# BIOFUEL IMPACTS ON CLIMATE CHANGE, THE ENVIRONMENT AND FOOD

Report to the Renewable Fuels Agency

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## INTRODUCTION

The belief that biofuels can mitigate climate change has driven governments around the world to promote the production of ethanol and biodiesel through policies that guarantee markets and offer incentives to producers and consumers. The total cost of these policies is measured in billions of dollars per year. Biofuels are also promoted for their potential to benefit the rural poor by increasing farm income and to serve national security interests that require domestic energy protection. With the world entering a global food crisis the likes of which have not been seen in more than three decades and with the greenhouse gas savings of biofuels now disputed, policy makers have begun to question their promotion of a technology that takes land away from its two predominant uses—food production and environmental preservation—and has not historically competed with oil.

Governments that seek to develop or revise policies related to alternative fuels do so in an environment with uncertainty about impacts and disagreement among experts in the field. In part, the lack of a consensus on the value of biofuels is the result of limited empirical data to substantiate general conclusions. In part it is because the measure by which biofuels are judged is evolving. In part it is because the impacts can be predicted only through complex economic models that are described by their creators as “black boxes,” impenetrable to those who didn’t have a hand in their formation and based on numerous assumptions any one of which could be contested and call into question the validity of the predictions. Furthermore, the impact of biofuels on climate change, food prices, deforestation and energy security are heterogeneous across feedstock, location, and production method. Such variation makes general conclusions difficult and complicates the development of policy, as we will discuss.

This report summarizes the knowledge of biofuels and their wide-ranging impacts presented by expert agronomists, microbiologists, and economists at the “Sustainable Biofuels” workshop at the University of Illinois, Urbana-Champaign on May 12 and 13. Where appropriate, the authors draw on their own research and outside sources to substantiate and elucidate the information gathered at the workshop. Where conclusions can be roughly defined as a consensus among workshop participants, they are. In other instances, opinions are attributed to their adherents through parenthetical attributions (attributions without dates refer specifically to presentations made at the conference). A list of conference speakers is provided at the end of this report as Appendix A. This report begins by discussing the motivation for biofuel policy, i.e. the perceived benefits of biofuels. It then considers, in section 2, the negative impacts of biofuels. The factors influencing the costs and benefits of biofuels are discussed in section 3. Section 4 describes the methodologies used for judging biofuel technologies, including life-cycle analysis and traditional economic welfare analysis. Section 5 discusses policy prescriptions and concludes.

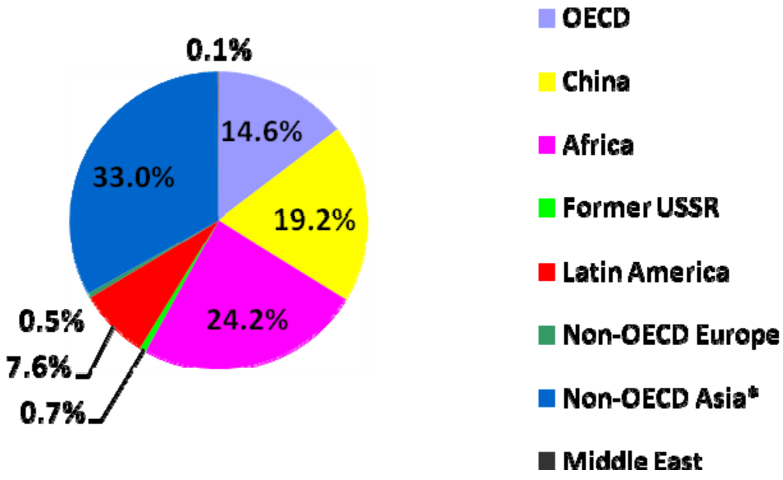
## WHY BIOFUELS?

The biofuel industry has been the beneficiary of government policy dating back more than 3 decades, when a half-century of cheap oil was disrupted by the energy crisis of 1973 and oil-importing countries were awakened to the dependency of their welfare on the beneficence of oil rich nations. In recent years, biofuel policy has expanded amid growing concern about global climate change and national security in an era of increasing energy demand and rapidly rising energy prices. These motivations impelled the leading biofuel-producing OECD countries (US, EU, Australia, Canada, and Switzerland) to spend at least $11 billion on biofuel subsidies in 2006. These countries accounted for 95 percent of OECD biofuel production (Global Subsidies Initiative 2007). This section considers the three primary motivations for biofuel promotion—reduction in oil-import dependency, rural development, and greenhouse gas mitigation—and their merits, though we will not reach definitive conclusions on whether these three policy goals justify government policy. We will rather present stylized facts that may be used in reaching such conclusions.

### Rural Development

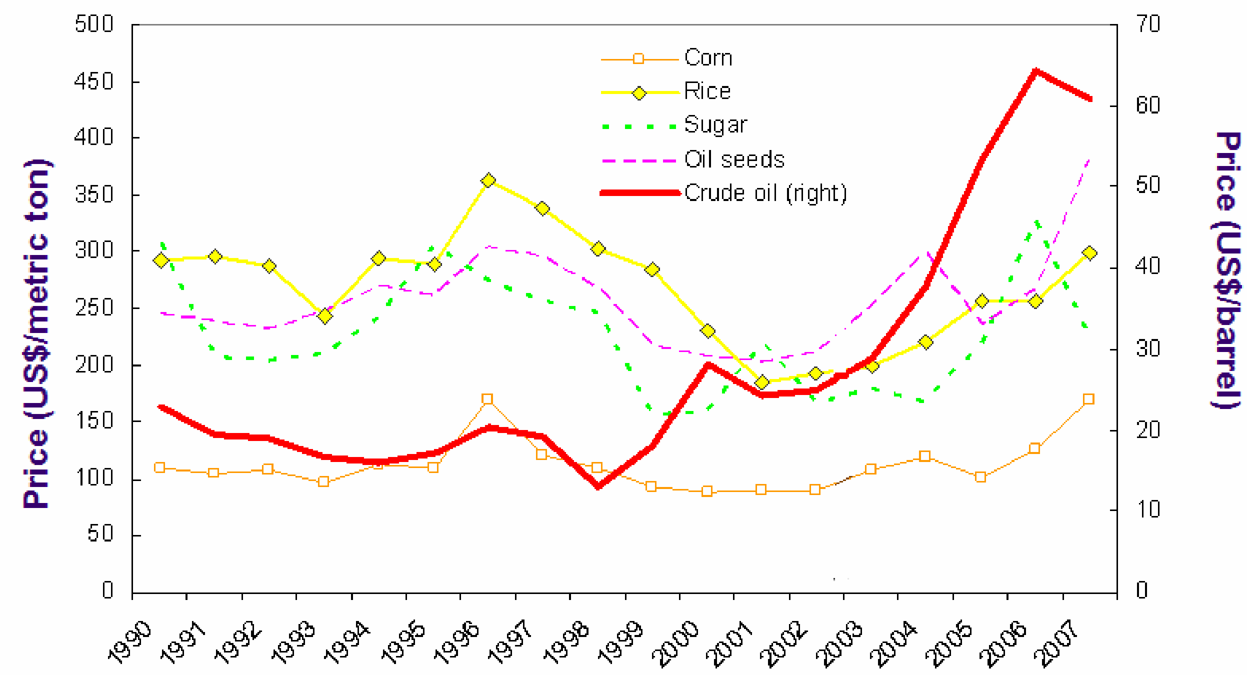
Because bioenergy creates additional demand for crop production and because the global distribution of combustible biomass favors developing countries (see Figure 1), biofuels are thought to provide potential for increasing farm income and aiding economic development. Economic theory predicts that, *ceterus paribus*, an increase in demand for a commodity increases its price. Farmers should benefit from receiving a higher price for their output. Even if agricultural production responds to the increased demand by increasing supply, so long as it does not increase as much as demand, farmers will enjoy higher prices. Even if there is a one-to-one response, farmers will enjoy higher revenues from increased production at the same price. We have seen neoclassical theory hold true, to some extent, in recent empirical observation. Corn prices, for instance, have been increasing in recent years and are expected to average between $5-6 per bushel in 2008, up more than 50% from a year ago, when the average price was $3.40. Wheat prices have also hit record highs and are expected to average $7 per bushel in 2008, up $0.35 in just 6 months. Though much of the popular media has blamed record high crop prices on the biofuel industry, it is uncertain to what extent biofuel demand for corn, sugar, soy, rapeseed and palm oil is responsible for increased prices. Population growth, income growth (which is associated with more land and crop intensive diets), a depreciating American dollar, poor harvests in some regions, and expectations of tightening markets in the future are all likely responsible for the high prices observed today. The best guess among economists is that biofuels contributed to 10-15% of food price increases (Zilberman and Wiebe).

**Figure 1: Distribution of combustible bioenergy resources around the world**



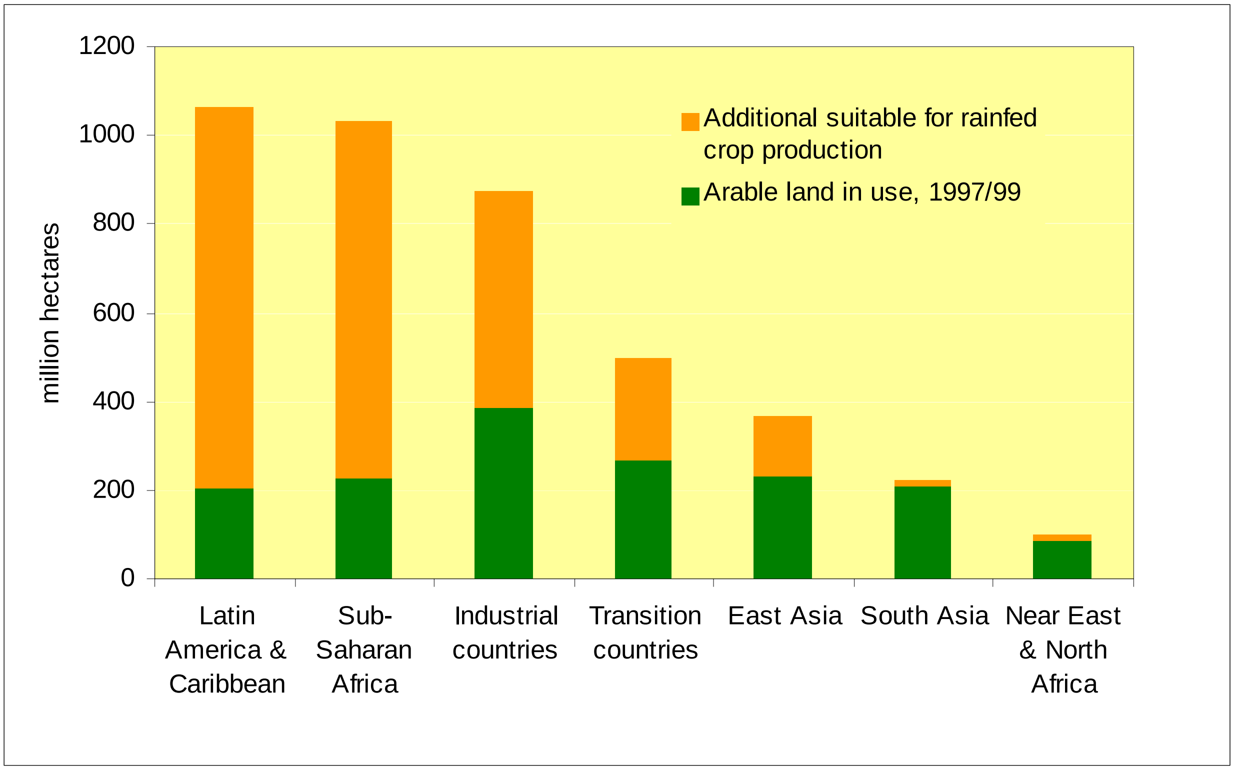
Farm income in the US is expected to reach a record $92.3 billion in 2008, up 4.1 percent from the record setting $88.7 billion in 2007 and up 51 percent from its ten year average. Average farm household income is forecast at $89,434, nearly 20 percent above the five year average from 2001-2006 (US Department of Agriculture). Figure 2 depicts world prices for several staple commodities and shows the considerable upward pressure on agricultural commodity prices in recent years.These statistics are no doubt encouraging news and suggest that biofuel may contribute to improving welfare on the farm. It should be noted, however, that higher commodity prices may be capitalized into land rents and the price of other inputs (from machinery to chemicals) and thereby reduce the benefit to farmers. In addition, whereas row crop producers will benefit from higher commodity prices, the distribution of benefits will not be equal across agriculture. Livestock farmers, in particular, are expected to suffer from the rising costs of feed, a major input in production. Already, it is reported that livestock farmers are substituting away from corn and soy to wastes from manufactured cereals and chocolate, as well as trail mix.

**Figure 2: Agricultural commodity prices since 1990 (source Msangi)**



The rural development benefits of biofuel are premised on the ability of developing countries to produce bioenergy crops and therefore transition from subsistence farming. As we will discuss in the subsequent section, the net welfare effect hinges critically on the impact of rising food prices on the poor. It is true that while many poor countries are unable to profitably farm major food crops due to poor climate and soil conditions, it is likely they can produce bioenergy crops. Eighty developing countries, for instance, grow and process sugarcane, the most efficient feedstock used today in commercial ethanol production (IFPRI 2005). A second generation of biofuels, which will yield feedstocks capable of growing on marginal and degraded lands that heretofore have been unprofitable to farm. In particular, Miscanthus can be grown on marginal land and irrigated with saline water and still yield greater ethanol per acre than existing feedstocks. Jatropha, an oil-bearing plant, can be grown on infertile soil and amid drought conditions and then used to produce biodiesel. India is expected to have as many as 30 million hectares that could be planted to Jatropha (IFPRI 2005). Developing countries are thought to perhaps bear a comparative advantage in production of biofuel feedstocks, owing to lower opportunity costs of land (Their bioenergy crops won't displace food crops). Figure 3 shows the share of arable land that could be brought into rain-fed production by region. Notably, South American countries and sub-Saharan Africa could quadruple their agricultural land base to accommodate bioenergy crop production.

**Figure 3: Agricultural land use and potential expansion by region (source: Wiebe)**



## Energy Security Concerns

Because biofuel can be produced domestically in many countries, it is believed to be important to improving the energy security of oil-importing countries. With oil at $120 per barrel and much of the world's oil production occurring in politically unstable regions of the world, governments aim to ensure their economies are not held hostage to OPEC and the whims of other oil-exporting countries. In theory, biofuel can be a critical way to reduce oil imports and generate a substitute to fossil fuel. Based on current production methodologies, however, it seems most countries will be unable to displace any significant share of their oil consumption and can, at most, hope to marginally reduce prices by increasing the supply of liquid fuels. Analysis suggests the US, Canada and EU-15 can displace ten percent of their gasoline consumption by biofuel if they recruit between 30 and 70 percent of their respective croplands. Brazil needs just three percent of its cropland to meet ten percent of its demand with sugarcane ethanol. As energy demand continues to grow, greater shares of cropland will be needed to displace the same shares of gasoline. These figures suggest biofuel will not soon replace gasoline as a predominant source of transportation fuel. Nevertheless, they point to the fact that biofuel can reduce oil imports and augment oil supply to reduce oil prices. Sexton et al. (2008) show that US ethanol production alone reduced gasoline prices 3% in 2006 and saved the world's gasoline consumers as much as $45 billion. To the extent biofuels do reduce oil imports and reduce oil prices, they can also be a mechanism for improving countries' terms of trade. Though not of significance in economic terms, improved terms of trade is often important from a political economy standpoint.

### Greenhouse Gas Mitigation

Concern about global warming has driven interest in fuels that emit less greenhouse gas emissions than oil. Biofuel has been billed as a cleaner fuel than oil. The primitive view, which has been complicated and proven quite misleading in recent years, is that carbon emitted in the combustion of biofuel is reabsorbed and sequestered in the energy crop used to produce biofuel. The process of sequestration and combustion is carbon neutral. This simplistic analysis has been replaced with life-cycle analysis that considers the greenhouse gas emissions of an energy source during the entire production and consumption process. It accounts for emissions in production of energy crop (from soil tilling, gas and diesel-powered farm equipment, emissions from production of fertilizers, and other inputs used in production), the conversion of energy crop to biofuel, the transportation of fuel to market, and the consumption of fuel. While analyses differ, the literature suggests there are modest greenhouse gas savings associated with the first generation of biofuel, composed principally of ethanol from corn and sugar and biodiesel from soy and palm oil (Farrell et al., 2006). Farrell et al. (2006) estimate greenhouse gas savings of 13% relative to fossil fuels on an energy equivalent basis. Tilman et al (2006) report greenhouse gas savings relative to traditional diesel fuel of 41%. These figures suggest biofuels are not the climate change panacea many believed they would be. As we will discuss in the subsequent section, new analysis that accounts for emissions from land conversion suggests biofuels may offer no carbon savings at all.

### Summary

Biofuel policy has been pursued to increase farm income, spur rural development, improve energy security and terms of trade, and address anthropogenic climate change. While the impact of biofuels on rural and developing economies has not been thoroughly quantified, theory and empirical observation suggest biofuels have boosted farm incomes and can provide poor regions of the world with a cash crop. As we will discuss in section 3, biofuels can reduce food security and raise food prices, effects which may impose particular burden on the poor and particularly non-farming poor. Biofuels can offer a partial solution to demand for domestic energy production in oil-importing countries. The ability of biofuels to address global warming is the subject of controversy as we discuss in section 3. What had been conventional wisdom that biofuels are carbon neutral is now universally recognized as being quite wrong. The question now is whether biofuels offer carbon savings relative to fossil fuel.

## THE NEGATIVE IMPLICATIONS OF BIOFUEL

While biofuels provide benefits to some constituencies and perhaps to the environment, they are also associated with significant costs that most acutely impact the poor. First, as energy production competes with food for harvests and land, the production of food declines and the price of food goes up. Biofuels are surely responsible in part for the current food crisis, though the blame from recent media is likely overstated. Second, biofuels may actually worsen global warming, increase car travel, reduce biodiversity, consume scarce water supplies and worsen water quality. We address these environmental concerns first, beginning with greenhouse gas emissions, and then biodiversity, water availability and water quality.

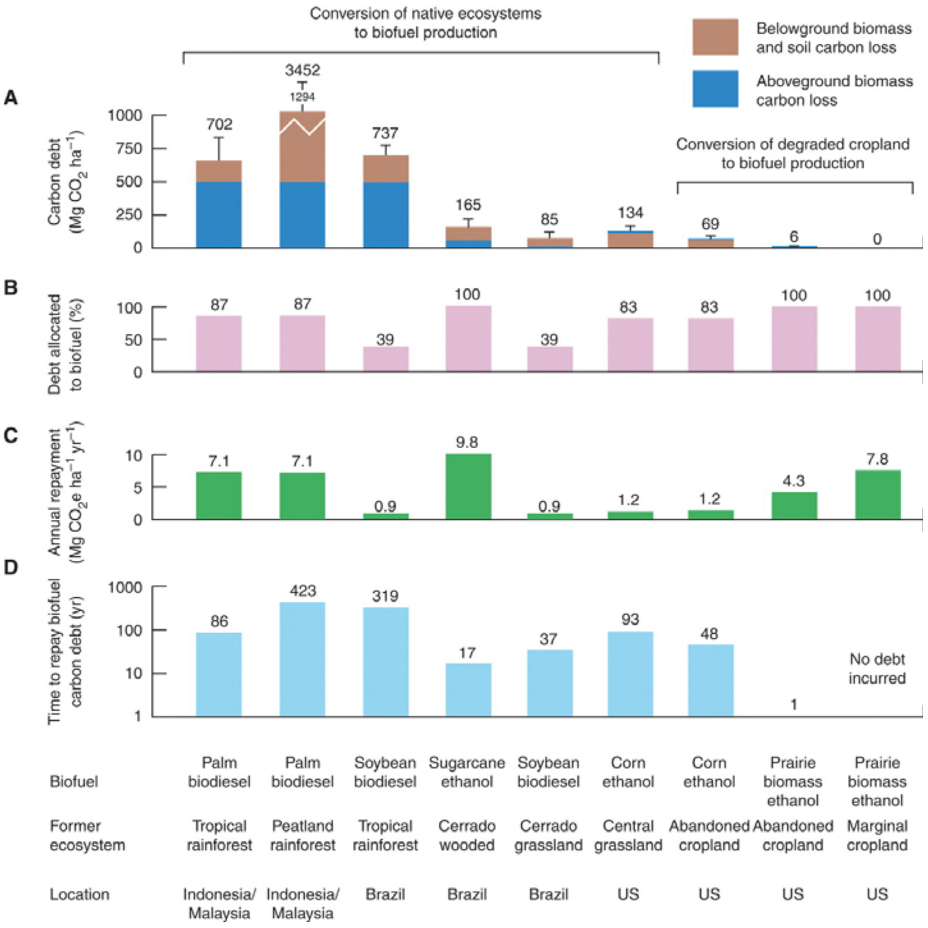
## Biofuel May Increase Greenhouse Gases

Even the life cycle analyses that reported only modest carbon savings from biofuels relative to fossil fuels may have overstated the climate change benefit of biofuels. They ascribed a carbon credit to biofuels to account for sequestration that occurs during the growth of energy crops, but they failed to account for the loss of carbon sequestration on forest and grasslands that are converted to energy crop production. Far from being carbon neutral, biofuels require energy for the cultivation of feedstock, transportation to refineries, conversion to ethanol in refineries, and transportation to market. Patzek and Pimentel (2005) produced the first life cycle accounting of carbon emissions for biofuel. In doing so, they established the playing field on which biofuels would compete. Their analysis, however, did not account for the cost of scaling up biofuel production, which includes emissions from land conversion and foregone carbon sequestration by natural habitat.

Searchinger et al. (2008) were the first to provide an accounting of the carbon emissions of corn ethanol that accounted for the effects of land use change. In particular, the growth of biomass sequesters carbon whether in forests or grasslands and stores it in plant material. If such lands are cleared and the biomass burned or left to decompose, then the carbon is emitted back into the atmosphere. Because biofuels create additional demand for land, they lead to expansion of crop land and the conversion of natural lands. A complete life cycle analysis of biofuels should account for the emissions from land use change as well as the foregone carbon sequestration natural forest and grassland would have produced over their lifetimes. With such an accounting, a 56 billion liter expansion US corn ethanol production would bring an additional 10.8 million hectares of land under cultivation and actually double carbon emissions over a thirty-year period relative to fossil fuels. It would take 167 years for corn ethanol to overcome the carbon debt it incurs from land use change and start providing carbon savings (relative to fossil fuels). Switchgrass, which yields more ethanol per acre, could provide carbon savings within four decades (Searchinger et al. 2008).

Similar analysis by Fargione et al. (2008) concludes that production of food-crop biofuels in the US, Brazil and Southeast Asia would induce land use changes that increase carbon emissions from 17-420 times the annual carbon savings of the biofuels, depending on assumptions about land-use change. Figure 8 (below) is reproduced from Fargione et al. and summarizes the carbon debt and time to repayment based on each of the feedstock and land conversion scenarios the authors assumed.

**Figure 8: Carbon debt of biofuels under 9 scenarios of production and land-use change (source Fargione et al. 2008)**



## Increasing car travel:

Because biofuels reduce the price of transportation fuel (by increasing supply), they encourage additional car travel by gasoline consumers (Khanna). In other words, biofuels actually increase vehicle miles traveled, which increases carbon emissions, worsens traffic congestion on roadways and can lead to additional traffic accidents (Khanna and de Gorter).

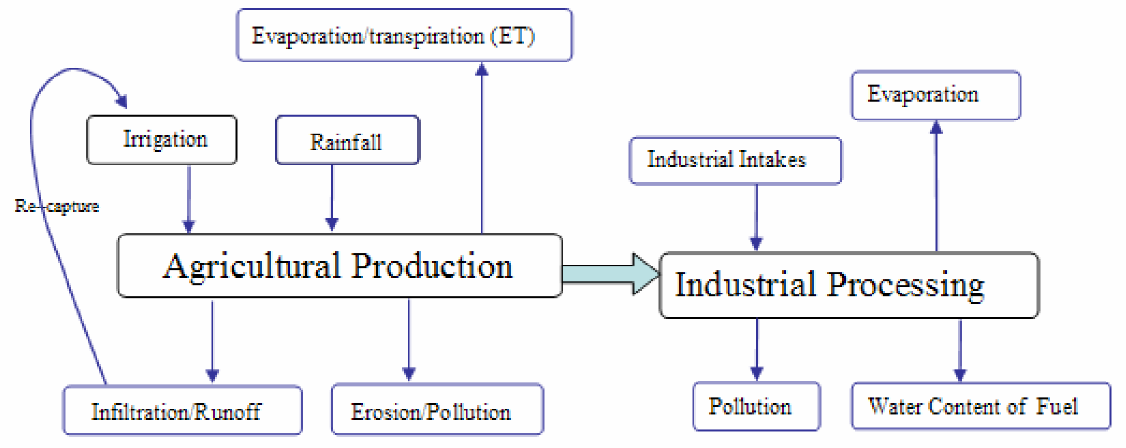
## Biodiversity Loss

The 10.8 million hectares of land that Searchinger et al. predict will be brought into production of 56 billion liters of corn ethanol will not only increase greenhouse gas emissions but also convert natural habitat to cropland. Fraiture, Giordano and Liao (2008) estimate that an additional 30 million hectares of cropland will be needed to meet food and biofuel demand in 2030. The reduction in natural land will lead to biodiversity loss, which some believe could be more costly at present than global climate change (Mooney and Hobbs 2000). Environmental lands and the biodiversity they encapsulate provide environmental services essential to human life, including waste assimilation, water purification, fire suppression, soil restoration, nutrient recycling, flood protection, draught prevention and carbon sequestration. Biodiversity also provides option value and existence value. In particular, breakthroughs in science, medicine and agriculture are the result of genetic discoveries in natural habitat. Biodiversity provides existence value and option value, in addition to these use values. The loss of biodiversity is costly and irreversible. While there is hope that climate change can be reversed, there is yet no way to bring back an extinct species. In the US, 70% of land in South Dakota that had been enrolled in the government's Conservation Reserve Program did not reenroll in 2008 (McCarl). The CRP pays farmers to lay fallow ecologically sensitive farmlands.

### Water Availability

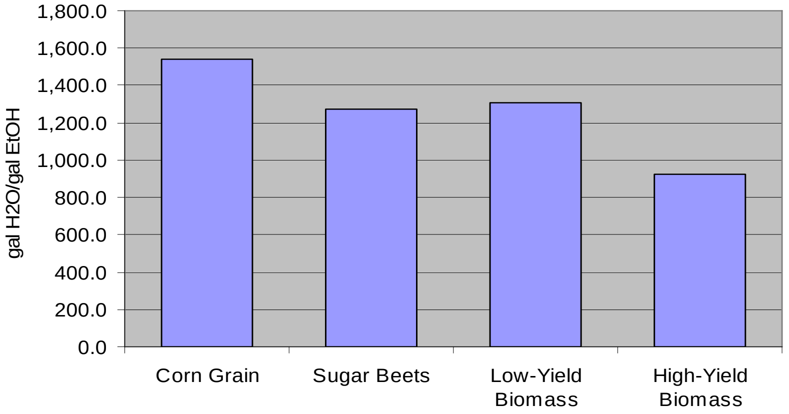
Evapotranspiration accounts for 99% of the water embedded in biofuels, but as Figure 7 shows, water enters into the production of feedstocks as well as the conversion of plant material to fuel.

**Figure 6: Water use in biofuel production**



A recent study commissioned by the California Air Resources Board investigates the probable water resource implications of an increase in California bioenergy production (Fingerman, 2008). There is a clear difference in fuel embedded water among the different feedstocks modeled in the analysis. Figure 8 shows the average embedded water in ethanol from corn grain, sugar beets, and hypothetical low and high-yielding biomass crops.

**Figure 7: Water embedded in biofuel for four feedstocks (source: Fingerman 2008)**



On average, the amount of water consumed in producing ethanol from these feedstocks across California ranges from 925 to 1,527 gallons of water per gallon of ethanol. By contrast, the amount of water required to produce the average daily diet in North America is 1320 gallons, while in Sub-Saharan Africa, this figure is less than 500 gallons (Serageldin, 2001). The water savings of second-generation biofuels, reported here as “High-Yield Biomass,” are significant and indicate that the challenges of current biofuels may be overcome with innovation.

The high water demands of biofuels—even cellulosic ethanol—do present a challenge to policymakers. Fresh water is scarce in many regions of the world and will be made scarcer with increasing production of biofuels. Perhaps nowhere is the increasing scarcity of water more evident than in China and India, where rapid economic growth has generated large increases in energy demand and a consequent interest in biofuel. As noted earlier, increasing per capita income in these countries is also driving demand for more water-intensive foods, such as meat.

By some estimates, the water consumed by energy crops through evapotranspiration could, by 2110, meet and even exceed the total water used for evapotranspiration by global croplands in 2002. Such an expansion of water demand may be accommodated in some countries, including Canada, Brazil, and Indonesia. In areas where water is already scarce, however, large-scale expansion of bioenergy may prove infeasible or ill-advised. China and India are promoting biofuels as a way to meet their rising energy demand and reduce their dependence on oil imports. Both countries already face severe water shortages and may face constraints on the production of biofuel (Zilberman).

The extent to which biofuel production draws in irrigation varies by region. Rain-fed rapeseed in Europe requires virtually no irrigation. Corn in the United States is largely rain-fed, so only 3% of irrigation withdrawals are devoted to biofuel crops (de Fraiture, Giordano, and Liao, 2008). In aggregate, only 2% of the 2,630 km3 of water withdrawn for irrigation is applied to biofuel crops (de Fraiture et al., 2008). Fraiture, Giordano, and Liao estimate an average of 2,500 liters of evapotranspiration and 820 liters of irrigation are needed to produce one liter of biofuel. They caution that regional variation is large, as is depicted in Figure 8, which is adapted from de Fraiture, Giordano, and Liao (2008).

**Table 7: Biofuels land and water use (source: de Fraiture et al. 2008)**

| | Ethanol (Million liters) | Main Feedstock | Feedstock used (Million tons) | Area planted to biofuel (million ha) | %total crop area grown for fuel | Crop water ET ($km^3$) | %total ET used for biofuel | Irrigation withdrawals for biofuel ($km^3$) | % of total irrigation withdrawals for biofuels |
|---|---|---|---|---|---|---|---|---|---|
| Brazil | 15,098 | Sugarcane | 167.8 | 2.4 | 5.0 | 46.02 | 10.7 | 131 | 3.5 |
| USA | 12,907 | Corn | 33.1 | 3.8 | 3.5 | 22.39 | 4.0 | 5.44 | 2.7 |
| Canada | 231 | Wheat | 0.6 | 0.3 | 1.1 | 1.07 | 1.1 | 0.08 | 1.4 |
| France | 829 | Sugarbeet | 11.1 | 0.2 | 1.2 | 0.90 | 1.8 | -- | 0.0 |
| Italy | 151 | Wheat | 0.4 | 0.1 | 1.7 | 0.60 | 1.7 | -- | 0.0 |
| UK | 401 | Sugarbeet | 5.3 | 0.1 | 2.4 | 0.44 | 2.5 | -- | 0.0 |
| China | 3,649 | Corn | 9.4 | 1.9 | 1.1 | 14.35 | 1.5 | 9.43 | 2.2 |
| India | 1,749 | Sugarcane | 19.4 | 0.3 | 0.2 | 5.33 | 0.5 | 6.48 | 1.2 |
| Indonesia | 167 | Sugarcane | 1.9 | 0.0 | 0.1 | 0.64 | 0.3 | 0.91 | 1.2 |
| S. Africa | 416 | Sugarcane | 4.6 | 0.1 | 1.1 | 0.94 | 2.8 | 1.08 | 9.8 |
| World Ethanol | 36,800 | | | 10.0 | 0.8 | 98.0 | 1.4 | 30.6 | 2.0 |
| Biodiesel | 1,980 | | | 1.2 | | 4.7 | | | 0.0 |

Fraiture, Giordano and Liao estimate that biofuel demand in 2030 will require 170 km3 of additional evaportranspiration and 180 km3 of additional irrigation. When one considers food crops will require 1,400 million hectares of land and 2,980 km3 of irrigation withdrawals, the biofuel-induced demand seems modest.

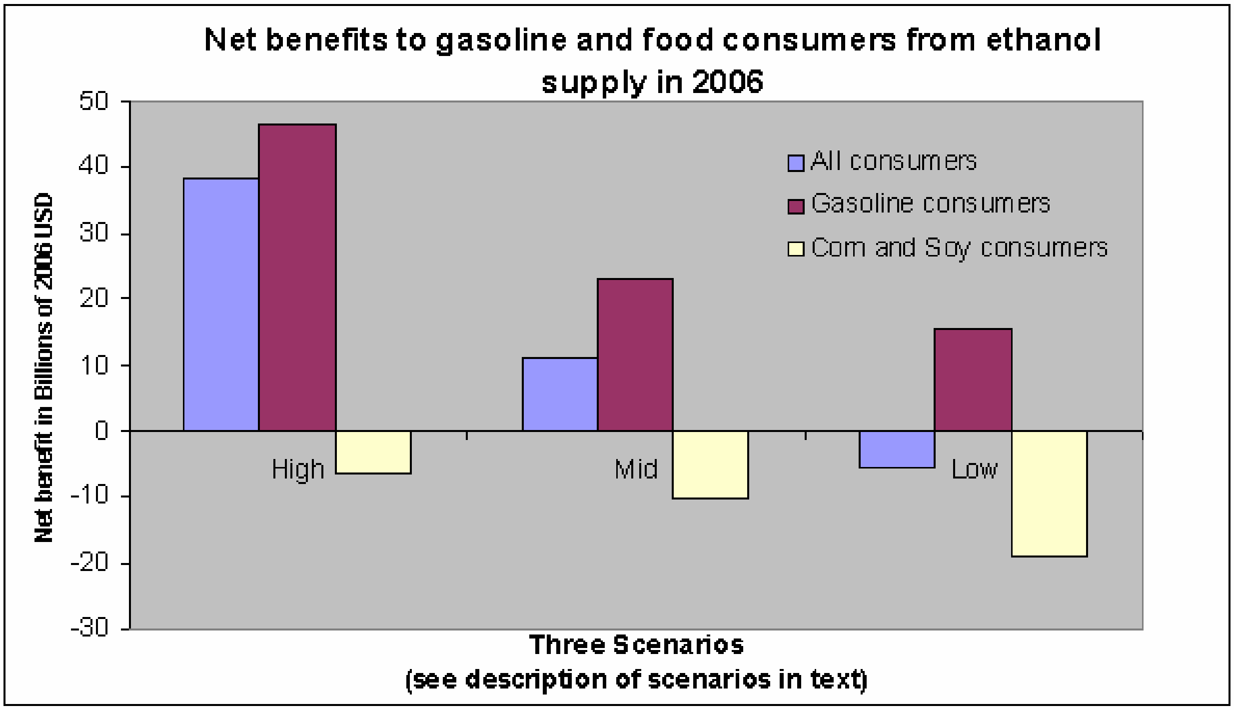
## Water Quality

Biofuels cause an increase in cropland and an increase in the value of marginal product of inputs in production, including fertilizers and pesticides. These effects will reduce water quality by increasing water pollution from farms (Zilberman).

**Food Security**

Perhaps the most dire consequence of biofuel production is the pressure it imposes on the food system. Whereas elevated carbon emissions have negative effects that will play out over decades and centuries, rising food prices and reduced food production will mean people go hungry, starve and die. To some extent, biofuel policies trade food in the stomach for fuel in the tank. They benefit energy consumers and hurt consumers of food, particularly the poor who devote a large share of their incomes to food. Partial equilibrium analysis of the US ethanol production tax credit demonstrates the distribution of benefits. As depicted in Figure 9, gasoline consumers benefit significantly from reduced prices whereas consumers of corn and soy lose. Figure 9 considers three assumptions on supply and demand elasticities and is intended to depict the range of potential benefits and provide orders of magnitude. Though not considered in this analysis, the effects on soy and corn consumers can be expected to carry over into other food products, particularly coarse grains (Zilberman).

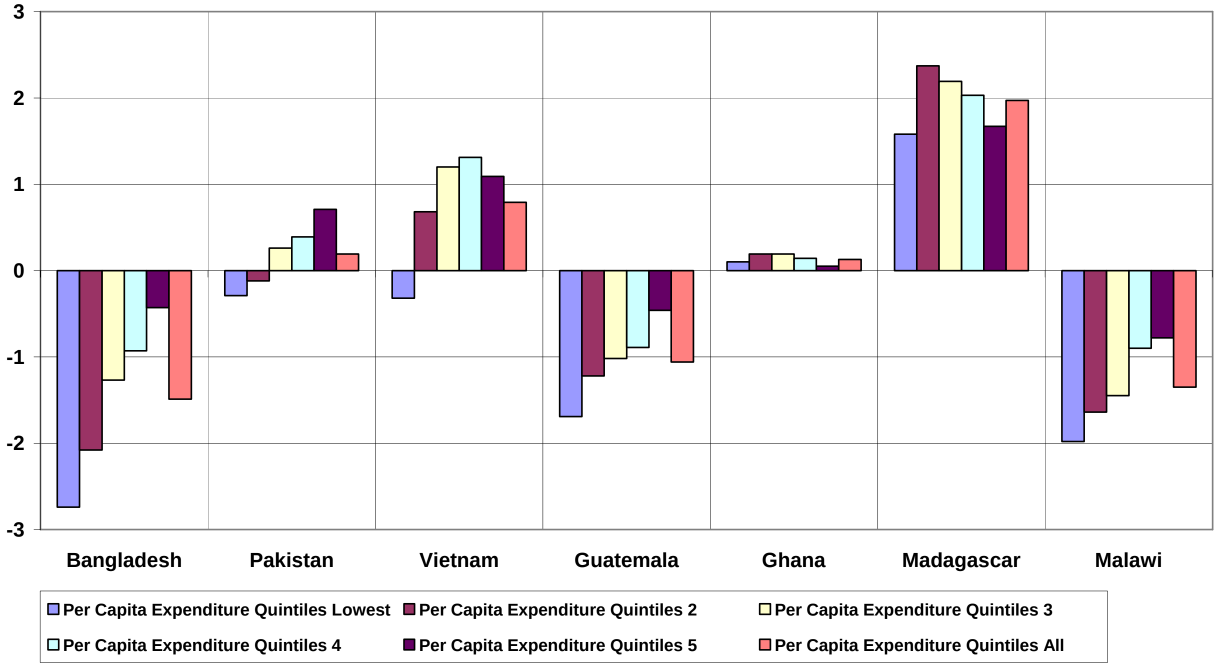
**Figure 9: Distribution of benefits of US ethanol production tax credit under three assumptions on elasticities (source: Zilberman / Rajagopal et al. 2008)**



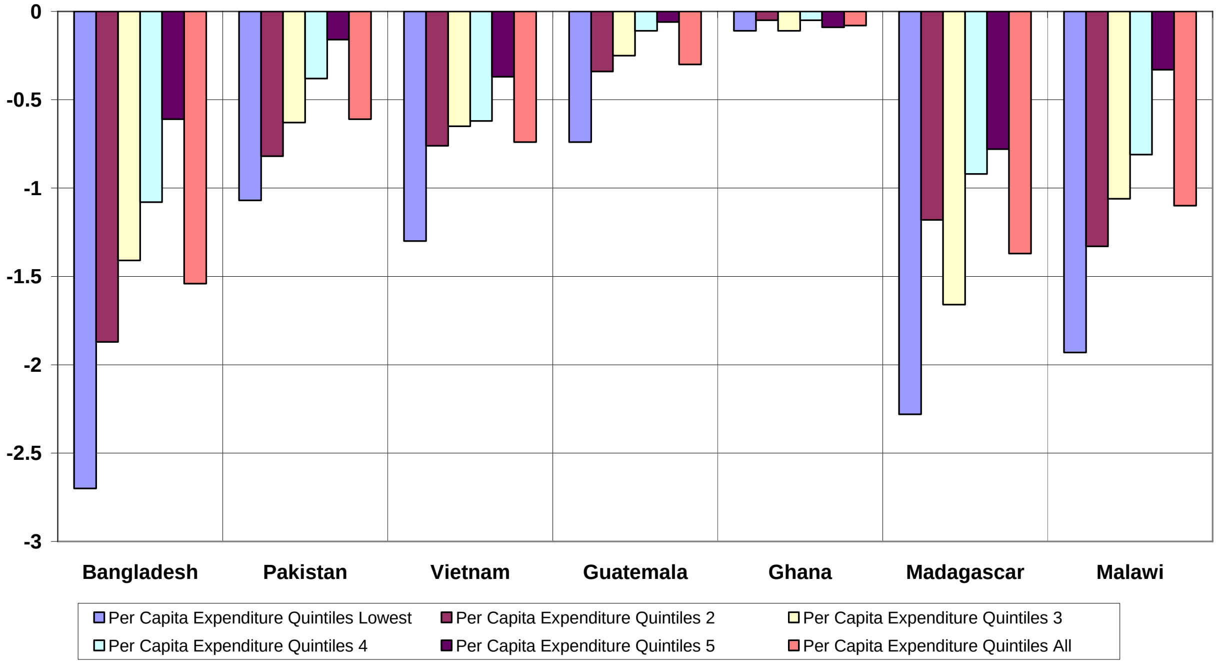
The effect of biofuels on the food market can limit their ability to improve welfare for the poor. As Figure 10 shows, the welfare effects of just a ten percent increase in food prices can be devastating to the welfare of rural poor, who often farm and can capture some limited benefit from high output prices. The effect of food price increases is even worse for the urban poor who are net consumers of food (Wiebe)

**Figure 10: Welfare changes for rural and urban poor of a 10% increase in food prices (source: Wiebe)**

Rural

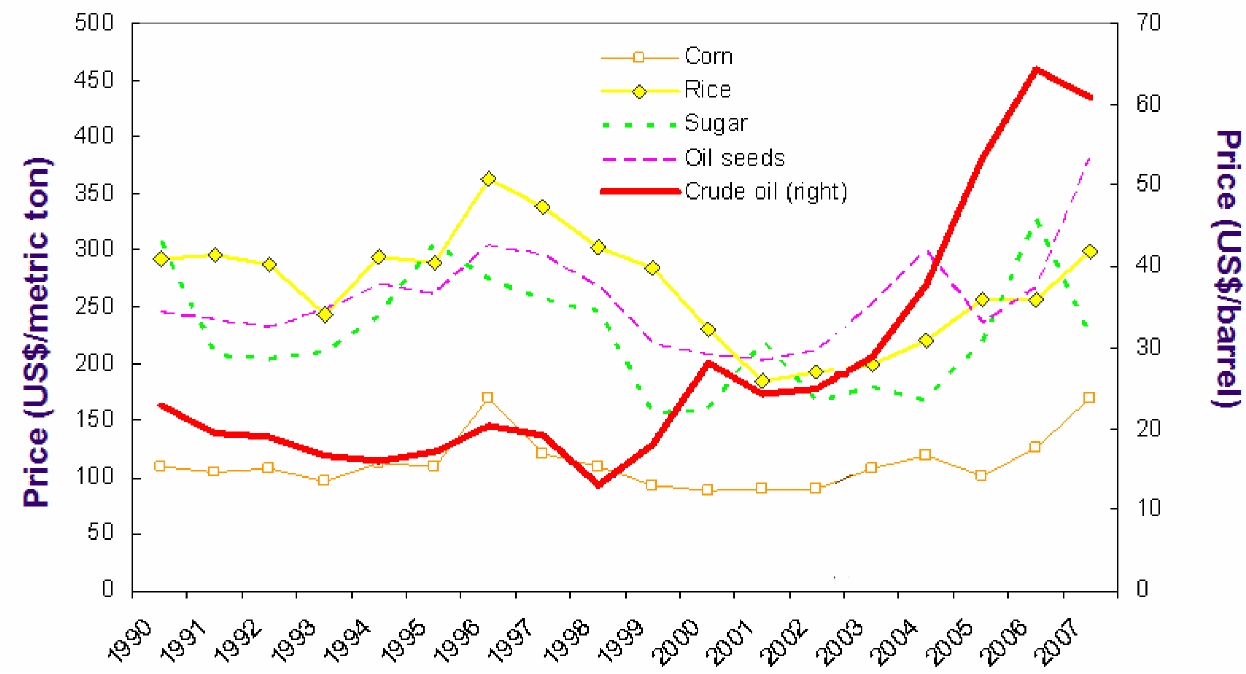


Urban



The current food crisis has brought considerable attention among policymakers and the media to the role of biofuels in the rapidly rising food price. For 30 years, we have known nothing but declining food prices. In the past few years, that has begun to change (Wiebe). Figure 11 shows price trends for selected commodities and crude oil. It shows the sharp increase in prices in recent years (Msangi).

**Figure 11: Prices for select commodities 1990-2007 (source: Msangi)**



Today's food prices for crops from soy to wheat and corn are hitting record highs, but biofuels are believed to contribute no more than 10-15% of the price changes (Wiebe and Zilberman). They are significant, but not dominant (Wiebe). As McCarl observed, "Rice prices have tripled in recent years, but its not like we are putting rice into biofuels." This suggests other drivers of high food prices, which include growing demand. A growing population is also growing wealthier. As per capita income rises, diets become more land intensive because meat is consumed in greater quantities. Devaluation of the American dollar may be a contributing factor as well as poor harvests in some regions and expectations of tight markets in the future. Inventories for staple crops are at lows not seen sense World War II; this creates a stealth effect on prices as inventories are drawn down and storage becomes cheap (Zilberman). In addition, rising costs of inputs (including gasoline and energy-intensive chemical fertilizers) provide upward pressure on prices. But undeniably, policies that mandate biofuel production contribute to the crisis situation we experience today. Wiebe estimates 5-10% of US agricultural land will be diverted to energy crop production. In the EU, 10-12% of cropland will soon be used to produce bioenergy. As we will discuss in the following section, technology can improve this situation be introducing second generation of biofuels that don't compete for food crops and produce more energy per acre. It can also improve agricultural productivity, permitting greater food production per unit of land.

Biofuels pose short-term risks to the poor because of the pressure they impose on the food market (Wiebe). In the medium to long term, biofuels raise rural income; the income effect can overcome the food price effect to present opportunities for welfare gains among the poor (McCarl). With appropriate policies, these short term risks can become long term opportunities (Wiebe). They will have diverse impacts on net producers and net consumers of food, both at the household level and at the country level. Rising resource values present opportunity and may lead to conflict (Wiebe). As we will discuss in the final section of this report, policy should support vulnerable groups and perhaps scale biofuel mandates to food inventories. A global food fund could be developed to support the hungry during food crises (Zilberman).

### Summary

Biofuels have the ability to help countries accomplish several strategic goals. But these benefits should be weighed against a careful accounting of their costs, which would include actual greenhouse gas emissions, effects on biodiversity, water quality and availability, and impacts on food security. New analysis that accounts for indirect land use changes suggest biofuels may actually increase greenhouse gas emissions. They are expected to reduce biodiviersity as they expand to natural land. They will increase use of fertilizer and pesticides, polluting water with runoff. They will increase demand for water use. Biofuels are likely responsible for 10-15% of the increase in food prices that has induced a global food crisis in 2008. Careful biofuel policy will be designed to mitigate these negative consequences of biofuels and provide for vulnerable groups.

## FACTORS THAT AFFECT BIOFUEL IMPACTS

The impact of biofuels on greenhouse gas emissions, food security, rural development, biodiversity, and water use are all influenced by a number of factors, including the feedstock used in biofuel production, innovation in agricultural technology and fuel technology, production processes, food inventories, and prices and policy. In this section, we discuss how each of these factors may influence accounting of biofuel impacts.

### Feedstocks

Not all biofuel feedstocks are alike. They vary in the amount of energy they yield per acre of land, the amount of inputs like fertilizer (which is energy intensive), pesticides, and water they require in production, and the extent to which they compete with traditional agriculture for land in food production. While today's biofuels are largely produced from food crops, including corn, soy, sugar, wheat, and rapeseed, a new generation of biofuel is likely to yield bioenergy crops that can be grown on marginal lands and not compete for food harvests. These new crops, which include miscanthus, switchgrass, and jatropha, can greatly improve the carbon accounting of biofuels because they are less factor intensive and yield more biofuel per unit of land than traditional crops. In this respect, they can greatly alter the calculations of Searchinger, which were conducted for US corn ethanol production, which is the least efficient form of biofuel production in the world. Sugar ethanol form Brazil fares better than corn ethanol by every standard. The second generation promises to do better still. Every feedstock has a yield per acre; the challenge is to use crops with higher yields per acre. Figure 12 summarizes the harvestable biomass per acre and gallons of ethanol per acre for several feedstocks. It demonstrates the variation in productivity across feedstocks and suggests that the carbon accounting of biofuels can improve tremendously with a transition from starch-based biofuels to cellulosic ethanol, which can convert grasses, shrubs and even trees to liquid fuel. Miscanthus, for instance, can yield as much as three times the ethanol per acre as traditional corn ethanol.

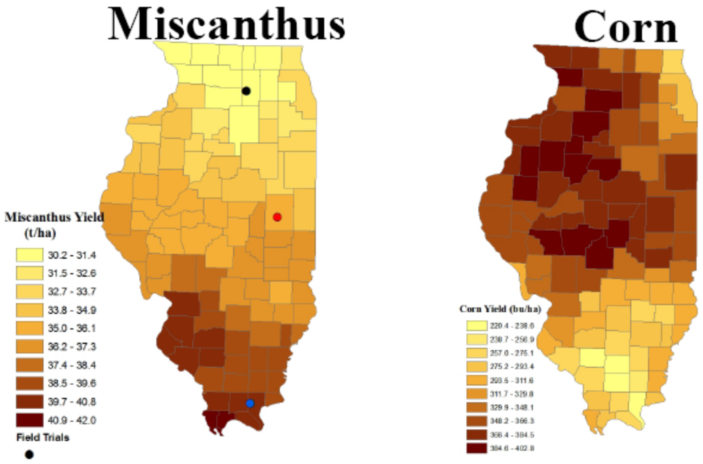
**Figure 12: Productivity matters – yields per acre for various feedstocks and their land use implications (source: Long)**

| **Crop** | **Harvest-able Biomass (tons/ acre)** | **Ethanol (gal/acre)** | **Million acres needed for 35 billion gallons of ethanol** | **% 2006 harvested US cropland[5]** |
|---|---|---|---|---|
| Corn grain[1] | 4 | 500 | 70 | 25.3 |
| Corn stover | 3 | 300 | 105 | 38.5 |
| **Corn Total** | **7** | **800** | **40** | **15.3** |
| **Prairie** | **2** | **200** | **210** | **75.1** |
| **Switch-grass** | **6** | **600** | **60** | **20.7** |
| **Miscanthus** | **17** | **1700** | **18** | **5.8** |

The productivity of biofuels is significant not just to carbon accounting, but also to land use change implications and factor intensity (on a per gallon basis). As demonstrated in the table above, more productive feedstocks require much less land, which will reduce pressure for conversion of natural lands. This mitigates the land use change emissions of biofuels and the loss of biodiversity, as well as land competition with food. Because less inputs are needed per gallon of biofuel produced, more productive feedstocks also reduce water pollution and reduce water scarcity.

In addition, some feedstocks can be grown on lands not suitable for food production. Cellulosic crops, for instance, can be grown in regions of the US South that are inhospitable to traditional agriculture (Long). Some can be grown in saline soil and irrigated with saline water (from oceans) (Long). And as Khanna shows for the state of Illinois, productive energy crop production can occur on lands that are least productive for food production. Figure 13 below shows this for Illinois: corn is more productive in the north, whereas miscanthus is most productive in the south of the state, making these two crops somewhat complimentary. Darker regions represent higher yields.

**Figure 13: Productivity of corn and miscanthus in Illinois (source: Khanna)**



The findings of Searchinger et al. assume net carbon sequestration is not possible with lands planted to biofuel crops. But some crops, such as miscanthus, permit soil carbon sequestration so that even if all carbon stored in biomass is released in combustion of ethanol, there is still net carbon storing from the ground (Long)

Feedstocks, then, are important to sustainability of biofuels and the ability of biofuels to address global warming. It is important, therefore, that the entire class of biofuels not be characterized by the carbon accounting of any one feedstock and that policy recognize the heterogeneity in biofuels.

## Technology

**Food:** In the past half century, agricultural productivity growth permitted gains in per capita food production even as the world population doubled. This achievement is even more remarkable considering the agricultural land base shrunk over this same period. The gains are the product of mechanization, modern irrigation, chemical fertilizers and pesticides, and certainly the Green Revolution, which capitalized on hybridization to create super crops. The ability to feed a larger world on less land is a significant success for agriculture. That success may have bred complacency and a belief that the world would not again have to suffer a food crisis. Thirty years of declining food prices served to reinforce this belief. But as we see today, such confidence was misplaced. Today, agricultural productivity growth is declining (as seen in Figures 14 and 15 below). Developing countries can no longer rely on the same sources of growth that permitted productivity gains in the past and will need to embrace agricultural biotechnology. The current food crisis and the slowing advances in productivity are likely the result of under-use of molecular and cell biology knowledge that permits the transfer of genes at a much more rapid and deliberate pace than the hybridization techniques used in the past to improve food production.

**Figure 14: Growth in yields for wheat (source: Zilberman)**

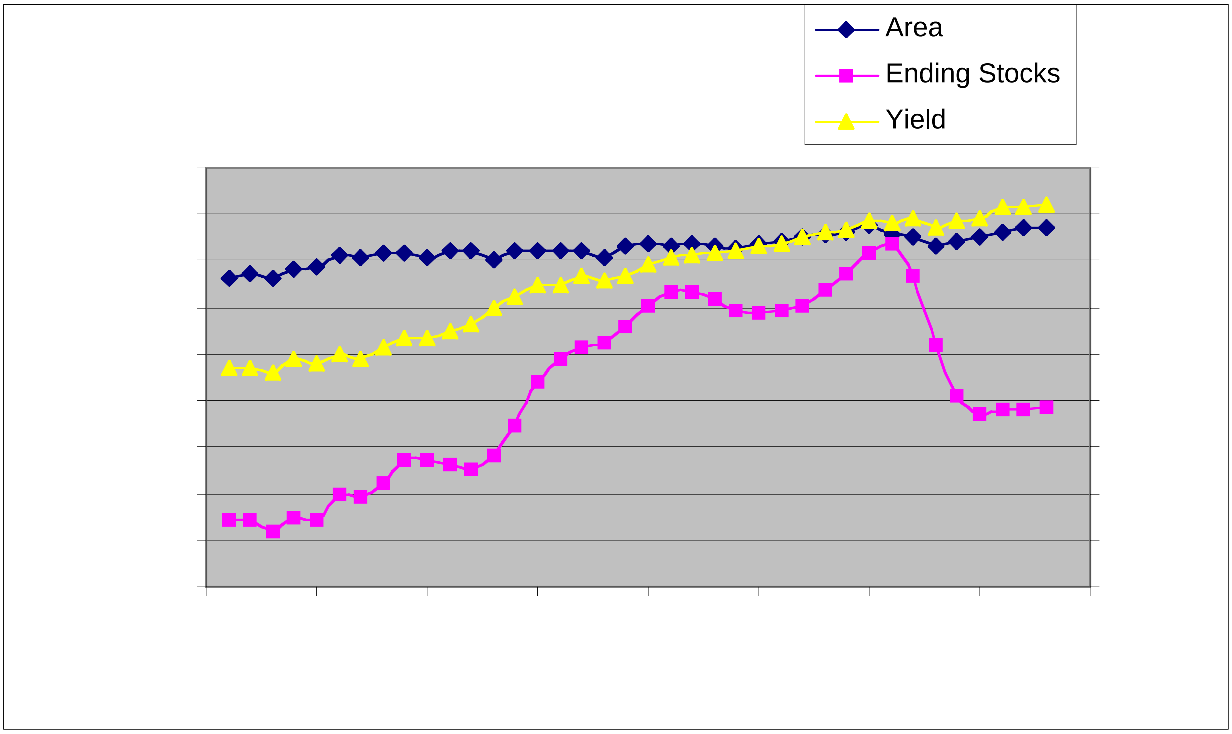
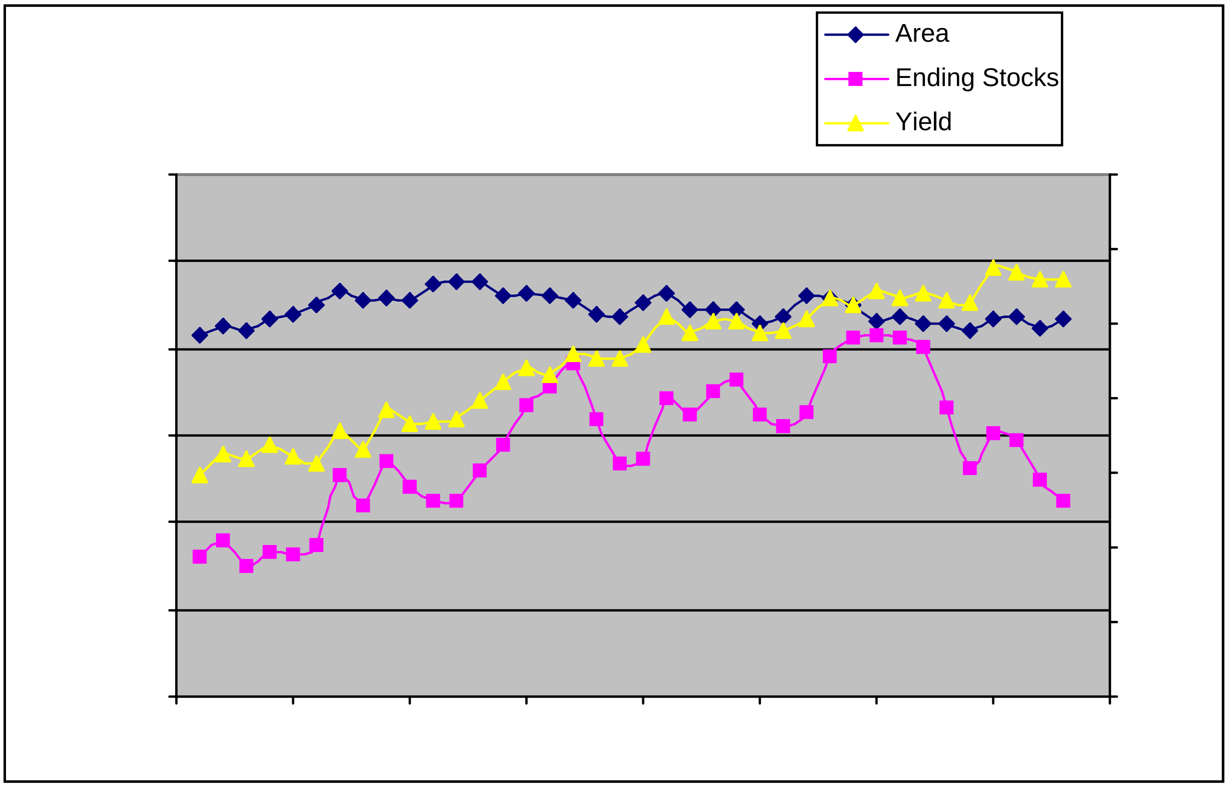


**Figure 15: Growth in yields for rice (source: Zilberman)**



Figures 14 and 15 show the slowing growth (and negative growth) for rice and wheat yields in recent years. In contrast, soybean, corn and cotton have experienced consistent growth due to adoption of agricultural biotechnology (Zilberman). Trends in cotton yields suggest that when Bt cotton and other first generation genetically modified organisms (GMO) technologies are adopted in developing countries, they have significant yield effects. They do not replace use of fertilizers, but do reduce the use of pesticides while mitigating pest damage.

Improved agricultural productivity reduces the footprint of agriculture. It allows provision of food for a growing population on a smaller agricultural land base. These advances are important as biofuel begins to compete for land. Agricultural biotechnology can reduce deforestation by freeing land traditionally planted to food crops for cultivation of energy crops. In other words, GMO reduces the indirect land use change consequences of biofuel and allow reduced carbon emissions and more biodiversity.

**Fuel:** As described previously, cellulosic feedstocks can greatly improve the benefits of biofuels and reduce the negative effects. To date, however, the mechanisms to convert the crops to ethanol are not commercially viable. Though demonstration projects are producing cellulosic ethanol, there is more work to be done before such production can be scaled up. As Long describes it, “We are not looking for major breakthroughs in deploymerization. We know these processes occur in nature.” The challenge is to identify genes, put them in cultures and determine an industrial way to replicate what is already occurring in nature. This challenge creates an imperative for additional advances in biofuel technology so the world can transcend corn and soy and develop liquid fuels from more productive sources.

Related to technology to convert dedicated energy crops is the ability to convert waste products to biofuel. If agricultural wastes, like stalks, roots and leaves could be converted to biofuel, then the land conversion that so worsens the carbon accounts of biofuels can be drastically reduced. Such wastes could come from traditional agricultural crops as well as from forest management that would make use of decaying plant material rather than allow carbon to leak from dying plants (Searchinger). Use of crop residues alone could produce sufficient ethanol to offset 27% of gasoline consumption (Rajagopal et al. 2007).

### Production Processes

The carbon consequences of biofuels are also closely tied to the methods of production. Biofuel production is an energy intensive process, from the cultivation of energy crops to conversion in refineries, and the extent to which more energu efficient technologies are developed and deployed and the extent to which clean energy is used can greatly influence the net carbon benefit of biofuels. In addition, reducing the distance feedstocks are transported to refineries and the distance refined ethanol is transported to market minimizes the carbon emissions from production. To illustrate the size of these effects, consider that nitrogen fertilizer is produced from energy that is 90% gasoline and 10% coal. If fertilizer production were to rely entirely on coal power, then the carbon benefit of biofuels would be reduced 61%. Similarly, most biofuel refineries today use a mix of coal and gas. If production were to use only coal power, then the carbon benefits of biofuel would fall by 50%. If they instead switched entirely to gasoline, the carbon benefits would increase by one-third (Zilberman).

### Inventories

Food and fuel price dynamics and shortages depend on inventories. Inventories can be used to reduce variation in prices and prevent unanticipated shortages that result from weak harvests (because of weather for instance). Recent price increases in food and fuel reflect record-low inventories and the expectation of greater demand for food crops due to biofuel mandates. Such mandates are expected to reduce future supply, which makes storage cheap and further reduces food availability in the present.

### Price and Policies

The adoption of biofuels and the impacts of adoption depend on market conditions and policies. Higher fuel prices and lower prices for agricultural commodities will tend to increase land devoted to biofuel production. If the cost of carbon is not internalized by the emitter, then there is no incentive for substitution of clean fuel. If the cost of carbon is internalized, however, we may see substitution of gasoline for coal in biofuel production. This would improve the greenhouse gas balance of biofuels. And if natural gas or solar or wind power were used, the carbon balance would be even better. This “green-green” solution can be achieved through policy. Conversion of natural land can also be reduced by policy that provides payment for environmental services. Food impacts can also be reduced by policies that tie biofuel support to the food situation and reduces subsidies and mandates as food inventories decline.

We reserve a more complete discussion of policy prescriptions to the final section of this report. This brief discussion is intended just to highlight that the impacts of biofuels on the environment, food, and energy is a function of market conditions and policy which determine the prices received by market participants.

## METHODOLOGIES

Life cycle analysis has become the dominant way to measure the performance of biofuels. The emphasis on LCA reflects the focus on the carbon benefit of biofuels. Though it has become the established method for judging biofuels, it is not the most comprehensive and is limited in significant ways. In this section, we discuss the limitations of LCA and introduce a new methodology that incorporates economics into LCA. We also discuss how traditional welfare analysis can be used to determine optimal biofuel policy.

### A New LCA

Life cycle analysis is a technique for estimating the overall effect of biofuels and other fuels on carbon and other emissions. It can be used to regulate biofuels, but focuses only on a narrow set of externalities and may, therefore, present an incomplete measure of the welfare effects of fuels. A typical LCA study concludes that each unit of a given fuel using a given production technology results in a percentage increase or decrease in emissions relative to a comparison fuel. LCA has its origins in analysis of fossil fuels. It is well suited to study of industrial processes, but may need to be adapted for modeling agricultural systems that are characterized by heterogeneity, non-point source pollution and uncertainty (Rajagopal). Traditional LCA provides conclusions that say nothing about future performance or scale effects. The land use changes incorporated in the analysis by Searchinger et al. were not incorporated in traditional biofuel LCAs. LCA does not explicitly model prices or market forces, although it does make assumptions about markets implicit in the technical and behavioral parameters of analysis. LCA is not needed for an all-encompassing carbon tax but it is quite important for policies that mandate a particular level of carbon emissions or that institute systems of tradable permits.

It is important to incorporate prices into LCA analysis because producers will switch fuels, alter input mix, and adopt technology in response to changes in the relative prices of inputs. These changes in the production process alter life cycle emissions. Life cycle analysis, therefore, should provide a function not a single point estimate of carbon emissions. Economics can add structure to LCA to provide functions. It begins with production functions, profit maximization, and incorporates a pollution function. Rajagopal and Zilberman develop a model that can be used to estimate the effects of a carbon tax on biofuel emissions. It shows, for instance, that a carbon tax raises the price of carbon intensive fuels and shifts biofuel input use to cleaner fuels, improving the net carbon benefits of biofuels between 17 and 18 percent depending on the increase in the relative price of coal (the dirty fuel). This framework provides a structure for incorporating land use changes and general equilibrium effects into LCA.

There is a need for computable general equilibrium (CGE) models to assess the magnitudes of indirect effects, including land use changes. There are several CGE models being used by economists today. They include the Food and Agricultural Policy Research Institute (FAPRI) model, the Global Trade Analysis Project (GTAP) model from Purdue University (used by Hertel and Tyner), the model of the International Food Policy Research Institute (IFPRI) and the FASOMGHG model developed by Bruce McCarl of Texas A&M University. These models are all based on linear projections that can ignore the potential for innovation. Innovation produces nonlinear trends and can render linear models inappropriate for analysis.

## Welfare Analysis

LCA does not account for the wide ranging impacts biofuels may have. It focuses on emissions and ignores impacts on food markets and other environmental damage. Furthermore, it does not incorporate opportunity costs. Traditional welfare economics can analyse biofuels in this broader context and may be a superior mechanism for considering policy impacts. For instance, as de Gorter notes, the use of cleaner inputs in biofuel production will improve the carbon balance of biofuels according to LCA. But the use of cleaner inputs in production will displace the use of clean energy elsewhere in the economy. The dirty inputs will shift elsewhere. Welfare will not have improved even though biofuels are cleaner. Given this analysis, policy based on LCA may give the false impression of favoring welfare improving technologies. To demonstrate the point, consider that coal is used in production of bourbon instead of the natural gas that is now used in biofuel production (de Gorter). These leakages can occur with any input in production, including land. In this sense, an input is an input. The distinction between inputs based on their use in biofuel production is a product of LCA.

Welfare economics analyzes the social costs and benefits of biofuel policies independent of their LCA emissions savings. Welfare analysis would take issue with analysis of indirect land use changes like that of Searchinger because the analysis penalizes biofuels for land use changes but not other outputs. If an output is an output, then welfare analysis is preferred to LCA. De Gorter demonstrates the point thusly: If corn for bourbon is banned, then consumers will switch to bear produced from barley. But barley produces less beer per acre than corn produces bourbon per acre. And beer contains less alcohol per liter than bourbon. And if corn is banned for ethanol, then should it not also be banned for bourbon, bacon, butter, and burgers (de Gorter)? Ethanol saves lives through reduced carbon dioxide emissions and other pollution. Bourbon, burgers, bacon and butter all kill people (de Gorter). As European Commissioner Peter Mandelson asks, “Why should we suggest there is an obligation on producers who export sugar cane biofuel, but not on those who export just plain sugar cane?” In the words of de Gorter, an output is an output. LCA is ineffective, then, in determining welfare effects of biofuels and policy.

Welfare economics determines how well policy maximizes a particular objective function or social welfare function that can be modeled to value climate change mitigation, biodiversity, food security, and distributional concerns. In this respect, it is more powerful than LCA.

## POLICY PRESCRIPTIONS AND CONCLUSIONS

The wide ranging implications biofuels have for the environment, food production, energy markets, and development complicate the development of welfare maximizing biofuel policy. The fact that biofuel impacts vary by feedstock, location, time, and production process further complicates the work of regulators. There are lessons that can inform decision makers.

The consensus among conference participants is that policy should aim to develop biofuel technologies that are expected to one day be able to compete on their own—without mandates or subsidies. Because biofuel production requires coordination among farmers, processors, oil refiners and motorists, there is a role for policy. Policy should serve to send appropriate signals to market participants by incentivizing beneficial activities and establishing markets for outputs. But again, policies should be temporary and should be removed in time so that biofuels will compete.

### Policy for Climate Change

**First Best Response—Carbon Tax and Payment for Environmental Services:** In economics, policies are categorized based on their efficiency. First-best policies are those that achieve socially desirable outcomes with the least cost in terms of deadweight loss. Economists nearly universally agree that the first-best response to anthropogenic climate change is the imposition of a global carbon tax on each unit of emissions equal to the marginal social cost of carbon emissions. Such a tax internalizes the externality associated with carbon emissions (the cost of global warming) to the one who emits the carbon. It essentially corrects a market failure that does not require people to pay for consuming clean air. Such a tax, known as a Pigouvian tax, would improve social welfare by reducing carbon emissions while creating no deadweight loss.

As Hochman et al. (2008) show, a carbon policy will induce greater supply of clean energy, which shifts production from fossil fuel to biofuel. This, in turn, induces land conversion and a loss of biodiversity. A carbon tax, then, may actually reduce welfare depending on whether biodiversity is more valuable than carbon emissions reductions. To ensure a welfare maximizing outcome, then a policy to price clean air must also be paired with a policy to price environmental services. A carbon tax should be matched with a land conversion tax, or, equivalently, payment for environmental services. To illustrate this point, let us consider the consternation in developed countries surrounding destruction of rainforest in Brazil. Land owners in Brazil do not capture all the benefit of their efforts to preserve nature because the benefits, in terms of biodiversity and carbon sequestration, accrue to people around the world. If land owners in Brazil were paid for the environmental services their lands provide, then rainforest would be converted to productive use only until its value in nature reached its value as cropland.

Together, a carbon tax and payment for environmental services are the first-best policy responses to climate change. They can maximize social welfare by pricing commodities the markets fail to price—clean air and biodiversity. It is important that these policies be adopted on a global level. While they may be adopted by individual or groups of countries in the hope that others will follow, a tax system in any one country will suffer leakage (McCarl). If a carbon tax makes emissions more costly in the UK, for instance, then emission-intensive activities, like industrial production, will shift to countries that have not imposed taxes or other regulation. The result will be to reduce carbon emissions in the UK but not reduce carbon emissions on a worldwide level. Because carbon emissions are a global public bad, emissions anywhere in the world effect people anywhere in the world. To the extent carbon emissions are associated with other forms of pollution that are local or regional public bads, a carbon tax can achieve other environmental goals. It will, however, be useless to curb global carbon emissions.

**Second Best Response—A fuel tax based on LCA:** Not all sources of carbon emissions can be observed by the regulator. Therefore, a fuel tax is proposed as a second-best way to regulate carbon emissions. Many countries and states already impose fuel taxes, though in many cases the taxes are not set to equal the marginal externality cost of fuel consumption. Fuel taxes are easy to impose because fuel purchases are observable. A fuel tax should vary according to class of fuel, with dirtier fuels taxes more heavily. LCA should be used to classify fuels according to their carbon benefits. The tax may also be adjusted locally to account for other externalities associated with fuel consumption, such as traffic congestion.

A fuel tax is considered a second-best policy instrument because fuel purchases are not perfectly correlated with carbon emissions. For instance, two consumers could purchase the same fuels to power their cars. One uses a new car with cleaner combustion and the other uses an old car. The old car emits far more carbon and other pollutants than the new car and yet the owner of the new car is taxed at the same rate as the owner of the dirty car. More generally, a fuel tax does not provide incentive for adoption of clean technologies. A carbon tax would because the output (carbon) is regulated rather than the input (fuel). This inefficiency of a fuel tax is a source of deadweight loss and makes a fuel tax inferior to a gas tax in economic terms.

A carbon tax or fuel tax is the most direct way to reduce carbon emissions and address global climate change. Another class of policies we consider is designed to help build a biofuel industry. The desire to build a biofuel industry largely assumes greenhouse gas savings relative to the next best alternative fuel, so these policies may be considered indirect methods of reducing greenhouse gases.

**LCA Thresholds and Certification:** To the extent policy makers wish to ban biofuels that have limited ability to mitigate greenhouse gas emissions or that are produced on converted environmental lands, they can establish LCA thresholds or certification standards. LCA thresholds are used in the US. Only biofuels that have sufficiently small life cycle emissions can be used to meet the US renewable fuel standard. Likewise, governments may count toward mandates or offer subsidies to those biofuels that are certified to meet desired standards. Governments have adopted credible standards for other farm output (such as the certified organic label). Some third party labels are credible as well (such as the Marine Stewardship Council label for fish and the Rain Forest Alliance and Bird Friendly labels for coffee and other food items). Such standards could be used to require environmental protection and sustainability on the part of producers seeking access to markets and incentives. They could, therefore, require exporting countries to invest in environmental preservation.

### Policy for Developing Biofuels

**Mandates:** Carbon and land conversion taxes are unlikely for political economy reasons. With gasoline prices at all time highs, politicians are wary to impose a carbon tax that would raise prices even further. Therefore, we consider a class of policies that could be used to develop a renewable fuels industry—subsidies and mandates. These policies constitute a third-best approach to carbon mitigation (after a carbon tax and a fuel tax).

The advantage of mandates is that they create a certain market for biofuels so that the profit potential of biofuels in not tied directly to market forces in food and energy. This encourages investment in biofuel innovation and capital. It also creates an inelastic demand for biofuel, which means that rising prices for food and energy will induce intensification and productivity gains, rather than land expansion (Babcock). Because land expansion releases considerable carbon emissions, this is not a minor issue. It is critical to the carbon balance of biofuels. The cost of the mandates will be borne by producers and fossil fuel consumers depending on the responsiveness of fuel supply and demand to prices. A subsidy, on the other hand, would impose the cost of the policy on all taxpayers. Mandates are also revenue neutral. Subsidies are deducted from the treasury.

Any biofuel policy should distinguish among biofuels on the basis of sustainability attributes. These could include, for instance, net carbon benefit (on an energy equivalent basis), yield per acre, dedicated energy crop versus food crop versus residue and waste, factor intensity, and conversion process. The point is that biofuels should be judged along several criteria that capture the impact they have on carbon emissions, biodiversity, water and air pollution, and food availability. More sustainable biofuels should receive larger mandates, though regulators should recognize that transition technologies may need to be permitted in the short run (Zilberman, de Gorter, Searchinger).

Blend mandates should be favored over consumption mandates because they are easier to achieve and smooth prices (de Gorter).

**Subsidies:** Although subsidies are a more market-based approach than mandates, the consensus among conference presenters is that subsidies, in the context of biofuels, are inferior to mandates. The principle reason is that biofuel subsidies will increase biofuel use, decrease gasoline use and have an ambiguous effect on greenhouse gas emissions—ostensibly the main motivation for biofuels policy anyway. The ambiguous effect on greenhouse gas emissions results from the fact that a biofuel subsidy makes lquid fuels cheaper, which encourages more travel and, therefore, more emissions. Subsidies are also opposed because they create an elastic demand for biofuel, which means that higher output prices will induce land expansion. With most food crops and with biofuel under mandates, demand is inelastic, so that output prices increase total factor productivity. In addition, subsidies create a less certain market environment for biofuels at the outset because the demand for biofuels is tied to the cost of biofuels relative to the cost of oil. The cost of biofuels is dependent upon food market conditions as well.

To the extent subsidies are pursued, they too should be targeted and the size of subsidy commensurate with performance along sustainability criteria. In addition, if subsidies are pursued, they should be pursued at the exclusion of mandates (de Gorter). A binding mandate in combination with a biofuel subsidy effectively lowers the price of fuel to consumers, inducing more consumption and more carbon emissions. This is because producers facing a binding mandate have no incentive to bid up the price of fuel. To take advantage of the subsidy, they reduce the price of fuel to consumers. The biofuel subsidy, therefore, effectively subsidizes gasoline. Even if the subsidy is sufficiently large so that the mandate is not binding, it still implicitly subsidzies gasoline by preventing the mandate to bind (de Gorter). It is estimated that the social cost of the ethanol production tax credit in the US (in combination with the blend mandate) will range from $29-50 billion by 2022 (de Gorter). The subsidy on top of the mandate deteriorates terms of trade in oil, increases the marginal excess burden of the subsidy, causes increased carbon emissions, increases local air pollution, worsens traffic congestion, causes more traffic accidents, and worsens oil dependency.

Some have suggested biofuel subsidies may be revenue neutral because they reduce farm crop subsidy payments. But as de Gorter notes, such analyses ignore the interaction of biofuel subsidies and farm price supports. The interaction of a biofuel subsidy (assuming production from food crops) and deficiency payments to farmers of food crops creates greater deadweight loss (de Gorter).

**Technology Investment:** For a number of reasons, economic theory predicts underinvestment in biofuel and food technology. First and foremost, regulatory uncertainty creates doubts in the minds of private institutions as to whether they will be able to capture the benefit of their investments. In general, R&D is associated with spillovers whereby others benefit from the innovation of an individual or firm but do not pay a price to the individual or firm for the benefits they enjoy. As with the Brazilian land owner, the innovating firm does not capture all the benefits of his investment and therefore will under-invest in R&D relative to the optimal level.

As was explained earlier, advances in food productivity can critically improve the welfare effects of biofuel (as well as prevent future food crises like the one we experience today). Investment in biotechnology has fallen off considerably since the 1990s. The decline in R&D spending is attributed to two primary causes. First, regulation in Europe established a de facto ban on agricultural biotechnology, severely limiting the market for GMO and thereby reducing the potential gains from innovation. Secondly, the emergence of some GMO is stalled because once the GM seed is in the public domain, it can be reproduced by the GM plants and used ad infinitum. This obviously constrains the potential of firms to recoup their investment and capture the benefits of their innovations. Finally, there is a lack of research to develop traits and seeds for developing countries because many cannot afford to pay for the innovations (Zilberman). A second generation of agricultural biotechnology is stalled for precisely this reason. It promises to yield drought resistant crops and crops capable of growing on marginal lands. For these reasons, there is a role for public investment in food technology, not just for the sake of bioenergy, but also for the sake of the human condition.

Improvements in energy crop technology and biofuel conversion technologies are also important. As is evident from the foregoing analysis, the first generation of biofuel from food crops must be viewed as a transition technology. But only additional research will ensure the transition to cellulosic ethanol actually occurs. Uncertainty about the future of biofuels, induced partly by volatile market conditions and partly by regulatory uncertainty, has slowed advances in bioenergy technology. Given this uncertainty, there will be underinvestment that can be made up with public sector support.

Targeted R&D can help advance fuel and food technology without causing the perverse outcomes we see associated with current policies. Because of the nature of these technologies and market failures, there will be underinvestment by the private sector relative to the socially optimal level. Government can and should provide additional investment. This is a consensus view among conference participants.

**Flexibility:** Biofuel policies should be responsive to changing conditions in the food and fuel markets. Biofuel subsidies, for instance, should be tied to oil prices. As fossil fuels become more expensive, biofuels should be able to compete (although biofuel input costs may rise as well). As food inventories decline, governments may need to scale back mandates or limit the diversion of food crops (and cropland) to energy production in order to avoid food crises.

### Policy for Food Security

As this conference revealed, there is real concern about the impact of biofuels on food security. The ability to mitigate food impacts will be crucial for the success of biofuels. As discussed earlier in this section, food and fuel technology can reduce food impacts by reducing the competition between food and fuel for land. Agricultural biotechnology permits more food to be grown on the existing agricultural land base. Productivity gains like those seen over the past half century could free significant farmland for energy crop production and still feed a world growing to 9 billion people (Zilberman). Fuel technology that develops cellulosic ethanol can make use of waste products, which don't require land, and yield energy crops that can produce more fuel per acre and can be grown on lands not suited for food crops. Biofuel policies should be flexible and adjust to food market conditions. Some other policies for addressing food security are considered below.

**Upper-bound on Biofuel Production or Biofuel Land:** Governments may find it necessary to restrict the production of biofuel or the land devoted to biofuel production in order to prevent the crowding out of food crops (Babcock).

**Tie Mandates and Subsidies to Food Inventories:** To avoid food crises, it may be necessary to tie subsidies and mandates to food inventories. As inventories decline, so to may biofuel policy need to decline (Zilberman). This would create a less certain market for biofuels and could slow innovation. It would, however, help prevent starvation and death.

**A Global Food Fund:** Biofuel policy must recognize that it will impose pressure on the food system and that this pressure will be felt most acutely by the poor (Zilberman, Msangi and Wiebe). Therefore, biofuel policy should perhaps be coupled with a policy to provide for vulnerable populations during periods of high food prices. A global food fund, for instance, could help secure food for the poor in times of crisis (Zilberman). It could be funded by revenues from a carbon tax or by a tax on gasoline producers.

### Other Considerations

**"Clean Deforestation":** If the habitat converted to production because of biofuels is deforested in a conscientious manner, the carbon emissions from deforestation can be greatly reduced or eliminated, though the foregone future carbon sequestration cannot. Searchinger assumes the biomass on converted land is either burned to make way for crops or allowed to decay. Either way, the carbon that had been stored in the biomass is released back into the atmosphere. If instead this biomass is used to produce cellulosic ethanol or otherwise used for energy, then it can displace other fuels and earn a carbon credit for the displaced fuel.Alternatively, technologies exist to burry carbon dioxide in the ground to produce “clean coal.” Surely biomass can also be buried to prevent the release of the stored carbon back into the atmosphere. These “clean deforestation” measures would greatly reduce the payback period of biofuels relative to that predicted by Searchinger.

**No Policy for Biofuels:** On a cost per carbon emissions reduction basis, Searchinger suspects biofuels are dominated by other clean technology, specifically plug-in hybrid car technology. He urges no biofuel policy unless the policy penalizes land use conversion. Zilberman argues, however, that policy makers must consider the opportunity costs of ignoring biofuels. Demand for transportation fuel will continue to grow. If additional supply is not generated from biofuels, then where will it come from? It could well come from sources of energy that are dirtier than biofuels and conventional fossil fuels, such as tarsands and coal to liquids.

**Bilateral Agreements with Biofuel Exporting Countries:** It would be inefficient to ban imports from countries that enjoy a comparative advantage in the production of biofuels, such as Brazil. However, importing countries may wish to impose standards on imported biofuels in order to ensure policy achieves goals for greenhouse gas emissions reductions and environmental protection. Imposing such standards is consistent with international trade agreements so long as they do not discriminate against any one country. Importing countries could also establish explicit agreements with exporting countries to achieve policy objectives. The UK could, for instance, agree to import Brazilian biofuel on condition that Brazil limits the expansion of biofuel and safeguards environmentally sensitive lands (de Gorter and Searchinger). Searchinger proposes the UK demand investment in rainforest protection by the Brazilian government as a condition for biofuel trade.

**Improve Knowledge of Lands with Low Conversion Cost:** As Khanna and Long point out, there is considerable land in the US Midwest that was once farmed and has been abandoned amid productivity gains. This land is minimally sensitive from an environmental standpoint and could be brought back into production with little cost in terms of biodiversity or emissions (because little biomass would be lost). A global accounting of such lands would be valuable in order to better assess the extent to which biofuels can be expanded without imposing upfront emission costs (from land conversion) and the loss of valuable environmental resources.

**Use Wastes and Residues:** Though the benefits of using waste and residue for biofuel have been detailed elsewhere in this report, there was such consensus that this is a good policy that we wish to call attention to it again. There was unanimity that the negative impacts on emissions, the environment and food production from conversion of wastes and residues to biofuel are nominal. Such technology could make use of the husk, stalk, root, and leaf residues from agricultural production. With forest management, dying biomass could be harvested for biofuel production as well.

## Conclusions

The Sustainable Biofuels and Human Security conference at the University of Illinois was convened in light of analyses suggesting biofuels emit more carbon than traditional fossil fuels. Discussion centered on the degree to which these analyses offered credible representations of the life-cycle carbon emissions of biofuels. No one took issue with the logic of the analysis in Searchinger et al. But several participants did lack confidence in the modeling that underpins the analysis:

- Babcock and Hertel suggested a need for more reliable data to power the model, including data on greenhouse gas emissions and sequestration associated with traditional agriculture, energy crop production, and natural habitat. There is only one study of these effects to date (Long).
- The carbon emissions from indirect land use changes are sensitive to which lands are assumed to be converted. Searchinger suspects biofuels will shift production to export destination markets, whereas Hertel expects production to shift to export competitor countries.
- Zilberman argued that the linear projections driving the programmable models do not reflect reality; innovation offers the real possibility of non-linear trends.
- In addition, de Gorter took issue with a focus on indirect land use changes when there are other indirect effects associated with biofuels and when other agricultural production is not held to account for land use change.
- Also, Searchinger assumes greenhouse gas emissions associated from deforestation would not occur absent biofuels. This is a strong assumption. The land could be converted for other purposes and destroyed by natural causes.

Policy should balance demand for a green energy source today with efforts to improve biofuels in the future and the need to address food security concerns. Policy must address ways of improving the greenhouse gas benefit of biofuels, reducing impacts on food markets, and developing a biofuel industry. Policy is complicated by heterogeneity in biofuel costs and benefits. Biofuel impacts vary by feedstock, by farming practices, by location, and by refining plant. Development of policy should recognize that not all biofuels are created equal. Policy should recognize that an input is an input and a crop is a crop, otherwise leakage will render the policy ineffective. Life cycle analysis may be used as a metric with which to judge the carbon impacts of biofuels and should be a factor in determining the size of support each biofuel receives. Welfare analysis may present a more comprehensive methodology for considering the wide ranging impacts of biofuels and for weighing opportunity costs.

The conference also revealed that while greenhouse gas benefits (or costs) may limit the appeal of biofuel, the bigger concern is food security implications. Therefore, unless food productivity continues to increase, biofuels may present a real challenge. The second generation of biofuels is appealing because it enables the use of waste, non-food crops, less land per unit of ethanol, and lands not suitable for food crop production. In many respects, the success of biofuel is tied to the success of biotechnology. If the world turns its back on biofuels based on the impacts of transition technologies, then we must wonder what other fuels will be introduced to meet the growing demand for transportation. These alternatives may well be dirtier than traditional fossil fuels and biofuels.

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# APPENDIX A: Conference Participants

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