Biofuels and Sustainability Reports

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Biofuels: Implications for Land Use and Biodiversity

Virginia H. Dale, Keith L. Kline, John Wiens, and Joseph Fargione

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Biofuels, generally defined as liquid fuels derived from biological materials, can be made from plants, vegetable oils, forest products, or waste materials. The raw materials can be grown specifically for fuel purposes, or can be the residues or wastes of existing supply and consumption chains, such as agricultural residues or municipal garbage. In this series of reports, sponsored by the Energy Foundation, we explore the production and use of biofuels from an ecological perspective. Each report addresses one aspect of biofuel production. The report topics are biodiversity and land use; forestry; grasslands, rangelands, and agricultural systems; and biogeochemistry. A capstone issue will present a synthesis of the ecological dimensions of biofuel production.

These reports, which were reviewed by an Advisory Committee, are based upon scientific manuscripts initially presented at a conference in Washington, DC, on March 10, 2008 (see www.esa.org/biofuels). The conference was hosted by the Ecological Society of America (ESA) and sponsored by a consortium of other scientific organizations, nongovernmental organizations, federal agencies, and the private sector. ESA also issued an official statement on the topic in January 2008, which can be found at:

http://www.esa.org/pao/policyStatements/Statements/biofuel.php

As innovations are made in the production and use of biofuels, ecologists worldwide will continue to actively monitor their impacts.

Cover photo credits: *Pennsylvania watershed, USDA Agricultural Research Service*
Henslow's sparrow, Max Henschell

Biofuels: Implications for Land Use and Biodiversity

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Relationships between people and their environment are largely defined by land use. Space and soil are needed for native plants and wildlife, as well as for crops used for food, feed, fiber, wood products and biofuel (liquid fuel derived from plant material). People also use land for homes, schools, jobs, transportation, mining and recreation. Social and economic forces influence the allocation of land to various uses. The recent increase in biofuel production offers the opportunity to design ways to select locations and management plans that are best suited to meet human needs while also protecting natural biodiversity (the variation of life within an ecosystem, biome or the entire Earth).

Forethought and careful planning can help society balance these diverse demands for land. At the same time, current energy infrastructure must become less reliant on the earth's finite supply of fossil fuels because they contribute to greenhouse gas emissions, cause environmental pollution, and jeopardize energy security. The sustainable development of renewable fuel alternatives can offer many benefits but will demand a comprehensive understanding of how our land-use choices affect the ecological systems around us. By incorporating both socioeconomic and ecological principles into policies, decisions made regarding biofuel production can be based on a more sustainable balance of social, economic, and ecological costs and benefits.

Researchers are actively studying the potential impacts of biofuels production on land use and biodiversity, and there is not yet a firm consensus on the extent of these effects or how to measure them.

In this report, we summarize the range of conclusions to date by exploring the features and benefits of a landscape approach to analyzing potential land-use changes associated with biofuel production using different feedstocks. We look at how economics and farm policies may influence the location and amount of acreage that will ultimately be put into biofuel production and how those land-use changes might affect biodiversity. We also discuss the complexities of land-use assessments, estimates of carbon emissions, and the interactions of biofuel production and the US Department of Agriculture Conservation Reserve Program. We examine the links between water and biofuel crops and how biofuel expansion might avoid "food versus fuel" conflicts. Finally, we outline ways to design bioenergy systems in order to optimize their social, economic and ecological benefits.

Land Use and Feedstock Options

A Landscape Approach

Many aspects of biofuels have been closely studied. Analyses have been conducted on the environmental implications of the production of some biofuel feedstocks (the plant materials used to make biofuels) and on the logistics of their harvest, handling, storage, pretreatment, and transportation from field to refinery. In order to help policy makers and the public understand the integrated environmental and socioeconomic consequences associated with the increased use of bioenergy crops, it is critical also to develop a landscape approach that takes into account changes in land use and management for bioenergy feedstocks that alter existing ecological properties. Such an approach can clarify the tradeoffs involved in making choices about land use for food production, bioenergy crops, biodiversity protection, and other societal needs.

This landscape approach needs to consider many factors, including the type and location of the plant species to be grown for biofuel feedstock, farming and harvesting systems involved in their production, transportation to refineries, the type and location of the production facilities, and transportation of the fuel to market.

Considerable attention has been given to annual crops from which biofuel can be produced, including soybeans and corn. However, other feedstock options are based on stems, stalks, or woody components of plants, so-called lignocellulosic materials. Perennial crops, which do not need to be replanted after each harvest, such as grasses and fast-growing trees are one such type of feedstock. These energy crops offer some environmental advantages compared to traditional annual crops, but they may demand innovative management techniques in order to be sustainable.

Urban wastes and leftovers or residues from industrial processing and agricultural crops can also be used as feedstocks. For example, corn stover includes the stalks, leaves, and empty cobs left from corn production. Wheat straw is material left over after grain has been

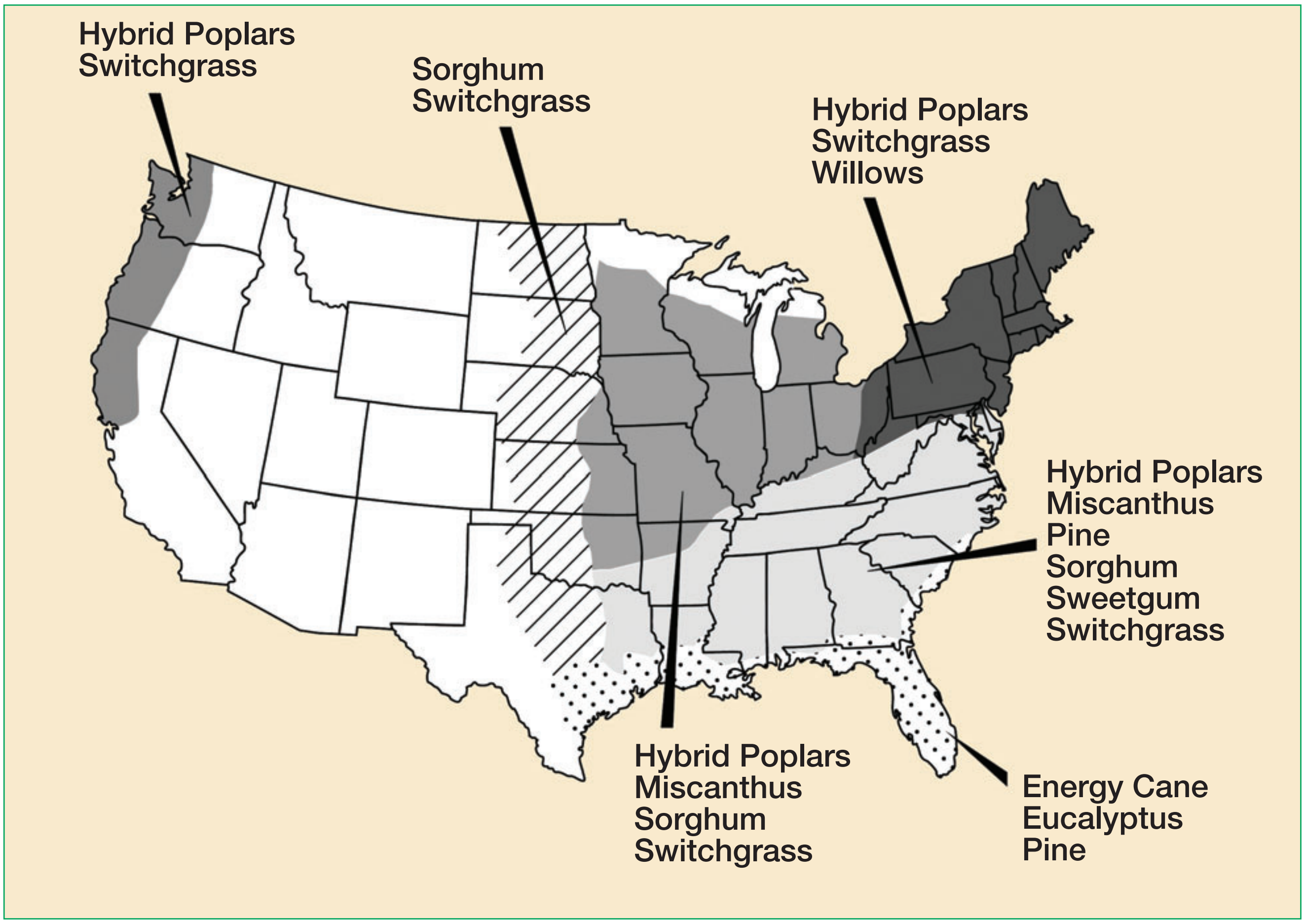

Figure 1. *Generalized map of potential rainfed feedstock crops in the conterminous US based on field plots and soil, prevailing temperature, and rainfall patterns [updated from Wright. 1994.* Biomass and Bioenergy **6**:191–209]

processed. When forests are thinned for fire prevention, the thinnings can be used for feedstock, as can wood residues from logging operations and wood-processing plants. There are several forms of municipal waste that can be processed and used to produce energy, including grass clippings, leaves, tree trimmings, paper and cardboard, and the used lumber and construction materials from building renovations. The pressed stalks from sugarcane production (known as "bagasse") along with other cane leaves and fibers are another feedstock with particularly large potential in sugar-producing nations such as Brazil.

Lignocellulosic feedstocks offer many potential improvements over corn ethanol, gasoline, or average electricity in terms of conversion efficiency and emissions. But each feedstock will have slightly different environmental effects that can vary from region to region or site to site. Some dedicated bioenergy crops have greater potential as biofuels than some crop residues, especially when full environmental costs are considered. However, due to the high costs of collecting and transporting biomass to processing plants where conversion to liquid fuels occurs, it will be difficult for any currently envisioned dedicated crop to compete economically with the large volumes of sugarcane residues that are already available from ethanol plants in Brazil. Perennial energy crops that are native species, such as switchgrass in many parts of the US, appear to offer considerable promise for both economic and environmental sustainability.

The long-term sustainability of bioenergy feedstock resources throughout the world depends on land-use practices and landscape dynamics, so assessing the ecological and environmental impacts of these alternative feedstock choices is a necessary part of determining their economic and social viability. Decisions regarding how crops are grown and managed will determine their effects on carbon sequestration, native plant diversity, competition with food crops, greenhouse gas emissions, water quantity, and water and air quality. If some crops prove too expensive to grow or process, then their prospects for market success will be limited in the absence of subsidies. Similarly, decision makers may limit or avoid the production of feedstocks whose environmental impacts are considered to outweigh their benefits.

The economic and environmental benefits of crops are often region-specific as well. Eucalyptus trees and tropical grasses, for example, are well-suited to the climatic conditions in parts of the southeastern US but would not do well in other areas. The viability of some potential feedstock crops in areas of the US based on soil conditions and prevailing temperature and rainfall was characterized in the 1980s and 1990s using data from field plots around the country (Fig. 1). Of the 25 species identified at that time, the only annual was sorghum, although sorghum's viability is heavily dependent on crop management. There are high net energy returns for other biofuel crops such as sugarcane and palm oil that are grown in tropical regions of the world. These crops are not a major part of biofuel production in the US, although they may affect global biofuel commodities markets and thus the economics of various biofuel feedstocks.

Crop and seed selection combined with certain best practices for cultivation can reduce input costs while maintaining high productivity, thereby improving both financial and environmental sustainability. These practices include low-till or no-till cultivation in integrated farming systems and other cultivation practices designed to minimize inputs such as fertilizers, pesticides, herbicides, and water. With careful land-use planning, crop rotations, and varietal selection, the management of energy crops can also increase profit margins for other farm commodities while reducing environmental effects due to agricultural activities.

Importantly, dedicated perennial bioenergy feedstock crops may offer economic advantages compared to annuals for some growers, but the environmental advantages depend greatly on the specific land-management practices used. Crop selection also requires research and safeguards to avoid invasive exotic plants, while recognizing that what is native and non-invasive in one region may not be so in another. Given all of these factors, the choice of an ideal bioenergy crop system will always be location- and market- specific.

Economic Pressures and the Viability of Biofuel Crops

Economic pressures can also determine the viability of biofuel crops. Farmers, like most business managers, prefer to minimize risk. Farmers are unlikely to replace conventional crops with biofuel crops unless they are confident that biofuel crops will offer equal or better profits given prevailing local farm conditions. Additional insight has been provided by the Biomass Research and Development Interagency Board, chaired by the US Departments of Agriculture and Energy, in a study of feedstock production scenarios using a policy simulation model developed at the University of Tennessee (POLYSYS). The study assessed the potential economic and land-use outcomes of bioenergy crop production to meet current federal renewable fuel targets under various scenarios. The study found that dedicated perennial crops are anticipated to initially require grower incentives in order to be competitive with conventional crops now being grown. The need for incentives is caused, in part, by the billions of dollars in farm subsidies and federal insurance that support conventional crops.

Economic Opportunities Extend Beyond Farming, But So Do Environmental Impacts

Biofuels represent new or increased economic opportunities to many rural regions of the US and elsewhere, and not just for farmers. Although growers could experience increased profits, many communities would see an increase in other job opportunities if refineries or processing plants were to open locally. This economic opportunity will need to be monitored carefully because the building and maintenance of biofuel infrastructure will represent another kind of land-use change. Building refineries, increasing truck traffic, and changing the economic dynamics of rural areas all constitute land-use changes that will have additional environmental impacts beyond the conversion of land to biofuel feedstock production alone.

Where Will the Land Come from for Biofuel Crops?

Some researchers anticipate that the push to develop and grow more cellulosic biofuel feedstocks will dramatically change the way land is used in the US, while other studies suggest that biofuel targets can be met with relatively minor adjustments. But no matter which crop is grown, land will be needed and land-use practices will be affected.

The 2007 Census of Agriculture determined that the US has roughly 373 million hectares that are owned or managed by agricultural producers. Of this total, 166 million were classified by the census as permanent pasture or rangeland, 30 million as woodland, and 165 million as cropland with the latter including 14 million hectares of "cropland-pasture." About 15 million hectares of farmland were also enrolled under various conservation reserve programs as of September 2007, and some of this conservation land overlaps with the other land classifications.

Biofuel feedstocks could be derived from all these farmland categories (as well as other non-farm sources). However, perennial bioenergy crops might be most appropriately considered as a component of conservation farming systems where their use is integrated with

Economics and Ecology: Different Ways of Measuring the World*

The disciplines of economics and ecology share a common linguistic root (the Greek oikos, roughly meaning "home"). Despite this commonality, economists and ecologists tend to approach the world in different ways. They differ in the basic units used to assess and predict the dynamics of systems (currency versus populations or species). There are more fundamental differences as well. Ecologists tend to drill down into biological details and underlying mechanisms more than do economists, whereas the latter tend to focus more on tradeoffs between competing forces or demands. Environmental issues are sometimes portrayed as a choice between economics or the environment. Debates about the economics and ecological implications of biofuels bring such issues to the fore, yet the real issue of concern is how the two can be integrated. Discussions about the development of different biofuel feedstocks must necessarily consider economics and ecology as well as the social conditions of the farmers. The real need is to use the cost-benefit framework developed by economists in ways that include the ecological as well as the economic and social costs and benefits. These ecological and social factors too often represent hidden costs that are left off of the balance sheet. Developing biofuel policies that acknowledge economic, social, and ecological realities requires comprehensive cost-benefit accounting that considers the integrated economic, social, and environmental systems.

*A perspective offered by J. A. Wiens

land-use planning and rotations that improve soil quality and reduce erosion and leakage of agricultural inputs. A well-designed approach for overall land use would consider the potential of the land for all human needs (food, feed, fiber, fuel, wood, and human occupation) as well as for biodiversity protection and would place each use in its most suitable location.

Land owned by farmers that is not currently cropped may be suitable for bioenergy crops. "Other cropland," for example, was reported as occupying 25 million hectares in the 2007 census and averaged nearly 30 million hectares over the past five census reports. "Other cropland" includes idle lands, land in cover crops for soil improvements and fallow rotations. The area in "other cropland" could be used for biofuel feedstock production from perennial plants in a way that reduces erosion and improves soils.

Of all of the potential locations that might be tapped for increased biofuel production, marginal lands, abandoned croplands, and abandoned pasture lands appear to offer significant environmental and economic potential, particularly if the biofuel crops are perennial and if sustainable land-management practices are employed. In the US, there are approximately 51 to 67 million hectares of this kind of land available; those areas could produce as much as 321 million tons of biomass per year. Globally there are about 385 to 472 million hectares of abandoned cropland that could produce between 1.4 to 2.1 billion tons of biomass [see Campbell et al. 2008. Environmental Science & Technology, 42:5791].

Several biotechnology firms are using a variety of methods, including genetic engineering, to develop ways to expand the range of conditions where perennial feedstocks (and other crops) can be grown. Improved crop varieties and farming practices have allowed the US to produce increasing amounts of food, feed, fuel and fiber using less land area over the past fifty years. Research may eventually enable the production of crops on current agricultural lands with far fewer inputs as well as permit expansion to areas once deemed marginal or too poor in quality to support agriculture. As crop breeding and biotechnology research continue to expand the range of growing conditions for biofuel feedstocks, the potential environmental effects must be carefully monitored. Areas containing important habitats for wildlife and that are rich in biodiversity that were not previously suitable for agriculture may become at risk of conversion to cropland and such areas merit special attention and protection.

Can Biodiversity and Biofuels Coexist?

Simply stated, biodiversity is the variety of life that exists in any one place at one time. Conservation work is often focused on protecting biodiversity through the establishment or maintenance of protected areas, and such efforts entail preserving the health and well-being of our planet for future generations. More and more, however, conservation is being enlarged to include the places where people live, work, and produce food and fiber. Farms have played a key role in this paradigm shift because a variety of organisms are able to persist and even thrive in agricultural landscapes. According to the Millennium Ecosystem Assessment of 2005, agricultural systems cover nearly one-quarter of the Earth's terrestrial surface although a small fraction is actively managed or harvested in any given year.

Ecologists have long posited that overall terrestrial biodiversity is increased when there is a variety of different plants growing in one area. Environmental sameness—homogeneity—tends to reduce biodiversity. There is evidence that this is true on farms as well as on other lands. For example, research in many areas has demonstrated that sites with high crop diversity tend to have larger numbers of birds, butterflies, beetles, and

What is "Marginal?"

What "marginal" land is depends on context. The definition of "marginal land" varies widely by country, local conditions, and the organization studying the issue. It is a relative term; the same qualities used to classify a site as being "marginal" in one place or for one purpose can result in land being considered productive in another place or for a different purpose. Therefore, there are great uncertainties among the wide-ranging estimates of availability and suitability of "marginal land" for bioenergy crops.

Economically, land is marginal if the combination of yields and prices barely covers cost of production. In practice, the term is generally used more broadly to describe any lands that are not in commercial use in contrast to lands yielding net profit from services. Depending on time and place, marginal land may also refer to idle, under-utilized, barren, inaccessible, degraded, excess or abandoned lands, lands occupied by politically and economically marginalized populations, or land with characteristics that make a particular use unsustainable or inappropriate.

Categorizing or quantifying marginal lands using satellite imagery is especially problematic, as areas that seem idle or marginal when viewed from above may actually be only temporarily fallow, have been recently cleared, or are being used in non-traditional ways.

Concerns arise when definitions or classifications of marginal land are used to justify change to a new land use without adequately considering land's diverse values. Land values may include ecological services the land provides, spiritual and cultural values that the land holds for local populations, and the often overlooked traditional uses by lower-income groups that depend on "marginal" lands for their livelihoods. Concerns also arise when special programs target the use of "marginal" lands for development because this identification alone can lead to perverse incentives; productive land can quickly be abused and converted to "marginal" status in order to qualify for such programs.

spiders than sites of the same size where there was only one kind of crop being grown. The various birds and beneficial insects, in turn, provide ecosystem services including the mitigation of crop pests.

Despite these biodiversity benefits, homogeneity tends to be more efficient and less expensive for farmers, so crops such as corn are grown almost exclusively as monocultures in the US. Planting decisions also rely on the expected financial return of the crop, and so are heavily dependent on market expectations. A decision to change from diverse crops to a single crop not only reduces the biodiversity of the areas that are planted on a farm but also contributes to the homogenization of the surrounding landscape, potentially further reducing biodiversity. Extensive landscapes with single cropping can also increase the "environmental footprint" of a farm, because the lack of diversity or repetitious use of land for a single species will tend to require more chemical inputs to control pests and more fertilizer to maintain yields.

Complexity of physical structure also enhances biodiversity, and perennial energy plants have the potential to provide diverse above- and below-ground complexity and thus habitat. A few studies have been conducted on perennial biofuel feedstocks compared to traditional annual crops to determine if these plantings might help to increase biodiversity on farms. The results from these studies suggest that, in general, biodiversity increases if more than one kind of crop is grown in any area over time and under management regimes designed to consider wildlife behavior, but some perennial crops may hold more potential for habitat enhancement than others. Biodiversity can also be enhanced by selected rotation regimes, inter-cropping, cover crops, and "green manures" along with shifts in pasture types and areas, livestock, tree crops, and woodlots in a systematic approach adapted to the conditions of a site.

Research has demonstrated the advantages of wildlife plantings interspersed with croplands, and some bioenergy crops could provide similar benefits in terms of habitat, erosion control, and increased soil carbon. Since many proposed bioenergy crops are relatively new and benefits may be highly site specific, data are not currently available to rank quantitatively the biodiversity values of various feedstocks.

Different Outcomes from Different Plants

Using native perennial plants as biofuel feedstock shows great promise in some areas of the US. Native energy plants are adapted to site-specific and region-specific conditions and for that reason may be less expensive to manage. They also can provide habitat for native wildlife as they grow. The degree to which such benefits are accrued, however, depends on land-use planning and the timing of harvests. In order to maximize their habitat value for birds and other native animals, for example, a grower would need to time planting and harvest of the crop to avoid nesting seasons. Programs that encourage such environmentally-friendly farm practices can increase the benefits of native perennial crops but may require greater economic incentives in order to succeed.

Perennial crops may prove to be especially useful when planted on land susceptible to erosion or degradation, or

The Carbon Debt Controversy

For a long time, biofuels were touted as the "green alternative" to petroleum-based gasoline. But some papers published in Science magazine early in 2008 noted a potential problem, and a debate about potential implications of biofuels has ensued. Calculations of the carbon savings offered by biofuels, author Joseph Fargione and his colleagues argued, depend heavily on where and how the crops for such fuels are produced (Science 319: 1235 [2008]). If rainforests, peatlands, savannas, or grasslands are converted into agricultural use for the production of biofuels, the producing countries or the countries that purchase the fuel create what the authors dubbed a "biofuel carbon debt."

According to Fargione and his team, if this first-time conversion of natural land is attributed to biofuels, anywhere from 17 to 420 times more carbon dioxide could be released than the annual greenhouse gas reductions that these fuels would provide from displacing fossil fuels.

In the same issue of the journal, a paper written by Timothy Searchinger et al. (Science 319: 1238 [2008]) concluded that indirect land-use change effects associated with an increased use of corn-based ethanol could potentially double greenhouse gas emissions in the next 30 years. Biofuels produced from switchgrass, if grown on areas formerly used for the production of corn, could potentially increase emissions by 50%, according to Searchinger's indirect land-use change estimates. These modeling results are based on assumed crop yields and biofuel demand that result in a continued increase in agricultural area. The expansion of agricultural area is assumed to come at the expense of other land uses in the same proportion as seen in historical land-use conversion patterns. "The loss of maturing forests and grasslands," the paper states, "also foregoes ongoing carbon sequestration as plants grow each year and this foregone sequestration is the equivalent of additional emissions."

Critics of the economic modeling approach to land-use change, Keith Kline and Virginia Dale, said in a subsequent letter to Science (Science 321: 199 [2008]) that quantifying land use is no small task. Because land use is a dynamic process, influenced by social, economic, technological, biophysical, political and demographic forces, the global economic models employed by Searchinger and others to attribute widespread deforestation to biofuels have not been corroborated by empirically observed land use changes. "Satellite imagery can measure what changed but does little to tell us why," they wrote. What pushes people to clear more or less new land is more intricate than the simple desire to make money from biofuels, they further argued. Existing modeling approaches being used to estimate biofuel carbon accounts do not adequately consider these forces.

Kline and Dale asserted that adequate land is available for energy crops and that choosing to use these previously cleared lands can enhance social and environmental sustainability while reducing pressures on forests. They pointed out that the two original papers did not account for the important interactions among biofuel policies, land degradation, fire, and climate change. In the absence of local policy or economic incentives and stability offered by improved cash crops including biofuels, land degradation and the widespread use of fire are likely to continue unabated. Understanding how biofuel policies influence land management and measuring the impacts of fire's use in agriculture are important aspects of future biofuel carbon accounting.

Both teams agree that a more comprehensive and science-based cost-benefit accounting system will be needed to adequately evaluate the full effects of biofuels. Such a system would need to account for any land-use changes that occur as a result of biofuel policies versus alternative energy supply scenarios. Complicating this task, both teams acknowledge, are the "indirect" effects of biofuels and other energy supply options. There are many obstacles to measuring how land use in one area may influence land conversion and management in other areas. Both teams note that biofuels produced from waste may be more sustainable than any crop-based system, that protection of sites valued for biodiversity is critical, and that it is essential to improve our capacity to properly assess the relative sustainability of different production scenarios. Meanwhile, debates on issues of carbon accounting continue at the time of this writing, and both data and models to improve projections of land use with and without increased biofuel production are being discussed. Like many arguments in science, both teams say that this kind of discussion is healthy and will help to move the science of ecology forward towards a greater understanding of the world.

as buffers around more conventional annual crops such as corn, soybeans, or wheat. Research has demonstrated that these buffer crops can provide habitat and be used to filter nutrients or contaminants that may be transported from upslope growing areas. Using such buffer areas as production zones for biofuels may prove to be both economically and environmentally beneficial.

The shift from growing annual crops to growing appropriately selected perennial crops is expected to improve soil quality. Soils benefit when no-till or low-till farming practices are employed because these practices significantly reduce soil disturbance and erosion. The roots of perennial plants tend to increase soil porosity (the capacity of soil to hold water) and the amount of water infiltration that can occur at a site. And when compared to traditional annual crops, perennial crops are likely to increase the amount of carbon the soil holds, especially in areas where the soil is of relatively poor quality.

As indicated earlier, crop residues can also be used as biofuel feedstocks, but the environmental implications of residue collection are extremely site specific, which may limit their potential in some locations. As with dedicated crops, the sustainability of using residues as feedstocks depends heavily on site conditions, crop production, residue collection rates, rotation and tilling practices. Soil degradation can occur or increase when residues are collected. Soil types, slopes, exposure, prevailing climate conditions in growing areas, and initial soil organic carbon (SOC) can be highly variable from one location to another, which affects the amount of residues that can be removed without negative impacts on the soil. Recent research results suggest that traditional wheat straw removal may continue over long periods of time without significant effects on SOC. In many locations, data suggest that more corn stover is needed to maintain sustainable levels of SOC than is required to control erosion; it will be very important to gain a clear understanding about how much crop residue is needed to retain SOC if stover and other residues are to be used for biofuel feedstock. Some researchers also have voiced concern that birds that regularly use crop residues for food resources may be displaced if these residues are harvested.

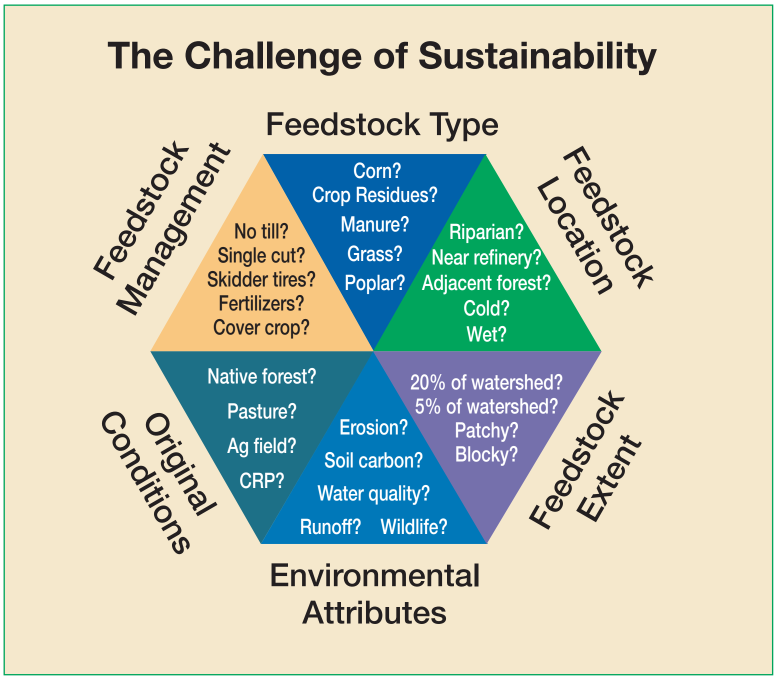

Figure 2. *The challenge of sustainability is addressing all six dimensions.*

Agriculture, Land Use and Biodiversity: Biofuels and the Conservation Reserve Program

The USDA Conservation Reserve Program (CRP) began in 1985 "to help control soil erosion, stabilize land prices and control excessive agricultural production" (Congressional Research Service 2009, Report RS21613). Since then, the program has expanded to provide technical and financial assistance to farmers and ranchers to address soil, water, and related natural resource concerns on their lands in an environmentally beneficial and cost-effective manner. Congressional intent included the development of market-based systems to manage agricultural commodity prices while conserving the nation's future ability to produce food and fiber. Under the CRP guidelines, farmers are encouraged to convert highly erodible cropland or other environmentally sensitive acreage to vegetative cover such as native grasses or trees. They sign contracts with the federal government to take such land out of crop production for ten or fifteen years, for which they receive a per-acre payment and are provided with technical assistance. Regionally, specific land-management practices are used on CRP lands to reduce soil erosion and sedimentation in streams and lakes, improve water quality, establish wildlife habitat and enhance forest and wetland resources close to farms. These practices enhance biodiversity by subsidizing habitat creation in areas that would otherwise be planted to row crops.

Enrollment and extensions in CRP are competitive processes whereby farmers bid to retire land, and contracts are awarded based on both the bid price and USDA's assessment of the land's conservation value using an Environmental Benefits Index (EBI). The EBI has been modified many times since its inception in the 1990s to reflect changing conservation priorities and has served as a national screening tool. For CRP's most recent general sign-up, USDA accepted about 400,000 hectares out of 570,000 hectares offered, based on available funding and the lowest bids received for land with the highest EBI scores. Similarly, USDA applied the EBI to prioritize re-enrollment and extensions as contracts approached expiration.

Many environmental groups and researchers have celebrated the success of CRP for biodiversity enhancement. Several grassland bird species have increased in abundance on lands enrolled in CRP, which is important because grassland birds have collectively experienced dramatic population declines over the last fifty years. It is also estimated that, without the 3 million hectares of CRP in the Prairie Pothole region of the US, over 25 million ducks would be lost from the fall migratory flight.

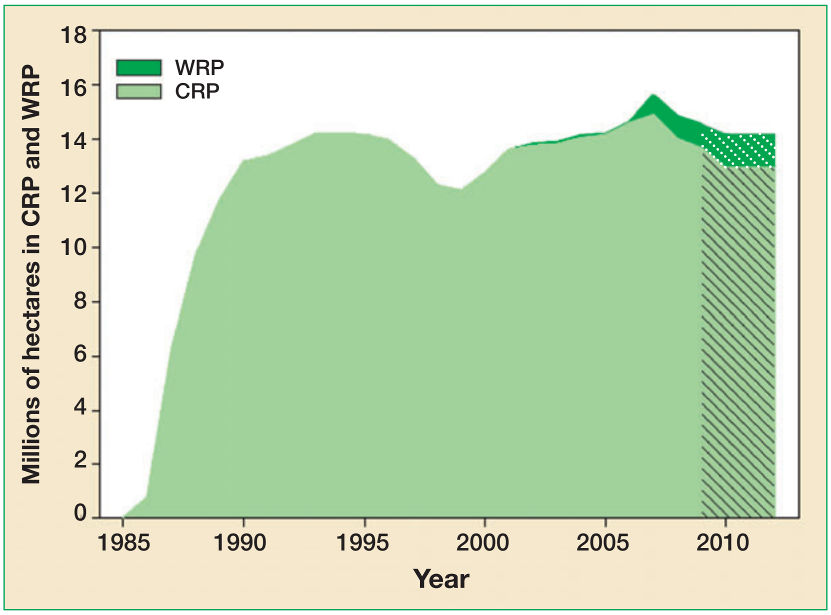

Figure 3. *Observed data run through 2009. Hatched areas are projections based on maximum allowable area under the 2008 Farm Bill. CRP: http://www.fsa.usda.gov/FSA/webapp?area=home&subject=copr&topic=rns-css WRP: http://www.nrcs.usda.gov/Programs/wrp/2012 caps: http://www.ers.usda.gov/FarmBill/2008/Titles/titleIIConservation.htm#conservation*

The amount of land in CRP is potentially limited both by landowner decisions and by Congress through caps in the amount of area and budget allocations to the program. Specifically, the amount of land in CRP can be limited if landowners choose to produce crops instead of enrolling in CRP or if Congress chooses to lower CRP caps or budgets to increase agricultural production. Demand for biofuels, which can affect commodity prices, could potentially affect both landowner decisions to produce crops and Congressional efforts to increase agricultural production. However, interest from landowners historically has exceeded CRP capacity. Further, Congressional decisions on CRP caps and funding are affected by many factors, including a desire to allocate more funding to other conservation programs.

CRP land areas have grown substantially since programs began in 1985, approaching the limits defined by Congressional authorizations and funding (Fig. 3). The 2008 farm bill reauthorized the CRP with a cap of 13 million hectares and a cost of over $2 billion per year. The cap is 3 million hectares less than the cap in the 2002 farm bill (P.L. 107-171) and nearly 2 million hectares below the peak enrollment in 2007. However, the CRP funding levels increased compared to the 2002 bill. Given current budget and scheduled contract expirations, USDA expects enrollment to fluctuate between 12 million hectares and the 13 million hectare cap over the next three years. The farm bill also includes measures to improve CRP environmental performance. It amends CRP pilot programs for wetlands and buffers and requires the application of enhanced EBI factors to improve soil resources, water quality, or wildlife habitat. It allows USDA to apply different EBI criteria according to the soil, water, and wildlife conservation needs in different states and regions.

Overall, USDA reports that a high percentage of expiring CRP contracts were already approved for re-enrollment or extension (82% of contracts for 28 million acres expiring 2007-2010), but a couple of states stood out with much lower rates. Re-enrollment or extension in South Dakota, for example, represented only 57% of the area in contracts expiring in that state by 2010. In most cases, if participants decide to return land to production after CRP contracts expire, they must manage the land under a Natural Resources Conservation Service (NRCS)-approved conservation system to remain eligible for federal farm program supports.

The 2008 farm bill expands other NRCS programs for long-term protection of wetlands, watershed protection, grassland reserves, conservation stewardship, and other soil and water conservation incentives on farmlands. If the Wetland Reserve Program (WRP) increases enrollment to the levels allowed under the farm bill (1.2 million hectares) and CRP reaches its cap, there will still be a decrease of about 1.5 million hectares in those two farm conservation programs compared to their combined peak size in 2007. In contrast to CRP and WRP, which increase wildlife habitat by removing land from crop production and requiring a land cover of perennial vegetation, most other programs in the farm bill involve implementing best management practices on existing farmland (e.g., contour farming or no-till agriculture). These practices benefit soil quality and aquatic species threatened by sediment and nutrient runoff, but do not create terrestrial habitat in fragmented agricultural landscapes as CRP does.

In total, NRCS is authorized to enroll more than 113 million hectares under the Conservation Title of the farm bill at an estimated cost of $2.7 billion (Fig. 4; USDA FY2010 Budget Summary and Annual Performance Plan, pg. 71). This represents a "rebalancing" of USDA conservation programs, with a decrease in the proportion of funding allocated to CRP and an increase in the proportion allocated to other programs such as the Environmental Quality Incentives Program (EQIP). This rebalancing is partly a product of research aimed at achieving an ongoing USDA policy goal to maximize environmental benefits per public dollar spent and it also reflects changing needs of society and other political factors. When all conservation programs and policies were reviewed in 2000, EQIP was found to be successful in part due to the statutory requirements to "maximize the environmental benefits per dollar expended." EQIP also had the largest unmet demand, with nearly 200,000 pending applications to improve environmental performance on 67 million acres (USDA 2001).

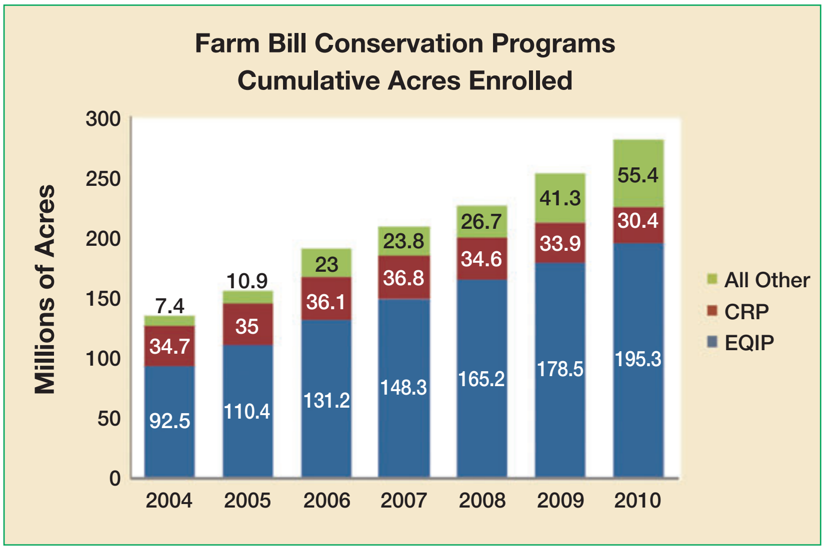

Figure 4. *USDA 2001. Food and Agricultural Policy: Taking Stock for the New Century http://www.usda.gov/news/pubs/farmpolicy01/content.pdf and chapter V: USDA. 2007. Conservation Reserve Program Monthly Summary October 2007. USDA. 2009. USDA Long-Term Agricultural Projection Tables. (10 June 2009; http://usda.mannlib.cornell.edu/MannUsda/viewStaticPage.do?url=http://usda.mannlib.cornell.edu/usda/ers/94005/./2009/index.html)*

Links between Water and Biofuel Crops

In choosing what to grow and where to grow it, available water quantity and crops' effects on water quality emerge as critical limiting factors. Some crops demand more water than others in order to be viable or economically profitable. Furthermore, management of any crop can alter sediment loads as well as the nitrogen (N) and phosphorus (P) concentration of water running off of fields or watersheds. Much is known about water quantity issues required for annual crops' growth at the local farm scale, and there is broad consensus that dedicated bioenergy crops should be grown where irrigation is not required. In addition, processing the harvested crop into biofuel can create high water demands that must be considered in the life cycle analysis of biofuel production.

A benefit of perennial energy crops is their ability to reduce sediment loads and concentrations of N and P in runoff and thus improve water quality in a local area. Less is known about the impacts of bioenergy crops on water quality at larger spatial scales (for example, the Mississippi River watershed). This is due in great part to the lack of monitoring systems and time-series data needed to understand effects. But when considering the broader scale impacts of crop and cultivation choices, the problem of hypoxia in the Gulf of Mexico provides a ready example of how choices made at the farm level can have broad environmental impacts or benefits at large spatial scales and for downstream ecosystems, extending from the edge of a farmer's fields, to entire regions of the country, and to marine environments beyond. When grown in appropriate locations, perennial energy crops may be able to enhance environmental benefits on a large scale.

Hypoxia in the Gulf: Broad Implications from Local Farm Choices

The Mississippi-Atchafalaya River Basin covers almost half of the US in an enormous swath of land that cuts vertically through the mid-section of the country and ends where these rivers empty into the Gulf of Mexico. The area includes predominant wheat- and corn-growing regions of the Midwestern US, supplying a large share of feedstock for current starch-based biofuels and offering a potential source for future feedstocks based on crop residues.

History suggests that land-use choices in these upstream agricultural lands have broad-reaching impacts on the environment (Fig. 5). The use of ferti-lizers containing N and P over several decades has led to an abundance of nutrients that flow downstream and eventually make their way to the northern part of the Gulf, where they feed algae blooms. As the algae grow, the water becomes murkier. The algae die and decompose, rapidly depleting the water of oxygen and creating areas where only a few organisms can survive, creating so called hypoxic, or "dead," zones.

Hypoxia occurs naturally in many waterways, but the size of the hypoxic zone in the Gulf of Mexico has grown considerably in the last fifty years. The Hypoxia Advisory Panel of the Environmental Protection Agency's Science Advisory Board reviewed the problem in 2007, and noted that there are opportunities to reduce N and P usage throughout the region. The panel recommended converting to alternative rotation systems and cropping systems such as the increased use of perennials. They also recommended the promotion of environmentally sustainable approaches to biofuel crop production, such as no-till farming, the reduced use of

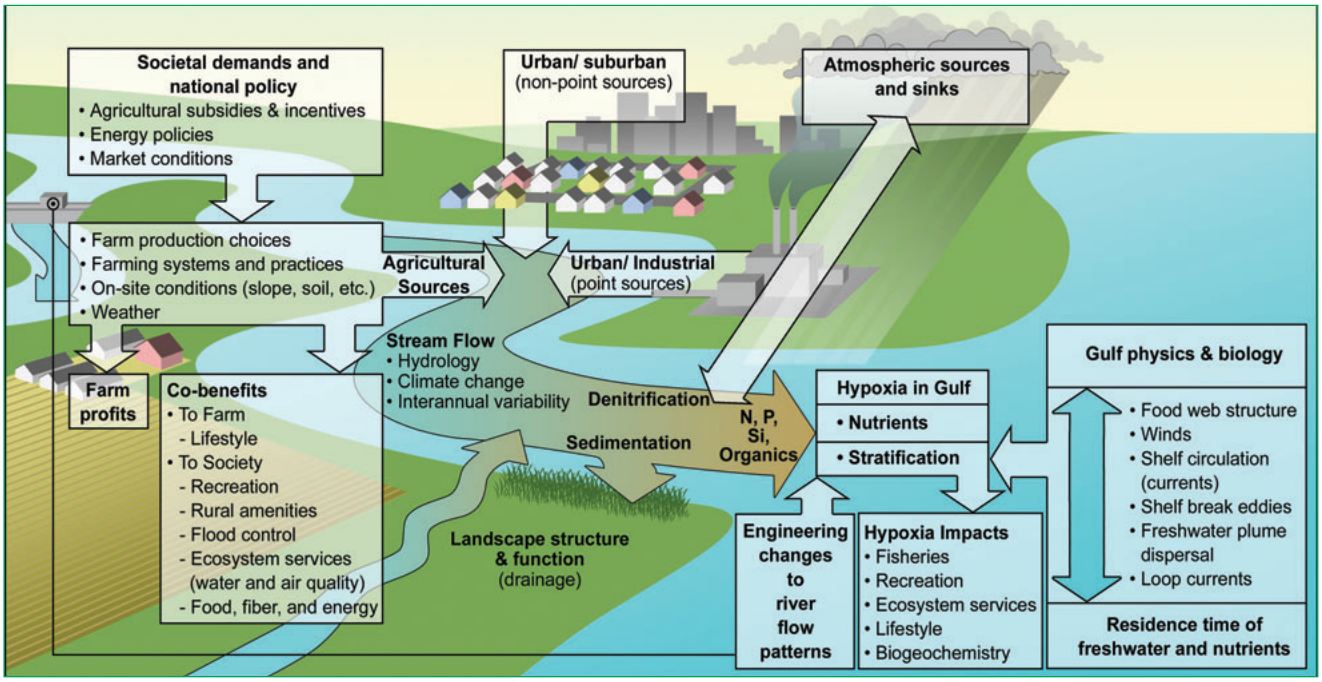

Figure 5. *Conceptual diagram of impacts of land-use choices on hypoxia in the Gulf of Mexico.*

fertilizer, and the use of riparian buffers in targeted areas of the basin. If bioenergy crops that use less water and fertilizer than traditional crops are grown, or even if they are initially planted only as stream buffers around conventional farm systems, then regional water quality can be improved and the annual decline in oxygen in waters of the Gulf can be reduced.

Food, Fuel, and Biodiversity

As with more general issues of land use, the interactions among food crops, biofuel feedstocks, and biodiversity protection are complex. Some articles have blamed sharply higher food prices worldwide on the increased production of biofuels, particularly ethanol from corn, in the US. Other, subsequent studies, however, have found that the increases in food prices were primarily due to many other interacting factors: increased demand in emerging economies, soaring energy prices, drought in food-exporting countries, cutoffs in grain exports by major suppliers, market-distorting subsidies, a tumbling US dollar, and speculation in commodities markets. Although ethanol production indeed contributes to higher corn prices, it is not a major factor in world food costs.

It is unclear what the interactions of food and fuel production will mean for biodiversity across the globe. Some biologists point out that economic pressure often forces those who live in poverty to turn toward other sources of nourishment. Indeed, robust bioenergy markets and improved prices for commodities could boost incomes and opportunities in developing nations where a much higher percentage of the population lives in rural areas and depends upon the land and agriculture for incomes. History suggests that this trend will lead to higher yields, reduced pressures on wildlife and forests, and eventual recuperation of forest cover. On the other hand, the current economic downturn and uncertainties in bioenergy markets could lead to lower prices and increasing poverty. Those who have no other option may increasingly turn to illegal logging, trade in threatened species, or poaching from national parks for income. Carving out patches of public forests for agriculture, as well as poaching and illegal logging in protected areas of the globe, are directly associated with lack of access to markets, faltering governance capacity, inequities, and lack of social services. To the degree that biofuel programs are enacted in conjunction with improvements in these areas, they may also contribute to decreasing the pressures on biodiversity.

Variations in weather, pests, and government policies have caused large and often unpredictable volatility in international grain and food commodity markets. Spiking food prices exacerbate malnutrition and poverty while plunging commodity prices can wipe out small producers. Government subsidies, insurance, and price supports including set-aside programs such as CRP, may help cushion the impacts of these market uncertainties, but at a cost to taxpayers. Economic theory suggests that highly diversified product markets and opportunities for substitution can reduce volatility. Growing crops with product lines that can shift to respond to multiple social needs for food, feed, fuel, and fiber represents one strategy to mitigate volatility and reduce the negative impacts on consumers and producers alike.

Opportunities in Sustainable Biofuels

As the future of biofuels unfolds, it will be important to use sustainability measures to gauge the success of these fuels. The environmental implications of biofuel choices are large, and their complexity calls for a systematic, landscape approach toward understanding the implications for land use change and biodiversity. By understanding and acknowledging the environmental tradeoffs of these new energy systems, we can begin to optimize their socioeconomic and ecological benefits.

It will be important to account for the value of biodiversity as it relates to landscape heterogeneity. Transportation costs tend to concentrate sources of feedstock production close to processing facilities, and this may also reduce the environmental footprint of bioenergy crops. Rotating crops, encouraging the planting of crops that can provide value as habitat, and placing values on biodiversity-rich set-aside areas will also prove valuable in the future.

Figure 6. *Population trends for the Henslow's sparrow (*Ammodramus henslowii*) in Illinois counties were related to the amount of CRP land. Recovery of this species was attributed primarily to the increase in perennial grasslands created by the CRP. (Herkert, J.R. 2007. Evidence for a recent Henslow's sparrow population increase in Illinois.* Journal of Wildlife Management **71**: 1229–1233.)

Large-scale land-use planning becomes especially important as many variables need to be considered in an integrated and systematic fashion. Growing perennial crops in strips along swales and conventional crop fields and on abandoned or idle cropland, combined with improvements in management and productivity of current cropland-pasture areas, may prove to be one of the easiest initial pathways to expand bioenergy crop production in a manner that is compatible with goals to maintain biodiversity and other ecosystem services such as water purification and flood protection. There are myriad ways that land-management practices such as no-till and low-till farming, planting riparian buffers, and minimizing fertilizer use can make the expansion of biofuel cropping a direct contributor to improving environmental quality. Many of these practices received increased support under the 2008 farm bill. More attention can also be focused on the development of feedstocks that do not compete for significant land resources; many look to waste products and, in the longer term, algae for this purpose. Although corn ethanol dominates the economic scene for biofuels in the US at the present time, transitioning to other, second-generation, cellulosic feedstocks is likely to provide the greatest yields most efficiently, with the least environmental repercussions.

Conclusions

The implications of biofuel production and feedstock choices for land use and biodiversity are important, ranging from effects on individual fields to watersheds (which can be as big as the 48% of the US that drains into the Gulf of Mexico) to potentially the entire world. The complexity of these issues calls for a systematic approach to understand the interactions between other forces, bioenergy production, and land-use changes. The many implications of biofuel and cropping system choices also require use of multiple indicators of sustainability costs and benefits at the different relevant spatial and temporal scales.

There are ways in which biofuels can be developed to enhance their coexistence with biodiversity. Landscape heterogeneity can be enhanced by interspersion of land uses, which is easier around production facilities with smaller feedstock demands. The development of biofuel feedstocks that yield high net energy returns with minimal carbon debts, or that do not require land for production, should be encouraged. Competing land uses (including food, fiber, and biofuel production, biodiversity protection, and urban and suburban expansion) should be subjected to comprehensive analysis and planning, so that incentives can be directed where they will do the most good.

Finally, the opportunity to design bioenergy feedstock systems to optimize socioeconomic and ecologic benefits must build from the growing scientific understanding of effects of bioenergy choices at different scales, quantitative metrics, and ways to deal with environmental tradeoffs.

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