B8224: Energy and Resource Economics

COURSE SYLLABUS

Professor: Travis Bradford  
Office Hours: TBD  
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TA: Natasha Bray  
Office Hours: TBD  
By e-mail appointment  
Email: nbray14@gsb.columbia.edu

Course Details: Spring 2014 - Tuesday and Thursday, 2:15-3:45pm, Room Uris 331

A. COURSE OVERVIEW

Energy and Natural Resources including water, food, and materials form the most basic and vital inputs to our economy, without easy access to which the level of global income we currently enjoy would be impossible. Energy, industry’s prime mover, and its related delivery architectures are vital to producing the wealth and welfare of modern society, and unequal access to and productivity with it goes a long way in explaining the observed heterogeneous levels of wealth and industrial output around the world; but the energy industry does not function in isolation and is supplied by and constrained by other natural resource inputs that shape the landscape and strategies of opportunities within it.

Economics is the study of scarcity, and understanding how individuals and businesses optimize in the face of limits informs everything in business from budgeting to investment to forecasting. 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 and natural resource industries, the technologies that are emerging, and the factors that will determine success in their commercialization.

The purpose of this course is to orient students to the dynamic opportunities that exist in the ongoing transformation of the global energy and natural resource industries. It does so by integrating two simultaneous threads of discussion. One thread looks primarily from the point of view of the energy industry, its supply chains, inputs, conversions, outputs, and feedbacks as well as the role water, agriculture, and materials play in making this system work. The second thread is the development of a set of economic and market analysis tools that will allow a rigorous analytic understanding of what is going on in these markets, how buyers and sellers think about market interaction, and the trajectories and occasional dislocations that occur.
The course begins with a couple of weeks of tools, calculations, and background material. It then sequentially examines various sectors of the energy industry, developing these tools, and using them to understand the relationships with various other resource input industries.

Outline of course and concepts:

- General Principals – Systems Thinking and Economic Tools [2 Weeks]
- Energy Sector Economics – Electricity [4 Weeks]
  - Energy-Water Nexus
- Energy Sector Economics – Transportation [2 Weeks]
  - Energy-Agriculture Nexus
- Energy Sector Economics – Storage [1 Week]
  - Energy-Materials Nexus
- Other Opportunities in Energy [3 Weeks]
  - Natural Gas and Fracking

Upon completing the course, students will have a tool chest of applied economic and competitive strategy tools for use in a wide range of future analytic exercises in the energy industry.

B. COURSE PROCEDURES

Course Concepts: This course assumes familiarity with topics in micro-economics, corporate finance, and some background in energy topics, including preferably having taken Geoff Heal’s course B8299-017: New Developments in Energy Markets. If you haven’t, it is possible to keep up, but the workload will be higher to gain needed context.

This course is designed to be cross-disciplinary, integrating skills from finance, economics, marketing, technology, regulation and policy, and entrepreneurship. As such, not everyone will be an expert in each of the tools or skills necessary for success, and lively discussion about each of the concepts and industries will help to fill out how these ideas are practically integrated.

Methodologically, there are some basic skills for measuring, costing, and valuing energy and electricity that must be understood to form the foundation of work in 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.

However, 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 in business 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 company or technology. 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 all future careers.

Energy and Natural Resource Economics
C. COURSE MATERIAL

REQUIRED
  o  *Thinking in Systems*, Donella Meadows, Chelsea Green, 2008
     (Available via online order, fastest may be Amazon Kindle or PC e-book app.)
  o  *Readings from the syllabus below and posted for students on Canvas*
  o  *Case Pack – will be provided*

OPTIONAL

D. GRADING

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

1. CLASS PARTICIPATION (30%)

   Class participation will count for 30% of the final grade. Thoughtful comments and focused questions that contribute to the learning environment are encouraged. Reading the material required before class will be necessary to make meaningful contributions. Grades will be based on attendance and quality (not quantity) of contributions. Other methods of class participation are available, including:
   ✓ 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 collaborating and collegial work environment inside and outside the class.
   ✓ Being in class, answering quizzes correctly using *Clickers (you must bring your Clicker to every class).*

2. FOUR SHORT (4) ASSIGNMENTS (40%)

   Four short assignments will be done in *groups of 2-3 people* and will account for 40% of the final grade. These assignments will examine deeper concepts from the readings and/or reinforce tools of measurement and metrics of energy, including generation and capacities, energy conversions, and calculation methodologies of cost and value of energy and electricity.

3. FINAL TOPIC PAPER (30%)

   The final will count for 30% of the final grade. The paper will be in *groups of 2-3 people* a written, 15-20 page executive memo on the analytic answer to a timely topical question. By the third week of class, I will publish some suggested questions, or you can choose one of your own, but should get approval before proceeding with your own. The purpose of the memo is to demonstrate original thinking on an issue using the analytic tools of the class.
E. GRADING POLICY
Late assignments will be docked one half of a letter grade for each day they are turned in late. 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. Final Projects will not be accepted late.

G. HOW TO GET HELP
Canvas Discussion Board – Problem Sets - In CourseWorks there will be a moderated discussion forum to address challenges each week. The TA’s will answer questions here as well. Important: All discussion board questions must be posted by each Tuesday night at midnight to guarantee they will be answered.

TA Office hours – Other Class Concept Support - TA office hours will be held BY REQUEST.

Help from Others – Carefully!!! - Students are also encouraged to address each other’s questions and participate in the discussion forum. However, as noted above, sharing final answers outside your group to problems is not allowed.

Office Hours – Professor Bradford – Strategic Course or Professional Advice – You sign up for slots in Prof. Bradford’s office hours using the CourseWork’s Sign-up function. You should use this time to talk about strategic questions on the course or for your professional advancement. Prof. Bradford hopes that all of you will find time to stop by at least once this semester, and more if the slots are available.

G. REQUIRED PREREQUISITES AND CONNECTION TO THE CORE
The learning in this course will utilize, build on and extend concepts covered in the following core courses:

<table>
<thead>
<tr>
<th>Core Course</th>
<th>Connection with Core</th>
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<tbody>
<tr>
<td>Managerial Economics</td>
<td>1. Supply and Demand – practical construction</td>
</tr>
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<td></td>
<td>2. Pricing and Elasticity, Fungibility</td>
</tr>
<tr>
<td></td>
<td>3. Uncertainty and Optimization</td>
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<tr>
<td>Financial Accounting</td>
<td>1. Income Statement vs. Balance Sheets</td>
</tr>
<tr>
<td></td>
<td>2. Stocks vs. Flows</td>
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<tr>
<td>Corporate Finance</td>
<td>1. Investment under uncertainty</td>
</tr>
<tr>
<td></td>
<td>2. WACC, Discounting, Growth Rates</td>
</tr>
<tr>
<td></td>
<td>3. Projecting Costs, Revenues, and Risks</td>
</tr>
<tr>
<td>Strategy Formulation</td>
<td>1. Value Added and Willingness to Pay</td>
</tr>
<tr>
<td></td>
<td>2. Opportunity Cost and Shadow Price</td>
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<td></td>
<td>3. Market Power</td>
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<tr>
<td>Global Economic</td>
<td>1. Trade Flows, Dumping, Anti-trust</td>
</tr>
<tr>
<td>Environment</td>
<td>2. Impacts of Resource Dependency – Security and Disruption</td>
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<tr>
<td>Decision Models</td>
<td>1. Data visualizations</td>
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<td></td>
<td>2. Competitive Forecasting</td>
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</table>

Students will be expected to have mastered these concepts and be able to apply them in the course.

Syllabus Date: November 2, 2013

Energy and Natural Resource Economics
10 things you should practically understand at the end of this course:

The list below sets out the objectives for the course. 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. Understand the energy and resource system status quo: industrial architecture, supply chain, incumbent dominant technologies, uses and users, pricing mechanisms, regulation, etc.
2. Understand energy and resource industries conceptually as constrained systems - including scarcity, negative externalities, limitations & repercussions, sunk costs
3. Be able to define unique and fungible goods in the any industry and know how to derive practical supply and demand curves for a specific market
4. Be able to convert physical energy and power flows and use the various units of measurements across the whole energy industry
5. Be able to calculate Levelized Cost of Energy (LCOE) and forecast its constituent elements, as well as be able to make appropriate comparisons using LCOE
6. Water - Explain the relationships and dependencies between the Energy and Water Industries, including limits, pricing, and risks driven by this link
7. Food - Explain the relationships and dependencies between the Energy and Food Industries, including limits, pricing, and risks driven by this link
8. Materials - Explain the relationships and dependencies between the Energy and Materials Industries, including limits, pricing, and risks driven by this link
9. Know and be able to apply economic tools used for analyzing market failures - myopia, pollution, informational asymmetries
10. Describe how policy structure, policy changes, and the prospect of policy changes impact financial decisions in each of these sectors
<table>
<thead>
<tr>
<th>Week</th>
<th>Title</th>
<th>Due</th>
<th>Topics covered (tools in BOLD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>2/11</td>
<td>Electricity Supply and Demand - Contracting Price</td>
<td>Ass. #1 (2/13)</td>
<td>Grid Purpose, Generation, Transmission, Distribution, Deregulation, Supply Curves, Load, Wholesale Market Structure and Function, Dispatchability, Bus Bar Costs, LCOE, Multiple Value Streams of Electricity, Financing Electricity Projects</td>
</tr>
<tr>
<td>2/20</td>
<td>COGS, LCOE, and WACC Financing Electricity Projects</td>
<td>Final Project Pre-Approval (2/25)</td>
<td>Project Finance, IPPs, Regulated Utilities, Net Metering, Cost of Capital (WACC), IRR, Fully-loaded costs, Discounting, Risk-weighting, COGS</td>
</tr>
<tr>
<td>2/27</td>
<td>Experience Curves and Disruptions</td>
<td>Ass. #2 (3/4)</td>
<td>Experience Curves, Learning, Technology, Market Disruptions, Distributed Generation, PV, BoS and Soft Costs, Supply and Demand Reconciliation, Forecasting Competing Costs</td>
</tr>
<tr>
<td>3/6</td>
<td>Water and Electricity</td>
<td></td>
<td>Withdrawals, Consumption, Pricing Water, Purification, Desalination</td>
</tr>
<tr>
<td>3/25</td>
<td>Transportation and Oil - Petroleum</td>
<td></td>
<td>Resource measurements, Reserves, Quality, Delivery Systems, Passenger vs. Cargo, Modes of Freight, Inter-modal, Energy Security</td>
</tr>
<tr>
<td>4/1</td>
<td>Agriculture and The Fuel versus Food Debate</td>
<td></td>
<td>Unintended consequences, Biofuels, Cellulosic, Algae, Drop-in Fuels, Feedstock/ Fuel Linkages, Tortilla Revolution</td>
</tr>
<tr>
<td>4/8</td>
<td>Energy Storage and Stationary Applications</td>
<td>Ass. #3 (4/10)</td>
<td>Storage, Energy Density, Power Density, Chemistries, Fuel Cells, LCOS Commodities, the Supercycle, Rare Earths, Periodic Table</td>
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<tr>
<td>4/15</td>
<td>The Natural Gas Revolution - Natural Gas</td>
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<td>Natural Gas, Stranded Gas, Fracking &amp; Shale Gas, CNG, LNG, Liquefaction, Forecasting Prices</td>
</tr>
<tr>
<td>4/29</td>
<td>Forecasting the Future of Energy – The outcomes of complex systems</td>
<td>Final Project (5/1)</td>
<td>Scenario Analysis, Key Drivers, Forecasting</td>
</tr>
</tbody>
</table>

Energy and Natural Resource Economics
Lecture Readings, Assignments, and Questions

General Systems and Economic Principles (2 Weeks)

1. **What is Energy and why does it matter? Measurements and Metrics [Week 1]**

   **Topics Covered:**

   **Readings:**
   - “Resource Revolution”, McKinsey Global Institute, November 2011 [*Exec. Summary and Chapter 7 only*]
   - Grantham, J., "Investor Letter - April, 2011", [on Canvas]
   - *Energy Metrics Article*

   **Assignments:** Bio Sheet due 1/31

   **[Optional] Active Reading Strategy:**

2. **Energy and Resources as an Economic System [Week 2]**

   **Topics Covered:**

   **Reading:**
   - *Thinking in Systems [Through the end of Section 1]*
   - “energy [r]evolution: A Sustainable Global Energy Outlook” Greenpeace International and EREC, 2012 [*Read Introduction, Executive Summary, Chapters 2 and 3, and SKIM Pages 54-87]*
   - UNEP/ SEFI/ BNEF, “Global Trends in Renewable Energy Investment” [*Executive Summary, Chapter 1 & 2 only]*

   **Thursday Case:**
   - BP  [In Case Packet]

   **[Optional] Reference:**
Energy and the Water Nexus (4 Weeks)

3. Supply and Demand – Contracting Price  [Week 3]
Understand Organized Electricity Markets and Efficiency

Topics Covered:
- Grid Purpose, Generation, Transmission, Distribution, Deregulation, Supply Curves, Load, Wholesale Market Structure and Function, Dispatchability, Bus Bar Costs, LCOE, Multiple Value Streams of Electricity, Financing Electricity Projects

Readings:
- Thinking in Systems  [Section 2]
- Binz, R. “Practicing Risk-Aware Electricity Regulation”, CERES 2012
- Accenture/ WEF, “Accelerating Smart Grid Investments”, 2009

Thursday Case (DR and EE):
- Groom Energy Solutions  [In Case Packet]

[Optional] Assessing and Financing EE:

Assignment #1 due 2/13

4. Utility-Scale Generation Options [Week 4]

Topics Covered:
- Project Finance, IPPs, Regulated Utilities, Net Metering, Cost of Capital (WACC), IRR, Fully-loaded costs, Discounting, Risk-weighting, COGS

Readings:
- WSGR, “Project Finance for Renewable Energy and Clean Technology Projects”
- Lazard LCOE – Version 7 [on Class Site]
- “Program on Technology Innovation: Integrated Generation Technology Options”, EPRI, June 2011 [YES, the entire thing – use active reading techniques]

Tuesday Case:
- Fox Islands Wind (A)  [In Case Packet]
Project Pre-Approval due 2/25

5. EXPERIENCE CURVES AND DISRUPTIONS [WEEK 5]

Topics Covered:
Experience Curves, Learning, Technology, Market Disruptions, Distributed Generation, PV, BoS and Soft Costs, Supply and Demand Reconciliation, Forecasting Competing Costs

Readings:
- “Experience Curves for Energy Technology Policy”, OECD/IEA, 2000 [Chaps. 1 and 4]
- Bower and Christensen, “Disruptive Technologies: Catching the Wave” [on Canvas]
- Solar Forecasting Methodology [on Canvas]

Tuesday Case:
- FirstSolar, Inc.  [In Case Packet]

Assignment #2 due 3/4

[Optional] Background:
- “Solar Primer” Jefferies & Company, Clean Technologies Primer [on Canvas]
- Solar Revolution, Chapters 1, 6, 7, and 10

6. WATER AND ELECTRICITY [WEEK 6]

Topics Covered:
Withdrawals, Consumption, Pricing Water, Purification, Desalination

Readings:
- “Burning Our Rivers,” River Network Report, April 2012
- Note on Water  [In Case Packet]

Note: The second session of this topic is scheduled on March 7 from 2:15 – 3:45PM in Warren 207
7. **Oil and Transportation Markets [Week 7]**

**Topics Covered:**
- **Resource** measurements, **Reserves**, Quality, Delivery Systems, Passenger vs. Cargo, Modes of Freight, Inter-modal, Energy Security

**Readings:**
- “The Oil Crunch: Securing the UK’s Energy Future” UK Industry Taskforce on Peak Oil & Energy Security (ITPOES), February 2010 *Through the end of Section 2 – page 14*
- Owen, et al., *The status of conventional world oil reserves – Hype or cause for concern?* Energy Policy, 2010
- “Repowering Transport”, World Economic Forum, February 2011
- Offshore Drilling Industry [In Case Packet]

**Thursday Case:**
- Keystone XL [In Case Packet]

8. **Biofuels and The Fuel versus Food Debate [Week 8]**

**Topics Covered:**
- Unintended consequences, Biofuels, Cellulosic, Algae, Drop-in Fuels, **Feedstock/Fuel Linkages**, Tortilla Revolution

**Readings:**
- “Biofuels Issues and Trends”, EIA, October 2012 *Through page 20*
- “Technology Roadmap: Biofuels for Transport”, IEA, 2011 *Through page 40*
- Flip through Optional Readings on China - Fuel-Water-Food [On Canvas]

**Thursday Case:**
- Cosan, Inc. [In Case Packet]

**Assignment #3 due 4/10**

[Optional] **Background:**
- "Betting on Science: Disruptive Technologies in Transport Fuels", Accenture, 2009
9. **Energy Storage for Transportation and Stationary Applications [Week 9]**

**Topics Covered:**
Storage, Energy Density, Power Density, Chemistries, Fuel Cells, LCOS, Commodities, the Supercycle, Rare Earths, Periodic Table

**Readings:**
- “Electricity Energy Storage Technology Options,” EPRI, December 2010
- “Transportation Electrification: A Technology Overview,” Electric Power Research Institute, July 2011 [*Through the end of chapter 3 Only*]
- “EV and PHEV Technology Roadmap” IEA, June 2011 [*Executive Summary ONLY*]
- “Lithium Use in Batteries,” USGS, 2012
- “Rare Earth Elements, The Global Supply Chain,” CRS Report, June 2012
- “Fight for Rare Earth,” Reuters, November 2010

**Thursday Case:**
- A123  [In Case Packet]

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10. **The Natural Gas Revolution [Week 10]**

**Topics Covered:**
Natural Gas, Stranded Gas, Fracking & Shale Gas, CNG, LNG, Liquefaction, **Forecasting Prices**

**Readings:**
- Note on Natural Gas  [In Case Packet]

**Thursday Case:**
- Caprica Gas  [In Case Packet]
11. CLIMATE CHANGE AND THE IMPACT OF ENERGY SYSTEMS [WEEK 11]

Topics Covered:

Readings:
- *Thinking in Systems* [Book, Section 3]
- “The Future of Coal: options for a carbon-constrained world”, MIT, 2007. [Chapters 2 to 4 ONLY – Pages 5-59]

Thursday Case:
- AEP - Carbon  [In Case Packet]

Assignment #4 due 4/24

12. FORECASTING THE FUTURE OF ENERGY - THE OUTCOME OF COMPLEX SYSTEMS [WEEK 14]

Topics Covered:
Scenario Analysis, Key Drivers, Forecasting

Readings:
- *Thinking in Systems* [Section 3]
- "Cleaner Technologies", DB Climate Change Advisors. [On Canvas]

Final Project due 5/1

**Blogs and News Sites to follow**
Here are a few sites/rss feeds you may want to stay up on for current events on the energy and renewable energy industries:
1. Prometheus Institute: http://prometheus.org/
2. Greentech Media: http://www.greentechmedia.com/
4. World of Renewables: http://www.worldofrenewables.com/
Appendix: Reference Documents for Background Information

**Energy System Statistics**
- “IEA Key World Energy Statistics 2012”, International Energy Agency
- “Monthly Energy Review” DOE Energy Information Agency (EIA)

**Energy Resource Industry Reference Documents**
- **Petroleum and Transportation**
  - “Understanding Today’s Crude Oil and Products Markets”. American Petroleum Institute, 2011
  - “On the Road in 2035”, MIT, 2008
- **Natural Gas**
  - “Natural Gas – From Wellhead to Burner Tip”, NaturalGas.org, 2012
  - “Natural Gas Business Overview”, NaturalGas.org, 2012
- **Electric Grid**
- **Coal**
  - “Coal Explained”, EIA, 2012
  - “Global Coal Risk Assessment”, World Resources Institute, November 2012
- **Hydropower**
  - “Hydropower Explained”, EIA, 2012
  - “Hydropower Roadmap” IEA, 2012
- **Nuclear Power**
  - “2009 Update to the Future of Nuclear Power”, MIT, 2009
- **Biomass and Biogas Electricity**
  - “CPUC GHG Modeling – Biomass” CPUC, August 2007
- **Wind Electricity**
  - “Global Wind Energy Outlook”, GWEC, 2012
  - EPRI – Wind Innovation
  - EPRI – Wind Integration
- **Concentrating Solar Electricity**
- **Ocean-based power: Tidal and Wave Electricity**
  - “Accelerating Marine Energy”, Carbon Trust (UK), 2011
- **Geothermal Electricity**
- **Distributed PV**
  - “Reducing the Cost of PV”, Rocky Mountain Institute, 2012