ES 231. Energy Technology

ES 229. Survey of Energy Technology

Graduate course (Half course, spring semester. Course meeting times WF 2:30-4, Location TBD)
Course catalog description: Principles governing energy generation and interconversion. Current and projected world energy use. Selected important current and anticipated future technologies for energy generation, interconversion, storage, and end usage. This course may be taken for a letter grade only, but companion course ES 229, "Survey of Energy Technology", has the same content and requirements, and has co-located class meetings, but may be taken pass/fail only.

Prerequisites: One semester of college-level physics, single-variable calculus, and familiarity with chemistry at the high school advanced placement level.

Rationale for the course

ES 231 or ES 229 is required for the University-wide Graduate Consortium in Energy and Environment, a program available to doctoral students in programs as varied as GSAS, SEAS, HMS, HSPH, KSG, HBS, HLS, HGSD, and HGSE and consists of half-courses in Energy Consequences; Energy Technology; and {Energy Policy or Energy Security}, as well as a reading seminar. Consequently, the pre-requisites do not include advanced undergraduate or graduate training in any discipline. The limited pre-requisites accommodate those graduate students who are not scientists or engineers but who have had the basic background in physics and chemistry needed to follow most of the technical content of the course. The breadth of the topics addressed in the course is so large that the technical depth will rarely go beyond that which can be built onto calculus-based Newtonian Mechanics and Advanced Placement high school chemistry. The exception is electricity: for one class meeting, some elementary concepts in Electricity and Magnetism will need to be introduced at the phenomenological level to permit a technical discussion of electrical energy technology. ES 231 is as challenging as a typical SEAS disciplinary graduate course and is acceptable in many degree programs. ES 229 is equally challenging but is recommended for those who are concerned that their academic backgrounds may put them at a significant disadvantage for a letter grade.

Desired Outcomes

Students will:
1. Understand the magnitude of the developing energy problem;
2. Develop an understanding of the technical and some economic aspects of a wide range of current and future technologies for energy generation, interconversion, storage, and end usage.
3. Develop the ability to ask critical questions and to effectively search for accurate information.
4. Begin to develop the ability to critically evaluate prospects and challenges for current and proposed energy technologies

Teaching Staff

Instructor: Professor Michael J. Aziz
Pierce Hall 204a; 5-9884

aziz at seas dot harvard dot edu
Office Hours: TBD

Teaching Fellow:
TBD

Grading

Grading will be based on:

1. Problem sets, approximately eight, 50%. (Due in class, Fridays at 2:40)
2. Mid-term exam, approximately 20%.
3. Final project, worth 30% plus points lost on mid-term.

Reading

There is no course textbook. Reading selections will come from a variety of sources. Occasionally the reading will be required in advance, and the discussion in class will be based on the presumption that you have done the reading. Often the reading will be supplementary or optional. Much of it will come from "Introduction to Energy Technology", by M.J. Aziz and A.C. Johnson, which is under construction. Chapters will be handed out in paper format but not electronically. Other reference books will put on reserve in Gordon McKay Library; a subset is also on reserve in Cabot Library.

Sections

There will be weekly section meetings in which the teaching fellow(s) will expand on some of the material discussed in class; address any commonly-held remedial background gaps when appropriate; work through quantitative problems to reinforce class material; and answer any questions related to the upcoming problem set or examination. While attendance is optional, it is strongly encouraged. Section meetings will be scheduled as soon as possible. You are welcome to attend any scheduled section.

Mid-Term Examination

An in-class mid-term exam is scheduled for Friday, March 9 or Wednesday, April 11, depending on the availability of the guest lecturers. There will be no make-up examination for the midterm exam. If notification of an unavoidable absence from an examination is given in advance to the instructor prior to the examination, the exam may be taken simultaneously in an alternate location if the student can arrange suitable proctoring.

Final Project

Instead of a final exam, each student will submit, by the last day of reading period, a final paper reporting a final project. The project should be the in-depth study of the technical or techno-economic aspects of some topic in energy technology, chosen in consultation with the teaching staff. The project should involve *substantial quantitative analysis* on the part of the student.

The contribution to your final grade of the final project is 30% plus the value of any points lost on the mid-term. So if you score 100% on the mid-term then the final project is worth 30% of your final grade, and if you score 0% on the mid-term then the final project is worth 50% of your final grade.

Problem Sets

There will be about eight homework sets distributed over the ~12-week semester and will be due at the start of class on Fridays. Solutions to the problems will typically be handed out at the first class following the due date.

Guidelines for submission:

1. Hand in your work either typeset or neatly handwritten on white, lined or gridded 8.5 x 11" sheets that are stapled together.
2. Along the top of the first page, put your name, the problem set number, the course number, and the names of your collaborators (as described below).
3. Put your solutions in numerical order as assigned.
4. Problem sets will be graded both for correctness and for clarity; graders are not required to guess the intended meaning of poorly written answers!
5. Your work should be neat and orderly; make large, clear, and clearly labeled diagrams.
6. Formulas and numbers alone won't do; a short written explanation (a phrase or two will often be sufficient) should accompany each solution to explain your reasoning.

Collaborating on problem sets:

1. Collaboration in planning and thinking through solutions to homework problems is encouraged, but no collaboration is allowed in writing up solutions. You are allowed to work with other students in discussing, brainstorming, and walking through solutions to homework problems. But when you are through interacting, you must write up your solutions independently. When you are stuck or finished, you may check your answers with someone else, but any written changes to your solutions must be made when you are on your own. This ensures that the understanding has lodged itself in your brain, rather than bypassing your brain on its way from your eyes to your fingers.

2. We expect and encourage you to collaborate with other students in the course in this manner. At the top of your homework solution, state with pride the names of the students with whom you collaborated in this manner. A lack of collaborators gives us cause to worry!

3. Before consulting others (students, TFs, instructors) make sure you have made a genuine effort to solve the problems by yourself: this is really important so you can see where your personal roadblocks are and focus on them. Problem sets are probably the single most important part of learning the material!

4. Some of the homework problems that we assign will be taken from textbooks or other published sources or other courses or previous offerings of this course. It is not acceptable to find these solutions and refer to them in any way.

Handing in problem sets:

1. Problem sets must be delivered in class by 2:40 p.m. on Friday each week, unless otherwise announced.
2. If a consistent pattern of late submission develops, we will have to develop policies that treat all students even-handedly and facilitate the graders doing their jobs.

Getting graded problem sets back:

1. Problem sets are returned during class.
2. If you miss class, pick up your graded problem set from your TF within 2 weeks of the due date.

Strategy for Success

Given the diverse background of students this course is designed to serve, you are not expected to master every aspect of every technology we discuss. If you meet the course prerequisites and you attend the lectures, read the assigned passages, and put genuine effort into the homework and the final project, then you should do fine.

Tentative Outline of Topics, Engineering Sciences 229/231, Spring 2013

Lecture numbers represent 80-minute class meetings, WF 2:30-4:00 starting W 1/30/13. The order below is not final; it is anticipated to change to accommodate guest lecturers' schedules. A final schedule will be posted when available.

Earth's Energy System. Global energy sources. Energy for human use: Pre-industrial revolution energy consumption; important developments. History, present, and projected distributions of primary energy and population. Energy consumption per capita and other measures of well-being. Carbon emissions. The Kaya identity. Intro to the modern energy system. Energy flows in the US. Projections.

Silver Bullets: Scale of the human energy challenge. What would it take for each of several major or anticipated major technologies to become the "silver bullet"? Options for CO_2 response. Stabilization wedges. Intro to concepts in energy economics.

First Law of Thermodynamics. Forms of Energy. Interconvertibility. States and Properties. Processes and cycles. Equations of state. Heat and Work interactions. First Law of Thermodynamics - closed and open systems. Flow Work. Shaft Work. Completely Useful, General Form Of The First Law.

Second Law of Thermodynamics. The heat engine, the heat pump, and the refrigerator. Cycle efficiency. Second Law of Thermodynamics for closed and open systems. Reversible and Irreversible Processes. Carnot Cycle and Carnot efficiency. Entropy. T-S diagrams. Entropy generation. Entropy balance for closed and open systems.

Electricity. Circuit elements. AC, DC, interconversion, transformers. Power transmission modes. Reactive power. Motors/generators. Power line losses. Electric power demand cycles. The U.S. electric grid.

Wind. Energy in wind. Origin of wind. Wind resource. Power extraction: relevant fluid dynamics and turbine mechanics, Betz limit. Generators and systems. Turbine size and scaling. Capacity factor, extraction factor. Variability, transmission, storage, grid stability issues.

Water and geothermal. Hydroelectric, waves, tides, salinity gradient resource. Energy in water. Harvesting devices. Currently harnessed power. Geothermal flux, regional variation and minimum requirement. Heat mining.

Power Cycles. Power cycles. Steam turbine. Gas turbine. Brayton and Rankine cycles used for power generation. Throttling process and Rankine refrigeration cycle. Power plants. Co-generation of heat and power. Regeneration. Stirling engine. Spark-ignition engine, Diesel engine, Jet engine and ideal cycles. Non-idealities.

Solar thermal heating and electricity generation. The solar resource. Variability. Concentrating optics and selected systems, e.g. solar troughs and towers, solar dish Stirling engine.

Photovoltaics. Solar spectrum. Simplified solid state physics. Solar cells. Efficiencies. Crystalline Si, thin film Si, other inorganic thin film; organic; other. Materials for large-scale thin-film PV. Abundance. High-volume production. Transparent conducting and IR reflecting materials. Production. Economics. Photochemical fuel production.

Nuclear power. Fission: basic reactions; fissionable and fertile isotopes; neutron balance. Selected reactor types; reactor safety and accidents; reactor products, recycling. Isotopic enrichment and implications for weapons proliferation. Fuel cycle. Waste and long-term storage. Nuclear power history. Fission economics. Fusion: basic reactions; reactor types and projections: scale, economics.

Combustion and Measures of Efficiency. Exergy/Availability/Work Potential. Process efficiency. Second Law efficiency. Chemical reactions. Combustion and Heating Values.

Coal. Coal: formation, resources, extraction. Coal-related hazards. Coal power plant. Coal-based Integrated Gasification Combined Cycle.

Oil and natural gas. Petroleum and natural gas. Formation. Composition. Rock strata, porosity and permeability. Geophysical imaging. Extraction. Estimating recoverable reserves.

Biomass. Photosynthesis. Structure and chemistry of sugar, starch, lignin, cellulose, lipids, plants, algae. Biofuels: past and present. Renewable vs. non-renewable sources. Renewable biomass sources: food crops, energy crops (incl. algae), waste streams. Biochemical conversion pathways. Fermentation. Long-term production potential worldwide. Waste, fertilizer use, land and water use issues, e.g. fuel vs. food. Current costs. Prospects for advances.

Non-conventional fossil fuels. Tar sands, shale gas, shale oil. Coal-bed methane. Methane hydrates.

Mid-Term Exam. Tentatively scheduled for Wednesday April 3.

Carbon sequestration. Carbon capture from flue gas and geological sequestration. Other approaches: reforestation, mineralization, ocean sequestration, air capture, accelerated weathering.

Electrochemistry, Batteries, and Fuel Cells. Basic electrochemistry. Batteries. Fuel cells.

Energy Storage. Storage needs. Figures of merit. Batteries: important types, theoretical limitations on specific energy storage and current proximity to limits. Pumped hydroelectric. Compressed Air Energy Storage. Flow batteries. Flywheels. Electrochemical capacitors. Superconducting magnetic energy storage. Thermal energy storage.

Synthetic fuels. Thermodynamics, processes, pathways of important thermochemical transformations. Syngas production from coal, biomass, muni waste, steam reforming. Water-gas shift reaction. Fischer-Tropsch synthesis of alkanes. Bio-diesel. Coal gasification and IGCC.

Transportation. Current consumption and trends. Options for future endpoints. Sources of automobile energy consumption and design options. Micro-hybrid and hybrid electric vehicle, plug-in hybrid electric vehicle, electric vehicle, fuel cell electric vehicle: technology and energy/power requirements. Well-to-wheels analysis. Hydrogen storage and transport.

Major industrial energy usage. Worldwide energy use and CO_2 emissions by industry. Iron and steel, aluminum, cement, chemicals, plastics, fertilizer. Agriculture, diet and carbon footprint. Opportunities.

Energy use in buildings. Heating and cooling, ventilation. Insulation; R-values and U-values. Windows. Active / passive solar heating. Lighting: incandescent, fluorescent, solid state. Space heating and cooling. Insulation; R-values and U-values. Windows. Passive solar heating. Heat exchangers, heat pumps and refrigerators. Thermoelectrics.

Options for a Sustainable Future.