SUMA5155 – Energy Markets & Innovation

COURSE SYLLABUS

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A. COURSE OVERVIEW

Existing energy sources and the infrastructures that deliver them to users around the world are undergoing a period of rapid change. Limits to growth, rapidly fluctuating raw material prices, and the emergence of new technology options all contribute to heightened risk and opportunity in the energy sector. The purpose of this course is to establish a core energy skill set for energy students and prepare them for more advanced energy courses by providing a basic language and toolset for understanding energy issues.

Using theoretical and practical understanding of the process by which energy technologies are developed, financed, and deployed, this course seeks to highlight the root drivers for change in the energy industry, the technologies that are emerging, and the factors that will determine success in their commercialization. Understanding these market dynamics also informs good policy design and implementation to meet a broad range of social welfare goals.

Upon completing the course, students should not only understand the nature of conventional and emerging energy generation and delivery, but also the tools for determining potential winners and losers and the innovative pathways to drive their further deployment.

B. COURSE PROCEDURES

This course is designed to be inter-disciplinary, integrating skills from finance, marketing, technology, regulation and policy, and entrepreneurship. However, no prior knowledge is required to excel in this course. It is intended to establish a foundation of knowledge and framework for further study.

Methodologically, there are some basic skills for measuring, costing, and valuing energy and electricity that must be understood, which are particular to the energy industry. Therefore, non-trivial mathematical and spreadsheet work will be required to show the necessary competence in these skills. Students should be reasonably comfortable with spreadsheet modeling for computation and financial projection before beginning the course, or choose a good partner for completing problem sets.

The hardest part of any work in emerging technologies (particularly in the fast-changing energy sector) is to integrate vast amounts of information into useful and actionable information. It is vital to cut through the haze of data and uncertainty to identify key drivers for success and then present the qualitative and quantitative information necessary to determine the likelihood of and best pathway to success for a given solution. Such analysis will be messy and complex and will likely necessitate substantial supplemental research, but in the end will derive great practical benefit in the skills of analysis and presentation that will be useful in nearly every future career.
C. COURSE MATERIAL

REQUIRED
1) The Energy System, Travis Bradford, MIT Press, 2018
   (order online soon from Amazon, hardcopy or Kindle version, I recommend Kindle)
2) Thinking in Systems, Donella Meadows, Chelsea Green, 2008
   (order online, fastest may be Amazon Kindle, or PC e-book app.)
3) Supplemental readings and videos from the syllabus below and occasional articles posted for students

RECOMMENDED

D. GRADING

Grading will be based on class participation, five problem sets, and a final exam. Students cannot take this course pass/fail.

1. Class participation (30%)
   Class participation will count for 30% of the final grade. A number of factors will contribute to your class participation grade:
   a. Contributions in class: Thoughtful comments and focused questions that contribute to the learning environment are encouraged (quality, not quantity, is the key factor here).
   b. Attendance: students are expected to attend all classes and recitations
   c. Contributions outside class: Providing links to articles, publications, videos, and data that support the classroom discussion (these can either be used this semester or may be used to support future classes), actively creating a collaborative and collegial work environment inside and outside the class, suggesting edits or additional articles and papers to support the continued development for the class.

2. Five (5) Problem Sets (40%)
   Five problem sets will be done in groups of up to 4 people and will account for 40% of the final grade. These problem sets will reinforce concepts of measurement and metrics of energy, including generation and capacities, energy conversions, and calculation methodologies of cost and value of energy, electricity, and carbon. The calculations will be supplemented with qualitative assessments of the results.

   Problem sets will be submitted online via CourseWorks. The deadline for each problem set is at 4:00 PM before the lecture the week they are due. Late problem sets will have grades deducted.

3. Final Exam (30%)
   The final will count for 30% of the final grade. It will both qualitatively and quantitatively test the fundamental concepts of class, the readings, lectures, and learnings from the problem sets. A list of the learning objectives is provided below, but should not be considered exhaustive for the purposes of the exam. Final Exams will only be given during the normal exam period.
E. GRADING POLICY

Late Problem Set assignments will be docked one letter grade for each day they are turned in late, and will not be accepted after that week’s recitation. Any requests for grade review will require extraordinary circumstances and will subject all other work to simultaneous review, which could result in either upward or downward revision. Problem Sets are to be done in groups of up to 4 people (and not shared beyond that).

**Academic Integrity Statement:**

I do not tolerate cheating and/or plagiarism in any form. Those students who violate the Code of Academic & Professional Conduct will be subject to the Dean’s Disciplinary Procedures.

http://new.sipa.columbia.edu/code-of-academic-and-professional-conduct

Please familiarize yourself with the proper methods of citation and attribution. The School provides some useful resources online; we strongly encourage you to familiarize yourself with these various styles before conducting your research. **Shared work beyond problem set groups will be considered plagiarism, and treated accordingly** – (mathematically, one single zero on a problem set in such a competitive class would work out to a substantial final grade impact).

G. BLOGS AND NEWS SITES TO FOLLOW

I cannot emphasize this strongly enough! You should begin the habit of reading relevant sector news every day. (EVERY DAY!) To keep up-to-date on current affairs in the E&E world, we recommend regularly reviewing the following websites and blogs, but would also love to learn of other resources you use that might be useful for others.

**Conventional Energy**


**Emerging Energy**

- Renewable Energy News  [https://www.renewableenergyworld.com/#gref](https://www.renewableenergyworld.com/#gref)
- Prometheus Institute  [http://prometheus.org/](http://prometheus.org/)
- Next Billion  [http://nextbillion.net/](http://nextbillion.net/)
THE 10 LEARNING OBJECTIVES

10 things you should learn from this course (and will be tested on):

The list below sets out the objectives for the course and provides the basis for questions for the final exam. You should note, however, that I will not treat these topics in the sequence and structure in which they are presented here. Rather, I expect you to use this list as a roadmap to navigate the class. It is your own responsibility to map the contents of the class to these ten objectives and ensure that, by the end of the class, you are capable of answering questions related to these objectives using tools acquired in the course. In the end, meeting these objectives is also the list I hope you will use to evaluate the course.

1. Become fluent in Energy System concepts and terminology – technologies; current and emerging sources of energy; four dimensions of energy transformation; final energy services, and industry terminology and definitions
2. Understand the energy as a system – stocks, flows, and feedback; sustaining vs. reinforcing loops; supply chains; five forms of capital; system dynamics; system resilience and buffers; sustainable development
3. Describe the physical conversion of energy through the system – laws of thermodynamics; power to energy conversion; losses; heat rates; temporal shifting; transmission and transportation; efficiency; storage; and emission calculations
4. Link the energy system to micro-economic principles – Supply and Demand; supply curve construction; market and market function; price formation; producer and consumer surplus; profit (rent) maximization; average vs. marginal costs; short-term vs. long-term
5. Develop a complete framework of costing methods for both Energy and Power – Levelized Cost of Electricity; fungible LCOE comparisons; capital costs; Total Cost of Ownership (TCO); production cost; when costs are not independent; cycle cost; Cost per mile (CPM); Break-even Price (BEP); abatement cost
6. Determine sources of value in energy systems – energy services; load; revenue; behavioral limitations; total addressable market; integrated streams of values for power and energy; fractured petroleum economics; indexing; energy/GDP linkages; energy poverty
7. Develop and intelligently use scenarios and forecasts of the future energy system – bottom up vs. top down methods; system peaks; margins and buffers; experience curves and learning; feedstock linkages; constraints, limits, and bottlenecks; asset lock-in; co-dependence; the tension between innovation versus depletion
8. Recognize and describe the role of competition in energy markets – sustaining versus disruptive loops; evolutionary changes vs. disruptive changes; market design; fungible comparisons; parity and disruption; product differentiation; switching
9. Understand the role and methods of investment in the energy system – compounding, financial analysis; project finance; project risk categories; debt vs. equity; venture capital; R&D; futures trading and speculation; retrofit and repowering; micro-finance
10. Know and apply tools used for analyzing energy market failures and solutions – myopia; externalities; informational asymmetries; natural monopolies; cartels; collective security; system collapse; policy interventions; market interventions
COURSE OUTLINE BY WEEK – with assignments

COURSE READINGS AND ASSIGNMENTS

- **Topic 1-2 (General Principles)** has a fairly large amount of industry and background reading – the course texts, “The Energy System” and “Thinking in Systems”, are introduced along with some more academic papers about obstacles to change, policy design and impacts, tragedy of the commons, externalities, etc. You should flip through and understand the data sources within the World Energy Assessment, BP Energy Assessment, IEO, IPCC Reports, etc.

- **Topic 3-7 (Electricity Systems)** begins as an understanding of the existing electricity market and uses that market to demonstrate how physical transformations are made and then valued in one of the largest formal markets in the world. Understanding the pressures facing this market allow for examination of various solutions including efficiency and demand response. It also assesses all of the utility- and distributed-scale generation options available today using a framework for determining competitiveness, including fungibility and values. A number of practical, economic, and forecasting competences will be developed throughout this section, including LCOE methodology, price determination, disruption, and the role of storage.

- **Topic 8-10 (Transportation Systems)** begins by looking at the use of transportation services and constraints imposed by access to petroleum resources. It then looks at where and how capital can be deployed profitably to change this infrastructure, supplement fuels, or switch to other combustion options, and the limiting forces to those innovations. Finally, examining how transportation re-integrates with electricity architecture gives us an opportunity to examine the nature of paired technologies.

- **Topic 11-13 (Other Energy Systems)** will integrate a wide range of situations and technology options into an examination of comprehensive systems. The role of natural gas in the thermal system, energy impacts on the economic system, carbon pricing, and new methods of delivering vital energy to the world's poorest combine to help us spot emerging business opportunities now and in the future.

- *Links are Hot – You should be able to click through.*
## Course Outline (Topic, Title, Assignments, Topics and Recitations)

<table>
<thead>
<tr>
<th>Topic</th>
<th>Date</th>
<th>Title</th>
<th>Due</th>
<th>Topics Covered</th>
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</thead>
<tbody>
<tr>
<td>General Principles (2 weeks)</td>
<td>Jan 17</td>
<td>1 Introduction to Energy Terms and Conversions</td>
<td></td>
<td>Laws of Thermodynamics, Energy vs. Power, Conversions, Stocks and Flows, Cost vs. Value vs. Price, Fungibility, Constraints, Normative vs. Positive</td>
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<tr>
<td>Electricity Systems (5 weeks)</td>
<td>Jan 31</td>
<td>3 Understanding Organized Electricity Markets - The Grid</td>
<td></td>
<td>Generation, Transmission, Distribution, Cost of Service Recovery, Deregulation, Load types, Dispatchability, Interconnection</td>
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<td></td>
<td>Feb 7</td>
<td>4 Generation Supply, Demand, and Price Determination - Fossil Fuel Generation</td>
<td>PS #1 –</td>
<td>Bus Bar Costs, LCOE, Price of Electricity, Multiple Value Streams of Electricity</td>
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<td></td>
<td>Feb 14</td>
<td>5 Project Finance and Development - Renewable Generation</td>
<td></td>
<td>Project Finance, Cost of Capital (WACC), IRR, Risk, Fungibility of Generation Alternatives</td>
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<tr>
<td></td>
<td>Feb 21</td>
<td>6 Demand Side Solutions - Energy Efficiency, Demand Response, and Storage</td>
<td>PS #2 –</td>
<td>Devices, Load, Energy Efficiency, Economic Demand Response Measures, Ancillary Services, Storage Alternatives, Smart Grid</td>
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<td>Feb 28</td>
<td>7 Experience Curves, Disruptions, and Solar Energy - Distributed Generation</td>
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<td>Experience Curves, Learning, Technology, Disruptive Technologies, Net Metering, Distributed Generation, Utility Transformation</td>
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<td>Mar 7</td>
<td>8 Wrapping up the Electricity System and Mid-term Review</td>
<td>PS #3 –</td>
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<td>Transportation Systems (3 weeks)</td>
<td>Mar 21</td>
<td>8 Oil and Transportation Markets - Transportation Systems - Petroleum</td>
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<td>Transportation Services, Passenger vs. Cargo, CAFE Standards, Unintended Consequences, Resource and Reserves, Quality, Peak Oil, Fracking, Delivery Systems, Energy Security</td>
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<td></td>
<td>Mar 28</td>
<td>9 Oil and Transportation Markets – Continued</td>
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<td>Apr 4</td>
<td>10 Alternate Fuel Sources - Biofuels - Natural Gas Vehicles</td>
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<td>Feedstocks, Food vs. Fuel, Biofuels, RFS, Flex-Fuel Vehicles, Asset Lock-in and Co-Dependence, Cellulosic, Algae, Drop-in Fuels</td>
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<td>Apr 11</td>
<td>11 Electricity in Transportation - Electric Vehicles</td>
<td>PS #4 –</td>
<td>EV, PHEV, FCE, Charging Networks, Grid Reliability, Stand-by Power, V2G, Spinning Reserves, Total vs. Addressable Market</td>
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<tr>
<td>Other Energy Systems (2 weeks)</td>
<td>Apr 18</td>
<td>12 Thermal Systems and Natural Gas - Natural Gas</td>
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<td>Thermal Energy, Natural Gas, Pipelines, Fracking &amp; Shale Gas, Liquefaction</td>
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<tr>
<td>Final Exam</td>
<td>May 9</td>
<td>FINAL EXAM (online)</td>
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## General Principles (2 Weeks)

### 1. **INTRODUCTION TO ENERGY TERMS AND CONVERSIONS**

**Topics Covered:**

**Readings:**
- *The Energy System* Preface & Chapter 1

### 2. **ENERGY AS AN ECONOMIC SYSTEM AND DEALING WITH MARKET FAILURES**

**Topics Covered:**

**Reading:**
- *Thinking in Systems* [Through the end of Section 1]
- *The Energy System* Chapter 2 & 3
- REN21, “Renewables 2022 Global Status Report” [Executive Summary, Chapter 1 & 2 only]

**[Scan] Data Sources:**
- “BP Statistical Review of World Energy” BP, 2022
- “IEA Key World Energy Statistics 2021”, International Energy Agency,
- “Monthly Energy Review” DOE Energy Information Agency (EIA), August 2020

**[Optional] Reference:**
### 3. UNDERSTANDING ORGANIZED ELECTRICITY MARKETS

**Topics Covered:**
- Generation, Transmission, Distribution, Cost of Service Recovery, Deregulation, Load types, Dispatchability, Interconnection

**Readings:**
- *The Energy System* Chapter 4

### 4. GENERATION SUPPLY, DEMAND, AND PRICE

**Topics Covered:**
- Bus Bar Costs, LCOE, Price of Electricity, Multiple Value Streams of Electricity, Risk

**Readings:**
- *Thinking in Systems* [Section 2]
- *The Energy System* Chapter 5 & 6, (Particular focus on Appendix 5)

### 5. PROJECT FINANCE AND DEVELOPMENT

**Topics Covered:**
- Project Finance, Cost of Capital (WACC), IRR, Fungibility of Generation Alternatives

**Readings:**
- *The Energy System Chapters 7 & 8*
- Lazard LCOE – Version 13

### 6. DEMAND SIDE SOLUTIONS

**Topics Covered:**
- Devices, Load, Energy Efficiency, Economic Demand Response Measures, Ancillary Services, storage alternatives, Smart Grid

**Readings:**
- *The Energy System* Chapters 9 & 10

### 7. EXPERIENCE CURVES, DISRUPTIONS, AND SOLAR ENERGY

**Topics Covered:**
- Experience Curves, Learning, Technology, Disruptive Technologies, Net metering, Distributed Generation, Utility Transformation

**Readings:**
- *The Energy System* Chapters 11 & 12
- [OPTIONAL] - Solar Revolution, Chapters 1, 6, 7, and 10
## Transportation Systems (4 Weeks)

8. **OIL AND TRANSPORTATION MARKETS**

9. **OIL AND TRANSPORTATION MARKETS (CONTINUED)**

   Topics Covered:
   - Transportation Services, Passenger vs. Cargo, CAFE Standards, Unintended consequences, Resource and Reserves, Quality, Peak Oil, Fracking, Delivery Systems, Energy Security

   Readings:
   - The Energy System *Chapters 13 & 14*

10. **ALTERNATE FUEL SOURCES**

    Topics Covered:
    - Feedstocks, Food vs. Fuel, Biofuels, RFS, Flex-Fuel Vehicles, Asset Lock-in and Co-Dependency, Cellulosic, Algae, Drop-in Fuels

    Readings:
    - The Energy System *Chapter 15*

11. **ELECTRICITY IN TRANSPORTATION**

    Topics Covered:
    - EV, PHEV, FCE, Charging Networks, Grid Reliability, Stand-by Power, V2G, Spinning Reserves, Total vs. Addressable Market

    Readings:
    - The Energy System *Chapter 16, Review Chapter 10 (Storage)*

## Other Energy Systems (2 Weeks)

12. **THERMAL SYSTEMS AND NATURAL GAS**

    Topics Covered:
    - Thermal Energy, Natural Gas, Pipelines, Fracking & Shale Gas, Liquefaction

    Readings:
    - The Energy System *Chapters 17 & 18*

13. **ENERGY AND THE GLOBAL ECONOMY**

    Topics Covered:

    Readings:
    - The Energy System *Chapter 19*

### ENERGY AND THE ENVIRONMENT

Topics Covered:
- Climate Change, UNFCCC, ETS Trading System, Carbon Accounting, Sustainable Development

Readings:
- The Energy System *Chapters 20 and postscript*
- *Thinking in Systems* [Section 3]
- *IPCC 6th Assessment Synthesis Report for Policy Makers*