 Th., Nov. 18 Tu., Nov. 23 We., Nov. 24 Th., Nov. 25 Tu., Nov. 30 We., Dec. 1 Th., Dec. 2 **15 hours**	Milling **[H11]** Group presentation & report Life Cycle **[H12]** Individual report, Fermentation & Lignocellulosic **[H13]** Active Learning Pretreatment **[H14]** Quiz 3 & Butanol **[H15]** **Thanksgiving** **Thanksgiving** Butanol and other fuel Final group presentations & report No Class	**Ethanol and butanol** 1. History 2. Corn kernel to ethanol 2.1 Wet milling (0.5) 2.2 Dry milling (0.5) 2.3 Life cycle assessment of corn to ethanol (1) 3. Lignocellulosic feedstock to ethanol 2.1 Pretreatment (and pyrolysis) (1) 2.2 Enzymatic hydrolysis (0.5) 2.3 Fermentation and product separation (0.5) 4. Mixed culture hydrolysis and butanol (1.5)
No Final	**No Final**	**No Final**

More reading:

- C. P. L. Grady Jr. , G. T. Daigger, and H. C. Lim, *Biological Wastewater Treatment*. 2nd Ed., Revised and Expanded, Marcel Dekker, Inc., New York, 1999.
- Wall, J., C. S. Harwood, and A. L. Demain (ed.). 2008. *Bioenergy*. ASM Press, Washington, DC.
- Speece, R. E. 1996. *Anaerobic biotechnology for industrial wastewaters*. Archaea Press,

Nashville, Tennessee.
- Madigan, M. T., and J. M. Martinko. 2006. Brock biology of microorganisms, Eleventh edition ed. Pearson/Prentice Hall, Upper Saddle River, NJ.
- Blanchard, P. H. 1992. Technology of corn wet milling and associated processes, vol. 4. Elsevier Science Publishers B.V., Amsterdam, The Netherlands.
- Perry, R. H., D. W. Green, and J. O. Maloney. 1997. *Perry's chemical engineer's handbook*, seventh ed. McGraw-Hill, New York.
- NRCS. 1996. Agricultural waste characteristics (chapter 4), p. 4-1-4-24. In J. N. Krider and J. D. Rickman (ed.), *Part 651, agricultural waste management field handbook (AWMFH)*. National Resources Conservation Services (NRCS), United States Department of Agriculture (USDA), Washington, DC.
- Johnson, D. W., R. T. Johnson, and E. J. Holubec. 1993. Cooperation in the class room. Interaction Book Company, Edina, MN.
- Johnson, D. W., R. T. Johnson, and K. A. Smith. 1991. Active learning: Cooperation in the college classroom. Interaction Book Company, Edina, MN.
- Lusk, P. 1998. Methane recovery from animal manures: A current opportunities casebook NREL/SR-25145. National Renewable Energy Laboratory.
- Ferry, J. G. 1993. Methanogenesis : Ecology, physiology, biochemistry & genetics. Chapman & Hall, New York.
- Metcalf/Eddy: Wastewater Engineering: Treatment and Reuse, 4th edition, McGraw Hill, Boston, MA.
- B. E. Rittman and P. L. Mcarty, *Environmental Biotechnology, principles and applications*, McGraw Hill, Boston, MA.
- C. N. Sawyer, P. L. McCarty, and G. F. Parkin, Chemistry for environmental engineering and science. 5th Ed., McGraw Hill, Boston, MA.
- W. Stumm, *Aquatic chemical kinetics, reaction rates of processes in natural waters,* John Wiley & Sons, Inc. , New York, NY.
- Larminie, James and Andrew Dick. 2003. *Fuel Cell Systems Explained*. John Wiley & Sons. West Sussex, England.
- Ag Energy Working Group. 2004. "25 X 25" Action Plan: Charting America's Energy Future (available on line at http://www.25x25.org/index.php?option=com_content&task=view&id=58&Itemid=148) accessed August 19, 2008
- Brown, Lester, R., 2008, PLAN B 3.0: *Mobilizing to Save Civilization*, Earth Policy Institute, W.W. Norton Company, New York (particularly Chapters 10 – 12).
- Gissen, David.2003. Big & Green: *Toward Sustainable Architecture in 21st Century*. Princeton Architecture Press. NY, NY. p. 192
- Goodstein, D., 2004. *Out of gas: The End of the Age of Oil*. W.W. Norton. New York. p 140
- Hendrickson, C. L. Lave and H. Matthews. 2006. Environmental Life Cycle Assessment of and Services: An Input-Output Analysis. Resources for the Future. Washington, DC.
- Interlaboratory Working Group. 2000. Scenarios for a Clean Energy Future (Oak Ridge, TN; Oak Ridge National Laboratory and Berkeley, CA; Lawrence Berkeley National Laboratory), ORNL/CON-476 and LBNL-44029, November. http://www.ornl.gov/sci/eere/cef (accessed 8/19/08)