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The Opportunities and Risks of Large-scale Production of Biofuels

Research is urgently needed to help decision makers better understand and address the potential social and environmental impacts of large-scale biofuels systems.

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Propelled by rising oil prices, the promise of economic development in rural areas, and escalating interest in developing sustainable alternatives to petroleum, support for biofuels has reached an unprecedented high. Over the last year, governments around the world have instituted new incentives for biofuels production, and private investment in the sector has increased dramatically. Recent international agreements, including the March 2007 pact between the U.S. and Brazil to accelerate biofuels development (*1*), likely will further spur the expansion of a global biofuels market.

Robust political and financial support for biofuels, however, has outpaced thorough analysis of the widespread impacts of biofuels systems. The analyses of biofuels systems to date have focused primarily on the technological aspects and challenges of such systems and on their relative efficiencies with respect to energy and carbon dioxide emissions; analyses have paid less attention to the broad set of social, environmental, and economic issues associated with the development and implementation of large-scale biofuels production. Yet, the potential for biofuels to serve as a sustainable engine of economic growth and to help solve the world's energy problems can be realized only if planning and implementation regimes successfully address these issues.

In December 2006, the Woods Institute for the Environment at Stanford University hosted a workshop that convened leading representatives of academic, corporate, investment, government, and non-governmental-organization communities to discuss the broader set of issues associated with large-scale production of biofuels. The workshop yielded both policy and research insights. Here we summarize some of the primary points that arose from the workshop discussions.

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Some environmental benefits of corn ethanol and soy biodiesel may be overstated. Greenhouse gas (GHG) emissions of corn ethanol and soy biodiesel, often thought to be at least modestly lower than petroleum gasoline and diesel (*2*), may be underestimated by conventional models. Most biofuel lifecycle accounting (LCA) models, which provide the bases for GHG impact estimates, are incomplete in a number of significant ways. For example, most assume a fixed, rather than dynamic, world and thus fail to capture important interactions such as those between changes in production and consumption of energy and materials, and changes in prices of major goods and services throughout the global economy. In addition, most conventional LCAs do not adequately account for many pollutants that affect climate, such as nitrogen oxide, carbon monoxide, and aerosols; do not account for the carbon-cycle and biogeophysical impacts of land-cover changes; and do not adequately represent the nitrogen cycle. Some recently developed LCA models, which have attempted to account for some of these factors, suggest that future average corn ethanol and soy biodiesel systems could have similar or greater GHG emissions than future gasoline or diesel fuel, although the uncertainty in these estimates is large (*3*). Robust, comprehensive LCA models that fully capture and account for the factors listed above are urgently needed.

Ethanol's local air quality impact also may be underestimated. While ethanol is commonly believed to be a cleaner burning fuel relative to gasoline, ethanol in fact may not provide any local air quality advantage over gasoline. New research suggests that while vehicles powered with E85 (85% ethanol, 15% gasoline) generally emit less toluene, xylene, and nitrogen oxides compared with gasoline-powered cars, they emit more acetaldehyde, formaldehyde, and total organic gas. These conditions increase ozone in Los Angeles and the northeast and decrease ozone slightly in the southeast, relative to gasoline, causing an overall increase in population-weighted ozone health problems in the U.S. Thus, replacing gasoline with a high-ethanol blend may result in no improvement in local air quality and its associated health effects; substituting E85 for gasoline could result in a roughly equivalent – or possibly greater – number of cases of air-pollution-related asthma, respiratory disease, and premature death in the U.S. (*4*)

The societal costs of large-scale biofuels systems could be high.
Many potential unintended consequences of a large-scale expansion of biofuels warrant policy attention. Over the past year, the increased demand biofuels production has placed on corn has resulted in a near doubling of the price of corn; the prices of other agricultural commodities also have begun to rise as farmers substitute corn for relatively less profitable crops such as soy and wheat, and as livestock producers switch away from corn-based feeds (*5*). In the absence of significant gains in existing crop yields, higher prices for agricultural feedstocks are likely to encourage the intensification and expansion of agriculture, which could exacerbate the existing strain agriculture puts on the environment.

One critical risk, as increased demand for biofuel feedstocks drives up prices for agricultural commodities, is the accelerated destruction of biologically rich ecosystems such as rainforests, wetlands, and native grasslands, and the cultivation of some environmentally sensitive lands that have been set aside from agricultural production under governmental conservation programs. In addition, burning or clearing forests and grasslands to make way for crops and tilling long-fallow lands could result in significant carbon releases. In the absence of strict enforcement of best management practices, increasing total acreage of crop cultivation, farming on marginal lands not well suited for agricultural production, and intensifying agricultural production (by, for example, rotating crops less frequently) could increase sediment erosion and fertilizer and pesticide pollution of surface and groundwater.

Higher agricultural commodity prices also could result in decreased food security and increased malnutrition in developing countries. While some poor farmers stand to benefit from a rise in commodity prices, the urban poor could be hurt. Overall, the vast majority of the world's one billion people living in chronic hunger consume more staple foods than they produce (*6*).

How a transition to biofuels occurs is important.
How the transition to biofuels is implemented – the actions taken now – will significantly influence the nature and magnitude of biofuels' environmental, economic, and social impacts. For example, certain agricultural management and production choices could significantly reduce ethanol's adverse environmental impacts. Important options include directing the expansion of agriculture away from native forests, wetlands, and grasslands; identifying and using lands that confer minimal conservation benefits or other critical goods and services; utilizing best agricultural management practices, including no-till farming; and powering ethanol processing plants with natural gas, agricultural co-products or residues, rather than coal.

In addition, governments still have the opportunity to guide the implementation of biofuels systems in a way that maximizes such systems' economic development benefits. Policymakers can help realize biofuels' potential as an engine for growth by removing trade barriers which currently block poor farmers' access to world markets, and by enhancing the capacity of developing countries to harness biofuels technologies to their advantage. Countries in which small-scale farmers are able to participate in the ownership of value-added processing and manufacturing facilities, for example, could see benefits in terms of economic growth, energy self sufficiency, and a healthier trade balance (*7*).

Greater innovation in high-leverage areas is needed.
While not yet commercially scalable, cellulosic ethanol appears to represent an improvement over corn ethanol on many metrics. If ethanol feedstock shifts away from food crops toward grasses, agricultural and forestry residue, and the organic portion of municipal solid waste, biofuels could be produced at lower cost with less interference with the food economy and with potentially fewer impacts on air, land, and water resources. The Department of Energy's recent award of up to $385 million in grants to companies working to develop cellulosic ethanol (*8*) is a positive step.

It is important to note, however, that while a shift to cellulosic feedstocks could enable a wide variety of plants and material to be used, the production of cellulosic ethanol also could perpetuate the monoculture approach of current corn ethanol and soy biodiesel production. Current research and development of cellulosic ethanol conversion technologies tend to focus on conversion processes suitable for only a single type of feedstock. To maximize the potential net benefits of large-scale cellulosic ethanol production, public research funds should be directed toward improving the ability of conversion processes to handle diverse feedstocks. Such technologies likely would encourage a more environmentally friendly feedstock menu of perennial grasses and trees, enable processing at a smaller scale (suitable for developing countries), and eliminate logistical problems of feedstock storage and seasonal variations in volume (*9*).

In the nearer term, scientific advancements toward achieving acceleration in crop yields while simultaneously protecting environmental quality and reducing GHG emissions could help meet crop production requirements while minimizing both interference with the food supply and pressure to expand corn production onto marginal land or valuable ecosystems (*10*). Public grants and subsidies to research institutions working to develop high-yield corn and other biofuel feedstock systems should encourage innovative crop and soil management technologies that contribute to a substantial increase in fertilizer and water-use efficiencies. The expected benefits of research devoted to improvements of food crop-based biofuel systems, however, should be weighed against the expected benefits of further research devoted to expediting the development of cellulosic technologies.

Conclusion

Much of the shift toward biofuels systems is occurring without careful consideration of the social, economic, and environmental implications of such systems here and around the world. Fast-tracked research is critical: in many cases, new levels of cooperation across a wide range of disciplines and new analytical tools are needed to help decision makers in the realm of biofuels best evaluate the local, regional, and global impacts of their actions. Science can play an important role in not only identifying these impacts, but also developing new technologies and policies that can minimize adverse impacts. If our experience with corn ethanol and soy biodiesel proves too costly from a social and environmental perspective, we risk losing public support for investment in biofuels in general and, as a result, the opportunity to develop a promising component of a sustainable transportation sector.

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[1] U.S. Department of State, *Advancing Cooperation with Brazil on Biofuels* (Fact Sheet, Office of the Spokesman, Washington, DC, March 9, 2007); www.state.gov/r/pa/prs/ps/2007/mar/81589.htm.
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[3] See, e.g., M. A. Delucchi, *Lifecycle Analyses of Biofuels* (Institute of Transportation Studies, University of California, Davis, Research Report No. UCD-ITS-RR-06-08, 2006); www.its.ucdavis.edu/publications/2006/UCD-ITS-RR-06-08.pdf.
[4] M. Z. Jacobson, *Environ. Sci. Technol.* **41**, [pp TBA] (2007).
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[6] United Nations Food and Agricultural Organization (FAO), *The State of Food Insecurity in the World* (FAO, Rome, 2004).

[7] See United Nations Conference on Trade and Development, *The Emerging Biofuels Market: Regulatory, Trade and Development Implications* (United Nations, New York and Geneva, 2006) (discussion of development challenges associated with biofuels).

[8] U.S. Department of Energy, *DOE Selects Six Cellulosic Ethanol Plants for Up to $385 Million in Federal Funding* (Press Release, Washington, DC, February 28, 2007); www.energy.gov/news/4827.htm.

[9] B. Paulos, G. Bonfert, "The Machine in the Garden"; www.ef.org/biofuels.

[10] K. Cassman, V. Eidman, E. Simpson, "Convergence of Agriculture and Energy: Implications for Research and Policy" (Council for Agricultural Science and Technology, Iowa, QTA 2006-3); www.cast-science.org.