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Impact of different bioenergy crop yield estimates on the cellulosic ethanol feedstock mix

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Abstract

Although a cellulosic ethanol mandate for 2022 is in place, significant political, economic, and agronomic uncertainty exists surrounding the attainability of the mandate. This paper evaluates the effects of bioenergy crop yield and cost uncertainty on land allocation and the feedstock mix for cellulosic ethanol in the United States. The county-level model focuses on corn, soybeans, and wheat as the field crops and corn stover, wheat straw, switchgrass, and miscanthus as the biomass feedstocks. The economic model allocates land optimally among the alternative crops given a binding cellulosic biofuel mandate. The model is calibrated to 2022 in terms of yield, crop demand, and baseline prices. The bioenergy and commodity prices resulting from a mandate are endogenous to the model. The scenarios simulated differ in terms of bioenergy crop types (switchgrass and miscanthus), bioenergy crop yields, bioenergy production cost, and the cellulosic biofuel mandate ranging from 15 to 60 billion gallons. Our results indicate that the largest proportion of agricultural land dedicated to either switchgrass or miscanthus is found in the Southern Plains and the Southeast. Almost no bioenergy crops are grown in the Midwest across all scenarios. The 15 and 30 billion liter mandates in the high production cost scenarios for switchgrass and in all miscanthus scenarios are covered to 95% by agricultural residues. Changes in the prices for the three commodities are negligible for low cellulosic ethanol mandates because most of the mandate is met with agricultural residues. The amount of bioenergy crops brought into production at the highest imposed mandate result in price increases ranging from 5% for corn and soybeans to almost 14% for wheat.

Keywords: Perennial grasses, land-use

Introduction

Rising concern about energy security and greenhouse gas emissions has led to the development of biofuel and biomass production in the United States. In 2011, U.S. corn ethanol production used 127 million metric tons of grain which represents almost 40% of corn production (FAPRI, 2012). Corn ethanol competes directly with food, feed, and export use of corn and suffers from indirect

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land-use change generated by the expansion of cropland in the rest of the world (Searchinger et al., 2008; Fargione et al., 2008; Hertel et al., 2010; Dumortier et al., 2011). Advanced (or cellulosic) biofuels can circumvent the problem of indirect land-use change and competition with other grain uses because they use non-food biomass such as agricultural and forest residues as feedstocks (Carrquiry et al., 2011; Babcock et al., 2011). In addition to ethanol production, cellulosic feedstock can also be used for co-firing in power plants because of its suitability to serve as a substitute for coal (Khanna et al., 2011b; Brechbill et al., 2011; Dumortier, 2013). Given the availability of biomass resources and the potential use for fuel and electricity production, questions concerning the effects of cellulosic feedstock production arise. The purpose of this paper is to analyze the effects of a binding cellulosic biofuel mandate on land allocation at the county level, the feedstock mix of cellulosic ethanol production, and commodity prices.

The legal basis for the development of biofuels at the federal level is the Energy Independence and Security Act (EISA) of 2007. It fosters the production of corn ethanol with the Renewable Fuel Standard (RFS) which establishes that “transportation fuel sold or introduced into commerce in the United States contains at least the applicable volume of renewable fuel”. The applicable volume of renewable fuel established by the RFS increases to 136 billion liters in 2022. Beginning 2010, the RFS requires the production of advanced biofuels from cellulosic feedstocks to reach 60 billion liters or 44% of renewable fuel production by 2022 and includes an allowable maximum of 56 billion liters of corn ethanol after 2015 (Khanna et al., 2011a). According to the Energy Information Administration, the 2011 U.S. consumption of ethanol was 48.7 billion liters which represents 9.6% of gasoline by volume and thus, is close to the 10% blending limit approved for motor vehicles at the individual level (EIA, 2012). Over the last years, the growth of corn ethanol production slowed down because the federal blenders credit (“Volumetric Ethanol Excise Tax Credit”) and the ethanol import tariff expired 2011 (FAPRI, 2012) as well as a production level coming close to the 2015 RFS requirement of 56 billion liters.

In addition to the EISA, federal policy proposals such as the American Clean Energy and Security Act of 2009 and the American Power Act of 2010 have been presented to create a cap-and-trade system in the United States. Both proposals would have affected the market for biomass production because renewable energy credits can be earned from co-firing biomass in coal-power plants. Although neither federal cap-and-trade act passed, 29 U.S. states have enacted a renewable portfolio standard (RFS) requiring electricity producers to generate a pre-determined level of power from renewable sources including biomass. From an energy security and political standpoint, the use of biomass as transportation fuels as opposed to co-firing is more popular because of the abundance of coal in the United States.

Currently, cellulosic biofuels face significant uncertainty due to economic (Babcock et al., 2011; Khanna et al., 2011a) and political issues (Meyer and Thompson, 2012). The high feedstock cost of cellulosic ethanol are directly related with the collection and transportation of biomass. Babcock et al. (2011) argue that cellulosic ethanol cannot compete with conventional ethanol and regular gasoline due to high costs and hence, a cellulosic industry is unlikely to emerge without government subsidies. They suggest that drop-in fuels such as nonester diesel or biobutanol are much more likely to emerge from cellulosic feedstocks because those fuels will not hit the blending limit for vehicle engines. The Food and Agricultural Policy Research Institute (FAPRI) projects that the mandate for the production of cellulosic ethanol will be waived and/or reduced

in the future because of insufficient capacity (FAPRI, 2012). The repeated waiver of the cellulosic mandate increases the uncertainty about the future policy for advanced biofuels (Meyer and Thompson, 2012). Heaton et al. (2008) argues that the biofuel mandate in the United States can be met with miscanthus alone based on the harvestable biomass. However, the study does neither incorporate the cost of producing miscanthus nor the opportunity cost associated with growing perennial grasses.

Previous literature quantifies regional production patterns (Perlack and Stokes, 2011; Mabee et al., 2011) and supply curves (Khanna et al., 2011a; Walsh et al., 2003) of biomass feedstocks. The work by Perlack and Stokes (2011), which is also known as the Billion-Ton-Study (BTS), characterizes biomass supply at the county level but without reporting crop price effects. Incorporating crop price effects is important because they affect the opportunity costs of changing from conventional crops such as corn and soybeans to bioenergy crops. Walsh et al. (2003) model agricultural production including energy crops in 305 agricultural statistical districts. Their analysis includes hybrid poplar and willow besides switchgrass as bioenergy crops but they do not include agricultural residues. Schneider and McCarl (2003) impose a CO₂ price and trace out the mitigation potential from the agricultural sector including bioenergy and biofuel production. Their U.S. model consists of 63 regions and includes the same bioenergy crops as Walsh et al. (2003) but does include the collection of agricultural residues.

In this paper, we focus on biomass production from agricultural residues, switchgrass, and miscanthus. Our model is also at the county-level scale like the Billion-Ton-Study (Perlack and Stokes, 2011) but we use alternative switchgrass and miscanthus yield estimates to evaluate the effects of those differences on crop and bioenergy production. We report the effects of collecting agricultural residues and growing bioenergy crops on cropland allocation, feedstock mix for cellulosic ethanol production, and commodity prices. We do not include the carbon mitigation strategies included in Schneider and McCarl (2003) because we are interested in biomass as a source of energy and not a source of carbon mitigation or sequestration. To model the production of biomass from energy crops and agricultural residue at the county level, we impose a cellulosic biofuel mandate and calculate the resulting biomass price which is necessary to meet the mandate. Based on this farmgate price, the landowner decides how much biomass to collect, harvest, and store. The model allows us to assess changing agricultural production patterns due to cellulosic biomass production that reallocates cropland throughout the United States.

We concentrate on the area of three major field crops (corn, soybean, and wheat) as potential acreage of corn stover, wheat straw, switchgrass, or miscanthus. The three crops represent about 68% of total field crop area in the United States in 2010 and are important feed and food commodities. Currently, there is no price on biomass and thus, landowners do not make crop residues available but will be in the future if the current Renewable Fuel Standard (RFS) is enforced (Khanna et al., 2011a). Compensation to harvest crop residues should have small effects on the land allocation decision of farmers and should not result in higher commodity prices which makes it attractive to contribute to the renewable energy mix. There are two reasons why significant land-use change could occur. First, if the biomass price is high enough, farmers might find it profitable to change from food crops such as corn and wheat to bioenergy crops which would subsequently lead to higher food prices and indirect land-use change. Second, if there are not sufficient agricultural residues available to cover the mandate, perennial grasses need to be put into

production to cover the difference. The two reasons are linked in the sense that a high biomass price would result if agricultural residues are not sufficient to cover the mandate.

The spatial effects for a cellulosic ethanol industry are yet to be determined because only a limited number of refineries are put in place and there remains significant uncertainty around the development of a cellulosic biofuel industry in the U.S. (Babcock et al., 2011). Because of the uncertainty surrounding bioenergy crop yields and production cost, we simulate six scenarios at the county-level by varying bioenergy crop yields and production costs. For each scenario, we impose four different binding biofuel mandates ranging from 15 to 60 billion liters increasing in 15 billion liter steps. The model is calibrated to 2022 expected yield, demand, and baseline prices.

Across all scenarios, our model indicates that bioenergy crops are primarily grown in the Southern Great Plains and the Southeast. It is not profitable in any scenario to grow switchgrass or miscanthus in the Corn Belt. In the high production cost scenarios for switchgrass and in all miscanthus scenarios, 95% cellulosic ethanol is derived from agricultural residues for the 15 and 30 billion liter mandates. With the exception of two scenarios, only the 45 and 60 billion liter mandates see a large share of bioenergy crops as a feedstock for cellulosic ethanol. Commodity prices changes are moderate for corn and soybeans and reach a maximum of 14% for wheat in the high yield, low cost switchgrass scenario. Those price effects are consistent with the finding that little acreage is dedicated to bioenergy crops in the Corn Belt.

Model

Our model includes three field crops (corn, soybeans, and wheat) and covers all counties in the contiguous United States that are engaged in the production in at least one of the crops, i.e., 2484 counties in our case. Depending on the price of biomass, the landowner harvests agricultural residues or changes to the production of bioenergy crops, i.e., switchgrass or miscanthus. We assume a representative landowner in each county who makes the decisions in terms of land allocation and production given crop and biomass prices. In the scenarios, we calculate a biomass price that results in the production of cellulosic feedstock sufficient to fulfil the exogenous cellulosic ethanol mandate. The three field crops are denoted with the subscript $j \in \{1, 2, 3\}$ and the landowners are denoted with $i \in \{1, \dots, 2484\}$. Variables and parameters associated with field crops, agricultural residues, and bioenergy crops are denoted with the superscripts f , r , and s , respectively. The national prices for crops and biomass are p_j and p_b , respectively. Babcock et al. (2011) raise concerns about the existence of a national biomass price because high transportation costs contribute to the existence of price differences across space which is especially true with cellulosic ethanol plants and/or co-firing power plants in place. Khanna et al. (2011a) and Perlack and Stokes (2011) use a national price on biomass to simulate supply patterns. Because the goal of this paper is to simulate the effects of biomass production on area allocation and cellulosic feedstock mix, we remain with this assumption of a national price and assume that it represents an incentive payment to produce biomass for energy production. However, once cellulosic ethanol plants are put online or a co-firing requirement is enacted, we expect a local biomass price to emerge.

For the three field crops, the landowner faces demand functions $Q_j = D(p, b)$ for crop j which are functions of the price vector p and the conventional biofuel demand b . For each crop, there

are three demand sectors: consumer/food, feed, and export. The demand for each sector m in our model is written as:

$$Q_j = D(p, b) = \sum_{m=1}^M \left[\gamma_{jm} \prod_{j=1}^J p_j^{\theta_{jm}} \right] + b_j \quad (1)$$

where γ_{jm} are the constants and θ_{jm} are interpreted as elasticities. We only include corn ethanol as the conventional biofuel in our model.

The crop residue from corn and wheat can be harvested for corn stover and wheat straw. There are six decision variables for landowner i : the area allocated to the three crops, the corn and wheat area harvested for residues, and the area allocated to the bioenergy crop. The net returns from field crops $B_i^f(\cdot)$ not accounting for the returns from agricultural residue collection is expressed as:

$$B_i^f(a_{ij}^f, a_{ij}^r) = \sum_{j=1}^3 p_j (a_{ij}^f + a_{ij}^r) y_{ij} - \sum_{j=1}^3 C_{ij}(a_{ij}^f, a_{ij}^r) \quad (2)$$

where the areas allocated to corn, soybeans, and wheat not harvested for agricultural residues are denoted by a_{ij}^f . Harvesting agricultural residue does not interfere with the supply of field crops and thus, the area allocated to field crops with residue collection is denoted by a_{ij}^r . The cost function $C_{ij}(\cdot)$ is assumed to be of the following form:

$$C_{ij}(a_{ij}^f, a_{ij}^r) = \alpha_{ij} (a_{ij}^f + a_{ij}^r) + \frac{1}{2} \beta_{ij} (a_{ij}^f + a_{ij}^r)^2 \quad (3)$$

where $\alpha_{ij} > 0$ and $\beta_{ij} > 0$ are county and crop specific cost parameters. Note that $\partial C_{ij}(\cdot) / \partial a_{ij}^f > 0$ and $\partial C_{ij}(\cdot) / \partial a_{ij}^r > 0$ which represents increasing marginal cost. This captures either the decrease of yields because marginal land with lower average yields is brought into production or the requirement of more inputs use for the same reason (Mallory et al., 2011). The net returns from collecting and selling crop residues is written as:

$$B_i^r(a_{ij}^r) = p_b \sum_{j=1}^3 \delta_{ij} y_{ij} a_{ij}^r - \sum_{j=1}^3 \eta_{ij} a_{ij}^r \quad (4)$$

where δ_{ij} summarizes the agricultural residue specific energy content and the county-specific residue removal coefficient. Equation (4) assumes that harvesting agricultural residues results in a fixed per hectare cost and does not influence the slope of the marginal cost function. Because a_{ij}^r enters equation (3) in a non-linear way, the problem is guaranteed to have a solution during the numerical analysis. The specification of the revenue and cost function also results in an all-or-nothing allocation of a particular crop to residue collection in county i . The profit from bioenergy crop production is written as:

$$B_i^s(a_i^s) = p_b \delta_i^s y_i^s a_i^s - \eta_i^s a_i^s \quad (5)$$

So the profit maximization for the landowner is the sum of equations 2, 4, and 5, i.e.,

$$B(a) = B_i^f(a_{ij}^f, a_{ij}^r) + B_i^r(a_{ij}^r) + B_i^s(a_i^s) \quad (6)$$

subject to a binding land constraint and non-negativity constraints. Setting up the Lagrangian and deriving the following first order conditions for a_{ij}^f , a_{ij}^b , and a_i^s :

$$p_j y_{ij} - \alpha_{ij} - \beta_{ij} (a_{ij}^f + a_{ij}^b) - \lambda + \mu_1 = 0 \quad (7)$$

$$p_j y_{ij} + p_{bm} y_{ij}^b - \eta_{ij} (a_{ij}^f + a_{ij}^b) - \lambda + \mu_2 = 0 \quad (8)$$

$$p_b \delta_i^s y_i^s - \eta_i^s - \lambda + \mu = 0 \quad (9)$$

$$\sum_{i=1}^3 a_{ij}^f + \sum_{i=1}^3 a_{ij}^b + a_i^s - A = 0 \quad (10)$$

$$a_{ij} \mu_j = 0 \quad (11)$$

where λ and μ are the Lagrange multipliers associated with the land and non-negativity constraints.

The next section describes the calibration of the theoretical model. The only exogenous variable in our model is the cellulosic biofuel mandate. The commodity and biomass prices are determined endogenously in our model based on the first order conditions, the demand equations, and the cellulosic biofuel mandate. Based on the biomass price, we find a competitive equilibrium such that equation (7-11) are satisfied. The numerical procedure will start with the given biomass price plus the three crop prices representing starting values. Based on the prices, landowners allocate their land and crop as well as biomass production emerges, if the resulting production is not consistent with the demand and the mandate at those prices, the algorithm continues until convergence. Agriculture is a perfectly competitive market and hence, all agents are price takers and do not take the effect of their acreage decision on output prices into account. Due to differences in the energy content of corn stover, wheat straw, and bioenergy crops, we express the biomass price in dollars per gigajoule (GJ).

Data and Model Calibration

Field Crops Model

The baseline model in the absence of any biomass production is calibrated to 2022 in terms of commodity prices, demand, yield, and area. The prices and price elasticities for food, feed, and export for demand equation (1) can be found in table 1 and are taken from FAPRI (2011a). We use the 2022 crop prices and demand quantities from FAPRI (2013) to determine the constant (γ_{jm}) as well as the use of 5.558 billion bushels (or 141.22 million metric tons) of corn for ethanol production.

The county-level harvested area is obtained from the National Agricultural Statistics Service (NASS) for 1975-2010. Yield and area for crop j in county i was set to zero if crop production occurred in less than two years between 2000 and 2010. We use the 2022 expected yields by crop and county from the University of Missouri Food and Agricultural Policy Research Institute Farm Cost and Return Tool (FAPRI CART) to determine the yield parameter y_{ij} used in our simulation. The base area a_{ij} is the average crop area harvested between 2000 and 2010 corrected to match total domestic use and exports in 2022. With no price on biomass, the areas correspond to a_{ij}^f in equation (2).

	γ_{jm}	PCO	PSB	PWH
Base price (per bushel)		\$4.47	\$10.83	\$5.90
Base price (per metric ton)		\$175.92	\$397.88	\$216.65
Food Demand/Consumer				
Corn	128.17	-0.23 ¹	-	-
Soybeans	710.78	-	-0.43 ²	-
Wheat	53.80	-	-	-0.08 ²
Feed Demand				
Corn	46.35	-0.20 ²	-	-
Exports				
Corn	672.57	-0.26 ²	-	-
Soybeans	1423.93	-	-0.63 ¹	-
Wheat	7095.97	-	-	-1.23 ²

Table 1: Prices and price elasticities for food, feed, and export. Sources (1) Chen (2010) and (2) FAPRI (2011b)

Besides the expected yield, FAPRI CART provides cost and return classified according to the USDA Economic Research Service Farm Resources Regions. To obtain county specific parameters α_{ij} and β_{ij} , we proceed in two steps. First, we use the FAPRI CART parameters on operating cost by crop and farm resource region for 2022 and set the parameter α_{ij} equal to the total operating cost composed of chemicals, custom operations, fertilizer, energy (i.e., fuel, lube, and electricity), interest on operating capital, repairs, seeds, and miscellaneous costs. If acreage is increased, we assume that more inputs are needed per hectare resulting in increasing marginal cost. The increase in marginal cost might be due to a necessary increase in fertilizer use or a reduction in yields because of decreasing land quality (Mallory et al., 2011). We assume that all counties in a particular farm resource region have the same α_{ij} . Second, assuming profit maximizing but price taking behavior allows the calculation of the county specific parameters β_{ij} because the landowner sets marginal revenue equal to marginal cost, i.e., $p_j \cdot y_{ij} = \alpha_{ij} + \beta_{ij} a_{ij}^f$. Given p_j , y_{ij} , α_{ij} , and a_{ij}^f enables us to obtain β_{ij} for the base year.

Removing all crop residues is not possible because a certain level of soil carbon and nutrients needs to be maintained. Crop residues also help to control for soil erosion. The Billion-Ton-Study (Perlack and Stokes, 2011) reports sustainable retention coefficient for corn stover and wheat straw at the county-level. The sustainable retention coefficient is the dominant factor in determining the biomass yield for crop residues. For the purpose of this paper, we do not take into account the uncertainty associated with the removal coefficient. (Perlack and Stokes, 2011) report to removal coefficients depending whether reduced-till or no-tillage is used after the residue removal. We use the reduced-tillage rate and assume that there is not effect on the crop yield due to the uncertainty of yield estimates under different tillage systems at the national scale. This will subsequently underestimate the amount of corn stover and wheat straw available for ethanol production. The residue to grain ratio on a dry basis is 1:1 and 1:1.5 for corn stover and wheat straw, respectively. Corn stover and wheat straw as well has bioenergy crops differ slightly in their energy content. The

heating values in gigajoules (GJ) per metric ton are 17.45, 17.63, and 18.51 for corn stover, wheat straw, and switchgrass/miscanthus respectively. The removal coefficients together with the residue to grain ratio and the energy content determines the county-specific value of δ_{ij} . The parameter δ_i^s for switchgrass/miscanthus represents directly the conversion from dry tons to gigajoule per hectare. Note that due to differences in the energy content of corn stover, wheat straw, and bioenergy crops, we express the biomass price in dollars per GJ (\$/GJ). The removal of crop residue requires the switch to conventional tillage or reduced tillage.

Three data sources for bioenergy crops are used in this paper. The first dataset on switchgrass (*Panicum virgatum*) yield by Jager et al. (2010) predicts county level yield by fitting an empirical model to observed field trials. The data has been used in the Billion-Ton-Study (BTS) (Perlack and Stokes, 2011) to evaluate the availability of biomass in the United States. The work by Baskaran et al. (2010) provides the second switchgrass yield dataset consisting of simulated yields using the Soil and Water Assessment Tool (SWAT). As reported by Baskaran et al. (2010), there can be significant differences among estimated switchgrass yields across the United States because large scale plantation has not yet occurred and thus, yields at the county level are unknown. Baskaran et al. (2010) evaluate lowland yields and to allow for comparison of the scenarios, only the lowland yields from Jager et al. (2010) are used. The differences between the two yield datasets can be categorized in four large regions: The only region where the SWAT model predicts higher yields per ha is in the southern part of Texas with a yield difference ranging between 1.5 to 2.5 tons per hectare. The BTS predicts higher yields in a strip ranging from Western parts of Texas to Western Kansas. Higher yield difference between 4-8 tons per ha are observed in the region ranging from the Eastern part of Iowa all the way to Pennsylvania. The last region where the BTS yields are significantly higher are in the Appalachian mountains. Note that with the exception of the Southern tip of Texas, all other counties are predicted to have higher yields in the BTS scenario. The miscanthus yield data is based on the work by Miguez et al. (2012). We will refer to the datasets from (Perlack and Stokes, 2011) and Baskaran et al. (2010) as “High Yield” and “Low Yield”, respectively.

The cost of producing corn stover and wheat straw includes the replacement of nutrients, harvesting, storing, and baling (Huang et al., 2009; Khanna et al., 2011a). The average nutrient replacement for corn stover and wheat straw is \$26/t and \$25/t, respectively (Perlack and Stokes, 2011). The collection and harvesting cost per hectare is assumed to be a function of yield $C(y_{ij}) = 69.04 - 18.89 \cdot \ln(y_{ij})$ for both crop residues based on (Perlack and Stokes, 2011). The storage costs are estimated to be \$8/t Huang et al. (2009).

To determine the production cost of switchgrass and miscanthus, we follow closely the model outlined by Jain et al. (2010). We assume a lifespan of 10 and 15 years for switchgrass and miscanthus, respectively. As in previous literature, we annualize all the costs to obtain yearly operating cost (Perrin et al., 2008; Jain et al., 2010). Duffy and Nanhou (2001) and Jain et al. (2010) suggest that no nitrogen fertilizer should be applied to switchgrass in the establishment year to avoid competition with weed. We assume that the nitrogen application rate depends on the biomass yield and 10 kg per ha per ton are applied (Perrin et al., 2008). The application rates for phosphorus, potassium, lime, atrazine, and 2,4-D are taken from Jain et al. (2010) and are assumed to be the same for all states under consideration. Note that the application rates are composed of a fixed rate per ha and a rate that depends on the biomass yield. National prices for the fertilizers,

herbicides, and pesticides are taken from the U.S. Department of Agriculture (USDA) National Agricultural Statistical Service (NASS) database for 2012.

We are conducting low cost and high cost scenarios with respect to the bioenergy crop production costs. Jain et al. (2010) indicate uncertainty with respect to nitrogen, phosphorous, and potassium application rates. Note that Jain et al. (2010) assume that this uncertainty has no effect on the yield, i.e., the yield in the long-run is unaffected by the nitrogen application rate. The cost of producing switchgrass is composed of mowing, raking, baling, storage, nutrient application, and annualized establishment costs. The mowing, raking, and baling costs are taken from Chen (2010) which also provide high and low baling costs. We annualize the establishment cost calculated by Huang et al. (2009) (except land rental and annual operating capital) assuming a 10 year lifespan and 7% discount rate. Jain et al. (2010) uses high and low fertilizer application rates of 56 and 140 kg N ha⁻¹. They assume that the long-run yield of switchgrass is the same for the low and high fertilizer application rate and the uncertainty comes from the rate necessary to achieve the long-run yield. Based on a price of \$1.20 per kg N, the price per ha of fertilizer applications is \$67.20 in the low cost scenario and \$168.00 in the high cost scenario. We calculate the net present value of all the operating cost by assuming a discount rate of 4% and then annualize the net present value as follows:

$$\text{Annual Cost} = r \cdot NPV \cdot \left(1 - \frac{1}{(1+r)^t}\right)^{-1}$$

Results and Discussion

We run eight different scenarios to analyze the effects of biomass production on bioenergy feedstock mix. Scenario 1 and 2 use the switchgrass yields from the Billion-Ton-Study (BTS) (Jager et al., 2010). Scenario 3 and 4 use SWAT simulated yields from Baskaran et al. (2010). The last four scenarios use the switchgrass and miscanthus yields simulated by Miguez et al. (2012). For each bioenergy yield estimates, we run a low cost and a high cost switchgrass production cost scenario. The scenarios are simulated for cellulosic ethanol mandates ranging from 15 to 60 billion liters. The 60 billion liters is equivalent to the total 2022 cellulosic mandate.

The effect on the feedstock mix is represented in figure 1. Note that in most scenarios, a majority of cellulosic ethanol is produced from agricultural residues. The price of corn only increases slightly because landowners planting corn do not have an incentive to switch to either soybean or switchgrass. Soybeans do not produce biomass and switchgrass is not profitable in the corn growing regions, especially the Corn Belt. Due to the ethanol expansion in recent years, land values are already at a very high level. However, wheat has a lower profitability compared to corn and despite being able to deliver wheat straw as a biomass, landowners still find it more profitable to change to switchgrass which leads to a reduction in the supply of wheat and thus, to an increase in wheat prices. The same issue arises for soybeans but to a lesser extent.

Figure 2 reflects the farm gate price necessary to produce the amount of cellulosic ethanol required to meet the mandate. Because miscanthus has a significantly higher yield (although also higher costs as well), the farmgate price necessary for miscanthus is a bit lower than for switchgrass. Counties and states in the Corn Belt where corn and soybean are still the more

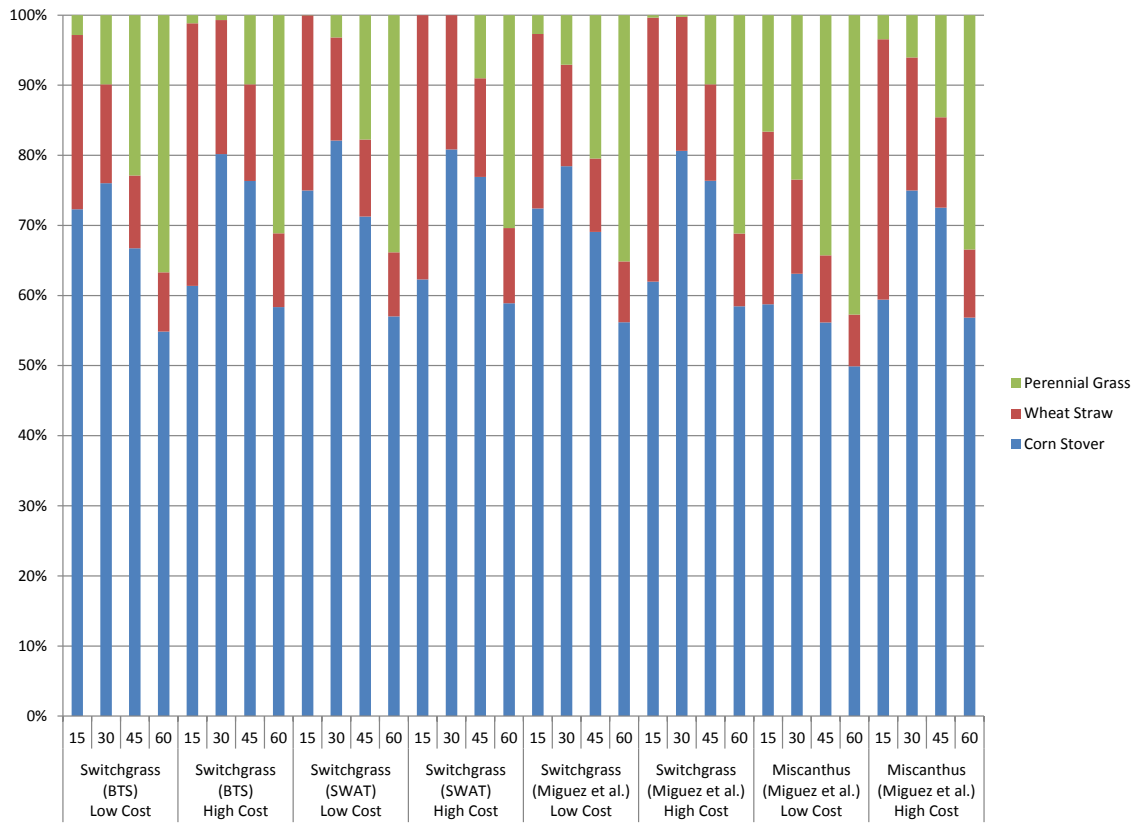


Figure 1: Feedstock Mix

profitable land-use and hence, do not see a large share of switchgrass. This holds even in the case of high switchgrass yields in those areas and low cost.

Conclusion

With cellulosic biofuels for the transportation sector as well as biomass for co-firing, changes might come to the U.S. biomass sector. This paper revisits the issue of biomass production and supply in terms of county-level net revenue effects and switchgrass share. Corn stover and wheat straw affect the crop production only to a small extent because the harvest of crop residues does not interfere with the crop production, i.e., limited diversion of cropland observed with the exception of soybeans. However, if the price of biomass increases sufficiently, it becomes profitable for land owners to transform cropland into perennial grasses, i.e., switchgrass in our model. Because switchgrass is replacing commodity crops, the price effects are felt at the national scale and counties not primarily in biomass production are affected as well. Because switchgrass has not yet been grown in the U.S. on a large scale, uncertainty remains with respect to switchgrass yields and production cost. In this paper, we use two sources of switchgrass yields and run four scenarios varying the production costs for both yield data. We find that there is significant variation in terms

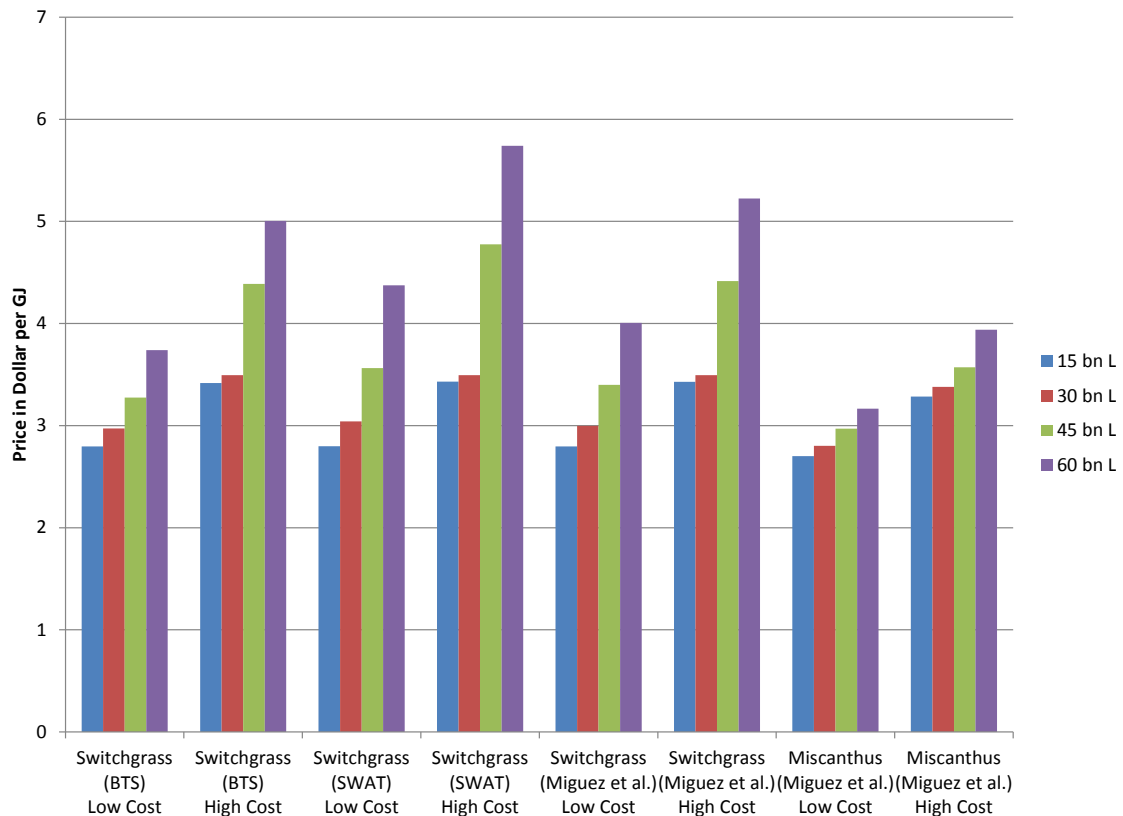


Figure 2: Farmgate price necessary to meet various ethanol mandates

of where switchgrass is grown and what the impacts on net revenue are. When costs are low, counties in the Great Plains profit the most because they either grow switchgrass or have a higher net revenue from wheat and wheat straw production.

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