ESENG 599 SUSTAINABLE ENERGY SYSTEMS
SAMPLE SYLLABUS

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Professor, Civil and Environmental Engineering
Co-Director, Center for Sustainable Systems

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 then explored: unconventional fossil fuels, carbon sequestration, emerging technologies (e.g., renewable sources: biomass, wind, and photovoltaics; fuel cells) and end-use efficiency and conservation.

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 or through the course ctools forum. Off-Campus students can participate by contributing to the ctools forum and through office hours and email exchanges.

COURSE RESOURCES

1. Course readings and other reference materials and websites are available on CTools: http://ctools.umich.edu/
2. Reference articles and reserve textbooks available at the Science Library (third floor of Shapiro 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. Energy Politics, David Howard Davis, 4th Edition St. Martin's Press, 1993.
m. Sustainability and Cities: Overcoming Automobile Dependencies, Peter Newman and Jeffrey Kenworthy, Island Press, 1999.
n. Vanek, F.M., and L.D. Albright. 2008. *Energy Systems Engineering: Evaluation and Implementation.* New York: McGraw Hill. Available online through Mirlyn: http://mirlyn.lib.umich.edu/Record/009414852

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/

COURSE OUTLINE

I. Introduction and Energy Fundamentals
II. Energy Production and Consumption
III. Renewable Energy Technologies
IV. Alternative Fuels and Vehicle Technology
V. Storage Topics
VI. Climate and Energy Policy
VII. Course Synthesis and Term Project Posters

SCHEDULE

PART I. INTRODUCTION AND ENERGY FUNDAMENTALS

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

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

Reading

World Energy Assessment Overview: 2004 Update UNDP, Date posted: 2005-02-01, Executive Summary p. 11-13, browse the rest.
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.

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

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 Glossary: http://www.eia.gov/tools/glossary/index.cfm and http://www.eia.gov/emeu/efficiency/ee_gloss.htm

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
Measurement issues

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/

PART II. ENERGY PRODUCTION AND CONSUMPTION (SUPPLY AND DEMAND)

5. Overview of Energy Production and Consumption

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

Readings

Chapter 5: The US Energy Use & Related Greenhouse Gas Emissions, Ross, M.
Annual Energy Review "Energy Perspectives"
Annual Energy Outlook With Projections to 2035 - Executive Summary
Chapter 6: International Energy Use and Emissions, Ross, M.
International Energy Outlook - Highlights

References

EIA *Annual Energy Review,* http://www.eia.doe.gov/emeu/aer/contents.html
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

6. Fossil Energy Resources

Distribution and Classification of Fossil Resources: Oil, Natural Gas, Coal
Unconventional: Coal Tar/Oil Sands/Shale Gas/Methane Hydrates
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.
What is shale gas: http://www.eia.gov/energy_in_brief/about_shale_gas.cfm
Two perspectives on Fracking:
www.shalegas.energy.gov/resources/081111_90_day_report.pdf (browse)
http://www.marcellusprotest.org/ (browse)
Oil Sands -- http://www.api.org/aboutoilgas/oilsands/ (browse)
"The End of Cheap Oil" C. Campbell/J.H. Laherrère, *Scientific American*, March 1998
USGS World Petroleum Assessment 2000 Executive Summary

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://arctic.fws.gov/issues1.htm
Offshore Oil
http://www.boemre.gov/offshore/

7. Electricity From Fossil Sources

U.S. and World Fuel Mix
Power Generation Technologies
Transmission and Distribution

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.
"Electricity" Chapter in EIA *Annual Energy Review*: http://www.eia.doe.gov/emeu/aer/pdf/pages/sec8.pdf

References

"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

8. Electricity from Nuclear Fuels and Other Generating Systems

What about Nuclear Power?
Nuclear Fuel Cycle
Japan Nuclear Disaster
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/nuclear_industry.cfm (browse)
What is Combined Heat and Power? http://www.eere.energy.gov/de/chp/chp_technologies/tech_basics.html

References

What is Distributed Power?
California Guide: http://www.energy.ca.gov/distgen/index.html
DOE Program: http://www.eere.energy.gov/de/
What is the smart grid? EPRI Smart Grid Demonstration

9. Electricity: Power Plant Economics and Regulation

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

Readings

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

References

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.

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.
Industry Analysis Briefs
http://www.eia.doe.gov/emeu/mecs/iab/index5e.html (browse)
Enkvist, PA, T Naucler, J Rosander "A cost curve for greenhouse gas reduction" McKinsey Quarterly (2007) Number 1: 35-45.
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.
Industrial Technologies Program (DOE)
http://www.eere.energy.gov/industry/
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.

11. Commercial and Residential Sectors

Commercial and Residential Buildings Energy Consumption
Heating and Cooling Loads and Degree Days
Building Envelope (e.g., walls, windows)
Lighting Options
E-Commerce and the Internet: Saving Energy?
Standby Power

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.

References

"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.
Commercial Buildings Energy Consumption Survey http://www.eia.doe.gov/emeu/cbecs/
Residential Energy Consumption Survey http://www.eia.doe.gov/emeu/recs/
Energy Star http://energystar.gov/
Residential Buildings Center for Sustainable Systems Factsheet
http://www.css.snre.umich.edu/css_doc/CSS01-08.pdf
Commercial Buildings Center for Sustainable Systems Factsheet
http://www.css.snre.umich.edu/css_doc/CSS05-05.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/
LEDs: http://www1.eere.energy.gov/buildings/ssl/

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.
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.

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/
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

Fall Break

Midterm Exam (in class) Parts I and II.

PART III. STRATEGY – TRANSITION TO RENEWABLE TECHNOLOGIES

13. Introduction to Renewable Energy

Overview of Technologies

Reading

Kammen, DM "The Rise of Renewable Energy" *Sci. Amer.* (2006) 295(3): 84-93.

References

World Renewable Energy Network (WREN) website
http://www.wrenuk.co.uk/
National Renewable Energy Laboratory website
http://www.nrel.gov/
Optimization Model for Distributed Power: HOMER
http://homerenergy.com/
US Renewable Energy Center for Sustainable Systems Factsheet
http://www.css.snre.umich.edu/css_doc/CSS03-12.pdf
Renewables in Global Energy Supply, IEA Factsheet (Sept. 2006)
Levelized Costs of Renewable Electricity
http://www.nrel.gov/analysis/tech_lcoe.html

13. 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/windandhydro/wind_basics.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.
"Overview of Wind Technologies" in Renewable Energy Technology Characterizations)
http://www.nrel.gov/gis/wind.html
Wind Powering America (NREL)
http://www.eere.energy.gov/windandhydro/windpoweringamerica/index.asp
Wind farm area calculator (NREL)
http://www.nrel.gov/analysis/power_databook/calc_wind.php

14. 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://www.eere.energy.gov/windandhydro/hydro_basics.html

15. Photovoltaics

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

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://rredc.nrel.gov/solar/old_data/nsrdb/redbook/atlas/

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

16. 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

Wood/Wood Waste Statistics EIA website:
http://www.eia.doe.gov/cneaf/solar.renewables/page/wood/wood.html

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.

PART IV. STRATEGY – ALTERNATIVE FUELS AND VEHICLE TECHNOLOGY?

17. Biomass: Transport Fuels

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

Readings

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

"What are biofuels and how much do we use?" *Energy in Brief* EIA
http://tonto.eia.doe.gov/energy_in_brief/biofuels_use.cfm

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

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

18. 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

Reading

PHEV on the Horizon, Building the Business Case *EPRI Journal* Spring 2008.
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.
Weiller, C., Plug-in hybrid electric vehicle impacts on hourly electricity demand in the United States. *Energy Policy* (2011) 39(6): 3766-3778.

References

Hybrid Electric and Fuel Cell Vehicles Program (NREL) http://www.nrel.gov/vehiclesandfuels/hev/
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/
Ogden, J "High Hopes for Hydrogen" *Sci. Amer.* (2006) 295(3): 84-93.

PART V. STRATEGY – STORAGE TOPICS

19. 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

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

19. 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.

References

Chapter 7 Carbon Sequestration, Vanek and Albright
"Carbon Dioxide Capture and Storage" *IPCC Special Report* (Summary for Policymakers and Technical Summary)

PART VI. CLIMATE AND ENERGY POLICY

20. 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

Climate Change 2007 - The Physical Science Basis Contribution of Working Group I to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change (IPCC)
http://www.ipcc.ch/
Emissions of Greenhouse Gases in the United States (EIA)
http://205.254.135.24/oiaf/1605/ggrpt/carbon.html
Climate Change 2007: Impacts, Adaptation, and Vulnerability, Summary for Policymakers, A Report of Working Group II of the IPCC p. 1-23.

21. Climate Change II: Climate Change Mitigation and Policy

Carbon Stabilization Targets
Stabilization Wedges
Kyoto Protocol
Climate Policy and Carbon Markets
Policies of Developed (EU Climate Policy) and Developing Countries (Clean Development Mechanisms)
State of Michigan (Strategies for a Carbon Constrained World)

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.

Stern Review on the Economics of Climate Change (Executive Summary)

Kyoto Protocol
http://www.undp.org/gef/new/ccinfo2.htm#sheet21

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

References

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

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.

Happy Thanksgiving!

22. Energy Policy Review I

Energy Prices
Learning Curves for Renewables
Renewable Energy Production Tax Credit
Renewable Energy Certificates
McKinsey Report on the Cost of Carbon Reduction

Reading

Short Term Energy Outlook, EIA (browse)
http://www.eia.doe.gov/emeu/steo/pub/contents.html

"Riding on the Experience Curve" Chapter 1 in *Experience Curves for Energy Technology Policy* OECD/IEA, 2000

Production Tax Credit Extension (see factsheet) and Other Federal Policies
http://www.awea.org/issues/federal_policy/index.cfm

Green Power 101: http://www.epa.gov/grnpower/

"Impact of Financial Crisis on Carbon Economics V2.1 of the GHG abatement cost curve" McKinsey 2010.

Reference

National Resources Defense Council (Energy Issues)
http://www.nrdc.org/energy/gasprices/default.asp
Emerging Markets for Renewable Energy Certificates NREL 2005
Chapter 26: Policies Based on Energy Prices, Ross, M.

23. Energy Policy Review II

Performance Standards (e.g., appliance standards, building codes)
Renewable Portfolio Standards
Alternative Fuels Standards
Tradeable SO2 Permits with Caps
Incentives and Tax Credits (Feebates, Gas Guzzler Tax, Rebates)
Investment in R&D

Readings

"Energy Policy" Chapter 17 in *Energy for Sustainability Technology, Planning and Policy* John Randolph and Gilbert M. Master Island Press 2008.
US DOE Appliance Standards browse site
http://www.eere.energy.gov/buildings/appliance_standards/
Energy Efficiency Requirements in Building Codes IEA 2008. P7-32.

References

Chapter 27: Focused Energy Policies, Ross, M.
US DOE Building Codes Program
http://www.energycodes.gov/
Renewable Portfolio Standards
http://www.eere.energy.gov/states/maps/renewable_portfolio_states.cfm
RPS in the States: Balancing Goals and Implementation Strategies Technical Report NREL/TP-670-41409 December 2007.
Consumer Energy Tax Credits
http://www.energy.gov/taxbreaks.htm
Ending the Energy Stalemate, National Commission on Energy Policy 2004
"Clean Energy-Environment Guide to Action, 2006." US EPA.
www.epa.gov/cleanrgy/stateandlocal/guidetoaction.htm
US Energy Policy (White House)
http://www.whitehouse.gobv/infocus/energy/

PART VII. SYNTHESIS: SUSTAINABLE ENERGY FUTURE

Term Project Presentations: Group I Posters

Term Project Presentations: Group II Posters
Individual Term Project Papers Due (Group I and II)

Course Review

Final Exam: Wednesday December 21, 4:00-6:00 pm

COURSE REQUIREMENTS AND EVALUATION

Class participation*	5%
Assignments	20%
Term Project	25%
Mid-Term Exam	25%
Final Exam	25%

* Class participation: Attendance in class is required. For off campus students this means viewing lecture videos. Other ways to participate include posing questions; answering questions; posting reference materials, articles, news on the ctools forum; providing feedback on lectures and course materials; and active participation in poster session.