NatSci 389H (formerly 390IH) – Team-oriented Lab Discovery in Renewable Energy [iCons 3E]

Syllabus

Spring 2014

Course Vision

This course involves student-driven, team-oriented laboratory projects focused on the interrelated principles of energy generation, conversion, storage and consumption, particularly emphasizing the science underlying renewable energy systems. Projects incorporate experimental techniques from the chemical, physical, mathematical, and life sciences. The intent of this course is to examine cross-disciplinary methods to address real world energy-related issues. Students will be expected to understand paths to energy solutions that cross many disciplines, and how an interdisciplinary approach may be used to solve energy problems faced by society.

The iCons Energy Laboratory encompasses a four-week "energy bootcamp" followed by two comprehensive Unit Projects, each led by a team of faculty experts in fields of research pertaining to the project subject. Topics for the Unit Project selection include energy conversion, energy storage, biomass energy, combinatorial energy design, capturing waste energy, and building efficiency.

The course is designed to provide necessary educational scaffolding, such that skills and knowledge acquired during the early part of the course can be used to inspire students to design and perform creative experiments as the semester progresses. The bootcamp portion of the course familiarizes students with fundamental principles of energy science, laboratory instrumentation and measurement. With these skills in hand, students are equipped to venture into the more challenging territory of Unit Projects. Each Unit Project utilizes a team project strategy that includes brainstorming, scientific literature research, consultations with experts, project design, proposal, experimental set up, data acquisition, evaluation, reflection, experimental modifications, more data acquisition, analysis, more reflection and reporting.

Objectives and Student Outcomes

- Learn about technology and tools used to investigate energy questions.
- Critically evaluate, compare and contrast experimental approaches to finding energy solutions.
- Discover scientific principles and concepts for experimental approaches to finding energy solutions.
- Learn problem-solving skills across many fields
- Work in teams to collaboratively solve problems, develop iterative question-building skills, and strengthen leadership qualities.
- Develop appreciation of the interdisciplinary nature of the scientific process and experimental solutions to problems.
- Master the quantitative aspects of experimental problems in energy.

- Quantitatively express findings and outcomes of projects.
- Use and interpret primary data in formulating hypotheses related to experimental outcomes.
- Gain confidence in your ability to seek answers through direct observation, experimental results, and analytical reasoning.
- Discover new cross-disciplinary paths to finding energy solutions.

Course Activities

In this course, students should expect

- Content: Developed around timely, relevant, and weighty societal challenges.
- Experimental Skills: Students will develop and enhance their natural sense of curiosity by using laboratory instruments to expand powers of observation.
- Design: Students will be challenged to design experiments that explore real-world renewable energy systems.
- Interdisciplinarity: Students from different fields come together to confront relevant challenges.
- Discovery: Students will engage in an active learning process, discovering scientific principles as they become required for mastery.
- Teamwork: Students will work in teams to solve problems and to discover concepts. Teams are formed and re-formed as different challenges are presented and different skills are needed.
- Analysis: Students will use primary sources (literature and data) to develop understanding through data interpretation and analytical reasoning.
- Human Connections: Students will learn to talk to experts on campus and beyond.
- Assessment: Student progress will be evaluated with assessment tools, journaling, peerreviewed work, oral presentations and written report.

Energy Bootcamp:

Designed to provide the necessary educational foundation, scaffolding and safety training, such that skills and knowledge acquired during this early part of the RE lab course will inspire students to design and perform safe and creative experiments as the semester progresses. Bootcamp familiarizes students with fundamental principles of energy science, laboratory instrumentation, and measurement. This includes an introduction to basic energy science (forms of energy; power; energy conversion, efficiency, density, and consumption) and exercises that familiarize each student with the lab equipment and measurement methods. Simple design problems will be introduced at this stage to build ability and confidence.

In Bootcamp students will learn core skills central to RE lab research, including measurement of:

- Energy storage capacity; calorimetry of fuels
- Electrical measurements; voltage, current, power
- Energy transfer efficiencies; fuels, light, and electricity

For each piece of instrumentation, students will be required to pass an exam on safe and appropriate use, and on the reliability and meaning of data. Once passed, students become “certified” for future use.

Example Unit Projects:

With Boot Camp skills in hand, students are equipped to venture into the more challenging territory of Unit Projects. Each Unit Project requires teamwork for brainstorming, scientific literature research, consultations with experts, project design, proposal, experimental set up, data acquisition, evaluation, reflection, experimental modifications, more data acquisition, analysis, more reflection, reporting, and last but not least, dissemination. Examples include (but are not limited to):

• **Solar Energy.** Investigation of photovoltaic (PV) solar energy conversion. Consideration of pros/cons of various PV materials, including cost. Evaluation of properties under real-world source/load conditions. Seek to explain performance in terms of basic processes, including light absorption, charge separation, and charge transport. Students address a *real-world energy challenge* as a systems problem, to optimize performance or performance per cost.
Integrates: physics, chemistry, materials science, electrical engineering.

• **Algae Energy**. Algal biomass is used as an example of biological energy conversion and storage (utilizing sun, waste heat, and waste CO_2). Evaluation of energy storage as combustible hydrocarbon, produced oil droplets, or subsequent conversion to ethanol by fermentation. Compare solar efficiency with PV materials. Evaluation of biological and physical conditions for maximum algal biomass production. Design and development of mechanisms for optimal biomass production.
Integrates: plant biology, ecology, biochemistry, chemistry, thermodynamics.

• **Fuel Energy Density.** Investigation of various fuels for their energy densities. Focus on liquids and solids; primarily ethanol, butanol, and gasoline, for comparison with coal and woody biomass. Correlations with atomic compositions and oxygen content.
Integrates: chemistry, biochemistry, thermodynamics, calorimetry.

• **Electricigens.** Bacteria such as geobacter that convert organic waste into electricity.[52] Measure efficiencies and rates of energy conversion. Probe viability and electrical power generation from bacteria under various stimuli and stresses.
Integrates: microbiology, ecology, physics, biochemistry.

• **Microbial Biomass Conversion.** Studying microbial communities converting cellulosic biomass to the diversity of these microbial communities with genomic analyses and bioinformatic tools. Tapping diversity of microbial communities for effective catalysts for cellulosic biomass conversion.
Integrates: microbiology, enzymology, chemical engineering, genomics.

• **Electrical Energy Storage.** Batteries, supercapacitors, and ultracapacitors. System approach to optimizing performance under specific real-world load conditions. Thermodynamics, kinetics and limiting factors. Optimizing energy capacity per weight, initial versus steady state power, and recharging rate. Design to minimizing losses in

application specific cases. Unconventional means of recharging.
Integrates: physics, chemistry, materials science, electrical engineering, thermodynamics.

• **Capturing waste energy.** Study to explore approaches to capture waste heat or waste mechanical energy using thermoelectrics, piezoelectric transducers or other conversion devices. For comparison, break down to fundamental processes to compare conversion efficiency and feasibility.
Integrates: physics, chemical engineering, materials science, electrical engineering, thermodynamics.

• **Heat Engine Performance.** Maximizing overall performance of a heat engine or generator. Considering the role of thermodynamics, materials, and environment to overall efficiency. Evaluating means of harvesting waste energy to boost overall efficiency.
Integrates: physics, chemistry, materials science, electrical engineering, thermodynamics.

• **Building systems energy efficiency.** System level evaluation of the energy budget of a miniature (4'x8') building. Explicit measurement of impact from building efficiency measures, such as low-E windows, passive solar, and insulation. Using solar electric and solar hot water, evaluate the requirements for a net zero energy system. Evaluate the impact of continuous control systems on performance.
Integrates: physics, chemistry, materials science, electrical engineering. A unifying theme in all these Unit Projects is the role of *Energy Conversion and Efficiency*. Student teams will be encouraged to choose topics from this list for their first Unit Project and to design blended and/or substantially new Unit Projects for their second project.

Prerequisites

- iCons 1 (NatSci 190IH) Global Challenges, Scientific Solutions, and
- iCons 2 (NatSci 290IH) Integrated Scientific Communication
- Two college science labs in the physical and/or life sciences (totaling 4 credits)
- Calculus

Meeting schedule

Class will meet once weekly for a 4-hour formal lab period. An additional 4-hour "open lab" period will be provided if needed to complete each week's activities.

Reading

A laboratory manual is provided for the Bootcamp section of the course. Students are expected to use online web resources to find some necessary data. For thorough preparation of unit projects, students are expected to utilize the books in the iCons3E resource library and research the scientific literature available through the UMass Libraries.

Equipment and supplies

Instrumentation: Voltage sources, digital multimeters, Kill-a-Watt (power meter), solar irradiance meter, calorimetry equipment, computers with Labview, Pasco sensors and interface, oscilloscopes, balances, thermometry, IR-based temperature meter, light sources, computer controlled positioners, digital spectrophotometry, autoclave, lighted growth chamber, centrifuge, microscope, hydrolyzer, fuel cell, UV-VIS spectrometer. *Supplies*: Solar cells, solar hot water module, batteries, heat engines, generators, force and torque sensors, bike generator, thermoelectic components, quartz crystal oscillators, thermistors, basic electronics, lab set-up materials, algal culture, growth media, glassware.

Week-by-Week Outline

(The actual weekly schedule for iCons III NatSci390 may change at the discretion of the course/section instructors. This sample schedule is intended as a likely sequence of projects in this course.)

Week 1: Bootcamp
• Introduction to fundamental principles of energy science (forms of energy; power; energy conversion, efficiency, density, and consumption). Biological energy.

Week 2: Bootcamp
• Electrical measurements; voltage, current, power.
• Energy storage capacity; calorimetry of fuels.

Week 3: Bootcamp
• Energy transfer efficiencies; fuels, light, and electricity.

Week 4: Bootcamp
• Complete sample design problems and exercises.
• Voting: project and team selection for Project I

Week 5: Unit Project I
• Pre-project questionnaire, brainstorming project design, scientific literature research, consultations with experts, pre-proposal, preliminary lab measurements.

Week 6: Unit Project I
• Refined project design, formal project proposal, experimental set-up, data acquisition, evaluation.

Week 7: Unit Project I
• Reflection, experimental modifications, more data acquisition, analysis. Data review.

Week 8: Unit Project I
• Reflection, project reporting: powerpoint presentation and written report. Post-project questionnaire. Voting: project and team selection for Project II

Week 9: Unit Project II
• Pre-project questionnaire, brainstorming project design, scientific literature research,

consultations with experts, pre-proposal, preliminary lab measurements.

Week 10: Unit Project II
• Refined project design, formal project proposal, experimental set-up, data acquisition, evaluation.

Week 11: Unit Project II
• Reflection, experimental modifications, more data acquisition, analysis.

Week 12: Unit Project II
• Reflection, experimental modifications, more data acquisition, analysis.

Week 13: Unit Project II
• Reflection, experimental modifications, more data acquisition, analysis. Data review.

Week 14: Unit Project II
• Reflection, project reporting: powerpoint presentation and written report. Post-project questionnaire.
• End of semester reflection.