PHYS 4400: Principles and Varieties of Solar Energy

Spring 2014. Instructor: Prof. Randy Ellingson

Tuesday & Thursday 12:30 – 1:45 pm; Location: R1, Room 2360

Syllabus, updated March 13, 2014

Goals for this course:

We will learn and discuss:

1. The basis of our solar resource (fundamentals of energy and the Sun):
    a. Energy and power: distinguish between different forms of energy; the value of each form of energy, energy sources, and determining average power and peak power in various scenarios.
    b. Light and photons: energy of a photon, power within a light source, generation and conversion of light, interactions between light and matter.
    c. The Sun: physics of the Sun, the photosphere, the solar spectrum, and the physics of blackbody radiation (sources of radiant energy).
    d. Sunlight and Earth's atmosphere: standard solar spectra, units of insolation, extraterrestrial vs. terrestrial spectra, air mass, atmospheric effects, direct vs. circumsolar insolation.
2. Conversion of solar energy:
    a. The greenhouse effect: atmospheric CO_2 concentration, greenhouse gases, fossil energy, effect on Earth's climate, weather vs. climate.
    b. Photosynthesis: scientific principles, quantified solar energy conversion, contribution to food supply, production of biofuels.
    c. Solar thermal energy: physics of conversion of light to heat, uses of solar thermal (building-integrated for water and air heating, solar thermal power plants).
    d. Wind energy: connection to the Sun, history, physics and technology, implementation, and industry trends.
    e. Photovoltaics (PV): purpose of PV devices, principles of the photovoltaic effect, architecture of a solar cell; working with the solar spectrum, one electron per photon, integrating the solar spectrum; device characterization (optical absorption and reflection, current vs. voltage, power conversion efficiency, quantum efficiency); types of PV cells; concentrating PV. Semiconductor physics for understanding PV devices.
3. Energy markets, policies, and the environment:
    a. Calculating the Levelized Cost of Energy
    b. Energy consumption: major fuels, Carbon impact, trends, role of energy efficiency.
    c. Renewable energy policies: US, Ohio, and global.
    d. Carbon management: cap and trade, carbon tax, case studies.

Guest Lectures (tentative):

- physics of the Sun (Prof. J.D. Smith, UT Physics and Astronomy)
- photosynthesis (Prof. Scott Heckathorn, UT Environmental Sciences)
- climate change (Prof. Jiquan Chen, Environmental Sciences)

- PV Project Development (Matt Longthorne, Solscient Energy)

- renewable energy policy in Ohio
- science of climate change
- Perspectives on the PV industry: CdTe solar cells
- Design, installation, and operation of a residential PV system
- Tour of PV module assembly plant

Final Exam: Tuesday, April 29, 12:30 – 2:30 pm.

Information and instructional methods.

1. Keep current with the coursework and complete assigned reading prior to lecture. As part of the class time, students will present solutions and information on relevant problems in order to initiate and facilitate discussion of important, fundamental, and/or interesting topics. Participation in class through questions and discussion is essential for the most effective learning. As necessary, read the assignment again after lecture to help consolidate your knowledge.

2. Complete the assigned homework on time; the instructor reserves the right to deduct points for late homework: 10% if late, then 10% additional for each day late.

3. Follow the University's Missed Class/Excused absence policy; here's one link:

http://www.utoledo.edu/facsenate/missed_class_policy.html

4. Turn cell-phones and pagers off when in class.

5. Know the University's class withdrawal rules:

http://www.utoledo.edu/offices/registrar/registration_dates_spring.html

(you must withdraw either on-line or in person at the Registrar's Office).

GRADING and EXAMS

Only material covered in class or in homework will be used for exams. There will be 2 types of exam:

1. Quiz

The quizzes will be 20-25 minutes and may include short answer and/or multiple choice questions (MCQ). Quizzes are intended to make sure you have understood the basic concepts taught up to that point in the course, and the quizzes are closed-book, closed-notes.

2. Final exam

The Final exam will be a combination of MCQ and problems. The Final exam will be open-book, open-notes (written or typed class notes only, no PowerPoint slides). Necessary physical constants and equations will be provided.

Grading

Grades will be determined according to: In-class participation: 15%. Homework: 35%. Three in-class quizzes: 25%. Final exam: 25%.

Textbook: No specific textbook is assigned. However, lectures may draw from the following:

- "The Physics of Solar Cells", by Jenny Nelson: http://www.amazon.com/Physics-Solar-Properties-Semiconductor-Materials/dp/1860943497/ref=sr_1_1?ie=UTF8&qid=1326207348&sr=8-1;
- Wikipedia (yes, this can be used a source, or a starting point, for rigorous academic investigation and discussion), and Georgia State University's HyperPhysics (http://hyperphysics.phy-astr.gsu.edu/hbase/hph.html);
- PV Education: http://www.pveducation.org/pvcdrom

Class dates: Jan. 9, 14, 16, 21, 23, 28, 30, Feb. 4, 6, 11, 13, 18, 20, 25, 27, Mar. 11, 13, 18, 20, 25, 27, Apr. 1, 3, 8, 10, 15, 17, 22, 24. Finals week: April 29 – May 3: **Final Exam → Tues., Apr. 29, 12:30 – 2:30 pm.**

Date	Topic(s)
Jan. 7, 9	Introduction; energy vs. power; overview of Earth's energy: forms of energy, sources and use, stored energy, average and peak power.
	Reading (complete before class). January 7. http://en.wikipedia.org/wiki/Energy (Parts 1-5); http://en.wikipedia.org/wiki/Power_(physics) (Parts 1-2, 5, 6). January 9: http://en.wikipedia.org/wiki/Light (Parts 1-5; for Units and Measures, familiarize yourself with and be prepared to explain Radiant Energy, Radiant Flux, Irradiance, Spectral Irradiance).
Jan. 14, 16	Light and photons: generation and destruction of light, interactions between light and matter, photon flux. Blackbody radiation.
	January 14: http://en.wikipedia.org/wiki/Photon (Parts 1, 2 (not 2.1), 11, and 12). January 16: http://en.wikipedia.org/wiki/Sun (Parts 1, 2, and 6). Blackbody radiation: http://en.wikipedia.org/wiki/Black-body_radiation (Parts 1-4)
Jan. 21, 23	Jan. 21 – guest lecture on the physics of the Sun (J.D. Smith, UT Astronomy). Insolation, solar spectra, extraterrestrial and terrestrial spectra, air mass, atmospheric effects, direct vs. indirect insolation, integrating the solar spectrum.
	January 21: The solar constant: http://en.wikipedia.org/wiki/Solar_constant . http://en.wikipedia.org/wiki/Sunlight (Parts 1- 4, 6, 9); Textbook sections 2.1, 2.2.
Jan. 28, 30	Introduction to energy conversion. Value of and need for energy conversion and energy efficiency; environmental impacts, and challenges. Fossil energy, the greenhouse effect, global climate change, weather vs. climate. January 30: In-class quiz (delayed).
	January 28: Textbook Chapter 1, and section 2.3; http://en.wikipedia.org/wiki/Energy_conversion
Feb. 4, 6	Feb. 4, 6: Photosynthesis. Scientific principles, quantified solar energy conversion, contribution to food supply. Feb. 6 – guest lecture on photosynthesis (Scott Heckathorn, UT Environmental Sciences).

	Feb. 4: January 30: http://en.wikipedia.org/wiki/Greenhouse_effect Feb. 6: http://en.wikipedia.org/wiki/Photosynthesis
Feb. 11, 13	Feb. 11: Biomass: conversion to thermal energy, liquid biofuels for transportation. Feb. 13: April 15: guest lecture on carbon in our atmosphere and environment – Jiquan Chen, UT Environmental Sciences.
	February 11: http://en.wikipedia.org/wiki/Biomass ; http://en.wikipedia.org/wiki/Biofuels February 13: http://en.wikipedia.org/wiki/Climate_change; http://www.camelclimatechange.org/articles/view/151215/
Feb. 18, 20	Feb. 18: Solar thermal energy. Generating heat from light; passive solar for space and water heating; solar thermal power plants (generating electricity from solar heat); thermoelectric conversion. Wind energy. Feb. 20: Wind energy.
	February 18: http://en.wikipedia.org/wiki/Solar_thermal_energy; Chapter on Solar Thermal Energy; http://en.wikipedia.org/wiki/Wind_power; Chapter on Wind Energy.
Feb. 25, 27	Photovoltaic effect and fundamental solar cell properties. Diode equation, dark current, light current. Efficiency, J_{SC}, V_{OC}, internal and external QE, maximum power point. Calculation of photocurrent density from quantum efficiency. Feb. 27: In-class quiz.
	February 25: Chapter 11 handout on PV.
Mar. 11-20	Construction of a PV cell: components including substrate or superstrate, transparent conducting layer, light-absorbing layer, charge-separation interface, back electrical contact. Introduction to semiconductor physics concepts: semiconductors; band structure; valence and conduction bands (HOMO-LUMO levels); bandgap energy; direct vs. indirect gap; electrons and holes ("charge carriers"); light absorption; n-type and p-type doping; the p-n junction. Charge carrier transport: drift and diffusion; charge carrier processes: carrier cooling, charge separation, recombination mechanisms (radiative and non-radiative).
	March 11, 13, 18: www.pveducation.org Sections 3 and 4. March 20: www.pveducation.org Sections 5 and 6.
Mar. 25, 27	Types of solar cells: Crystalline and polycrystalline silicon PV, thin-film PV, organic and nanostructured PV. CdTe solar cells; a-Si solar cells. Nanomaterials: advantages and disadvantages in PV.
	March 25: www.pveducation.org Section 7.

Apr. 1, 3 **Apr. 8, 10**	April 1: Characterization of PV cells and modules April 3: In-class quiz. PV system economics: energy and money; energy payback time; calculating the Levelized Cost of Electricity (LCOE), (also known as the Levelized Energy Cost); cost components. Renewable energy policies (US, Ohio, and global). Introduction to energy market economics, policies, and the environment: major fuels, carbon impact, trends, the role of energy efficiency April 8: guest lecture on PV project development (Matt Longthorne, Solscient Energy). April 10 – tentative guest lecture on the acquisition, installation, and operation of a residential PV system (Brooks Martner, Lafayette, CO).
	April 1: www.pveducation.org Section 8. April 3: http://en.wikipedia.org/wiki/LCOE
Apr. 15, 17	TBD
	TBD
Apr. 22, 24	April 22: Presentations on PV LCOE. April 24: Review.
April 29	Final Exam: **12:30 – 2:30 pm.**