BRUSSELS FORUM

PAPER SERIES

EVALUATING BIOFUELS

THE CONSEQUENCES OF USING LAND TO MAKE FUEL

TIM SEARCHINGER

THE GERMAN MARSHALL FUND OF THE UNITED STATES

G | M | F The German Marshall Fund of the United States

STRENGTHENING TRANSATLANTIC COOPERATION

The German Marshall Fund of the United States
1744 R Street, NW
Washington, DC 20009
T 1 202 683 2650
F 1 202 265 1662
E info@gmfus.org

This publication can be downloaded for free at http://www.gmfus.org/publications/index.cfm. Limited print copies are also available. To request a copy, send an e-mail to info@gmfus.org.

GMF Paper Series

The GMF Paper Series presents research on a variety of transatlantic topics by staff, fellows, and partners of the German Marshall Fund of the United States. The views expressed here are those of the author and do not necessarily represent the view of GMF. Comments from readers are welcome; reply to the mailing address above or by e-mail to info@gmfus.org.

About GMF

The German Marshall Fund of the United States (GMF) is a non-partisan American public policy and grant-making institution dedicated to promoting greater cooperation and understanding between North America and Europe.

GMF does this by supporting individuals and institutions working on transatlantic issues, by convening leaders to discuss the most pressing transatlantic themes, and by examining ways in which transatlantic cooperation can address a variety of global policy challenges. In addition, GMF supports a number of initiatives to strengthen democracies.

Founded in 1972 through a gift from Germany as a permanent memorial to Marshall Plan assistance, GMF maintains a strong presence on both sides of the Atlantic. In addition to its headquarters in Washington, DC, GMF has seven offices in Europe: Berlin, Bratislava, Paris, Brussels, Belgrade, Ankara, and Bucharest.

About Brussels Forum

Brussels Forum is an annual high-level meeting of the most influential American and European political, corporate, and intellectual leaders to address pressing challenges currently facing both sides of the Atlantic. Participants include heads of state, senior officials from the European Union institutions and the member states, U.S. Cabinet officials, Congressional representatives, Parliamentarians, academics, and media. For more information, please visit www.brusselsforum.org.

Evaluating Biofuels

The consequences of using land to make fuel

Brussels Forum Paper Series

March 2009

Tim Searchinger*
The German Marshall Fund of the United States

*Tim Searchinger is a transatlantic fellow with the German Marshall Fund of the United States (GMF) where he focuses on trade and development, agriculture policy, and the environment. He is also a research scholar and lecturer at Princeton University. Before joining GMF, Mr. Searchinger was co-director of the Center for Conservation Incentives at Environmental Defense where he supervised work on agricultural incentive programs.

1 Introduction

In 2008, the developed world relearned the ancient lesson that food is not inherently plentiful and cheap. It also began to learn a new lesson that in an era of global warming the productivity of land is based not merely on its capacity to generate food and fiber but also to store carbon. Using land for one purpose involves serious tradeoffs with the others. Biofuels helped generate the conditions for this education.

Spurred by subsidies and mandates of various kinds, biofuel production began to grow rapidly in the United States and Europe in the 1990s and by 2007 provided 1.8 percent of the world's transport fuels (OECD 2008b). Studies emerged claiming that the world could meet half or more of world energy needs and still feed its people even while devoting much of its agricultural land to produce bioenergy (National Research Council 2000; Fischer 2001; Hoogwijk 2004). At the end of 2007, the U.S. government imposed and the European Commission proposed even larger mandates for oil companies to mix biofuels into their sales of gasoline and diesel and to do so quickly. For many people, realizing the potential of biofuels depended only on the degree of world commitment and the limited time it would take scientific researchers to find cheaper and more efficient ways of making ethanol from biomass rather than food crops, in particular from new breeds of rapidly growing grasses and trees.

Yet even by the end of 2007, world cereal prices had more than doubled from levels between 1999 and 2002, while vegetable oil prices had roughly tripled (FAO 2008, Figure 1). As prices rose yet further in the spring of 2008, the poor in many developing countries rioted, reputable agencies such as the Food and Agriculture Organization (FAO) and the World Bank attributed a significant part of the price rise to biofuels, and the press in the United States and Europe took notice. With the global recession and good harvests in 2008, prices have come down, and some people following press reports would believe the problem is over. But crop prices are now fluctuating from 50 to 100 percent higher than prices around the turn of the century, and continued expansion of biofuels is likely to maintain tight crop markets that can again trigger huge price increases if weather falters in any particular year.

At the same time, academics (including this author) began estimating formally what environmentalists in developing countries had concluded on their own, that devoting productive cropland to fuels in the United States and Europe would drive farmers around the world to clear more land to replace the food. This clearing threatens not only valuable habitats but the release of large quantities of carbon dioxide (Searchinger 2008a; Fargione 2008). Plants and soils hold at least three atoms of carbon for every atom in the atmosphere, and land use change has contributed around 20 percent of carbon dioxide emissions in recent decades (Watson 2001). These papers argued in essence that biofuels were helping to solve the energy side of climate change only by making the land-use side worse.

By the end of 2008, at least ten major technical institutions had released highly cautionary to harshly critical reports on biofuels. In addition to the World Bank and FAO, they included the Joint Research Center of the European Commission, the European Economic and Social Committee, and national technical agencies in the United Kingdom and the Netherlands (for a summary, see Searchinger 2008d). These institutions called on developed countries to change their policies.

The challenges to biofuels mostly derive from this competition with food and forest, yet other critics have challenged also their high economic costs and their relatively modest inherent efficiencies compared to other renewable fuels and other uses of biomass. As these criticisms have mounted,

By the end of 2008, at least ten major technical institutions had released highly cautionary to harshly critical reports on biofuels.

defenses have of course emerged. While impacts of biofuels on retail food prices in the United States and Europe have sometimes been exaggerated, and while the precise mix of land use effects is hard to predict with certainty, the many technical agencies have concluded correctly that biofuel policies should proceed carefully and should focus on those sources of biomass that do not divert the productive capacity of land. Despite this emerging consensus, it is not at all clear that government policies will reflect this emerging view.

Biofuel policies should proceed carefully and should focus on those sources of biomass that do not divert the productive capacity of land.

2 Biofuels and the Competition for Land

The world is a big place with roughly 1.5 billion hectares of cropland, 3.5 billion hectares of grasslands or savannahs, and 4 billion hectares of forests (depending on definitions) (Watson 2001). Each of these lands takes up carbon from the atmosphere and provides benefits to mankind. But the carbon takes different forms, and the amount of carbon these lands take up, i.e. their productivity, varies greatly. The vast bulk of biofuels today derive from the output of the world's highly productive lands, in particular its good croplands in the United States, Europe, and Latin America. Using productive lands for biofuels, whether productive of food, timber products, or carbon storage, competes with other uses. The dominant questions for biofuel policy today focus on the costs and benefits of devoting productive land to biofuels, rather than to other human needs.

A. Fundamental importance of land to the greenhouse gas equation

With the U.S. election of Barack Obama, the leading U.S. and European heads of state are now all committed to large, quick reductions in greenhouse gas emissions. Whatever other motives lie behind biofuels, biofuels are unlikely to prove acceptable over the next several decades unless they dramatically reduce greenhouse gases. Indeed, many world leaders, including Obama, have proposed an 80 percent reduction in greenhouse gases by 2050. Because some sources of greenhouse gas emissions can be controlled only to a limited degree, and others will avert control at all, those new energy sources that can be developed will have to be virtually emissions-free to achieve anything approaching that goal.

Land use plays a critical role in calculating the greenhouse gas benefits and costs of biofuels. Unfortunately, we now know that previous calculations of greenhouse gas benefits were highly flawed because they provided a one-sided accounting of the use of land.

The theoretical potential of biofuels to reduce greenhouse gas emissions depends on the capacity of plants to take carbon dioxide out of the atmosphere and store it as carbon in their tissues. When cars burn fuels made from plants, they only put that carbon back into the atmosphere. By contrast, burning gasoline and diesel takes carbon out of underground storage in the form of crude oil and adds it to the atmosphere. Apart from all the energy and other emissions involved with producing biofuels, conventional calculations therefore view biofuels as carbon neutral.

Lifecycle analyses explicitly show this uptake of carbon in plants as the source of biofuels' potential greenhouse gas benefits. A lifecycle analysis for biofuels compares the greenhouse gas emissions from biofuels with those from gasoline or diesel fuel in the different stages of production and use. Table 1 sets out the emissions from the GREET model used commonly in the United States and the model used by the British government. Row 1 shows the emissions involved in growing the biofuel plant, such as the tractor fuel and fertilizer, and for the gasoline side, the emissions from mining the crude oil. Row 2 shows the emissions from refining the plants or crude oil into ethanol, gasoline, diesel, or biodiesel. Row 3 shows the emissions from burning the fuel in a vehicle, and these emissions are essentially identical for biofuels and fossil fuels. Adding up these three columns in row 6 shows that in these stages alone biofuels from crops produce more greenhouse gases than gasoline, and biofuels from cellulose produce roughly the same emissions as gasoline. But critically, conventional lifecycle analyses award biofuels a carbon credit for the carbon taken up by the plants incorporated into the biofuel, shown in row 4, which is what generates the greenhouse gas benefit as shown in row 7.

Unfortunately, growing plants for biofuels requires land, and that land is not brought into existence to grow biofuels. If not used for biofuels, land

The dominant questions for biofuel policy today focus on the costs and benefits of devoting productive land to biofuels, rather than to other human needs.

Understanding the role of land in comparing greenhouse gas emissions from biofuels and conventional fuels

Why calculating land use change just means accounting for the costs of using land as well as the benefits

Table 1. GREET and U.K. default values CO_2 emissions for various fuels, grams (CO_2 equivalent) per mega joule of energy in fuel

			GREET Gasoline	GREET Corn Ethanol	GREET Biomass Ethanol	GREET Diesel
1	Production Emissions		4	24	10	5
2	Refining and Retail Transport		15	40	9	11
3	Combustion		72	71	71	68
4	Land Use Effects	*Land Use Benefit* carbon removed from air by plants used for biofuels	0	−62	−62	0
5		*Land Use Cost* emissions from cropland expansion to replace crops on land diverted to biofuels (as estimated by Searchinger et al. 2008a/Searchinger & Heimlich 2008)	0	104	111	0
6	Total without any land use effects (rows 1+2+3)		91	135 (+48%)	90 (−1%)	84
7	Total counting land use benefit only (rows 1+2+3+4)		91	73 (−20%)	28 (−70%)	84
8	Total counting land use benefit and cost (rows 1+2+3+4+5)		91	177 (+93%)	138 (+51%)	84

* Percentages are for biofuel compared to gasoline or diesel. GREET figures are from Argonne National Laboratory 2007. U.K. figures are from the U.K. Renewable Fuels Agency 2008a.

GREET Soy Biodiesel	U.K. Default Values –Diesel*	U.K. Default Palm to Biodiesel	U.K. Default Rape Biodiesel for the U.K.
23	3	8–9	52
23	14	35–36	0
69	69	69	69
–76		–69	–69
110–180		?	?
115 (+37%)	86	112–114 (+30% to +33%)	121 (+41%)
39 (–57)	86	43–45 (–50% to –48%)	52 (–40%)
+149 to +219	86	?	?

would typically already be growing plants that are removing carbon from the atmosphere. Lands that support forests, for example, transform carbon in the air into trees, roots, and eventually organic soil material, all of which withhold carbon from the atmosphere. Land that supports crops transforms carbon in the atmosphere into food, which returns to the atmosphere only because we eat it (or we eat the livestock that eat the crops) and emit the carbon dioxide as we burn food for energy. But if people continue to eat, which is of course a good idea, they will to a significant degree turn other forests or grasslands into croplands, sacrificing their carbon storage.

Unfortunately, growing plants for biofuels requires land. If not used for biofuels, land would typically already be growing plants that are removing carbon from the atmosphere.

Row 5 of Table 1 shows the costs of dedicating U.S. corn land to ethanol and U.S. soybean land to biodiesel as estimated by Searchinger 2008a and Searchinger 2008c. When calculations count land costs as well as benefits, biofuels increase global warming emissions. These studies provide only one set of estimates, but a proper lifecycle analysis must always count not only what we gain by dedicating land to biofuels but also what we give up.

In general, biofuel advocates agree that if biofuels directly replace forest or grassland, the greenhouse gas emissions should calculate the "carbon debt" that results from plowing them up, which are large. But many biofuel champions argue that when existing cropland generates biofuels, calculating indirect land use effects is inappropriate. Some argue that resulting land use change should be the responsibility of those who plow up land, not the farmer who produces the biofuel. Some also argue that indirect land use should not be assigned to biofuels because land use is left out of the analysis of many other activities, and because indirect land use effects are hard to calculate.

But the traditional lifecycle analyses that show potential greenhouse gas benefits for biofuels already inject land into the equation because they

Most hectares productive enough to produce average U.S. corn yields would also regenerate into trees if left alone. Using that spare hectare for corn ethanol would therefore increase carbon dioxide in the air compared to leaving it alone and allowing it to regenerate into trees.

credit biofuels with the carbon taken up in plants grown on that land. Without this carbon credit, biofuels show no benefits. If land use is to be counted, the question must be whether using land for biofuels generates a net benefit, not a gross one. Just as a proper economic study of biofuels cannot assume that land comes rent-free, so a greenhouse gas accounting cannot assume that land comes carbon free. Unless lifecycle analyses calculate land use on a net basis, including both benefits and costs, they are crediting biofuels with a gain only for moving carbon from one box to another.

B. The carbon opportunity cost

Because biofuels are essentially a land use strategy, the land's carbon opportunity cost provides the simplest, and in many ways best, method for calculating whether the strategy reduces greenhouse gas emissions. This method compares the carbon savings from using land to make biofuels, which is based on the gasoline and diesel fuel they displace, with the carbon savings of leaving land in its existing use or using it in other potential ways.

To illustrate this cost, imagine a hypothetical spare and bare hectare of good U.S. land in the Midwestern United States (a hectare is 2.47 acres), a hectare that society can direct into one use or another. If used to grow corn for ethanol at the corn yields expected in 2015, and accounting for the value of food by-products, that hectare will replace enough gasoline to save three tons of carbon dioxide according to the most commonly used "GREET" model (Searchinger 2008a).[1]

Yet, most hectares productive enough to produce average U.S. corn yields would also regenerate into trees if left alone.[2] That would sequester carbon dioxide in the branches, roots, and soil for decades at a probable rate of 7.5 to 12 tons.[3] Using that spare hectare for corn ethanol would therefore increase carbon dioxide in the air compared to leaving it alone and allowing it to regenerate into trees. Biofuels in the tropics have a similar result. One study calculated annual biofuel savings of sugarcane at the high end at roughly 9 tons per hectare per year, and palm oil at 7.5 (Gibbs 2008), but reforestation rates in the tropics probably sequester carbon dioxide at rates of 14 to 28 tons per year (Righelato 2007).

Converting an existing mature forest to produce ethanol is typically worse. Depending on the forest type, the forest would give up from 355 to 900 tons of carbon dioxide within a few years, which means 12 to 30 tons per year over 30 years.[4] If the hectare were to come out of younger, regrowing forests, the up-front loss of carbon would be lower, but the transition would also sacrifice ongoing carbon sequestration from the regrowing trees of probably at least 7 tons per hectare per year. In either case, using the land for biofuels sacrifices more carbon

[1] According to GREET, the hectare's worth of ethanol saves 1.8 tons of carbon dioxide, but the process generates distillers grains that provide an amount of animal feed equivalent to four tenths of a hectare of corn according to some recent analysis (Klopfenstein 2008). In effect, because only 0.6 hectares of good corn land is really being used to save 1.8 tons of carbon dioxide, one hectare saves 3 tons.

[2] Many corn acres are in land that was originally prairie, which generates large carbon sequestration benefits as well as potential forage for animals, but without deliberate effort today to install fire on the landscape, most corn acres would regenerate as forest.

[3] The lower figure represents an average annual carbon sequestration of re-growing European evergreen and deciduous forests, incorporating disturbances such as fire and harvest as estimated by Dr. Richard Houghton at the Woods Hole Research Center and includes wood harvests (Searchinger 2008a, Supporting Online Materials Table D-9). A survey of carbon studies of forest plantations in the United States estimated average sequestration rates of more than 13 tons of carbon dioxide per year, similar to figures cited by the IPCC (Jackson 2004; Watson 2001)—and while plantation forestry concentrates carbon in harvestable tree stock, there is no reason to believe it sequesters more carbon overall than natural regeneration.

[4] These figures represent a range of temperate and tropical forest types based on figures cited in Gibbs (2008), Searchinger (2008b) and Fargione (2008).

than it saves. If the hectare of biofuels came out of grassland around the world, the estimates of up-front loss range from 65 tons in the tropics to roughly 200 tons in Canadian grasslands, a rate of 2 to 6.5 tons per year over 30 years (Fargione 2008; Searchinger 2008b; Gibbs 2008). But using grasslands also sacrifices meat and dairy products because nearly all grassland is grazed. Replacing those livestock products would push grazing into other areas, such as a forest, which will release yet more carbon.

The use of wetlands has the highest carbon cost because wetland soils typically hold vast quantities of carbon, which returns to the atmosphere when wetlands are drained for agriculture. Peatland rain forests in Indonesia and Malaysia have provided much of the new land for expansion of palm oil. Doing so releases carbon over 30 years at rates variously estimated between 43 tons to 170 tons per hectare per year (Fargione 2008; de Santi 2008).

Potential ethanol from cellulosic biomass may improve the tradeoff but not change it dramatically. For example, ethanol from switchgrass at high yields and conversion efficiencies would save 8.6 tons of carbon dioxide per hectare per year, still not enough to turn a carbon profit compared to allowing spare land to regenerate as trees.[5] Some entrepreneurs and plant scientists believe biomass yields from miscanthus or other fast-growing grasses can reach stratospheric yields (Khosla 2008). Yields of 36 tons of biomass (not pure carbon) per hectare per year would save greenhouse gases compared to reforesting a spare, bare hectare in temperate zones. But even at those yields, taking into account these land use opportunity costs, ethanol would reduce emissions compared to gasoline only by 29 percent.[6] And even those yields would not warrant converting existing forest or wetlands or allowing most tropical sites to regenerate as forest.

Using land for biofuels comes at a high carbon opportunity cost for the intuitive reason that land with the rainfall and soils necessary to be highly productive for biofuels would probably also produce a great deal of forest or food. In addition, turning biomass into biofuels takes a great deal of energy, probably more than 50 percent, so even if that energy comes from the biomass itself, at best one half of the carbon works its way into liquid fuel (IEA 2008, p. 319). Dedicating land to biofuels is only likely to provide meaningful net benefits if the land today supports little plant growth but could support plant growth abundantly for biofuels.

Some argue that a forest may not be a realistic alternative to using land for biofuels (at least for land that is not already forest). But abandoned agricultural land forms the basis for many estimates of biofuels potential, as farmland switches locations around the world (Hoogwijk 2005), and millions of hectares of abandoned cropland revert to forest each year (Barker et al. 2007; p. 67). Directly or indirectly, the world really does choose one land use or another. Perhaps more profoundly, land use change

Using land for biofuels comes at a high carbon opportunity cost for the intuitive reason that land with the rainfall and soils necessary to be highly productive for biofuels would probably also produce a great deal of forest or food.

[5] This calculation assumes yields of 18 tons per hectare per year—described by the Department of Energy as achievable with "intensive genetic selection and research" (Perlack 2005)—and 90 gallons of ethanol per ton, roughly 20 percent higher than yields projected for the first plants and using the GREET model to calculate savings per ton (Searchinger 2008b).

[6] The GREET model calculates greenhouse gas emissions per liter of fuel. Gasoline produces 1988 grams of greenhouse gases (CO_2 equivalent) per liter (Searchinger 2008b, Table 1A). Biomass ethanol, according to GREET's analysis that ignores land use change, generates 593 grams per liter of gasoline equivalent, so each such liter of cellulosic ethanol saves 1395 grams. At 36 tons per hectare of biomass and 343.3 liters of gasoline equivalent per ton, a hectare produces 12,359 liters, which at savings of 1395 grams/liter implies savings of 17.2 tons of carbon dioxide each year. But if we treat 10 tons of carbon dioxide as the opportunity cost for that hectare, the amount of carbon likely to be sequestered per year by regenerating forest in the United States, the additional costs amount to 809 grams per liter, or put another way the real savings per hectare are only 7.2 tons per year. That amounts to savings of 586 grams per liter, a reduction of 29 percent compared to the 1988 grams of emissions per liter of gasoline.

already contributes 17 percent of the world's total greenhouse gases (Barker 2007), and allowing more land to retain more carbon is the only way to address this challenge. Using productive land for biofuels inherently makes this challenge harder to solve.

C. What happens when biofuels divert existing cropland

The biofuel mandates of the United States and Europe both exclude biofuels from feedstock grown on newly-cleared forests and many grasslands. Champions of biofuels usually agree that emissions from such direct changes in land use should count in global warming accounting. The dispute lies in whether and how to calculate indirect land use changes when biofuels divert existing cropland. Although the opportunity cost analysis provides a useful way of understanding these costs, it does not answer what will actually happen to world land use. This answer requires economic models, and estimating land use change due to biofuels has touched off a wave of different modeling efforts. To date the analyses all show significant emissions from land use change (e.g., Gurgel 2007; Hertel 2008; OECD 2008b), but in varying amounts. Should these differences matter?

As a policy matter, perhaps not. Diverting cropland to biofuels[7] can only have three kinds of results: one, the food is not replaced; two, the food is replaced by plowing up new cropland from forests or grasslands; and three, farmers replace the crops by boosting yields on their existing land. The different economic models may predict different combinations of the three results, but they all represent serious costs, and the more productive the land devoted to biofuels, the greater these costs will be.

[7] As noted, for many biofuel crops, a significant amount of food value remains. For example, biodiesel uses only the vegetable oil generated by soybeans and rapeseed, leaving the valuable meal for livestock. Ethanol from corn or wheat creates a whole new residue that also has feed value. For each hectare devoted to one of these biofuels, only a part of the hectare is truly diverted from food production.

Reduced food consumption

All three effects from biofuels occur because diverting crops or cropland raises prices, triggering a market response. As one market response, demand for crops declines. The last 18 months have reminded us why increased crop prices are not a good idea.

Between 2000 and the spring of 2008, world cereal prices rose 300 percent and vegetable oil prices by 400 percent (FAO 2008a). Reasonable weather calmed panicked markets by the fall, and the worldwide economic recession has further lowered prices. As a result, news accounts suggest that prices have collapsed. But even in the midst of the global recession in the winter of 2009, rapeseed oil and corn prices, primary biofuel crops, have remained more than 50 percent higher than in 2000-2002.[8]

To the extent biofuel critics have blamed these rises in crop price for increased retail food prices in the United States and Europe, they have probably exaggerated. Crop prices are a small fraction of the retail food prices paid in grocery stores, and an even smaller fraction in restaurants. But the impact on the poor in developing countries is large, particularly on the roughly one billion people who live on $1 per day or less and who are likely already chronically malnourished, and the three billion who live on less than $2 per day (Runge 2007; FAO 2008b). The one billion poorest spend more than half and sometimes up to 80 percent of their incomes on food, and eat low in the food chain, so doubling the price of crops and vegetable oil has a harsh effect. Some of that effect shows up in decreased food consumption and malnutrition. Other effects show up in reduced income for other necessities. Those poor farmers who have significant crops to sell benefit from higher prices,

[8] Data from the International Monetary Fund online for rapeseed oil Rotterdam delivery and from the Chicago Board of Trade.

but analysis has shown that high food prices harm many more poor people than they benefit (FAO 2008b; von Braun 2007).

Biofuels as a percentage of total world crop use are not large. According to FAO data, they consumed just less than 5 percent of the world's cereals and roughly 8 percent of the world's vegetable oil in 2007 (OECD 2008a, Tables 2.3 and 2.5). Vegetable oil is an important crop that can provide 15 percent or more of the calories for many of the world's poor. But the key to understanding the impact of biofuels on food prices is the rapid growth rate. The world needs additional food each year to feed a growing and selectively wealthier population whose fortunate people demand more meat. Even with some modestly adverse weather on average between 2005 and 2007, the world produced enough additional cereals and vegetable oil to meet these demands. But biofuel producers diverted the great bulk of these additional crops, which required that the additional food come out of stocks (OECD 2008a, Tables 2.2, 2.3, 2.4, and 2.5). When stocks fall, consumers bid up prices.

This rapid growth of demand for biofuels explains why most economists concluded that biofuels played a major role in spurring the increase in food prices this decade. Economists at Purdue University for the Farm Foundation (Abbott 2008) and at the World Bank (Mitchell 2008) provided the most thorough reports. Apart from biofuels, these reports showed that currency declines by the dollar also played a significant role. Other factors included shifts toward smaller crop inventories, higher energy prices, and poor weather in parts of the world—although good weather in some areas mostly balanced out bad weather in others. More generally, once stocks become low, panic behavior can send prices dramatically higher, including efforts by some major food-producing countries to limit exports in the spring of 2008. Yet, the tight stocks created by rapid increases in the demand for biofuels obviously played a major role in motivating this behavior.

Some press reports have suggested a wider range of opinions on the impact of biofuels than actually existed, at least among the economists who have released reports. These press reports to some extent reflect confusion between estimates of biofuel impacts on world crop prices, which are high, and impacts on retail food prices in the United States, which are low. Edward P. Lazear, chairman of Council of Economic Advisors, testified before the U.S. Congress in 2008 on results from an analysis by the Council of Economic Advisers, aquitting biofuels of a major price effects, but those results mostly focused on retail prices, and the Council never released the actual study nor the newly created model on which it was based.

Other confusion reflected the difference between estimates of long-term price changes in equilibrium conditions and shorter-term effects. The large price increases of recent years have reflected shortages of supply. In the longer term, markets have time to adjust, and in a theoretical equilibrium, crop price increases should only reflect modestly increased costs of production, not any shortage premium. For example, for a scenario in which the United States, Europe, Canada, and Japan supply 10 percent of their transport fuel through biofuels, a Dutch study predicted an 18 percent increase in cereal prices compared to biofuels remaining at 2001 levels and a rise in oilseed prices of 26 percent (Banse 2008). Modeling from the Organisation for Economic Co-operation Development (OECD) of smaller increases in biofuels predicted proportionately similar price effects (OECD 2008b). As these models suggest, over the long term, prices will come down. Yet, many of these price increases are still quite significant viewed from the vantage point of the poor.

Just as importantly, people also live in the short term. So long as biofuels continue to increase at rapid rates, markets will not achieve equilibrium, and we can expect prices something like those today,

The key to understanding the impact of biofuels on food prices is the rapid growth rate.

Higher crop prices imply that some of the crops diverted to biofuels are not replaced, which dampens greenhouse gas emissions. To most people, however, these reductions in demand are probably a worse result than agricultural expansion

which even in a recession are significantly higher than long-term averages. Large annual increases in biofuels called for by government policies also imply continuing tightness in world markets and therefore a high risk that poor harvest years or other factors could again touch off extraordinary price increases similar to those in the spring of 2008.

Higher crop prices imply that some of the crops diverted to biofuels are not replaced, which dampens greenhouse gas emissions. How much depends on the amount of the reduction in food, and one recent model analysis of corn ethanol for the California Air Resources Board finds that perhaps half of the diverted food (after accounting for by-products) is not replaced. Most model analyses find smaller impacts, and at least one leading economist has marveled at the small reduction in demand that occurred despite the sharp rise in prices in 2007 (Westhof 2008). To most people, however, these reductions in demand are probably a worse result than agricultural expansion because too large a share of these reductions falls on the world's most unfortunate.

Agricultural land expansion

In a second response to diverted food, farmers expand cropland or pasture. This expansion releases carbon dioxide as discussed above. "Expansion" due to biofuels in some regions may also include keeping cropland in production that would otherwise revert to forest or grassland.

The amount of carbon released from new cropland depends on the type of land converted, but several factors work to balance out the significance of where the expansion occurs. For example, land expansion in Brazil into rainforest and savannah sacrifices higher levels of already stored carbon, but bringing recently abandoned cropland in Eastern Europe back into production sacrifices more future carbon sequestration, and each may sacrifice roughly the same amount of carbon overall.[9] Expanding into drier lands sacrifices less carbon per hectare, but because yields are lower (at least without irrigation), more land is needed. Using a mature, carbon-rich forest sacrifices more carbon up front, but using a regrowing forest foregoes more carbon sequestration over time. The different land uses will not always balance out entirely, and some lands are exceptionally rich in carbon, such as peatlands, but there is a kind of "conservation of productivity" principle: The better the land used for biofuels, the more biofuels but also the higher carbon cost of converting that land from its alternative use.[10]

[9] A great deal of cropland in Eastern Europe was abandoned in the 1990s. If that were to revert half to forest and half to grassland and a hectare resequesters 75 percent of its original carbon by 30 years from now, the cost of devoting that hectare to biofuels equals 328 tons according to estimates of original carbon stocks of European forest and grassland presented in Tables D-9 and D-10 of Searchinger et al. (2008b). That figure is roughly the same as the 337 tons per hectare released on average from the mix of forests and savannahs converted in Latin America in the 1990s (Searchinger 2008a).

[10] One recent paper, using a crop tillage model, found that land converted from grassland and forest to cropland would actually regain and even add soil carbon quickly if planted using no-till and a winter cover crop (Kim 2009). (No-till drills a hole for a seed and drops in the seed without turning over the soil.) At a minimum this modeled result does not correspond with the differences in soil carbon typically found in croplands and grasslands in the United States and elsewhere. New studies have also cast serious doubt on a critical premise behind the model that no-till farming builds soil carbon: studies that look at the whole soil profile do not find benefits on average (Baker 2007; Blanco-Canqui 2008). No-till farming also tends to trigger more releases of nitrous oxide, a powerful greenhouse gas, which by some estimates would largely eliminate the greenhouse gas savings from the conventional estimated soil benefit of no-till (Duxbury 2008). Although any increase in nitrous oxide contribution would last for more than 100 years, even occasional plowing would probably release much or all of the increased carbon from no-till if it does occur (Grandy 2007). In total, serious doubts about soil carbon gains from no-till, the easy loss of any gains that do occur, and the increase in nitrous oxide all make it unlikely that no-till farming by farmers who convert grassland and forest will significantly reduce the greenhouse gas emissions associated with agricultural expansion. This paper (Kim 2009) also failed to recognize that loss of soil carbon is only part of the carbon cost. For example, because the sacrifice of grassland also sacrifices some meat or dairy production, it will trigger at least some further land use change to replace that food and associated carbon loss.

Price-induced yield Increases

Crop yields have grown throughout the last hundred years, and they will continue to grow in the future with or without biofuels. Some biofuel defenders argue that because yields will or could improve, biofuels need not cause land use change. But these "secular" yield increases, meaning increases unrelated to biofuels, help keep down the level of deforestation needed to feed a growing population. Using an acre of land for biofuels still sacrifices other uses of that land. These ongoing yield increases that will occur with or without biofuels have great significance for the world's land use and carbon emissions, but the merits of biofuels have to be judged independently.

On the other hand, when biofuels divert crops and prices rise, farmers all over the world also have an incentive to try even harder to produce more food on their existing cropland. They may use more fertilizer, pesticides or water, or try out more expensive, high-producing seeds. Over time, because of higher returns to agriculture, research may expand. Land expansion will by no means replace all food. But the land expansion that does occur will typically convert lands with lower yields than existing cropland because farmers generally use the best cropland first. The two effects on yields will to some extent balance each other off. To illustrate one mathematically simple example: If higher prices spurred by biofuels push up yields on existing cropland enough to replace half of the food diverted to biofuels, but if the new cropland needed to replace the other half is half as productive, the average effect on world yields from higher prices is zero. In other words, the same amount of land expansion would occur as if there were no yield changes at all.

Some people have argued that because yield expansion since World War II has provided the great bulk of the food needed to meet the world's growing demand, we can assume that improved yields spurred by higher prices will replace nearly all the food diverted to biofuels. This argument misses the fact that yields would have increased regardless of growing demand. In the absence of that growing demand, world cropland would have shrunk. The unanswered question is how much increased demand, reflected in higher prices, has further pushed yields higher in the past, and how much higher prices, spurred by biofuels, will push yields in the future.

It turns out that this question is very hard for economists to answer. Not surprisingly, some studies have found that when farmers use little fertilizer or other inputs, high prices can significantly spur yields, and evidence suggests that prices may have stimulated U.S. farmers to use more fertilizer in the 1960s (Menz 1983). But once farmers already started using large quantities of fertilizer, U.S. studies found that prices had almost no effect on yield (Menz 1983; Choi 1993). These intuitive results suggest that prices will stimulate yields relatively little in developed countries but could do so more in developing countries. Unfortunately, some developing areas, such as sub-Saharan Africa, may also have political or economic structures that fail to pass on or easily allow farmers to respond to these higher prices. Sub-Saharan Africa and Latin America also have abundant potential new cropland, and at least two studies have found that higher prices in those regions primarily encourage expansion into new areas (Bruinsma 2003, p. 133).

Even if prices stimulate yields significantly, land use change emissions are likely to remain large. And from a policy perspective, using yield gains to replace biofuels has its own costs, which fall into three categories.

- Intensifying agriculture has large environmental costs. Increased fertilizer promises more pollution of already highly polluted coastal

These ongoing yield increases that will occur with or without biofuels have great significance for the world's land use and carbon emissions, but the merits of biofuels have to be judged independently.

Many controllable factors could in theory change the world land use situation for good or bad, but if those factors are independent of biofuels, they neither make biofuels a better strategy nor a worse one.

waters (Vitousek et al. 1997). Agriculture already consumes 85 percent of all the freshwater consumed by people, causing great harm to aquatic species and creating competition with other water needs (Foley 2005; Ambler-Edwards 2009). In many countries, there is little or no potential irrigated water left, and mining of groundwater threatens existing irrigation. Shortages have already caused the UN to organize attention to the freshwater crisis (UNESCO 2006), problems which climate change is expected to exacerbate. Intensifying agriculture implies greater reliance on chemical inputs and irrigation water and will exacerbate these problems.

- Some of the methods of intensifying agriculture will increase greenhouse gas emissions as well. For example, data gathered by the Iowa Soybean Association indicate that while on average farmers today use only around one pound of nitrogen per bushel of corn, it takes eight additional pounds of nitrogen to produce one more bushel of corn (Iowa Soybean Association 2005). Nitrogen use generates nitrous oxide, a powerful greenhouse gas, and boosting yields through additional nitrogen in the U.S. Corn Belt may trigger more greenhouse gas emissions than replacing food through additional cropland use around the world.[11]

- Because the present rate of yield increases is not adequate to avoid the need for more cropland around the world, the world already needs to boost yields dramatically to avoid further deforestation. For example, while the U.S. Department of Agriculture (USDA) predicts that cereal and oilseed yields will grow at 0.8 percent per year based on recent trends (Trostle 2008), cereal yields would need to grow at twice that rate by 2020 just to feed the population without plowing up more forest and grassland.[12] Requiring that biofuels supply 10 percent of the world's transportation fuel by 2020, which has become a ubiquitous national policy, would essentially require that cereal yield growth rates triple the USDA's current projection to avoid land use change. Meanwhile, growth rates for oil seeds would have to double present growth rates, rates for sugarcane would have to increase sevenfold, and rates for palm oil yields would have to increase threefold.[13] The world's capacity to boost yields, at least within a limited time, is not unlimited and itself represents an opportunity cost.

Put simply, the world already needs to find ways to stimulate this productive capacity to reduce greenhouse gas emissions from land use change. Using that capacity to replace food diverted to biofuels makes it much harder and much less likely that the world will be able to avoid significant ongoing deforestation as it makes more food for more people.

D. Doubts about the land use challenge

Defenses against these land use concerns have emerged over the last year. In my view they are not convincing.

[11] According to Searchinger et al. 2008a, land use change caused emissions of 104 grams of greenhouse gases, CO_2 equivalent for each mega joule of corn ethanol (a unit of energy). If instead that corn were replaced through extra fertilizer in Iowa, the additional seven pounds of nitrogen per bushel at a 2 percent rate of formation into nitrous oxide would generate 132 grams of greenhouse gases, CO_2 equivalent.

[12] The growth rates presented in this paragraph are based on calculations by Ralph Heimlich and the author using projected world food demands by the OECD and FAO for 2017 (OECD 2008a), extrapolated to 2020, and FAO data on yield growth rates for different major crop types from 1996-2005.

[13] These calculations prepared by Ralph Heimlich used a scenario for world biofuel demand developed by Etech4 for the "Gallagher" review in the U.K., a scenario that projects future biofuel sources at rates mostly proportional to current production sources but with a growing share for sugarcane ethanol. It also uses projected increases in food demand from OECD 2008a through 2017 and extrapolates them to 2020.

Making Land Available for Biofuels: Some experts have argued that with concerted efforts to increase crop yields or improve livestock efficiency, or increase vegetarianism (Kolmes 2008), the world can reduce its demands for agricultural land and thereby free up land for biofuels. Each of these changes would reduce world deforestation but would do so with or without biofuels. Each hectare devoted to biofuels still comes with a carbon cost because that hectare is not doing something else. Many controllable factors could in theory change the world land use situation for good or bad, but if those factors are independent of biofuels, they neither make biofuels a better strategy nor a worse one.

Multiple Causes of Deforestation: Some defenders have argued that biofuels are not the only cause of deforestation. That statement is certainly true but irrelevant: The only question is whether additional demands on the world's crops and croplands are an incremental cause.

Others argue that the causes of deforestation are too varied to assume that agricultural demand will translate into deforestation. This argument requires a more subtle response. To some extent, this argument confuses two questions: Where will deforestation occur, and what factors drive deforestation overall? Multiple factors always explain why deforestation occurs in some areas rather than others; for example, cropland will expand more where the infrastructure is available to support it. But studies have broadly concluded that increasing the economic return to agricultural use serves as a strong incentive to deforestation in general. (For a quick summary of this debate, see Kline 2008.)

More persuasively, defenders argue that forestry is sometimes to blame for deforestation. That again is the driving force in some locations—although forests will typically regenerate at least partially if land is not then converted to agriculture. In other regions, timber revenues combine with agricultural returns to provide the combined economic justification for land conversion. (In Brazil, for example, harvesting a few big trees may pay for some of the cost of ultimate agricultural conversion.) In fact, because timber markets may make land conversion cheaper, forestry may make land conversion more responsive to relatively small increases in agricultural prices. (For a discussion of these arguments, see Khosla 2008.)

Overall, many forces influence the amount and types of land that will be converted in response to higher agricultural demand, and all the various models try in some ways to take these forces into account. That explains, in part, why all models so far estimate land conversion will come from a mix of forest and grassland. In my attempt (Searchinger et al. 2008a), we simply assumed that new cropland in the future would reflect the patterns of new cropland in the 1990s, roughly split between forest and grassland/savannahs.[14] That pattern inherently reflected the various forces pushing land in one direction or another. Although the future is always somewhat unpredictable, the best potential additional cropland for the world consists mostly of tropical forests (Bruinsma 2003), and there is good reason to believe carbon-rich lands will provide much of the world's new cropland and pasture to replace agricultural lands diverted to biofuels.

The best potential additional cropland for the world consists mostly of tropical forests, and there is good reason to believe carbon-rich lands will provide much of the world's new cropland and pasture to replace agricultural lands diverted to biofuels.

Unexpected Short-Term Economic Responses: Most mainstream U.S. economic analysts (including those at USDA and the Food and Agricultural Policy Research Institute (FAPRI), which is the institute most typically consulted by federal officials), have projected that U.S. corn ethanol will significantly displace soybean production in the United States and motivate soybean expansion in Brazil. In 2007, U.S. soybean acres were way down, yet in 2008,

[14] Some observers misinterpreted the amount of forest conversion estimated in Searchinger et al. (2008b) because the category of tropical open forest in Latin America, perhaps inappropriately labeled, essentially represented Brazilian Cerrado savannah.

soybean production in the United States came back at the expense of other crops. Meanwhile, soybean production in Brazil has yet to surge ahead. Ethanol defenders claim these developments cast doubt on indirect land use change.

Partly, the distinction may reflect the time horizon. In the short term, many other factors can influence market responses: a high Brazilian currency exchange rate and a soybean disease outbreak have limited the recent expansion of soybeans in Brazil. But precise market responses may also prove unpredictable because of government and other market developments. In the United States, the U.S. Congress reduced the Conservation Reserve Program (CRP), which holds land out of production, by seven million acres, opening up more U.S. cropland than predicted by economic studies in 2007. Meanwhile, rapid cotton expansion in India and China have kept world cotton prices down and have led to much larger reductions in U.S. cotton acreage than predicted by analysts as farmers shifted to soybeans, corn, and other more profitable crops. These market responses still involve expansions of agricultural land, such as replacement of CRP grasslands, yet the shifts may differ from prior predictions. Ultimately, markets have to respond to biofuels in one of the three ways described above, and land for biofuels expansion will be one of these responses. The fact that precise responses may be hard to predict is not necessarily a cause for comfort.

3 Avoiding Competition for Land

The many biofuel studies from international and European technical agencies that emerged over the last year recognized that biofuel competition over land expresses itself not merely in greenhouse gas emissions, but also in hunger and in environmental impacts from additional agricultural intensification, and that all are undesirable (Searchinger 2008d). With differing degrees of vehemence, each study recommended that biofuel policy should focus on feedstocks that do not significantly compete with alternative land use needs. In the U.K., for example, the "Gallagher Review" by the Renewable Fuels Agency broadly canvassed expert opinion, commissioned technical reviews, and concluded: "Although there are high levels of uncertainty in the data, the science and in the modeling of the indirect effects of biofuels, the balance of evidence shows a significant risk that current policies will lead to net greenhouse gas emissions and loss of biodiversity through habitat destruction" as well as "rising prices" of concern for the world's poor (U.K. RFA 2008b). The RFA and these other agencies have drawn a distinction not just between food crops and biomass, but between feedstocks that use productive land and those that do not. As the Gallagher Review recommended, "Policies must therefore be focused upon ensuring that agricultural expansion to produce biofuel feedstock is directed toward suitable idle or marginal land or utilizes appropriate wastes, residues, or other noncrop feedstock."

What is the potential and what are the challenges of these alternative feedstocks?

Waste biomass

Much of the case for biofuels has relied on the potential availability of waste biomass. In the United States, the Department of Energy has helped make the case for biofuels by estimating potential biomass at over a billion tons, enough potentially to make over 100 billion gallons, which could potentially provide most of the U.S. transportation fuel (Perlack 2005). Roughly two-thirds of that biomass would avoid competition with land as it consists of crop residues, the wood left behind in logging operations, and other forms of waste. Some of the world studies that have focused on biomass potential have also found huge theoretical potential for using timber and agricultural residues, although mostly in the developing world (Hoogwijk 2005). If these studies are correct, then there is even less justification for promoting biofuels that compete with other land use needs.

Waste and residual biomass also has the advantage that it is cheap or free. Studies at Purdue University and Iowa State, among others, have calculated that corn stalks will provide a much more economical source of biomass than planting perennial grasses on the good cropland of the U.S. Corn Belt—in part because ethanol demand for crops is pushing up the price of that good cropland. Exceptional forest supplies may also occasionally become available. In Canada and now parts of the United States, rising temperatures have allowed pine bark beetles to kill millions of hectares of pine forests. Using that biomass before it burns for biofuels would provide many benefits.

Utilizing these wastes still raises major logistical and environmental challenges. For example, timber harvest waste is only available after a harvest, which at best occurs only on multi-year cycles. To keep a biofuel plant running, it must therefore have access to a range of forest wastes within a tight drawing radius. That raises particular questions about using timber waste from federal lands, and many conservationists have feared that supply problems would lead to pressures to harvest actual trees to keep biofuel plants running. Small-scale, mobile ethanol facilities would be most desirable. Crop residues, such as corn stalks, would provide a steadier supply to a biofuel plant, but new collection systems must evolve to harvest them and

Much of the case for biofuels has relied on the potential availability of waste biomass. Waste and residual biomass also has the advantage that it is cheap or free.

Former forests converted to grazing provide perhaps the most promising set of lands.

bring them to a plant. Crop residues also play a vital role protecting against soil erosion and maintaining carbon and nutrients in soils, and crop residues worldwide already provide household energy use, building materials, and bedding and feed for animals (Smil 1999). Keeping harvests of residues to acceptable levels and in association with proper management presents a significant challenge.

Municipal waste may hold the most promise because it is already concentrated and may come with the additional financial reward of a tipping fee for getting rid of it. One analysis at Berkeley put the potential for ethanol from municipal waste in the United States at 2 to 9 percent of 2003 U.S. gasoline demand (Jones 2007).

Marginal land

Attention has alternatively focused on using "marginal land." The Indian government has called for the conversion of millions of hectares of "wastelands" to biofuel production. The Roundtable on Sustainable Biofuels, a broad multi-stakeholder dialogue, has held workshops on identifying marginal lands. Yet to provide a large greenhouse gas benefit, lands must be marginal not merely from an agricultural standpoint but also from any carbon-growth standpoint, such as forest. And that raises a question. If lands are marginal for these other purposes, why would they be highly productive of biomass? Most "marginal lands" are dry, and even drought-tolerant biofuel crops, such as jatropha, produce much lower yields in dry areas. Many "marginal lands" are used by some of the world's poorest people. Many of India's wastelands are not physically capable of growing anything, and forestation presents another important option for those that are (Balooni 2007). The most promising lands for biofuels would be those that have suffered high soil degradation that undermines their use for food crops, but that might be amenable to fast-growing grasses or newly-engineered trees.

Unfortunately, no one has yet produced a map identifying specific good examples.

One research group at the Carnegie Institution has analyzed potential biomass from abandoned agricultural lands that have not yet reverted to forest, using that as one definition of marginal land (Field 2008). If 100 percent of the biomass generated by each such hectare were transferred at 100 percent efficiency into biomass energy, the study estimates such lands could provide 7 percent of the world's primary energy needs today, including more than 20 percent of the transport fuel. But it will take at a minimum 50 percent of the energy in this biomass to turn the other energy into a liquid fuel. And in light of the dispersed spread of these lands, it would be remarkable if 20 percent could be economically utilized for biomass. This analysis, therefore, suggests that viewed realistically, this definition of "marginal lands" could perhaps yield 2 percent of the world's transport fuel.

Another more forgiving approach to "marginal land" focuses on the world's grasslands and savannah. Grasslands and savannahs occupy 3.5 billion hectares, well more than twice the world's cropland. Yet, these lands are mostly quite dry, and nearly all grazed, which means they already provide food. As a broad category, there is no inherent reason to believe these lands would be more highly productive of biofuels than they are of carbon for other purposes. Many savannahs also have great biological value. Brazil's Cerrado has more than 7,000 plant species, 44 percent of which are found nowhere else (Klink 2005).

Former forests converted to grazing provide perhaps the most promising set of lands. These lands receive enough rainfall to grow biomass well, but as a whole are underutilized even though they supply meat and dairy products. Much of the case for biofuel production in Brazil rests on the broad availability of such low intensity cattle lands.

The sugarcane industry believes that expanding into cattle lands avoids deforestation because the lost cattle production can be, and is, offset by intensified cattle production elsewhere through greater use of fertilizer and better cattle breeds. On the other hand, conservation groups in Brazil argue that most of the expanded production of cattle in Brazil continues to occur through expansion into the Amazon. They contend that while Brazil could offset grazing lands converted to sugarcane through better management, that expansion is today also sending an additional signal for land conversion. One possible solution might be to tie sugarcane expansion for biofuels to measurable additional efforts to intensify existing pastures to avoid adding to economic signals for expansion into forest, whether in Brazil or elsewhere in Latin America.

Previous estimates of biofuel potential have vastly overstated the potential availability of the world's lands. In some cases, they identified any abandoned agricultural lands that would otherwise revert to forest, and in other cases, they identified vast stretches of the world's grasslands as potential lands for biofuels with little proof that those grasslands are now underutilized. Some of the better underutilized lands may also be necessary for food. Yet on balance there is probably potential to make meaningful levels of biofuels from waste biomass and residuals, and probably some potential to use marginal lands that otherwise would store little carbon or produce little food.

On balance there is probably potential to make meaningful levels of biofuels from waste biomass and residuals, and probably some potential to use marginal lands that otherwise would store little carbon or produce little food.

4 Financial and Efficiency Concerns

Beyond environmental concerns, critics have also raised a number of questions about the costs of biofuel subsidies. It takes at least 50 percent of the energy in biomass to turn the other half of that energy into a liquid fuel.

Financial costs of biomass

Beyond environmental concerns, critics have also raised a number of questions about the costs of biofuel subsidies. According to the OECD, subsidies for 2006 already amounted to $11 billion, ranging by major country from $0.80 to $7 per liter of fossil fuel saved (OECD 2008b). The OECD estimated that subsidies would grow to $27 billion per year for 2013–2017 assuming the same levels of support at predicted levels of production, which still fall below the new mandates (OECD 2008b). Most lifecycle analyses of biofuels calculate greenhouse gas savings without accounting for land use change that might result in emissions increases (Searchinger et al. 2008b, Appendix A of supporting materials), but even crediting these traditional analyses, the OECD has calculated the cost at $960 to $1700 per ton of CO_2-equivalent saved (OECDb). These costs far exceed the costs of of reducing carbon dioxide through other means, costs estimated typically in the range of $50 to $200 per ton by greenhouse gas studies (IEA 2008b).

These subsidy figures also do not include the cost to consumers of higher crop prices. Once government policies promote increased demand, price signals must be allowed to encourage farmers to increase the supply, but the costs of generating that demand should count as a cost of biofuels as well. That cost would almost certainly amount to tens of billions of dollars across the world at least in the short term. The precise estimate depends on the estimate of the effect of biofuels on crop prices and whether shorter-term or longer-term prices are counted.

Future costs of biofuels, relative to gasoline and diesel, depend on improvements in cellulosic energy technology, the source of biomass, and the price of gasoline and diesel. At high oil prices, ethanol from corn can be cheaper than gasoline, but only at moderate corn prices. The International Energy Agency (IEA) offers an optimistic assessment that cellulosic biofuels could become competitive with gasoline priced at $65 a barrel for oil, but that depends on technological improvements and cheap biomass (IEA 2008). To date, only ethanol from sugarcane in Brazil can compete on its own with gasoline (OECD 2008b).

Alternative uses of biomass

Apart from environmental concerns, the IEA and the European Commission's Joint Research Center have pointed out that using biomass to produce electricity or heat provides a cheaper and more efficient mechanism of saving greenhouse gases and replacing fossil fuel (IEA 2008; De Santi 2008). It takes at least 50 percent of the energy in biomass to turn the other half of that energy into a liquid fuel. Even if that energy comes from the biomass itself, there is a huge energy loss. By contrast, crude oil is already a liquid fuel, and it takes relatively little energy to convert crude oil into gasoline or diesel. On the other hand, burning biomass for heat or energy approaches the same efficiency as burning a fossil fuel. As a result, biomass is an efficient substitute for fossil fuels in generating electricity and heat, but it is an inefficient substitute for liquid fuel.[15]

Biofuel advocates correctly point out that electricity generation has more renewable fuel alternatives than transportation. In the long run, the world may therefore be able to replace all of its electricity with renewable alternatives such as wind and solar, but the world may still need biofuels to power part

[15] This comparison is independent of the relative efficiency of generating and utilizing electricity, heat, or internal combustion engines for transport. That efficiency depends on the technology for generating fuel and the ultimate end use. So long as fossil fuels are now used to generate all of these needs, biomass could save fossil fuels if used for any of these purposes. The key comparison here is the relative efficiency of using biomass, compared to fossil fuels, for generating electricity or heat versus its use for generating vehicle energy through a liquid fuel. Using biomass to generate electricity can approach the same general efficiency as using a fossil fuel, but using biomass to generate liquid fuel is far less efficient than using oil.

of its transportation fleet. As the IEA points out, biofuels may provide the only viable mechanism for replacing fossil fuel use for airplanes and perhaps ships and heavy trucks. Yet, until other forms of renewable energy have fully replaced fossil fuels, biomass can still more cheaply and efficiently replace fossil fuel when used for energy and heat. Indeed the IEA's global warming strategy for energy depends heavily on using biomass for electricity (assuming it can be produced sustainably) (IEA 2008b).

The alternative uses of sustainable biomass may not always be practicable or economical. Transporting biomass is expensive and liquid fuels less so, as such biomass needs to be used locally and may not always be able to connect into a grid. Because liquid fuels provide a means of storing energy and because they compete with oil rather than coal, they may provide the more practical or economical means of using biomass in some circumstances. To date, however, the analyses suggest that using biomass for electricity will typically generate greater and cheaper greenhouse gas savings.

5 The Future of Biofuel Policies

Despite the welter of concerned studies that came out in 2008, the European Union in December enacted a directive that requires each country to consume 10 percent of its transport fuel by 2020 in the form of renewable energy. That might include renewably-produced electricity but probably means biofuels for the most part. This law joins the Energy Independence and Security Act passed by the U.S. Congress in December 2007, which requires 36 billion gallons of biofuels by 2022, four times current levels.

To avoid adverse land use changes, each directive includes some restrictions on the kinds of lands that can be directly plowed up to grow biofuels: in the United States, virtually any forest or natural grassland; in Europe, only categories of high carbon, or biologically diverse land. Unfortunately these land use rules by themselves will have little significance because any producer could get around them simply by building two tanks. For example, a palm oil producer could use one tank to hold all food palm oil produced from already cleared forest and direct that oil to biodiesel and qualify for the European mandate. But a second tank could receive palm oil from newly cleared plantations and supply the world's great demand for palm oil for food. For the world's land use, the important factor is the total level of crop demand, not the precise origin of any particular crops.

Reflecting this problem, the U.S. law requires that 21 of the 36 gallons reduce greenhouse gas emissions by at least 50 percent (60 percent for 16 billion gallons) after taking account of emissions from indirect land use change. Despite the strong support for such an approach by the European Parliament, the final directive adopted in December 2007 represented a compromise with the European Commission and the member states, led then by France. This directive does eventually require a 50 percent greenhouse gas reduction and requires that the European Commission propose a mechanism for accounting for emissions from indirect land use change by the end of 2010, but whether that mechanism is ultimately incorporated into the directive is subject to future decision-making.

These approaches raise the question of whether incorporating changes in land use into greenhouse gas calculations provides a sufficient defense against these adverse land use changes. Estimating these emissions requires economic and land use models. There are many challenges, and two questions rise above all:

1. How should governments resolve modeling uncertainties, including those regarding yield responses to price discussed above, and possibly changing government land use policies?

2. In light of these uncertainties, how should governments handle risk? As the EU's Joint Research Center found, if palm oil expansion into peatlands replaces only 2.5 percent of Europe's vegetable oil diverted to biodiesel, the emissions from this land use change alone eliminate the greenhouse gas benefits of European biodiesel (De Santi 2008). Of course if that percentage is higher, as seems likely, the impact becomes strongly adverse. How should calculations reflect these risks?

I believe the modeling analyses are robust enough to show that using existing cropland for biofuels probably results in large carbon costs from land use change that at a minimum keep the potential greenhouse gas benefits from biofuels use low even under favorable assumptions to biofuels. Using good lands also presents a risk of extremely high carbon emissions that must be factored into the equation. Faced with the obligation to develop precise numbers, regulators would be wise to try to merge different model results while also building in a factor to account for the risks. Biofuels made from existing cropland and other reasonably productive lands should not qualify as providing 50 percent or larger greenhouse gas savings.

Yet, even as the models should be robust enough to make this showing, the focus only on the effects of land use competition on greenhouse gases ignores hunger and the other environmental impacts of such competition, including biodiversity, water shortages, and pollution. Few people probably want to reward biofuels for increased hunger, yet without consciously endorsing this approach, a sole focus on greenhouse gases would do so because the greater the increases in hunger, the fewer the greenhouse gases from biofuels. As most of the major agency reports have now recommended, biofuels should avoid or at least greatly minimize competition with food and forest altogether.

How could policy encourage only the biofuels from these feedstocks as an administrative matter? U.S. and European mandates for biofuels already recognize serious limitations on the kinds of feedstocks that are environmentally acceptable and thus contemplate sophisticated certification systems to assure that biofuels meet. These certification systems must tie fuels to the land used to grow them all around the world. That will provide many incentives and opportunities to cheat. Experience has shown that it is hard even to keep Italian olive oil from becoming adulterated with foreign-produced walnut oil although the two oils are chemically distinct. When biomass sources differ only on the basis of where they are grown, they will be even harder to tell apart once they have entered world commerce.

Instead of subsidizing the biofuel per se, an alternative approach would subsidize the production of the feedstock from specific degraded lands. If the goal is to try to produce biofuels on otherwise unproductive land, this approach allows the identification of such lands up front. Similarly, if the feedstock is a waste product, the policy can subsidize the collection and delivery of that waste.

Such a policy would avoid one of the worst risks of mandating a specific level of biofuels. Once the biofuels market responds to a mandate, governments put themselves in a position of having to buy out the responding business should biofuels eventually prove to be environmentally unfriendly or wholly uneconomic as new energy technologies evolve. A more measured subsidy focused on the reclamation of degraded land for biofuels avoids the creation of this implicit guarantee, and reclaimed land would provide other benefits even if the use of biofuels are ultimately scaled back.

Instead of subsidizing the biofuel per se, an alternative approach would subsidize the production of the feedstock from specific degraded lands.

That still leaves the question of whether we should encourage biofuels at all, and if so, by how much and in what timeline. Much of the enthusiasm over biofuels obviously derived from the notion that biomass was carbon-free because it would always grow again. This notion did not recognize that using land to grow plants for biofuels means not growing them for something else.

The best case for biofuels lies in the difficulty of replacing all other transport fuels with other low-carbon alternatives. Most people working with transport fuels believe that the most promising greenhouse strategy should focus on electrifying cars, and fueling that electricity with wind, solar, or coal associated with the capture and storage of its carbon emissions. But that strategy depends on major progress in batteries, long-distance, smoothly-functioning electricity grids, and the evolution of these low-carbon electricity sources. And few alternatives appear to exist to biofuels as an ultimate fuel source for airplanes. Biofuels provide one of our best options for providing transport energy in the long term for those sources.

Yet the long term is not the short term and implies different strategies. In the short term, greenhouse gas reduction strategies for transport fuels should focus on pushing electrification technologies. In the short term, truly sustainable biomass is more efficiently used for electricity and heat. In the short term, greenhouse gas emissions can be most cheaply and readily reduced by focusing our money elsewhere.

Public policy should now focus on showing we can produce one billion gallons the right way.

For the long term use of biofuels, public policy should now focus on technological development and demonstrating that we can in fact produce biofuels while avoiding competition with food and forest and can administer a system that does so. Instead of 50 to 100 billion gallons produced however and as quickly as we can, public policy should now focus on showing we can produce at least one billion gallons the right way.

References

Abbott, P.C., Hurt, C., & Tyner, W.E. (2008). *What's Driving Food Prices*. Farm Foundation. Oak Brook, Ill.

Ambler-Edwards, S., et al. (2009). Food *Futures: Rethinking UK Strategy*. Royal Institute of International Affairs Chatham House. London.

Argonne National Laboratory. (2007). *Greenhouse gases, regulated emissions, and energy use in transportation (GREET) computer model*. Argonne, Illinois.

Baker, J.M., Ochsner, T.E., Ventera R.T., & Griffis, T.J. (2007). Tillage and Soil Carbon Sequestration—What Do We Really Know? *Agriculture, Ecosystems and Environment*, *118*, 1-5.

Balooni, K. K. Singh. (2007). Prospects and Problems of Afforestation of Wastelands in India: A Synthesis of Macro and Micro-Perspectives. *Geoforum*, *38*, 1276-1289.

Banse, M., van Meijl, H., & Woltjer, G. (2008). *The Impact of First Generation Biofuels on Global Agricultural Production* (Working Paper, Agricultural Economic Research Institute (LEI), Wageningen UR). The Hague, Netherlands.

Barker et al. (2007). *Technical Summary in Climate Change 2007: Mitigation*. Contribution of Working Group III to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change. Cambridge University Press: Metz, B., Davidson, O.R., Bosch, P.R., Dave, R. & Meyer, L.A. (Eds.).

Blanco-Canqui, H., & Lal, R. (2008). No-tillage and Soil-Profile Carbon Sequestration: An On-Farm Assessment. *Soil Science Society of America Journal*, *72*, 693-701.

Bruinsma, J. (Ed.). (2003). *World Agriculture: Toward 2015/30, an FAO Perspective*. Food and Agriculture Organization of the UN. Rome.

Choi, Jung-sup & Hemberger, P.G. (1993). How Sensitive Are Crop Yields to Price Changes and Farm Programs? *Journal of Agriculture & Applied Economics*, *25*, 237-44.

De Santi, G. (Ed.), Edwards, R., Szekeres, S., Neuwahl, F. & Mahieu, V. (2008). *Biofuels in the European Context: Facts and Uncertainties*. Joint Research Center of the European Commission. Ispra, Italy.

Duxbury, J.M. (2005). Reducing Greenhouse Warming Potential by Carbon Sequestration in Soils: Opportunities, Limits and Tradeoffs in R. Lal, N. Uphoff, B.A. Steward & D.O. Hansen (Eds.), *Climate Change and Global Food Security* (435-450). Boca Raton, Florida: CRC Press.

European Commission Directorate General for Agricultural and Rural Development. (2007). *The Impact of a Minimum 10% Obligation for Biofuel use in the EU-27 in 2020 on Agricultural Markets* (AGRI G-2/WM D). Brussels, Belgium.

Fargione, J., et al. (2008). Land Clearing and the Biofuel Carbon Debt. *Science*, *319*, 1235-38.

Field, C., Campbell, J.E. & Lobell, D.B. (2008). Biomass Energy, the Scale of the Potential Resources. *Trends in Ecology & Evolution, 23*, 65-72.

Fischer, G. & Schrattenholzer, L. (2001). Global Bioenergy Potentials through 2050. *Biomass & Bioenergy*, *20*, 151–159.

Foley, J.A., et al. (2005). Global consequences of land use. *Science*, *309*, 570-574.

Food and Agriculture Organization of the United Nations (FAO). (2008a). *Soaring Food Prices: Facts, Perspectives, Impacts and Actions Required*. Rome.

Food and Agriculture Organization of the UN (FAO). (2008b). *The State of Food and Agriculture: Biofuels: Prospects, Risks and Opportunities*. Rome.

Gibbs, H.K., et al. (2008). Carbon Payback Times for Tropical Biofuel Expansion: The Effects of Changing Yield and Technology. *Environmental Research Lett*ers, 3, 034001.

Grandy, S.A. & Robertson, G.P. (2007). Land-use intensity effects on soil organic carbon accumulation rates and mechanisms. *Ecosystems*, *10*, 58-73.

Gurgel, A., Reilly, J.M. & Paltsev, S. (2007). Potential Land Use Implications of a Global Biofuels Industry. *Journal of Agriculture & Food Industrial Organization, 5*, Article 9.

Hertel, T.W., Tyner, W.E. & Birur, D.K. (2008). *Biofuels for All? Understanding the Global Impacts of Multinational Mandates*. Center for Global Trade Analysis, Purdue University.

Hoogwijk, M., A., Faaij, B., Eiuckhout, B. de Vries, & Turkenburg, W. (2005). Potential of Biomass Energy Out to 2100, for Four IPCC SRESS Land-Use Scenarios. *Biomass and Bioenergy*, *29*, 225-57.

International Energy Administration (IEA). (2004). *Biofuels for Transport: An International Perspective*. Paris.

International Energy Administration (IEA). (2008). *Energy Technology Perspectives*. Paris.

Jackson, R. & Schlesinger, W.H. (2004). Curbing the U.S. Carbon Deficit. *Proceedings of the National Academy of Sciences*, *45*, 15827-15829.

Jones, A., O'Hare, M., & Farrell, A. (2007). *Biofuel Boundaries: Estimating the Medium-Term Supply Potential of Domestic Biofuels*. UC Berkeley Transportation Sustainability Research Center. Berkeley, California.

Khosla, V., Searchinger, T., & Houghton, R.A. (2008). Biofuels Clarifying Assumptions: Exchange. *Science, 322*, 372-374. doi: 10.1126/science.322.5900.371b.

Kim, H., Kim, S. & Dale B.E. (2009). Biofuels, Land Use Change, and Greehouse Gas Emissions: Some Unexplored Variables. *Environmental Science & Technology*, *43*, 961-967.

Kline, K.L, Dale, V.H., & Searchinger, T. (2008). Biofuels: Effects on Land and Fire: Exchange. *Science*, *321*, 200.

Klink, C. & R. Machado. (2005). Conservation of the Brazilian Cerrado. *Conservation Biology* 19, 707-713

Klopfenstein, T. J., Erickson, G.E., & Bremer V.R. (2008). Board Invited Review: Use of Distallers Byproducts in the Beef Cattle Feeding Industry. *Journal of Animal Science*, *86*, 1223-1231.

Kolmes, S.A. (March, 2008). Food, Land Use Changes, and Biofuels [E-Letter Responses]. *Science*, *319*, 1238-1240. doi: 10.1126/science.1151861.

Menz, K M. & P. Pardey. (1983) Technology and U.S. corn yields: Plateaus and price Responsiveness. *Amer. J. Agr. Econ*. 65, 558-563

Mitchell, D. (2008). *A Note on Rising Food Prices* (Policy Research Working Paper 4682). World Bank Development Prospects Group. Washington, DC.

National Research Council Report. (2000). *Biobased Industrial Products: Priorities for Research and Commercialization* (National Research Council and Committee on Biobased Industrial Products). Washington, DC: National Academy Press.

Organisation for Economic Co-operation nd Development (OECD) & Food and Agricultural Organization of the United Nations. (2008a). *OECD-FAO Agricultural Outlook 2008-2017*. Paris, France and Rome, Italy.

Organisation for Economic Co-operation nd Development (OECD). (2008b). *Economic Assessment of Biofuel Support Policies* (Directorate on Trade and Agriculture). Paris, France.

Perlack, R.D., Wright, L.L., Turhollow, A.F., & Graham, R.L. (2005). Biomass as Feedstock for a Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply. U.S. Department of Energy and U.S. Department of Agriculture. Washington, D.C.

Peterson, J. (2008). *Energy Production with Agricultural Biomass—Environmental Implications and Analytical Challenges*. European Environmental Agency. Copenhagen.

Righelato, R. & Spracklen, D.V. (2007). Carbon Mitigation by Biofuels or by Saving and Restoring Forests. *Science*, *317*, 902.

Runge, C.F. & Senauer, B. (2007). How Biofuels Could Starve the Poor. *Foreign Affairs, 86*(3), 41–53.

Searchinger, T., et al. (2008a). Use of U.S. Croplands for Biofuels Increases Greenhouse Gas Emissions Through Land Use Change. *Science*, *319*, 1238-1240.

Searchinger, T., et al. (2008b). Use of U.S. Croplands for Biofuels Increase Greenhouse Gas Emissions Through Land Use Change [Online Supporting Materials]. *Science, 319*, 1238-1240. doi: 10.1126/science.1151861.

Searchinger, T. & Heimlich, R. (2008c). Paper presented at Farm Foundation workshop on lifecycle emissions from biofuels: *Greenhouse Gas Emissions from Soy-Based Biodiesel Incorporating Land Use Change*. Miami Beach, Florida. (Proceeding in Press).

Searchinger, T. (2008d). *Summaries of Analyses in 2008 of Biofuels Policies by International and European Technical Agencies*. The German Marshall Fund. Washington, D.C.

Searchinger, T. (2008e). *Response to New Fuels Alliance and DOE Analysts Criticisms of Science Studies of Greenhouse Gases and Biofuels* [monograph]. Retrieved from http://www.princeton.edu/~tsearchi/writings/Response_to_Criticisms_of_New_Biofuel_Studies.pdf.

Smil, V. (1999). Crop residues: Agriculture's largest harvest. *Bioscience, 49*, 299-308.

Tilman, D., Cassman, K.G., Matson, P.A., Naylor, R. & Polasky, S. (2002). Agricultural sustainability and intensive production practices. *Nature*, *418*, 671-676.

Trostle, R. (2008, July Revised). *Global Agricultural Supply and Demand: Factors Contributing to the Recent Increase in Food Commodity Prices*. Economic Research Service, U.S. Department of Agriculture. Washington, D.C.

U.K. Renewable Fuels Agency. (2008a) *Carbon and Sustainability Reporting Within the Renewable Transport Fuel Obligation Technical Guidance Part Two Carbon Reporting—Default Values and Fuel Chains*. London

U.K. Renewable Fuels Agency. (2008b). *The Gallagher Review of the Indirect Effects of Biofuel Production*. London.

United Nations Educational Scientific and Cultural Organization (UNESCO). (2006). *Water a Shared Responsibility; The United Nations World Water Development Report 2*. Paris.

Vitousek, P.M., et al. (1997). Human alteration of the global nitrogen cycle, sources and Consequences. *Ecological Applications*, *7*, 737-50.

Von Braun, J. (2007). *The World Food Situation: New Driving Forces and Required Actions*. International Food Policy Research Institute. Washington, D.C.

Watson, R.T., et al. (Eds.). (2001). *Land Use, Land-use Change and Forestry*. Intergovernmental Panel for Climate Change. Geneva.

Westhof, P. (2008). Farm Commodity Prices: Why the Boom and What Happens Now? *Choices*, *23*, 6-10.