Johns Hopkins University

Energy Policy and Climate Program

Emerging Energy Technologies and Applications

DRAFT
425.636.51
Fall 2019
Jenkin
Monday, 6:00 – 8.45 PM
1717 Massachusetts Avenue, N.W., Washington D.C.
Room TBD

Note: This syllabus is a draft as I am currently finalizing the course and the syllabus for Fall 2019. The final syllabus will be circulated prior to the start of the first class.

Course Summary: This elective 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 main focus of the course will be to broaden and deepen the coverage of the how some of the emerging energy technologies work, that were either not covered or only lightly covered in the core course. Electricity generation or storage related topics include (1) Fuel cells and batteries, including hydrogen fuel cells, batteries with different lithium-ion chemistries, and flow batteries, including integration with solar and wind (2) ocean wave devices, with an emphasis on the energy in traveling ocean waves, and how some of this wave energy can be absorbed and converted to electricity, through ideas related to natural frequency and forced damped oscillations, (3) new approaches to carbon capture and sequestration (CCS), such as the proposed Allam cycle - which is a type of closed cycle combustion turbine (CT), where the use of super-critical carbon dioxide rather air as the working fluid facilitates CCS (4) nuclear energy, from small modular fission to fusion. The course will also look at some important applications of electricity, including light emitting diodes (LEDs). The 2014 Nobel prize for physics went to inventors of the first blue LEDs using high band-gap semi-conductors, like indium gallium nitride which has made their widespread use for high quality white light applications possible. LEDs - as will be explained - are similar to (the p-n junctions in) PV cells but with higher band gaps, and operated to run backwards using an electrical source, so that electrical power is converted to visible light with much higher efficiency than with traditional incandescent light bulbs.

Teaching Style: The course will be delivered primarily through lectures and discussion. One of the primary goals of this course is for all students to gain a good grasp of underlying scientific, economic, and environmental principles of the energy and energy technologies that are covered. The mathematics used will be kept at a straightforward level.
**Instructor:** Dr. Thomas Jenkin is an Adjunct Lecturer at Johns Hopkins University and also works as Short-Term Consultant to the World Bank on a variety on energy, and energy technology related projects, with a particular focus on energy storage and its use to integrate renewable energy. Before that he spent nearly 14 years as a Senior Energy Analyst at the National Renewable Energy Laboratory (NREL) in Washington DC. He can be contacted by e-mail at Tjenki23@jhu.edu.

He developed the original core Principles and Application of Energy Technology (PAET) and has taught the in-class version since 2010. He has also developed and taught an advanced elective (PAET II) in alternate years since 2012.

**Course Requirements:** The main method of grading beyond some consideration of class participation will be through three problem sets. 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, and three problem sets will be weighted as indicated below

1. Three Problem Sets (with equal weighting)  75%
2. Presentation  15%
3. Class participation  10%

**Problem sets:** 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. The approximately timing for starting the three problem sets is the weekend before the 4th class, the 7th (or 8th) class and the 11th class (or shortly thereafter).

**Presentation:** Students will research a topic of interest related to the course (agreed with the instructor) and give presentation on their research and findings (about 15 minutes per student). These presentations will be split between weeks 13 and 14 of the class.

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 question thoughtfully (even if not always correctly), and keeping up with the reading.

**Course Readings:**

There is no required text for much of the course. These areas will be covered by through the lectures and through assigned papers and reports that will be available on the internet, electronically via JHU or handed out (see Syllabus and Readings for the preliminary list).

There is, however one required text that supports parts of the science and technology, which you should already have from the related core class. This text is:

Outline
The course is still being finalized so that the number of classes for the different topics is not indicated below, and more readings are being added. The revised syllabus will be circulated prior to the start of class. In addition, the decision to include more on PV (Topic 5b) may mean that one of the last 4 topics may be modified or shortened.

[Additional readings are being added, and so reading list is incomplete at this point]

**Topic 1: Introduction and overview of the course.** The first class provides an introduction and overview of the main areas to be covered during this course, and considers some ideas related to heat and work in more detail (see next topic).

**Topic 2: Some ideas from mechanics, heat and work.** This short module is intended bring people to a common level of understanding of different forms of energy, the ideas of conservation of energy and momentum, force and work, why heat flows from hot to cold and why it matters. This module will be started after the introduction, and then completed at different points throughout the first half of the course. These ideas will be used throughout the course.

**Topic 3: Energy storage and energy storage technologies: for typically within day timescales and focus on batteries.** Energy storage is one of the major themes of this course and this topic introduces the role of energy storage and the many services that it can provide to the electric grid, and explains what factors are likely to drive its growing role in the integration of renewable energy. Much of the early discussion will be somewhat technology agnostic, though with some focus, by way of examples on the use of pumped hydro and batteries. We then deal with how batteries work in some detail for a range of different chemistries, and why it matters e.g., what is the difference between Li-ion NMC and LFP chemistries, lithium ion and flow batteries and “saltwater” batteries.

To understand the use of batteries we also consider simple electrical circuits and loads, including example of resistive loads (e.g. for incandescent lightbulbs and LEDs). Emerging electricity and energy systems are likely to have increasing amount of solar, wind and battery storage and this will be discussed (see also Topic 4).

*Readings:* A&J (2017). 10.8 Integrating renewables, 10.9 Energy storage, 10.10, pumped hydroelectric, 10.15 Batteries, 10.16 Economics of batteries, 6.6 Pumped hydro


**Topic 4: Longer term energy storage: from days to weeks to seasons: Fuel cells, electrolysis and hydrogen**

With increasing deployment of solar and wind it is likely that the role for longer term energy storage may grow, including the use of variable renewable energy (VRE) to split water into hydrogen (H₂(g)) (which requires and stores energy relative to water H₂O(g)) to either use directly e.g., with fuel cells, or after conversion to easier to use/denser hydrocarbon fuels, including methanation (for natural gas) and methanol conversion.

For completeness, we also cover other different energy storage technologies: compressed air, flywheels, and the use of heat storage for concentrated solar power (CSP) [though many of relevant timescales fall in topic 3]

**Topic 5a: Electrical generators (AC), transmission, and loads/motors.** This section considers how electricity is generated using synchronous generators, then transmitted and then used, including synchronous and asynchronous induction motors. Applications of generators and motors also include hybrid and electric vehicles. The emerging shift to more distributed systems and the use of distributed energy resources (DER) including PV and storage is also considered in 5b.


**Topic 5b: PV, Existing and emerging technologies.** In the core course the basics of PV cells was covered. We revisit briefly crystalline silicon (c-Si) and mc-PV cells which represent over 90% of installations, with a focus on the role of diffusion to create the electric field in p-n junctions. We then look briefly at some of the emerging prospects, including the development and use of multi-junction cells and the growing interest in perovskite solar cells.

*Reading:* A&J (2017). For PV cells 8.1 to 8.3, Box 8.2, and Box 11.1


**Topic 6: LEDs and other examples of loads, including a brief history of lighting.** The ability to convert first chemical energy to light rather than heat has a long history; radiation we can see is characterized by lumens per watt. Light emitting diodes (or LEDs) are essentially PV cells run backwards with wider band gaps. Improvements over the last decade have made LEDs much more efficient and cost effective at producing high quality “light”/lumens than incandescent light bulbs (ILBs). We will also consider how and why ILBs represented an enormous advance over candles.


**Topic 7: Nuclear energy - Fusion**

If fusion on Earth is successful it is likely to be done by combining heavier hydrogen nuclei ($^2$H$_1$ (or D) and $^3$H$_1$ (T)) in a one step process at very high temperatures (over 100 million degree C) to form helium, with the release 17.6MeV energy; the energy released per atom or molecule is enormously higher than for chemical reactions (e.g. it is nearly 10 million x greater than the heat released from combustion natural gas (CH$_4$) (about 9eV per molecule)). The single step fusion process planned on Earth is intended to be much more efficient than the very slow and inefficient multi-step process used to power the Sun. Fusion in the Sun is extremely inefficient and that is a very good thing (and we will discuss why?). For on Earth fusion the most likely fusion reactor will be a Tokamak whose design and operation will be explained, including coverage of the on-going ITER project. Perhaps not surprisingly, there are a number of challenges to overcome to implement this potentially clean and plentiful source of energy, and many of these will be discussed.


**Topic 8: Carbon capture and sequestration – from degrees of carbon neutrality to negative emission technologies (NETs)**

They are a number of different proposed methods for carbon capture and sequestration (CCS) and traditionally CCS is often discussed in terms of whether the separation of CO$_2$ is pre and post combustion of fossil fuels (or biomass for negative emissions; see below), and CO$_2$ is then compressed and stored. Example of interest to be discussed include the Allam cycle [a closed Brayton cycle which uses CO$_2$ as
the working fluid, which carbon capture much easier]. Relatedly, the carbon dioxide might extracted from
the atmosphere and fixed in a variety of way without necessarily considering combustion. Discussion will
include the use of trees (afforestation/reforestation), direct air scrubbers (DACCS) or other methods with
negative emission technologies (NET) (e.g., enhanced mineralization, the use of biochar, including some
that broach on geoengineering (e.g. ocean alkalization).
EASAC Policy report, Negative emission technologies. What role in meeting Paris Agreement targets? 2018,

**Topic 9: Ocean and waves**

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 might be used to capture
energy and generate mechanical and then electrical power, where the idea of natural frequency,
forced oscillations and damping are important. These include conversion of energy in ocean waves
e.g. via point absorbers, oscillating water column (OWC), attenuators, and tidal based device (where
tides are waves with very long wavelengths and long periods (slightly more 12 hours)).

, 6.2 Power output for hydroelectric power, 6.17 Wave energy, 6.18 Wave power devices, 6.19-21
Environmental, economics and outlook.
King, George, *Vibrations and Waves* Chapter 1: Simple Harmonic Motion (pp1-12), Chapter 5:
Traveling Waves (page105-112 and 116-120), Wiley (2009).
De O. Falcio, Antoio, “Wave Energy Utilization: A Review of the Technologies”, *Renewable and

**Topic 10: Nuclear energy – Fission**

Nuclear energy has never achieved its original vision of being “too cheap to meter” [though interestingly
PV is moving somewhat in that direction] and has in fact suffered historically from being expensive, often
due to cost overrun when being built. Nevertheless, research and development is promising for this
carbon free resource in a number of areas – with the caveat unless simply displaced by rapidly improving
economics of PV. Will briefly review how a pressurized light water reactor works, before expanding to
emerging developments, such as the potential use of small modular reactors, using different Gen IV
technologies, including the use of molten salt thorium reactors.

Modern reactors, 9.10 Nuclear waste disposal
Hargraves, Robert, and Ralph Moir. "Liquid Fluoride Thorium Reactors: An old idea in nuclear power gets

**University Policies**

University policies are described in the JHU-AAP [academic catalog](http://advanced.jhu.edu/current-students/policies/) and are detailed on the AAP website [http://advanced.jhu.edu/current-students/policies/](http://advanced.jhu.edu/current-students/policies/)

**General**

This course adheres to all University policies described in the academic catalog. Please pay close
attention to the following policies:

**Students with Disabilities**

Johns Hopkins University is committed to providing reasonable and appropriate accommodations to
students with disabilities. Students with documented disabilities should contact the coordinator listed
on the [Disability Accommodations](http://advanced.jhu.edu/current-students/policies/) page. Further information and a link to the Student Request for Accommodation form can also be found on the [Disability Accommodations](http://advanced.jhu.edu/current-students/policies/) page.
Ethics & Plagiarism

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 Notice on Plagiarism.

Dropping the Course

You are responsible for understanding the university’s policies and procedures regarding withdrawing from courses found in the current catalog. You should be aware of the current deadlines according to the Academic Calendar.

Getting Help

You have a variety of methods to get help on Blackboard. Please consult the resource listed in the "Blackboard Help" link for important information. If you encounter technical difficulty in completing or submitting any online assessment, please immediately contact the designated help desk listed on the AAP online support page. Also, contact your instructor at the email address listed in the syllabus.

Copyright Policy

All course material are the property of JHU and are to be used for the student's individual academic purpose only. Any dissemination, copying, reproducing, modification, displaying, or transmitting of any course material content for any other purpose is prohibited, will be considered misconduct under the JHU Copyright Compliance Policy, and may be cause for disciplinary action. In addition, encouraging academic dishonesty or cheating by distributing information about course materials or assignments which would give an unfair advantage to others may violate AAP’s Code of Conduct and the University’s Student Conduct Code. Specifically, recordings, course materials, and lecture notes may not be exchanged or distributed for commercial purposes, for compensation, or for any purpose other than use by students enrolled in the class. Other distributions of such materials by students may be deemed to violate the above University policies and be subject to disciplinary action.

Code of Conduct

To better support all students, the Johns Hopkins University non-academic Student Conduct Code has been integrated and updated to include all divisions of the University. In addition, it is important to note that all AAP students are still accountable for the Code of Conduct for Advanced Academic Programs.

Title IX

Confidentiality and Mandatory Reporting

As an instructor, one of my responsibilities is to help create a safe and inclusive learning environment on our campus. I also have mandatory reporting responsibilities related to my role as a Responsible Employee under the Sexual Misconduct Policy & Procedures (which prohibits sexual harassment,
sexual assault, relationship violence and stalking), as well as the General Anti-Harassment Policy (which prohibits all types of protected status based discrimination and harassment). It is my goal that you feel able to share information related to your life experiences in classroom discussions, in your written work, and in our one-on-one meetings. I will seek to keep information you share private to the greatest extent possible. However, I am required to share information that I learn of regarding sexual misconduct, as well as protected status based harassment and discrimination, with the Office of Institutional Equity (OIE). For a list of individuals/offices who can speak with you confidentially, please see Appendix B of the JHU Sexual Misconduct Policies and Laws.

For more information on both policies mentioned above, please see: JHU Relevant Policies, Codes, Statements and Principles. Please also note that certain faculty and other University community members also have a duty as a designated Campus Safety Authority under the Clery Act to notify campus security of certain crimes, as well as a duty under State law and University policy to report suspected child abuse and/or neglect.