CHE 494: Solar Fuels Engineering

Spring 2018 Course Syllabus

Instructor and Office Hours

Prof. Meenesh R. Singh
Office: CEB 217
Office Hours: Tuesdays 10:30 – 11:30 am

Credit Hours- 3 (Undergraduates) and 4 (Graduates)

Course Email Address

The email related to the course may be sent to mrsingh@uic.edu. Please include "CHE 494" in the subject line.

Lectures

T 9:15 – 10:30 AM in CEB 218

Th 9:15 – 10:30 AM in CEB 218

Course Description

Solar fuels engineering involves design and implementation of processes and systems for efficient utilization of solar energy to produce chemicals and fuels. Such systems are referred to as a solar fuels generators, which are made of five components such as- i) *light absorber* – a semiconductor material that absorbs sunlight to produce electrons and holes, ii) *oxidation catalyst* – an electrocatalyst that uses holes from light absorber to oxidize hydrogen-donor such as H_2O to produce H^+ and O_2, iii) *electrolyte* – liquid or ionomer material to transport H^+ for the reduction reaction, iv) *fuel forming catalyst* – an electrocatalyst that uses electrons from the light absorber and H^+ from the electrolyte to produce fuel, and v) *separator* - an ionomer membrane to prevent crossover of the fuel to the oxidation catalyst. This course will provide the underlying physics, thermodynamics and transport characteristics of individual components of solar fuels generators. A major objective is to teach a course such that undergraduate and graduate students can understand the subject matter. This will require explanation of unfamiliar topics, such as the physics of holes and electron transport in solids, n-p junctions, charge collection under illumination, electron transfer reactions at the catalysts interface, ion transport in concentrated electrolyte, multiphase transport, and reaction to the students with chemical engineering, mechanical engineering, electrical engineering, chemistry and physics who often do not have the required background knowledge.

Course Learning Goals:

1. Learn the definition of some key metrics to evaluate the performance of solar fuels generator and appreciate the critical importance of characterization of electrolyte, catalysts, light absorber, and membrane in the design of solar fuels generator.
2. Gain an understanding of the Nernst-Planck equations as a way of analyzing electrochemical processes and be able to apply it to a new, unseen problem in energy conversion and storage.
3. Gain an understanding of the important science underlying many electrochemical systems including capacitors, batteries, solar cells, fuel cells, and electrolytic cells.
4. Use a combination of this science base, prior chemical engineering knowledge, and the engineering analysis to solve design and operating problems in electrochemical systems such as solar fuels generators.
5. Become familiar with some of the typical engineering equipment used for each process studied.

Recommended Texts [No one text covers the whole curriculum]:

1) Nelson, Jenny. *The physics of solar cells*. World Scientific Publishing Co Inc, 2003. [For unit 1 and 2]
2) Newman, John, and Karen E. Thomas-Alyea. *Electrochemical systems*. John Wiley & Sons, 2012. [For units 1, 2, and 4]
3) Bard, Allen J., et al. *Electrochemical methods: fundamentals and applications*. Vol. 2. New York: Wiley, 1980. [For unit 3]
4) Goodridge, F., and Kenneth Scott. *Electrochemical process engineering: a guide to the design of electrolytic plant*. Springer Science & Business Media, 2013. [For unit 4]

Teaching and Learning Methods

A variety of teaching and learning approaches will be used in this course. Classes will vary to suit the topic under study and will include a mix of lectures, structured tutorials, demonstrations, and group based workshops. All classes will be organized to maximize interaction between the instructor and the students. The emphasis will be on developing a strong understanding of scientific basics and tools for analysis, rather than a descriptive presentation of equipment and processes.

Syllabus and Schedule

<u>Unit Titles</u>

1. *Thermodynamics of Solar Energy Conversion and Electrochemical Processes*

   Energy production and consumption, solar economy, solar energy spectrum, black body radiation, thermodynamic limit of solar energy conversion to work, solar thermal conversion, Shockley-Queisser limit of multijunction light absorbers, thermodynamics of electrochemical cells, thermodynamic limit of solar fuel generators.

2. *Kinetics and Transport Processes in Photo/electrochemical Cells*

   Energy losses in electrochemical cells, kinetics of charge transfer reactions, Butler-Volmer reactions, Marcus theory of electron transfer, ion transport in dilute and concentrated electrolytes, ion transport in ionomers, electron and hole transport in semiconductors, photon absorption and transport in semiconductor, double layer, and liquid junctions.

3. *Experimental Techniques in Electrochemistry*

   Cyclic voltammetry, chronoamperometry, chronopotentiometry, polarography, and impedance spectroscopy.

4. *Modeling, Simulation, and Scaleup of Photo/electrochemical Cells*

   Modeling and simulation of primary current distribution, secondary current distribution, and tertiary current distribution; integrated models for photo/electrochemical cells; scale-up of the electrochemical plant.

Schedule

Week 1 to 3	Introduction, Unit 1
Week 4 to 8	Unit 2
Week 9 to 11	Unit 3
Week 12 to 13	Unit 4
Week 14 to 15	Student project presentations and course review

Timeline and Assessment

Item	Date	Weighting
Team Formation	February 1st	-
Mid-Term Review of Projects	March 8th	30%
Final Report Submission	April 24th	30%
Final Presentation	April 31st	40%

Team project: Students will work in teams of three or four students on a realistic and open-ended problem on some aspect of solar-driven electrochemical or photoelectrochemical processes. The project will involve problem definition, planning, request for laboratory data (but no laboratory work by the student team), calculations and possibly development of a numerical model using Matlab, an oral presentation, and written report.