

# NRE 501: Biofuels and Bio-Based Carbon Mitigation

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## Course Rationale

Carbon mitigation involves a range of strategies designed to reduce the net emissions of carbon to the atmosphere. Biologically-based carbon mitigation strategies fall into three general areas: carbon management (for example through the altered management of agricultural soils or crop residues), carbon sequestration (for example through the conversion of marginal agricultural land to forests or wetlands), and the use of biofuels. The ability of the United States to enter into international agreements to reduce net C emissions will depend partly on technology and understanding of each of these strategies and their potential effects on emissions reductions. The idea to grow more trees sounds simple, but forest industries depend on timber flow from currently managed forests, and the effectiveness of C sequestration through afforestation of additional land will depend on soil and vegetation history as well as compete with other land uses.

Bioenergy and biofuels are an important and rapidly growing type of bio-based C mitigation. The production of ethanol has doubled in the past 10 years, and US states and other nations are striving to adopt renewable portfolio standards for generation of electricity. Germany, for example, has committed to generating 20% of its electricity from renewable sources by the year 2020. Researchers in Canada are studying the effectiveness of growing poplar trees for production of cellulosic ethanol and the impact that it will have as a loss of fiber for the forest-products industry. In her 2008 State of the State address, Michigan governor Granholm emphasized the potential for production of biofuels from Michigan forests (including the production of cellulosic ethanol from forest-products waste). In a recent case study in China, researchers used satellite remote sensing to identify biomass production areas, together with an analysis of transportation costs to select a construction site for bioenergy production.

## Course Format, Audience, Assignments, and Grading

This course is designed to serve a current need in the SNRE Sustainable Systems MS curriculum while also serving other students including those in Terrestrial Ecosystems, the Erb Institute, and those pursuing our new dual degree with Engineering. In addition, the proposed 500-level will make this course open to advanced undergraduates including PitE students. The expected class size is 20 to 40 students. This proposal will be submitted through the SNRE Sustainable Systems Field of Study. The course will be offered every 2<sup>nd</sup> winter beginning in winter 2009.

This will be a 3-credit lecture course with an example time slot of Tues (1 h lecture), Th (1 h lecture), plus 1 hour discussion per week. A GSI (Graduate Student Instructor) is requested to lead two discussion sections (of 10 to 20 students each) late in each week (after the 2<sup>nd</sup> lecture of the week),

giving students the opportunity to discuss readings as well as to review lecture material in a smaller group.

Assignments will include readings and a term research paper that will be completed in two installments. As a way of understanding the rapidly changing field of bio-based carbon mitigation, each student will research one aspect of carbon management, sequestration, or bioenergy, building on the material covered in lectures and readings. Grades will be based on a midterm and final exam (closed book, closed notes; 40%), participation in weekly discussion sections (20%), and the research term paper (40%).

## Course Overview

This course will provide a foundational but in-depth introduction to biologically-based strategies of carbon mitigation in the context of understanding and achieving targets for reduction of global and national net C emissions. The course will provide a two-week introduction to the processes of production and decomposition in terrestrial and wetland ecosystems focuses solely on plant-soil C balance. This will provide a basis for understanding the effectiveness of various strategies for management and sequestration as well as the siting and production of organic substrates for biofuels. The types of ecosystems considered will include forests, grasslands, human-dominated suburban-exurban landscapes, agricultural land, and subsets of these lands used for biofuel production, as well various types of wetlands that could be used for carbon management or sequestration.

Strategies for altered carbon management and sequestration must be understood in terms of altering the current trajectories of C storage in the soils and vegetation of a site, landscape, or region. Methods to quantify changes in carbon storage, including carbon accounting, will be developed and understood in the context of historical and present-day rates of change in C storage associated with land management and land use / land cover change. In addition, the residence time of carbon, once stored, will be analyzed in terms of ecophysiological processes and the risk of future disturbance or land use change. The discussion of carbon balance will cover multiple spatial scales, from individual ecosystems or sites to landscapes made up of fragmented, heterogeneous patches of land use / land cover, to regions and to the global C budget. Landscapes and regional issues in Michigan and the Great Lakes will be included but not overly emphasized.

One third to one half of the course will focus on bioenergy and biofuels. The course will provide an overview of the source of organic substrates used for bioenergy and biofuels, including crops specifically grown for this purpose (including corn, switchgrass, rape, sugar cane, palm oil, and poplar trees) and the use of wastes from agriculture and forestry. The course will provide an overview of the chemistry of production of various biofuels, the energy required for their production, the energy they yield, and coproducts in their production. This will allow an analysis of energy balance, net carbon mitigation per unit energy, and economics of bioenergy and biofuel production. We will cover the environmental impacts of biofuel growth and production, including competition for other land uses, fertilizer use and nutrient runoff, and water use. We will draw on our earlier treatment of ecology and physiography to

consider the siting of biofuel production, both nationally and internationally (including Canada, Europe, and China). Finally, an energy-balance and carbon-mitigation analysis of case studies of biofuel production will be conducted, bringing us back to the context of national and international goals for net C emissions reductions that we began with at the start of the course.

## **Schedule and Syllabus**

### Week 1: Introduction to bio-based carbon mitigation

Projections of energy use, energy mixes, carbon and energy intensity, and C emissions  
Introduction to carbon accounting and carbon emission offsets  
“Stabilization wedges” as a framework for analyzing reduction in net C emissions  
Types of bio-based carbon mitigation: Carbon management, carbon sequestration, and bioenergy  
IPCC definitions of afforestation, additionality, emissions reduction, and other concepts

### Week 2: Biological processes controlling carbon balance

Plant functional types, growth, plant respiration, and net primary productivity  
Nutrient limitation, nutrient deposition, fertilizers, and nutrient cycling  
Decomposition, heterotrophic respiration, and net ecosystem production

### Week 3: Physiographic controls on carbon balance

Soil taxonomy, soil series and maps, soil texture, carbon, and characteristics  
Landform, landscape position, hydrology, soil moisture, standing water  
Climate, temperature, evapotranspiration, light, and growing season  
Physiography and carbon balance across types of ecosystems

### Week 4: Carbon accounting

Carbon accounting in international agreements; carbon emission offsets, carbon trading  
Carbon budgets produced by the scientific community  
Modeling methods for carbon accounting and carbon budgets

### Week 5: Carbon accounting (cont'd)

Inventory methods for carbon accounting  
Carbon accounting based on remote sensing and geo-informatics

### Week 6: Historical and current trajectories of C balance

Historical storage and release of carbon from ecosystems, landscapes, and regions  
Understanding trajectories and time scales of carbon storage  
Risk and residence time of C stored in soils and vegetation

## Midterm exam

### Week 7: Carbon management in forests

The potential for increased C storage through forest and timber flow management  
Wood products, sectors, consumption, and recycling  
The economics of forestry and forest carbon storage

### Week 8: Carbon management in other land uses

Managing soils and crop residues, carbon balance on agricultural land  
The potential for altered carbon balance in wetlands  
The potential for altered carbon balance in heterogeneous landscapes

### Week 9: Biological carbon sequestration

C sequestration through afforestation  
C sequestration through wetland construction or C mitigation through wetland protection  
The potential for increased C storage through other land use / land cover change

### Week 10: Types of bioenergy and biofuels

Types of biofuels and the chemistry of biofuel production  
Substrates for biofuel: agricultural and forestry crops and waste

### Week 11: Economics of Bioenergy and biofuel production

Production factors and economics of biofuel production  
Fiber versus carbon as a basis for analysis  
Coproducts of biofuel production  
Using biomass for heat, electricity generation, or transportation fuel

### Week 12: Environmental impacts of biofuel production

Impacts of biofuel production for ecosystem services and habitats  
Fertilizer use, water use, and competition for other land uses  
Potential effects on human health

### Week 13: Siting for biomass and bioenergy production

Siting for biomass production based on ecology, soils, and physiography  
Siting based on economics, transportation, and opportunity costs  
Siting based on environmental impacts  
US and international siting for biofuel production

## Week 14: Net C and energy effects of biofuel use; course wrapup

Energy-balance analysis of biofuel production

Carbon accounting, mitigation, and the potential role of biofuels

Bio-based carbon mitigation and sustainable development

Course wrapup and final thoughts

## Exam week: Final Exam

### Readings (Tentative)

- Beedlow, P. A., D. T. Tingey, D. L. Phillips, W. E. Hogsett, and D. M. Olszyk. 2004. Rising atmospheric CO<sub>2</sub> and carbon sequestration in forests. *Frontiers in Ecology and the Environment* 2:315-322.
- Caspersen, J. P., S. W. Pacala, J. C. Jenkins, G. C. Hurtt, P. R. Moorcroft, and R. A. Birdsey. 2000. Contributions of land-use history to carbon accumulation in U.S. forests. *Science* 290:1148-1151.
- Currie, W. S., R. D. Yanai, K. B. Piatek, C. E. Prescott, and C. L. Goodale. 2003. Processes affecting carbon storage in the forest floor and in downed woody debris. Pages 135-157 in J. M. Kimble, L. S. Heath, R. A. Birdsey, and R. Lal, editors. *The Potential for U.S. Forests to Sequester Carbon and Mitigate the Greenhouse Effect*. Lewis Publishers, Boca Raton, FL.
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- Hill, J., E. Nelson, D. Tilman, S. Polasky, and D. Tiffany. 2006. Environmental, economic, and energetic costs and benefits of biodiesel and ethanol biofuels. *Proceedings of the National Academy of Sciences* 103:11206-11210.
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- McKenney, D. W., D. Yemshanov, G. Fox, and E. Ramlal. 2006. Using bioeconomic models to assess research priorities: a case study on afforestation as a carbon sequestration tool. *Canadian Journal of Forest Research* 36:886-900.
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- Pacala, S., and R. Socolow. 2004. Stabilization wedges: Solving the climate problem for the next 50 years with current technologies. *Science* 305:968-972.
- Post, W. M., and K. C. Kwon. 2000. Soil carbon sequestration and land-use change: processes and potential. *Global Change Biology* 6:317-327.
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- Shi, X., A. Elmore, X. Li, N. J. Gorenco, H. Jin, X. Zhang, and F. Wang. 2008. Using spatial information technologies to select sites for biomass power plants: A case study in Guangdong Province, China. *Biomass and Bioenergy* 32:35-43.
- Sohngen, B., and R. Sedjo. 2006. Carbon sequestration in global forests under different carbon price regimes. *Energy Journal*:109-126.
- Solberg, B. 1997. Forest biomass as carbon sink - economic value and forest management / policy implications. *Critical Reviews in Environmental Science and Technology* 27(Special):S323-S333.
- Swisher, J. N. 1997. Incremental costs of carbon storage in forestry, bioenergy and land-use. *Critical Reviews in Environmental Science and Technology* 27(Special):S335-350.
- Seidl, R., W. Rammer, D. Jager, W. S. Currie, and M. J. Lexer. 2007. Assessing trade-offs between carbon sequestration and timber production within a framework of multi-purpose forestry in Austria. *Forest Ecology and Management* 248:64-79.
- Vesterdal, L., E. Ritter, and P. Gundersen. 2002. Change in soil organic carbon following afforestation of former arable land. *Forest Ecology and Management* 169:137-147.
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- Yemshanov, D., and D. McKenney. 2008. Fast-growing poplar plantations as a bioenergy supply source for Canada. *Biomass and Bioenergy* 32:185-197.

### Readings – Additional, for course prep.

- Daniels, J. 2008. The Trouble with Corn: SNRE professor discusses impact on water resources. Press Release March 28, 2008, School of Natural Resources and Environment, University of Michigan.
- Grunwald, M. 2008. The clean energy scam. *Time* magazine, April 4, 2008.
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- Yang, P., and B. M. Jenkins. 2008. Wood residues from sawmills in California. *Biomass and Bioenergy* 32:101-108.