Summary of workshop on:

LINKING BIOPHYSICAL AND ECONOMIC MODELS OF BIOFUEL PRODUCTION AND ENVIRONMENTAL IMPACTS

November 13-14, 2008
Gleacher Center, Chicago

Organized by: Madhu Khanna (University of Illinois) and Scott M. Swinton (Michigan State University) with Atul Jain (University of Illinois) and R. César Izaurralde (Joint Global Change Research Institute, Pacific Northwest National Laboratory).

Sponsored by: Energy Biosciences Institute (EBI),
Great Lakes Bioenergy Research Center (GLBRC),
Cooperative State Research, Education and Extension Service (CSREES), USDA,
Center for Advanced BioEnergy Research (CABER), U. of Illinois

Concerns about energy security, rising oil prices, declining oil reserves and global climate change are fuelling a shift towards bioenergy as a renewable alternative to fossil fuels. Public policies and private investments around the globe are aiming to increase local capacity to produce biofuels. The first generation of liquid biofuels is derived from food – ethanol from sugarcane and corn grain, biodiesel from oilseed crops. However, evidence is growing of harmful effects from first-generation biofuels on land use, food prices and the environment. Hence, there is a need to explore the potential for using alternative energy crops and feedstocks that are productive in terms of the fuel they can provide per acre of land and that are environmentally sustainable.

A second generation of liquid biofuels can potentially be produced from cellulosic feedstocks. Lack of sufficient historical experience with growing and collecting the alternative cellulosic feedstocks needed for second generation biofuels makes it necessary to use simulation models. Such models can elucidate how production inputs affect both cellulosic feedstock yields and environmental outcomes, such as water quality, carbon sequestration and biodiversity under varied growing conditions.

Research into biofuel production and environmental impacts is inherently interdisciplinary, involving the linking of a) biophysical models that simulate energy crop yields and their environmental impacts with b) economic decision models that reflect the incentives of landowners to adopt crops and practices that lead to the highest return to producers. Although various component methods exist, a major research challenge is to link them to analyze scenarios for technological and policy changes that will trigger land use changes with implications for food/feed production and prices and impact on greenhouse gas fluxes, water quality and biodiversity.

Workshop objectives

As explained in welcoming remarks by Madhu Khanna and Scott Swinton, a key concern motivating this workshop and research at both the EBI and the GLBRC is the need to develop sustainable biofuels and to bring knowledge from a number of different disciplines to investigate the impacts of biofuels along multiple dimensions. Leading U.S. and European scholars gathered together to explore some of the important challenges associated with economic and environmental modeling of sustainable biofuel production, especially of cellulosic feedstocks. They presented and discussed the state of the art in modeling methods being applied to study bioenergy crops with a focus not on modeling results, but rather on key research gaps and methodological challenges – such as broadening spatial and temporal scales, incorporating new environmental services, and modeling new types of landscapes and industrial process logistics. The workshop provided an interdisciplinary forum for exchanging research ideas, critically assessing work in this area and encouraging collaborative efforts. There were six main themes of the workshop:

1) Biophysical models of yields of bioenergy crops;
2) Soil carbon modeling with bioenergy crops;
3) Linking yield models with economic decision making;
4) Water quality and biodiversity impacts of biofuel crops;
5) Modeling land use implications of biofuel crops;
6) Integrative modeling approaches.

Frank Boteler welcomed the participants on behalf of CSREES and described the strategic plan of the U.S. Department of Agriculture (USDA) for bioenergy development in the United States. Steve Long described the mission of the EBI to foster interdisciplinary research on the campuses of Berkeley and Illinois and emphasized the importance of examining the economic and environmental implications of biofuels.

Cathy Kling of Iowa State University opened her keynote address by quoting George Box's epigram, "All models are wrong; some are useful." In reviewing the challenges associated with economic and environmental modeling, Kling stressed the importance of understanding the interrelationship between scale and complexity of models and of developing integrated, innovative models of water quality effects from diverse agricultural producers working in heterogeneous landscapes. She illustrated her research at two different scales: First, at regional scale over several U.S. states, she examined farm decisions in the Upper Mississippi River Basin using USDA's National Resource Inventory data for analyzing policy solutions for addressing the problem of hypoxia in the Gulf of Mexico. Second, at sub-field scale, she described using GIS field level data for the Walnut Creek watershed in Iowa to examine the water quality effects of conservation practices and the optimal targeting of such practices. She described the design, advantages and limitations of evolutionary algorithms to select the optimal combinations of conservation practices and locations to achieve water quality objectives at least cost.

Biophysical models of yields of bioenergy crops

The organized workshop sessions began by examining key biophysical process models and current challenges in their development and adaptation to biofuel crops. The first session focused on the challenges of modeling the yields of switchgrass and miscanthus. The ALMANAC model employed by the USDA and presented by Jim Kiniry, USDA Agricultural Research Service, has been used to model the growth of a number of crops using field level data. Kiniry described the applications of ALMANAC to simulating growth of western range species, improved pasture grasses and the production, nutrient cycling and water use by biofuel crops like switchgrass and miscanthus in the Great Plains states. Atul Jain, University of Illinois and EBI, then stressed the need for accurate, location-specific modeling of water, nitrogen, and carbon cycles to determine the growth potential and environmental impacts of cellulosic feedstocks. In each case, the environmental benefits touted for biofuels will be determined by where and how crops are grown. Fernando Miguez, University of Illinois and EBI, framed the discussion by pointing out that a history of switchgrass experimentation in the US and miscanthus production in Europe can provide empirical data with which to test the model results presented.

Soil carbon modeling with bioenergy crops

The second session explored soil carbon modeling, which is key to understanding the links between agricultural practices, such as soil tillage, and resultant greenhouse gas (GHG) fluxes. Wilfred (Mac) Post of the Oakridge National Laboratory and the GLBRC discussed extensions to the CENTURY model to improve the modeling of soil carbon fluxes for atmospheric carbon sequestration. Current research focuses on modeling the role of microbes in the formation and breakdown of micro- and macro-aggregates of soil organic matter and minerals. Micro-aggregates play a key role in carbon sequestration. Their stability is sensitive to both tillage and biocides.

William Parton of Colorado State University, the lead developer of the CENTURY model and its daily version, DAYCENT, presented three ways of linking economic and ecosystems models with a focus on climate change: 1) fully linked, 2) economic to ecological, and 3) ecological to economic. The DAYCENT model bases its ecosystem modeling on net primary productivity (NPP) and net GHG flux (based on methane, nitrous oxide and carbon dioxide fluxes). These outcomes are modeled via daily plant growth, soil temperature, water movement, nitrogen cycling, and crop yields. Economic to ecological modeling of GHG changes begins with economic models to predict land use change, then relies on ecological models to predict ecosystem responses. By contrast, ecological to economic modeling starts by modeling ecological outcomes (both marketable, such as crop yield, and non-marketable, such as GHG flux) from a variety of management practices and then examines the economic implications of those outcomes as the basis for economic choices. DAYCENT, which has been used both ways, is being adapted to include miscanthus and switchgrass, with special research into nitrous oxide dynamics.

As discussant, Mark David of the University of Illinois and EBI, presented a side-by-side comparison of denitrification model routines from the biogeochemical models DAYCENT and DNDC and the agronomic models EPIC, SWAT, and DRAINMOD-NIT. He found little difference in model results for annual N fluxes, but major seasonal differences.

Linking yield models with economic decision making

In the context of economic models of crop producer behavior, Daniel de la Torre Ugarte of the University of Tennessee presented the structure of the U.S. national scale POLYSYS linear programming model, an example of the economic to environmental modeling approach. POLYSYS uses the agricultural statistical district (ASD) as its primary scale unit, capturing the four major soil types per ASD and 20 major crop rotations per soil type and ASD. He expressed concern that the U.S. Department of Agriculture is gathering and distributing less of the farm cost and price data needed to support models like POLYSYS. The economic model includes crop and livestock sectors and determines agricultural income while the environment module uses EPIC to model soil erosion, chemical runoff and leaching, nutrient availability, soil organic carbon and other environmental variables. Current developments of the model include a shift to ALMANAC for modeling environmental outcomes.

Madhu Khanna of the University of Illinois and EBI discussed her research on modeling the impacts of biofuel production changes on economic welfare and GHG fluxes. Her group is developing a national, price-endogenous linear programming model of land use change at the county level. The model draws upon county-level crop budgets and uses a ten-year rolling time horizon to capture the investment decisions involved in perennial biofuel crops such as miscanthus and switchgrass. By capturing feedbacks between crop supply, land use and input requirements, the model simulates evolving prices as land and crop markets adjust to changes.

The discussion by Scott Swinton of Michigan State University and GLBRC focused on how the appropriate scale for economic-environmental modeling changes with ecosystem services of interest. Most models of agricultural effects on GHG fluxes do so at the plant scale, so effects are independent of the surrounding landscape and linear extrapolation is viable. Hydrological outcomes depend on location in the watershed. By contrast, biodiversity effects, such as the effect of natural enemies on agricultural pests, depend on the relevant habitat surrounding a given site, complicating modeling by making biodiversity impacts conditional on surrounding crops and non-crop areas.

Water quality and biodiversity impacts of biofuel crops

Water quality and biodiversity are interconnected issues at the heart of concerns regarding agricultural expansion. With agriculture accounting for approximately 70% of America's water usage, as well as for issues such as the aforementioned damage to water resources throughout the Mississippi River Basin, water was a key issue in this conference. Cesar Izaurralde of the Pacific Northwest National Laboratory at the University of Maryland and the GLBRC gave an overview of the GLBRC's sustainability research. Izaurralde's work on modeling individual watersheds uses the APEX/EPIC and SWAT models to simulate crop yield and environmental impacts based on the unique characteristics of particular ecosystems.

Wopke van der Werf of Wageningen University (Netherlands) elucidated data requirements and modeling approaches for measuring the value of biocontrol from the natural enemies of agricultural pests. Using data from Europe and the United States, he showed that diverse agroecosystems are most effective and efficient when they include noncrop areas that serve multiple purposes, such as habitat for natural predators, reducing pesticide runoff, preventing erosion, producing wood or biomass, as well as aesthetic or cultural benefits. He identified management of the spatial configuration of noncrop areas as an emerging challenge for agro-ecological modeling.

Building on the van der Werf presentation, Doug Landis, Michigan State

University and the GLBRC, highlighted the role of the surrounding landscape in providing wildlife habitat. Using examples of birds and beneficial insects, he showed how species numbers depend upon the vegetation composition of the surrounding landscape. Incipient modeling efforts aim to capture these neighborhood effects. Landis cautioned that centralized biorefineries could create pressure for biofuel crop monocultures within a certain radius.

Incorporating science into economic analysis

The theme of the keynote address by David Zilberman, University of California, Berkeley and EBI was incorporating science into economic analysis. He pointed out that "sustainability can not be attained without (interdisciplinary) knowledge to form policy actions." Interdisciplinary research is often driven by the need to explain or model reality and can involve several disciplines working in parallel or in an integrated manner. He provided several examples of interdisciplinary research that incorporate scientific information in economic models to explain adoption of conservation technologies, to undertake an assessment of risks of policies and processes to human and environmental health and to develop policies to reduce the environmental contamination caused by pesticides. Policy research is inherently interdisciplinary because one needs to consider technical options, individual behavior and politics in designing effective solutions. He concluded with the observation that the ideal to aim for is policy research based on a foundation of economics, scientific knowledge, and common sense.

Modeling land use implications of biofuel crops

The presentations on impacts of large scale biofuel crop production began with Guenther Fischer of the International Institute for Applied Systems Analysis (IIASA) in Austria, who reviewed a joint IIASA-FAO study of land use change in response to biofuel mandates. IIASA uses global, geographically referenced data organized by agro-ecological zone in a multicriteria optimization model to predict land use changes to the year 2100 at 10-year intervals. He showed that the land area available for biofuel production is very limited if one excludes land currently used for food and forest or is unproductive or protected.

Uwe Schneider of the University of Hamburg (Germany) has developed a European Forest and Agricultural Sector Optimization Model (EUFASOM), using similar principles as in the FASOM model of Bruce McCarl of Texas A&M University. EUFASOM is a mixed integer linear programming model that maximizes economic surplus, with endogenously determined prices. Schneider illustrated the use of the model for calculating the minimum cost and minimum area of wetland habitat reserves needed to preserve 70 species of vertebrates, and modeling atmospheric carbon sequestration in agricultural soils over time by simulating crop rotations using EPIC jointly with EUFASOM.

As discussant, André Faaij of Utrecht University (Netherlands) surveyed a range of biofuel impact studies. He called for improving modeling of technological change and farm management, improving model integration of water and biodiversity, explicitly modeling non-agricultural lands, marginal lands and production residues, and better capturing of price feedbacks and government behavior.

Integrative modeling approaches

The challenges of integrative modeling were addressed both via bioeconomic optimization models and life cycle analysis models. Bruce McCarl of Texas A&M University reflected on his experience from developing FASOM and FASOMGHG, the greenhouse gas version of the Forest and Agricultural Sector Optimization Model. These economic surplus optimization models forecast over a 100-year time horizon using 5-year steps. They are integrated with a variety of biophysical simulation models. He made observations about "land mines" to avoid in integrated modeling, including these: GIS data are seductive, but need ground-truthing. Be cautious about extrapolation. Remember economic principles such as factoring in transportation costs, recognizing willingness-to-pay behind demand, and including the appropriate set of production activities. Ongoing processes to include in dynamic models are technological change, price response to changing supply, and the effects of climate change. Among the many challenges for modeling biofuel futures are the evolution of climate, water supplies, and markets; capturing technological progress; indirect land use change; integrating aggregate market models with highly detailed spatial biophysical data; reliably incorporating environmental services; building in risk; and incorporating new crops.

Paul Meier of the University of Wisconsin and the GLBRC outlined challenges associated with life cycle analysis of biofuels, which requires the integration of biophysical models of biofeedstock production, industrial models of processing in the biorefinery, and energy flow models. Life cycle analysis of GHG effects of biofuels are sensitive to terrestrial emissions, agronomic practices, crop yield, processing efficiencies, co-products (and what they displace, as the case of distillers grains and solubles displacing feedgrain), secondary transportation effects (from refinery to consumption point) and indirect land use effects. The effects of co-products and indirect land use change are significant and difficult to model. Reflecting on the ultimate reliability of model outputs, Meier closed with a quote that was a suitable bookend to the George Box quotation with which Cathy Kling had opened the workshop. He quoted Art Jeffrey's reminder that, "The purpose of models is insight, not numbers."