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Sustainable Biofuels and Human Security

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Introduction

By JÜRGEN SCHEFFRAN AND
GALE SUMMERFIELD

This issue of *Swords and Ploughshares* brings together papers selected from a series of three workshops on sustainable biofuels and human security held at the University of Illinois at Urbana-Champaign in May and November 2008 and April 2009. The workshops were sponsored by the Women and Gender in Global Perspectives Program (WGGP), the Program in Arms Control, Disarmament and International Security (ACDIS), the Center for Advanced BioEnergy Research (CABER), and the Center for African Studies, with support from many units across campus. Generous support was provided by a Hewlett International Conference Grant, the Sloan Foundation's Industry Studies Group, the Energy Biosciences Institute, the John D. and Catherine T. MacArthur Foundation, the College of Agricultural, Consumer and Environmental Sciences (ACES) Global Connect Program, and the College of Liberal Arts and Sciences (LAS).

Biofuel production has soared in this decade with backing from government mandates. Seeking to address global warming, promote alternatives to fossil fuels, and increase independence in energy production, many countries have been striving to become key players in the global trade for biofuels as well as increase domestic energy production. Food security and sustainability issues, however, have clouded the future for first-generation biofuels. Second-generation production processes, based on cellulosic material and algae, are emerging, but they are not yet commercially viable on a large scale. The papers in this collection address the social and sustainability dimensions of the biofuel debates, including links between biofuels and food price volatility, poverty, and direct and indirect changes in land use.

In the first paper, Jürgen Scheffran provides an overview of key issues in the bioenergy debate, including the demand for biofuels and their impact on different dimensions of security—specifically, energy security and climate change, land use, food and water security, human security, and social impacts. He refers to the ongoing efforts to develop and incorporate criteria for the sustainable use of biofuels into political mandates and the potential for technical and economic developments to meet these mandates and criteria.

The paper by Hans Blaschek discusses the changing bioeconomy and brings in the science of biofuel production, while stressing the importance of multidisciplinary approaches. He discusses current bioenergy platforms, the new biology of genomics on biomass conversion, and the biorefinery of the future, which will produce multiple products.

Clifford Singer takes both a short-run and a long-run view of biofuel policies with respect to fossil fuels. He contrasts the policy implications for reducing petroleum/natural gas and coal consumption, stressing that reduction of carbon emissions from coal use is the more pressing need and one that requires international policy agreements. He then challenges the assertion that oil is strategically important to the United States, stating that "policy was and is made by people conditioned by their historical experience." Singer concludes that the food versus fuel debate in the 2020s will be quite different from the present one because of changes in technology and the growth in demand for food. Quantitative studies of probability distributions for different outcomes should, he argues, inform policy and funding decisions.

Mary Arends-Kuenning discusses the connections between biofuels, food prices, and global poverty. Using Brazil as an example, she points out the differences in gains and costs in urban and rural areas. In her paper, Arends-Kuenning stresses the importance of undertaking more research in agricultural development and points to the possibility that moving to cellulosic feedstocks for biofuels may reduce some of the pressure on food prices.

Anil Hira also discusses the links between biofuel production and food prices, noting that higher prices for poor farmers could be beneficial from a development perspective. In his paper, he emphasizes that the key motivations behind biofuel policy were the pressures of high petroleum prices and the goal of energy independence (as well as concerns about terrorism). Although he points out that greater conservation in gasoline consumption is part of the solution, he presents the case that biofuels are the main viable alternative to petroleum at present. Furthermore, the use of sugarcane in Brazil to produce ethanol is currently the most efficient production method and should be part of the immediate alternative energy scenario.

Timothy Smith, Kristell Miller, and Justin Lindenberg address the role that sustainability standards can play in the biofuel market. They point out that without such standards, biofuel expansion is likely to be widely based on feedstocks such as corn (the United States plans to increase production significantly by 2022), but that expansion will not adequately take into account social concerns. Private groups rather than governments are taking the lead in developing standards, but already a confusing array of different approaches has emerged. This paper helps the reader better understand what each standard means, as well as the contributions that standards can potentially make to the development of biofuels that are sustainable and that promote the elements of human security identified in this collection.

The paper by Steffen Mueller and Ken Copenhaver focuses on land use changes and their importance for sustainability. They question the accuracy of remote sensing, a commonly used method for measuring indirect land use changes from biofuel crop production, in different regions (Illinois, Brazil) and different ecosystems (forest, cropland, and savannah). They find that the combined error range may exceed the predicted land use change between important ecosystem transitions for biofuel analyses such as the conversion of tropical rainforest to cropland in Brazil. They recommend that regulatory agencies consider the limitations of remote sensing in the rulemaking process for incorporating land use considerations into biofuel production, and they discuss a new approach.

The final paper in the collection by Gale Summerfield is a note on China, which is now essentially tied with the European Union for the position of third largest ethanol producer following the United States and Brazil. The food versus fuel debate is much more sensitive in China, where economic success is accompanied by a growing demand for meat and milk, complicated by significant constraints on agricultural land and water. Marginal lands in southwest China that may soon be used for large-scale biodiesel feedstocks are areas in which losses in biodiversity could be costly. Today, China is slowly pursuing a biofuel agenda and trying to position itself to be a player in markets for second- and third-generation biofuels.

This collection of papers presents different views of the specialists who participated in the workshops at the University of Illinois at Urbana-Champaign. Some authors are enthusiastic about promoting the domestic production and use of biofuels as well as the international trade in biofuels. Others are more concerned about sustainability, land use, and food security. Overall, the contributions explore common ground by addressing concerns about and suggesting solutions for bioenergy futures that meet criteria of sustainability and human security.

Short Takes

The use of vegetable oils for engine fuels may seem insignificant today, but such oils may become in the course of time as important as the petroleum and coal tar products of the present time.

—Rudolph Diesel, 1912

The fuel of the future is going to come from fruit like that sumac out by the road, or from apples, weeds, sawdust—almost anything. There is fuel in every bit of vegetable matter that can be fermented. There's enough alcohol in one year's yield of an acre of potatoes to drive the machinery necessary to cultivate the fields for a hundred years.

—Henry Ford, 1925

[It is a] crime against humanity to divert arable land to the production of crops which are then burned for fuel.

—Jean Ziegler, United Nations special rapporteur on the right to food, 27 October 2007

Biofuels have been represented by some as a silver bullet to the climate change threat, and by others as a fatal mistake set to destroy forests and increase hunger; they are neither.

—Achim Steiner, UN Under-Secretary General and Executive Director, UN Environment Programme, in his introduction to the 2008 report of the German Advisory Council on Global Environmental Change

Biofuels present both opportunities and risks. The outcome would depend on the specific context of the country and the policies adopted. Current policies tend to favour producers in some developed countries over producers in most developing countries. The challenge is to reduce or manage the risks while sharing the opportunities more widely.

—Jacques Diouf, Director-General of the Food and Agriculture Organization (FAO) of the United Nations, 7 October 2008

Developing the next generation of biofuels is key to our effort to end our dependence on foreign oil and address the climate crisis—while creating millions of new jobs that can't be outsourced.

—Steven Chu, U.S. Secretary of Energy, 5 May 2009

Biofuel Conflicts and Human Security: Toward a Sustainable Bioenergy Life Cycle and Infrastructure

by JÜRGEN SCHEFFRAN

▶ **Although the bioenergy potential is huge, harvesting biomass is demanding because of the comparatively low efficiency of photosynthesis, requiring large areas of land to collect and distribute bioenergy.**

▶ **Government support to the U.S., EU, and Canadian biofuel supply and use in 2006 was about $11 billion per year, projected to rise to $25 billion per year on average by the middle of the next decade.**

The world is facing an important challenge in moving toward a sustainable energy system and reducing the vulnerability of its energy supplies to future disruptions, disasters, and conflicts. Growing concerns about energy security have increased the demand for domestic renewable energy sources that would replace fossil fuels and meet the national and international needs for electricity, heating, and fuel while reducing the dependence on foreign resources (NRDC 2004). Concerns about global warming are spurring the search for low-carbon energy alternatives to fossil fuels that meet the targets for reductions in emissions of greenhouse gases (GHGs) in the Kyoto Protocol and follow-on agreements (Worldwatch 2006).

A significant source of renewable energy is biomass, harnessing the energy from the sun and fixing it as solid material to serve various energy needs. Although the bioenergy potential is huge, harvesting biomass is demanding because of the comparatively low efficiency of photosynthesis, requiring large areas of land to collect and distribute bioenergy. Dedicated crops can contribute to a variety of energy uses, including electricity production through biomass incineration and refinement into biogas and biofuels such as ethanol and biodiesel (Rosillo-Calle and Walter 2006). On the global level, about 79 percent of all renewable energy is generated from biomass, corresponding to 10.4 percent of global energy use. By comparison, nuclear power provides 6.5 percent (*Economist* 2007).

Recent years have seen a dramatic shift in policy support for biofuels in many parts of the world (Scheffran forthcoming). An increasing number of countries are promoting biofuel production and use, largely through public support rather than reliance on market forces. Those countries have set ambitious political targets for the substitution of fossil fuels by biofuels in the transportation sector, attracting public and private investments to stimulate biofuel production and use. Besides budgetary support measures (direct support or tax concessions), governments are widely applying blending or use mandates that require biofuels to represent a minimum share or quantity in the market of transportation fuels. They are also adopting trade restriction measures, such as import tariffs, that in some cases protect less cost-efficient domestic biofuel industries from lower-cost foreign competitors. Support to the U.S., EU, and Canadian biofuel supply and use in 2006 was about $11 billion per year, projected to rise to $25 billion per year on average by the middle of the next decade (2013–2017) (OECD 2008).

In 2007 the global production of biofuels amounted to 16.4 billion gallons per year, corresponding to 1.8 percent of total global transportation fuel consumption in energy terms (OECD 2008). Brazil's share was about 20 percent, the U.S. share 3 percent, and the European Union's share less than 2 percent. Fuel ethanol accounts for most of the world's biofuels, with production of 13.1 billion gallons in 2007, followed by biodiesel with 2.7 billion gallons. Almost half of the ethanol is produced in the United States, 38 percent in Brazil, 4.3 percent in the European Union, and 3.7 percent in China.

Currently, corn ethanol is the major renewable fuel in the United States. It is now sold across the country and is blended in half of the nation's gasoline. Although the vast majority of ethanol is blended at 10 percent to gasoline, ethanol blends at higher volumes, such as 85 percent (E85), are available for use in flex-fuel vehicles (FFV), especially in Midwestern states. Ethanol production has increased from about 1.6 billion gallons in 2000 to 9 billion gallons in 2008. In January 2007, the number of ethanol plants in operation was 110; by August 2009, there were 170 operating biorefineries, with a total production capacity of about 13 billion gallons per year (RFA 2009). The economic crisis of 2008–2009 has slowed down the expansion.

The Energy Policy Act of 2006 established concrete targets for renewable fuels and a tax credit of $0.51 per gallon (Farrell et al. 2006). According to the 2007 Energy Independence and Security Act (EISA) Renewable Fuel Standard (RFS), at least 7.5 billion gallons of renewable fuel must be blended into motor vehicle fuel by 2012, and 36 billion gallons of biofuels must be produced by 2022, including 15 billion gallons of corn ethanol as an upper limit and 21 billion gallons of advanced biofuels derived from renewable sources other than corn (RFA 2006). Doubling corn ethanol and expanding cellulosic ethanol from the current near-zero levels to take a leading role in the next decade pose enormous challenges to the infrastructure needed. According to the U.S. Government Accountability Office, there are significant barriers to producing biofuels at a lower cost than petroleum fuels (GAO 2007). Considerable investments are required to make biofuel production cost competitive with petroleum-based transportation fuels and overcome the technical and economic barriers at all stages of the production and supply chain—from crop production, feedstock harvesting, transportation, and processing to biofuel distribution and use (CRS 2007).

▶ **Corn ethanol is the major renewable fuel in the United States. It is now sold across the country and is blended in half of the nation's gasoline.**

In addition, the environmental impact of biofuels must be addressed, considering material, water, land, and energy inputs as well as emissions, and waste streams along the entire life cycle. Recent studies and media reports have questioned the energy and carbon balance of the current generation of corn-based ethanol, and have highlighted impacts of the biofuel boom on various security dimensions, including energy security and climate change, water, and food security. Under these conditions, corn ethanol and other biofuels have to demonstrate their environmental sustainability and economic viability. To succeed, bioenergy systems will have to become fully competitive with fossil energy and avoid some of the current distortions such as subsidies for domestic and import barriers on foreign biofuels.

▶ **Although biofuels promise greater security as a sustainable energy resource, at the same time they induce environmental, social, and economic changes that may have security implications.**

Security Dimensions of Bioenergy Futures

Although biofuels promise greater security as a sustainable energy resource, at the same time they induce environmental, social, and economic changes that may have security implications. High oil prices and the dependence on energy imports from the Middle East have increased the demand for alternative energy paths that enhance energy security. Home-grown domestic energy sources offer development opportunities for structurally weak rural areas and lead to structural changes in land use and agriculture (Rosillo-Calle and Walter 2006). As a result, support is particularly strong from the agricultural community, which expects fast-expanding future markets for grain and land resources, creating new income and job opportunities for the agricultural sector. An economic study of existing ethanol plants estimates that a 50 million gallon ethanol plant with 75 percent local ownership would create 220 new jobs (Iowa State University 2006). Extrapolated to biodiesel, this plant would result in 1.16 jobs created per million liters of annual production. The Renewable Fuel Association (RFA 2006) has predicted the creation of more than 200,000 new jobs in all sectors of the U.S. economy; if realized, this would represent an increase in the U.S. gross domestic product (GDP) of $200 billion between 2005 and 2012, and a resulting increase in farmers' incomes by $43 billion. A UN study on the potential of green jobs found that renewable energy generates more jobs than employment in fossil fuels (UNEP 2008). Projected investments of $630 billion by 2030 would translate into at least 20 million additional jobs in the renewable energy sector.

Advanced bioenergy could possibly help to satisfy the growing energy demands of developing countries. Worldwide, about 2.4 billion people depend on the traditional energy uses of biomass, such as the burning of straw, dung, and wood for cooking, lighting, water pumping, and other basic needs—uses that are often inefficient, unhealthy, and non-sustainable (Ezzati and Kammen 2001). It is estimated that more than 1.5 million people a year die from the pollution caused by these open fires. Simple technical improvements to stoves can to a large extent prevent the health risks posed by biomass use, while at the same time doubling or even quadrupling its efficiency (WBGU 2009). Because of the high productivity of energy crops in tropical and subtropical regions, locally produced advanced bioenergy (such as ethanol from sugarcane or biodiesel from palm oil) could potentially provide income and employment in rural areas and in turn facilitate sustainable development in these regions (Hazell and von Braun 2006). According to the UN Foundation (2006), "Biofuels have the potential to alleviate poverty, create sustainable rural development opportunities, reduce reliance on imported oil, and increase access to modern energy services." In June 2005, the UN Foundation launched the Biofuels Initiative aimed at promoting the sustainable production and use of biofuels in developing countries.

To be successful, bioenergy projects need to be adapted to the specific regional conditions in developing countries, which are often best addressed by small-scale projects. A recent study explored fifteen "start-up" bioenergy projects in twelve countries in Latin America, Africa, and Asia where the local community benefited from improved energy access for both domestic and business use (FAO/PISCES 2009). Examples are jatropha electrification in Mali, a charcoal project in Senegal, palm oil and biogas projects in Tanzania, vegetable oil recycling in Peru, and biodiesel-based water pumping in Orissa. Such projects demonstrate that small-scale bioenergy production with improved energy efficiency and better use or organic waste material reaps benefits for rural communities in poor countries.

Even though biofuels have a significant development potential, they could induce adverse consequences for human security if produced in an unsustainable manner. Concepts of human security put the security of human beings into the center (UNDP 2007) and focus on “shielding people from critical and pervasive threats and empowering them to take charge of their lives” (CHS 2003). In the biofuel debate, most significant are the implications for poverty and food security. A 2007 report by the International Crops Research Institute of the Semi-Arid Tropics (ICRISAT) points out that large-scale biofuel production “could provide impetus for a corresponding drive to large-scale farming, pushing the poor off their land and excluding them from the biofuel revolution. It could also lead to the replacement of food crop cultivation with biofuel crops on large areas of land, driving up food prices for those who can least afford it. The result would be more, not less poverty and hunger” (ICRISAT 2007). The International Food Policy Research Institute (IFPRI) predicts that an aggressive biofuel scenario—without technological breakthroughs increasing productivity—could lead to significant price increases for some food crops (von Braun and Pachauri 2006). The cultivation of energy crops “implies a close coupling of the markets for energy and food. As a result, food prices will in the future be linked to the dynamics of the energy markets” (WBGU 2009). Large-scale biofuel production could threaten human security and political stability in parts of the world. Competition from biofuels for land and food crops has already contributed to increases in the prices of staple foods, such as the sharp rise in the price of corn and tortillas in Mexico in 2006 (Runge and Senauer 2007).

▶ **To be successful, bioenergy projects need to be adapted to the regional specific conditions in developing countries, which are often best addressed by small-scale projects.**

▶ **Unsustainable expansion of energy crops may increase the pressure on available water resources, an issue that requires further research.**

With the economic crisis in 2008, both energy and food prices dropped dramatically. In its 2008 report *Economic Assessment of Biofuel Support Policies*, the OECD suggests that the medium-term impacts of current biofuel policies on agricultural commodity prices are important, but should not be overestimated. Twelve percent of global coarse grain production and 14 percent of global vegetable oil production could be used for biofuels, up from 8 percent and 9 percent, respectively, in 2007. However, with full implementation of the 2007 U.S. EISA and the new EU Directive for Renewable Energy, these numbers could rise to 20 percent and 13 percent, respectively (OECD 2008). Many countries are facing critical questions about their biofuel industries, some of which have been discussed in a UN report (UN 2007).

With low-density bioenergy production, land use is a critical issue. For example, to replace 10 percent of its gasoline demand with ethanol, the United States would need to devote approximately 15 percent of its agricultural land area to ethanol-generating bioenergy crops. With all possible efficiency gains (higher yields, more efficient energy conversion, lower fuel consumption in cars), federal goals could be achieved on one-sixth of the land area than would be required without these gains for ethanol production, making it possible to produce far more biomass on the same land or use less land and achieve an equivalent energy output (National Commission on Energy Policy 2004).

And yet intensification of existing production systems affects the biological diversity of the land. Claiming new agricultural land comes at the expense of natural ecosystems (for example, when forest land is cleared), which contributes to the current global crisis of biological diversity (WBGU 2009). Bioenergy systems based on annual crops on agricultural land conflict with the goals of soil protection, while perennial crops may help to restore degraded land. If the removal of residues from agriculture- or forestry-based ecosystems is not restricted, the soil may be depleted of organic substances and mineral nutrients (WBGU 2009). Unsustainable expansion of energy crops may also increase the pressure on available water resources, an issue that requires further research. Another key issue is the environmental impact from changes in agrichemical uses (especially nitrogen and phosphorus from fertilizers and pesticides) via leaching and surface flow from farms to other habitats and aquifers (Goolsby et al. 2000). This situation requires a comparison of alternative crops or cultivation methods (Boody et al. 2005) with projected requirements for crops grown with improved or alternate methods (Tilman, Reich, and Knops 2006; Donner and Kucharik 2003).

Indirect land use issues have also attracted attention in the recent public and scientific debates (Fargione et al. 2008; Searchinger et al. 2008; Gallagher 2008). These issues are rising food commodity prices and their effects on food security for the poor, the displacement of agricultural production onto uncultivated areas with impacts on biodiversity, and releases of carbon from the soil to the atmosphere. Bioenergy is intended to be climate-neutral because the carbon emitted during energy use has been initially sequestered by plants from the atmosphere, but in the practical implementation additional emissions are incurred during the production process. The clearing of land for biofuel production releases greenhouse gases that contribute to global warming. Emissions created by the conversion of ecosystems that contain a high proportion of carbon (such as forests and wetlands, as well as some natural grasslands) generally negate the climate change mitigation effects of bioenergy and may even exacerbate climate change. It has been estimated that the carbon release from land clearing can require a payback time of GHG savings of several decades up to centuries to compensate for the clearing of land for some biofuel pathways (such as forest clearing for soya to biodiesel in the United States). In other cases, payback time could be less than a decade—for example, grassland conversion to palm for biodiesel or sugarcane for bioethanol (Gallagher 2008).

Life Cycle Analysis and the Biofuel Infrastructure

Developing the bioenergy supply chain from sunlight to bioproducts requires an integrated approach to overcome the barriers and develop biomass-based resources into a viable and sustainable alternative to petrochemical sources for chemicals and energy. Process optimization and integrated life cycle analysis (LCA) provides important tools for maximizing the benefit-cost ratio and minimizing the adverse impacts of bioenergy. Complex issues are raised about the production and processing of raw materials, logistics and facility location, and the distribution of biofuels at the regional, national, and international levels. Infrastructure requirements include the growing, harvesting, storing and preparing of the feedstocks most appropriate to local environmental and economic conditions; designing biorefineries, connecting multiple biomass materials with multiple bioproducts through various conversion processes; transporting and distributing feedstocks and bioproducts; and overseeing the overall structure of distributed bioenergy networks (Worldwatch 2006).

▶ **Adverse environmental, economic, and social impacts of biofuel growth are to be minimized by using life cycle assessment as a scientific tool for sustainable biofuel production.**

Scientific understanding plays an essential role in addressing critical questions and providing sound input into policymaking. Adverse environmental, economic, and social impacts of biofuel growth are to be minimized by using life cycle assessment as a scientific tool for sustainable biofuel production. Existing life cycle models include the GREET (Greenhouse gases, Regulated Emissions and Energy use in Transportation) model of Argonne National Laboratory (Wang 2004), and the Berkeley Energy Resource Groups Biofuel Analysis Meta-Model (EBAMM) (Farrell et al. 2006). Previous LCAs of biofuels did not include land and water use or economic and social factors.

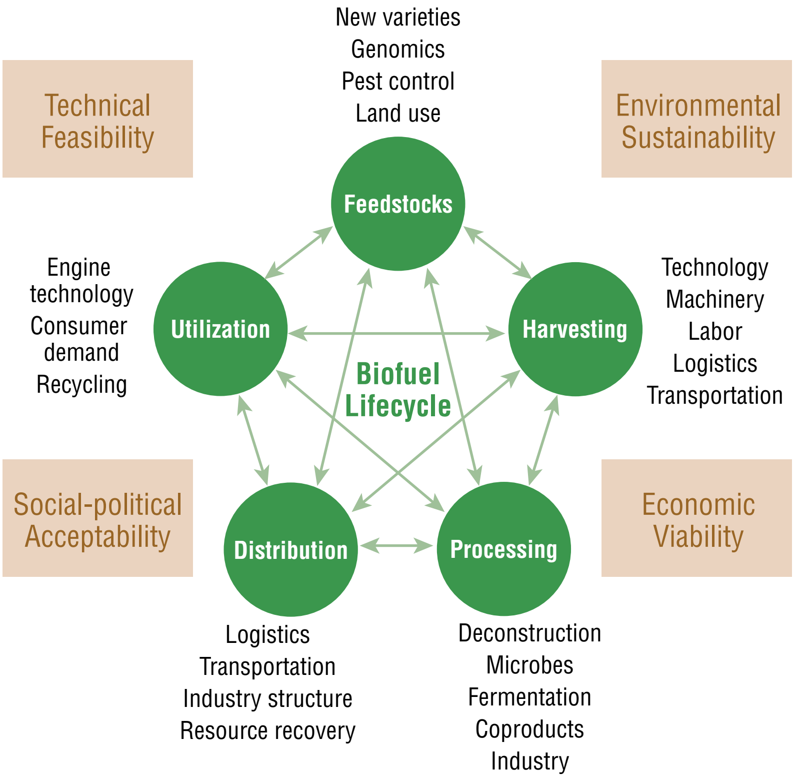

Figure 1 Components of the biofuel life cycle, key variables and evaluation criteria.

One measure of the environmental impacts of biofuels is the energy balance created by a crop, which is the ratio of the energy output from fuel to the fossil energy input to produce and use fuel. These net values are likely to vary substantially, depending on plant selection, growth and harvesting methods, as well as transportation and conversion processes. In various studies the energy output to input ratio for corn ethanol ranges from 0.8:1 to 1.45:1, while gasoline achieves 0.8:1 at best (Pimentel 2003; Kim and Dale 2004; Sheehan et al. 2004; Brinkman et al. 2005; Farrell et al. 2006; Hill et al. 2006). With advanced production techniques and process optimization methods, this energy balance will be considerably improved. For cellulosic ethanol, the energy output-to-input ratio is expected to rise up to around 10.

Another measure is the level of greenhouse gases emitted during the biofuel production and usage process. GHG savings vary significantly across biofuels. Relative to the fossil fuels displaced by biofuels, greenhouse gas emissions are reduced 12 percent by the production and combustion of ethanol over its whole life cycle and 41 percent by biodiesel. (Hill et al. 2006). Ethanol produced from sugarcane may reduce GHG emissions by 80 percent or more compared with emissions from fossil fuels. These differences can be ascribed to specific attributes such as sugar content and fossil fuel inputs (OECD 2008). With current policy support, reductions of GHG emissions and use of fossil fuels amount to around 1 percent of the total, making biofuels based on current technologies a rather expensive path to energy security and mitigation of climate change (around US$ 1,000 per metric ton of CO_2-equivalent saved) (OECD 2008) Biological carbon sequestration can make production, deconstruction, and fermentation processes of biofuels more “carbon negative” by removing CO_2 from the atmosphere through photosynthesis and CO_2 storage in biomass, soils, and sediments (Post and Kwon 2000).

A comprehensive framework of life cycle systems analysis would combine the various components of the biofuel life cycle with a set of evaluation criteria (Figure 1). It includes five components (feedstocks, harvesting, processing, distribution, and utilization) in a local landscape and incorporates key variables and new dimensions (systems dynamics, microeconomic agent-based modeling, GIS-based spatial modeling, transportation infrastructure, recycling, and waste management). Land use and environmental issues (for example, nitrogen, carbon, energy balances) will be addressed by modeling the optimal spatial allocation of cropland for feedstock production and the mix of feedstocks to meet various criteria for biofuel production under various policy scenarios. Evaluation criteria include technical feasibility, economic viability, environmental sustainability, and socioeconomic acceptability. Life cycle analysis will help to evaluate the overall impact of process improvements on biofuel production, including dramatic improvements to biocatalytic rate, productivity, and yield to redefine biorefinery performance.

The new generation of biofuels based on cellulosic materials, as well as integrated biorefineries that take any organic material as an input to produce co-products and electricity, are expected to have much better cost effectiveness, energy ratio, water use, and greenhouse gas balance. While major progress in these areas is expected in the coming decade, the energy and carbon efficiency of the current generation of biofuels may be improved by short-term intermediate solutions during a transition period. Examples are the use of nonfossil sources (such as perennial grasses like *Miscanthus*) for energy input into ethanol production, or utilizing co-products from corn-ethanol production, such as distillers' dried grains and solubles (DDGS) as animal feed.

Modeling and optimization tools play an important role in finding the best bioenergy infrastructure in terms of the multiple criteria. This includes the design and location of biorefineries and finding the best routes in the transportation network, consistent with regional feedstock production patterns and the location of demand for ethanol (Khanna et al. 2008; Scheffran and Bendor 2009; Kang et al. forthcoming). An integrated supply analysis simulates the collection, storage, and transportation of biomass supply to a biorefinery, taking into consideration the trade-off between biorefinery capacity, production costs, and transportation distances. Methods of multicriteria analysis help to rank alternative infrastructure designs of feedstock logistics and bioprocessing. Biofuels become more competitive if co-products (such as DDGS in the US Midwest or bagasse in Brazil) are optimally utilized. Finding the best mix can lead to significant cost reductions for the future biorefinery. Integrated models incorporate the best selection of the feedstock, farm, biorefinery site, size, and technology by utilizing GIS-based decision tools.

▶ **Bioenergy is intended to be climate-neutral because the carbon emitted during energy use has been initially sequestered by plants from the atmosphere, but in the practical implementation additional emissions are incurred during the production process.**

▶ **The new generation of biofuels based on cellulosic materials, as well as integrated biorefineries that take any organic material as an input to produce co-products and electricity, are expected to have much better cost effectiveness, energy ratio, water use, and greenhouse gas balance.**

The Policy Debate and Sustainability Standards

A comprehensive LCA framework can help to establish ecological and social sustainability standards. To render bioenergy use sustainable, complex regulatory measures need to be taken which represent a major challenge for a policy-making system (WBGU 2009). Concerns about the impacts of growing bioenergy use on land use, food production and the environment require establishment of bioenergy production and consumption in a sustainable manner that minimizes these impacts. In addition, bioenergy systems will have to become more market oriented to avoid some of the distortions from subsidies and tariffs and become fully competitive with fossil energy. By producing biofuels in a socially acceptable and fair manner, the biofuel industry can bring significant income and sustainable development into rural areas and local markets (John and Watson 2007).

The demand and political support for biofuels have been affected in parts of the world because of the growing debate on potential impacts from their increased use. The EU has weakened its mandates for biofuels and begun to establish conditions and criteria for the sustainable use and certification of biofuels. A similar discussion has occurred in the United States. In particular, the U.S. Energy Independence and Security Act of 2007 states that cellulosic biofuels must offer at least a 60 percent life cycle greenhouse gas reduction relative to conventional gasoline when both direct and indirect emissions are taken into account.

A "Biopact" for a North-South trade in biofuels, as suggested by Mathews (2007), aims at establishing ecological and social standards instead of trade barriers to open fair market access and implement sustainability standards for tropical biofuels. Another initiative is the Roundtable on Sustainable Biofuels. A comprehensive assessment of the indirect impacts of biofuels prepared by Gallagher (2008) represents the review by the UK Renewable Fuels Agency. The report concludes "that there is a future for a sustainable biofuels industry but that feedstock production *must* avoid agricultural land that would otherwise be used for food production. . . . The introduction of biofuels should be significantly slowed until adequate controls to address displacement effects are implemented and are demonstrated to be effective." According to this report, there is probably sufficient land for food, feed, and biofuels. Biofuels production must target idle and marginal land and use of wastes and residues. Specific incentives are required to stimulate advanced technology, and stronger, enforced global policies are needed to prevent deforestation. A carbon and sustainability reporting scheme would monitor fuel supplier performance and name, praise and shame suppliers as appropriate.

Searching for common standards requires compromises of conflicting viewpoints. An example is a report by the National Research Council (2009) of which a summary has been published in *Science* (Tilman et al. 2009). Its conclusion:

> The search for beneficial biofuels should focus on sustainable biomass feedstocks that neither compete with food crops nor directly or indirectly cause land-clearing and that offer advantages in reducing greenhouse-gas emissions. Perennials grown on degraded formerly agricultural land, municipal and industrial solid waste, crop and forestry residues, and double or mixed crops offer great potential. The best biofuels make good substitutes for fossil energy. A recent analysis suggests that more than 500 million tons of such feedstocks could be produced annually in the United States.

▶ Bioenergy systems will have to become more market oriented to avoid some of the distortions from subsidies and tariffs and become fully competitive with fossil energy.

▶ Specific incentives are required to stimulate advanced technology, and stronger, enforced global policies are needed to prevent deforestation.

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Prospects for the New Bioeconomy

by HANS P. BLASCHEK

What are the possibilities for the new bioeconomy? This article will try to answer this question by looking at the state of current bioenergy platforms, the impact of the new biology of genomics on biomass conversion, and the biorefinery of the future. Here a *biorefinery* is defined as a facility that integrates biomass conversion processes and equipment to produce fuels, power, and chemicals from biomass. The biorefinery concept is analogous to today's petroleum refineries, which produce multiple fuels and products from petroleum.

> ▶ **Because of the food versus fuel debate and concerns about the net energy balance, ethanol production from corn in the United States is expected to level off.**

The State of Current Bioenergy Platforms

Any discussion of what the future may hold when it comes to the bioeconomy requires an examination of where the United States is today in its bioenergy platforms. Both dry and wet mill ethanol production from cornstarch (U.S.) and ethanol production from sugarcane (Brazil) are regarded as essentially mature technologies for producing bioethanol. Currently, dry-grind ethanol plants produce about 60 percent of fuel ethanol in the United States. Because of the food versus fuel debate and concerns about the net energy balance, ethanol production from corn is expected to level off (von Braun 2007). However, some incremental increases in the energy efficiency of these processes can be expected as co-product utilization (such as distillers' grains and bagasse) is incorporated into the next generation of plants. Currently, distillers' grains from corn ethanol production is used as animal feed, and most of the bagasse from sugarcane production is burned for power generation.

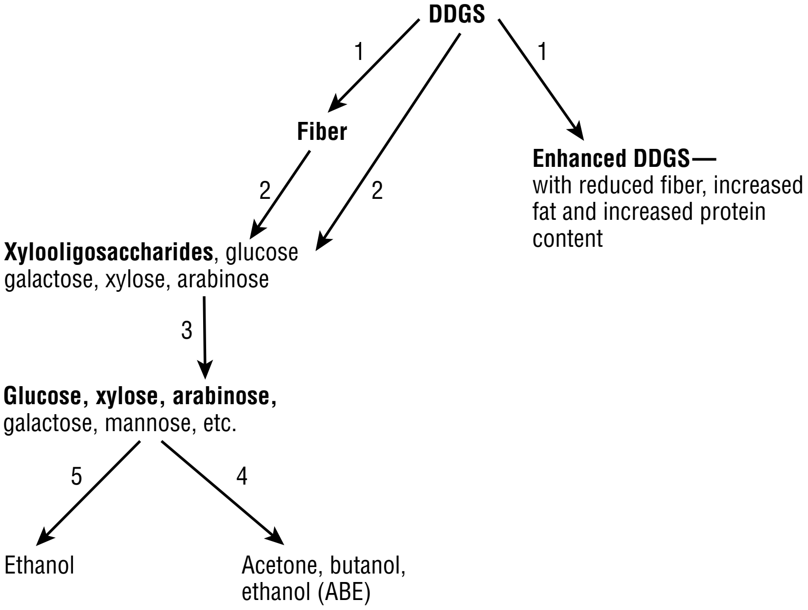

Figure 1 Pretreatment and conversion of DDGS to value-added products. 1 = elusieve process (Srinivasan et al. 2005); 2 = electrolyzed water pretreatment (Wang, Feng, and Luo 2004); 3 = enzymatic hydrolysis; 4 = ABE fermentation by solventogenic clostridia (Ezeji, Qureshi, and Blaschek 2004); 5 = ethanol fermentation by E. coli FBR 5.

The United States is expected to produce 7 million metric tons of distillers' grains by the end of 2009. Some experts are predicting that the country's production of distillers' grains and solubles (DDGS) will reach 15 million metric tons in a few years. In addition to starch, distillers' grains contain fiber, which is composed of cellulose, xylan, and arabinan. If these co-products were further hydrolyzed and converted into liquid fuels or other bioproducts, the efficiency and profitability of bioethanol plants would improve even further. Such an improvement, however, would require developing technologies for the deconstruction and enzyme treatment of the fiber component present in DDGS. Members of the Midwest Consortium for Biobased Products recently completed a comprehensive study on the utilization of DDGS that has been published in a special edition of *Bioresource Technology*. Part of this study examined the fermentation of DDGS hydrolysates to biobutanol by the solvent-producing clostridia (Ezeji and Blaschek 2008).

Figure 1 outlines the potential steps for the pretreatment and conversion of DDGS to simple 5 and 6 carbon sugars and fermentation to value-added products such as acetone, butanol, and ethanol.

Ethanol production from corn is reaching its maximum production levels, and it is anticipated that cellulosic ethanol will play a bigger role in order to fulfill a target of 30 percent of U.S. gasoline demand by 2030. Although most investigators suggest that ethanol from corn is slightly net energy positive, ethanol production from cellulose results in an improved net energy balance and significantly fewer greenhouse gas emissions. Work carried out at Argonne National Laboratory by May Wu and colleagues (2007) suggests that the production of higher alcohols such as biobutanol from biomass will help to improve the overall picture for greenhouse gas (GHG) avoidance (Figure 2).

Butanol as a second-generation liquid fuel offers the following significant advantages over ethanol:

- It has a higher energy content than ethanol.
- Unlike ethanol, it can be stored under humid conditions—it lacks solubility with water (higher flash point and lower vapor pressure).
- It can be used in internal combustion and diesel engines—less corrosive.
- It can be shipped through existing pipelines.
- It can serve as a replacement for gasoline or as a chemical.

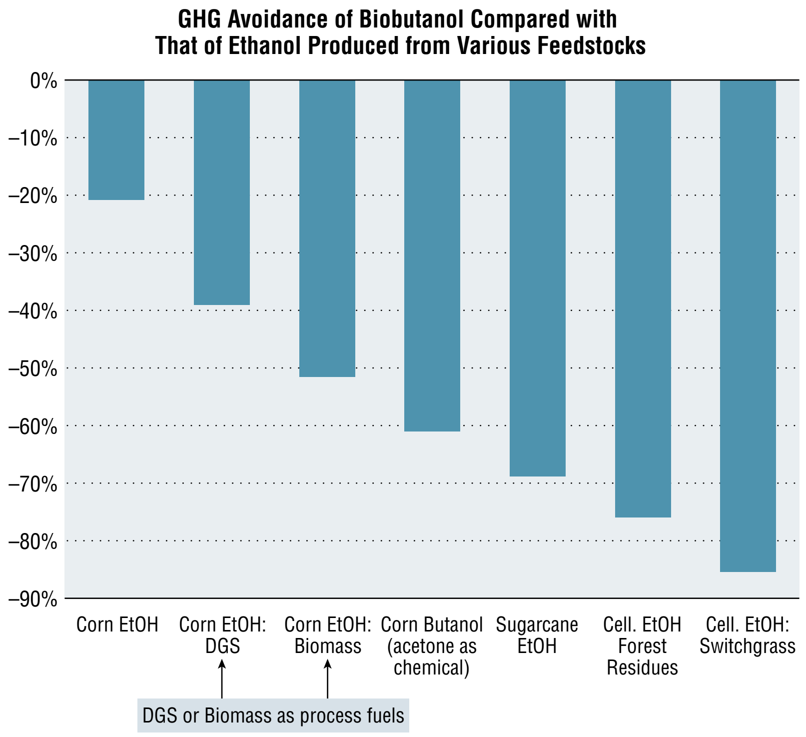

Figure 2 Greenhouse gas avoidance by utilization of various feedstocks and production of different biofuels. EtOH = ethanol.

Ezeji and his colleagues (2007a) have offered an overview of recent developments in the genetics and downstream processing of biobutanol. The development of an integrated system for biobutanol production and removal may have a significant impact on the commercialization of this process using the solvent-producing clostridia.

The challenge on the sugar platform side of the conceptual biorefinery will be to scale up technologies for cell wall deconstruction to the point where they become practical on a commercial scale. Although it is feasible to produce sugars from lignocellulosic biomass, the concern is related mostly to the inhibitors of fermentation (for example, furfurals, acetic acid, and coumaric acid) produced during the pretreatment process (Ezeji, Qureshi, and Blaschek 2007b).

In addition to economics, and specifically the price of petroleum, concerns about a sustainable environment appear to be driving the push to use alternative feedstocks such as corn stover, switchgrass, *Miscanthus,* and tropical maize or sweet sorghum. The economics of perennials are particularly favorable because *Miscanthus* is expected to yield 15 tons of biomass per acre compared with corn, which has a yield of 160 bushels (about 4 tons) per acre. At a level of 50 percent removal, corn stover alone is expected to provide 90 million tons of fermentable sugars for conversion to fuels and chemicals without negatively affecting soil fertility. Although some modifications may have to be made to the current harvesting equipment, corn stover is readily available, it is largely unused, and therefore its production requires little additional investment or resources.

Today, biomass provides about 3-4 percent of the energy consumed in the United States. It is anticipated that biomass could satisfy between 25 and 50 percent of the world's demand for energy by the middle of the twenty-first century. An examination of the bioenergy value chain from sunlight to bioproducts suggests that a multidisciplinary approach is required to overcome limitations to making crop-based resources a viable alternative to petrochemical-based systems for chemicals and energy (Figure 3). Because of the interdisciplinary nature of this field, efforts are under way to develop new bioenergy courses and curricula to respond to demand in this area (Blaschek et al. 2008).

Impact of the New Biology of Genomics on Biomass Conversion

The current limitations and bottlenecks in the production of second-generation biofuels based on lignocellulosics include needed improvements in the efficiency of bioconversion of plant fibers to value-added products and more efficient recovery of these high-value products (Figure 4). Biological conversion involves the utilization of both 5 and 6 carbon sugars by various microbes such as yeast and bacteria. *Saccharomyces cerevisae* is currently being engineered to ferment arabinose, *Zymomonas mobilis* to ferment xylose and arabinose, and the solventogenic clostridia to saccharify and ferment simultaneously.

Germplasm →	Cultivation →	Harvest/Transport →	Processing →	Biofuel
Crop Scientist	Farmers	Engineers	Microbiologists	Engineers
Plant Breeders	Agronomists	Economists	Engineers	Chemists
Plant Genetics	Plant Pathologists		Molecular Biologists	
	Ecologists			
	Soil Scientists			

Figure 3 The bioenergy value chain and associated expertise needs.

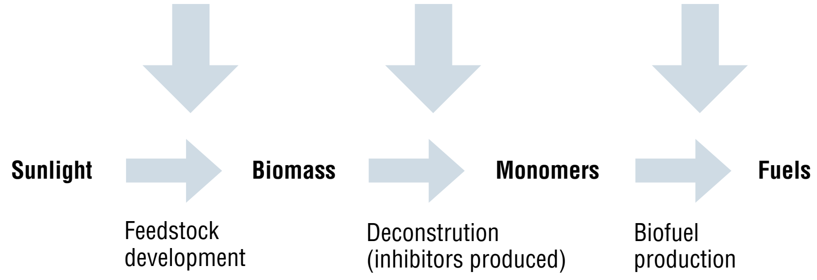

Figure 4 Road map and bottlenecks to biofuel production.

▶ It is anticipated that cellulosic ethanol, resulting in an improved net energy balance and significantly fewer greenhouse gas emissions, will play a bigger role in order to fulfill a target of 30 percent of U.S. gasoline demand by 2030.

▶ Concerns about a sustainable environment appear to be driving the push to use alternative feedstocks such as corn stover, switchgrass, *Miscanthus*, and tropical maize or sweet sorghum.

▶ Biomass provides about 3-4 percent of the energy consumed in the United States today. It could satisfy between 25 and 50 percent of the world's demand for energy by the middle of the twenty-first century.

Because of the need for multidisciplinary expertise in this area, the use of plant and microbial genomic-based approaches leading to translational bioengineering and process scale-up has been compared by some observers to the nation's Apollo Project in the 1960s. The "New Biology" of genomics allows the application and integration of systems biology and metabolic engineering of fermentation pathways to overcome technical barriers to the production of biofuels from lignocellulosic substrates.

One approach to the development of new plant biomass sources calls for examining maize germplasm collections for particular cell wall characteristics such as lignin content and compositions. Because of their recalcitrance, the selection of maize lines with low lignin content would be expected to improve fermentation processes. In addition to lignocellulose as a potential feedstock, tropical maize or "sugar corn" may be a potential short-term feedstock solution. According to work recently carried out at the University of Illinois, sugar corn requires low nitrogen input, can be grown in temperate climates, and contains high concentrations of sucrose, glucose, and fructose. Just like sugarcane, the sugars in tropical maize can be directly fermented without pretreatment and enzyme treatment, which makes this feedstock potentially very interesting as a near-term alternative for the production of fuels and chemicals (http://www.bioenergy.uiuc.edu).

The Biorefinery of the Future

The "New Biology" of genomics also allows examination of gene function and expression, which will, in turn, allow development of road maps for construction of new plant and microbial strains with characteristics tailor-made for the production of a particular biorefinery-based product. This technology will result in improved economics and efficiencies and direct competition of bioproducts for feedstock chemicals currently produced by the petrochemical industry.

Some current examples of biorefinery activities include the investigation by Dupont and BP of biobutanol (an advanced 4-carbon biofuel), the production of 1,3 propanediol as a polymer platform, the construction of a commercial-scale biorefinery to produce polylactide polymers, the announcement by ADM of pilot-scale testing of corn fiber as a substrate for bioproducts, and the commercial-scale production of ethanol from wheat straw by Iogen. This is only the beginning of the possibilities for the biorefinery of the future. It is anticipated that both a sugar-based and a syngas-based platform will allow the conversion of various feedstocks (including plant materials and waste products) to numerous chemicals and fuels. The biorefinery of the future is expected to be similar in magnitude to and able produce a variety of products quite like today's mature and vertically integrated petrochemical refinery (Figure 5).

In summary, the future is bright for the bioproduction of fuels and chemicals. An overview of the biofuel production cycle appears in Figure 6.

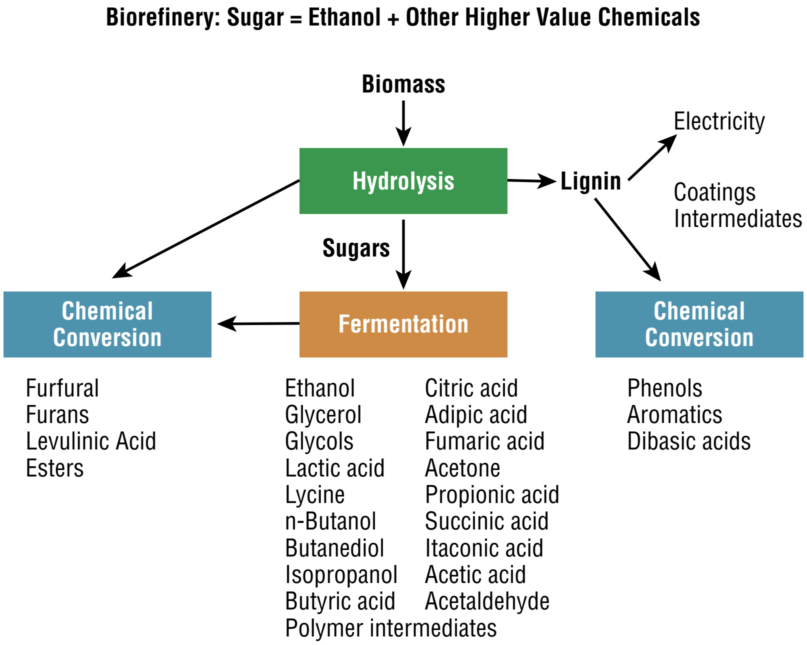

Figure 5 The biorefinery of the future.

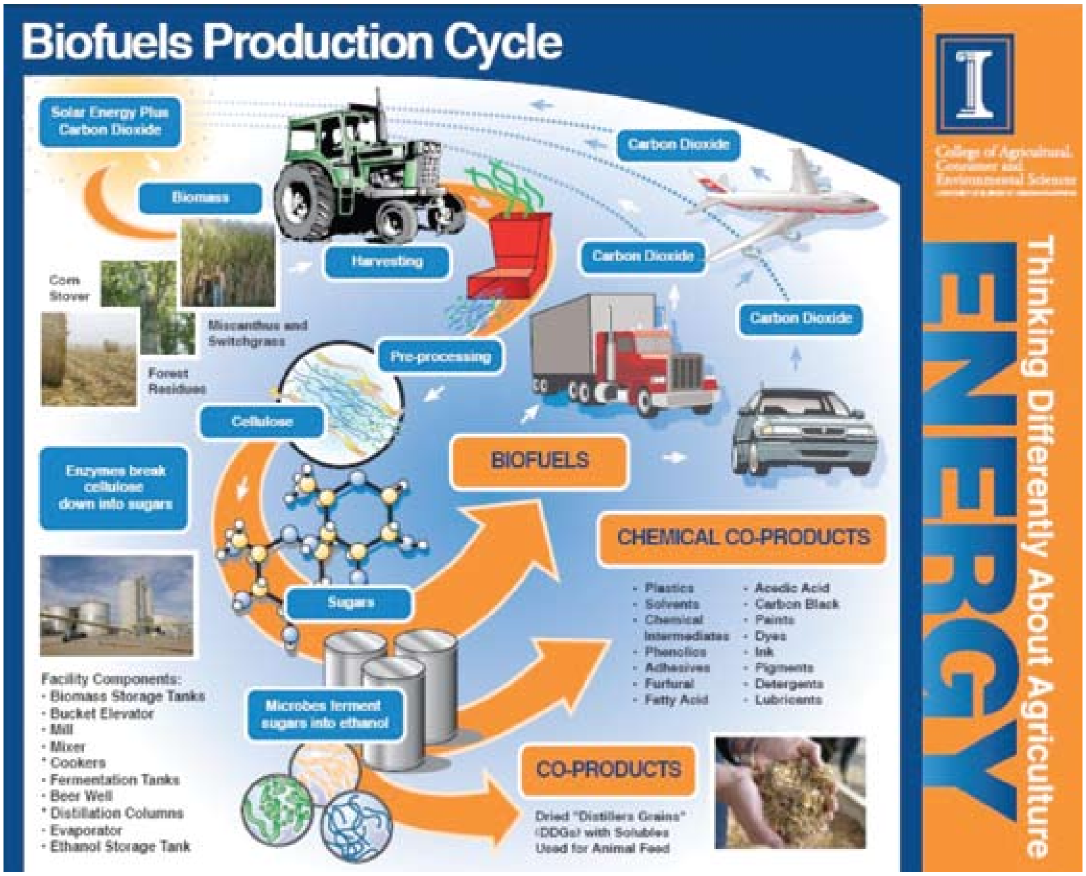

Figure 6 Overview of the biofuels production cycle.

▶ **Because of the need for multidisciplinary expertise, the use of plant and microbial genomic-based approaches leading to translational bioengineering and process scale-up has been compared to the nation's Apollo Project in the 1960s.**

▶ **New technology will result in improved economics and efficiencies and direct competition of bioproducts for feedstock chemicals currently produced by the petrochemical industry.**

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Biofuels in the Broader Context

by CLIFFORD E. SINGER

Much of the recent controversy over biofuels has focused on how much their production affects food prices and alters atmospheric greenhouse gas concentrations. It is quite likely that these issues will have to be addressed seriously in the long term as other energy sources gradually replace fossil fuels, for it is unlikely that electricity can fully replace fluid fuels as an energy source for long-distance transportation. Also production and use of hydrogen independent of biotechnology are not likely to be cost-competitive enough to drive biofuels completely from the transportation sector. These observations suggest that biofuels may indeed play a significant role in the inevitable eventual transition away from fossil-dominated energy supplies.

There is, however, an important difference between the issues that need to be addressed in the long term and the rationale behind controversial mandates for the use of biofuels in the European Union and the United States. This article frames these rationales into a long-term perspective as a basis for examining how durable the near-term government mandates for increasing use of biofuels are likely to be. The point here is not to critique these mandates, but rather to provide a sober appraisal of the various factors likely to affect the rate of market penetration by biofuels.

▶ **The European Union's focus on the environmental impacts of a greater emphasis on biofuels has given it somewhat greater flexibility in its biofuel mandates than the United States.**

▶ **The U.S. emphasis on reducing reliance on imported oil from a security perspective could make the U.S. biofuel mandates more responsive to changes in oil prices.**

▶ **No matter how much the EU and United States attempt to limit their own use of fluid fossil fuels, eventual global emissions of about a trillion metric tons of carbon are likely to be avoidable only if there are dramatic technological advances that differentially give preference to other energy sources.**

The rationales behind the EU and U.S. mandates for biofuel use differ in their degrees of emphasis on environmental versus national security motivations. The European Union has been at least nominally focused primarily on the environmental impacts of a greater emphasis on biofuels. This focus has given the EU somewhat greater flexibility in its biofuel mandates—for example, in response to concerns about the expansion of palm oil plantations in Southeast Asia having a net negative environmental impact. The U.S. emphasis has been more on reducing reliance on imported oil from a security perspective, albeit within the context of legislation that requires biofuel use to result in some reduction in net carbon emissions per unit of energy in the fuels produced as compared with gasoline. This emphasis could make the U.S. biofuel mandates more responsive to changes in oil prices both because the existing legislation allows some administrative flexibility and because an extended period of modest fluid fossil fuel prices could prompt changes in legislated mandates. On both sides of the North Atlantic, political pressure to protect the interests of producers in the agricultural sectors counters environmental concerns and market pressures and establishes a tendency for biofuel production levels not to decrease once they are established at a given level.

When it comes to limiting carbon emissions, a critical question is how much emphasis should be put on limiting the use of coal versus fluid fossil fuels, oil and natural gas. When it comes to national security, a critical question is whether greater reliance on biofuels is a cost-effective approach.

Carbon Emissions

Concerning the cumulative carbon emissions in this century, there is an important distinction between fluid fossil fuels and coal: the depletion of more inexpensively extracted sources of oil and natural gas is likely to significantly increase their cost per unit energy compared with that of coal. On the one hand, then, carbon emissions from these fluid fossil fuels are self-limiting because of the concomitant depletion of inexpensively extractable resources. On the other hand, near-term reductions in fluid fossil fuel use by the EU and United States are unlikely to have much impact on the ultimate cumulative global use of these fuels.

So far, the world has used about a trillion barrels of oil. Exploration and extraction costs for oil typically range from about $5 to $25 a barrel. (All dollar figures here are in terms of year 2008 purchasing power.) Thus the global depletion of a trillion barrels probably drove the average oil recovery costs up to the vicinity of $15 a barrel. Another trillion barrels of oil probably can be recovered at up to about $30 a barrel, another trillion at up to $45 a barrel, and a total of about 6 trillion barrels at up to $90 a barrel, a price at which oil so far still appears to be economically competitive with other transportation energy sources. Burning 6 trillion barrels of oil will release about half a trillion metric tons of carbon into the atmosphere. A comparable amount of carbon emissions is likely to accompany the burning of natural gas to the point where use of other energy sources becomes competitive with a global natural gas market. These are very rough estimates, but they suffice to make the point that no matter how much the EU and United States attempt to limit their own use of fluid fossil fuels, eventual emissions of about a trillion metric tons of carbon are likely to be avoidable only if there are dramatic technological advances that differentially give preference to other energy sources over fluid fossil fuels. Near-term mandates for the use of biofuels may have some influence on the pace of such technological developments, but the primary determinant of what becomes possible in this century is more likely to be the overall pace of development of biotechnology generally.

The situation for coal is very different. On a global basis, compared with fluid fossil fuels, the

▶ **The near-term replacement of oil products with biofuels could distract attention and resources from the very challenging task of placing effective global limits on coal use.**

▶ **By 2006, the U.S. Department of Defense (DOD) was accounting for only 1.8 percent of U.S. oil consumption, and fossil fuels were accounting for less than 3 percent of the U.S. national defense budget.**

▶ **Nevertheless, the idea that oil imports are strategically important is very persistent, especially in the United States, as is the idea that stimulating consumption of alternative forms of transportation energy in the near term is strategically valuable.**

depletion of a trillion metric tons of coal is likely to have a much less dramatic impact on the direct mining and fuel shipping costs of using more coal. It follows that an effective global agreement on limiting the use of coal is the linchpin of effective global limits on atmospheric carbon dioxide concentrations. The near-term replacement of oil products with biofuels is likely to have very little effect and could even distract attention and resources from the very challenging task of placing effective global limits on coal use.

In April 2009, the U.S. Environmental Protection Agency formally began the process of complying with a 2007 Supreme Court interpretation of the Clean Air Act by declaring carbon dioxide and five other greenhouse gases to be pollutants subject to regulation of emissions. Barring a successful court challenge or a weakening of the underlying legislation, limitations on carbon dioxide emissions will follow. If limitations result in an across-the-board carbon emissions trading system, its impact on the use of coal should be much larger than its impact on use of fluid fossil fuels. This is because coal arriving at U.S. utilities at a cost of $40 per short ton costs about $55 per metric ton of carbon content, crude oil purchases at $40 per barrel cost about $330 per metric ton of carbon content, and industrial natural gas purchases at $8 per thousand cubic feet cost about $580 per metric ton of carbon content (or $290 per metric ton if natural gas prices fall by a factor of two below the prices typical in late 2008). If the intermediate- to long-term elasticities of demand for these three fuels are in any way comparable, then the energy sector should respond to across-the-board carbon emissions limits quite forcefully by limiting coal consumption.

National Security

The historical roots of the rationale for limiting oil imports for national security reasons are examined in detail in my recent book *Energy and International War: From Babylon to Baghdad and Beyond* (World Scientific Publishing, 2008). The information that follows on this topic is referenced in that book. Briefly, adequacy of oil supplies played a critical military role in the final year of World War I and throughout World War II. After World War II, hardships during the exceptionally harsh European winter of 1946–1947 raised the specter of revolutionary chaos, prompting the United States to commit to supporting a Western European economic recovery complete with secure energy supplies. However, sometime between the bombing of Hiroshima and the end of the Cuban missile crisis in 1962, observers free of the weight of historical inertia could have realized that the idea that oil was strategically important was obsolete. But policy was and is made by people conditioned by their historical experience. This point is made abundantly clear by the following language from the 1979 Revision of the Strategic and Critical Minerals Act: "The quantities of materials stockpiled under this act should be sufficient to sustain the United States for a period of not less than 3 years during a national emergency that would necessitate total mobilization of the economy of the United States *for a sustained conventional global war* of indefinite duration" (emphasis added).

The Cuban missile crisis made it clear that three or more years of sustained conventional war leading to loss of access to strategic imports was not plausible for the United States in the nuclear age. However, the implications of Albert Einstein's oft-quoted observation that "the release of atom power has changed everything except our way of thinking" had not yet sunk in.

The idea that oil imports were strategically important economically, harking back to the events of 1946–1947 and before, was dubiously reinforced by the shortages of gasoline in the United States in 1973 and the recessions that followed the steep oil price increases of 1973 and 1980. With the wisdom of hindsight provided by an understanding of the origins of the current deep recession, it becomes clearer that the principal driver in both cases was an overexpansion of the money supply. The increases and moderation in oil consumption that accompany expansion and contraction, respectively, of the overall economy provided and then undermined opportunities for oil producers to charge high prices. Because the petroleum sector has long constituted a modest fraction of the total EU and U.S. economies, the oil intensity of production has now sunk low enough that strong growth in the gross domestic product (GDP) could be sustained during the long run-up in oil prices from 1988 to 2008. The collapse in financial liquidity precipitated by U.S. subprime mortgage problems was likely to cause a recession irrespective of oil prices, which instead went along for the ride.

By 2006, the U.S. Department of Defense (DOD) was accounting for only 1.8 percent of U.S. oil consumption, and fossil fuels were accounting for less than 3 percent of the U.S. national defense budget. Two U.S. oil platforms in the Gulf of Mexico were sufficient to produce the amount of oil used annually by DOD, at production costs of under $30 a barrel. The military oil consumption of Japan and the United States' allies in the North Atlantic Treaty Organization (NATO) was presumably even lower. Thus adequate evidence is now available to suggest that oil imports are neither militarily nor strategically significant economically for the United States and its major allies. Fundamentally, the economies of Saudi Arabia, Russia, Venezuela, Iran, and the smaller Persian Gulf states are far more dependent on the fluid fossil fuel trade than are those of the major importers. Simultaneous disruption of production in enough of these states to produce oil price spikes far more problematic than those of 1980 and 2008 are both unlikely to occur over the next decade and unlikely to be prevented by higher biofuel consumption in the oil-importing nations.

Nevertheless, the idea that oil imports are strategically important is very persistent, especially in the United States, as is the idea that stimulating consumption of alternative forms of transportation energy in the near term is strategically valuable. These ideas are born of historical experience. They are reinforced by those who have an economic interest in biofuel production, by those who have an economic interest in trying to maintain a U.S. capability for unilateral military intervention in oil-producing regions, and by those who have political interest in the continuity of such beliefs. As long as the U.S. public widely perceives the existence of a substantial external threat, the disconnect between the security situation and the perception thereof when it comes to the strategic importance of oil-producing regions is likely to persist. The apparent intractability of the struggle in Afghanistan with the Taliban and its sympathetic forces motivated by economic disaffection, particularly in Pakistan, is likely to help the broad-based U.S. perception of a substantial external threat persist well into the next decade, even absent another major attack on U.S. soil.

In theory, U.S. lawmakers could preferentially raise the price of imported oil in order to address the perceived security problem of a high fraction of imports. Import tariffs could gradually rise until exporters agree to negotiate production levels from existing and as yet untapped oil resources in a way that stabilizes prices. Exporting and importing governments could share profits in the form of royalty and tariff revenues. Oil prices to consumers would then rise gradually—for example, at some modest multiple of production cost increases. Such an arrangement could take much of the risk out of fielding systems using alternative transportation energy sources, including biofuels. However, a fierce lobbying effort, including by the major oil exporters, can be expected to defeat any such a proposal in the near future. Moreover, even if such an approach were politically feasible, political pressures in the United States and more reliable profit margins for domestic production and possibly for tariff-exempt Canadian production would probably hold the average cost of oil on the domestic market, at least through the mid-2020s, to below $60 a barrel (again in terms of year 2008 purchasing power). Thus, despite the potential advantages of such an approach, it is unlikely to be adopted or to have a major effect on the near-term use of biofuels even if adopted.

▶ The political will behind the goal of reaching about 20 percent biofuels in the U.S. national transportation fuel mix is likely to be sorely tested.

▶ Academics may play a significant role in shaping the debate in the European Union as they critically examine the roles that biofuel production and use, fluid fossil fuels, and coal play in regional and global environments.

Market Penetration by Biofuels: A Sober Appraisal

The political imperatives behind increasing biofuel use in the United States are thus likely to confront a market situation over the next decade in which biofuels are substantially more expensive than transportation fuels derived from petroleum, compressed natural gas, or both. A tipping point may come at about the time the average fraction of ethanol in gasoline moves toward exceeding the amount that can be used in the existing auto fleet. This limit is perhaps a bit but not much larger than the 10 percent of ethanol currently blended into gasoline as an anti-knock additive. What happens at that tipping point will depend on a delicate balance of market and political forces and so is hard to predict. It is clear, however, that the political will behind the goal of reaching about 20 percent biofuels in the U.S. national transportation fuel mix is likely to be sorely tested.

In the European Union, where the push for greater use of biofuels is being driven more by environmental concerns, that push may be more sensitive to reassessment of biofuels' net environmental benefit. Quasi-independent analysts such as academics may play a significant role in shaping the debate in the European Union as they critically examine the roles that biofuel production and use, fluid fossil fuels, and coal play in regional and global environments.

The considerations just outlined apply up to the beginning of any major run-up in oil prices. It can be reliably said that the past does not predict the future, but it does give some hints. Oil prices fell rapidly after the peak in 1980, and they did not start a run-up similar to that in the 1973–1980 period until 1998. If the past were to repeat the future in a strict temporal sense, then one would not expect another major run-up in oil prices until about 2026, eighteen years after the 2008 peak. What may or may not be more relevant to the spiking phenomenon is the rate of cumulative depletion of oil resources, which will very likely be faster in the post-2008 period than it was in the 1980–1998 interval. The rate of depletion of the more inexpensively extractable oil resources will, however, likely be relevant to the base price below which oil prices cannot long linger. At current production levels, this base price is likely to increase by about $5 a barrel per decade, based on the rough estimate just made here of costs versus cumulative resource depletion. If prices do not rise sharply again for another 10–20 years and consumption does not rise sharply before that, then the minimum sustainable price is likely to be in the range of $25–35 a barrel. Whether the global market price actually falls this low just before a subsequent steep rise will depend both on the cohesiveness of the often fractious Organization of Petroleum Exporting Countries (OPEC) and on whatever intervening events cause substantial disruption of oil production.

Should another major run-up in global oil prices occur—for example, sometime in the 2020s—the impact on biofuel production will likely be substantially different than it was in the 1998–2008 period. On the one hand, by then researchers will probably have made substantial progress in the technology of biofuel production, a research area that tends to build on incremental advances in a wide variety of different laboratories and production facilities. On the other hand, the global consumption of agricultural products in the food sector is expected to increase substantially by the 2020s, even if global population growth continues to decelerate. Even though after 2008 the run-up in agricultural commodity prices that was somewhat aggravated by competition from the biofuel sector proved transient, the impact of such competition might be more sustained during a subsequent surge in global oil prices. Much may depend on whether government policies encourage the production of biofuel feedstocks on prime agricultural land or manage to steer increased production of these feedstocks toward marginal lands.

▶ Much may depend on whether government policies encourage the production of biofuel feedstocks on prime agricultural land or manage to steer increased production of these feedstocks toward marginal lands.

The picture of the future sketched here is but one of a number of possible outcomes, some more likely than others. The formulation of public policy and funding priorities in the biofuel area thus needs to be well informed by a quantitative study of probability distributions for various outcomes. The lessons of the past should not be overly relied upon for guidance about the future, but neither should they be ignored.

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Biofuels and Global Poverty

by MARY ARENDS-KUENNING

In the first half of 2008, as food prices spiked and the media were filled of reports of food riots in countries such as Haiti, organizations devoted to poverty alleviation blamed the situation on government biofuel policies in the United States and the European Union. From July 2007 to July 2008, rice prices increased by 150 percent, corn prices by 100 percent, and soybean prices by about 75 percent (World Bank Commodity Price Data). On the one hand, some critics argued that the demand for corn to manufacture ethanol in the United States was diverting corn from the food chain and causing prices to rise. On the other hand, advocates of biofuels argued that other factors were to blame for the rise in food prices and that biofuel production had great potential to pull many of the world's rural-based poor out of poverty. As the significant price drops in fall 2008 demonstrate, the reality is complex and varies across countries and regions. In this article I present data from Brazil to illustrate concepts and specific examples of such reality.

▶ **Media coverage of how changes in food prices affect poor people in developing countries neglects the crucial fact that the impacts depend on whether one is discussing the rural poor or the urban poor.**

▶ **To the extent that biofuels lower fuel prices, the poor will benefit. However, fuel prices account for a lower share of poor people's consumption than food.**

The Effects of Food and Fuel Prices on the Poor

Media coverage of how changes in food prices affect poor people in developing countries neglects the crucial fact that the impacts depend on whether one is discussing the rural poor or the urban poor. Households that are net consumers of food—that is, almost all of the urban population—are unambiguously harmed by increases in food prices. And the poorer the household, the more negative is the impact. According to Engel's law, which holds across countries and within countries, as households become wealthier they spend a smaller percentage of their income on food. Because food is what economists call a necessity, the elasticity of demand for food is between 0 and 1. For example, Americans spend about $0.15 of each additional dollar on food. A recent study of the poor in thirteen developing countries found that they spend between $0.54 and $0.74 of each additional dollar on food (Bannerjee and Duflo 2007). In addition, poor people consume less processed food than do wealthy people, and so poor people are directly affected by increases in the prices of staples such as corn. When the prices of most commodities are increasing, the ability of the poor to find less expensive substitutes for rice or corn is limited, whereas for a processed food only a small proportion of the price of the food might be affected by the price of the staples used to make it.

High food prices can, however, benefit the rural poor. The media do not cover in as great a depth the positive impact of high prices on developing country farmers, who can then sell their production at the higher prices. The rural poor consist of those who own small amounts of land and those who are landless. The extent to which poor small farmers benefit from high food prices depends on the economies of scale in production and on access to food markets. Many poor farmers in countries such as those in sub-Saharan Africa lack access to markets, which limits their ability to respond to higher food prices. Crops that have large efficiencies of scale, such as sugarcane in Brazil, have less potential to improve the lives of small farmers than do crops that do not have such efficiencies. The landless poor earn most of their income from their labor. Therefore, for the rural landless to benefit from high food prices, farmers must increase their demand for labor, which drives up wages for poor laborers. Higher food prices also have indirect effects on the rural poor. Higher incomes in rural areas have multiplier effects when farmers spend their money on rural goods and services. The producers of these goods and services employ the rural poor. As for the poorest of the poor in rural areas, many cannot grow enough food to meet their families' needs and are net consumers. They may gain from price increases as producers, but they are hurt by them as consumers.

Although the urban and rural poor are affected differently by increases in food prices, both groups benefit from lower fuel prices. Therefore, to the extent that biofuels lower fuel prices, the poor will benefit. However, fuel prices account for a lower share of poor people's consumption than food. For example, in Brazil the 20 percent of the households with the lowest income devote 35 percent of their total expenditures to food and only 8 percent to transportation. The richest 10 percent of households devote 10 percent of their expenditures to food and 17 percent to transportation.

Poverty Rates

Globally, poverty rates tend to be higher in rural areas than in urban areas. As countries become wealthier, people migrate out of rural areas to urban areas. However, in Latin America poverty is becoming primarily an urban problem as the population becomes highly urbanized. In Brazil, the second largest producer of ethanol in the world, less than 20 percent of the population lives in rural areas. By contrast, in sub-Saharan Africa the population is primarily rural, with over 75 percent of the population of the poorest countries living in rural areas.

In both rural and urban areas, poverty rates are set by comparing household income to a poverty line, defined as the minimum income that a government or other policymaker decides is necessary for households to achieve a minimum standard of living. For the rural agricultural population, high food prices affect income as well as the cost of living. For the urban population, income is not affected by food prices, but the cost of living is. How poverty lines are defined differs across countries and across institutions, but most are defined so that they depend on food costs. For example, in Brazil one poverty line commonly in use is based on the cost of a typical diet that meets the minimum nutritional requirements of the household. The poverty line is set as equal to the cost of the diet plus extra income to meet the minimum basic needs of shelter and clothing. Specifically, researchers look at a country's household consumption data, determine the cost of the diet based on what households consume, and then see how households with income equal to the cost of that diet spend their income. The poverty line is then adjusted to take into account the percentage of income that a household with just enough money to afford the basic diet decides to spend on other goods.

▶ For the rural agricultural population, high food prices affect income as well as the cost of living. For the urban population, income is not affected by food prices, but the cost of living is.

▶ Researchers are debating the extent to which government biofuel policies were responsible for the run-up in world food prices that peaked in the summer of 2008.

▶ International organizations disagree with the U.S. and EU governments about the role of U.S. and EU policies in global food crises.

Biofuel Policies and the Poor

To determine how government biofuel policies in developed countries affect the poor in developing countries, analysts should first examine the extent to which biofuel policies affect global food prices. Then, they should adjust national poverty lines to account for changes in the cost of living brought about by higher global food prices and compare the adjusted poverty lines with household incomes. For those persons whose incomes are positively affected by higher food prices, analysts should adjust those incomes and compare them with the adjusted poverty lines.

Researchers agree that the rise in food prices experienced between early 2007 and the summer of 2008 had many causes. The source of the controversy is the magnitude of the effects of the various causes. In addition to biofuel policy, on the demand side the factors include a rising world population, rapid economic growth in China and India, increases in speculation, and a weaker U.S. dollar. Economic growth in developing countries leads to rising demand for meat, milk, and eggs—foods that require grain as livestock feed. On the supply side, rising oil prices, slowing growth in agricultural production, and poor weather in Australia, Russia, Ukraine, and South Africa were factors in higher food prices. Once food prices began to rise, developing countries enacted policies such as export taxes and export bans that led to further increases in food prices (Trostle 2008; Lustig 2008; Mitchell 2008).

Currently, researchers are debating the extent to which government biofuel policies were responsible for the run-up in world food prices that peaked in the summer of 2008. In the academic literature, the question is not yet settled because the peer review process takes time. Most of the studies available do acknowledge that biofuels played a role, but they do not attempt to determine the magnitude of the impacts of the various factors. Of those few studies that do so, estimates of the extent to which biofuel prices caused the increase in global food prices range from 75 percent, according to a World Bank report (Mitchell 2008), to 12 percent, according to a report by the U.S. Federal Reserve Board of Governors (Baier et al. 2009).

In world agricultural markets, the biofuel producers and food exporters large enough to affect world prices are Brazil, the United States, and the European Union. Most researchers agree that Brazil is an efficient producer of ethanol using sugarcane. Sugarcane production in Brazil yields 710 gallons of biofuel per acre, compared with 403 gallons per acre from corn in the United States (Trostle 2008). Brazil has not converted much land from the production of food grains to the production of biofuels, so Brazil's biofuel policy has not affected food grain prices significantly. However, Brazil's biofuel policy has increased the world price of sugar by 12 percent, according to the Board of Governors study. Of all biofuel policies worldwide, the U.S. and EU policies are the most controversial and potentially have the largest impact on global food prices.

International organizations disagree with the U.S. and EU governments about the role of U.S. and EU policies in global food crises. In the summer and fall of 2008, the World Bank, Food and Agriculture Organization of the United Nations, Center for Global Development, and International Food Policy Research Institute (IFPRI) came out with reports that emphasized the role of biofuel policy in rising global food prices. The World Bank, which attributed 75 percent of food price increases to biofuels, based its high estimate on the speculation in grain markets and restrictive developing country policies that stemmed from biofuels. Lustig (2008) of the Center for Global Development argues that the timing of the acceleration in world prices that began in 2006 coincided only with changes in ethanol policy in the United States and biodiesel policy in Europe and not with discrete changes in other factors.

U.S. government agencies and U.S.-based researchers who conclude that biofuel policy had a small impact on world food prices argue that other researchers are confusing correlation with causation. They note that the price of grains makes up a small portion of the total price of processed foods. In the United States and EU, the primary impact on consumers has been through dairy and meat prices. However, the poorer the household, the higher is the

▶ **U.S. government agencies and U.S.-based researchers who conclude that biofuel policy had a small impact on world food prices argue that other researchers are confusing correlation with causation.**

▶ **There is a consensus that U.S. biofuel policy has increased the price of corn; the controversy surrounds the magnitude of effects and the extent to which increases in corn prices affected the prices of other commodities.**

▶ **If scientists are able to make cellulosic ethanol economically viable, the impact of biofuels on food prices will probably lessen.**

share of the diet from grains. In Brazil, the poorest income group consumes per capita per year 32 kilograms of rice, 15 kilograms of beans, 12 kilograms of beef, and 10 kilograms of chicken. By contrast, the richest income group consumes per capita per year 23 kilograms of rice, 10 kilograms of beans, 20 kilograms of beef, and 14 kilograms of chicken (Schlindwein and Kassouf 2007).

When building models of the world grain markets, researchers make assumptions that are crucial to their results. The Federal Reserve study (Baier et al. 2009) includes a spreadsheet in which readers can plug in their own assumptions for different countries. The authors conclude that to generate numbers like those produced by the World Bank (Mitchell 2008), one would have to assume that grain supply and grain demand are very unresponsive to changes in price and that farmers readily switch acreage from grains such as wheat and rice to biofuel crops such as soybean and corn. They argue that these assumptions are contradictory, because indirect effects are large when farmers can easily switch supply from one crop to another, which is behavior incompatible with an unresponsive grain supply.

There is a consensus among the research cited here that U.S. biofuel policy has increased the price of corn, with even the low estimates indicating increases of 20 percent. The controversy surrounds the magnitude of effects and the extent to which increases in corn prices affected the prices of other commodities. When corn prices increase, farmers switch from producing soybeans to producing corn. Also, demand for other grains such as wheat might increase as consumers switch from eating corn tortillas to wheat bread.

What does the research indicate about increases in poverty rates stemming from high food prices? Heady and Fan (2008) discuss recent studies that use simulation techniques to investigate the impacts of large increases in food prices on poverty rates in developing countries. One World Bank study found that because many of the rural poor in sub-Saharan Africa consume more food than they produce, rural poverty rates would increase more than urban poverty rates in two out of three African countries (Ivanic and Martin 2008). Another study by the Food and Agriculture Organization (Zezza et al. 2008) indicated that the most vulnerable households are urban or rural landless, less educated, larger, and without access to infrastructure. An Inter-American Development Bank study indicated that Brazil's poverty rate rose from 28.3 percent to 31.5 percent as a result of a 68 percent increase in global grain prices. This study assumed that consumers did not change their consumption patterns in response to price increases, which indicates an overestimate of the impacts.

Summary

The impact of government biofuel policy on poverty in developing countries varies across regions within countries and across household types. To the extent that biofuels compete with food, urban consumers lose out. Poor rural producers might benefit to the extent that they are able to take advantage of higher food prices and to be competitive producing biofuel feedstock. Even the poor in rural areas who are not net producers of food themselves might benefit if the demand for their labor increases. This article has focused on current biofuel technologies, which use corn, soybean, and sugarcane as feedstock. If scientists are able to make cellulosic ethanol economically viable, the impact of biofuels on food prices will probably lessen.

Whether or not biofuel production was primarily responsible for the dramatic increases in food prices from 2007 to 2008, greater investment in agricultural research and infrastructure presents a win-win situation. High food prices affect consumers and farmers differently, but both groups would gain from increased agricultural productivity. Farmers would be able to produce more food with the same inputs, thereby raising their incomes. Consumers would benefit from lower food prices as the supply of food increases. Since the 1980s, the amount of foreign aid spent on agriculture has fallen. The innovations in plant breeding that brought about the Green Revolution have bypassed much of sub-Saharan Africa, and the returns on research there are likely to be high. Investments in infrastructure such as roads enable small farmers to be able to get their production to market.

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Biofuels: Getting to the Real Facts and Promise about the Food vs. Fuel Debate

by ANIL HIRA

Over the last year, alarm bells have gone off about rising food prices, and many articles and reports have cited biofuel production as a leading cause. *Time* called its cover story on the issue “The Clean Energy Scam” (March 27, 2008), and the *Economist* has carried several articles, including one titled “The Silent Tsunami: Food Prices Are Causing Misery and Strife Around the World” (April 17, 2008). Both articles pointed the finger squarely at biofuel subsidies and protection as one of the major causes of the soaring prices. The resulting pressure for remedial measures led to retrenchment of plans to increase biofuel production in parts of Europe, including the UK, and growing calls throughout the world to scale down or eliminate biofuel production.

▶ **Articles in *Time* and the *Economist* inaccurately pointed the finger squarely at biofuel subsidies and protection as one of the major causes of soaring food prices.**

As in any policy debate of the public’s interests, academics play an important but often not well-publicized role. Academic research, including a conference I attended at the University of Illinois at Urbana-Champaign in November 2008, has revealed that commentators on biofuel production should be much more careful before passing any judgment on biofuels. This became obvious when the economic crisis in fall 2008 induced a sharp decline in both oil and food prices while biofuel production continued to rise. Various short- and long-term factors have to be considered, but the overall picture is not mysterious. Thus the inaccurate portrayal of biofuels in the media is all the more consternating.

▶ **Oil revenues are fueling conflict more than improving prospects for development in much of the world.**

An Overview

The push for biofuels has stemmed from the spectacular rise in petroleum prices, which has jeopardized the world economy, people’s way of life, and the chance of any rapid rise in the standard of living. Another factor is that in an age of terrorism the United States and Europe are tired of dealing with the security mess in the oil-producing states in the Middle East. North Americans have recognized that their own expenditures on gasoline are indirectly funding attacks against them. Clearly, they need to find solutions to reduce this dependence.

During the recent U.S. presidential campaign, it was suggested that Americans could drill their way out of their dependence on foreign oil. This approach, however, will not make much of a dent in the problem. Most estimates suggest that new drilling would contribute only marginally to the U.S. energy supply, and it would be undertaken in some cases at a high environmental risk. Moreover, whatever North Americans do domestically will not affect the overall price of petroleum, which is based on world market prices. Many analysts have pointed out that it is not just North Americans’ own profligate consumption, but also the heightened appetites of India and China in line with their spectacular economic growth over the last decade that have led to increases in fuel prices. World demand, by all accounts, is expected to continue to increase, not decrease. And at the moment, the prospects of discovering huge new and readily accessible (that is, economical) sources of petroleum do not seem great. Indeed, most analysts cannot fathom a scenario in which new supplies could possibly keep up with the growth in demand. This situation is inciting companies and countries to take part in increasingly unsavoury deals with corrupt and dangerous states, leading to kidnappings in Nigeria and the Sudan and piracy in Somalia, among other things. Oil revenues are thus fueling conflict more than improving prospects for development in much of the world.

The most obvious and (theoretically) attractive way out of this mess is to find ways to reduce consumption. There is no question but that mass transportation systems in much of North America are underfunded and poorly supported. Improvements in economic signals such as raising gas taxes and setting a carbon tax to reflect true environmental costs have hit major political roadblocks. Although politicians talk eloquently about the possibilities of a “green jobs revolution,” they are considerably more reluctant to state how such a revolution would be funded or touch on the more obvious and less costly solution of changing the way people do things. It simply does not seem to be in North Americans’ cultural DNA to think about reducing consumption, in spite of the huge abyss between the haves and have-nots and the growing environmental problems their way of life is causing. Thus what seems to be a simple part of the solution is really a very long-term campaign that will require a combination of crises, leadership, and social awareness and movements, possibly over generations.

But what about the short and medium term? Some critics of biofuels point to ready alternatives that are renewable and therefore preferred. In the long run, they may be proven right, but just now such claims simply do not jibe with where North America is technologically. The first main hurdle is to develop an economical energy storage capability. At the moment, energy is generally produced when it is needed—a use or lose situation. The integration of energy systems has to a limited extent improved the ability to use imports and exports so that energy capacity is not wasted. However, transmitting energy over distance is also a costly enterprise, and thus

▶ **What seems to be a simple part of the solution—reducing consumption—is really a very long-term campaign that will require a combination of crises, leadership, and social awareness and movements, possibly over generations.**

▶ **More research is needed into how to reduce the costs of hydropower development and thus overcome the political resistance to what is the most proven and cleanest renewable technology.**

▶ **Strong protectionism is preventing the development of a viable global biofuel market, and each state is focusing on promoting biofuels based on the products it produces.**

there are serious limits to how much can be gained in this manner. The most obvious renewable source, hydroelectricity, is rarely mentioned by energy critics. Hydro, such as the Three Gorges Dam in China, has a black eye from the environmental destruction and displacement of local peoples and habitats it has wrought. It also requires heavy state investments, because so far only large-scale plants have proven to be generally economically efficient, which is something few states are able to pull off in this era of financial stringency. Finally, only a limited number of sites possess the conditions suitable for new hydro operations. Still, countries such as Brazil and Canada could expand their hydropower, and so this option should be more seriously considered. More research is needed into how to reduce the costs of hydropower development and thus overcome the political resistance to what is the most proven and cleanest renewable technology.

Some renewable sources, particularly wind power, are developing rapidly in terms of their technology and cost-effectiveness. However, wind power has its own drawbacks. Because it depends on air currents, it is either intermittent or limited to certain locations, it can affect bird migratory patterns, and often locals are resistant to having large wind farms on their landscapes. Therefore, wind can make a limited but important contribution to the emerging energy mix.

Solar power is much more expensive to install and therefore less economically viable in the immediate term. Countries such as Germany have been very proactive in promoting solar power, and perhaps in several decades a technological breakthrough that brings down its costs will enable its spread. Other technologies, such as tidal and geothermal, are far more limited, both in terms of their level of technology and in terms of their contribution in the future.

The Role of Biofuels

Thus the conundrum remains: what can be done in a petroleum-dependent system, where the lubricant of the economy, from agriculture to transportation to industry and from moving to heating to plastics, is becoming increasingly expensive and in short supply. Can biofuels play an immediate role? Under particular conditions, they certainly can.

The first issue to tackle is food prices. Because farmers are the poorest and hungriest citizens of the world, higher food prices are not necessarily a bad thing. However, much of the world's agriculture is subsidized to the hilt by the Northern states—the United States, Europe, and Japan—thereby eliminating the possibility that farmers in the South can compete on any fair basis. Also, serious costs are associated with the petroleum inputs to agriculture, from fertilizer to tractors to transporting foods to markets, and so obviously biofuel production has had only a partial effect on food prices. Thus more care should be given to claiming that higher food prices are always a bad thing. There are too many examples of precipitous drops in commodity prices driving farmers in the developing world out of business and into poverty to support such a notion.

The second issue is that not all biofuels are alike. Because biofuels are tied to agriculture, its malignant subsidies, and the desire to reduce the ravages of the petroleum-based economy, they have been viewed in good part through a national security and domestic politics lens. Therefore, strong protectionism is preventing the development of a viable global biofuel market, and each state is focusing on promoting biofuels based on the products it produces. Thus Europe strongly promotes rapeseed oil and the United States and Canada corn. Corn prices, in particular, have gone up, and the net effect has been to reduce support for ethanol production in North America. Corn is used in many different ways in the food chain, from direct use to feeding livestock to producing corn syrup. There have also been questions about the net carbon effects of biofuel crops in view of the heavy subsidies and protection such crops enjoy.

The overall efficiency of biofuel production depends on two factors: (1) the net energy benefit of the crop itself and (2) the trade-offs for producing that energy in other forms—in other words, the price of petroleum. In terms of the first factor, sugarcane is by far the most efficient crop for producing biofuel. Common estimates are that it is eight times more efficient than corn (which is, in turn, more efficient than rapeseed oil). Thus creating a global biofuel market based on sugarcane fuel would clearly be the best way to begin to reduce petroleum dependence. The second factor comes into play because the price of petroleum, though on a long-term upward trajectory, is, like that of any other commodity, quite volatile. The breakeven price for sugarcane-based ethanol is often placed at about $70 a barrel of oil. Because the price of oil was well above $100 a barrel for much of 2008, it seems sugarcane-based fuel is certainly economically viable. Therefore, returning to an earlier point, because people spend money on food, transport, industry, and heating, doesn't it make sense to calculate rationally the cheapest way to produce such goods and services? If so, sugarcane-based biofuels have to be part of the mix.

There are, however, important caveats. Not all sugarcane production is equally efficient. Brazil is one of the cheapest producers in the world because it has an extensive system of natural irrigation. Therefore, it makes sense to promote Brazil as a major producer of ethanol for the world, and it still has large capacity for expansion. Other countries in the tropical belt, typically the most impoverished parts of the world, could also become exporters, thereby increasing their export revenues and their standards of living. But many steps must be taken before that can happen. There are major obstacles to biofuel trading, some of which were discussed earlier. A huge overhaul and investment are also required in transporting the fuel and refurbishing the entire production chain for ethanol, down to retail gas stations. There is also the question of renovating the vehicle fleet in most countries. A normal car engine can accommodate a 10 percent ethanol mix without damage, but the current flex-fuel vehicles produced in Brazil can accommodate a much wider range of mixes, thereby allowing flexibility in markets, depending on the price of ethanol relative to that of petrol. Flex-fuel vehicles could be produced around the world, reigniting the auto industry along with development of hybrids and electric cars.

▶ There are major obstacles to biofuel trading; a huge overhaul and investment are also required in transporting the fuel and refurbishing the entire production chain for ethanol, down to retail gas stations.

The record of biofuel producers also needs refurbishing. In countries such as Malaysia and Indonesia, large palm oil plantations have created severe environmental damage. In Brazil, destruction of the Amazon is not an issue because most sugarcane production is concentrated around the state of São Paulo. Moreover, Brazil has improved the efficiency of its process over time by learning how to burn the stalks and waste for cogeneration of electricity. However, important adjustments must be made in terms of the high social costs to Brazilian sugarcane producers, who often work under quite difficult circumstances. These adjustments can be made without losing the promise of biofuels, which can play a vital role in the transition to a reduced-petroleum economy.

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Sustainable Biofuel Standards and Certification

by TIMOTHY M. SMITH, KRISTELL MILLER, AND JUSTIN LINDENBERG

Concerns about energy supply, national security, climate change, and economic development have dominated domestic and transnational dialogues in recent years. Long-term demand pressures on energy from the developed and developing world, political instability in many oil-exporting countries, immense variability in the price of oil, and negative effects on local and global environments are adding significant fuel to the fossil fuels fire. It is at the center of these challenges where many countries see biofuels as a viable answer. Regardless of country or region, biofuel advocates are promising improved energy security and greater economic development opportunities for rural communities based on an increased supply of "green home-grown" energy. Particularly for developing countries, biofuels are viewed as important new export opportunities and a means of reducing import bills for energy-deficient countries in the global South. Therefore, biofuels will likely be a key part of an international response targeting improved energy diversification and new viable clean energy sources. However, those choosing among the host of strategies available to achieve these outcomes often face the competing social, economic, environmental, commercial, and political factors at work both between and among international actors.

▶ **Biofuels are viewed as important new export opportunities and a means of reducing import bills for energy-deficient countries in the global South.**

▶ **If scientists have learned anything over the last few years during which the public has been hopping on and off of the biofuel bandwagon, it is that not all biofuels are created equal.**

Although much attention has been paid to the environmental and social aspects of biofuels, currently little agreement exists on sustainable production levels, sources of this production, and under what conditions this production could be supplied. Much research has focused on "well-to-wheel" analyses of biofuels, exploring issues of feedstock availability and composition, production technologies, facility energy sourcing, and tailpipe emissions (Farrell et al. 2006; Woods and Bauen 2003; Worldwatch Institute 2006), but the vast majority of this work has been directed toward issues of carbon intensity. Only very recently have the analyses begun to systematically address impacts to water, soil quality, human health, and ecosystem services (Hill et al. 2009; Lal 2009; Van Der Velde et al. 2009). In the absence of controversial indirect land use effects, biofuels—including even the least efficient cornstarch-based ethanol forms—are widely thought to be more favorable than petroleum fuels in terms of net energy balance and carbon-intensity. However, if scientists have learned anything over the last few years during which the public has been hopping on and off of the biofuel bandwagon, it is that not all biofuels are created equal. A perfectly well-intentioned purchase of biodiesel may not provide the expected reductions in greenhouse gas (GHG) emissions if the palm oil plantation supplying the feedstock for this fuel is located in what was a tropical peatland rainforest that has been drained, cleared, and burned to make way for increased production. Likewise, the energy security benefits provided by U.S. corn-based ethanol may be jeopardized if its process heat is provided by increasingly challenged coal sources, if its production depends on the increased production of water-intensive irrigated corn, or even if the removal of corn residues (stalks and leaves) to produce cellulosic ethanol result in poorer soil quality and greater nitrate runoff. Even the most efficient first-generation ethanol[1] produced from Brazilian sugarcane may be deemed unacceptable if fair labor practices are not observed or land acquisition abuses persist.

Recent accounts in both the popular and scientific press have produced second thoughts about the social and environmental impacts of, in particular, large-scale biofuel production. On the environmental front, the global agenda is aimed at tackling trends of water scarcity, threats to biodiversity, and climate change—many of which are related to land use and land use change. From a social perspective, poverty reduction, land rights, labor rights, and health and nutrition top the bill (United Nations 2000, 2002). In each of these areas, biofuels are often considered as much of a threat as an opportunity, and the policy and market mechanisms available to address these risks are no less complicated. The potentially negative effects of biofuel production just described are generally not taken into account in market transactions or trade mechanisms, in that most environmental and social costs are not included in the price commanded for these global commodities. Therefore, as society continues to place greater value on these external costs—such as global warming, social justice, and access to clean water—institutions must impose instruments that address both the local and global impacts of biofuel development.

At the global level, a significant debate on the social and environmental performance of biofuels revolves around global trade and domestic and international trade-distorting policies. As biofuel advocates lobby for greater trade liberalization of ethanol and biodiesel to address global energy needs (for example, by reducing barriers associated with import

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[1] *First-generation* refers to biofuels that have been derived from sources such as starch, sugar, animal fats, and vegetable oil, using currently available conventional processing methods.

tariffs, subsidies, taxes/credits, and blending targets/quotas), most agree that this will inevitably lead to significant increases in global biofuel production, particularly in the tropics (Masami, Mitchell, and Ward 2007). Thus, many have urged that any movement to further liberalize trade should simultaneously incorporate meaningful environmental and social safeguards against the potentially negative effects of large-scale production.

Further complicating this dialogue are concerns from developing nations about the technical barriers of nonproduct-related process and production methods (PPMs) associated with sustainability criteria. Although, generally speaking, nondiscrimination against domestic or foreign "like" products is a golden rule within World Trade Organization (WTO) regulations, distinguishing products based on how they are made (PPMs) is taboo within the WTO committees. Agreed upon provisions within the negotiations of the Uruguay Round, which ultimately created the WTO, aim to ensure that national programs and standards do not create unnecessary obstacles to international trade. Although national governments are taking a closer look at PPMs in policy and standards development, agreement around which standards to apply remains elusive and the application of these new approaches in international trade environments remains substantially untested. Voluntary certification and labeling schemes, by contrast, are considered to be outside of the scope of the WTO, so long as governments remain uninvolved. For this reason, and in response to the deficiencies of national governmental regulation and weak transnational institutions, voluntary certifications of sustainable biofuels are often identified as a necessary component of efforts to safeguard environmental and social performance internationally (Kirton and Tebilcock 2004).

▶ Many have urged that any movement to further liberalize biofuel trade should simultaneously incorporate meaningful environmental and social safeguards against the potentially negative effects of large-scale production.

▶ It is important to distinguish between the multiple biofuel sustainability certification initiatives taking shape, because the motivations for their creation and the stakeholder pressures shaping their criteria are quite different.

Private Certification of Sustainable Biofuels

Sustainability standards and certifications are not new or unique to biofuels. Over the last three decades, the public monopoly on regulation has begun to bend to the forces of market mechanisms. In the environmental and social domains, in particular, governance outside of traditional state-centered regulation has proliferated. Private actors take areas of governmental intervention into their own hands and apply to it instruments that customarily are in the private sphere. At times, they even identify and take on new issues that have not yet been addressed by public intervention. In this process, private actors gain the authority to decide, direct, make rules, and obtain performance from others (Cashore, Auld, and Newsom 2004)—although the legitimacy of this authority may vary (Raines 2003). In many recent instances, private proposals for addressing environmental and social externalities have not been limited to one initiative. Rather, rival initiatives have emerged, with several stakeholder groups (representing various social, political, and economic interests) organizing in network form to compete over the emerging rules of the game. These nongovernmental, market-driven forms of governance have appeared in diverse areas such as sustainable forestry, green building design and products, sustainable agriculture and fisheries, fair trade, cleaning products, personal health care products, electronics, and retail carbon offsets.

Specific to biofuels, multiple sustainability certification initiatives are taking shape and evolving at both the fuel and feedstock levels. It is important to distinguish between these initiatives, because the motivations for their creation and the stakeholder pressures shaping their criteria are quite different. At the fuel level, sustainable biofuel standards are emerging primarily out of the North (United States and Europe) with diverse objectives and priorities. Most notable are those of the Roundtable on Sustainable Biofuels (RSB), an initiative of the Swiss Federal Institute of Technology in Lausanne, which recently unveiled "Version Zero" of their principles and criteria for sustainable biofuels. In the United States, a similar multistakeholder effort has emerged in an attempt to develop a consensus-based Sustainable Agriculture Practice Standard (SAPS), which includes an annex that specifically addresses biofuels. Although the future of this standard is unknown—it has been contested by the U.S. Department of Agriculture, among others, and is currently undergoing procedural redefinition under a recent American National Standards Institute (ANSI) ruling—the standards development organization overseeing its development continues to defend the draft standard.[2] Finally, the Sustainable Biodiesel Alliance (SBA), headquartered in Austin, Texas, has also developed principles and baseline practices for biodiesel sustainability.

Although a metastandard approach for sustainability criteria for bioenergy feedstocks is gaining interest among the RSB and some policymakers within the European Union (Gilbertson et al. 2007), existing initiatives include, but are not limited to, the Forest Stewardship Council (FSC), the Roundtable

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[2] The Leonardo Academy is providing process administration to develop a consensus-based national sustainable agriculture standard through the ANSI process. However, Scientific Certification Systems (SCS) has played a significant role in developing the content and criteria of the standard, based on its previously established proprietary sustainable agriculture profiling efforts. Even though this effort is more broadly addressing agricultural products, we include it here because of its explicit inclusion of biofuel processors.

on Sustainable Palm Oil (RSPO), and Round Table on Responsible Soy (RTRS). Established in 1994, the FSC is one of the most well-documented certifications currently in operation. Currently certifying about 7 percent of the world's productive forests, the FSC is interested in expanding "its solutions to non-timber management objectives, such as climate change and biofuels," and that interest has been an official component of its global strategy since 2007. In 2004, spearheaded by the World Wide Fund for Nature (WWF), the Roundtable on Sustainable Palm Oil was established to address the pressures of increased palm oil production. Its principles and criteria have been used to certify over 1.3 million tons of sustainably produced palm oil, although less than 15,000 tons have been sold (WWF 2009). Finally, although still under development, the Round Table on Responsible Soy is currently in its third round of public consultation on draft principles and criteria.

▶ Biofuel sustainability certification initiatives have formed in response to a new and emerging governance arena in which the rules of environmental and social performance are shaped by competitive processes of private sector stakeholders.

Each of these initiatives has formed in response to a new and emerging governance arena in which the rules of environmental and social performance are shaped by competitive processes of private sector stakeholders (such as corporations, nongovernmental organizations, technical experts, and smallholders), and in which individual national governments may participate but cannot be seen as materially influencing outcomes. The following sections briefly discuss areas of commonality and difference between the major standards and certification efforts of sustainable biofuels and biofuel feedstocks. Specifically, the sections cover the broad findings from a comparison of three emerging biofuel initiatives (RSB, SAPS, and SBA) and three feedstock initiatives (FSC, RTRS, and RSPO). Even though these efforts are largely in their infancy, their growth and influence are expanding rapidly in both policy arenas and markets.

▶ A general consensus between standards points to sustainable biofuels supporting local communities and the rights of those living in those communities.

Sustainable Biofuels Initiatives

In the current efforts of the RSB, SAPS, and SBA, some of the areas of nearly universal agreement that are surfacing can form baseline definitions and norms from which privately governed sustainable biofuels standards might be assessed. By definition, all the sustainable biofuels standards examined address environmental, social, and economic criteria. Environmentally, each standard requires sustainable biofuels production to entail lower emissions than fossil fuels, to protect high-conservation areas, and to not degrade the air, soil, or water. Socially, it is generally agreed that sustainable biofuels should not be produced under conditions of unfair labor practices or those that endanger the health or safety of workers. A general consensus between standards also points to sustainable biofuels supporting local communities and the rights of those living in those communities. It is generally agreed that second- and third-generation biofuels—that is, those from waste oil, residual crops, and nonfood sources of cellulosic feedstocks—should be emphasized on both environmental and social bases. Finally, though not explicitly stated in each of the standards, it is nearly universally agreed that sustainable biofuels are those produced efficiently and viably without subsidies or other economic incentives.

Although these broad areas of agreement are important to the emergence of legitimate private governance of sustainable biofuels, they do not in any way suggest equivalency between initiatives. Substantial differences exist across criteria categories and specific approaches toward compliance. Driven in large part by the varying composition of stakeholders behind each emerging standard, pronounced differences exist on the handling of greenhouse gas emissions and global warming potential, agrochemical use, genetically modified organisms (GMOs), local production, and indigenous peoples' rights. In addressing greenhouse gas emissions, both the RSB and SBA recognize life cycle assessment approaches to GHG emissions associated with growing, processing, and transporting biofuels. SAPS, however, approaches this criterion quite differently, including only "energy inputs" in its calculations of energy efficiency and greenhouse gas indices and omitting GHG emissions from indirect land use change, excessive tillage, or use of chemicals. Thus the focus of SAPS at the biofuel processor level centers on a calculation of the net fossil fuel gain of its products. As for GMOs, the RSB suggests that they can be used to improve productivity and environmental performance. By contrast, the SBA advises against their use and complete transparency when GMO use is unavoidable. SAPS flatly states that "the Producer shall not use genetically modified organism (GMO) planting materials." The largely domestic orientations of SAPS and the SBA tend to reduce the emphases on indigenous peoples' rights, whereas broader development goals are clearly a central social focus of the RSB. One particularly distinguishing tenet of the SBA initiative is localization. It is the opinion of the SBA that, to be considered sustainable, biofuel production must be local—that is, produced locally to be used locally. By contrast, the RSB aims to encourage rural economies and indigenous peoples through local ownership and employment, thereby promoting energy security and uplifting local economies.

Sustainable Biofuels Feedstock Initiatives

The RSPO, FSC, and RTRS are built upon similar platforms of specified principles and criteria—that is, distinguishing characteristics used to evaluate certified products or processes. Advocates of the

Consensus among standards development organizations and their stakeholders has yet to be achieved on biodiversity, pesticide and chemical use, genetically modified organisms, and areas of high conservation value.

By 2022, U.S. ethanol imports are expected to reach about 3 billion gallons, a nearly sixfold increase over 2008 levels.

metastandard approach propose the use of existing feedstock sustainability standards as qualification mechanisms for biofuel sustainability standards at-large. Thus achieving a consensus around feedstock sustainability criteria is a work in progress. An examination of the three primary feedstock certification standards included in this analysis suggests that substantial consensus exists around the principles of labor conditions, land use rights, environmental impact assessments, and soil and water quality. And yet differences certainly remain in these areas, particularly on the specific language and the stated intent within each standard toward the degree of compliance necessary for certification.[3] These differences lead to potentially different environmental or social performance outcomes in the implementation and enforcement of standards, but at the standard development level significant commonality exists nevertheless.

Consensus among these standards development organizations and their stakeholders has yet to be achieved on biodiversity, pesticide and chemical use, genetically modified organisms, and areas of high conservation value. Although standards are based on a consensus within groups, such as for the newly developing biofuel standards, the values employed by such groups help shape the criteria of competing standards. For example, the FSC "strictly prohibits" the use of genetically modified organisms, while the RTRS has yet to address the topic because of differing opinions among organizing committee members. In the area of pesticide and chemical use, the World Health Organization and international agreements, including the Rotterdam Convention, make recommendations and set prohibitions on significantly detrimental pesticides and chemicals. The RTRS and FSC are on board with the recommendations prohibiting the use of such substances, whereas the RSPO claims that it will "reduce and/or eliminate" these materials. Specifically addressed by the FSC and RSPO, biological diversity has yet to be mentioned by the principles and criteria of the RTRS.

Market and Policy Implications

The negative implications of developing alternative energy systems based on nonsustainable biofuel production are substantial. Current Energy Information Agency estimates project U.S. biofuel production of ethanol alone to more than double by 2022, with nearly all of this growth stemming from the traditional corn grain–based technologies (EIA 2008). More striking is the same report's estimates of future U.S. imports of biofuels; 2022 ethanol imports are expected to reach about 3 billion gallons, a nearly sixfold increase over 2008 levels. Without meaningful sustainability protections, expansion of this magnitude, coupled with similar biofuel growth targets across the globe, will inevitably place significant stress on landscapes, soil and water resources, local air quality, global climate change, and the social institutions of producing nations coping with labor migration, land rights, workers' rights, and broader indicators of social equity. In view of the global scope of biofuels, their complex direct and indirect environmental and social implications, and the current global financial and economic crisis, it is difficult to envision substantial changes to the global governance of sustainability and sustainable development of biofuels. Thus, for the foreseeable future, the operationalization of sustainable biofuels markets will rely on these relatively new, and largely unproven, forms of private governance.

The comparisons provided in this article merely highlight the vast array of activities surrounding standards development for sustainable biofuels over the last few years and elucidate the competitive nature of the rival initiatives seeking to influence the rules of the game. Although academic and practitioner communities have made great strides toward gaining a fuller understanding of the emergence and effects of environmental standard setting, of industry self-regulation, and of private governance as both a challenger and a counterpart to state authority, very little is known about how rival sustainability initiatives (such as those seen in the sustainable biofuels arena) evolve and affect sustainable outcomes. Interestingly, over time and in ways not well understood, many of these initiatives appear to have consolidated and converged, with a few "winning" systems surviving, implying a certain level of environmental or social quality. Yet it is unclear whether the vetting processes leading to the market success of a particular standard also results in sufficient environmental or social performance improvements.

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[3] All the environmental impact assessments of new production and cultivation require some sort of impact assessment and management plan. The RSPO, however, includes provisions to require systems to ensure continuous improvement of environmental performance. The FSC, within its criteria addressing forest plantations, specifies that only plantations established before FSC inception in 1994, or those established on degraded lands (reforestation) or substituting agricultural uses, are acceptable candidates for new cultivation. Similarly, on soil quality and degradation, the RSPO specifies only the maintenance of soil fertility and yield, whereas the FSC, and to a slightly lesser extent the RTRS, places greater emphasis on issues of soil structure and biological quality in addition to fertility. Finally, it remains to be seen whether language differences on the handling of land rights ("fair dealings" versus "well-being" versus "consent and compensation") will result in significant differences in practice.

For biofuels, the differences emerging between rival standards and their criteria tend to reflect the stakeholders engaged in their development and the regional and political landscapes within which they are created. Criteria themselves, though often the source of much comparison, tend to be a difficult dimension by which a standard developer might create competitive advantage over rival initiatives. Criteria are often transparent, easily replicated, and, like knowledge-intensive technical innovations, suffer from "weak appropriability regimes" (Van de Ven 2005: 367). Thus it might be reasonable to conclude that competitiveness may be more directly related to the composition of stakeholders engaged in the initiative and the unique set of resources they bring to the table, allowing criteria to shift and evolve as standard development organizations jockey for position in the evolving sustainable biofuels marketplace. This phenomenon has been observed in other areas of sustainable product standards and certifications, and there is little evidence to suggest that similar efforts addressing biofuels will differ significantly. In this light, it is important to better understand the organizational motivations for joining and leaving initiatives, the conditions leading to the proliferation of additional sustainable biofuels initiatives, the determinants of competitive advantage for standard developers, and how competition between these initiatives alter criteria and sustainability outcomes over time. Finally, identifying the appropriate roles for national governments and transnational organizations in shaping the rules, norms, and standards of sustainable biofuels will most likely be a necessity as these institutions shape carbon management, product, and energy policies.

▶ **Without meaningful sustainability protections, expansion of biofuel trade of the magnitude predicted will inevitably place significant stress on landscapes, soil and water resources, local air quality, global climate change, and the social institutions of producing nations.**

▶ **It is unclear whether the vetting processes leading to the market success of a particular standard also results in sufficient environmental or social performance improvements.**

As privately governed standards developers approach sustainable biofuels, they face larger, more regulated markets, higher environmental and social stakes, and (arguably) shorter time horizons to enact change. Time will tell whether voluntary market-driven sustainable biofuel standards are up to the test.

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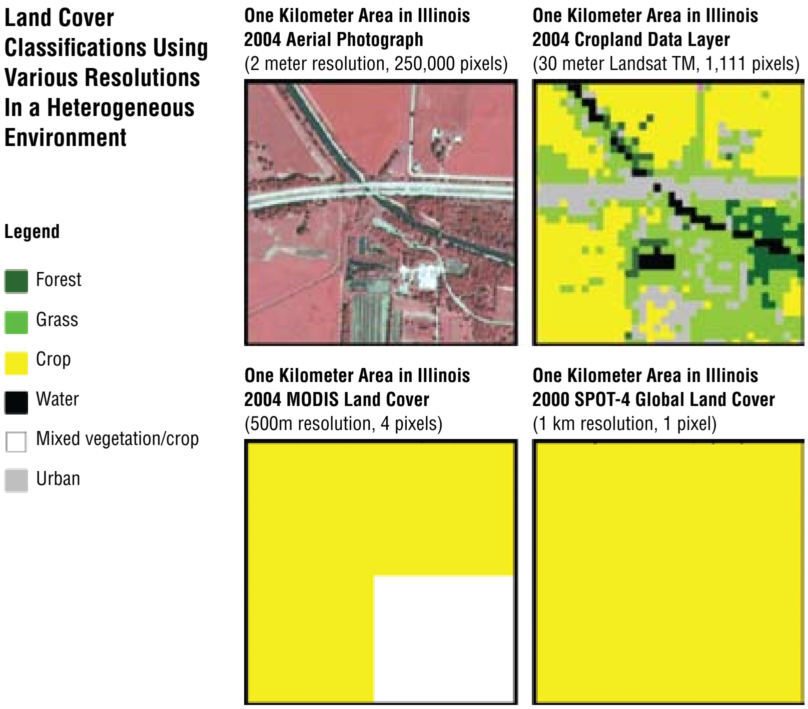
Use of Remote Sensing to Measure Land Use Change from Biofuel Production

by STEFFEN MUELLER AND
KEN COPENHAVER

Over the last three years, academics and others have frequently recognized that expanded production of biofuels is one means of reducing the U.S. dependence on foreign transportation fuels. However, several studies assert that the crop demand for biofuel production may prompt conversion of native ecosystems to agriculture. This conversion process of ecosystems may, in turn, result in carbon releases from native biomass and negatively affect the greenhouse gas (GHG) profile of biofuels (Righelato and Spracklen 2007; Searchinger et al. 2008).

▶ Studies assert that the conversion process of native ecosystems to agriculture for biofuel production may result in carbon releases from native biomass and negatively affect the greenhouse gas profile of biofuels.

The California Air Resources Board and the U.S. Environmental Protection Agency (EPA) are currently in the advanced stages of developing rules on how to quantify and include GHG emissions when comparing the environmental impacts of different fuel pathways (California Environmental Protection Agency 2009). The initiating legislation for the rulemaking process are California's Low Carbon Fuel Standard (LCFS) and the federal Renewable Portfolio Standard (RPS), which require the GHG emissions from biofuels to be assessed on a full life cycle basis, including contributions from direct and indirect land use change.



Land Cover Classifications Using Various Resolutions In a Heterogeneous Environment

Legend

🟩 Forest
🟩 Grass
🟨 Crop
⬛ Water
☐ Mixed vegetation/crop
▨ Urban

One Kilometer Area in Illinois
2004 Aerial Photograph
(2 meter resolution, 250,000 pixels)

One Kilometer Area in Illinois
2004 Cropland Data Layer
(30 meter Landsat TM, 1,111 pixels)

One Kilometer Area in Illinois
2004 MODIS Land Cover
(500m resolution, 4 pixels)

One Kilometer Area in Illinois
2000 SPOT-4 Global Land Cover
(1 km resolution, 1 pixel)

Figure 1 Scene 1 in Illinois: satellite imagery with different resolutions.

GHG emissions from direct land use change are generally considered those associated with the direct supply chain of biorefineries (Plevin and Mueller 2008). For corn ethanol, such emissions include those from land converted to a corn crop to meet the incremental demand of an ethanol plant. Economics-based indirect land use change models take into account market forces that induce land use change on domestic but mostly foreign land that is not part of the direct supply chain (Kim, Kim, and Dale 2008). For example, one proposition of these modeling efforts is that increased ethanol production in the United States leads to more widespread planting of corn, which reduces the area available for soybean production, thereby reducing U.S. soy exports. In turn, other countries such as Brazil will adjust their agricultural land use and ultimately convert native land to meet the soybean shortfall created by U.S. biofuel production.

The quantification of the GHG impact from this process is captured by models in a two-stage process: (1) the adjustments in land surface area converted to crop production in different countries are quantified for various U.S. biofuel production scenarios (for example, the number of new hectares in corn or soybeans in each country), followed by (2) an assessment of what types of ecosystems are being converted to crop production (for example, rainforest to corn or savannah to soybeans). Most datasets used to assess the types of ecosystems conversions under way for biofuel production are based on remotely sensed imagery. However, we are not aware of a sound assessment of the accuracy of remote sensing for land use changes associated with biofuel production. The hypothesis of this study is that the accuracy of these global remotely sensed information products is insufficient for determining land use changes from biofuel production.

The use of remotely sensed imagery for the determination of land cover is well documented. Since the 1970s and the launch of the first Landsat satellite by the U.S. National Aeronautics and Space Administration (NASA), this imagery has been classified with good success into land cover parcels. The type of cover usually indicates the land use. For example, if the land cover is pavement, it is safe to assume the land use would be human development or urban. When compared from year to year, satellite imagery can identify changes in land use. If an area is identified as agriculture one year and human development the next, it may be assumed that the area is one of urban encroachment.

Comparison of Spatial Resolutions for Different Sensors

The recent introduction of remote sensing datasets into the assessment of land use change associated with the possible expansion of agriculture to accommodate biofuel production seems obvious. Remote sensing offers an opportunity to directly image the extent of land use change, but the errors associated with the classification must be taken into account. For example, if 15 percent of forested areas is incorrectly identified in year one and 10 percent is incorrectly identified in year two, the error range totals 25 percent. Another common problem with land use change is the nature of the occurrence itself. Land use change usually occurs in transition areas between two land cover types such as forestry and agriculture. These transition areas are prone to misclassification from a mixed pixel effect. A pixel is the minimum area on the ground for which one value associated with the intensity of light reflected from the earth's surface is being recorded. If the area within a pixel consists of more than one land cover type, it can be misclassified, especially from one year to the next. These errors may seem minor, but when one is assessing land use change on a regional scale over millions of hectares, small percentage errors can indicate large, incorrect changes. The higher the number of pixels recorded by a sensor for a given surface area, the higher is the spatial resolution of the imaging system.

▶ The study presented here hypothesizes that the accuracy of global remotely sensed information products is insufficient for determining land use changes from biofuel production.

Figure 1 shows a 1-kilometer area in Illinois captured with sensors on board different satellites. Depending on the spatial resolution of the sensors on the satellites, the 1-kilometer area is divided into different amounts of pixels. At the top left of Figure 1 is an aerial photograph of the scene showing agricultural land, water, urban buildings, and roadways. Indeed, buildings and roadways make up a significant part of the scene.

At the top right of Figure 1 is the same scene by means of the 30-meter resolution Landsat Thematic Mapper (TM) sensor used by the U.S. Department of Agriculture (USDA) for the NASS Cropland Data Layer from 1999 to 2005. The USDA NASS Cropland Data Layer classification for 2004 using the Landsat TM captures the waterway, grass, forest, and urban areas. Currently, USDA NASS is using the AWiFS sensor for the Cropland Data Layer with a resolution of 56 meters, which is close to that of Landsat (AWiFS also has a shorter revisit time of five days versus seventeen days for TM, which increases accuracy).

In the lower left corner of Figure 1 is the same scene by means of the 2004 Global Landcover Classification's 500-meter resolution from the MODIS sensor. According to the EPA, its modeling efforts for life cycle analyses of the Renewable Portfolio Standard are relying on MODIS satellite data. The figure reveals that the use of MODIS results in significant reductions and that one pixel now combines forest, crop, and urban areas into one "crop" category.

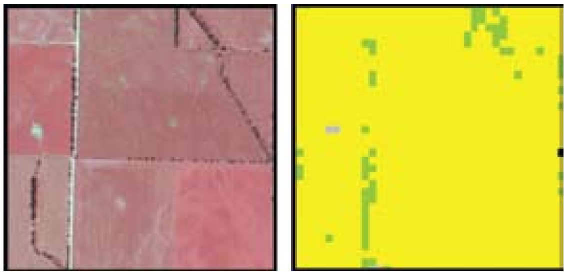
In the lower right corner of Figure 1 is the Illinois scene with a 1-kilometer resolution from the SPOT-VEGETATION sensor, which, for example, is used for the "New IPCC Tier-1 Global Biomass Carbon Map for the Year 2000" (Ruesch and Gibbs 2008). By means of this sensor, the complete scene is further reduced and characterized as cropland. Figure 2 provides a similar demonstration for a more homogeneous land cover scene in Illinois. The MODIS and SPOT sensors combine the mixed land cover in that scene into one cropland category.

For the study described here, we chose the best possible sensors to determine the accuracy of modeling direct and indirect land use while acknowledging the trade-off between resolution and cost (availability). Therefore, direct land use change was modeled using the higher resolution AWiFS sensor, whereas indirect land use change was modeled using MODIS because this sensor produces a global land cover product. The region chosen for direct land use modeling was the corn supply area for an ethanol plant in Illinois; indirect land use change was modeled for Illinois and Brazil.

Land Cover Classifications Using Various Resolutions In a Homogeneous Environment

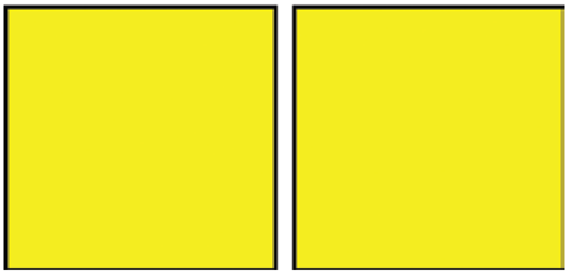
Legend

- 🟩 Forest
- 🟩 Grass
- 🟨 Crop
- ⬛ Water
- ☐ Mixed vegetation/crop
- ⬜ Urban



One Kilometer Area in Illinois 2004 Aerial Photograph (2 meter resolution, 250,000 pixels)

One Kilometer Area in Illinois 2004 Cropland Data Layer (30 meter Landsat TM, 1,111 pixels)



One Kilometer Area in Illinois 2004 MODIS Land Cover (500m resolution, 4 pixels)

One Kilometer Area in Illinois 2000 SPOT-4 Global Land Cover (1 km resolution, 1 pixel)

Figure 2 Scene 2 in Illinois: satellite imagery with different resolutions.

Direct Land Use Change

In a previous study, we assessed land use change in a 40-mile circle surrounding an ethanol plant in Illinois (Mueller and Copenhaver 2008). For this study, we have further analyzed the data because it is representative of the accuracies that can be achieved in direct land use change assessments. The assessment uses the USDA NASS Cropland Data Layers for 2005, 2006, and 2007 (developed by USDA NASS using AWiFS imagery with 56-meter resolution and five-day revisit time for agricultural areas) combined with the 2001 National Land Cover Dataset (NLCD) for nonagricultural classifications, which is currently the most recent version.[1] The overall accuracy of the cropland data for Illinois in 2007 is 97.6 percent (cropland data include only agricultural classes).[2] The error range for land use change between two years, in this case for Illinois, would approximate 2 × (1 – 0.976) = 4.8 percent.

However, the accuracies of the 2001 NLCD are lower and not consistently assessed. The NLCD has not been formally assessed for accuracy on a national basis, but overall accuracy assessments have been estimated at 83.9 percent (Homer et al. 2007). Furthermore, roadways and field fringes introduce further inaccuracies. Therefore, the accuracy assessment of our direct land use parcel employed an additional vetting routine.

The data revealed that 39,841 hectares out of the 601,994 hectares in corn (or 7 percent) during the study year 2007 would have been predicted to change from nonagricultural use to corn. However, in further analysis, we performed additional vetting of the data by applying a routine to the masked area that subtracted a 0.3 hectare buffer along the roadways. Subtracting the roadway buffers resulted in a significant drop in the nonagricultural categories from a total of 39,841 hectares to 1,663 hectares, or 0.27 percent of predicted nonagricultural land use change. We took about fifty test samples with aerial photography to confirm that these parcels were indeed roadway buffers or field fringes around agricultural land (see Figure 3). The characteristics of roadway buffers and fringes are such that very minor changes in vegetation can prompt change in land use classifications. Furthermore, an additional 10,771 hectares that, in the imagery evaluation routine were classified as agricultural to nonagricultural to agricultural conversion (an unlikely scenario) over the three-year period 2005–2007, were categorized separately. Test samples again confirmed that agricultural to nonagricultural to agricultural conversions are misclassified. In fact, the land remained in continuous corn rotations.

We conclude that for direct land use change assessments for biofuel production in which the emphasis is on changes from nonagricultural land to agricultural land the lower accuracy of the NLCD as well as roadways and field fringes may lead to significant overestimations of land use change (39,841 hectares from nonagricultural use to corn versus 1,663 hectares). Therefore, the data require additional vetting for direct land use assessments (Table 1). Because the additional vetting affected primarily (nonagricultural) NLCD classifications, it is clear that the vetting process raised the lower accuracy associated with the NLCD to cropland data levels (in excess of 95 percent).

▶ **Land use change usually occurs in transition areas between two land cover types such as forestry and agriculture.**

▶ **The region chosen for direct land use modeling in this study was the corn supply area for an ethanol plant in Illinois; indirect land use change was modeled for Illinois and Brazil.**

This 2.8-hectare area was classified as woodlands in 2006 and corn in 2007, but it appears to have been in agricultural production both years. Trees surrounding the field likely led to the misclassification in 2006.

Figure 3 Field fringe test sample.

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[1] A new version is expected in 2010. Information on the National Land Cover Dataset is available from the website of the Multi-Resolution Land Characteristics Consortium (MRLC) at http://www.mrlc.gov.

[2] Accuracies for all USDA NASS Cropland Data Layers are available at http://www.nass.usda.gov/research/Cropland/metadata/meta.htm.

Table 1 Unvetted and Vetted AWiFS (NASS USDA) Crop Data

	2007 crop area in 2006	
Land use	**NASS unvetted hectares**	**NASS vetted hectares**
Corn	276,370	275,324
Soybeans	269,417	267,764
Winter wheat	5,848	6,081
Other small grains	299	111
Winter wheat/soybean double cropped	113	45
Alfalfa	2,809	1,238
Other crops	4,537	3,815
Fallow/idle cropland	2,760	651
Grass/pasture/nonagricultural[a]	37,639	1,611
Woodland[a]	1,401	49
Urban/developed[a]	747	2
Water[a]	49	0
Wetlands[a]	4	0
Agric. in 2005 to nonagric. to agric.	0	10,771
Field and roadway fringes	0	34,531
Total analyzed	601,994	601,994

[a] Of the total of these nonagricultural categories, 39,841 of the NASS unvetted hectares were converted to corn and 1,663 of the NASS vetted hectares were converted to corn.

Indirect Land Use Change

NASA offers a global land cover product that was developed from the agency's MODIS sensors on board the Terra and Aqua satellites. As pointed out earlier, the MODIS remote sensing data have been considered for land use change modeling of biofuels for regulatory purposes. Therefore, the accuracy of land use change predicted with MODIS land cover data was selected for further assessment.[3] The MODIS sensor collects images at 250-meter, 500-meter, and 1-kilometer resolution pixels over the earth's entire surface on a daily basis. The dataset, known as MCD12Q1, is processed at the 500-meter resolution. The global land cover product was developed on an annual basis from 2001 to 2005 by combining cloud-free MODIS images throughout the year and analyzing these multitemporal datasets for land cover based on the reflectance and a detailed network of ground truth information.

The MCD12Q1 actually comes in different land cover classification schemes, including one developed by the University of Maryland and another that breaks agriculture into cereal and broadleaf crops. This analysis used the International Geosphere-Biosphere Programme (IGBP) land cover types, but they were aggregated to facilitate data analysis (see Table 2).

An analysis of land cover predicted for Brazil for 2001 and 2004 by the MCD12Q1 dataset does show a decline in the number of hectares in forest and shrubland and an increase in cropland, but it also shows a considerable increase in savanna and a significant decrease in the mixed/crop class (Table 3). These classifications indicate that there is some potential confusion about the amount of natural vegetation being converted into cropland.

The accuracy associated with these MCD12Q1 land cover classifications should be taken into consideration when determining the relevance of change measured with these datasets. The NASA land cover team gathered ground truth points from various locations throughout the world and then compared those points with the results from the land cover classification. For the current version of the MCD12Q1, version five, there are no published errors; the most recent published errors are for version three (Boston University 2009). Because it is unlikely that version five will have achieved a significant increase in accuracy for the purposes of this analysis, the accuracies associated with version three will be used. Table 4 lists the probabilities, in confidence values, that each pixel will meet the accuracy of the ground truth used to develop the map.[4]

▶ Analyses of land cover predicted for Brazil indicate that there is some potential confusion about the amount of natural vegetation being converted into cropland.

▶ We conclude that the MODIS datasets are fairly inaccurate for predicting land use changes from or to forested areas in Illinois and areas with similar ecosystems.

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[3] The MODIS dataset can be downloaded at no charge by the general public at ftp://e4ftl01u.ecs.nasa.gov/.

[4] The table is reproduced from http://www-modis.bu.edu/landcover/userguidelc/consistent.htm.

▶ The accuracy of remote sensing for land use analyses generally varies by the type of land use and the resolution of the sensor.

Table 2 Reclassification of IGBP Classes

IGBP classification scheme	Classification scheme used for this analysis
Water	Water
Evergreen needle-leaf forest	Forest
Evergreen broad-leaf forest	Forest
Deciduous needle-leaf forest	Forest
Deciduous broad-leaf forest	Forest
Mixed forest	Forest
Closed shrublands	Shrub
Open shrublands	Shrub
Woody savannas	Savanna
Savannas	Savanna
Grasslands	Grassland
Permanent wetlands	Wetland
Croplands	Crop
Urban and built-up	Urban
Cropland/natural vegetation mosaic	Mixed
Permanent snow and ice	Other
Barren or sparsely vegetated	Other

If a class has a confidence value of 70 percent, each location in this class has a 30 percent probability of incorrect classification. Anyone assessing changes in a class from year to year, then, must take this error into account. If the amount of change in the class is less than the amount of potential error, there is a real chance that the change may be incorrect. For example, if a class consists of 1 million hectares in 2001 and 800,000 hectares in 2004 but its accuracy is 70 percent, then that class could be off by up to 300,000 hectares in 2001 and 240,000 hectares in 2004, creating a total error of 540,000 hectares. With the potential error of 540,000 hectares for a 200,000-hectare change, it may be difficult to use this change with a high level of confidence.

For this analysis, the potential error for each class was applied to the 2001 and 2004 MODIS datasets. Specifically, the error was applied to the hectares for each individual class and then combined to ensure accuracy (see Table 5). These errors, when applied to the data, bring into question efforts to calculate change in a number of these classes to or from crop. The combined error range for land use change in forestland, for example, could total 90 million hectares. In Brazil, about 28 million hectares are in crops each year. Figure 4 illustrates the scale of these values. The combined error range for land use change for savanna is even greater—almost seven times as many hectares in question (192 million) as land in crops (28 million). If the error range far exceeds the land use transitions predicted for biofuel production, then these datasets are not suited to support sound analyses in this field. In fact, the Global Landcover Validation report states that the purpose of the MCD12Q1 datasets is to assess global land cover and that they should not be used to assess interannual change (Strahler et al. 2006).

Finally, we analyzed MODIS imagery for Illinois and compared the results with tabular survey data compiled by the U.S. Forest Service and the USDA NASS. Figure 5 shows that MODIS underestimates the surface area of forests by 75 percent, whereas

Table 3 NASA MCD12Q1 Land Cover Classification Dataset, 2001 and 2004

Land cover	2001	2004	Difference
Forest	393,451,000	382,090,000	–11,361,000
Shrub	5,394,000	2,720,000	–2,674,000
Savanna	272,622,000	312,837,000	40,215,000
Grassland	45,449,000	23,965,000	–21,484,000
Wetland	10,450,000	11,296,000	846,000
Crop	27,869,000	28,110,000	241,000
Urban	3,924,000	3,921,000	–3,000
Mixed/crop	85,737,000	79,866,000	–5,871,000
Barren/snow	705,000	225,000	–480,000

Table 4 Global Confidence Values by Land Cover Class

IGBP land cover class	Confidence value (percent)
1. Evergreen needleleaf	68.3
2. Evergreen broadleaf	89.3
3. Deciduous needleleaf	66.7
4. Deciduous broadleaf	65.9
5. Mixed forest	65.4
6. Closed shrubland	60.0
7. Open shrubland	75.3
8. Woody savanna	64.0
9. Savanna	67.8
10. Grasslands	70.6
11. Permanent wetlands	52.3
12. Cropland	76.4
14. Cropland/natural vegetation	60.7
15. Snow and ice	87.2
16. Barren	90.0
17. Water	n.a.
Average value, all classes	70.7
Area-weighted average	78.3

n.a. = not available.

Table 5 Hectares Possibly in Error from MODIS Land Use Change Analysis

Land cover	Hectares possibly in error in 2001	Hectares possibly in error in 2004	Total
Forest	46,910,000	43,070,000	89,980,000
Shrub	1,870,000	980,000	2,850,000
Savanna	89,910,000	102,500,000	192,410,000
Grasslands	13,360,000	7,050,000	20,410,000
Crop	6,580,000	6,630,000	13,210,000

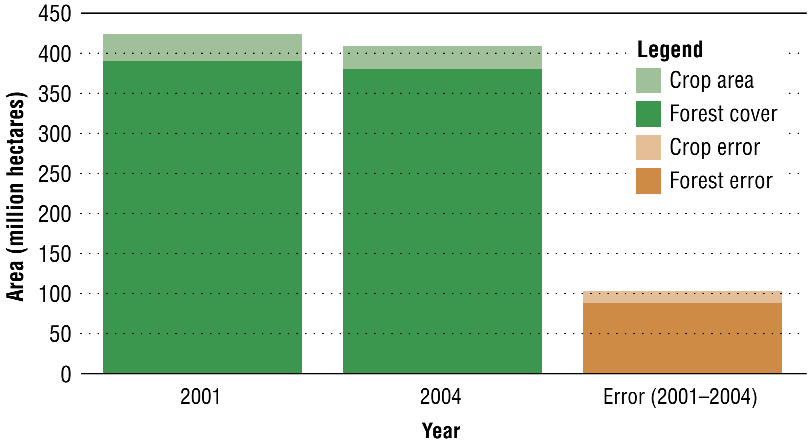
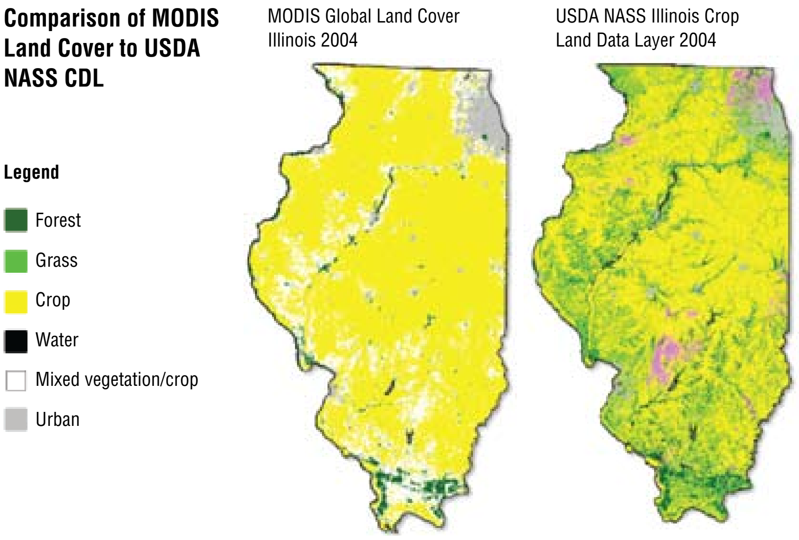


Figure 4 Land use and land use error for Brazil, determined using MODIS.



Class	MODIS Acres for Illinois in 2004	Tabular Data
Forest	1,127,000	4,423,000
Cropland	26,989,000	23,515,000

Figure 5 MODIS imagery for Illinois.

it overestimates the surface area of cropland by 15 percent. We conclude that the MODIS datasets are fairly inaccurate for predicting land use changes from or to forested areas in Illinois and areas with similar ecosystems (such as other Midwestern states).

Conclusions

The accuracy of remote sensing for land use analyses generally varies by the type of land use and the resolution of the sensor. For changes in crop types between two years, for example, Landsat or AWiFS imagery can achieve a combined error range as low as 4.8 percent (Illinois, 2.4 percent error for each year), which is sufficiently accurate in combination with survey data for many types of cropland statistics (including the USDA NASS Cropland Data Layer sets).

For this study, we assessed the accuracy of remote sensing for land use changes—both direct and indirect—expected from biofuel production. For direct land use change assessments for biofuel production in the United States that look at changes from nonagricultural land to agricultural land, the lower accuracy of the current National Land Cover Dataset as well as roadway and field fringes may lead to significant overestimations of land use change. Without additional vetting, we would have predicted land use changes from nonagricultural land to agricultural land of 39,841 hectares (or 7 percent of all hectares in corn in a given area), whereas the vetted data revealed that only 1,663 hectares were probably converted to agricultural land (or 0.27 percent of all hectares in corn in a given area). Because the additional vetting affected primarily (nonagricultural) NLCD classifications, it can be asserted that the vetting process raised the lower accuracy associated with the NLCD to cropland data levels (in excess of 95 percent for land use change assessments).

Looking at indirect land use changes in Brazil, we found that for land use changes such as those that might be associated with biofuel production (forest to cropland), the combined error range between two years was larger than the predicted change. The combined error range for forest land use change, for example, could total 90 million hectares, whereas the total amount of land in crops in Brazil is about 28 million hectares a year. If the potential error far exceeds the predicted change, then using these datasets is tenuous at best.

As for indirect land use change in Illinois, for forest ecosystems MODIS underestimates the surface area by 75 percent. For cropland, MODIS overestimates the surface area by 15 percent. We conclude that the MODIS datasets are fairly inaccurate for predicting land use changes from or to forested areas in Illinois and areas with similar ecosystems (such as other Midwestern states).

In summary, direct land use changes for biofuel production can be assessed using higher resolution imagery from sensors such as Landsat and AWiFS (30 meters and 56 meters, respectively) if the data are further vetted for field and roadway fringes. The accuracy of this process is likely in excess of 95 percent. An assessment of indirect land use changes for biofuel production using imagery from SPOT-VEGETATION or MODIS produces results with high inaccuracies. In fact, the combined error range may exceed the predicted land use change between important ecosystems such as the conversion of tropical rainforest to cropland in Brazil. Regulatory agencies such as the California Air Resources Board and the U.S. Environmental Protection Agency, which are in a rulemaking process to incorporate land use considerations in biofuel production, must consider the limitations of remote sensing for this purpose. We recommend that land cover products based on high resolution AWiFS imagery for transition regions associated with indirect land use change be created.

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A Note on China in the Global Biofuel Scenario

by GALE SUMMERFIELD

The change in ethanol production in the early to mid-2000s illustrated how rapidly the global biofuel market can shift, raising concerns about human security issues in the process. Global ethanol production essentially doubled between 2002 and 2007, from 23.7 million tons to 44.2 million tons (Jun et al. 2009: 2; also see RFA 2009). Until 2005, Brazil had been the main biofuel (ethanol) producer, using sugarcane as the feedstock. In 2006 the United States overtook Brazil in ethanol production, and China became the third largest producer in the world, although at much lower levels than Brazil and the United States (Jun et al. 2009; RFA 2009). Global enthusiasm over the potential for biofuels was soon dampened, however, by challenges focused on whether current production methods and feedstocks actually reduce carbon emissions as well as possible links to food price rises and volatility of prices for food and petroleum. Although efforts are growing to develop second- and third-generation biofuels using cellulosic feedstocks or algae, ethanol remains the dominant biofuel in 2009.

▶ **In 2006 the United States overtook Brazil in ethanol production, and China became the third largest producer in the world, although at much lower levels than Brazil and the United States.**

▶ **As internal stocks of grain began to fall and world prices of grains (and petroleum) began to rise, Chinese officials introduced in 2007 prohibitions on the use of food grains in biofuel production.**

This article briefly examines China's biofuel policy, looking closely at its social dimensions. Energy security is an important concern for this growing economy, which imported almost half of its petroleum needs (350 million tons) in 2006 (Qiu et al. 2008: 112). Food security, however, is even more of a concern, and in response to rising food prices in 2007 China substantially slowed its biofuel program.

▶ **To reduce the connection between food and fuel locally, China began looking to other countries to provide feedstocks.**

China's Ethanol Program

China began its biofuel program in the early 2000s. A central goal was to utilize decaying food stocks to supply the program. Other goals included promoting energy independence and food security, reducing global warming, and increasing rural incomes (IISD 2008). In 2001 an ethanol refinery was built in Henan with a 200,000-metric ton capacity (Li and Chan-Halbrendt 2009). The results seemed promising. In Henan, 1.05 million metric tons of stale grains were used to produce 30,000 million tons of fuel, thereby saving the government 200 million yuan in subsidies (Dong 2007: 6). Building on this success, the government erected other facilities and initiated a pilot program in 2004 in five provinces: Heilongjiang, Jilin, Liaoning, Henan, and Anhui. These provinces were required to use a 10 percent ethanol blend (E10) in gasoline.

In 2006 the E10 program was expanded to twenty-seven cities in the provinces of Shandong, Jiangsu, Hebei, and Hubei. Maize had been the main feedstock, but as internal stocks of grain began to fall and world prices of grains (and petroleum) began to rise, Chinese officials introduced in 2007 prohibitions on the use of food grains in biofuel production. Although maize and some wheat continue to be used in production (with maize still about 80 percent of the feedstock for ethanol in 2009), the intention is to reduce or eliminate them as feedstocks. Meanwhile, there is growing interest in biodiesel and nongrain foods, such as cassava and sweet sorghum. The first plant using cassava opened in Guanxi in 2007.

Today, ethanol production dominates; the output in 2007 was about 1.5 million tons, which is comparable to that of the EU (Jun et al. 2009; IISD 2008). Much less biodiesel is produced, about 190,000 metric tons in 2006 (IISD 2008). Ethanol is highly regulated and highly subsidized in China. In 2006 subsidies of about US$115 million supported ethanol production via direct output-linked payments, tax breaks, and low-interest loans as well as the mandatory use of the 10 percent blend in gasoline in selected provinces (IISD 2008: 11). Biodiesel was initially less interesting to the Chinese because the country is a net importer of vegetable oils. As technology develops, however, biodiesel is expanding and is less regulated.

To reduce the connection between food and fuel locally, China began looking to other countries to provide feedstocks. A biorefinery on Hainan Island in southern China is importing cassava from Laos. In 2008 China and Nigeria signed an agreement to build a cassava-based ethanol plant in Nigeria that would produce by-products of fertilizer and flour. China's biofuel agreements continue to expand, including other African countries, Brazil, and the United States. Officials are especially interested in developing cellulosic and algae processes. New agreements will bring in new production technologies from other countries, such as the one with Coskata in Illinois for a method using agricultural and forest waste products, and one with PetroSun for a plant using algae. An innovative research project in Langfang near Beijing uses carbon from coal sequestration to feed algae that then produce biodiesel (APEC 2009; Watts 2009; Chambers 2008).

Human Security and China's Biofuel Program

The human security aspects of biofuel production and consumption are related to basic needs (such as food and employment), environmental sustainability, and people's agency. A few key human security issues associated with China's biofuel program are examined in this section.

Estimates of the number of jobs generated by biofuel production vary widely, depending on the amount of indirect employment included. Ethanol refining uses very little labor; the typical ethanol refinery in the United States, for example, employs

▶ Detailed statistics on biofuel employment creation have not been published, but Chinese reports estimate that about a thousand jobs are created by each ethanol facility.

▶ Raising the price of grains because of the new sources of demand, such as that for biofuels, could reduce the rural-urban income gap, but a process that resulted in a large transfer from urban to rural areas would not be feasible politically.

▶ Chinese officials are experimenting with growing biofuel feedstocks on marginal lands in areas such as southwest China, where a large jatropha effort is under way, and the northeast, where cellulosic feedstocks are being grown.

only about thirty-five people (RFA 2009). Detailed statistics on biofuel employment creation have not been published, but Chinese reports estimate that about a thousand jobs are created by each ethanol facility. This number is likely to include indirect employment (IISD 2008). Most jobs in biofuels stem from opportunities related to growing, harvesting, and transporting feedstocks, marketing finished fuels, and developing and marketing by-products. It is likely that entrepreneurial activities will arise from the by-products in China, but they have not yet materialized to any notable extent. The creation of several hundred thousand jobs in this sector is possible, but opportunity costs will be associated with trade-offs in any land switched from growing food crops to growing feedstocks.

Food security is the main human security issue for China's biofuel policy (Xinhua 2009). China's prime agricultural land is divided up into more than 200 million small farms that are the backbone of the rural Chinese economy. Inequality between city and countryside is problematic; rural per capita income is much lower than urban. Raising the price of grains because of the new sources of demand, such as that for biofuels, could reduce the rural-urban income gap, but a process that resulted in a large transfer from urban to rural areas would not be feasible politically. Moreover, many rural residents are net consumers of grain and would also be hurt by higher prices. Rising grain prices already led to the slowing of the biofuel program in 2007, and grain commodity inflation continues to be a problem in China.

Instead of raising the incomes of farmers through production of grain-based or other feedstocks on the best agricultural land, the Chinese are looking for alternative locations and technologies for biofuel production. For example, officials are experimenting with growing biofuel feedstocks on marginal lands in areas such as southwest China, where a large jatropha effort is under way, and the northeast, where cellulosic feedstocks are being grown. However, these marginal lands are not necessarily unused, and some are environmentally fragile (Phalan 2009). A full cost accounting should include issues of biodiversity, water, village income from current land use, and other uses of the land by villagers.

Conclusion

After only a few years, China has pulled back from its initial enthusiasm for developing liquid biofuels. Food security is an especially critical issue for this country, which already has one of the smallest amounts of agricultural land per capita and has dwindling grain reserves and a history of famines. Higher incomes are quickly translating into growing demands for better diets and more milk and meat, thereby putting even more pressure on agricultural land. Officials have chosen a more gradual approach to the current generation of biofuels. Still, China is one of the largest ethanol producers globally, and it is developing cellulosic and algae processes. Despite its pressing energy needs, China is pursuing biofuels just enough to hold a strong second-tier position (behind the United States and Brazil) in the global biofuel scenario.

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