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# **Implied Objectives of U.S. Biofuel Subsidies**

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## **Abstract**

Biofuel subsidies in the United States have been justified on the following grounds: energy independence, a reduction in greenhouse gas emissions, improvements in rural development related to biofuel plants, and farm income support. The 2007 energy act emphasizes the first two objectives. In this study, we quantify the costs and benefits that different biofuels provide. We consider the first two objectives separately and show that each can be achieved with a lower social cost than that of the current policy. Then, we show that there is no evidence to disprove that the primary objective of biofuel policy is to support farm income. Current policy favors corn production and the construction of corn-based ethanol plants. We find that favoring corn happens to be the best way to remove land from food and feed production, thus providing higher commodity prices and income to farmers and landowners. Next, we calculate two sets of alternative biofuel subsidies that are targeted to meeting income transfer objectives and either greenhouse gas emission reductions or fuel energy reductions. The first of these assumes that greenhouse gas emissions and high crop prices are joint objectives, and the second assumes that fuel independence and high crop prices are the joint objectives. Finally, we infer the social willingness to pay for biofuel services. This, in turn, allows us to propose a subsidy schedule that maintains (inferred) social preferences and provides a higher incentive for farmers to choose production of cellulosic materials. This is particularly relevant since the 2007 energy act sets a renewable fuels standard that relies heavily on cellulosic biofuel but does not specify a higher “per gallon” incentive to producers.

**Keywords:** biofuels, biofuel subsidies, energy security, feedstock, greenhouse gas emissions, social preferences, value-added agriculture.

## **Implied Objectives of U.S. Biofuel Subsidies**

U.S. biofuel subsidies have been justified on at least four grounds. Two of the justifications pertain to positive externalities associated with reducing the need for U.S. oil imports and reducing carbon emissions. (See for example the Energy Independence and Security Act of 2007.) The remaining two justifications are associated with rural development. The first of these is based on the economic activity associated with the construction and operation of biofuel facilities (Dorr, 2006), and the second is the stimulus that higher commodity prices provide to farm income (Tyner and Taheripour, 2007).

The purpose of this paper is to evaluate and compare the magnitude and sign of the four benefits that have been used to justify existing biofuel subsidies. We begin with the maintained hypothesis that existing subsidy levels are structured as they are as a result of a rational and informed policy-making process. By measuring the costs and benefits associated with the stated objectives, we can then infer the weights that policymakers likely placed on the four stated objectives. We then show that the existing subsidy structure is inconsistent with the first three justifications and explain how the structure would need to change to make it consistent with the first and second objectives, respectively. Then, we show subsidy schedules that support the first and fourth objective, and the second and fourth objective. Next, we infer the weights that policymakers may assign to some of the objectives to propose a schedule that also complies with social preferences. These results are particularly relevant because the 2007 energy act makes clear that policy changes are needed, and it provides specific direction for these changes. However, it does not actually change the existing market-based incentive structure in the way that is needed to achieve these new objectives.

We begin by quantifying the gains from different biofuel production systems in terms of energy displacement and greenhouse gas emissions. We are greatly assisted in this process by the availability of a systems engineering model called GREET that has helped resolve some of the controversy surrounding the life cycle assessment (LCA) of energy and carbon balances associated with these systems. Then, we supplement the quantity measures available from this system with our computed associated measures of economic relevance. This allows us to compare the costs of reducing negative externalities via biofuels with that of the least-cost alternative of achieving the same reduction. Next, we examine biofuels policy in terms of the two rural development objectives discussed earlier. We then calculate the relative subsidies that would be needed to meet some of the specific goals in the 2007 energy act.

### **U.S. Biofuel Subsidies**

The U.S. biofuels industry has benefited from financial support from the government in many forms. Arguably, the largest support is provided through the volumetric excise tax credit (usually known as the blenders credit) first introduced in 1978 through energy policy. The Energy Tax Act of 1978 represented a change in the direction of federal energy legislation. It was the first time that a government program shifted from promoting oil and gas to supporting production of fuel from renewable sources. This act provided a subsidy of \$0.40 per gallon of ethanol blended at a rate of at least 10% and used as a motor fuel. The subsidy rate for ethanol has been adjusted several times in the last thirty years; it was set to \$0.60 in the Tax Reform Act in 1984 and gradually decreased to its current rate of \$0.51 in 2005.

The blenders tax credit for biodiesel was initiated much later, through the American Jobs Creation Act of 2004. Since then, biodiesel blenders have been credited \$1 per gallon of biodiesel from oilseeds or animal fat and \$0.50 for biodiesel from recycled cooking oil.

A second stated objective for promoting biofuels is a reduction in the rate at which greenhouse gases (GHG) are emitted into the atmosphere. The legislation collectively referred to as the Clean Air Act Amendments of 1990 was the first environmental policy to have a significant effect on the supply of renewable energy. New oxygen requirement mandates of 2% were introduced to control for carbon emission. As a result, ethanol became widely used by gasoline producers. Recent diesel regulations for ultra-low-sulfur fuel were expected to increase biodiesel demand by blenders in the same fashion (Duffield and Collins, 2006). However, recent usage levels seem to indicate that biodiesel is not the preferred additive of fuel suppliers under current market conditions.

The overall use of renewable fuel was labeled the Renewable Fuel Standard (RFS) for the first time in the Energy Policy Act of 2005. The initial RFS specified minimum amounts of renewable fuel to be used each year, starting with 4 billion gallons in 2006 and raised in increments of 700 million gallons each year until 2012. This schedule was restructured in the Energy Independence and Security Act of 2007. The new schedule sets a renewable fuel volume of 9 billion gallons for 2008 and increases it annually to attain 36 billion gallons in 2022. Each annual target is mandated by minimum levels of biofuel by type to be used. Conventional biofuels are defined as those derived from cornstarch and expected to gain 20% life cycle GHG emission reductions. Advanced biofuels are mainly cellulosic biofuels, sugarcane-based ethanol, and biomass-based diesel. All advanced biofuels are

expected to achieve GHG emission reductions of at least 50%. The rate at which the volume of conventional biofuels is planned to increase annually diminishes until it reaches 15 billion gallons in 2015. Advanced biofuels are scheduled to grow at an increasing rate, to account for 58% of overall renewable fuels in 2022.

### **Biofuel Subsidies Motivated by Externalities**

The net energy and emission balances of biofuels, particularly corn-based ethanol, have been the focus of heated debate, with several studies finding seemingly opposite results. In a side-by-side comparison of representative analysis of corn-based ethanol, Farrell et al. (2006) found that scholars reporting negative energy balances tended to ignore co-products or used obsolete data. Similar results are reported by Hill et al. (2006), who analyzed both corn-based ethanol and soy-based biodiesel. While the comparisons provided by Farrell et al. indicate that corn-based ethanol requires far less petroleum to produce energy than does gasoline, ethanol's GHG emissions balance (as compared to that of gasoline) depends on the production process employed.

To capture the main differences across biofuels and production systems, we conducted a life cycle analysis of energy displacement (both petroleum and total fossil) and GHG emission reductions from an array of renewable sources using the GREET model.<sup>1</sup> In particular, our analysis includes several of the biofuel pathways introduced in recent work by Wang, Wu, and Huo (2007) (table 1). These pathways include averages capturing the existing corn ethanol industry as well as several different types of new plants. These new plants are categorized based on their use of natural gas or coal and whether they dry the feed by-product before sale. Ethanol fuels based on cellulosic

materials such as switchgrass and corn stover are included as well as biodiesel produced from soybean oil.

Table 2 presents the amount of fossil energy needed to produce and consume a million British thermal units<sup>2</sup> (mBtu) of energy, for both well-to-pump (WTP) and pump-to-wheel (PTW) stages. WTP refers to the energy used by the upstream production process all the way to the pump. The PTW stage captures the fuel combustion during vehicle operation. While the energy in the PTW phase is all of fossil origin for gasoline and diesel, none of the energy consumed in this stage is sourced from fossil energy when biofuels are used.

To read table 2, start with the row labeled gasoline. The WTP number 225,641 Btu/mBtu suggests that it takes about 225,641 Btu of fossil energy to remove 1 million Btu of energy (in the form of crude oil) from the ground, refine it, and transport it to the gas station. When this energy is then used to power the automobile, all 1,225,641 Btu of fossil energy are essentially used and eliminated. When we do the same analysis for an ethanol plant that dries its distiller's grains with natural gas, the fossil energy cost associated with production of inputs, agricultural activities, feedstock transportation, producing the ethanol, and transporting the energy to the pump is 728,205 Btu per mBtu. When this mBtu of energy is used by the automobile, no additional fossil energy is used. In this sense it can be argued that ethanol has a positive energy balance and that ethanol uses 40.6% less fossil energy than gasoline.

Clearly, the highest reductions in fossil energy use are obtained with cellulosic ethanol, followed by biodiesel. Within corn-based ethanol production, differences exist based on the process fuel used and the co-products marketed. The average fossil energy

consumption of ethanol production is lower for ethanol plants that do not dry the co-product before sale, and it is highest for coal-fired plants that do dry the co-product.

Current U.S. law provides the same \$0.51-per-gallon credit for all ethanol regardless of the type of plant, source of input (corn or cellulose), and fossil energy used. Therefore, we can safely conclude that fossil energy savings was not the primary motivation for the existing subsidy structure. This is not a surprise because the motivations described earlier have typically emphasized a reduction in crude oil imports and not a reduction in fossil energy use. We have included this fossil energy analysis because it links the rest of our work to the energy balance controversy.

Table 3 presents the amount of petroleum energy needed to produce and consume 1 mBtu of energy, with a breakout for the WTP and PTW phases. Ethanol and biodiesel are much more efficient in saving crude oil than they are in saving fossil energy. This is because much of the energy used to produce ethanol comes from coal used to make steel and natural gas. All the pathways analyzed would lead to about a 90% reduction in petroleum energy used when replacing gasoline or diesel with the comparable biofuel. Note that the petroleum energy displaced is similar for all ethanol production systems, which alone is consistent with the existing fixed U.S. ethanol subsidy structure.

The fuel pathways analyzed also differ in their effectiveness to reduce GHG emissions when substituting for gasoline or diesel. Table 4 indicates that while reductions in GHG emissions of almost 40% are possible with corn-based ethanol, the production of ethanol in coal-fired plants that market dried distillers grains with solubles (DDGS) does not provide GHG emission reduction benefits. As with the fossil fuel energy displacement measure, cellulosic ethanol and biodiesel perform better than corn-based

ethanol when GHG emission reductions are the target. Note the enormous differences across energy production systems. Had GHG emissions been the motivation for the existing subsidy structure, then the subsidy for coal-fired plants would have been much lower than for plants fired with natural gas that sell only wet distillers grains.

### **Externalities Expressed on a Per Gallon Basis**

The results have been presented so far in terms of benefits per mBtu of energy produced and used. However, support is expressed by subsidies per gallon. To see the implications of the current subsidy structure more clearly, the benefits presented in tables 2 through 4 are translated and expressed in this section on a “per gallon of biofuel” basis.

Table 5 reports the benefits in terms of LCA of fossil and petroleum energy savings and GHG emission reductions obtained by 1 gallon of ethanol or biodiesel for the pathways analyzed to replace petroleum fuels. These results assume a low heating value energy content of 76,000 Btu per gallon of ethanol and 124,000 Btu per gallon of biodiesel. These results show that because of its higher energy density, biodiesel dominates across all categories. It is interesting to note that the subsidy level for biodiesel (currently \$1.00 per gallon, or approximately twice the per-gallon subsidy level for ethanol) is almost in line with its relative energy savings. A small reduction in the biodiesel subsidy relative to the ethanol subsidy would bring the subsidy structure exactly in line.

### **Cost of the Purchased Externality**

All of the foregoing results have been expressed in terms of the services provided per unit of energy or volume of biofuels produced and consumed. It is instructive to examine the

implications of the current subsidy structure in terms of the cost of the externality that is being purchased. These results are shown in table 6.

Fossil energy reduction is currently reimbursed at an average rate of \$14.7 per mBtu, whereas the same reduction could have been bought at \$10.4 per mBtu from a natural-gas-fueled plant that markets wet distillers grains with solubles (WDGS). The same energy displacement service would cost only \$6.00 were cellulosic ethanol to become commercialized.

Current subsidies would imply that GHG emission reductions “cost” \$350 per ton of carbon dioxide equivalent when purchased from the existing ethanol industry. However, natural gas plants marketing WDGS and cellulosic ethanol plants would provide the same benefit for a cost that is 50% and 77% lower, respectively. At the other extreme, coal-fired plants marketing DDGS would actually increase GHG emissions (or at least provide no reductions). As of early 2008, the current market price for one ton of carbon dioxide equivalent on the Chicago Climate Exchange was \$1.90 per ton for 2010 delivery.<sup>3</sup> Notice, however, that this 2010 contract had an open interest of only 350,000 tons. This low volume may underestimate the real value of GHG emission reduction because the United States has not introduced any cap on emissions. Nevertheless, there is a striking difference between the market value of carbon emission reductions and the current cost of the same reductions via biofuel subsidies. If the only motivation for biofuel subsidies was to reduce GHG emissions, then we could conclude that the purchase price of these emission reductions is approximately two hundred times the price available elsewhere.

If we assume a one-for-one relationship between net fuel savings provided by biofuels and U.S. fuel imports, we can also get a sense of the costs of reducing our dependence on foreign oil via biofuels. These values are shown in the fourth column in table 6. The values show that it costs from \$6 to \$8 to reduce U.S. fuel imports by one million Btu. To put this value in perspective, the early 2008 value of a million Btu of natural gas on the New York Mercantile Exchange is in the range of \$7 to \$8 depending on the delivery month.<sup>4</sup> These energy values were far lower when the current subsidy system was constructed. The market values for one million Btu from diesel and from gasoline did not exceed \$8 until 2004, well after the current regulations were signed. This comparison suggests that the cost of reducing foreign oil imports is high—in fact, approximately equal to the market value of this product.

We can find an estimate of the cost of reducing the amount of imported oil by calculating what it would have cost to produce gasoline from the cheapest and most abundant U.S. energy source, coal. In 2001 the U.S. National Energy Laboratory commissioned a comprehensive study of the likely cost of production of ultra-clean fuels from coal via the “syngas” method (Gray and Tomlinson, 2001).<sup>5</sup> This is the same production method used to produce fuel in Germany during the Second World War and in South Africa during trade restrictions associated with apartheid. The authors calculated that this method could produce fuel for \$41.57 per barrel crude oil equivalent assuming full capture of all CO<sub>2</sub>. The authors also calculated that a Section 29 credit of \$0.52 per mBtu would be sufficient to commercialize the technology given market expectations at that time. They also indicated that the coal reserves of the United States would be sufficient to supply these plants with enough coal to achieve energy independence.

Policymakers chose not to provide this \$0.52/mBtu credit and instead chose to subsidize biofuels in the range of \$6.00 to \$8.00 per mBtu. This suggests that at the time the decision was made, the reduction in crude oil imports was not a primary objective. However, as we will show, if it is true that the additional cost of biofuel policies relative to green coal policies could be justified on the grounds of an income transfer to crop growers and land owners, then the current policy structure makes sense.

### **Rural Development Associated with Biofuel Plants**

As described in Dorr 2006, a successful biofuel policy will also result in increased rural development through construction costs and the economic activity generated by the plants themselves. However, Miranowski et al. (2008) conclude that some of the corn feedstock that is used in ethanol plants will be made available through modest reductions in meat and dairy production, and particularly in reduced meat exports. They compare two scenarios, representing low and high ethanol prices, and show the job impacts by 2016. Higher ethanol prices induce more ethanol production, and this creates 5,999 extra jobs.<sup>6</sup> However, higher ethanol production is also associated with higher corn prices, and this causes a net job loss in the livestock sector in the range of 17,157 to 20,847. Unfortunately, this paper does not provide the indirect impact on jobs from reduced livestock production. It seems likely that once these indirect effects are taken into account, the job loss comparison would weigh even more heavily against ethanol production. This follows from the fact that meatpacking is a labor-intensive activity. The intuition behind the results obtained by Miranowski et al. is that livestock production is a labor-intensive way to add value to corn relative to ethanol production.

The Miranowski et al. study evaluates neither the economic activity generated by increased crop and land prices nor the profit distributions from crop production and ethanol plants. In this sense, the authors may have missed the key contribution of the industry. We can, however, conclude that biofuel policy cannot be motivated solely on the economic activity of the plants themselves.

### **Biofuel Subsidies as a Transfer to Crop Producers and Landowners**

The provision of fiscal incentives to ethanol and biodiesel producers can be translated into enhanced prices for different agricultural products as long as those incentives are sufficient to entice commercial investment in the plants. If the structure of incentives is such that the final profitability of a certain feedstock is increased relative to that of a competing crop, the subsidy will affect farm-level decisions in terms of land allocation and farm income. Hence, the structure of subsidies might promote a given crop, which will expand at the expense of other crops or idle land.

Secchi and Babcock (2007) have shown that increasing corn prices via ethanol will increase the opportunity cost of cropland and in so doing will increase the equilibrium price of all crops. This means that a successful biofuels policy will result in a predictable increase in revenues to crop producers and, eventually, landowners. With an inelastic demand for all crops taken together, any leftward shift in the food supply curve will have a significant and predictable price effect.

The largest and so far most obvious impact of U.S. biofuel policy has been the rapid increase in crop prices associated with the shift of a large number of acres out of food and feed production and into energy production, with the aid of high crude oil

prices. For example, the futures price for corn for delivery on the Chicago Board of Trade in December 2008 increased from \$2.60 per bushel when the contract started trading in 2006 to \$4.97 in early 2008. The price for November 2008 soybeans increased from \$6.50 to \$11.89 during the same period. Prices for delivery in 2009 and 2010 have followed a similar pattern as it became obvious that higher energy prices coupled with existing biofuel policies would cause continued growth in biofuel production. About 15% of the price increase in both futures occurred after the signing of the 2007 energy act, suggesting that this act is also viewed as being a positive force for crop prices.

The fact that crop prices have grown with biofuel production does not prove that higher crop prices were caused by biofuels. However, Tokgoz et al. (2007) provide a very simple model that links crude oil prices and ethanol subsidies to corn prices in a way that has almost exactly replicated actual market behavior. In this model, crude oil prices and thus gasoline prices are exogenous. For a given gasoline price, the demand for ethanol is perfectly elastic at its energy value. A perfectly elastic demand implies that all of the blenders credit is transferred to the ethanol producer. Tokgoz et al. then calculate the break-even corn price and assume that ethanol production will increase until this price is reached.

Storage arbitrage in the corn futures market is important. Any anticipated increase in the future demand for ethanol will be reflected in the corn futures prices. Additionally, any increase in the corn futures prices for contracts in the distant future will usually translate into an increase in prices for nearby futures and for cash. In the corn market, with storage arbitrage the cash price of corn will rise to the breakeven price, less storage

costs. In this model, the \$0.51 blenders credit effectively increases the per bushel price of corn by \$1.42 per bushel as long as this credit is expected to continue.

The supply of biofuels, on the other hand, is bounded in this model. Land is a scarce input, and high demand drives feedstock producers to less-advantaged soils to increase volume of production. Hence, farmers face a production function that has decreasing returns to scale (DRTS). Several recent real-world examples support this argument. First, we observe that acres outside of the Corn Belt, which are less suitable for growing corn, shift to corn in almost every state. Second, we see farmers moving away from a soybean-corn rotation to continuous corn in spite of yield penalties associated with this shift. Lastly, less-productive land that was previously chosen to be in the Conservation Reserve Program is moving back into corn production because of its higher profitability (Feng, Rubin, and Babcock, 2008). As long as farmers are free to choose between crops in their rotation, the increase in corn prices will be translated into growth in all crop prices.

With a DRTS production function (or upward-sloping supply curve) of feedstocks and an infinitely elastic demand function for the biorefinery, we can conclude that any exogenous increase in fuel prices or/and a unit subsidy will be captured entirely into feedstock producers' or landowners' surplus in the long run.

Figure 1 illustrates the relationship between ethanol and corn production. In 2007, the increase in corn production almost matched the increase in the capacity of the ethanol industry. However, plants that are under construction are expected to double the capacity of the industry.

This data and price changes that have been observed on futures markets suggest that biofuel policy, coupled with high energy prices, has removed and will continue to remove land from food and feed production. In so doing, it has increased returns to crop growers, and landowners eventually will also see these returns. The next question we need to ask is whether current policy appears to have been designed with this outcome in mind.

Given conversion rates of biofuels, the associated long-run revenue increase per acre due to the tax blenders credit can be established for each feedstock. Since a fixed payment per gallon would result in all corn-based ethanol plants receiving the same subsidy per unit of corn utilized in ethanol production (assuming all plants achieve the same yield of 2.8 gallons per bushel), we do not distinguish between energy sources used at the refinery stage in this section. Hence, we will consider only four feedstocks for biofuel production: corn, soybeans, corn stover, and switchgrass.

Table 7 shows that under the current policy, cornstarch receives a much higher subsidy on a per-acre basis than any other feedstock. Notice that the payments per acre to cornstarch are more than three times the payments expected for soybean acreage. They also exceed payments that would be provided to cellulosic materials by between 20% and 280%. This might explain in part the results of a study by Tokgoz et al. (2007), which concluded that as long as producers can choose between switchgrass for ethanol, soybeans for biodiesel, and corn for ethanol, they will choose to grow corn. Moreover, if the economic terms are such that farmers have incentives to haul and sell corn stover, the subsidy per corn acreage reaches \$275.6 and the tendency to favor corn becomes even higher.

The current subsidy structure therefore seems to be tilting the scale in favor of corn production, and as long as this subsidy structure remains in place, corn will be the

preferred source of biofuels. The 2007 energy act implicitly recognizes this issue by mandating the blending of 15 billion gallons of conventional biofuels, 16 billion gallons of cellulosic biofuels and 1 billion gallons of biodiesel by 2022. Had the framers of the act been satisfied with the existing incentive structure, they would not have provided separate mandates for corn and cellulosic ethanol. The energy act does not, however, provide for any change in credits or subsidies designed to bring about this change. This data suggests that current U.S. biofuel policy is consistent with the objective of increasing returns to crop growers and eventually to landowners. If this is a true objective, we can ask why the policy favored corn over soybeans. To answer that question, we gathered the required data to reconstruct profit margins of corn-based ethanol and soy-oil-based biodiesel over time. Prices for the biofuels were reconstructed based on their energy value, according to the fuel each would replace. Figure 2 presents profit margins based on historical data of feedstock, fuel, and co-products prices of a dry milling ethanol plant and biodiesel refinery. The industries' processing costs are assumed to be \$0.40 and \$0.30 per gallon of ethanol and biodiesel, respectively. This assumption is drawn from numerous peer studies that review biofuels production costs (for example, Paulson and Ginder, 2007; Gallagher and Shapouri, 2005). (Supporting material for figure 2 can be provided by the authors upon request.)

Noticeably, ethanol production was closer to being viable than biodiesel on the period of policy adjustments. While a subsidy of \$0.51 per gallon of ethanol generates positive profits for the blender in most periods and certainly in the long run, a subsidy of \$1 per gallon of biodiesel did not provide consistent profits in early periods observed.

This may help explain part of the bias in favor of corn. Quite simply, corn ethanol was closer to commercial viability than biodiesel.

Another reason for favoring corn is that soybeans produce both meal and oil whereas corn provides ethanol and a feed substitute for corn. Any demand-driven increase in soy oil prices will not translate directly into increases in soybean prices because the demand for soy meal is not affected. In fact, as we will show, relatively small removals of soybean oil from the food chain lead to an increase in soy oil prices rather than soybean prices, thus restricting the ability of the biodiesel industry to grow and the ability of policy to drive up soybean prices.

Figure 3 shows indices of actual corn and soy oil prices from 1984 to 2005 and graphs this index against the fuel value of the biofuel minus its feedstock cost. This latter value is a proxy for the non-subsidized profitability of the biofuel industries. Most of these values are negative in the case of ethanol while all are negative for biodiesel. Thus, the figure shows that in the absence of subsidies, neither industry would have added much value to the feedstock by converting it to fuel. As the prices of corn increased along the horizontal axis, the profitability of ethanol production fell. The same is true for soybean oil prices, but the rate at which profits declined is greater than that for ethanol. These historical data show that it is more difficult to translate a demand increase for soybean oil into an increase in soybean prices via biodiesel than it is to translate an increase in demand for corn for ethanol into corn prices. Relatively small changes in soybean oil prices would rapidly choke off the growth of biodiesel production without necessarily increasing the price of soybeans. In fact, it may even be true that the most

effective way to increase soybean prices is to divert land into energy production via corn and then let the cross-elasticity of supply increase soybean prices.

### **“Correct” Subsidy Schedules**

If we assume that the primary objective of biofuel subsidies is to remove land from food and feed production but now overlay that objective with a secondary objective of reducing net fuel use or GHG emissions (goals that are explicitly stated in the 2007 energy act), we can calculate the new subsidy levels that achieve these secondary objectives while maintaining the primary objective.

Table 8 shows the blenders credit that equalizes the payment for the external benefit that is provided assuming that the subsidy of \$0.51 per gallon currently provided for corn-based ethanol is the proper amount. The overall level of spending resulting from a base level of \$0.51 per gallon from corn is presumably justified on the grounds of farm income support. Using the GHG emission reductions as a target, ethanol plants that use natural gas are underpaid relative to the average plant. The current subsidy structure, in general, under-pays ethanol plants that market their co-products in wet form. Notice also that the equivalent subsidy under a GHG target would entail a tax of \$0.07 per gallon of ethanol produced in coal-fired plants that market DDGS. If the purpose of the policy is to achieve petroleum energy displacements and to transfer money to crop growers and landowners, then the subsidy scheme in the fourth column of table 8 is correct. This subsidy system is close to the existing policy and would require a very minor downward adjustment in the subsidy for soy-based biodiesel.

## Inferred Weights of Secondary Objectives

Keeping the same assumptions, we may infer the weights that policymakers assign to each of the two secondary objectives. We make use of the benefits in terms of petroleum energy and GHG emission reductions from table 5 (denoted here by  $r_{pet}$  and  $r_{GHG}$ , respectively), and then assign coefficients ( $w_{pet}$ ,  $w_{GHG}$ ) that would yield current subsidy levels ( $s$ ). Formally, the following system of equations should hold:

$$r_{pet}^i \cdot w_{pet} + r_{GHG}^i \cdot w_{GHG} = s_i, \text{ where } i = 1, \dots, n$$

denotes the subsidized biofuel systems.

Since current policy ignores the differences among ethanol production paths, the system of equations narrows down to two equations only: current ethanol and soy oil biodiesel. Therefore, the two inferred coefficients can be deduced easily. Although the different units prevent a direct comparison, we can safely claim that the coefficients<sup>7</sup> imply that policymakers value 1 g of carbon dioxide as high as 6.3 Btu of petroleum. In other words, each cent of subsidy is currently buying a reduction of 1 g of carbon or equivalently 6.3 Btu of petroleum reduction.

Next, we use these coefficients to extrapolate the appropriate subsidy that would weigh the two benefits the same across all biofuel systems. The sixth column of table 8 presents a suggested schedule in line with current subsidy rates and the coefficients implied by the stated objectives of the 2007 energy act. First, this schedule would make subsidies for corn-based ethanol vary in a range of \$0.12 per gallon among different production paths. Secondly, the compensation for switchgrass-based ethanol needs to be \$0.20 higher than its current rate according to the coefficients implied by current biofuel policy. Interestingly enough, computing the subsidy on a per acre basis subject to the

proposed schedule shows that switchgrass might be subsidized as high as corn under these terms. The 2007 energy act mandates an RFS that depends heavily on cellulosic biofuels, but it does not provide an incentive high enough for farmers to plant cellulosic crops. Our proposed schedule provides stimulus for planting switchgrass in conjunction with the (inferred) amount that society is willing to pay for its benefits.

## **Conclusions**

U.S. biofuel policies evolved in a period of high energy price volatility, increasing climate change awareness, and substantial technological advances, and yet these policies have been very stable and have enjoyed enormous political support. These policies have greatly favored the construction of corn-based ethanol plants. This paper attempts to examine the source of this political support by examining the four reasons that have been put forward to justify existing policies and by asking whether the structures of the policies are consistent with those stated objectives. We are able to show that the structures of the policies would be very different if the primary objective was a reduction in greenhouse gas emissions. We also find that if the primary purpose of the policies was to reduce dependence on foreign oil then funds would have been far more efficiently spent on green coal technologies. There is strong evidence to suggest that the primary purpose of these policies was to remove land from food and feed production and in so doing to increase farmers' and landowners' incomes.

Corn-based ethanol subsidies were favored (and introduced first) because corn-based ethanol was far closer to commercialization than cellulosic ethanol or biodiesel at the time. Therefore, funds spent on this industry could be expected to have the greatest

influence on corn demand and crop prices. Corn-based ethanol subsidies also had the advantage of translating directly into higher corn prices, and higher crop prices in general, than would have been the case with soy-oil-based biodiesel. This conclusion follows because it is difficult to increase soybean prices by stimulating demand for soy oil. The additional soybeans needed would depress soybean meal markets, causing the biodiesel industry to choke off its own feedstock market without stimulating a supply response.

Evidence from the recent literature and commodity prices suggest that biofuel policies have achieved their primary implied objective and have allowed large income transfers to crop growers and landowners. The signing of the 2007 energy act and the likely participation of the United States in a global carbon emission reduction treaty has recently stimulated interest in the use of biofuel policy to reduce carbon emissions. This paper calculates two sets of alternative biofuel subsidies that are targeted to meet income transfer objectives and either GHG emission reductions or fuel energy reductions. The first of these assumes that GHG emissions and high crop prices are joint objectives while the second assumes that fuel independence and high crop prices are the joint objectives.

Inferred weights of secondary objectives are the grounds for a proposed subsidy schedule that is consistent with the primary objective and maintains current social preferences. This schedule provides higher credit to biofuel systems that generate larger positive externalities and additionally enhances the economic incentives to produce cellulosic ethanol.

## Endnotes

<sup>1</sup> GREET stands for Greenhouse Gases, Regulated Emissions, and Energy Use in Transportation. The model has been developed since 1995 at Argonne National Laboratory. The model, with over 3,500 registered users worldwide, has been used extensively by governmental agencies, energy companies, universities and research institutions, automotive companies, and non-governmental organizations (Wang, Wu, and Huo, 2007).

<sup>2</sup> The British thermal unit (BTU or Btu) is a unit of energy used in the United States, particularly in the power, steam generation, and heating and air conditioning industries. The term “Btu” is used to describe the heat value (energy content) of fuels, and also to describe the power of heating and cooling systems, such as furnaces, stoves, barbecue grills, and air conditioners. The unit “mBtu” was originally defined as one thousand Btu presumably from the Roman numeral system where “M” stands for one thousand (1,000). In this article, we use the term “mBtu” to indicate one million Btu, reflecting the more modern usage of this term (source: Wikipedia).

<sup>3</sup> See <<http://www.chicagoclimatex.com/market/data/daily.jsf>>.

<sup>4</sup> See <[http://www.nymex.com/ng\\_fut\\_csf.aspx?product=NG](http://www.nymex.com/ng_fut_csf.aspx?product=NG)>.

<sup>5</sup> See <<http://www.angtl.com/pdfs/GREENCOAL.pdf>>.

<sup>6</sup> To calculate this value directly from their paper, subtract the 8,972 value for direct jobs in table 2 (the low-ethanol-production scenario) from the 14,971 value for direct jobs in table 3 (the high-ethanol-production scenario).

<sup>7</sup> 6E-6 for each Btu of petroleum and 3.75E-2 for each kg of carbon reductions.

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**Table 1. Summary of Fuel Pathways Analyzed**

Ethanol	Corn	Current average production	80%DM <sup>a</sup> 20% WM
		2010 average production	87.5%DM 12.5% WM
		Natural Gas with DDGS <sup>b</sup>	100%DM
		Natural Gas with WDGS <sup>b</sup>	100%DM
		Coal with DDGS	100%DM
		Coal with WDGS	100%DM
	Cellulosic	Corn stover	
		Switchgrass	
Biodiesel	Soybean oil		

<sup>a</sup> DM (WM) denotes dry (wet) milling plants; 80% of the fuel for DM plants is from natural gas and 20% is from coal, while 60% of the fuel for WM plants is from natural gas and 40% is from coal.

<sup>b</sup> DDGS is dried distillers grains with solubles (90% dry matter), and WDGS denotes wet distillers grains with solubles (30%-35% dry matter).

**Table 2. Well-to-Wheels Fossil Energy Use (in Btu per mBtu of fuel produced), and Associated Reduction in Fossil Energy Consumption Relative to Gasoline or Diesel**

Fuel	Technology/ Feedstock	WTP	PTW	WTW	Reduction
		Btu/mBtu	Btu/mBtu	Btu/mBtu	vs. gas/diesel
Gasoline	Current	225,641	1,000,000	1,225,641	-
	Future	225,641	1,000,000	1,225,641	-
Avg. EtoH	Current	769,231	0	769,231	37.2%
	Future	764,103	0	764,103	37.7%
New EtoH	NG-DDGS	728,205	0	728,205	40.6%
	NG-WDGS	579,487	0	579,487	52.7%
	Coal-DDGS	830,769	0	830,769	32.2%
	Coal-WDGS	635,897	0	635,897	48.1%
Cellulosic EtoH	Switchgrass	102,564	0	102,564	91.6%
	Corn Stover <sup>a</sup>	110,308	0	110,308	91.0%
Diesel <sup>b</sup>		221,883	1,000,000	1,221,883	-
Biodiesel	Soybean oil <sup>b</sup>	529,978	0	529,978	56.6%

Source: Figure 6 in Wang, Wu, and Huo (2007).

<sup>a</sup> From Wu, Wang, and Huo (2006).

<sup>b</sup> This study.

**Table 3. Well-to-Wheels Petroleum Energy Use of Various Fuels in Btu per Million Btu of Fuel Produced and Used, and Associated Reduction in Fossil Energy Consumption Relative to Gasoline or Diesel**

<b>Fuel</b>	<b>Technology/ Feedstock</b>	<b>WTP</b>	<b>PTW</b>	<b>WTW</b>	<b>Reduction</b>
		<b>Btu/mBtu</b>	<b>Btu/mBtu</b>	<b>Btu/mBtu</b>	<b>vs. gas./diesel</b>
Gasoline	Current	110,000	1,000,000	1,110,000	-
	Future	110,000	1,000,000	1,110,000	-
Avg. EtoH	Current	100,000	0	100,000	91.0%
	Future	90,000	0	90,000	91.9%
New EtoH	NG-DDGS	85,000	0	85,000	92.3%
	NG-WDGS	85,000	0	85,000	92.3%
	Coal-DDGS	90,000	0	90,000	91.9%
	Coal-WDGS	90,000	0	90,000	91.9%
Cellulosic EtoH	Switchgrass	70,000	0	70,000	93.7%
	Corn Stover <sup>a</sup>	66,600	0	66,600	94.0%
Diesel <sup>b</sup>		112,196	1,000,000	1,112,196	-
Biodiesel	Soybean oil <sup>b</sup>	129,377	0	129,377	88.4%

Source: Figure 8 in Wang, Wu, and Huo (2007).

<sup>a</sup> From Wu, Wang, and Huo (2006).

<sup>b</sup> This study.

**Table 4. Well-to-Wheels GHG Emissions of Various Fuels in CO<sub>2</sub>-Equivalent Grams per Million Btu of Fuel Produced and Used, and Percent Reduction Compared to Current Gasoline or Diesel**

Fuel	Technology/ Feedstock	WTW	Emission Reduction
		g CO <sub>2</sub> -eq/mBtu	
Gasoline	Current	99,130	-
	Future	99,130	-
Avg. EtoH	Current	80,000	19.1%
	Future	78,261	20.9%
New EtoH	NG-DDGS	71,304	27.8%
	NG-WDGS	60,870	38.3%
	Coal-DDGS	101,739	-2.6%
	Coal-WDGS	80,870	18.3%
Cellulosic EtoH	Switchgrass	14,783	84.3%
	Corn Stover <sup>a</sup>	13,878	86.0%
Diesel <sup>b</sup>		100,302	-
Biodiesel	Soybean oil <sup>b</sup>	40,521	59.6%

Source: Figure 11 in Wang, Wu, and Huo (2007).

<sup>a</sup> From Wu, Wang, and Huo (2006).

<sup>b</sup> This study.

**Table 5. Well-to-Wheels Benefits Provided per Gallon of Biofuels Produced and Used Replacing Gasoline or Diesel**

<b>Fuel</b>	<b>Technology/ Feedstock</b>	<b>Fossil Energy Reduction</b>	<b>Petroleum Energy Reduction</b>	<b>GHG Emission Reduction</b>
		<b>Btu/gal</b>	<b>Btu/gal</b>	<b>Kg/gal</b>
Avg. EtoH	Current	34,687	76,760	1.45
	Future	35,077	77,520	1.59
New EtoH	NG-DDGS	37,805	77,900	2.11
	NG-WDGS	49,108	77,900	2.91
	Coal-DDGS	30,010	77,520	-0.20
	Coal-WDGS	44,821	77,520	1.39
Cellulosic EtoH	Switchgrass	85,354	79,040	6.41
	Corn Stover	84,765	79,298	6.48
Biodiesel	Soybean oil	85,796	121,869	7.41

**Table 6. Current Compensation Provided by the Blenders Credit to Services Provided by Different Systems**

<b>Fuel</b>	<b>Technology/ Feedstock</b>	<b>Fossil Energy Reduction</b>	<b>Petroleum Energy Reduction</b>	<b>GHG Emission Reduction</b>
		<b>\$/mBtu</b>	<b>\$/mBtu</b>	<b>\$/ton</b>
Avg. EtoH	Current	14.7	6.6	350.8
	Future	14.5	6.6	321.5
New EtoH	NG-DDGS	13.5	6.5	241.2
	NG-WDGS	10.4	6.5	175.4
	Coal-DDGS	17.0	6.6	- <sup>a</sup>
	Coal-WDGS	11.4	6.6	367.5
Cellulosic EtoH	Switchgrass	6.0	6.5	79.6
	Corn Stover	6.0	6.4	78.7
Biodiesel	Soybean oil	11.7	8.2	134.9

<sup>a</sup> GHG emissions are increased compared to gasoline by using ethanol produced in a coal-fired plant that dries co-products (see table 5).

**Table 7. Assumptions to Obtain the Amount of Biofuels Produced by Acre of Land and the Payments That Would Result under the Current Scheme**

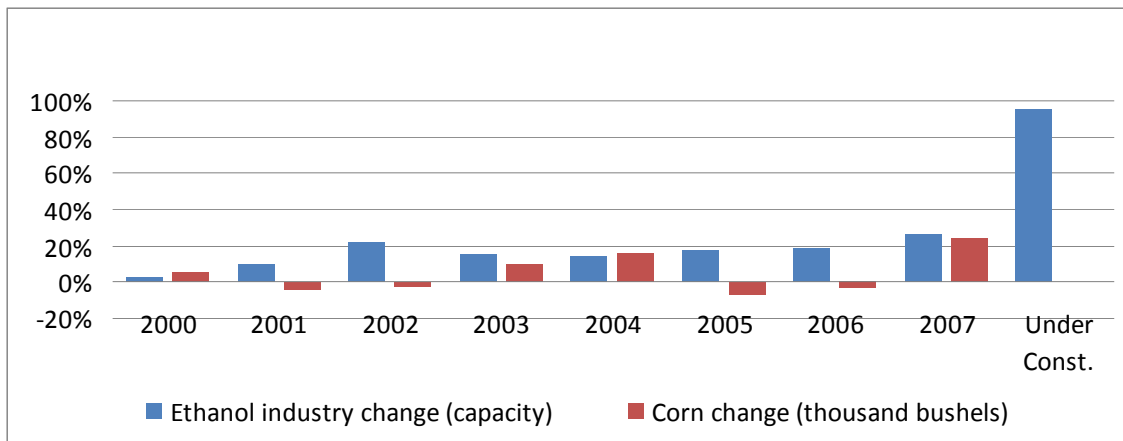
	<b>Yields</b>	<b>Biofuel Production gal/acre</b>	<b>Current Subsidy<sup>a</sup> \$/acre</b>
Corn (bu/acre)	153	428	218.5
Soybean (bu/acre)	45	63.1	63.1
Corn Stover (kg/acre)	1600	112	57.1
Switchgrass (kg/acre)	5,000	350	178.5

*Note:* Yield assumptions: (a) the oil contents of soybeans is 18%, (b) 7.7 pounds of vegetable oil per gallon of biodiesel, (c) 2.8 gallon of ethanol per bushel of corn, (d) 70 gallons of ethanol per ton of cellulosic materials, (e) 40% of 4,000 kg per acre of corn stover can be sustainably collected (Kadam and McMillan, 2003; Perlack and Turhollow, 2003).

<sup>a</sup> Assumed to be fully passed to farmers.

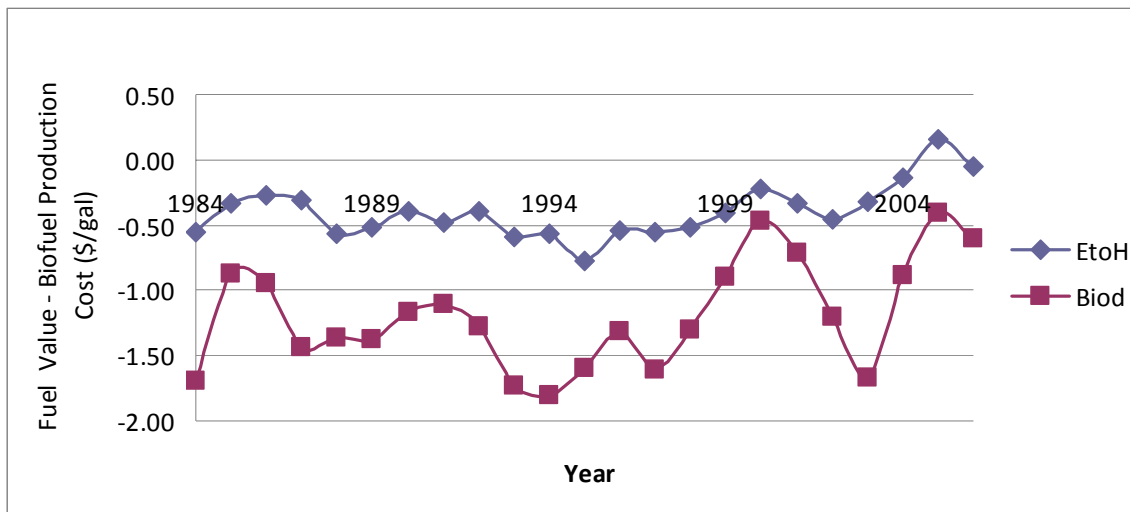
**Table 8. Subsidy Equivalent per Gallon for Different Pathways Based on the Services Provided Given the Current \$0.51 Blenders Credit for any Given Gallon of Ethanol**

<b>Fuel</b>	<b>Technology/ Feedstock</b>	<b>Fossil Energy Reduction</b>	<b>Petroleum Energy Reduction</b>	<b>GHG Emission Reduction</b>	<b>Inferred Subsidy Schedule</b>
		<b>\$/gallon</b>	<b>\$/gallon</b>	<b>\$/gallon</b>	<b>\$/gallon</b>
Avg. EtoH	Current	0.51	0.51	0.51	0.51
	Future	0.52	0.52	0.56	0.52
New EtoH	NG-DDGS	0.56	0.52	0.74	0.54
	NG-WDGS	0.72	0.52	1.02	0.57
	Coal-DDGS	0.44	0.52	-0.07	0.45
	Coal-WDGS	0.66	0.52	0.49	0.51
Cellulosic EtoH	Switchgrass	1.25	0.53	2.25	0.71
	Corn Stover	1.25	0.53	2.27	0.71
Biodiesel	Soybean oil	1.26	0.81	2.60	1.00



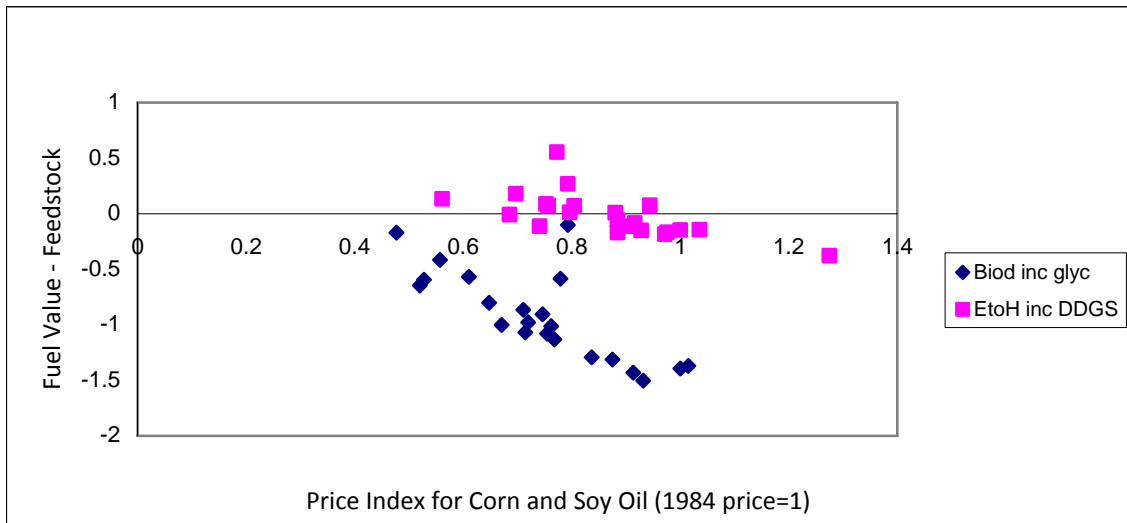
Sources: Constructed by authors based on National Agricultural Statistics Service and Renewable Fuels Association data.

**Figure 1. Ethanol industry and corn yield trends**



Sources: Constructed by authors based on Economic Research Service, Energy Information Administration, and National Agricultural Statistics Service data.

**Figure 2. Historical profit margins of biofuels**



*Sources:* Constructed by authors based on Economic Research Service, Energy Information Administration, and National Agricultural Statistics Service data.

**Figure 3. Fuel value and feedstock prices**