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The Impact of Biotech Corn Traits on Ethanol Production

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Abstract: The U.S. appears committed to the ongoing use of ethanol biofuels. In order to realize the desired benefits, ethanol production must continue to become more efficient. Although many technologies have emerged to improve efficiency this article focuses on the role that corn biotechnology might play. Biotechnology offers the potential to increase yields and lower input use as well as aid the conversion of corn to ethanol. This could have a meaningful impact on the energy balance and greenhouse gas emissions of ethanol production. This article finds those impacts to be significant, although likely to be eclipsed by cellulosic biofuels. However, the realization of any such benefits is conditioned by prevailing market and policy conditions. In a world where the market is less constrained by policy, increased yields afforded through biotechnology would increase corn production, which leads to lower corn price and larger ethanol production volume. When expected policies, most notably the Renewable Fuel Standard, are considered the impacts of biotechnology change. The Renewable Fuel Standard effectively limits the amount of corn based ethanol that is consumed as it shifts production towards cellulosic feedstocks. Despite the increase in corn production and reduced corn price there are only marginal increases in ethanol production volume. Accordingly, the RFSs support of competing biofuels might limit some dimensions of the ethanol industry including its ability to fully benefit from corn biotechnologies.

In the last decade biofuels have attracted increasing attention for their potential to reduce greenhouse gas emissions (GHG), provide sustainable energy supplies, and divert chronic agricultural commodity surpluses to new productive uses. In anticipation of the benefits many supporters have coalesced, making large investments in biofuels.

More recently, some of the benefits have been questioned amid rigorous debate. Corn ethanol, which comprises the vast majority of biofuels produced in the US, has been the focus of the scrutiny. Critics claim that corn ethanol is inefficient, using as much energy as it displaces. A comparison of ethanol life cycle analysis (LCA) studies (Farrell et al., 2006) explains the confusion by showing the diverse range of net energy ratios that have been derived, from negative (e.g., Patzek, 2004; Pimentel & Patzek, 2005) to significantly positive (Shapouri, Duffield, & Wang, 2002; Wang, 2001).

The debate over the environmental benefits of corn ethanol is equally ambiguous. Farrell et al. (2006) suggest that GHG emissions of ethanol are virtually on par with that of gasoline. Other studies (Fargione et al. 2008; McCarl et al., 2005; Searchinger et al., 2008) claim that when the increased land required to grow feedstocks is accounted for, GHG emissions may be significantly higher.

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The socio-economic impacts of corn ethanol production and policies have become perhaps the most hotly debated issue. While ethanol production has sought to create additional uses and demand for corn beyond its traditional food and feed markets, the recent spike in corn and other agricultural commodity prices has been viewed as an unfortunate consequence. Studies, both at the national (e.g., Tokgoz et al., 2007) and international (e.g., Hertel et al., 2008) level have linked the increasing use of corn for biofuel production with higher grain prices and, ultimately, somewhat higher food prices.

The ongoing debate suggests that the benefits of corn ethanol may not yet be clear cut. Given the early stage of development in corn ethanol production, technologies and policies should continue to evolve, improving the efficiency and balance of benefits. In this article we explore the potential contribution of coming technical advances on the development of the US corn ethanol market. Although different types of potential technological innovations exist, we focus on one, corn biotechnology, evaluating how it might influence corn ethanol's energy, environmental, and market impacts. We also examine how market structure and government policies could condition the influence of corn biotechnologies on ethanol production.

2. The Pipeline of Corn Biotechnology

Corn has been an attractive ethanol feedstock due, in large part, to an advanced and efficient system of breeding, production, and handling. In recent years, this system has been put to work to optimize corn for ethanol production. At the ethanol facility a number of improvements have been made to the process of converting corn to ethanol. Such advances have produced steady processing efficiency gains raising yields from 2.5 gallons per bushel (ga/bu) in 1980 to 2.8 in 2007 (Wu, 2008). During this same period the average corn yield rose from 104 to 150 bushels of corn per acre (bu/ac) in the U.S. (USDA, 2008). From these two types of improvements alone, the amount of ethanol that could be derived from an acre of corn grew 62%, with the lion's share of this increase coming from advances in corn production.

Improved corn productivity has come from the use of improved hybrids, precision agriculture, improved machinery, integrated pest management, reduced tillage and other innovations. One of the more recent additions to this arsenal is biotechnology. Corn hybrids improved through modern biotechnology have been found to lower production costs, increase yields and reduce the environmental footprint of corn production (Fernandez-Cornejo & Caswell, 2006; Kalaitzandonakes, 2003). Accordingly, since their introduction in 1996, biotech hybrids resistant to certain insect pests or some key broad spectrum herbicides have been commercialized and quickly adopted. In 2007, 3 out of 4 corn acres in the US were planted with such hybrids (USDA NASS, 2008). Continuing research and development has produced an increasingly robust pipeline of novel corn traits (Table 1). While the pipeline builds on the efficacy of the first generation offerings it also promises new traits such as drought resistance, increased nitrogen utilization and improved yield potential.

These agbiotech traits could impact ethanol production by (a) increasing corn yields; (b) modifying corn composition; (c) expanding corn acreage; (d) decreasing energy use in corn production; and (e) decreasing energy use in ethanol processing. Each trait may have more than one relevant impact. Drought tolerance, for instance, could increase corn yields, expand corn production to previously unsuitable lands, and decrease energy used for irrigation. Both the multifunctionality and the stackability of biotech traits hint at their promise. However, this multiplicity also makes *ex ante* impact analysis more difficult. In order to examine the potential impact of such new corn traits on ethanol production, we consider simplified scenarios that focus on the aggregate yield and input use effects of the biotech pipeline but ignore other potential impacts (e.g. decreased pesticide use, increased use of no till practices).

Table 1. The corn trait pipeline of key biotechnology firms

Syngenta	Expected Date	Monsanto	Expected Date	Dupont/Pioneer	Expected Date
VIP broad lep	2009	Drought tolerant corn	<2013	Stalk rot resistant	2009
Optimum GAT	2010	Drought tolerant corn II	<2015	Increased etoh 2&3	<2018
Corn rootworm II	2012	Nitrogen efficient corn	<2017	Corn rootworm II & III	<2018
Corn amylase	2009	High yielding corn	<2015	Corn borer II & III	<2018
Increased ethanol	2011	Yieldgard II (VT Pro)	2009	Drought tolerance	2013-15
		Yieldgard Rootworm III	<2017	Nitrogen efficiency	<2018
		High lysine corn	<2011	Increased yield	<2018
		High oil corn	<2017	Improved feed	2011-2013
		Increased etoh	current	High extractable starch	current

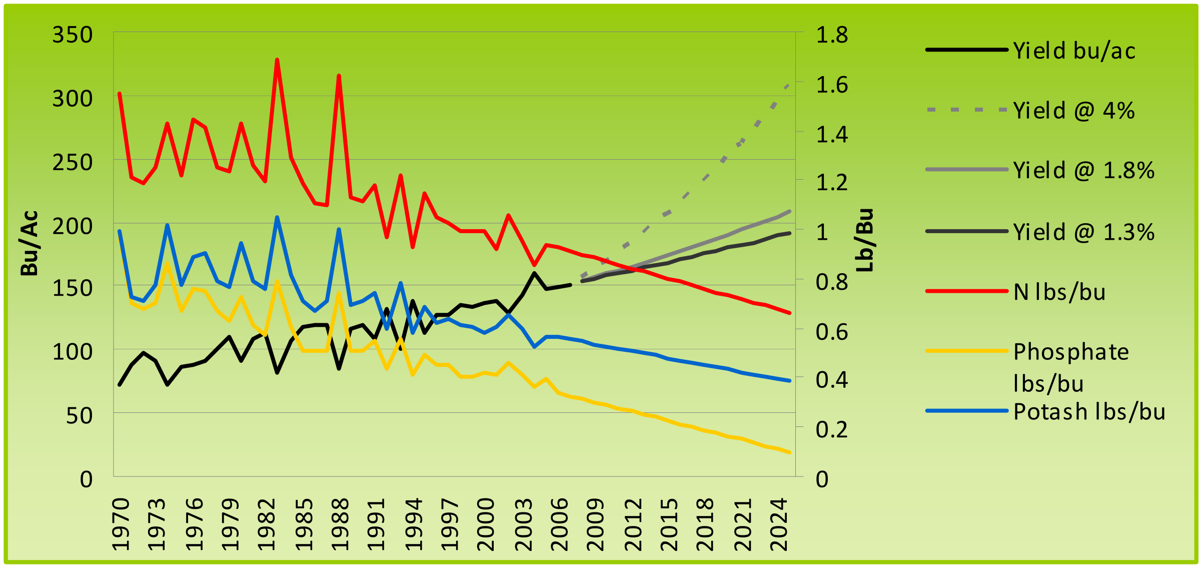
Source: company information

Prevailing long term trends show national corn yields have been growing at a rate of 1.3% per year over the last 20 years (USDA NASS, 2008). If such growth rate were carried forward, it would place the average yield of corn at approximately 175 bu/ac in 2018 and 192 bu/ac in 2025 (Figure 1). However, certain agbiotech developers have indicated that introduction of new biotech traits will accelerate the historical rate of yield growth in the near future. Monsanto, for example, anticipates that by 2030 average corn yields could be twice as large as those of today (Monsanto, n.d.).

Here we consider two possible scenarios of accelerating corn yields from novel biotech traits. First a 1.8% yield growth trend that is meant to reflect a more conservative scenario of continued adoption and evolution of first generation biotechnologies and gradual transition into second generation biotechnologies. Second, we consider an aggressive “upper bound” scenario of a 4% average yield growth rate, which slightly exceeds the projections of doubling the average corn yield in the next twenty years. These linear yield paths mean that by 2018 average corn yields in the US would grow to 184 bu/ac under the more conservative scenario and 233 bu/ac under the more aggressive scenario. Average yields would then further grow to 209 and 307 bu/ac respectively by 2025 (Figure 1).

These yield enhancements subsume the influence of a wide array of crop efficiencies targeted by the new biotech corn traits including resistance to drought and more efficient use of nutrients. Incremental improvements in such crop characteristics have been pursued through traditional corn breeding and other technologies for decades. As a result, between 1970 and 2005, while corn yield increased by 90%, the amount of nitrogen (N) fertilizer used per bushel declined by 36%, paralleled by reductions in phosphorous (P) and potassium (K) (USDA, 2007). In our analysis, we assume that new biotech corn traits can sustain these trends in input use. However, it is likely that these trends will ultimately be restricted by the nutrient removal of grain. Regardless, we assume that in 2025 a bushel of corn will require 0.66 lbs of Nitrogen, 0.1lbs of Phosphorous, and 0.39 lbs Potash (Figure 1).

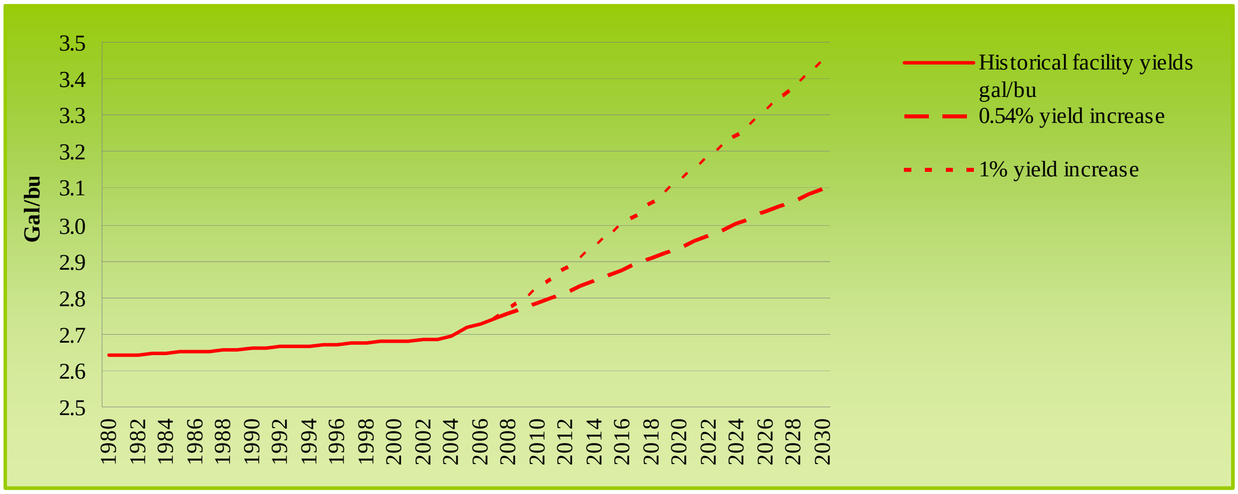
Figure 1. Historical and future trends in corn yields and fertilizer use



Agricultural biotechnology is also promising to positively impact ethanol processing efficiency—most notably with novel highly fermentable corn and high amylase corn hybrids. Existing highly fermentable corn hybrids have, on average, a 5% higher starch content which can result in a 2.7% increase in ethanol yield (Haefel et al., 2004). High amylase corn is promising to decrease the processing costs at the dry mill by essentially eliminating the liquefaction step—including much of the heat, water, tankage, sulfuric acid, and alpha-amylase associated with it (Urbanchuk, 2007). Other traits could further increase the amount of ethanol that can be extracted from a bushel of corn, facilitate the conversion process, or increase the value of co-products. Here we aggregate all such potential impacts of the agbiotech pipeline at the ethanol facility by considering scenarios of overall improved process efficiency. In the case of the LCA the efficiency is modeled as process energy reductions, and in the market analysis, the amount of ethanol yielded per bushel is used. In both cases these changes are assumed to occur at similar rates—a conservative annual rate of 0.54% and a more aggressive rate of 1% annually. Figure 2 shows the ethanol yield paths.

It is important to note that these yield growth rates are complicated by theoretical yield limits. The theoretical yield of ethanol from a bushel of corn containing 33.9 lbs of starch is 2.93 gallons. This theoretical maximum however, may be expanded as the starch profile of corn is increased and as cellulosic technology allows the fiber in corn to be converted to ethanol. The use of highly fermentable corn varieties has demonstrated the capability to increase ethanol yield by 2.7% (Haefele et al, 2004), potentially increasing the maximum to 3.01 gal/bu. The conversion of corn fiber would separately increase the theoretical maximum to 3.35 gal/bu (DOE EERE, 2008). Taken together this implies a theoretical maximum of corn at 3.44 gal/bu. Figure 2 shows the lower ethanol yield path crossing the theoretical starch yield limit in 2020 and the more aggressive in 2014. At which point it is assumed that either corn fiber is converted to ethanol and/or fermentable content of the kernel is otherwise increased.

Figure 2. Historical and future trends in ethanol conversion yields



3. Methods and Results

Given the diverse mode of action of the various new traits in the biotech pipeline, analysis of their potential impacts requires a system-wide approach. We use two types of analyses here: Life Cycle Analysis (LCA) and economic analysis using a partial equilibrium model of the US agricultural and biofuel economy. LCA allows us to examine whether the new corn biotechnologies could improve the environmental and energy profile of corn ethanol. The economic analysis allows us to determine whether these novel biotech traits could change the market fundamentals (e.g. demand, supply, prices) of corn ethanol and its feedstock while accounting for the interconnectedness of agricultural commodity markets and the influence of government policies.

Life Cycle Analysis

Many of the environmental benefits associated with biofuels (e.g., energy balance and GHG emissions) are best assessed using LCA. Energy balance is especially pertinent, as it provides insight on the relative efficiency changes that might be possible through biotech innovation. LCA evaluates the total “variable energy” use required to produce ethanol, including in corn production, ethanol manufacture, transport, and distribution. The energy analysis further includes losses in the individual processing steps, as well as losses associated with the extraction, refining, and distribution of the energy to the system. The “capital energy” contribution resulting from depreciation of equipment and machinery used to produce ethanol is also considered.

For our analysis we use the GREET model (Wang, 2008). In addition to its analytical advantages, the open source code adds to the transparency of the methodology and empirical results. Certain potential agronomic impacts of corn biotechnologies were directly incorporated into GREET in the form of yield increases and reductions in the per bushel fertilizer use (as illustrated in Figure 1). Other potential farm-level effects associated with increased corn yields required calculations exogenous to GREET. For this, simple assumptions were made using USDA ARMS data (2006) and the energy budget of Shapouri et al. (2002). Energy used for seed production, grain hauling, and drying was changed proportionately to the volume of grain produced. Conversely, energy used for field operations (tillage, harvest, spraying) and pesticide use was held proportionate to the area of land used per bushel of grain. The resulting energy budgets were applied to the GREET model and then compared to the baseline where yield growth rates and reductions in input usage are on par with historical trends.

All yield scenarios resulted in energy savings at the farm (Table 2). Staying on the historical yield and fertilizer use trends implies reductions in the gross energy consumption of 11% by 2017 and 25% by 2025. A shift in the annual yield growth to 1.8%, our more conservative yield scenario, offers moderate additional energy savings. Under the more aggressive scenario of 4% annual yield growth, however, energy savings are significantly higher—22% by 2017 and 36% by 2025.

Reductions in fertilizer use were responsible for a large portion of the energy savings. Only under the more aggressive scenario does yield begin to eclipse fertilizer use as the larger source of savings. This implies that biotechnology's ability to lower fertilizer use per bushel of corn produced could be important in achieving energy efficiency goals. Our empirical results also suggest that yield growth had a larger impact on petroleum use as machinery use decreased on a per bushel basis. Our analysis shows that the aggressive yield scenario reduces petroleum use dramatically when compared to a scenario of historical yields carried forward to 2025: 37% vs. 19%.

Table 2. GREET energy use changes associated with corn yield increases

	Baseline	**Historical Yield Trend**		**Conservative Yield Growth Scenario**		**Aggressive Yield Growth Scenario**	
Yield Path (annual % growth)	1.3	1.3	1.3	1.8	1.8	4	4
Year	2007	2017	2025	2017	2025	2017	2025
Yield bu/ac	151	172	191.6	180.6	208.5	224	306.84
N g/bu	413.7	351.1	301.1	351.1	301.1	351.1	301.1
P g/bu	148.2	91.0	45.2	91.0	45.2	91.0	45.2
K g/bu	251.9	209.2	175.0	209.2	175.0	209.2	175.0
Input/Impact Reductions							
Total energy		-14%	-25%	-16%	-27%	-22%	-36%
Petroleum		-10%	-19%	-14%	-22%	-24%	-37%
NOx		-14%	-26%	-17%	-29%	-24%	-40%
CO2		-11%	-21%	-13%	-22%	-18%	-30%
Input/Impact Reductions							
Total energy		-2%	-3%	-2%	-3%	-2%	-4%
Petroleum		-10%	-17%	-12%	-21%	-22%	-34%
NOx		-9%	-17%	-11%	-19%	-16%	-26%
CO2		-4%	-7%	-4%	-7%	-6%	-9%

Corn production, however, accounts for a relatively small share of the total energy use in ethanol production. After all the direct and indirect costs have been accounted for, corn only comprises 19% of the total energy consumption of a gallon of ethanol. Thus yield growth from novel biotech traits generated modest energy savings when the full production process of ethanol was considered—between 2% and 4% across all scenarios.

The assumed yield growth from the corn biotech pipeline offered more meaningful benefits to the petroleum balance of ethanol. Crop production accounts for a large share of the petroleum used in the production of ethanol. Accordingly, under the conservative yield growth scenario, petroleum use in ethanol declined by 14% in 2017 and 24% in 2025. Under the more aggressive yield scenario, petroleum use was reduced by 18% and 31%, respectively. Reductions in NOx emissions were equally significant.

Analysis of the potential impacts of biotech traits targeting an improved ethanol conversion process is similarly instructive. We assume that corn varieties with altered composition (e.g. high starch, high amylase) decrease the direct energy requirement of ethanol processing 0.54% per year in the conservative case and 1% in the aggressive case. These rates would equate to approximately a 5% direct energy reduction in 2017 and 10% in 2025 in the conservative scenario and double that in the more aggressive scenario. The 5% reduction in direct energy inputs is realized as a 2% reduction in the total energy and a 4% reduction in CO2 needed to produce a gallon of ethanol. At a 20% reduction in direct energy (i.e. the aggressive case in 2025), total energy use falls by 7% while CO2 falls by 14%.

The effects of increasing corn yields and improvements in the efficiency of the conversion process are additive and could be examined together. Under the scenario of moderate annual yield growth in corn production of 1.8% and 1% annual reduction in direct conversion energy the result is a 5% decrease in energy use in 2017 and 9% in 2025 (Table 3). Petroleum use decreased by 13% and 22% in the respective time periods. With the more aggressive yield increases, energy use decreased by 6% in 2017 and 10% in 2025 while petroleum use decreased by 23% and 36% respectively.

Table 3. GREET energy use changes from baseline with corn yield increases and decreased energy requirements for ethanol conversion

Year	2017	2025	2017	2025		
Corn Yield Path	1.8	1.8	4	4	Herbaceous Biomass	Corn Stover
Conversion Energy Path	-1%	-1%	-1%	-1%		
Total energy	-5%	-9%	-6%	-10%	-14%	-23%
Petroleum	-13%	-22%	-23%	-36%	-23%	-19%
NOx	-14%	-25%	-19%	-32%	19%	16%

To put these impacts into perspective it is instructive to compare this improved corn ethanol system to that of cellulosic ethanol. Stock assumptions in GREET (Wang, 2008) were used employing a yield of 90 gal. of cellulosic ethanol per ton of biomass, which is believed to be appropriate for the time period considered here (e.g. Tiffany, 2007). These cellulosic scenarios were then compared to a baseline of 2007/08 production of corn ethanol, in similar fashion to the preceding scenarios. The conversion of herbaceous biomass decreased energy use by 14%, petroleum by 23% and led to increases in fuel related NOx emissions. Corn stover offered more robust energy savings with a decrease of 23% and petroleum use by 19%. In either case it would appear that the cellulosic system could outpace corn biotechnology in reducing the energy demands of ethanol. However, corn ethanol might excel at reducing petroleum consumption and certain fuel related GHG emissions.

Economic Analysis

The energy, environmental and economic impacts of the biotech pipeline in corn ethanol production may not always move in parallel. One reason for this is that the corn feedstock represents a much higher share of ethanol's cost than its energy use. To this point, in the LCA baseline examined above, corn production is associated with approximately 35% of the direct energy used to produce ethanol and 19% of the total energy. In comparison, between 2005 and 2008 corn represented between 41% and 76% of the total costs in ethanol production at representative dry mills (Hofstrand, 2008).

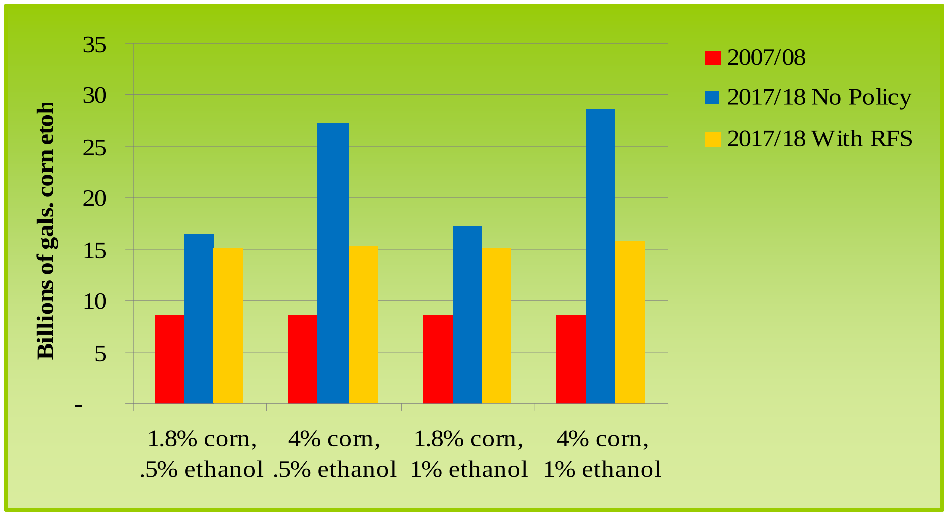
We explore these issues in some detail by evaluating the economic implications of the same innovation scenarios examined above within the context of a partial equilibrium model. The scenarios used for the economic analysis are similar to those used in the LCA with corn yields increasing by either 1.8% or 4%. However, instead of reducing processing energy, as in the LCA, we increased the amount of ethanol that could be derived from a bushel of corn by either .54% or 1% (Figure 2).

Using these yield paths, we first analyze the potential impacts of increased corn productivity on the supply of ethanol in the US. To emphasize the conditioning effects of market structure and government policies, we first calculate such supply response under some unrealistic but instructive assumptions. Namely, we assume that corn area is constant, the amount of corn directed to feed and exports is constant, and the amount of ethanol imports does not change. Under these assumptions, we can determine how much ethanol supply could grow with increasing yields by calculating the residual of the corn market that is available to ethanol production.

In 2007/08, the U.S. was scheduled to produce 8.6 billion gallons of fuel ethanol (Figure 3 "2007/2008"). Under the more conservative yield scenario, approximately 17 billion gallons could be produced in 2017/18 (Figure 3 "2017/18 No Policy"). Under the more aggressive yield scenario, the productive capacity of the U.S. would grow to 27 billion gallons. Further doubling the growth rate in the ethanol conversion yield from 0.54% to 1% per year increases the capacity by another billion gallons.

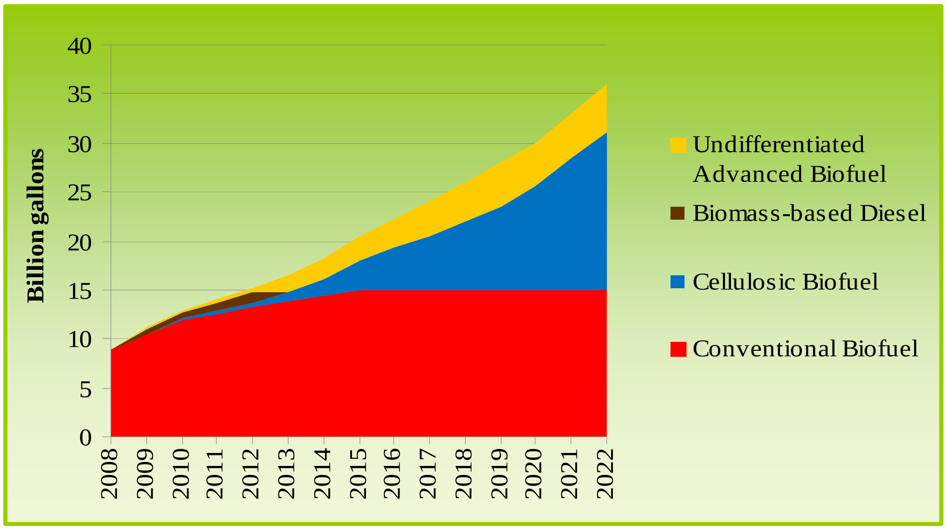
Although these large increases in corn ethanol production provide a sense of the potential impact of the biotechnology pipeline, they do not reflect reality as market dynamics and government policies are not regarded. A number of policies have been implemented to support ethanol production complicating market response to the technological improvements. Perhaps most notable of these policies is the RFS which sets supply and demand mandates.

Figure 3. Market impacts of corn and ethanol yield increases



The RFS encourages corn ethanol growth from 8.6 billion gallons in 2008 to 15 billion gallons in 2015 where the mandate then remains fixed (Figure 4). During this period separate cellulosic and "other advanced" biofuel mandates are put in place and increased, extending total biofuel production to over 25 billion gallons in 2018. This means that 9 of the 25 billion gallons of biofuel mandated in 2018 will need to come from cellulosic and "other advanced" feedstocks, regardless of the cost to make these fuels. Only if increased corn supply could lower corn price (and thus ethanol price) to a point where consumers were willing to consume more than 25 billion gallons of biofuel could the market for corn ethanol expand. However, other corn uses (e.g. export, feed) also expand with declining corn prices making it unlikely that corn price would fall to that level. As expected, when the RFS is explicitly considered and corn market is allowed to adjust to price changes, corn ethanol production is effectively capped at around 15 billion gallons (Figure 3 "2017/18 With RFS").

Figure 4. The Energy Independence & Security Act of 2007



In order to evaluate the influence of market complexities and government policies on the potential impacts of the biotech pipeline in ethanol production, we use the US FAPRI model—a detailed economic model of major US agricultural commodity and biofuel markets (Thompson et al., 2008). In addition to carrying market trends out to 2018 the model incorporates the foreseeable policy environment, where all relevant policies are held constant or at announced levels, including the RFS. We report key results from this analysis in Table 4.

Our empirical results suggest that between 2008 and 2018 under the most aggressive corn and ethanol yield scenario corn acreage decreases by 3% while production increases by 13%. Corn prices fall by 21% resulting in a 33% expansion in exports and a 14% increase in domestic feed use. Production and price of other grains decrease under pressure from the expanding corn supply and declining corn price.

Table 4. Market Effects of Corn Biotechnology Scenarios Under the RFS

Annual Corn Yield Increase:		**1.8%**	**4.0%**	**1.8%**	**4.0%**
Annual Conversion Yield Increase:		**0.5%**	**0.5%**	**1.0%**	**1.0%**
Corn	Planted Area	0%	-3%	-1%	-3%
	Production	2%	13%	2%	13%
	Domestic Use	1%	8%	0%	7%
	Exports	5%	33%	7%	33%
	Price ($/bu.)	-3%	-21%	-4%	-21%
Soybean	Planted Area	0%	2%	1%	3%
	Soybeans ($/bu.)	0%	-2%	0%	-2%
Sorghum	Planted Area	-2%	-9%	-2%	-9%
	Sorghum ($/bu.)	-2%	-13%	-2%	-13%
Ethanol	Production	0%	1%	0%	3%
	Corn Dry Milled	0%	2%	-2%	1%
	Corn Cost of Ethanol	-3%	-21%	-7%	-23%
	Ethanol ($/gallon)	-2%	-12%	-4%	-13%
	Distillers Grains ($/ton)	-3%	-20%	-2%	-19%
	Net Operating Return	1%	-8%	-3%	-5%
	Net Imports (Ethyl Alcohol)	-4%	-13%	-8%	-13%

During this period the amount of corn ethanol produced increases only mildly, and cellulosic biofuels decline. Perhaps most interesting to this paper is the negative effect of yield enhancements on the economics of the ethanol facility. Although the cost of corn in ethanol production decreases by 23%, this decrease is conditioned by a 13% decrease in ethanol price and a 19% decrease in distiller dried grain price.

Next consider a world without an RFS. The technology scenarios have a starkly different impact on the market (Table 5). As might be expected ethanol production is up 15%, a level much higher than in the world with the RFS. The ethanol industry also accounts for a larger share of the increased corn production and the export market relatively less, although it too is up 28% from the baseline. The stronger ethanol demand and the absence of the competing biofuel mandates lead to less downward pressure on ethanol prices. With ethanol price only declining

4% from the baseline, the more efficient ethanol plants see large revenue increases—47% in the case of the aggressive scenario. These results illustrate the significant role that government policies can play on the impacts of the biotech pipeline in corn ethanol production.

Table 5. Market Effects of Corn Biotechnology Scenarios in a World with No RFS

Annual Corn Yield Increase: **Annual Conversion Yield Increase:**		**1.8%** **0.5%**	**4.0%** **0.5%**	**1.8%** **1.0%**	**4.0%** **1.0%**
Corn	Planted Area	0%	-1%	0%	-1%
	Production	2%	15%	2%	15%
	Domestic Use	2%	11%	2%	11%
	Exports	4%	27%	4%	28%
	Price ($/bu.)	-3%	-19%	-3%	-19%
Soybean	Planted Area	0%	1%	0%	2%
	Soybeans ($/bu.)	0%	2%	0%	2%
Sorghum	Planted Area	-2%	-8%	-2%	-8%
	Sorghum ($/bu.)	-2%	-11%	-2%	-12%
Ethanol	Production	2%	13%	5%	15%
	Corn Dry Milled	2%	14%	2%	14%
	Corn Cost of Ethanol	-3%	-18%	-6%	-21%
	Ethanol ($/gallon)	0%	-3%	-1%	-4%
	Distillers Grains ($/ton)	-4%	-23%	-7%	-25%
	Net Operating Return	6%	41%	11%	47%
	Net Imports (Ethyl Alcohol)	2%	10%	4%	11%

4. Concluding Comments

Our analysis suggests that significant benefits may be possible from corn yield increases and reductions in input use derived from biotech traits. These include large reductions in the amount of petroleum used for crop production; meaningful reductions in gross energy use and certain greenhouse gas emissions; as well as decreased costs and increased revenue of ethanol production that stem from a more efficient feedstock and processing system. Favorable plant economics coupled with the increased corn production have the potential to significantly increase ethanol production in the US.

We also find that the magnitudes of these benefits are influenced by government policies and market structure. The RFS, for example, would limit the utilization of corn for ethanol in favor of other fuels despite the efficiency improvements from the biotech pipeline. This may be justified as cellulosic fuels appear to offer reductions in energy consumption and greenhouse gas emissions. However, the cost competitiveness of cellulosic biofuels is currently unclear and so is the industry's ability to develop a system that can effectively produce and handle the vast amounts of feedstock necessary to fulfill the RFS. Given the early stages of development we expect that government policies will continue to evolve along with technological innovation.

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