AGRICULTURE

Sustainable Biofuels Redux

Science-based policy is essential for guiding an environmentally sustainable approach to cellulosic biofuels.

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Last May's passage of the 2008 Farm Bill raises the stakes for biofuel sustainability: A substantial subsidy for the production of cellulosic ethanol starts the United States again down a path with uncertain environmental consequences. This time, however, the subsidy is for both the refiners ($1.01 per gallon) and the growers ($45 per ton of biomass), which will rapidly accelerate adoption and place hard-to-manage pressures on efforts to design and implement sustainable production practices—as will a 2007 legislative mandate for 16 billion gallons of cellulosic ethanol per year by 2022. Similar directives elsewhere, e.g., the European Union's mandate that 10% of all transport fuel in Europe be from renewable sources by 2020, make this a global issue. The European Union's current reconsideration of this target places even more emphasis on cellulosic feedstocks (*1*). The need for knowledge- and science-based policy is urgent.

Biofuel sustainability has environmental, economic, and social facets that all interconnect. Tradeoffs among them vary widely by types of fuels and where they are grown and, thus, need to be explicitly considered by using a framework that allows the outcomes of alternative systems to be consistently evaluated and compared. A cellulosic biofuels industry could have many positive social and environmental attributes, but it could also suffer from many of the sustainability issues that hobble grain-based biofuels, if not implemented the right way.

Although many questions about biofuel sustainability remain unanswered—indeed, some remain unasked—what we now know with reasonable certainty can be readily summarized. First, we know that grain-based biofuel cropping systems as currently managed cause environmental harm. In addition to questions of carbon debt created by land cleared elsewhere to replace displaced food production (*2*–*4*), farming our existing landscapes more intensively, with even greater quantities of biomass extracted, can easily exacerbate existing environmental problems. The effects of more intense agriculture are well documented: increased soil erosion, greater nitrate and phosphorus loss, and a decline in biodiversity, with concomitant impacts on ground and surface water quality, air quality, and biodiversity-based services such as pest suppression and wildlife amenities. Business as usual writ larger is not an environmentally welcome outcome.

Second, because grain-based ethanol will likely remain in the nation's energy portfolio, it is important to understand that appropriate practices can soften its environmental impact.

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Although the price of cellulosic feedstocks will likely remain lower than that of grain, the added costs of pretreatment and enzymes for cellulosic biomass refining will likely continue to make grain competitive with cellulosic feedstocks for the foreseeable future, even considering cheaper cellulosic biomass. There are many factors affecting the relative prices of ethanol derived from different feedstocks, but with the current infrastructure investment in grain ethanol refineries, it seems likely that grain ethanol will continue to consume a substantial proportion of U.S. corn production—25% in 2007, >30% in 2008—for at least the next decade. Thus, it makes sense to consider ways to minimize the environmental costs of additional intensive grain production.

We know, for example, that no-till farming can slow erosion and build soil organic matter where residue inputs are sufficient; that advanced fertilizer technologies can improve crop nitrogen capture and reduce nitrous oxide fluxes; that cover crops and riparian plantings can sequester soil carbon and intercept nitrate leakage and phosphorus runoff; that rotational diversity and inclusion of unmanaged habitat can better support pollinators and other beneficial insects, as well as wildlife; and that crop genetic improvements can reduce the need for pesticides and can increase stress tolerance and water- and nutrient-use efficiency. But improved practices require incentives to ensure their adoption, and current adoption rates are slow or stalled. Significant mitigation of the adverse environmental consequences of more intensive grain production requires incentives that work.

Third, we know that the development of cellulosic feedstocks has substantial promise for avoiding many of the environmental challenges that face grain-based biofuels. In the long term, most cellulosic feedstocks are expected to be generated from perennial crops grown specifically for that purpose. Pereniality eliminates the need for most chemical inputs and tillage after an establishment phase and lessens the need for nitrogen fertilizer. Further, cellulosic crops can be grown as more complex species mixes, including native polycultures (*5*) grown for additional conservation benefits. Moreover, the cultivation of cellulosic crops has the potential to promote soil carbon sequestration, reduce nitrous oxide emissions, provide to ecosystems in the surrounding landscape biodiversity-based services such as pollination and pest suppression, and afford much higher rates of energy return than grain-based systems.

But however promising, these environmental benefits are by no means given. Whether they are realized will depend on which, where, and how cellulosic biofuels are produced. And tradeoffs are unavoidable. Siting cellulosic biofuel crops on marginal lands, rather than on our most productive croplands, could mean preventing competition with food production and concomitant effects on commodity prices, as well as minimizing or even avoiding the carbon debt associated with land clearing. However, marginal lands can also be rich in biodiversity, may require sizable inputs of nutrients and water to make production economically viable, and may carry the opportunity cost (*6*) of forgone future carbon sequestration.

Management practices, including crop choice, intensity of inputs, and harvesting strategy, also will have a strong influence on the sustainability of cellulosic biofuels. For example, extensive monocultures may be economically favorable relative to polycultures but may reduce landscape diversity and the ecosystem services that more-diverse landscapes provide. Some proposed biofuels crops are exotic (*7*) and others are known to be invasive (*8*), which can have further negative influences on local-to-regional biodiversity. Other cellulosic crops may require substantial chemical inputs and irrigation, with the potential for water pollution, nitrous oxide emissions, and, in arid regions, further competition for water. In addition, excessive removal of "waste" residue from annual cropping systems will rob the soil of carbon (*9*), increase erosion (*10*), and reduce soil fertility. Also, excessive forest thinning will reduce long-term forest productivity and wildlife habitat. In sum, the potential benefits of cellulosic crops could too readily be negated by inattention to choices of location and management practices.

Globally, to produce an important amount of energy with biofuels will require a large amount of land—perhaps as much as is in row-crop agriculture today. This will change the landscape of Earth, not just the United States, in a significant way. To avoid perverse outcomes, such as U.S. policies that cause carbon debt elsewhere, we also need to keep a global perspective that recognizes effects of U.S. decisions on both the magnitude and direction of land-use change elsewhere.

The identification of unintended consequences early in the development of alternative fuel strategies will help to avoid costly mistakes and regrets about the effects on the environment. Policies that support long-term sustainability of both our landscapes and our atmosphere are essential if we are to chart a low-carbon economy that is substantially better than business as usual.

Getting to such an economy will also require a more comprehensive and collaborative research agenda than what has been undertaken to date. In particular, there is an urgent need for research that emphasizes:

(i) a systems approach to assess the energy yield, carbon implications, and the full impact of biofuel production on downstream and downwind ecosystems, however distant from the point of production;

(ii) a focus on ecosystem services—including those that are biodiversity-based—to provide the information necessary for the development and implementation of land-management approaches that meet multiple needs; and

(iii) an understanding of the implications of policy and management practices at different spatial scales—from farm and forest to landscapes, watersheds, food-sheds, and the globe—and an assessment of alternative cost-effective policies designed to meet sustainability goals.

Decision-makers at all levels need to understand that applying best available practices to biofuel crop production will have positive impacts both on the sustainability of our working lands and on providing a long-term place for biofuels in our renewable energy portfolio—and that the policies necessary to ensure this outcome are not currently in place. Legislated environmental performance standards for cellulosic ethanol production could, for example, go far toward promoting sustainable outcomes. Such standards could range from a prohibition of specific practices, such as growing invasive species for feedstock or removing excessive annual crop residue, to the provision of incentive payments based on avoided greenhouse gas emissions, both direct and indirect. We know enough today to begin formulating these standards, and both the industry and the environment will benefit from their early identification and refinement.

Sustainable biofuel production systems could play a highly positive role in mitigating climate change, enhancing environmental quality, and strengthening the global economy, but it will take sound, science-based policy and additional research effort to make this so.

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