ChBE/ME/MSE 4759: Electrochemical Energy Storage and Conversion.
(3 credit hour, senior-level elective)

Unit Instructors: Seung Woo Lee, Marta Hatzell, Hailong Chen, Matt McDowell
Additional Instructors: Paul Kohl, Thomas Fuller, Michael Filler (ChBE) Faisal Alamgir (MSE)

TextBook: "Electrochemistry and Electrochemical Engineering, An Introduction", Alan C. West, ISBN 978-147-007604-7

Grading: Exams (typically two in-class exams)- 40%, homework-20%, independent study project-10%, quizzes-5%, Final exam-25%.

Attendance: Attendance at all classes is expected. Periodic quizzes are given to encourage attendance.

Background: ChBE 4759 is an elective class for senior-level undergraduate students in ChBE and other engineering disciplines. The course was developed from the content of the graduate course ChBE 6130, Electrochemical Engineering. Its creation was motivated by the interest in the energy storage and conversion among the ChBE undergraduates. ChBE 4759 has been offered twice as an elective course (ChBE 4803) in Fall 2014 and Fall 2015 for a total enrollment of 70 students. The students rated the "Overall Effectiveness" on CETL survey at 4.6 (2014) and 4.9 (2015). The written comments from the students were very positive with no significant deficiencies identified.

ChBE wishes to offer this course on an annual basis as a senior-level elective. Students from two other Schools, ME and MSE, have enrolled in this course.

Course Purpose and Description: Energy is a fundamental issue facing society world-wide. Electrochemical devices play an important role in energy storage and conversion, especially at certain power-levels. The scope of applications include: (i) small, mobile electronic systems (e.g. phones and computers), (ii) large power sources for transportation (e.g. electric vehicles), and (iii) very large, grid-storage devices. Evolving renewable energy sources have a critical dependence on electrochemical energy storage. The hydrogen economy depends on electrochemical devices for hydrogen production (i.e. electrolyzers) and conversion (i.e. fuel cells).

The course is appropriate for students interested in the general topic of energy and more specifically electrochemical devices used to store or convert energy from one for to another. Senior-level engineering students with a background in thermodynamics and transport are qualified to take the course. The ChBE prerequisites are for the students to have completed their required courses in these three areas.

Learning Objectives: Upon completion of this course, the students are expected to have the following knowledge.

1. Understand how thermodynamics, kinetics and mass transport apply to electrochemical devices.

2. Understand the effect of temperature on Gibbs energy and entropy, and how that applies to electrochemical systems.

3. Understand the nature of the energized electrode and double layers.

4. Understand the two-electrode/electrolyte nature of electrochemical devices.

5. Understand the specific construction of several battery and fuel cell systems.

6. Understand how the performance of specific battery and fuel cell systems derives from fundamental thermodynamic, kinetic and transport principles.

7. Understand battery and fuel cell charge/discharge and efficiency characteristics.

8. Understand the fundamental issues and practical outcomes of safety in battery, fuel cell and electrolyzer systems.

Course Syllabus: All electrochemical devices (e.g. batteries, fuel cells and electrolyzers) are based on fundamental electrochemical principles. These electrochemical principles are derived from (i) thermodynamics, (ii) kinetics, and (iii) mass transport. In the first half of the course, the students learn the 'fundamentals of electrochemistry'. This involves applying their previous knowledge of thermodynamics, kinetics and transport to electrochemical systems. In the second half of the course, the fundamental of electrochemistry are applied to specific battery, fuel cell and electrolyzer systems. Practical aspects of these systems, such as manufacturing methods, performance metrics, safety, and wear-out mechanisms are also presented.

The students have the opportunity to explore aspects of electrochemical systems of particular interest to them in more depth. An independent study project is assigned where students acquire more depth on a particular aspect of their choosing. All reports are shared with the full class. Some of the homework assignments call for the analysis of battery performance. In some cases, real data on current batteries is collected by the students and used as the basis for the analysis. The application areas include an historical perspective and future-prospects discussion. Select reading from specialized reference books, text books and journal papers are assigned to supplement the textbook.

Schedule of Topics:

Week 1: The course begins with a survey of our energy needs, world-wide distribution, and the role of different energy conversion and storage devices, including electrochemical technologies. It is shown how all electrochemical devices are based on fundamental thermodynamic, kinetic and mass transfer concepts.

Week 2: Fundamental thermodynamic concepts are developed and applied to electrochemical systems. This includes the development of electrochemical potentials, and the effect of temperature on the Gibbs Energy and entropy of the system.

Week 3: Thermodynamic concepts are expanded to include the use of Poisson's Equations and the conditions for equilibrium, the Nernst Equation.

Week 4: The conditions for equilibrium are expanded to include junction potentials, which are the basis for many sensors including pH and ion selective electrodes.

Week 5: Fundamental concepts in chemical kinetics are developed for electrochemical processes. Kinetic concepts are used to develop rate equations and the basic current-voltage behavior for electrochemical events.

Week 6: Fundamental concepts in mass transport are applied to electrochemical systems. The concepts of diffusion, migration, and convection are developed for charged and uncharged species in electrochemical systems.

Week 7: Specific cases of binary electrolytes are used to understand the effect of mass transport and concentration gradients in batteries and fuel cells.

Week 8: The thermodynamic, kinetic and mass transfer concepts are brought together and used to describe the charge/discharge behavior of batteries. The effect of surface area, electrode thickness and temperature are explored. Homework assignments include analysis of charge and discharge curves with some data collected in-class.

Week 9: The technology, manufacturing methods, and metrics for specific primary batteries are described.

Week 10: The technology for primary batteries is completed and used to introduce secondary batteries. Nickel-based secondary battery technology is discussed.

Week 11: The technology of lead-acid batteries is presented using the thermodynamic, kinetic and mass transfer concepts developed earlier in the course.

Week 12: The theory of porous electrodes is developed and applied to lithium-ion technology. The manufacturing methods and metrics of lithium-ion technology are presented.

Week 13: The concept of the fuel cell and electrolyzer are introduced. Concepts in thermodynamics, kinetics and mass transfer are used to understand the particular performance aspects of fuel cells.

Week 14: The technology and performance of alkaline, molten carbonate, and solid oxide fuel cells are presented.

Week 15: The technology and performance of polymer membrane fuel cells are presented.