SUSTAINABLE ENERGY SYSTEMS

(NRE 574, PUBPOL 519, ESENG 599)
Fall Term 2014

SYLLABUS

Time	Tuesday and Thursday, 2:30 – 4:00 pm
Location	1040 Dana Bldg.
Instructor	**Gregory A. Keoleian** Peter M. Wege Endowed Professor of Sustainable Systems Professor, Sustainable Systems, School of Natural Resources and Environment Professor, Civil and Environmental Engineering Director, Center for Sustainable Systems
Office	3504 Dana Bldg.
Phone	764-3194
E-mail	gregak@umich.edu
Office Hrs	On-Campus students: Tuesday and Thursday, 4:00 – 5:00 pm Off-Campus students: Tuesday, 7:00 – 8:00 pm and Thursday, 7:00 – 8:00pm
Graduate Student Instructors	**Trevor McManamon** tmcman@umich.edu *(and GSI for off campus students)* Optional Recitation: Tuesday 6pm-7pm in 3038 Dana Bldg. Office Hours for Off-Campus students (ESENG 599): Wednesday, 9:00 – 10:00 pm; Thursday 4:30 – 5:30 pm **Therese Miranda-Blackney** tmiranda@umich.edu Optional Recitation: Monday 6:00 – 7:00 pm 3038 Dana Bldg. Office Hours: Monday and Wednesday 4:30-6:00 pm 3552 Dana. **Brett Simon,** bssimon@umich.edu Office Hours: Tuesday and Thursday 8:30AM-10:00AM in the 4th Floor Dana Commons

DESCRIPTION

This course examines the production and consumption of energy from a systems perspective. Sustainability is examined by studying global and regional environmental impacts, economics, energy efficiency, consumption patterns and energy policy. First, the physics of energy and energy accounting methods are introduced. Next, the current energy system that encompasses resource extraction, conversion processes and end-uses are covered. Responses to current challenges such as declining fossil fuels and climate change are explored with an emphasis on emerging renewable energy technologies (e.g., biomass, wind, and photovoltaics), building technologies, alternative vehicle technologies, and end-use efficiency and conservation.

This is an interdisciplinary course that integrates the following analytical tools for advancing energy sustainability:

Technology Assessment
Economic and Policy Analysis
Energy Analysis and Environmental Sustainability Assessment

Students from SNRE, Engineering, Public Policy, Business, and other fields provide important perspectives useful for transforming energy systems to enhance sustainability.

FORMAT

Learning in this course is facilitated through lecture, readings, discussion, in class exercises, assignments, and term projects. Analytical skills are developed and demonstrated through problem sets, a term project and the mid-term and final exams. Required readings on ctools reinforce topics and concepts covered in lecture; reference materials on ctools (optional reading) include supplemental articles, reports, data and web sites. For On-Campus students, class participation is a key element of the course and critical analysis and discussion of course topics is expected in class and through the blog. Off-Campus students are expected to participate by contributing to the blog.

COURSE RESOURCES

1. **Course readings and other reference are available on CTools**: http://ctools.umich.edu/
2. **Reference textbooks available through UM library**

a. *Energy for sustainability: technology, planning and policy* Island Press 2008.
b. *Sustainable energy: choosing among options* MIT Press 2005.
c. *World energy assessment: energy and the challenge of sustainability* / New York, NY: United Nations Development Programme, c2000.
d. *Energy systems and sustainability* / Oxford: Oxford University Press in association with the Open University, 2003.
e. *Renewable energy: power for a sustainable future* / Oxford: Oxford University Press in association with the Open University, 1996.
f. *Renewable Energy* Edited by T. Johansson et al. Island Press, 1993
g. *Renewable and Efficient Electric Power Systems* Wiley 2004.
h. *Energy Principles, Problems, Alternatives*, Joseph Priest Addison Wesley 4th Edition, 1991.
i. *Energy and Problems of a Technical Society*, J. J. Kraushaar, and R.A. Ristinen, John Wiley, 2nd Edition, 1993.
j. *Learning about energy* David J. Rose New York: Plenum Press, 1986.
k. *CRC handbook of energy efficiency* / edited by Frank Kreith, Ronald E. West. Boca Raton, Fla. : CRC Press, 1997. ***Shelved in: MEDIA UNION Reference - 2nd Floor (Non-Circulating)
l. Vanek, F.M., and L.D. Albright. 2008. *Energy Systems Engineering: Evaluation and Implementation.* New York: McGraw Hill. Available online through Mirlyn
m. *Hidden Costs of Energy: Unpriced Consquences of Energy Production and Use*. National Academy of Sciences 2010. overall conclusions and recommendations; full book
n. Smil, V. 2010. *Energy Transitions: History, Requirements, Prospects*. Praeger, Santa Barabara, CA, ix + 178 pp. chapter 1
o. Smil, V. 2008. *Energy in Nature and Society: General Energetics of Complex Systems*. The MIT Press, Cambridge, MA, xi + 480 pp. most of book
p. Smil, V. 2010. *Energy Myths and Realities: Bringing Science to the Energy Policy Debate.* American Enterprise Institute, Washington, DC, xiv + 213 pp. chapters 1 and 2

3. **Key energy websites:**

a. US Department of Energy, Energy Information Administration: http://www.eia.doe.gov/
b. International Energy Agency: http://iea.org/
c. US DOE Office of Energy Efficiency and Renewable Energy (EERE): http://www.eere.energy.gov/
d. Renewable Energy World News and Network: http://www.renewableenergyworld.com/
e. OpenEnergyInfo Gateway to world energy information/ data http://en.openei.org/wiki/Main_Page

COURSE OUTLINE

Part A. Introduction and Energy Fundamentals

1. Sustainability challenges and opportunities (Sept 2)
2. Physics of energy (Sept 4)

Part B. Energy and Carbon Accounting

3. Energy accounting I: EIA convention (Sept 9)
4. Energy accounting II. LCA convention (Sept 11)
5. Energy growth analysis and carbon accounting (Sept 16)

Part C. Energy Supply

6. Fossil energy resources (Sept 18)
7. Electricity from fossil resources (Sept 23)
8. Electricity from nuclear fuels and other generating systems (Sept 25)
9. Electricity: Power Plant Economics and Regulation (Sept 30)

Part D. Energy Demand

10. Industrial and Commercial Sectors (Oct 2)
11. Residential Sector (Oct 7)
12. Transportation Sector (Oct 9)

MIDTERM (Oct 16)

Part E. Renewable Energy Technologies and Policy

13. Introduction renewable energy technologies and policy (Oct 21)
14. Wind energy (Oct 23)
15. Hydropower (Oct 28)
16. Solar energy (Oct 30)
17. Biomass: electricity (Nov 4)
18. Biomass: transport fuels (Nov 6)

Part F. Other Emerging Sustainable Energy Technologies and Policy

19. Which option? EVs, HEVs, PHEVs, FCVs Electric Vehicles (EV), Hybrid Electric Vehicles (HEV), Plug in Hybrid Electric Vehicles (PHEV) or Fuel Cell Vehicles (FCV) (Nov 11)
20. Building technologies and policy (Nov 13)
21. Storage technologies: electricity storage and carbon storage (sequestration) (Nov 18)

PART G. Course Synthesis

22. Climate science: global energy balance (Nov 20)
23. Climate mitigation and policy (Nov 25)
24. Term project posters (Dec 2 and 4)
25. Course review (Dec 9)

FINAL EXAM (Dec 12)

PART A. INTRODUCTION AND ENERGY FUNDAMENTALS

Sept. 2 **1. Sustainable Energy Systems: Issues for the 21st century**

What are the critical challenges for a sustainable energy future?
Sustainable energy systems: definitions, indicators.
Key energy stakeholders
Course objectives

Reading

Global Energy Assessment Toward a Sustainable Future Key Findings Summary for Policymakers Cambridge University Press xii – xviii (browse the rest).
http://www.iiasa.ac.at/Research/ENE/GEA/doc/GEA-Summary-web.pdf
Goldemberg, J. "The promise of clean energy" *Energy Policy* (2006) 34: 2185–2190.

Reference *Energy for the Poor: Underpinning the Millennium Development Goals* Department for International Development, United Kingdom, August 2002.
"Energy and Air Pollution" in *GEO (Global Environment Outlook) Yearbook*, UNEP (2006).
The Link Between Energy and Human Activity. Paris: International Energy Agency, 1997.
Hidden Costs of Energy: Unpriced Consquences of Energy Production and Use. National Academy of Sciences 2010. overall conclusions and recommendations; full book

Sept. 4 **2. Physics of Energy: Laws of Thermodynamics**

Energy Forms and Conversion
First and Second Laws and Efficiencies
Devices: Heat Engines, Refrigerators and Heat Pumps
Instantaneous and Average Power

Reading

Chapter 2: The Physics of Energy, Ross, M.

References

Principles of Heat Engines (p. 197- 200) and Refrigeration (p. 362-363) in *Energy systems and sustainability* G. Boyle, B. Everett and J. Ramage Eds. Oxford University Press, 2003
Thermodynamics resource (some useful material but much is more advanced than this course): http://hyperphysics.phy-astr.gsu.edu/hbase/heacon.html#heacon

PART B. ENERGY ANALYSIS AND CARBON ACCOUNTING

Sept. 9 **3. Energy Accounting I: EIA Conventions**

Energy Carriers: Liquid, Gaseous and Solid Fuels, Electricity
Primary Energy
Heat Rates and Power Plant Efficiency
Site Energy
Measurement issues

Reading

Chapter 4: Energy Carriers and Energy Accounting, Ross, M.

References EIA main glossary: http://www.eia.gov/tools/glossary/index.cfm and EIA energy efficiency glossary: http://www.eia.gov/emeu/efficiency/ee_gloss.htm

Sept. 11 **4. Energy Accounting II: LCA Conventions**

Resource Energy (Total Fuel Cycle Accounting)
Total Fuel Cycle (Upstream and Combustion) Energy
Feedstock (Embodied in Materials) and Process Energy
Life Cycle Energy Analysis

Reading

Chapter 4: Energy Carriers and Energy Accounting, Ross, M.

References

Keoleian, G. et al. "Application of LCI to Fuel Tank System Design" *Intl JLCA* 1998.
GREET (Argonne National Lab): http://greet.es.anl.gov/

Sept. 16 **5. Energy Growth Analysis and Carbon Accounting**

- International and US Statistics
- Energy and Carbon Intensity
  - Carbon Emission Factor
  - Role for Conservation and Energy Efficiency
- Growth Rates
  - Growth Rate Formalism
  - Forecasts and Future Scenarios

Readings

Chapter 5: The US Energy Use & Related Greenhouse Gas Emissions, Ross, M.
Excel growth chart tutorial
Annual Energy Outlook With Projections to 2035 - Executive Summary
International Energy Outlook - Highlights

References

EIA *Annual Energy Review (superseded -- see MER for key annual tables),*
http://www.eia.doe.gov/emeu/aer/contents.html
EIA *Monthly Energy Review (MER)* http://www.eia.gov/totalenergy/data/monthly/
EIA *State Energy Profiles,* http://tonto.eia.doe.gov/state/
Key World Energy Statistics - International Energy Agency
Worldwide Trends in Energy Use and Efficiency - International *Energy* Agency, 2008
U.S. Energy System Center for Sustainable Systems Factsheet
http://www.css.snre.umich.edu/css_doc/CSS03-11.pdf
GHG Emission Factors: http://www.eia.gov/oiaf/1605/emission_factors.html
The Outlook for Energy A View to 2040 – Exxon Mobil

PART C. ENERGY SUPPLY

Sept. 18 **6. Fossil Energy Resources**

- Distribution and Classification of Fossil Resources: Oil, Natural Gas, Coal
- Unconventional: Oil Sands/Oil Shale/Shale Gas/Coal Bed Methane
  - Oil Sands and GHG emissions
  - Shale Gas and Hydraulic Fracturing (fracking)
- Projections of Future Supply, What is Peak Oil
- Drilling Offshore in the US?

Readings

Chapter 7: Energy Resources in *Energy Resources in Mineral Resources, Economics and the Environment,* Kesler, S.
Oil sands basics http://ostseis.anl.gov/guide/tarsands/index.cfm (browse)
Oil shale basics -- http://ostseis.anl.gov/guide/oilshale/ (browse)
Shale gas basics : http://www.eia.gov/energy_in_brief/about_shale_gas.cfm
"The End of Cheap Oil" C. Campbell/J.H. Laherrère, *Scientific American*, March 1998
USGS World Petroleum Assessment 2000 Executive Summary
Two perspectives on Fracking:
http://www2.epa.gov/hydraulicfracturing (browse)

http://www.marcellusprotest.org/ (browse)

References

BP Statistical Review of World Energy
http://www.bp.com/statisticalreview

EIA Projection of Long Term Supply
http://www.eia.doe.gov/pub/oil_gas/petroleum/presentations/2000/long_term_supply/

Chapter 5: Fossil Fuel Resources in *Energy Systems Engineering* Vanek and Albright (mirlyn on-line)

Chapter 3: Fossil Energy Resources, Ross, M.

Potential Oil Production from the Coastal Plain of the Arctic National Wildlife Refuge: Updated Assessment (EIA) May 2000, p vii – viii.

NETL Oil and Gas Supply: http://www.netl.doe.gov/technologies/oil-gas/index.html

A.D. Charpentier *et al* Understanding the Canadian oil sands industry's greenhouse gas emissions *Environ. Res. Lett.* (2009) 4 014005 (11pp).

EOS. 2010. The Marcellus shale: resources and reservations. *Eos (Trans. Am. Geophysical U.) 91(32):* 278-79.

Peaking of World Oil Production: Impacts, Mitigation, & Risk Management, Hirsch Report, February 2005

Potential Impacts of Proposed Oil and Gas Development on the Arctic Refuge's Coastal Plain: Historical Overview and Issues of Concern
http://training.fws.gov/Pubs7/arctic_oilandgas_impact.pdf

Offshore Oil
http://www.boemre.gov/offshore/

Sept. 23 **7. Electricity From Fossil Sources**

U.S. and World Fuel Mix
Power Generation Technologies
Transmission and Distribution
Can Supply Meet Demand? Capacity Factor, Load Curves, Peak Demand
Plant Efficiency and Life Cycle Efficiency
Your electricity bill

Readings

G. Aubrecht "Production and Distribution of Electricity" Chapter 6 in *Energy* Prentice Hall, 1995.

References

"Electricity" in EIA *Monthy Energy Review*:
http://www.eia.gov/totalenergy/data/monthly/#electricity

"Centralized Electric Power Systems" Chapter 9 in *Energy for Sustainability Technology, Planning and Policy* John Randolph and Gilbert M. Master Island Press 2008.

Life Cycle Assessment of Coal-fired Power Production June 1999 • NREL/TP-570-25119
http://www.nrel.gov/docs/fy99osti/25119.pdf

Sept. 25 **8. Electricity from Nuclear Fuels and Other Generating Systems**

What about Nuclear Power?
Nuclear Fuel Cycle
Japan Nuclear Disaster and Impact on the Nuclear Industry
Cogeneration/ Combined Heat and Power
Distributed Power, Microgrids; the "Smart Grid"

Readings

"Advanced Nuclear Energy Technologies" in *World Energy Assessment: Energy and the Challenge of Sustainability* UNDP September 2000, p. 306-318 + notes

Nuclear Fuel Cycle – World Nuclear Association
http://www.world-nuclear.org/education/nfc.htm

Deutch, JM and Moniz, EJ "The Nuclear Option" *Sci. Amer*. (2006) 295(3): 76- 83.

International Atomic Energy Agency: http://iaea.org/ (browse)

US Nuclear Industry: http://www.eia.gov/energy_in_brief/article/nuclear_industry.cfm (browse)

Fukushima Accident:
http://www.iaea.org/newscenter/news/2012/fukushima1yearon.html (browse)

What is Combined Heat and Power?
http://www1.eere.energy.gov/manufacturing/distributedenergy/chp_basics.html

What is the Smart Grid?
http://www.smartgrid.gov/the_smart_grid#smart_grid

References

What is Distributed Power?
California Energy Commission: http://www.cpuc.ca.gov/PUC/energy/DistGen/

Resources: EPRI Smart Grid Resource Center and http://www.smartgrid.gov/

Sept. 30 **9. Electricity: Power Plant Economics and Regulation**

Fixed and Variable Costs (Capital, Fuel, O&M)
Wholesale and Retail Prices; Energy Markets
Tradeable SO2 Permits with Caps
Demand Side Management and Conservation

Readings

Chapter 19: Simple Economic Analysis of a New Power Plant, Ross, M.

References

NREL Energy Technology Cost and Performance Data for Distributed Generation:
http://www.nrel.gov/analysis/tech_cost_data.html

Levelized Cost of Electricity Calculator: http://www.nrel.gov/analysis/tech_lcoe.html

Life Cycle Environmental and Economic Assessment of Willow Biomass Electricity: A Comparison with Other Renewable and Non-Renewable Sources Center for Sustainable Systems, Report No. CSS04-05R, University of Michigan, 2005.

"*Generation Technologies for a Carbon-Constrained World" EPRI* Journal(2006) Summer Issue.

Hullman, NE, JG Koomey, DM Kammen "What History Can Teach Us about the Future Costs of U.S. Nuclear Power" *Env. Sci. Tech*. (2007) April 1: 2088-2093.

Cap and Trade (US EPA): http://www.epa.gov/captrade/basic-info.html

PART D. ENERGY DEMAND

Oct. 2 **10. Industrial Sector**

Energy Consumption by Manufacturers: Fuel and Non-fuel
Energy and Carbon Intensity
Efficiency Gains, Theoretical Limits
Cost of Conserved Energy

Readings

A. Lovins "Energy Strategy: The Road Not Taken" *Foreign Affairs* (1976) 55(1): 65-66.

Understanding Manufacturing Energy and Carbon Footprints DOE 2012
http://www1.eere.energy.gov/manufacturing/pdfs/understanding_energy_footprints_2012.pdf
Worrell et al., "Energy efficiency and carbon dioxide emissions reduction opportunities in the US iron and steel sector" *Energy* (2001) 26: 513-536.

References

Chapter B4: Industrial Energy Consumption & Efficiency, Ross, M.
Advanced Manufacturing Office (DOE)
http://www1.eere.energy.gov/manufacturing/industries_technologies/index.html
http://www1.eere.energy.gov/manufacturing/rd/footprints.html
Consumption of Energy for All Purposes (First Use) by Value of Shipments and Employment Size Category and Region - Manufacturing Energy Consumption Survey (MECS)
http://www.eia.doe.gov/emeu/mecs/contents.html
Theoretical Minimum Energies to Produce Steel, Executive Summary, U.S. Department of Energy Office of Industrial Technologies, March 2000.

Oct. 2 **10. Commercial Sector**

Commercial Buildings Energy Consumption
Heat and Cooling Loads
LEDs
E-Commerce and the Internet: Saving Energy?
LEED

Reading

Commercial Buildings Center for Sustainable Systems Factsheet
http://www.css.snre.umich.edu/css_doc/CSS05-05.pdf
LEED US Green Building Council: http://www.usgbc.org/leed (browse)

Reference

Commercial Buildings Energy Consumption Survey
http://www.eia.doe.gov/emeu/cbecs/
LEDs: http://www1.eere.energy.gov/buildings/ssl/

Oct. 7 **11. Residential Sector**

Residential Buildings Energy Consumption
Heating and Cooling Loads and Degree Days
Building Envelope (e.g., walls, windows)
Modeling heat loss through windows
Building Codes and Appliance Standards

Readings

"Energy Conservation" Chapter 7 in *Energy and the Environment,* Kraushaar and Ristinen, 1999.
EERE Energy Savers: www.energysavers.gov/ (browse website)
Jochem, EK "An Efficient Solution" *Sci. Amer*. (2006) 295(3): 64- 67.
US DOE Building Codes Program
http://www.energycodes.gov/ (browse site)
US DOE Appliance Standards
http://www.eere.energy.gov/buildings/appliance_standards/ (browse site)

References

Residential Energy Consumption Survey http://www.eia.doe.gov/emeu/recs/

"Energy Efficiency for Buildings" Chapter 6 in *Energy for Sustainability Technology, Planning and Policy* John Randolph and Gilbert M. Master Island Press 2008.
"Home Energy Saver", Developed by the Environmental Energy Technologies Division at Lawrence Berkeley National Laboratory http://hes.lbl.gov/
Chapter 8 Residential Energy, Ross, M.
Energy Star http://energystar.gov/
Residential Buildings Center for Sustainable Systems Factsheet http://www.css.snre.umich.edu/css_doc/CSS01-08.pdf
L. Lutzenhiser "Social and Behavioral Aspects of Energy Use" *Annu. Rev. Energy Environ*. (1993) 18: 247-89
Real Goods Catalog (energy efficient products) http://realgoods.com/

Oct. 9 **12. Transportation Sector**

Freight vs Personal
Historical Statistics
VMT Growth
Fuel Economy Trends
Other Key Drivers Impacting Sustainability: Criteria emissions, Price, Safety, Sprawl
Technology Options
Policy Options

Readings

Heywood, JB "Fueling Our Transportation Future" *Sci. Amer.* (2006) 295(3): 60- 63.
Chapter 22: Transportation: Activity & Energy Use, Ross, M.
"Conclusions: Key Findings and Paths Forward" Chapter in Sustainable Transportation Energy Pathways Edited by Joan Ogden and Lorraine Anderson, Institute for Transportation Studies, UC Davis, 2011. (browse)

References

Transportation Energy Data Book – Oak Ridge National Laboratory http://www-cta.ornl.gov/data/
DOE/EPA Fuel Economy Guide http://www.fueleconomy.gov/
Annual Urban Mobility Study, Texas Transportation Institute http://mobility.tamu.edu/ums/
Greene, D.L., and J.M. DeCicco, "Energy and Transportation Beyond 2000," in *Transportation in the New Millennium.* Washington, DC: National Research Council, Transportation Research Board, January 2000.
Personal Transportation Center for Sustainable Systems Factsheet http://www.css.snre.umich.edu/css_doc/CSS01-07.pdf
Smog Formation - Ground Level Ozone US EPA Site http://www.epa.gov/air/ozonepollution/index.html
National Resources Defense Council (Energy Issues) http://www.nrdcl.org/energy/gasprices/default.asp

Oct. 13-14 **Fall Break**

Oct. 16 **Midterm Exam (in class) Parts A, B, C, D.**

PART E. RENEWABLE ENERGY TECHNOLOGIES AND POLICY

Oct. 21 **13. Introduction to Renewable Energy**

Overview of technologies
Economics
Learning Curves for Renewables
Land Use and Siting
Key policy mechanisms
Renewable Portfolio Standards
Production Tax Credits
Renewable Energy Certificates

Reading

US Renewable Energy Center for Sustainable Systems Factsheet
http://www.css.snre.umich.edu/css_doc/CSS03-12.pdf
NREL Renewable Electricity Futures Study website (browse)
http://www.nrel.gov/analysis/re_futures/
National Renewable Energy Laboratory website (browse)
http://www.nrel.gov/
"Riding on the Experience Curve" Chapter 1 in *Experience Curves for Energy Technology Policy* OECD/IEA, 2000
Production Tax Credit and Extension
http://energy.gov/savings/renewable-electricity-production-tax-credit-ptc
http://www.ucsusa.org/clean_energy/smart-energy-solutions/increase-renewables/production-tax-credit-for.html
Renewable Energy Certificates (RECs):
http://www.epa.gov/greenpower/gpmarket/rec.htm

Reference

Interactive mapping tools from NREL: http://maps.nrel.gov/
Green Power 101: http://www.epa.gov/grnpower/
World Renewable Energy Network (WREN) website (browse)
http://www.wrenuk.co.uk/
Levelized Costs of Renewable Electricity
http://www.nrel.gov/analysis/tech_lcoe.html
Emerging Markets for Renewable Energy Certificates NREL 2005
Renewable Portfolio Standards map
http://www.dsireusa.org/documents/summarymaps/RPS_map.pdf
RPS in the States: Balancing Goals and Implementation Strategies Technical Report NREL/TP-670-41409 December 2007.
Delucchi, MA and MZ Jacobson "Providing all global energy with wind, water and solar power, Part I *Energy Policy* (2011) 39: 1154-69 and Part II 1170-119.
Kammen, DM "The Rise of Renewable Energy" *Sci. Amer.* (2006) 295(3): 84-93.
Optimization Model for Distributed Power: HOMER
http://homerenergy.com/
Meta analyses of renewable energy technologies: NREL LCA harmonization project
http://www.nrel.gov/analysis/sustain_lcah.html
Deploying Renewables: Best and Future Policy Practice IEA 2011
A Framework for Project Development in the Renewable Energy Sector NREL 2013 (NREL/TP -7A40-57963)
http://www.nrel.gov/docs/fy13osti/57963.pdf

Oct. 23 **14. Wind Energy**

Wind Turbine Technologies
Wind Resources and Modeling
Energy Performance and Environmental Impacts
Economics and Economic Development Impacts

Readings

Chapter 21: Renewables: Electricity from the Wind, Ross, M.
Executive Summary and Overview, *20% Wind Energy by 2030 Increasing Wind Energy's Contribution to U.S. Electricity Supply* DOE/GO-102008-2567 • July 2008.
Wind Energy Basics (EERE): (browse)
http://www.eere.energy.gov/basics/renewable_energy/wind_turbines.html

References

Chapter 12 Wind Energy Systems, in *Energy Systems Engineering* Vanek and Albright (mirlyn online)
"Wind Energy" in *Renewable energy: power for a sustainable future.* Oxford: Oxford University Press in association with the Open University, 2004.
NREL Wind maps
http://www.nrel.gov/gis/wind.html
Wind Powering America (EERE)
http://www.windpoweringamerica.gov/
American Wind Energy Association: http://www.awea.org/

Oct. 28 **15. Hydropower and Other Renewable Electricity Sources**

Hydropower Potential and Impacts
Geothermal Potential and Technology
Other: Tidal and Wave Energy

Readings

Hydroelectric Power USBR 2005
Hydropower Overview, USBR and IEA
DOE Geothermal Technologies Program (including technology overview)
http://www.eere.energy.gov/geothermal/
EERE Marine and Hydrokinetic Technology:
http://www1.eere.energy.gov/windandhydro/hydrokinetic/techTutorial.aspx

References

Renewables for Heating and Cooling Untapped Potential, IEA 2007.
World Commission on Dams http://www.internationalrivers.org/node/348
DOE Hydropower Technologies Program (including technology overview)
http://www1.eere.energy.gov/water/index.html

Oct. 30 **16. Photovoltaics**

PV and BIPV Technologies
Solar Resources and Modeling
Energy Performance and Environmental Impacts
Economics and Net Metering

Readings

Keoleian, G.A., and G. McD. Lewis, "Application of Life Cycle Energy Analysis to Photovoltaic Module Design" *Progress in Photovoltaics* (1997) 5(4): 287-300.
PV technology web site (EERE): browse
http://www.eere.energy.gov/basics/renewable_energy/photovoltaics.html

Chapter 20 Renewables: Photovoltaic Electricity, Ross, M.

References

Chapter 10 Solar Photovoltaic Technologies, in *Energy Systems Engineering* Vanek and Albright (mirlyn online)

Solar Radiation Resource Maps of US
http://www.nrel.gov/gis/solar.html

Solar Radiation Resource Data of US
http://rredc.nrel.gov/solar/old_data/nsrdb/

Solar Energy Industry Association (US): http://www.seia.org/

Nov. 4 **17. Biomass: Electricity**

Biomass Technologies Introduction
Biomass Productivity and Modeling
Biopower: MSW, willows/switch grass/ poplar, wood waste

Readings

U.S. Billion-Ton Update: Biomass Supply for a Bioenergy and Bioproducts Industry US DOE, August 2011 Executive Summary
http://www1.eere.energy.gov/biomass/billion_ton_update.html

Keoleian, G.A. and T.A. Volk. "Renewable Energy from Willow Biomass Crops: Life Cycle Energy, Environmental and Economic Performance." *Critical Reviews in Plant Sciences*, (2005) 24:385–406.

Wood-biomass-for-energy Forest Products Lab USFS 2004

References

Biomass Energy Data Book (ORNL): http://cta.ornl.gov/bedb/index.shtml

Life Cycle Assessment of a Biomass Gasification Combined-Cycle Power System NREL 1997

Biomass Energy — Focus on Wood Waste Federal Energy Management Program ORNL 2004-02581/abh, July 2004.

Nov. 6 **18. Biomass: Transport Fuels**

Biofuels: Bioethanol, Biodiesel, Algal, Jatropha
Biofuels and Water
Land Use Impacts
Food vs Fuel
Renewable Fuels Standards

Readings

Biomass for Renewable Energy, Fuels, and Chemicals (Chapter 2) Klass, D.L. p. 29-50

Alternative Fuels Data Center (EERE): http://www.afdc.energy.gov/ (browse)

Tilman, D, et al. Beneficial Biofuels--The Food, Energy, and Environment Trilemma. (2009) *Science* **325**, 270-271.

EPA Lifecycle Analysis of Greenhouse Gas Emissions from Renewable Fuels EPA-420-F-09-024 May 2009.

Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus USDA/DOE May 1998 (browse)

Renewable Fuel Standards (RFS):
http://www.epa.gov/otaq/fuels/renewablefuels/index.htm
(browse)

References

DOE Biomass Technologies Program (including technology overview)
http://www.eere.energy.gov/biomass/

McCarl, B.A. "Bioenergy in a greenhouse mitigating world," American Agricultural Economics Association, *Choices* 23(1): 31-33, 2008.
R. Dominguez-Faus, et al. "The Water Footprint of Biofuels: A Drink or Drive Issue?" *Environ. Sci. Technol.* 2009, *43,* 3005–3010
Righelato, R., and D.V. Spracklen. 2007. Carbon mitigation by biofuels or by saving and restoring forests? *Science* 317: 902, 17 August.
Wang, D, W May, H Huo "Life-cycle energy and greenhouse gas emission impacts of different corn ethanol plant types" Environ. Res. Lett. 2 (2007) 024001 (13pp).
Pimentel, D. and T.W. Patzek "Ethanol Production Using Corn, Switchgrass and Wood; Biodiesel Production Using Soybean and Sunflower" *Natural Resources Research* (2005) 14:1 65-75.
Clarens AF, Resurreccion EP, White MA, and Colosi LM, "Environmental Life Cycle Comparison of Algae to Other Bioenergy Feedstocks," *Environmental Science & Technology*, vol. 44, pp. 1813-1819, 2010.
Doornbosch, R., and R. Steenblik. 2007. Biofuels: Is the Cure Worse Than the Disease? Report from the Roundtable on Sustainable Development. Paris: Organization for Economic Cooperation and Development (OECD), September.
Fairless, D. Jatropha The little shrub that could maybe? *Nature* Vol 449|11 October 2007: 652-655.
Assessment of greenhouse gas emissions in the production and use of fuel ethanol in Brazil, Government of the State of São Paulo April 2004.
Sustainability of Brazilian bio-ethanol Universiteit Utrecht Copernicus Institute Report NWS-E-2006-110.
Fargione, J. J. Hill, D. Tilman, S. Polasky, P. Hawthorne "Land Clearing and the Biofuel Carbon Debt", / Scienceexpress (7 February 2008).
Searchinger, Timothy et al. 2008. Use of U.S. Croplands for Biofuels Increases Greenhouse Gases through Emissions From Land-Use Change. *Science* 319: 1238-1240.
UK Renewable Fuels Agency Review of the Indirect Effects of Biofuels http://www.dft.gov.uk/rfa/reportsandpublications/reviewoftheindirecteffectsofbiofuels.cfm
US DOE Biomass Program: http://www1.eere.energy.gov/bioenergy/

PART F. OTHER EMERGING SUSTAINABLE ENERGY TECHNOLOGIES AND POLICY

Nov. 11 **19. Which Option? Electric Vehicles (EV), Hybrid Electric Vehicles (HEV), Plug in Hybrid Electric Vehicles (PHEV) or Fuel Cell Vehicles (FCV)**

EV, Regenerative Braking
HEV, Matching Load with Efficient Powerplants
PHEV, Extend Range of Electric Drive
FCV, The Fuel Cell Powered Hybrid Vehicle
Incentives and Tax Credits (Feebates, Gas Guzzler Tax, Rebates)

Reading

Hybrid and Plug-In Electric Vehicles Basics: http://www.afdc.energy.gov/vehicles/electric_basics_hev.html (browse)
Hydrogen Fuel Cell Vehicles Basics: http://www.afdc.energy.gov/vehicles/fuel_cell.html (browse)
Demirdöven, N. and J. Deutsch "Hybrid Cars Now Fuel Cell Cars Later" *Science* (2004) 305: 974-976.

Turner, J.A. "Sustainable Hydrogen Production Turner" *Science* (2004) 305: 972-974.
PHEV on the Horizon, Building the Business Case *EPRI Journal* Spring 2008. (browse)
Weiller, C., Plug-in hybrid electric vehicle impacts on hourly electricity demand in the United States. *Energy Policy* (2011) 39(6): 3766-3778. (browse)

References

MacPherson, N.D., G.A. Keoleian, and J.C. Kelly, "Fuel economy and greenhouse gas emissions labeling for plug-in hybrid vehicles from a life cycle perspective" Journal of Industrial Ecology (2012) 16(5): 761-773.
Well-to-Wheel Energy Use and Greenhouse Gas Emissions of Advanced Fuel/Vehicle Systems - North American Analysis:
http://www.transportation.anl.gov/pdfs/TA/163.pdf
The Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation (GREET) Model:
http://www.transportation.anl.gov/modeling_simulation/GREET/
Kelly, J.C., J.S. MacDonald, and G.A. Keoleian, "Time-dependent plug-in hybrid electric vehicle charging based on national driving patterns and demographics" *Applied Energy* (2012) 94: 395-405.
Ogden, J "High Hopes for Hydrogen" *Sci. Amer.* (2006) 295(3): 84-93.
Fuel Efficient Vehicle Tax Incentive Information Center:
http://www.fueleconomy.gov/feg/taxcenter.shtml

Nov 13 **20. Building Energy Technologies and Policy**

Smart buildings
Lighting and LEDs
Heating/cooling technologies
Energy Star Program
Effective Policies

Readings

De Kleine, R., G.A. Keoleian, J.C. Kelly "Optimal replacement of residential air conditioning equipment to minimize energy, greenhouse gas emissions, and consumer cost in the US" *Energy Policy* (2011) 39(6): 3144-3153.

EERE Building Energy Technologies Program
http://www1.eere.energy.gov/buildings/index.html (browse site)
Smart Buildings
http://www.ibm.com/smarterplanet/us/en/green_buildings/overview/index.html
(browse site)
US DOE Appliance Standards (browse site)
http://www.eere.energy.gov/buildings/appliance_standards/
US DOE Building Codes Program (browse site)
http://www.energycodes.gov/

References

Energy Efficiency Requirements in Building Codes IEA 2008. P7-32.
Consumer Energy Tax Credits
http://www.energy.gov/taxbreaks.htm
LEDs: http://www1.eere.energy.gov/buildings/ssl/

Nov. 18 **21. Electricity Storage Technologies**

Batteries, Capacitors, Flywheels, Pumped Hydro

Readings

Energy Storage for the Electricity Grid: Benefits and Market Potential Assessment Guide, Sandia National Laboratories, Albuquerque, NM and Livermore, CA: 2010. SAND2010-0815 pages 1-13.

References

Energy Storage Glossary (GE): http://geenergystorage.com/glossary

Electricity Storage: Technologies and Regulation, National Regulatory Research Institute, June 11, 2011.

Electricity Energy Storage Technology Options EPRI 2010.

Nov. 18 **21. Carbon Sequestration**

Five Sequestration Strategies: Biological (Terrestrial) Sequestration, Carbon Capture, Geologic Sequestration, Ocean Sequestration, Advanced Concepts Clean Coal?

Readings

DOE Sequestration Site
http://www.fossil.energy.gov/programs/sequestration/index.html

Socolow, R. "Can We Bury Global Warming" *Sci Amer* (2005) July 49-55.

Hawkins, DG, DA Lashof and RH Williams "What To Do About Coal" *Sci. Amer.* (2006) 295(3): 68- 75.

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Chapter 7 Carbon Sequestration, Vanek and Albright

"Carbon Dioxide Capture and Storage" *IPCC Special Report* (Summary for Policymakers and Technical Summary)

K.S. Lackner "Capture of carbon dioxide from ambient air" *Eur. Phys. J. Special Topics* (2009) 176: 93-106.

PART G. COURSE SYNTHESIS

Nov 20 **22. Climate Change I: Climate Change Science**

Earth's Energy Balance
Greenhouse Effect
Greenhouse Gases
Feedback Mechanisms

Reading

"An introduction to global warming" John R. Barker and Marc H. Ross Am. J. Phys. 67(2): 1216-1226

References

Fourth and Fifth Assessment Reports of the Intergovernmental Panel on Climate Change (IPCC)
http://www.ipcc.ch/

Emissions of Greenhouse Gases in the United States (EIA)
http://www.eia.gov/oiaf/1605/ggrpt/carbon.html
http://www.eia.gov/energy_in_brief/greenhouse_gas.cfm

Climate Change 2007: Impacts, Adaptation, and Vulnerability, Summary for Policymakers, A Report of Working Group II of the IPCC p. 1-23.

Nov. 25 **23. Climate Change II: Climate Change Mitigation and Policy**

Carbon Stabilization Targets
Stabilization Wedges

Climate Policy and Carbon Markets
Policies of Developed (EU Climate Policy) and Developing Countries (Clean Development Mechanisms)
Regional, State, City

Readings

Climate Change 2007 - Contribution of Working Group III Report to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC) "Mitigation of Climate Change" Summary for Policymakers.

Pacala, S. and R. Socolow "Stablization Wedges: Solving the Climate Problem for the Next 50 Years with Current Technologies" *Science* (2004) 305: 968-972.

References

Stern Review on the Economics of Climate Change Executive Summary

US Climate Action Plan: http://www.whitehouse.gov/share/climate-action-plan

Pew Center on Global Climate Change
http://www.pewclimate.org/

The American Clean Energy and Security Act (Waxman-Markey Bill)
http://www.pewclimate.org/acesa

EIA Country Analysis Briefs
http://www.eia.doe.gov/emeu/cabs/contents.html

United Nations Framework Convention and Kyoto Protocol
http://unfccc.int/resource/convkp.html
http://unfccc.int/kyoto_protocol/items/2830.php/

State and Local Climate Energy Program (US EPA):
http://www.epa.gov/statelocalclimate/index.html

The Stabilization Triangle: Tackling the Carbon and Climate Problem With Today's Technologies. Climate Mitigation Initiative, Princeton University.

Socolow, RJ and Pacca, SW "A Plan to Keep Carbon in Check" *Sci. Amer.* (2006) 295(3) 50 – 59.

ORNL Review, "Both Directions at Once: Can America simultaneously achieve energy independence and address global warming?" Oak Ridge National Laboratory Review 42(2), 2009.

Nov. 27 **Happy Thanksgiving! (no class)**

Dec. 2 **24. Term Project Presentations: Group I Posters**

Dec. 4 **24. Term Project Presentations: Group II Posters**

Dec. 4 **Individual Term Project Papers Due (Group I and II)**

Dec. 9 **25. Course Review**

Final Exam: Friday December 12, 4:00-6:00 pm

COURSE REQUIREMENTS AND EVALUATION

Class participation*	10%
Assignments	20%
Term Project	20%
Mid-Term Exam	25%
Final Exam	25%

* Class participation: Attendance in class is required. For off campus students this means viewing lecture videos. Participation includes leading class discussion and contributing to the class blog; posing questions and answering questions; sharing articles and news; providing feedback on lectures and course materials; and active participation in the poster session.