Course Description:
This course builds on a number of ideas covered in the core Principles and Applications of Energy Technology course (425.601) – and as with the first course uses and integrates a broad range of ideas from science, engineering and economics. The course has two distinct but overlapping themes that will be often be covered in parallel.

The main focus of the course (in terms of time spent) will be to broaden and deepen the coverage of the how some of the energy technologies discussed in the core course work, with a slightly more formal discussion and use of ideas from mechanics, thermodynamics, and in addition discuss a range of technologies not covered in that course (e.g. fusion, wave and tidal based technologies, hydroelectric power, LEDs). The general principles of generating power, transmitting it over large distances, and being used by loads will also be covered.

A second theme of the course will extend the coverage of the system operation and economics of electricity markets, both today, and in a future that might have large amounts of renewable energy (RE) added, which will also raises system integration issues related to the use of storage, CTs and demand side management and market design and efficiency issues related to revenue coverage to meet reliability requirements.

Teaching Style: The course will be delivered primarily through lectures and class discussion.

Instructor: Dr. Thomas Jenkin is a Senior Energy Analyst at the National Renewable Energy Laboratory (NREL) based in Washington, DC and has taught at Johns Hopkins since 2008. He can be contacted by e-mail at Tjenki23@jhu.edu and my intention is to respond to try to respond to all e-mails within 48 hours. He designed and first taught this elective in the Summer 2012, and again in Summer 2014. He also designed the core course: “Principles and Applications of Energy Technology” which he has taught nine times since 2010 (Summer 2015, Spring and Fall 2014, Summer 2013, Spring and Fall 2012, Summer 2011, Spring and Fall 2010), as well as another energy related courses since 2008.

Course Requirements: The main method of grading beyond some consideration of class participation will be through three problem sets and a class presentation. The problems sets will contain both conceptual and numeric problems. The problems sets will be designed to consolidate understanding of the course material covered (rather than test innate mathematics ability).
**Grading and Grading Scale:** In determining grades for the course, class participation, problem sets and presentations will be weighted as indicated below

1. Research and brief in class presentation on topic of interest 15%
2. Three Problem Sets (with equal weighting) 75%
3. Class participation 10%

**Research presentation:** Students will each choose a small research topic to investigate and explain the results of their research to the rest of the class in a brief (10 slide) presentation. These final slide presentations will be spread across the last two classes (5 students presenting in each class, when we will also be covering lecture material for about half of each of those classes) [TBD how much I will actually present – it will depend on numbers etc]

Students are largely free to choose any energy technology topic they find of interest, and the instructor is happy to work with students to help generate ideas. The topic needs to be decided on by the start of the 5th class, and 2-page “ideas” slides will be presented by all students in class 7.

**Problem sets:** For the problem sets deadlines will be specified in advance for all pieces of work. The dates (tentative) for issuing the three problems sets are

- Sunday before 3rd class for Problem set 1
- Sunday before 6th class for Problem set 2
- Sunday before 9th class for Problem set 3

The problem sets are designed to be completed within a 2 to 3 weeks. After a grace period of 3 days after the 3-week deadline, the final grade for all students for that problem set will be determined by what has been submitted at that point.

For the research topic and associated presentation there will be no extension to the deadlines – as the products are presentations of ideas midway through course, and of findings on the last two classes.

The grading scale for students enrolled for credit is A, A-, B+, B, B-, C, and F.

**Class participation:** Activities that contribute to strong class participation include being active in discussions in class, asking or answering questions thoughtfully (even if not always correctly), and keeping up with the reading.

**Course Readings:**
This course will draw from many sources - rather than one or two textbooks, and in particular the course will often use original articles from the field of energy technology, engineering, physics and economics. This will allow students to get used to learning from relevant literature – which is how one often does it when trying to do energy analysis, and also become comfortable with trying to identify the main points in an article, even when parts of the paper are unfamiliar. The course structure, slides and reading reflects my background, interests and experience.

That said the following books are recommended to supplement some (but only some) of the engineering and science parts of the course. The first book:

This book you will already have from the core course and is useful though it has a tendency to be a bit terse at times [though the second edition is significantly better than the first edition]

The following additional books are required for this course. For thermodynamics – with a lot of examples:

Potter, Merle, *Thermodynamics for Engineers*, Schaum’s Outline Series.

And small book that is helpful in a number of subtle points


Some more challenging reading – but ultimately as “good as it gets” in terms of providing insight, physical intuition and understanding on energy, work and heat (to browse through some part during the course - and after it).


Note: (1) All these books together should total less than $100 (2) We are not going to go through each of these books from start to finish as they contain significantly more material than we wish to cover. Rather these books will be used “selectively” to deepen your understanding and allow you to read around some topics that we will cover in slides. You will also find them very useful after the course, especially Feynman.

Note: Despite the titles of these books I am not expecting you to be “engineers”. The course will be challenging but I will provide sufficient background material to enable motivated students with a wide background to do well in the course provided they complete their assignments on time.
Overview of the Topics to be covered

Course Details
This is the third time this course will be given and I will try be responsive to interests of students – so some parts may be emphasized more than others. In particular the later “modules” may be modified. I plan to do this course in a “parallel track” – so that ideas from different modules (e.g. technologies and markets) will often be taught in the same class. Below is a outline of core topics and some of the ideas that will be covered; I plan to make changes to my design and outline of topics and ideas, the order in which some material is presented, and also to the reading as the course progresses. I will, however provide students detailed information on what topics will be covered in upcoming classes. The reading list is not complete at this point and will be revised and updated during the course, a significant fraction of which is optional (denoted “optional”). I will provide explicit guidance in class on what readings are required and what readings are optional (at least one week before the reading is due).

As with the in-person core course, the reading is not intended to cover what I teach. Rather they are intended to supplement parts of what I cover.

A significant part of class in Week 7 will be used for a brief discussion of project ideas, and a significant part of classes in Weeks 13 and 14 will be used for different students to present the results of their “small” project.

Not all the topics listed below are likely to be covered in 14 classes given time constraints – but I will make sure the areas of most interest to the class are covered.

Revisit conservation of energy and conservation of momentum, and how this leads to the idea of forces—Work defined in terms of Fdx or -pdV, including representation of the latter with p-V diagrams. Various related topics will be covered including: (1) work-energy theorem, (2) ideas related to rotation, such torque and angular momentum, and (3) diffusion (of particles or heat). In general, these and related ideas are explained in the context of examples, such as pressure, the flow of heat, how neutrons are moderated, the creation of electric field in a p-n junction in a solar PV cell. The subject of waves, their motion and the energy they carry is covered in water energy module.

Readings
Potter, Merle, *Thermodynamics for Engineers*, Scham’s Outline Series (2006), Chapter 1 (R)

Other readings may be added

2. Energy, Entalphy, Entropy and Heat Engines: Applied Thermodynamics [2.5 classes]
Extends some idea in mechanics to incorporate heat and apply these ideas.

Introduction to thermodynamics
- Internal energy (U), enthalpy (H), latent heat and heat capacities (Cv and Cp)
- Heat transfer (conduction, convection and radiation)
- First and second laws of thermodynamics and why they matter, and idea of entropy (S)
- Reversible and irreversible processes, and how to calculate work done during (i) adiabatic and (ii) isothermal expansion or compression
- Carnot Cycle
Applied thermodynamics with a focus on real heat engines

- Gas Turbines (Brayton cycle)
- Water-steam (Rankine) cycles used in coal thermal, CCGT and nuclear plants
- Combined cycle gas turbines (CCGT)
- Gasoline engines (Otto cycle)

Some other sources of electricity [if time and interest]
- Batteries and Fuel cells

Other cycles and/or processes we may consider here or in other modules, Organic Rankine Cycles (ORC) and related geothermal binary, CAES and adiabatic CAES, jet engines, air-conditioning and refrigeration.

Readings:

Other readings may be added

3. Water Energy Technologies I – Hydroelectric power [1 class]
This section focuses on hydroelectric power. Topics include: hydroelectric power, including examples, and types of hydro-turbine e.g. Pelton vs. Kaplan turbine, and efficiency considerations; multi-dam hydroelectric system (using BPA as example); services provided, pumped hydro and storage

Reading

Other reading may be added

4. Electricity Sector: Market Structure, Operation and, Large-scale Integration of Renewable, including role of storage, CTs and DSM [2 to 3 classes]
This is a wide set of topics that will be spread across a number of classes, and will decide on emphasis– but will include review of recent studies and discussion of.
- Electricity system operation and market design: regulated vs. restructured markets
  - Economic system wide dispatch and operation, efficiency and reliability.
  - Market design –regulated markets
  - Market design – restructured markets
    - Energy only vs. energy and capacity markets
    - Capacity market design considerations
    - Impact of high VRE, including what is happening in US and Germany
- Ancillary services (for the system)
  - Regulation
  - Load Following
  - Spinning and Non-Spinning Reserves
Flexible capacity, including ramping
- Externalities e.g. social cost of carbon, and their inclusion in cost benefit analysis
- Impact of addition of large amount of RE on system, and potential role for storage, DSM and CTs
- Case Study: GE PJM Renewable Integration Study – Some high-lights
- Contracts e.g. PPAs – what about solar etc. MIT*

Other potential topics for discussion
- Valuation of assets under risk and uncertainty, and treatment of CT as a real option*
- Thinking about the future under risk and uncertainty, hedging and use of contracts.*

Readings

High Renewable Energy Penetration and Impact on the Electricity System (Follow MIT Study, and recent Western and Eastern studies) – with storage handled in later class).


Other reading may be added

4. Water Energy Technologies II: Waves and Tidal [1 class]
This section focuses on what is often called hydrokinetic power. First we will discuss what “waves” are and how they can be represented when they “travel” including “where” the energy is and where is comes from. This then allows us to consider wave based technologies, and also tides (which also waves with very long wavelengths and time periods) might be used to capture energy and generate mechanical and then electrical power. These include use of ocean wave e.g. via point absorbers, oscillating water column (OWC), attenuators, and tidal based devices.

Reading [to update]

King, George, *Vibrations and Waves* Chapter 1: Simple Harmonic Motion (pp1-12), Chapter 5: Traveling Waves (page105-112 and 116-120), Wiley (2009).


Other reading may be added

5. **Electricity: Generators, Transmission Lines and Loads, including Motors. [1.5 to 2 classes]**

This section will cover key elements of electricity and magnetism (effectively the physical ideas behind Maxwell’s equations), including electric fields, magnetic fields, currents, resistance, voltage, and real power (P = IV (or more strictly IVCos(θ)), and its application. Of particular relevance is the law of electromagnetic induction (often named after Faraday) which explains how generators work. Electricity can be used to drive a variety of loads, such as motors to washing machines, to refrigerators to microwaves to incandescent light bulbs. To get electricity from A to B you need to transmit it, ideally without losing much of the electrical power in the process. This is done via transmission lines at high voltage, and we will explain how this is done, while introducing ideas such transformers, capacitance, induction and reactive power. Examples of other loads will covered another topic.

Readings


Other reading may be added
6. Fusion (1 class)
Fusion energy is generated when hydrogen (or helium) isotopes combine to form helium with two protons and two neutrons, and release a large amount of energy in the process. Fusion take place in the Sun, and considerable effort has been made to carry out a similar process on Earth, most often though the use of Tokamaks. Fusion and the design of machines to harnessing the energy of fusion to generate electricity will be covered in this class.

Readings

7. Solar Energy (1 to 1.5 classes)
In this topic we extend coverage of solar PV (and to a lesser extent Solar CSP). Will include:
- Operation of a solar cell reconsidered, including
  - More detailed treatment of p-n junction
  - Multi-junction PV
  - Thin film PV
- CSP – covered elsewhere
- Examples of projects

Reading
Feynman, Richard, Leighton, Robert B., and Sands, Matthew, (1963), The Feynman Lectures of Physics, Volume III: Quantum Mechanics; Addison-Weasley, Chapter 14, Semiconductors.
King presentation (Details to be added)
Other reading may be added

8: Loads (1 to 1.5 classes)
After electricity is generated and transmitted over long distances it is “stepped down” in voltage (using transformers) to different voltages and then used to power appliances. We discuss this process as well as how a number of useful appliances (or loads) work.
- Simple circuits – in a house or building
- Incandescent light bulbs and Light Emitting Diodes (LEDs)
- Other load examples e.g. microwave ovens, refrigerators and HVAC systems.

Readings may be added

Note: Other topics may be added or emphasized more depending on interest of students
University Policies: General
University policies described in the JHU-AAP academic catalog. A few to pay close attention to are noted below.

JHU Code of Conduct. All students are to abide by the Code of Conduct. The JHU Code of Conduct is available at http://advanced.jhu.edu/wp-content/uploads/2013/01/AAP1101_CodeofConduct.pdf

JHU Ethics Statement: The strength of the university depends on academic and personal integrity. In this course, you must be honest and truthful. Ethical violations include cheating on exams, plagiarism, reuse of assignments, improper use of the Internet and electronic devices, unauthorized collaboration, alteration of graded assignments, forgery and falsification, lying, facilitating academic dishonesty, and unfair competition. Report any violations you witness to the instructor. Read and adhere to JHU’s policy: http://advanced.jhu.edu/students/plagiarism/

Plagiarism
The copying or use of others’ work without proper attribution and citation as part of any class assignment will constitute plagiarism. Any incidence of plagiarism or other instances of academic is conduct will be dealt with in accordance with Johns Hopkins University policies without any initial warning. Please read and adhere to JHU’s policy: http://advanced.jhu.edu/students/plagiarism/

JHU Disability services. The Johns Hopkins University is committed to providing reasonable and appropriate accommodations to students with disabilities. Students in Advanced Academic Programs (AAP) who are in need of accommodations should visit http://advanced.jhu.edu/current-students/current-students-resources/disability-accommodations/ for the appropriate steps and documentation needed. Requesting accommodations before the semester is preferable, but not required. The student should submit the Request for Accommodation Form prior to the beginning of each semester (s)he is registered to ensure that accommodations continue for that semester. Depending on the accommodation, there may be a time delay before accommodations can be implemented. More about this is available at this weblink. For any AAP disability matters please use this email alias: aapdisability@jhu.edu.

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Further information and a request for accommodation form can be found at:
http://advanced.jhu.edu/students/disability-accommodations/

Dropping the course. AAP has a very tight schedule for dropping classes and being able to obtain a refund. You are responsible for understanding the university’s policies and procedures regarding withdrawing from courses. And you should be aware of the current deadlines and penalties for dropping classes.