Note: Small changes may be made to this syllabus before the start of course, and thereafter some of the reading in this syllabus may be updated during the course – in which case an updated syllabus will be made available.

Course Description: The course examines energy supply and consumption, and how these activities impact the environment, with a focus on understanding the potential technology, market structure and policy implications for climate change. Particular emphasis is devoted to the electricity and transportation sectors, which combined represent over two-thirds of U.S. energy supply and use. Students will gain a solid understanding of the science, technology, economics, and environmental impact associated with various electricity generation technologies, including renewable energy, such as wind and solar (both PV and Concentrated Solar thermal), conventional thermal electricity generation (existing and future) - which include coal, natural gas and nuclear based technologies, and the role carbon storage and sequestration. In addition to supply side technologies we will also briefly consider some potential demand side opportunities, and this will include some discussion of energy efficiency and of the so called evolving “smart grid”. Electricity storage which in many ways stands at the nexus of supply and demand will also be considered. Transportation topics will address a variety of technologies, including hybrids and fuel cells, as well as the potential role for alternative fuels, including biofuels.

Climate change and the potential impact and mitigation of carbon dioxide will be considered throughout the course, recognizing that there is no single technology or policy “silver bullet” – but rather a portfolio of technologies approach will be needed, and that the international perspective is both critical and challenging. General discussion of energy markets and technologies will be data driven wherever possible, so that students gain a sound understanding of the magnitude of the various energy-related quantities involved and how they are interrelated. Information and data from a wide variety of public sources will be used throughout the course and students will gain from the course a better sense of where to find and how to use energy-related information.

1 These sources, which lead to a plethora of acronyms include, but are not limited to Energy Information Administration (EIA), Environmental Protection Agency (EPA), National Renewable Energy Laboratory (NREL), Resources for the Future (RFF), Federal Energy Regulatory Commission (FERC), World Resources
The role of risk and uncertainty will be highlighted throughout the course where appropriate. Broadly, there is tremendous uncertainty about how the future will unfold, including: if and when a policy will be implemented, what the impact of a policy will be, whether or not some new technologies will become feasible at all, and if so when and at what cost (both in terms of required investment and environmental impact).

It is should be evident from the significant breadth of this course that there will be a need to be selective in the depth of coverage, and this will be the case; a more detailed treatment of some topics covered in this course potentially lend themselves to entire courses e.g., transportation or energy efficiency. Lectures and discussion will focus on conveying the fundamental science and technology, economic, and environmental impact in a clear straightforward, but not simplistic manner. There is a significant benefit to providing the broader energy picture in this way because many of these topics and approaches are inherently interlinked. In summary, the course will provide the core underlying principles and ideas, as well as provide numerous citations and sources that will enable the student during the course, or later, to pursue areas of interest in greater depth.

**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 associated with both individual technologies and portfolios of technologies. The mathematics used will be kept at a straightforward level.

**Instructor:** Dr. Thomas Jenkin has been an Adjunct Instructor at Johns Hopkins for over 10 years, where he teaches courses on energy, and the science, engineering and economics of energy technologies on both a plant and system basis. He also works as a Short Term Consultant for the World Bank on a variety of energy related projects, a number of which focus around energy storage. He can be contacted by e-mail at Tjenki23@jhu.edu. He developed this course and first taught it in Spring 2010 (and subsequently in Fall 2010, Summer 2011, Spring and Fall 2012, Summer 2013 and Spring and Fall 2014, Summer 2015 and Spring 2017 and 2018).

**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) 90%
2. Class participation 10%

**Problem sets:** The problem sets are designed to be completed within a 2 to 3 weeks after they are given out or issued [via e-mail]. 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 of the 3 problem sets to be issued is the weekend before the 4th class, the 7th (or 8th) class and the 11th class (or shortly thereafter).

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.

Institute (WRI), Intergovernmental Panel on Climate Change (IPCC), Lawrence Berkeley National Laboratory (LBNL), International Energy Agency (IEA), the Department of Energy’s (DOE) Office of Energy Efficiency and Renewable Energy (EERE), and the American Wind Energy Association (AWEA).
Course Readings:

There is no required text for the parts of the course that deal with economic, environmental impact and policy in depth, and indeed parts of the technology and science. 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 aspects of the course, as well as some parts of the economic and environmental impact. This text is:


It is important to note that this text (“Energy Science (Andrews & Jelley (2017))”) will, at times go further than the course lectures into the science (both in terms of a slightly different coverage of technologies (broader than this course in some areas, narrower in others)), as well as going into more technical detail for some of the technologies we do cover, but will be a useful future resource. This course also assumes less scientific background than this book and so covers some of these topics more comprehensively, in a sense from the “ground up”, with an emphasis on providing the physical intuition behind how these technologies work. More generally, the science and technology aspects of the course are provided in detail with handouts.

This course we will go further into the economics, environmental impact, market and resource considerations than this text, though the emphasis of the course remains on better understanding how different energy technologies work.

One recent report issued by the US Department of Energy provides a lot of visual information that sets out how much renewable energy there is in the US and worldwide, by technology type, both currently - and showing changes over the last 10 years. It is a bit much to read or look at “all at once” – but you should find it very useful to get a better sense of the current “market” as we go through the course.


https://www.nrel.gov/docs/fy18osti/70231.pdf

Other readings will be distributed in class or by e-mail or assigned from the internet (See Reading List below). Please note that the syllabus will be updated from time to time to incorporate additional readings.

Field Trip (Optional)

When the course was last given in Spring 2018 a weekday afternoon field trip to a nearby municipal waste-to-electricity thermal power plant with a tour was arranged (from 3pm to 5pm). Many students were able to attend and found it both enjoyable and interesting. It is hoped to arrange a similar trip this Spring 2019 for students.

Earlier versions of this course suggested the use of the earlier edition of this book published in 2007.

Unfortunately the plant only receives visits during working hours.
Syllabus and Readings

General Comment

The classes will follow the syllabus below quite closely, with the following caveats. Depending on topic, the level of interest and discussion some topics may take slightly longer or shorter than suggested by the simple to 1 to 11 numbering. In particular wind and solar are both closer to about 1.5 to 2 classes each [where each class is assumed to be 2 hrs and 45 minutes with a few brief breaks], which is offset in part in the syllabus with some other topics occupying less than a class (e.g., which applies to both carbon capture and sequestration (CCS) and electricity storage). Conventional generation (indicated by 5&6), which includes coal, nuclear and natural gas generation, and includes discussions of real and idealized “heat engines” covers about 2.5 to 3 classes, with nuclear separated out as one class and dealt with towards the end of the course. We are unlikely to have time to cover the last topic on Energy Efficiency (11) in detail – but reading is provided [though ideas related to energy efficiency are discussed through the course]

1: Introduction and Energy Supply and Demand: United States and Worldwide

This part of the course provides an overview of the topics and major issues to be addressed in the course, as well as a discussion of course mechanics and a brief introduction to the related reading materials. The class will then review energy supply and consumption from both a U.S. and international perspective, with a view to framing some of the major environmental challenges, especially associated with controlling future carbon emissions, and the likely need for a portfolio of technologies approach to reduce emissions. The class will also introduce some of the fundamental scientific principles associated with energy, such as energy conservation, as well as how energy and power are converted between different units.

- EIA, Annual Energy Outlook 2018, Presentation February 2018
  https://www.eia.gov/outlooks/aeo/
- EIA, Annual Energy Outlook 2018, Presentation, John Conti, February 2018 (Much shorter than above)
- Energy Science (Andrews and Jelley (2017)). Chapter 1: An Introduction to Energy Science: Sections 1.1 to 1.6, 1.7 (Optional) Chapter 2 – Thermal Energy: Sections 2.1, 2.2, 2.3. Read 2.4 and 2.5 during Topic 2, 2.6 and 2.7 later during topics 5 and 6. Chapter 3, 3.1 to 3.5 during first 2 to 3 weeks.
- Chapter 12 – Energy and Society: Sections 12.1 - and read rest of Chapter through the course..

2: Introduction to the Electricity Sector in the United States

This class provides an overview of the electricity sector in the United States, with an emphasis on generation. It will cover both generation, and the transmission and distribution infrastructure, including

---

4 Initially it will be sufficient to skim through this paper, and read it more deeply as we go through the course.

5 The specific sections to be read from Chapters in Energy Science: Andrews and Jelley (2017) will be specified in class several weeks ahead of their use. The sections sometimes include more technical “derivation” boxes (in blue); these derivations are not required reading or part of the course, unless explicitly noted. Sections are usually quite short typically ranging from half a page to 2 pages in length.
the role of regulation and market competition. The class will cover how different types of generation capacity (baseload, intermediate, peaking) are dispatched to meet the daily hourly load profiles, and how this affects prices and environmental emissions. The economics of various generation technologies (on both a marginal and levelized cost basis) will be covered, including the impact of fuel prices and price volatility. Part of the latter half of the class will cover the attempt to deregulate the California electricity markets and why and how the market failed in 2000.


Energy Science (Andrews and Jelley (2017)). Chapter 2: Thermal Energy: Sections 2.4, 2.5, 2.6, 2.7* and 2.8. Chapter 3: Energy from Fossil Fuels: 3.1 to 3.5, 3.6, 3.7* [>3.7 later]. Chapter 10: Section 10.1, 10.2-10.3*, 10.4-10.8 power generation. Chapter 12, Sections 12.1, 12.2 on economics of power plants, and rest of Chapter throughout course.

3: Wind Power and Hydro

The majority of this class will cover wind power. Specifically, it will cover the science behind the technology (“how it works”), the economics and environmental impact of wind farms and also discuss some market structure, policy and resource considerations, including the use of economic incentives (such as production tax credits (PTCs)), technological improvements, installed capacity and how changing fossil fuel prices and other commodity costs are affecting the relative and absolute economics of this technology. The latter part of the class will cover hydroelectric power which has some interesting similarities and differences to wind.

Note: A similar approach – with varying degrees of detail and rigor, will be used for other technologies.


https://emp.lbl.gov/publications/2017-wind-technologies-market-report


Energy Science (Andrews and Jelley (2017)). Chapter 7- Wind Power: Sections 7.1 to 7.5, 7.6* and 7.9 to 7.17, and Chapter 6 - Hydropower, Wave Power and Tidal Power: Sections 6.1, 2.2, 6.4*6.5 to 6.11 for hydropower [Not covered in this course – Tides and Waves].

4: Solar Energy

6 This paper is quite long. Skim through it initially, though it is useful for understanding how the real challenges associated with deregulating power markets.
The majority of this class will cover solar energy and focus on the two main technologies – Photovoltaic (PV) cells and Concentrated Solar (Thermal) Power (CSP), including how PV is used as distributed or grid-independent resource. As for wind the class will cover the science (“how it works”), economics and environmental impact of solar technologies and also discuss some market structure, policy and resource considerations. PV discussion will range from single cell silicon PV to the use of multi-junction cells that are (often) used in concentrated PV (which is not the same as CSP).


Energy Science (Andrews and Jelley (2017)). Chapter 5 – Solar Thermal: Sections 5.2, 5.2.2*, 5.3, 5.4-5.8, Chapter 8 – Photovoltaics 8.1 – 8.3, 8.6, 8.7. 8.9-8.12.

5 &6: Conventional Generation: Coal, Gas and Nuclear

This selection of topics, which is likely to be two to three classes will cover “conventional” generation, specifically coal, natural gas and nuclear powered technologies following a similar format to the earlier treatment of renewable energy technologies. Both current and anticipated future technologies will be covered. All these technologies work on the principle of a “heat engine” which places significant physical limits on achievable energy efficiency of conversion of heat to useful work (in this case mechanical energy - which is then very efficiently converted to electricity), and this will be explained. To do this we will cover some basic ideas in thermodynamics (energy conservation (1st law) and limits to energy conversion to useful work (as in generating electricity, say) (2nd law, including the concept and use of entropy). Idealized (Carnot) and real heat-to-useful work “engines”, including (i) thermal steam turbines (using two phase Rankine Cycle) (used in coal thermal plants and nuclear power plants) and (ii) natural gas powered combustion turbines (CTs) (using a (single phase vapor) Brayton cycle), as well as combined cycle gas turbine (CCGTs). An entire class will be used to discuss nuclear fission and how nuclear power reactors work, with a focus on most common pressurized (light) water reactors (PWRs).

It is critical to understand the potential role of these technologies since they represent the vast majority of the existing sources of power, and are likely to play a prominent role going forward, though the exact role will be dependent of policies, technological improvements and natural resources – which vary significantly by State in US and more generally worldwide. The environmental impact of these technologies and technological barriers to future investment vary markedly and these issues will be discussed.

These technologies often have significant advantages (e.g. nuclear from a carbon mitigation perspective) and challenges (e.g. coal, and to a lesser extent gas from a carbon perspective and nuclear from treatment of waste and potential nuclear proliferation concerns). These issues will be discussed explicitly.

Technologies used in the US to reduce “acid rain” resulting from SO2 and NOx emissions, primarily from coal generation will also be discussed briefly.


7: Carbon Capture and Sequestration (CCS)

An important consideration of whether coal technology becomes an environmentally attractive option is whether the carbon dioxide emissions can be separated and then stored (or sequestered) in a cost effective manner. This class will cover carbon capture and sequestration, and will include discussion of technological, economics, environmental and policy challenges, and well as how the role of uncertainty factors into investment decisions; to a considerable extent the economic feasibility of CCS is likely to depend on how future carbon dioxide emissions are priced.


Energy Science (Andrews and Jelley (2017)). Chapter 3: Energy from Fossil Fuels; Sections 3.7

8: Electricity Storage & Integration Issues & Geothermal

This class first will cover the potential role electricity storage. There are a variety of potential electricity storage technologies, including pumped hydro, compressed air energy storage (CAES), batteries and capacitors that can provide an array of grid and generation applications, that in principle could lead to a more operationally efficient grid, including deferring the need for new transmission and distribution build, and facilitating the integration of large amounts of wind. There are a number of barriers to the large scale implementation of storage, however, including cost and market structure considerations. The environmental benefits of storage are less clear cut, and somewhat application and location specific, and this will be discussed.

A second topic covered will be geothermal energy. This is really quite a separate topic from storage covered above – though it does use energy stored in the Earth’s crust.


Energy Science (Andrews and Jelley (2017)). Chapter 11 – Electricity and Energy Storage: Sections 10.9 to 10.13, 10.15, 10.15.1, 10.15.2*, 10.15.3, 10.15.5 on storage technologies. [Fuel cells optional – here, but move to transportation as optional].

9: Biomass Energy and Introduction to Transportation
This class will cover Biomass and Biofuels; what they are, their sources, and how they can be used for heat, power generation and transportation. The class will include discussion of whether biofuels can be considered largely carbon neutral, the relative effectiveness of different biomass sources (sugar cane vs. corn vs. cellulosic), including the social and policy implications of subsidies and competing uses for land (e.g. food vs. fuel), and their potential value in reducing dependence on oil.


Energy Science (Andrews and Jelley (2017)). Chapter 4 - Biomass. The entire chapter is worth reading.


**10: Transportation**

The transportation sector is a major user of crude oil, and in the United States there is significant desire to reduce dependence on oil for transportation for both environmental and security reasons. Reduced oil dependence and lower carbon emissions may come about from an array of potential alternative vehicle technologies and fuels, including the use of ethanol, (fuel-battery) hybrids (including plug-ins) and fuel cells, some of which have major infrastructure and policy implications. The various technology options will be discussed.

Energy Science (Andrews and Jelley (2017)). Chapter 11 (11.3)

**11: Energy Efficiency – Demand Side Considerations, including the Smart Grid**

Energy efficiency improvements represent an important way to significantly reduce the use fossil fuels in a cost-effective manner. From a generation and transportation perspective this has largely been covered in earlier classes. This class will focus on energy efficiency from a demand side perspective (e.g. buildings and industry and demand-side management in the power sector). The penetration of some existing demand-side technologies is remarkably low given their currently realizable economic benefits and some of the reasons for this, and potential policy solutions will be discussed.


Energy Science (Andrews and Jelley (2017)). Chapter 11 (11.1 and 11.2)

---

7 There is quite a highly charged debate going on over the benefits and costs of biomass from a carbon neutrality perspective. This paper covers one side of the argument. Other papers will be added to this syllabus to facilitate a class discussion on the topic. It should not be assumed necessarily that the instructor endorses everything written in this paper, or for that matter other reading material.
Note: All the Energy Efficiency readings are “optional” in the sense that it is expected we will not have time to cover this last topic detail, and so the reading is provided. Energy efficiency will, however, be discussed through the course.

**University Policies**

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

**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](http://advanced.jhu.edu/current-students/policies/).

**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](http://advanced.jhu.edu/current-students/policies/). 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](http://advanced.jhu.edu/current-students/policies/), 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](http://advanced.jhu.edu/current-students/policies/) and the University’s [Student Conduct Code](http://advanced.jhu.edu/current-students/policies/). 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.