U.S. Renewable Fuel Standard 2: Impacts of Cellulosic Biofuel Production

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I. Introduction

Recent price, demand/supply, and trade movements in global commodity markets have drawn increasing attention to the impact of biofuel production and policy on these markets. At the same time, many nations view domestic biofuel production as a way of improving rural development, increasing energy security, and reducing greenhouse gas emissions. The implications of these national policies has garnered the interest of researchers and policymakers; however, inquiries have tended to focus primarily on the impacts of conventional ethanol production, using primarily coarse grains in the U.S./EU and sugarcane in Brazil.

Provisions in the 2007 Energy Independence and Security Act (EISA) require significant use of biofuels derived from cellulosic materials, the primary feedstock for so-called 'next-generation' biofuels.[1] While production levels of these cellulosic feedstocks have been below target levels in the early implementation phase of the revised Renewable Fuel Standard (RFS) (referred to here as RFS2) set in the EISA, more aggressive future standards will likely have to be met. Because these feedstocks potentially compete for land with traditional agricultural commodities, meeting the cellulosic biofuel mandate in the RFS2 has the potential to impact agricultural, land, and energy markets on a global scale.

This study provides a preliminary analysis of the economy-wide impacts of the production of cellulosic-based ethanol mandated in the U.S. renewable fuel standard. Studies on the macroeconomic impacts of conventional ethanol have

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[1] Cellulosic biofuel refers to the process of transforming lignocellulosic feedstocks (comprised of lignin, cellulose, and hemicellulose) into fuels. This is in contrast to conventional biofuels, which transforms starch into fuel. In the U.S., conventional ethanol production comes primarily from corn.

revealed significant impacts on global agricultural commodity markets and land values at both the intensive and extensive margins. Cellulosic feedstocks, such as agricultural residues, perennial grasses, and other dedicated energy crops have much different production characteristics and have the potential to interact differently with other agricultural commodities.

Although there are numerous candidate crops for next-generation bioenergy pathways, this work focuses on switchgrass. Switchgrass has long been a candidate feedstock for biofuel production, and can be characterized by high establishment costs, and relatively low annual operating costs. However, switchgrass must be grown on land that potentially competes with other conventional crops. Therefore it is plausible to expect switchgrass production to induce broader economy-wide impacts, both domestically and globally.

We evaluate the impacts of the cellulosic mandate using several metrics and assumptions about the feedstock mix. First, we examine the impact of the mandate on global commodity prices and quantities. Second, we examine changes in U.S. export markets, and how these dynamics are driven by assumptions regarding the competition between bioenergy feedstocks and traditional crop and livestock industries. Third, we consider the impact of the mandate on both the intensive and extensive land use margins. Specifically, we analyze the changes in land values in the U.S. between crops. Similar types of analyses are used to infer the implications for greenhouse gas emissions due to land use changes; however this study focuses on improving and better understanding the implications of acreage changes.

Assessing the mandate using these metrics will allow both the policy and research communities to begin considering some of the expected and unintended policy consequences of the second phase of the U.S. Renewable Fuel Standard. It is also important to consider the heterogeneous production characteristics of various cellulosic feedstocks and how they might affect domestic and global commodity markets differently. This study takes the first step by considering a single candidate feedstock.

This paper is organized as follows. Section 2 reviews the relevant literature. There are two strands that are important for this analysis. First, the global assessment literature used to analyze the economy-wide impacts of biofuel policy, and second, the advanced feedstock production literature. Section 3 describes the computational model and data used for analyzing the mandate. A methodology and assumptions used for creating new feedstocks sectors are documented. Section 4 reports preliminary results. Section 5 concludes.

II. Literature Review

Global Biofuel Assessment Studies

Previous literature has addressed a range of issues regarding conventional (starch-based) ethanol production and the implications of various national biofuel policies. With corn ethanol production well on its way, the ‘next-generation’ feedstocks are clearly cellulosic. However, as of 2010 there is no commercial production of cellulosic ethanol (CRS, 2010); thus the cellulosic portion of the EISA mandate is clearly a daunting challenge.

To date, only pieces of the RFS2 mandate have been analyzed in the literature. For example, several studies (e.g., the billion-ton study by Perlack et al., 2005) have examined the potential supply of cellulosic feedstocks. Others have examined potential yields of feedstocks, and production costs of feedstocks. Those that have looked at economic/environmental impacts of cellulosic production have done so in a partial-equilibrium framework that has been limited in scope or coverage. Indeed, many studies examine the impacts to localized areas, such as counties or states.

BRDI (2008) utilize the Policy Analysis System (POLYSYS) model from the University of Tennessee to consider the impacts from 20 billion gallons of cellulosic biofuels by 2022 (along with the USDA baseline projections). The majority of the 20 billion gallon production target comes from crop residues (64 percent), with corn stover responsible for 70 percent of that amount. To produce 20 billion gallons of cellulosic-derived biofuels, 16 to 19 million acres of land are needed for the non-residue feedstocks.

The Food and Agricultural Policy Research Institute (FAPRI) baseline models the first-generation portion of the EISA mandate; however, they assume that the cellulosic portion is waived. The FAPRI baseline does include the possibility of cellulosic production, and in their most recent baseline (FAPRI, 2011) they project the amount of corn stover used in ethanol production to be 3,858 metric tons (compared to 128,922 metric tons of corn used for ethanol production). There is no switchgrass used for ethanol production.

In a series of papers, Marshall and Sugg (2009, 2010) examine the economic/environmental impacts of utilizing cellulosic feedstocks for transportation fuels. In the first paper (2009), the authors question the results from Perlack et al. (2005). In particular, the authors note that the assumption of no-till adoption is unrealistic; and that removal of corn stover at levels needed to meet the EISA mandate would come at great environmental costs. Marshall and Sugg (2010) utilize the same model as the 2009 study (Regional Environment and Agriculture Programming (REAP) model) to analyze the impacts of large-scale switchgrass production. Such production will involve substantial increases in land acreage (new acreage and from existing cropland) and result in large changes to agricultural prices.

A CGE-based study by Gehlhar, Winston, and Somwaru (2010) considers several alternatives to meeting the U.S. mandate. Their model, United States Agricultural General Equilibrium (USAGE), is CGE, and thus it considers inter-industry linkages; however, the model is limited to the U.S., and has no land-use/environmental component. Nevertheless, they find that the mandate could benefit the U.S. economy, due to higher household wages, higher household incomes, and lower energy import prices.

Another CGE-based study, by Gurgel, Reilly, and Paltsev (2007) investigates the potential impacts of utilizing cellulosic biofuels as a climate-mitigation strategy. Their energy-intensive model: Emissions Prediction and Policy Analysis (EPPA) allows for cellulosic biofuel production globally while taking into account land-use change. Their results indicate that global prices for agriculture (they do not break out this sector) and forestry products rise 5-10 percent, and that the amount of land needed to grow the cellulosic feedstocks is similar to the amount of land used to grow crops in the present day.

Feedstock Production Overview

A central hypothesis that this study addresses is how cellulosic feedstocks, grown as inputs into the same biofuel industry, interact with world agricultural markets. It is critical therefore to properly model the production characteristics of these heterogeneous feedstocks. Extensive commercial production for cellulosic feedstocks does not yet exist; however, numerous agronomic and economic studies have been conducted to explore the optimal methods for growing, harvesting, storing, and transporting cellulosic feedstocks.

CRS (2010) and Brechbill and Tyner (2008) review the production literature for a variety of cellulosic feedstocks, covering corn stover, switchgrass, miscanthus, forest residues, and short-rotation trees. This study aggregates these findings to construct a generic feedstock sector perennial crop (switchgrass). Miscanthus, a more productive crop per acre than switchgrass, could also be used as a candidate feedstock, although we do not expect this restriction to significantly impact our results as the production characteristics are generally similar.[2] Table 1 provides a summary of the seeding, harvest, storage, and transportation costs for switchgrass production. While yields are expected to vary considerably across growing regions in the United States, integration into a global framework requires a fairly high level

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[2] Incoporating miscanthus and other cellulosic feedstocks is our focus for further research.

of aggregation. This study assumes an average yield of 4 tons/acre of useable biomass. Advanced cellulosic biofuel production is capable of producing approximately 90 gallons per ton of feedstock, which implies meeting the RFS will requires approximately 4.8 millions acres of land in 2014 and 44 million acres by 2022 (Wang, 2010). It is assumed that switchgrass can be grown on any land suitable for corn or wheat production.

Table 1: Switchgrass Production Cost per Acre Summary

	Establishment Year	Harvest Year
Seeding	**$82.28**	**-**
Chemicals	**$61.32**	**$136.96**
Harvest	**-**	**$27.50**
Storage	**-**	**$12.38**
Transportation	**-**	**$3.08**
Total Costs/Price w/ Zero Profit	**$72.00**	

III. Methods/Data

In order to capture the interactive effects of the mandate across regions and time, we employ the revised Future Agricultural Resources Model (FARM), a global dynamic-recursive CGE model. The model utilizes the GTAP 7 economic data set as a point of departure for developing the necessary biofuel sectors required to properly model the global impacts of the U.S. Renewable Fuel Standard.

The model has been expanded here to include a detailed biofuel component that includes four types of ethanol as well as a dried distiller's grains with solubles (DDGS) coproduct from corn, or wheat-based ethanol production. Conventional ethanol pathways include corn-to-ethanol, sugar-to-ethanol, and wheat-to-ethanol. An advanced ethanol sector has been constructed to use a perennial bioenergy feedstock (switchgrass) in the conversion process. All ethanol is assumed to be a perfect substitute for gasoline. Output from the DDGS sector is used as an input in the livestock industries as a source of feed. One feature of FARM is the modeling of joint production activities. A constant elasticity of transformation (CET) function is used to split the output of the coarse grain ethanol-refining sector into ethanol for fuel and DDGS. Previous operations data suggests that DDGS production accounts for approximately 20% of the revenue accruing to ethanol plants in the U.S. and this characteristic has been maintained in FARM (Tiffany and Eidman, 2003).

FARM is a dynamic recursive model, which allows for multi-period simulations of the RFS, coupled with expected economic development from exogenous population growth and changes in factor productivity. The dynamic framework allows for several periods of the mandate to be modeled simultaneously. Table 2 documents the RFS2 mandate.

Table 2: U.S. RFS Volumetric Mandates (billion gallons)

Year	Conventional Biofuels	Cellulosic Biofuels
2014	14.4	1.75
2022	15	16

In order to capture potential land-use effects induced by conventional and advanced biofuel production, FARM uses the GTAP land cover data set, expanded to include land used for corn and switchgrass production. The latter is assumed to follow similar distribution patterns across agro-ecological zones as wheat in the U.S. Competition for land on the intensive and extensive margins follows the constant elasticity of transformation approach outlined in Hertel et al (2008). Correctly modeling global land-use changes is required for quantifying direct and indirect emissions from land-use; although this last step has been omitted from this analysis in an effort to focus on non-emissions indicators.

Policy Scenarios

In order to isolate the effects of a candidate cellulosic feedstock used for biofuel production on global agricultural markets, we run a series of simulations. These scenarios are not meant to reflect the levels of each feedstock that will be used, but rather to explore the different interactions in global markets.

First we establish a baseline scenario that includes little ethanol production in the U.S. and abroad. The model is calibrated to 2004 data when U.S. corn ethanol production levels were approximately 3.4 billion gallons. Next we establish the conventional ethanol mandate scenario, denoted 'S1' below, where the model simulates a 15 billion gallon production level. It is assumed that this mandate is binding and production cannot exceed this level. Finally, we simulate the conventional ethanol mandate alongside a 500 million gallon cellulosic ethanol mandate, denoted 'S2'[3]. Although this level is approximately a third of the 2014 cellulosic mandate, modeling challenges required simulating a significantly lower amount. This level is still well beyond current U.S. cellulosic biofuel production and is also large enough to provide insights into the larger economy-wide impacts of the cellulosic mandate. Future work will consider the full cellulosic mandates.

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[3] Meeting the full RFS2 mandate mentioned in Table 2 has been met with some difficulty. This is perhaps justified by the research from FAPRI (2011) who do not model the full mandate.

IV. Results/Discussion

Our results echo those of other studies on the impact of the conventional ethanol mandates in the U.S. Renewable Fuel Standard established in EISA. Simulations of the cellulosic component of the RFS show similar effects, although somewhat more muted than for corn. This result is partly due to the difference in the volumetric simulations conducted, which are much lower for cellulosic ethanol than conventional ethanol.

Tables 3 and 4 document price and output movements for several key agricultural and energy commodities. As expected, the conventional ethanol mandate in the RFS2 dramatically increases the demand for corn, increasing domestic corn prices and putting competitive pressure on other agricultural commodities. The impact on global agricultural markets is strongest for the conventional ethanol mandate and differs slightly amongst regional trading partners. Domestic ethanol prices increase significantly as a result of the mandate. This increase pushes up refined petroleum prices slightly, which in turn slightly decreases demand (and total output) for refined petroleum products.

Table 5 reports predicted U.S. export fluctuations from both scenarios. The cellulosic ethanol mandate mildly reduces U.S. exports of corn and other coarse grains beyond the effects of the conventional ethanol mandate. This effect from the cellulosic mandate is strongest in the wheat market, as switchgrass will primarily compete with land suitable for wheat production. It is important to note that this result is likely sensitive to the chosen cellulosic feedstock. While we would expect similar results for other perennial grasses used as miscanthus, using agricultural residue or short-rotation trees will likely produce very different results. It is therefore essential that future work consider heterogeneous cellulosic feedstock candidates for ethanol production.

Figure 1 shows predicted changes in land values across several select regions and agricultural commodities. The results confirm that competition between crops for land is driving the price and output movements reported above. Production of all crops not used as an input to ethanol refining is partially displaced in the U.S. by corn in the conventional ethanol mandate and switchgrass in the cellulosic ethanol mandate. As U.S. exports decrease, land values for corn and other coarse grains increase, providing incentives for landowners abroad to convert land into the production of these commodities. Interesting, the so-called indirect land use change effect (ILUC) of both the conventional and cellulosic mandates is not as strong as other reported estimates. These land-use changes have been cited as a potentially important contributor to the life-cycle greenhouse gas emissions induced by U.S. biofuel policy.

V. Conclusion

Incorporating the mandated expansion of cellulosic ethanol production into global biofuel impact assessments is essential for evaluating the stated objectives and consequences of U.S. bioenergy policy. This study uses a single candidate cellulosic feedstock, switchgrass, to provide insights into the possible domestic and international economic impacts of the U.S. Renewable Fuel Standard. Effects similar to those experienced due the expansion of conventional ethanol are found, but to a lesser extent. However, if cellulosic biofuels draw feedstocks that compete for agricultural land, increased demand for these feedstocks are likely to have larger economy-wide implications than shown in this study. Modeling large-scale cellulosic mandates is difficult and is an important area of future work.

Table 3: Percentage Change in Prices from Conventional and Cellulosic Ethanol Production

	USA		West EU		China		MidEastNAf		Latin America		India	
	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2
Agricultural Commodities												
Corn	13.56%	14.22%	0.54%	0.71%	0.67%	0.81%	0.42%	0.70%	0.91%	1.15%	0.36%	0.47%
Wheat	2.48%	3.13%	0.30%	0.44%	0.39%	0.55%	0.40%	0.68%	0.61%	0.85%	0.31%	0.42%
Other Coarse Grains	3.37%	3.75%	0.30%	0.44%	0.40%	0.54%	0.36%	0.61%	0.62%	0.82%	0.31%	0.42%
Vegetables	3.37%	3.98%	0.30%	0.45%	0.40%	0.43%	0.36%	0.59%	0.62%	0.80%	0.31%	0.42%
Paddy Rice	3.28%	4.08%	0.41%	0.56%	0.26%	0.38%	0.20%	0.46%	0.55%	0.76%	0.30%	0.41%
Livestock	1.69%	2.31%	0.27%	0.40%	0.34%	0.47%	0.48%	0.75%	0.86%	1.09%	0.31%	0.43%
Forestry	1.39%	1.55%	0.29%	0.43%	0.26%	0.38%	0.31%	0.57%	0.39%	0.59%	0.29%	0.39%
Energy Commodities												
Petroleum Products	0.64%	0.88%	0.28%	0.53%	0.26%	0.47%	0.28%	0.60%	0.31%	0.66%	0.28%	0.56%
Conventional Ethanol	18.50%	18.81%	0.28%	0.41%	0.39%	0.52%	0.00%	0.00%	0.37%	0.58%	0.29%	0.41%

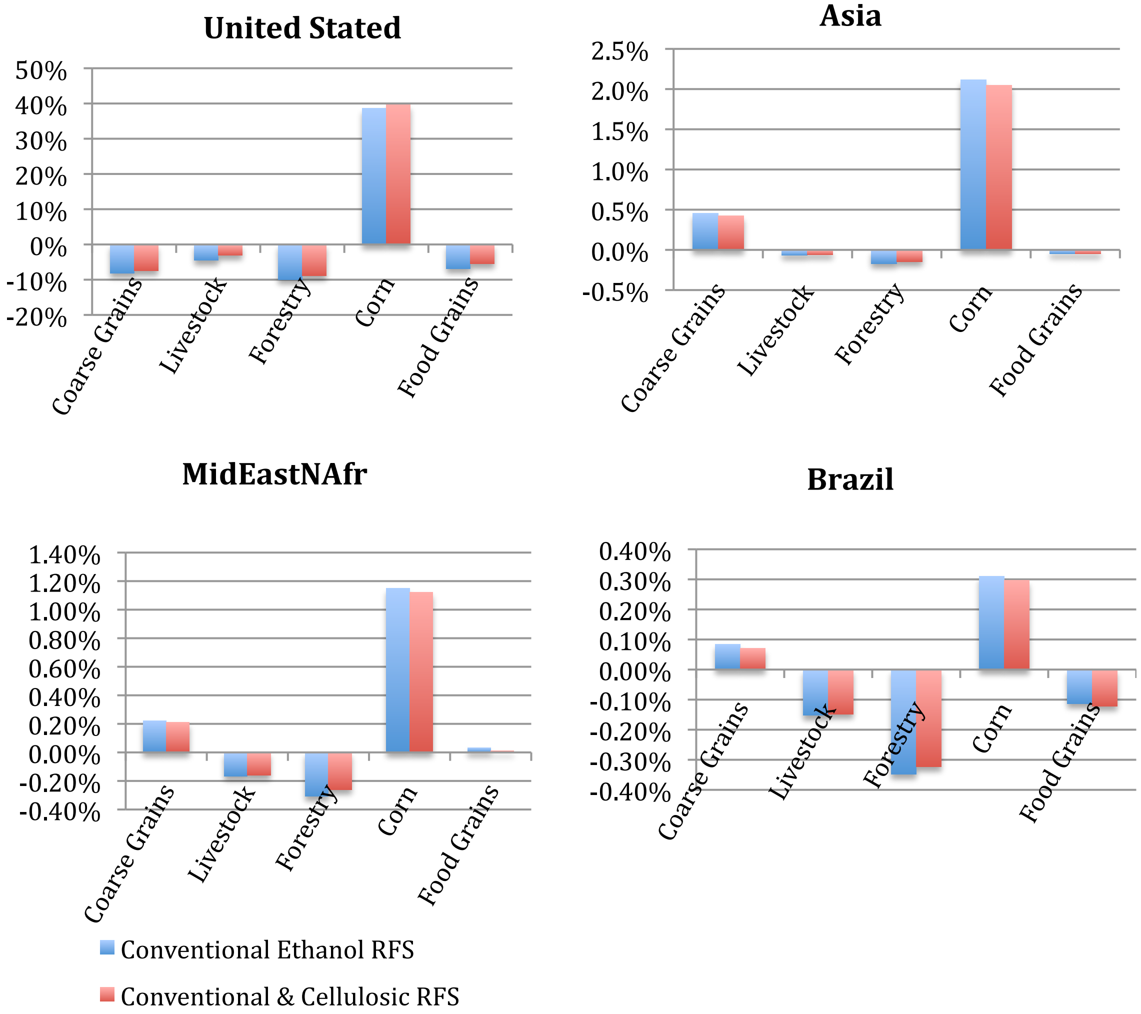
Table 4: Percentage Change in Output from Conventional and Cellulosic Ethanol Production

	USA		West EU		China		MidEastNAf		Latin America		India	
	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2	S1	S2
Agricultural Commodities												
Corn	60.65%	60.39%	0.24%	0.24%	2.14%	2.21%	1.51%	1.56%	1.48%	1.52%	0.36%	0.47%
Wheat	-2.97%	-3.57%	0.08%	0.12%	0.04%	0.06%	0.14%	0.20%	0.31%	0.39%	0.31%	0.42%
Other Coarse Grains	-2.29%	-2.48%	0.08%	-2.48%	0.49%	0.52%	0.39%	0.43%	0.30%	0.33%	0.31%	0.42%
Vegetables	-3.39%	-3.85%	0.11%	0.14%	-0.02%	-0.03%	0.02%	0.05%	0.20%	0.22%	0.02%	0.02%
Paddy Rice	-2.59%	-3.12%	0.14%	0.18%	-0.03%	-0.03%	0.04%	0.09%	0.28%	0.35%	0.00%	0.00%
Livestock	-1.02%	-1.32%	0.02%	0.02%	-0.06%	-0.07%	-0.14%	-0.12%	-0.29%	-0.29%	0.31%	0.43%
Forestry	-0.92%	-0.98%	0.01%	0.01%	0.01%	0.01%	-0.02%	-0.03%	-0.01%	-0.10%	0.29%	0.39%
Energy Commodities												
Petroleum Products	-0.13%	-0.21%	0.28%	0.53%	0.26%	0.47%	0.28%	0.60%	0.31%	0.66%	0.28%	0.56%
Conventional Ethanol	580%	582%	0.28%	0.41%	0.39%	0.52%	0.00%	0.00%	0.37%	0.58%	0.29%	0.41%

Table 5: Percentage Change in U.S. Agricultural Exports to Select Regions

	WestEU		China		MENA		India		Latin America	
Agricultural Commodities	S1	S2	S1	S1	S2	S2	S1	S2	S1	S2
Corn	-21%	-22%	-18%	-22%	-20%	-20%	-22%	-22%	-17%	-18%
Wheat	-3.83%	-4.69%	-2.86%	-4.19%	-3.48%	-4.05%	-4.19%	-5.16%	-2.69%	-3.23%
Other Coarse Grains	-1.70%	-1.84%	-3.84%	-4.89%	-3.90%	-4.02%	-4.89%	-5.30%	-3.10%	-3.26%
Livestock	-2.65%	-3.52%	-2.62%	-2.54%	-2.34%	-2.94%	-2.54%	-3.45%	-1.85%	-2.53%

Figure 1: RFS-Induced Changes in Land Value for Select Regions



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