Risk, Infrastructure and Industry Evolution

Proceedings of a conference June 24-25, 2008, in Berkeley, California

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Energy Biosciences Institute

Biofuel: Distributional and Other Implications of Current and the Next Generation Technologies

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Introduction

The emergence of bioenergy offers the prospect of significant climate change mitigation, as well as greater energy independence for many countries. It presents the possibility of substitution between two essential but very different commodities, energy and food. This apparent trade-off, coupled with concerns about environmental protection, has created important controversies in the biofuel policy dialogue. Enthusiasm for biofuel may have reached a pinnacle two years ago when President George W. Bush suggested ethanol could break the U.S.'s addiction to oil and imposed a renewable fuel standard in the Energy Policy Act of 2005. Federal requirements for biofuel production are not just a response to evidence of human-caused global climate change, but also to rising oil prices and to national security concerns that increasingly call for domestic energy production and less reliance on imports from the volatile Middle East.

Though these forces continue to build pressure for oil alternatives, support for biofuel has waned and even become the subject of protest amid growing recognition that biofuel production can adversely affect food supplies and environmental systems (see, for example, Etter, 2007; Sexton *et al.*, 2007). It has also become clear that the current generation of biofuel will not come close to breaking U.S.'s addiction to oil (Rajagopal *et al.*, 2007). Nevertheless, and in spite of doubt about the usefulness of biofuel, it is evident the current technologies have provided short-term benefits in terms of increased gasoline supply and higher farm incomes. The second generation of biofuel promises to score better on the environmental front and to be a more viable substitute to oil (Farrell *et al.*, 2006).

The future of biofuel is being explored in laboratories across the country. In what constitutes the most significant manifestation of the education-industrial complex since biotechnology a decade ago, oil companies are funding alternative energy projects at major research universities (Sexton *et al.*, 2007). Agreements between University of California-Davis and Chevron and University of California-Berkeley and BP, for instance, can make the University of California a leader at the frontier of biofuel research. While it is not yet known whether biofuel will prove to be a viable alternative to oil or remain merely a fuel extender, it is already reshaping agriculture and creating a nexus among policies for agriculture, energy and the environment.

Forces of Change

Global warming weighs more heavily on the public conscience than it did even a few years ago. The American people increasingly view climate change as a threat they can help mitigate. For instance, a 2007 Yale University – Gallup survey found 48 percent of Americans believe global warming is now, or will soon have, dangerous impacts on people—a 20 percentage point increase from 2004. Also, 82 percent of Americans believe they can personally help mitigate global warming (Leiserowitz, 2007).

The evolution of public opinion has led Washington to pursue policies that address climate change and has prompted industry to compete on environmental friendliness and pursue strategies to reduce carbon emissions on their own. Major oil companies tout their use of renewable energy and their exploration of new technology. Car manufacturers compete for the cleanest fleets. Fortune 500 companies plant trees, bury carbon, capture methane, and invest in wind and solar energy to offset their carbon emissions. Consumers pay to offset emissions from their travel and buy cars with environmental virtue.

The growing demand by consumers for low-carbon products may also be a function of rising energy prices, which help make emission reducing behaviors not just virtuous, but also economical. In mid-November, consumers faced a seasonal record \$3.11 per gallon for gasoline, up \$0.86 from one year ago (USDOE-EIA, 2007). Fossil fuel prices are expected to continue climbing, driven by demographic trends and

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by increasing costs of oil extraction. The world population is expected to grow by roughly half in the next 50 years and per capita income is on the rise. A growing number of people, therefore, are demanding a growing number of consumption goods, leading to greater demand for energy.

Nowhere are these trends more acute than in China, where economic development has allowed its 1.3 billion people to begin dreaming of owning cars. In China, there are presently 14 cars for every 1,000 people, whereas in the United States, there are 800 cars for every 1,000 people (OPEC, 2007; UNECE, 2005). If Chinese per capita energy consumption reaches that of the United States, as it seems destined to, world energy demand will more than double. China went from being a small net exporter of oil in 1993 to the world's second largest importer in 2006, behind only the United States (USDOE-EIA, 2006). This demand-side pressure is combined with constraints on the supply-side, producing volatile and rapidly rising energy prices. The oil market is tight, with an average daily consumption of 83 million barrels, just below the world's installed productive capacity. Furthermore, oil extraction becomes more costly as firms must drill deeper and in more difficult terrain and turn to more costly and dirty extraction from oil sands.

Finally, energy security is closely linked to national security, and industrial countries, in particular, must take careful account of energy in their foreign policy. Those with high levels of import dependence often find the need for partnerships that challenge other domestic and international objectives. Oil revenues give exporting countries the liberty to adopt policies inimical to the interests of the United States and other importing countries. Importing countries may also try to secure oil supplies by adopting policies friendly to suppliers. This further reduces the ability of the United States and similarly dependent countries to affect foreign policy (Council of Foreign Relations, 2006).

These forces are changing the way the world thinks about energy and will be instrumental in forging a new energy paradigm where demand and supply of new, clean, renewable energy plays a much more prominent role. In this context, biofuel has emerged as a leading contender to replace fossil fuel, though the time until it supplants petroleum is measured in decades rather than years. Biofuel offers an important but partial solution to the pressures arising from climate change, burgeoning global energy demand, and national security. However, it is by no means the only rational response to these trends. A wide spectrum of energy conservation measures, alternative polluting technologies, and alternative clean technologies are also worthy of consideration in our energy future. For example, despite being unpalatable in some political circles, a carbon tax is recognized as the best way to address global climate change (e.g. Mankiw, 2007). This approach would internalize the cost of emissions to the polluters responsible for them. This eliminates an economic distortion derived from the fact that carbon is a non-marketed good (or bad in this case). Because non-point source pollution, such as carbon emissions, cannot be effectively observed by the regulator, taxes on inputs (such as gasoline and electricity), can be adopted instead. Internalizing the cost of carbon emissions to the polluters is unpopular, however, with 70 percent of Americans opposed to higher taxes on energy inputs (Leisurowitz, 2007).

Upward pressure on oil prices can be alleviated and demand for domestic production fulfilled (at least in part) by removal of regulatory barriers that preclude full utilization of domestic oil reserves. In the United States, it is estimated 100 billion barrels of crude oil—about 15 years of annual domestic oil consumption — lie in untapped reserves under federal land and coastal water (Ostroff, 2008). Oil supplies can also be augmented by new technologies that convert coal to liquid fuel and make use of oil sands in Canada. These technologies are costly and are much more polluting than traditional oil production.

In the race to replace fossil fuel, biofuel has received considerable attention in the popular press and among policymakers. It is not, however, the only energy answer to climate change. The electric car, for instance, equipped with a battery and needing no liquid fuel, only requires a charge every 100 miles, is another technology alternative. Emitting only water in combustion, hydrogen is another seemingly attractive alternative fuel. The cost of engineering fuel cell vehicles powered by hydrogen is significant however. In addition, production of hydrogen can be polluting and its distribution will require new infrastructure.

Why Biofuel

Where electric and hydrogen technologies have stalled in recent years, biofuels have surged, the beneficiary of more than $6 billion in subsidies in the United States (Koplow, 2006). Not only can biofuel reduce carbon emissions, but it can be produced around the world, derived from crops like corn, soybeans, and sugar cane. It is also renewable.

Biofuel also has the advantage of requiring only minimal changes to end-use technologies (Rajagopal *et al.*, 2007). Biofuel can be distributed through existing retail gasoline networks and requires very minor adjustments to engine technology. Transportation of ethanol from the point of production in the Midwest to market is costly. It must be moved by train or truck rather than through a network of subterranean pipes that move gasoline throughout the United States. Ethanol is water soluble and would corrode existing pipes (Reynolds, 2000).

Finally, whereas carbon taxes and oil drilling are unlikely policy responses for political economy reasons, biofuel promotion has been popular among key constituencies, including environmentalists and farmers. Not only could biofuel subsidies ease tensions of the new energy paradigm, they could also boost farm income and spur rural development. A $0.51 per gallon ethanol production tax credit, and a requirement to produce 7.5 billion gallons of biofuel per year by 2012, contributed to record-high farm profits in 2007 and to reductions in traditional support payments (USDA-ERS, 2008).

The recent United States and global experience with biofuel, and the accumulated research by economists, biologists and agronomists, have called into question much of the conventional wisdom of biofuel and raised doubts about the technology's role in our energy future. A frank assessment of costs and benefits is warranted.

The Good

First, biofuel represents a partial solution to climate change, but certainly not a panacea, at least not yet. Early assessments that biofuel was carbon neutral failed to account for the considerable energy used to convert energy crops to liquid fuels, as well as the foregone carbon sequestration on lands converted from nature or food production. Life cycle analyses have attempted to determine not just the greenhouse gas savings of biofuel, but also its net energy content. Such analysis depends critically on defining system boundaries and varies by production method. Corn ethanol, the predominant biofuel produced in the United States, is considered the least efficient technology and achieves, at best, modestly positive net energy content and greenhouse gas savings. The best estimate of emission savings relative to gasoline is 13 percent, though estimates range from a 32 percent savings to a 20 percent increase (Farrell *et al.*, 2006). While marginal improvements in these results can be achieved through adoption of existing technologies, significant greenhouse gas savings are not expected until the second generation of biofuel is introduced. Ethanol from sugarcane and biodiesel from soybeans and palm oil are more efficient.

Second, biofuel crops can be grown in many regions of the world and, though it is unlikely to displace any considerable share of oil in the near term, it does lessen demand for oil imports and improve energy security for oil importing countries (OECD/IEA, 2007). Figure 1 shows the capacity for different regions of the world to capitalize on renewable technologies. Importantly, developing countries have high biomass capacity, which suggests biofuel may aid rural development.

Table 1 presents estimates of potential oil displacement by biofuel production from seven principal grain and food crops. The seven crops account for 42 percent of all cropland. If the entire harvest of these seven crops were diverted to energy production, more than half of global oil demand could be met by biofuel. Dedication of such substantial land resources is unlikely. A more realistic diversion of 25 percent of these crops to energy uses would offset 14 percent of gasoline use (Rajagopal *et al.*, 2007). Similar analysis suggests the United States, Canada and EU-15 can displace 10 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 10 percent of its demand with sugarcane ethanol. As energy

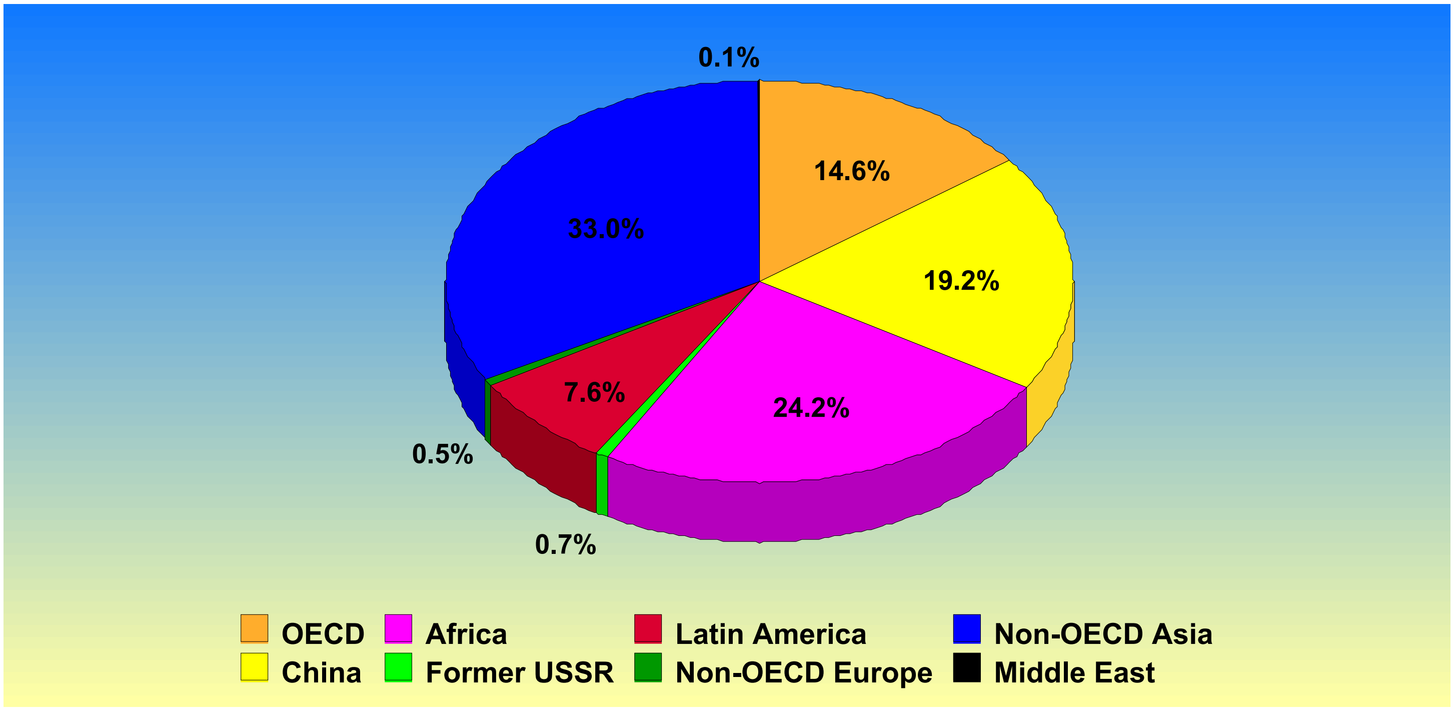

Figure 1. Distribution of Combustible Renewables and Waste (Source: IEA Energy Statistics)

Table 1. Potential Oil Displacement by Biofuel

Crop	Global Acreage	Global Average Yield	Global Production	Conversion Efficiency	Land Intensity	Maximum Ethanol	Gasoline Equivalent	Supply as % of 2003 Global Gasoline Use
	(million acres)	(tonnes/ acre)	(million tonnes)	(gal/tonne)	(gal/acre)	(billion gallons)	(billion gallons)	%
Wheat	531	1.1	602	90	41	54	36	12
Rice	371	1.7	630	114	78	72	48	16
Corn	358	2.0	711	106	85	75	50	17
Sorghum	111	0.5	59	100	21	6	4	1
Sugarcane	49	26.3	1,300	18	197	24	16	6
Cassava	47	4.7	219	48	90	10	7	2
Sugarbeet	13	18.6	248	29	219	7	5	2
Total	1,480					248	166	56

Source: Rajagopal *et al*., 2007

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.

Third, whereas the environmental and energetic contributions of current biofuel technology have been questioned (see, for instance, Searchinger *et al*., 2008 and Farrell, 2006), its role as a short-term buffer to rising gasoline prices is not in dispute, just largely ignored. The effect of biofuels on energy prices has been neglected in the literature. Following a model we developed (Rajagopal *et al*., 2007), we estimate the net welfare effect of ethanol in the short-run by comparing the current scenario to one in which there is no ethanol or biodiesel. We simulate the latter using information only on prices, quantities and elasticities of supply and demand of three major commodities that are affected by ethanol, namely, gasoline, corn, and corn's closest substitute, soybeans. This modeling approach has been used to simulate the short-run welfare effects of environmental policy (see, for instance, Lichtenberg, Parker, and Zilberman's 1988 study of pesticide regulation). We also disaggregate the effects between the United States and the rest of the world (ROW). We assume identical elasticities across the two markets, so the distribution of net benefits and costs between the two groups is directly proportional to the quantity consumed.

Absent ethanol supply, gasoline prices in 2006 would have been higher than those observed. By augmenting petroleum supply, ethanol production reduced prices for fossil fuels, benefiting its consumers. Biofuel production, however, raises the price of food commodities by reducing the supply of crops for food processing. Given elasticities of demand, we can estimate the welfare effects of ethanol production. The results are sensitive to the magnitudes of elasticities, so we simulate the distribution of benefits among consumers of gasoline, corn and soybeans under various elasticities. These simulation results are presented in Figures 2 and 3, which show the sensitivity of total net benefits to changes in elasticities of supply and demand for corn and soybeans for two sets of gasoline supply and demand elasticities, namely, (0.25, -0.25) and (0.75 and - 0.75). In Figures 4 through 7, we present results for three scenarios, which we identify as high, mid and low. The scenarios are described next.

Three Scenarios

The high scenario is an optimistic one involving high inelasticity of supply and demand for gasoline and high elasticity of supply and demand for corn and soybeans. Ethanol has the highest positive impact on gasoline prices and least negative impact on corn and soybean prices under this scenario. The low scenario is a pessimistic scenario involving low inelasticity (equivalently, high elasticity) of gasoline supply and demand and high inelasticity in food commodities. Ethanol has the least positive impact on gasoline prices and the highest negative impact on corn and soybean prices. The mid scenario assumes moderately elastic supplies and demands. The parameters of these three scenarios are summarized in Table 2 below.

In the intermediate scenario we find that gasoline consumers world-wide gained about $23.1 billion, while the total cost to consumers and to U.S. tax payers (in the form of subsidy payments) was $12.2 billion. Thus, under plausible conditions and partial equilibrium analysis, ethanol production is associated with a net benefit to consumers worldwide. Overall the ROW consumers gained $9. 5 billion, while U.S. con-

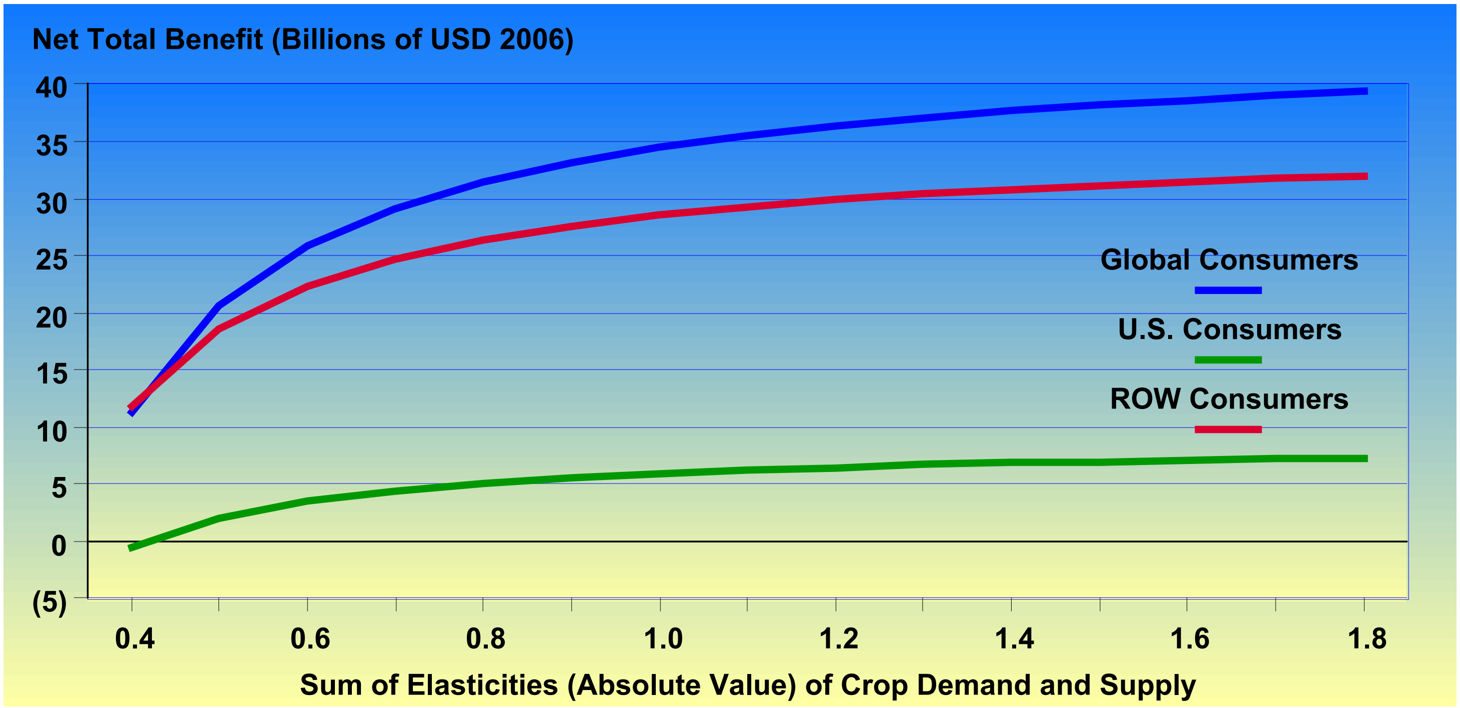

Figure 2. Total Net Benefit to Consumers (Corn, Soy and Gasoline Combined) as a Function of Sum of the Elasticities of Crop Supply and Demand for a Given Gasoline Elasticity of Supply (0.25) and Elasticity of Demand (-0.25)

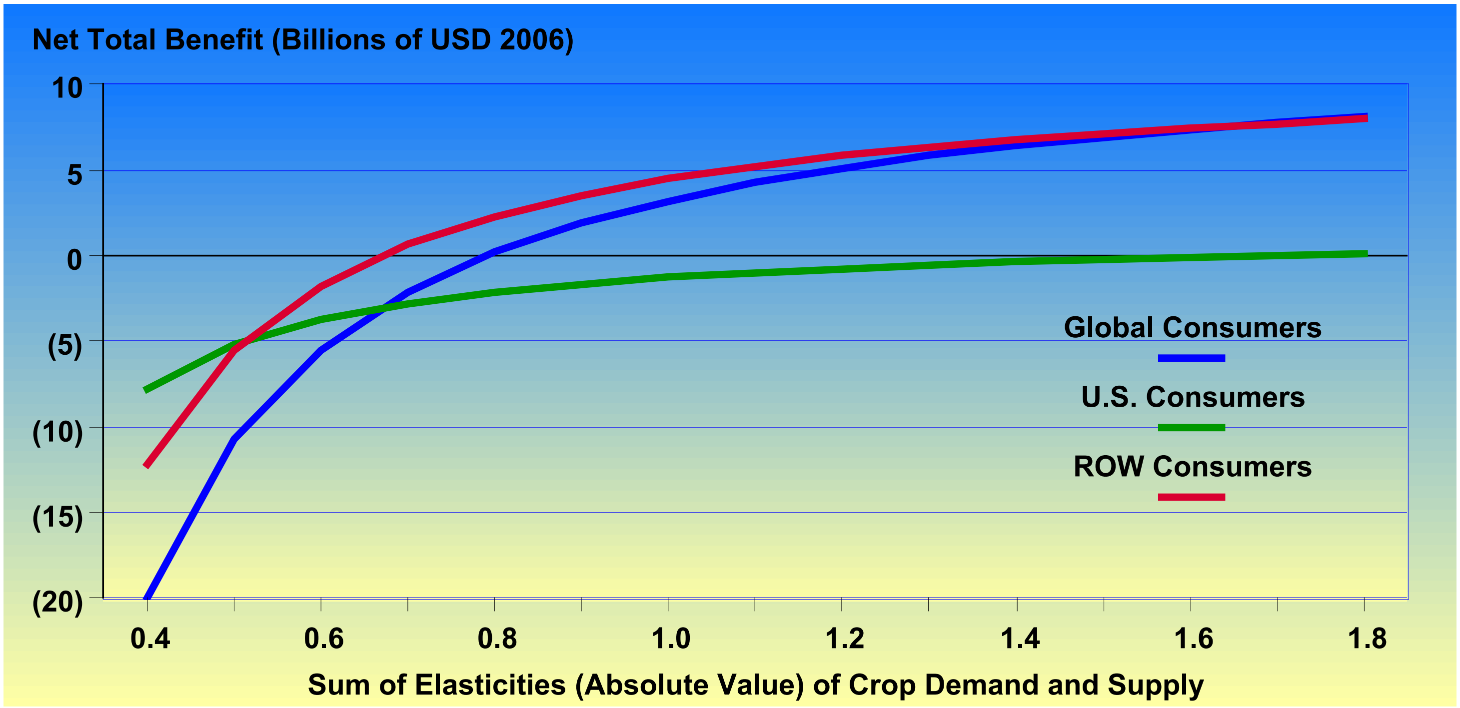

Figure 3. Total Net Benefit to Consumers (Corn, Soy and Gasoline Combined) as a Function of Sum of the Elasticities of Crop Suply and Demand for a Given Gasoline Elasticity of Supply (0.75) and Elasticity of Demand (-0.75)

Table 2. Elasticity Assumptions of Three Scenarios

	Elasticities			
Scenarios	Gasoline Demand	Gasoline Supply	Corn & Soy Demand	Corn & Soy Supply
High	-0.25	0.25	-0.75	0.75
Mid	-0.50	0.50	-0.50	0.50
Low	-0.75	0.75	-0.30	0.30

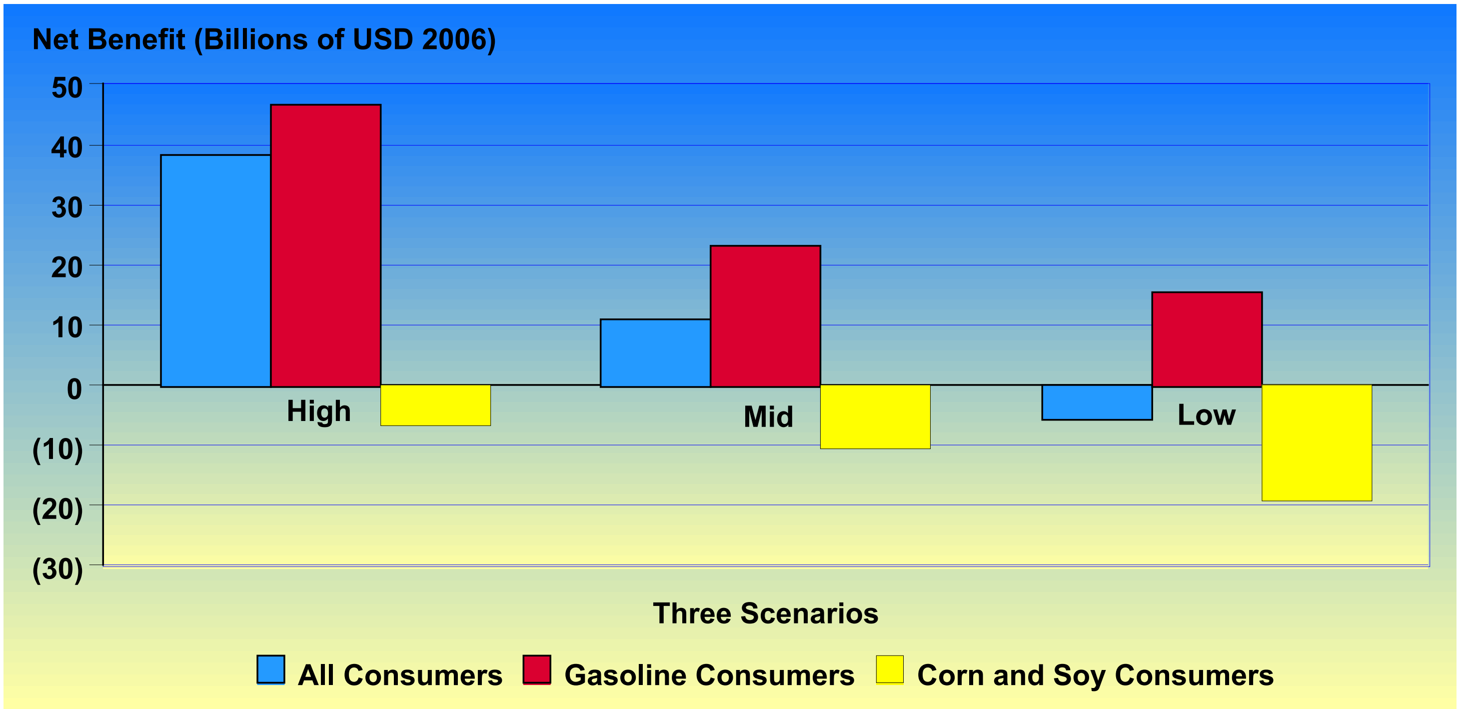

Figure 4. Net Benefits to Gasoline and Food Consumers from Ethanol Supply in 2006

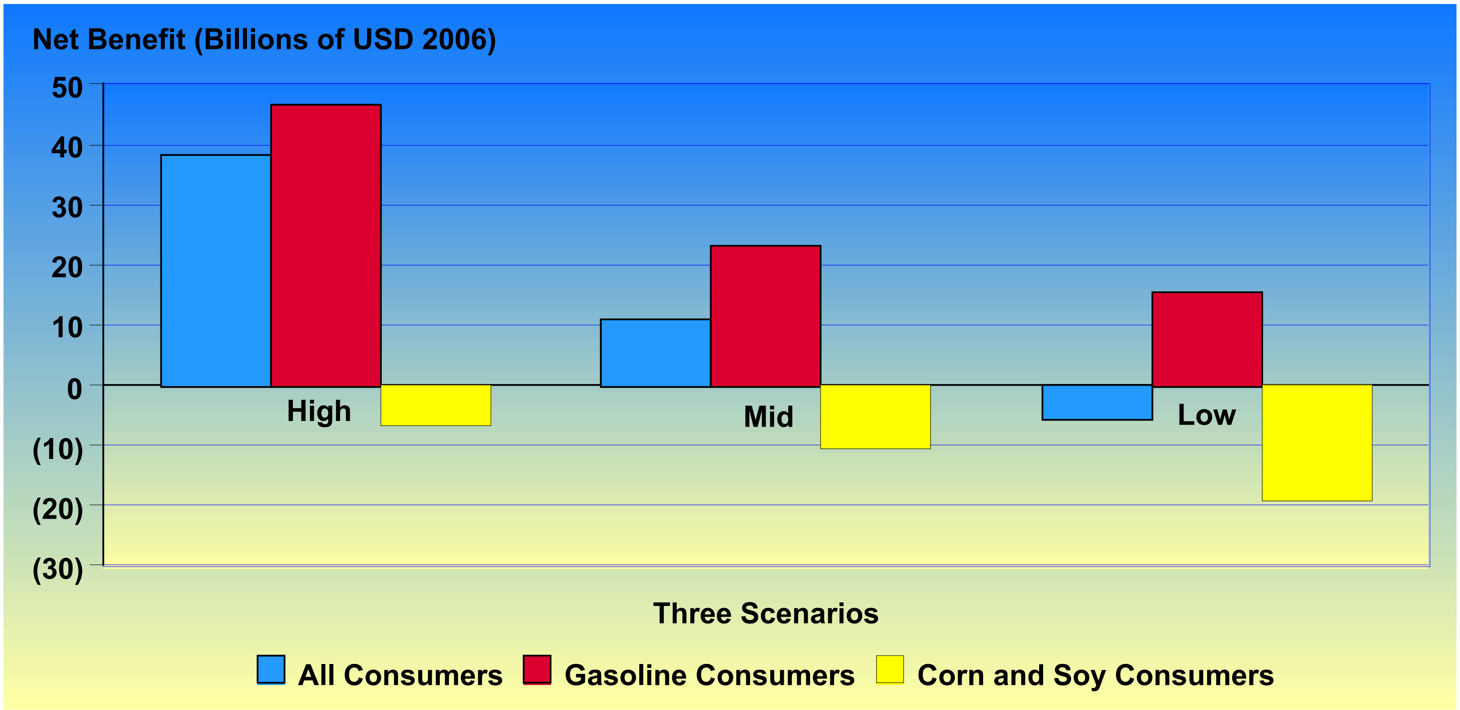

Figure 5. Net Benefits to Consumers in the United States from Ethanol Supply in 2006

sumers gained $0.5 billion (net of taxes). In the United States we find that gasoline consumers gained about $5.4 billion, while total cost to corn and soybean consumers was $2.9 billion and the cost to tax payers of the U.S. Volumetric Excise Tax Credit was $2 billion. Higher food prices also benefited U.S. producers of corn and soybeans by $3.6 billion (ROW producers gained by $9.5 billion).

While it has been claimed that ethanol reduced federal outlays for corn subsidies, our simulations reveal that corn prices would have likely remained above specified loan rates for 2006 without ethanol-induced price increases. Observed corn prices in 2006 reflect increased demand due to economic growth in large developing countries. The cost of ethanol subsidies, therefore, are not likely to have been offset by reduced subsidies to corn.

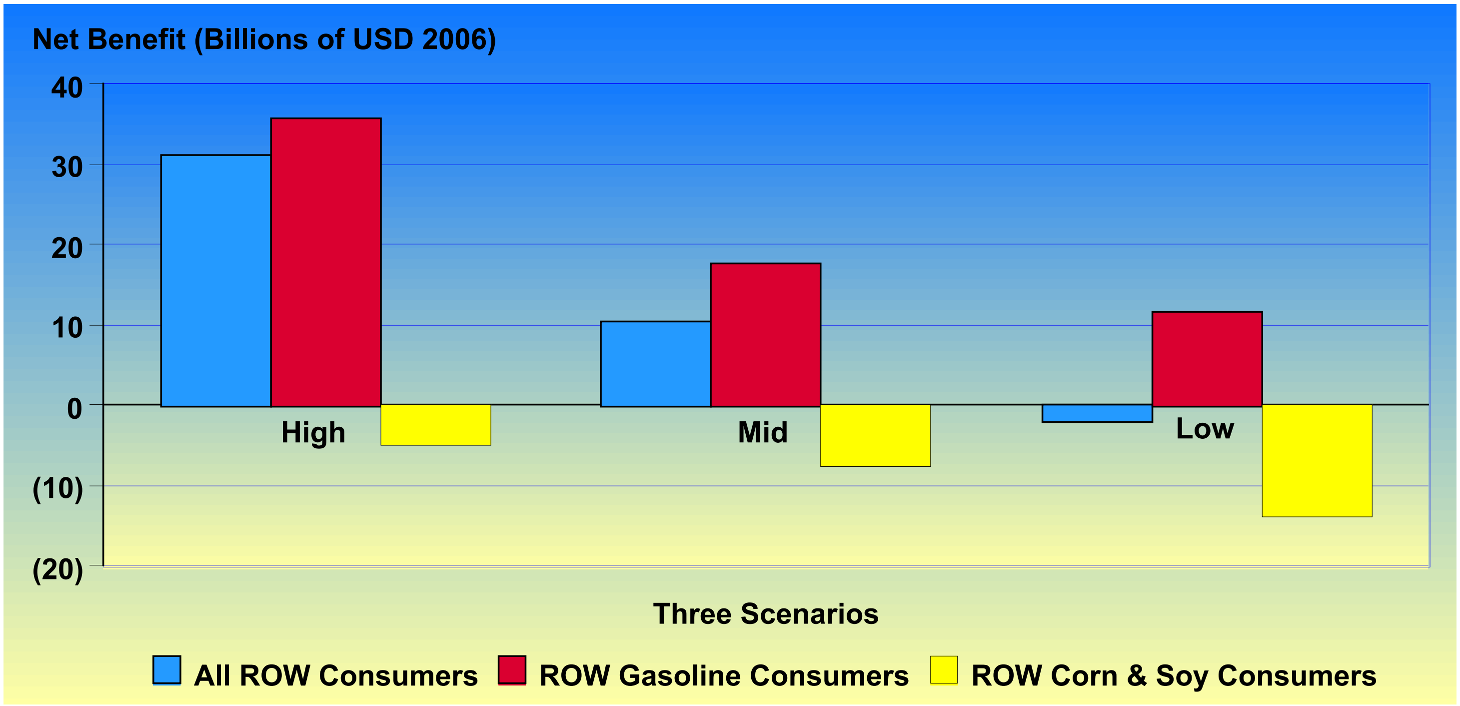

Figure 6. Net Benefits to ROW Consumers from Ethanol Supply in 2006

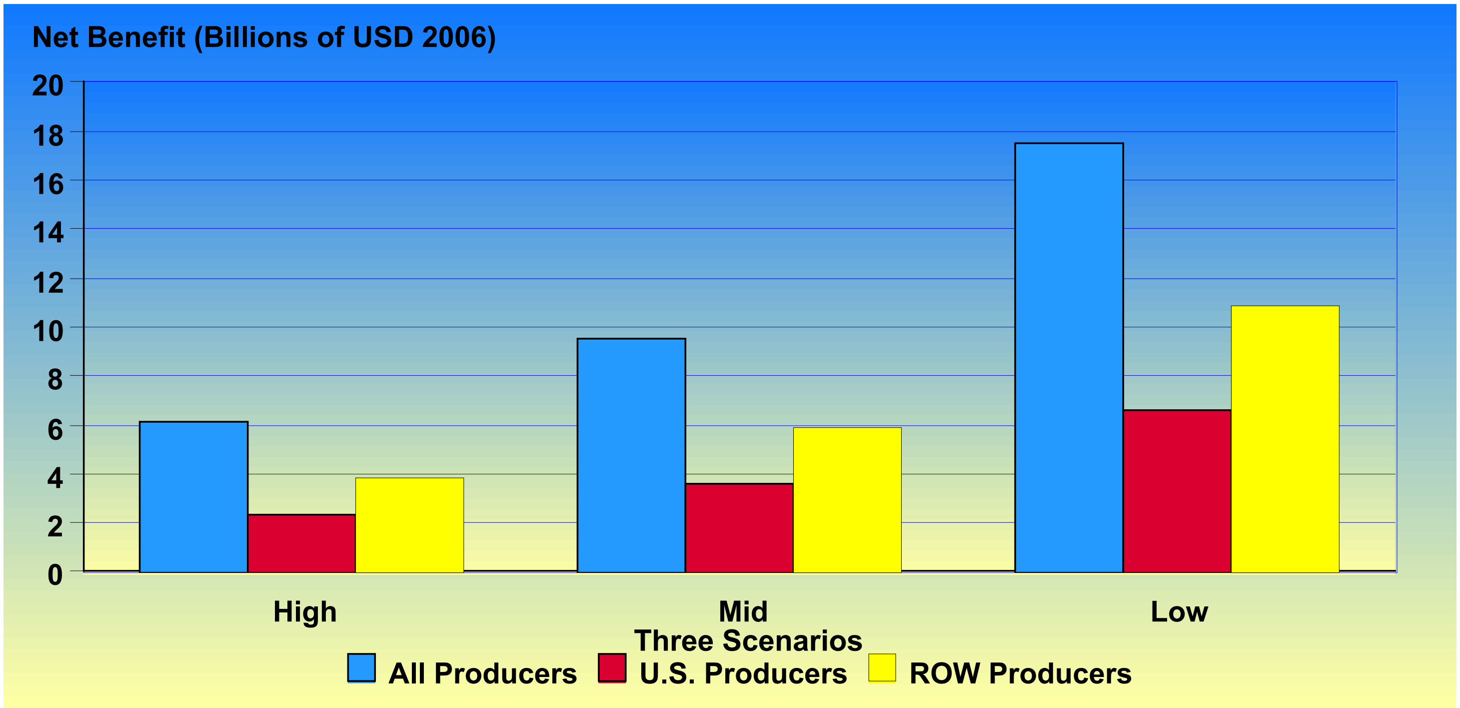

Figure 7. Net Benefits to Corn and Soy Producers from Ethanol Supply in 2006

This analysis ignores the loss to oil producers worldwide. Rhetoric among political leaders suggests these losses may not be of great concern from a policy standpoint. It should also be emphasized that this is a partial analysis. It does not consider the impact on sugar markets. It ignores market distortions, other than the production subsidy, and does not consider the effect of scarcity-induced price increases in other displaced commodities, such as wheat. We have not estimated the consumer benefit resulting from changes in emissions of carbon and other pollutants due to ethanol or the welfare effects of tariffs on ethanol imports.

The Bad

Large scale production of biofuel will impose significant stress on agriculture, which is already under pressure to reverse the trend of diminishing per capita food production even as population growth continues and productivity increases from standard inputs, like chemical pesticides, decline. The FAO reports there are 852 million undernourished people around the world and that food production per capita is decreasing (FAO, 2004). The demand for agriculture to provide an alternative source of energy adds to this pressure. Current biofuel technology is land intensive, so as production increases, land will be recruited from its two other principal uses—food production and environmental preservation. These results are already evident in the United States and around the world as food crops are replaced with sugarcane, corn, soybeans and palm (Dong, 2007; Westcott, 2007; OECD/FAO, 2007). United States farmers responded to demand for energy crops by planting the largest corn crop since 1944 (USDA, 2007). Corn prices headed close to \$4, reaching \$3.80 in the United States in November. Globally, corn prices have doubled since the start of 2007 and reached a 10-year high. Wheat prices reached a 10-year high and soybeans touched a two-and-a-half-year high. As a result, prices are rising for food commodities from soda and milk to beef and chicken. Livestock producers, facing high prices for corn feed, have resorted to feeding cereal scraps, trail mix, and chocolate to pigs.

In the United States, where corn is a relatively small share of the diet, the food price effect of biofuel is small. But in developing countries, in which corn is a larger part of the diet, the effect is significant. In Mexico, for instance, tortilla prices have doubled (The Economist, 2007). In China, the government has halted construction of corn-ethanol refineries in response to rising food prices (Wall Street Journal, 2007).

The demand for land imposed by biofuel production will similarly take land out of environmental preservation (Westcott, 2007; Searchinger *et al*., 2008). This will lead to deforestation and biodiversity loss. Increased biofuel production means an expanding agricultural land base, greater use of polluting inputs like pesticides and fertilizers, greater demand for water, which will mean less water for de facto in-stream uses, and greater potential for soil erosion. Economists have estimated anywhere between 1 and 16 million acres of Conservation Reserve Program land may be brought into production. Water battles are already being waged in the Mid-Western United States among different user groups along shared and depleting water resources.

Even absent biofuel, agricultural production is considered to be the biggest source of non-climatic global change (Tilman *et al*., 2001). Biodiversity loss is presently considered to be more costly than climate change (Mooney and Hobbs, 2000). Environmental services like waste assimilation, water purification, draught prevention, fire suppression, carbon sequestration, genetic diversity, and future medical breakthroughs are threatened by the loss of native lands.

Agricultural biotechnology can reduce the tension among energy, food, and the environment. We must distinguish, however, between agricultural biotechnology that improves food production and that which improves energy crop production, recognizing some technology may do both. Improvements in energy crop production may worsen the pressure biofuel exerts on food production and environmental preservation by encouraging increased bioenergy production. Improvements in food crop technology, on the other hand, are seen to unambiguously reduce the pressure on food and the environment by permitting higher yields per acre.

The Ugly

As the foregoing discussion illustrates, agriculture faces a significant challenge. Food is not in abundance today and it is expected to be even more scarce in the future as biofuel production increases. Global corn and wheat stockpiles have fallen to 25-year lows (Morrison, 2006). The stockpile system creates a stealth effect for prices, and we have yet to see the full price implications of these depletions, including increased volatility. Existing agricultural capacity can compensate for cyclical stock depletion, but rising to meet a sustained demand shift is another matter. Historically, this kind of scarcity can only be overcome by recruiting more resources to agriculture, usually in response to higher prices.

Given dramatic initial differences in per capita income, a multinational food auction would doubtless be won by higher-income bidders, with dire consequences for food security in low-income countries. History has definitive lessons for leaders whose populations enter food crises. Political consensus evaporates, leaving an ultimatum between regime change and martial law (Bradsher, 2008; Vidal, 2007; and Wong, 1982).

Low income families spend a greater share of their budgets on food relative to the rich, so higher food prices will particularly hurt the poor. Where as food is a necessity, gasoline is, in many parts of the world, a luxury consumed in greater quantities by the rich. Therefore, biofuel may pose an ugly tradeoff – the poor go hungry so the wealthy can more cheaply fuel their automobiles.

The Future

While the current generation of biofuel, made mostly from sugars and starch, may be ill-equipped to replace considerable oil consumption and make significant reductions in carbon emissions, and while it may pose an ugly tradeoff between food and fuel, the next generation of biofuels are developed and designed to do much better. The future of biofuel will convert cellulosic material to ethanol by hydrolysis and fermentation. These new conversion technologies, already at work in pilot projects, will make grasses, shrubs and trees potential biofuel feedstocks (Khanna, 2007). They will also permit the use of food crop residues, such as stalks and husks, in biofuel production. Table 3 reports potential ethanol yield from two potential cellulosic energy crops—miscanthus and switchgrass—and crop residues.

These feedstocks—and cellulosic crops generally—yield more ethanol per unit of land than ethanol from sugar or starch, and free traditional crops like corn and wheat for food uses. In addition, these crops can be grown on marginal land and are less factor-intensive than first generation feedstocks. This means the second generation of biofuel will be more environmentally friendly in terms of reducing chemical applications and erosion. However, they open up the possibility of bringing marginal land into production, which can lead to deforestation. Table 3 depicts a scenario in which 14 percent of world cropland is devoted to growing miscanthus and switchgrass to produce ethanol equal to 64 percent of world gasoline consumption. Adding crop residue to biofuel production can offset 91 percent of gasoline use (Rajagopal *et al*, 2007).

Given the constraint of land, the diversion of 200 million hectares to energy production may seem improbable and likely to hurt food production and the environment. An analysis by Waggoner (1995), however, suggests agriculture could provide a daily diet of 3,000 calories to 10 billion people using 200 million fewer hectares of cropland by 2050. But this projection requires the continuation of agricultural productivity gains observed in the past half-century, during which per capita food production increased despite a doubling of the world population. In the past, chemical pesticides and fertilizers and innovations in irrigation permitted increasing yields. Today, many pesticides suffer from resistance build-up and additional gains from mechanization and irrigation seem unlikely.

Agricultural biotechnology is demonstrated to greatly improve yield and reduce pesticide use on staple crops such as corn, soybeans, and cotton (Qaim and Zilberman, 2003; Huang *et al*., 2002; Qaim and de Janvry, 2005; Traxler *et al*., 2001; Thirtle *et al*., 2003). The current generation of agricultural biotechnology includes crops genetically modified (GM) to induce either pest resistance or herbicide resistance. The productivity gains provided by this technology lessen the impact of land lost to energy production. Regrettably, the spread of existing GM crops and the development of new transgenic traits have been hampered by regulatory barriers in Europe and elsewhere. Genetically modified crops have been banned by some countries that pursue a precautionary approach out of concern about uncertain long-term effects.

With biofuels and related technologies, the adoption process is complex and requires coordination at four different levels of the economy: farmer, processor, retailer, and consumer. Policies are needed to coordinate the adoption decisions and mitigate risk. Policy may induce demand among consumers, regulate energy companies, incent production among processors, and offer price assurances to farmers.

Adoption of biofuel will transform agriculture. The opportunities for risk-reducing and cost-saving integration can be expected to consolidate agriculture and give rise to more and bigger agribusiness. As food and energy production and environmental preservation become linked by biofuel, agricultural, energy, and environmental policy will need to be integrated. An expanded research agenda in natural resources and agriculture is needed to address the new energy challenge.

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Table 3. Oil Displacement Potential of Second Generation Biofuel

Crop	Global Acreage	Global Average Yield	Global Production	Conversion Efficiency	Land Intensity	Maximum Ethanol	Gasoline Equivalent	Supply as % of 2003 Global Gasoline Use
	(million acres)	(tonnes/ acre)	(million tonnes)	(gal/tonne)	(gal/acre)	(billion gallons)	(billion gallons)	%
Switchgrass	247	4.0	1,000	87	353	87	58	20
Miscanthus	247	8.9	2,200	87	777	192	129	44
Crop Residues			1,500	77		117	78	27
Total						396	265	91

Source: Rajagopal *et al*., 2007

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