WRI POLICY NOTE

WORLD RESOURCES INSTITUTE

ENERGY: BIOFUELS

No. 5

FIELDS OF FUEL: MARKET AND ENVIRONMENTAL IMPLICATIONS OF SWITCHING TO GRASS FOR U.S. TRANSPORT

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KEY FINDINGS:

This study examines the impacts of increased commercial switchgrass production on U.S. agricultural land-use patterns, commodity prices, and the environmental impacts of cropping systems in the agricultural sector. Commercial-scale switchgrass production is projected to involve substantial increases in agricultural land acreage, with new acres coming from a combination of conservation reserve program (CRP) acreage, other cropland currently used as pasture, a reduction of winter fallow in production rotations, and displacement of existing crop production. The displacement of existing crop production reduces domestic crop supply and generates market impacts in the form of increased prices and reduced exports for existing crops, which creates the potential for significant indirect land use impacts associated with changing commodity production patterns beyond the borders of the United States and outside the scope of this study. Domestic environmental implications are also simulated; commercial-scale switchgrass production may be associated with reduced erosion and improved nutrient pollution performance on U.S. working croplands, but projected increases in nitrogen application and the associated nitrous oxide emissions could offset soil carbon sequestration benefits and result in substantial increases in greenhouse gas (GHG) emissions from the agricultural sector. Furthermore, the loss of substantial amounts of conservation reserve program acreage and pasture land could have significant impacts on dimensions of environmental quality not covered by this analysis, including habitat quality and biodiversity.

POLICY RECOMMENDATIONS

1. Federal biomass research programs should prioritize research on the long-term environmental impacts of scaling up production of switchgrass and other biomass crops. All projects that receive federal funds to explore crop yield improvements should be required to explicitly address the soil, water, and GHG implications of the new production methods.
2. Federal biomass research programs should also perform system-wide studies to identify potential impacts of scaled up biomass production, including switchgrass, on landscape-level ecosystem services like provisioning of habitat, maintenance of surface water quality, and support of biodiversity.
3. Reducing the uncertainty associated with carbon impact estimates of biofuels under current regulatory programs such as the federal Renewable Fuel Standard and California's Low Carbon Fuel Standard will require increased investment in research on agricultural land-use dynamics in the United States, including regional availability of idle cropland and the returns to land in alternative uses such as pasture and forestry.
4. Payments rewarding GHG performance in agricultural production, through offsets or cost-share programs, for instance, should, wherever feasible, be awarded based on actual performance rather than assumed performance of a class of production practices. Actual performance for any given practice can be highly variable across soils and climatic regions.

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5. Performance-based payments for carbon mitigation should be based on a comprehensive quantification of the impact on emissions across all changes in production practice. While no-till is generally believed to have soil carbon sequestration benefits, for instance, if a switch to no-till is accompanied by increased levels of nitrogen application, the resulting nitrous oxide emissions could offset the soil carbon benefits associated with switching to a no-till, perennial farming system. The no-till practice alone should not be rewarded without a consideration of the GHG impacts of all accompanying changes in production practice.
6. Existing and proposed policies in support of biofuel production, including the 2007 Renewable Fuel Standard and the Volumetric Ethanol Excise Tax, should be revised to include a broad array of safeguards to protect air, soil, and water quality in addition to climate.

When President Bush mentioned switchgrass in the 2006 State of the Union address, listeners across the country responded with a collective "huh?" But in part due to that highly visible endorsement, and in part due to the explosive growth of the ethanol industry and the rapid advancement of ethanol conversion technologies, this modest prairie grass species has now become a household word. As large sections of the U.S. ethanol industry push hard to move beyond the current generation of corn-based ethanol and introduce technologies that will allow use of a much broader range of feedstocks for ethanol production, increased attention is being paid to new feedstocks that have the potential to be produced at large commercial scale. In this Policy Note we explore the potential for the use of switchgrass as a domestic energy source, as well as some of the environmental issues associated with producing it at a large scale.

INTRODUCTION

Switchgrass is a perennial prairie grass that is native to the United States in areas east of the Rocky Mountains. It commonly occurred in tall grass prairie ecosystems, which once covered most of the Midwest and now survive in protected pockets over only 10% of their original extent. Active management of the species began as a forage crop in the 1970s, and attention turned toward it as a possible bioenergy crop in the 1980s (Parrish et al., 2005). Switchgrass is considered a prime candidate for biomass production due to its high production capacity, low material input requirements (water and fertilizer in particular), strong potential soil and water conservation values, and compatibility with existing agricultural production methods and harvesting equipment (Vogel et al., 2002; McLaughlin et al., 2006).

Initial efforts to harvest energy from switchgrass used the crop for co-firing with coal in electricity generation. More recently, attention has turned to the use of switchgrass as a feedstock for ethanol—an alternative to gasoline that can be domestically produced. Currently, most ethanol in the United States is produced from the starch in corn kernels, which easily breaks down into a simple sugar, like the sugar from sugar cane, that is then fermented into ethanol. Research and development efforts, however, are focusing on developing technologies that would allow for the breakdown and fermentation of other common complex sugars such as cellulose and hemicellulose. Such technologies would enable the use of a much broader range of feedstocks for ethanol production, including the green, leafy parts of corn and other agricultural residues, municipal solid wood waste, and dedicated energy crops such as short rotation woody crops (i.e. hybrid poplar and willow) and herbaceaous perennials like switchgrass.

Cellulosic feedstocks for biofuels such as ethanol are often considered to have significant environmental advantages relative to conventional, annually produced grains such as corn. However, recent research suggests that the on-site impacts of land-use change represent only one component of the full land-use repercussions associated with feedstock production. If land uses displaced by switchgrass production pack up and move elsewhere, that initial change could trigger a cascade of off-site land-use conversions. Such off-site conversions are called indirect land-use changes and are associated with a large spectrum of indirect environmental impacts depending on where and what types of conversions take place. Due to the global nature of commodity markets, such impacts can occur either domestically or internationally, and it has been argued that the indirect impacts of U.S. feedstock production for ethanol may threaten globally important ecosystems such as the Amazon Forest (Searchinger et al., 2008).

One way to minimize disturbance of global commodity markets, and the environmental impacts such disturbances could have overseas, is to ensure that feedstock production does not displace production of other food and feed crops. Switchgrass, for instance, is widely marketed as a low-input perennial production system that can be successfully grown on marginal lands that are not already used for food or feed production. Evidence that switchgrass production would be limited to marginal lands rather than competing for prime cropland with existing commodity crops is scarce, however, as is specific information on the available extent and location of such marginal lands in the United States.[1]

Estimating the environmental impacts of scaling up switchgrass production for bioenergy production will require greater insight into the questions raised above about the land-use decisions made by farmers, constraints on those decisions in the form of policy or land availability, and the likely response of world markets to changes in domestic production. Although limited in scope, this analysis touches on many of these issues in exploring the potential supply, and associated environmental impacts, associated with the domestic introduction of a market for switchgrass.

Switchgrass Potential

Current estimates of switchgrass yield are highly variable both by source and by geography, with observed average yields ranging from 5.5-21.6 T/ha/year (see McLaughlin et al., 2005 for a review of yield studies). At conversion efficiencies of 85 gallons of ethanol per ton of biomass, those biomass yields translate into estimates of 467 to 1,836 gallons per hectare (ha) of switchgrass planted, or the energy equivalent of 313-1,230 gallons of gasoline/ha/year.[2] With concentrated breeding, however, switchgrass is expected to have considerable scope for increases in per acre productivity; one study estimates projected ranges in 2025 of 10.1-26.2 T/ha/year (McLaughlin et al., 2006). Such theoretical breeding advances could result in yields of 900 to 2,300 gallons of ethanol per ha from switchgrass. For comparison purposes, yields of ethanol from corn and sugar cane have been estimated to be roughly 800 and 1,700 gal/ha, respectively (Fulton et al., 2004).

Because more gallons of ethanol can be produced per hectare, there are clearly land-use efficiency gains achievable from using switchgrass as a feedstock relative to existing production systems based on corn grain. There are other potential input-efficiency gains as well. Switchgrass is very efficient at moving nutrients into its roots for storage overwinter then using those nutrients to rapidly jumpstart growth in the spring. The large resulting root systems allow the plant to efficiently absorb nutrients and water in the soil, which should permit switchgrass to thrive on reduced inputs relative to other annual crops. Estimates of the percent of switchgrass biomass that occurs in the root systems range from 35% to as high as 50%. In comparison to corn, which puts only 25% of its biomass into its roots, switchgrass also is expected to more efficiently capture nutrients before they are flushed from the field as water pollution. Similarly, because switchgrass regularly sloughs off and renews its root systems, it constantly replenishes soil carbon and may be a powerful tool in efforts to increase carbon sequestration on working agricultural lands. Field-scale research on this topic has reached mixed conclusions, however; a fair amount of research has found significant soil carbon accumulation from switchgrass production (McLaughlin et al., 2005; Ma et al., 2000a), while occasional studies have found no significant change in soil organic carbon (Thomason et al., 2004). Ma et al. (2000b) conclude that differences in soil carbon sequestration by switchgrass are significantly determined by site characteristics and cultivar selection.

Field-scale studies of switchgrass productivity and impacts, however, provide only a partial glimpse into the impacts of switchgrass production. There remain many unanswered questions about the aggregate direct and indirect impacts of establishing a commercial-scale switchgrass market on other agricultural commodity markets such as corn and wheat, as well as on larger scale agricultural land-use patterns and practices and their environmental impacts. Early studies reported that farmgate prices of $40–45/DT would make switchgrass production competitive on substantial amounts of cropland and CRP acreage (de la Torre Ugarte et al., 2003; McLaughlin et al., 2002), which could cause significant changes in patterns of production and enrollment in conservation programs. More recent studies have estimated per ton costs of switchgrass production that range from $36 to $114 depending on cultivar, soil, and region (see Mooney et al., 2009 for a review of studies). In a detailed analysis of switchgrass production and supply in Indiana, Brechbill and Tyner (2008) estimate average per ton production costs for switchgrass of $51.38–$54.54, depending on scale of operation and equipment ownership arrangements. Such cost of production numbers represent a floor on the expected price of switchgrass; switchgrass will not be supplied unless cost of production is met, but net returns to switchgrass production must also be competitive with alternative uses of the land to induce farmers to change land uses and production practices.

In this analysis, we introduce cost, return, and environmental impact figures for switchgrass production enterprises into a national agricultural production model to more explicitly evaluate how farmers' production decisions change with the introduction of a switchgrass market and potential returns from switchgrass production at various prices. We then estimate the implications of those decisions for the supply of switchgrass and other agricultural commodities, as well as for the aggregate environmental impacts of crop production for food and fuel.

WRI ANALYSIS

To evaluate the environmental and economic impacts of increased ethanol production from switchgrass, WRI uses the Regional Environmental and Agricultural Production model (REAP)—a national scale agro-environmental production model developed and maintained by the U.S. Department of Agriculture's Economic Research Service (ERS).[3] The results of the REAP analysis are then integrated with impact estimates derived from the Environmental Policy Integrated Climate (EPIC), a plant growth and environmental impact model. The combined model allows us to project how introduction of a market for switchgrass at a fixed price will translate into regional changes in crops grown, tillage practices used, and crop rotations employed, and to then estimate the net environmental impacts of those changes. In measuring environmental impacts we look specifically at agricultural GHG emissions, which are often under-represented in federal policy dialogues about GHG reductions, as well as at nitrogen and phosphorus losses from the field and rates of soil erosion, which have been the focus of most existing and pilot agricultural conservation programs.

SWITCHGRASS PRODUCTION INFORMATION

Very little information exists on how switchgrass would be produced at commercial scale in different parts of the country. Early switchgrass breeding and research focused on the production of switchgrass for forage rather than for ethanol production; the two uses may have very different desirable attributes and breeding objectives. To gather information on regional differences in switchgrass production, WRI collaborated with the Department of Agriculture's Natural Resources Conservation Service (NRCS) to survey its field offices on the production practices and harvest methods that field officers projected would be used in their regions for switchgrass production.

Although switchgrass is often described as a low-input-intensity crop, the responses regarding nitrogen application from our informal survey of production practices ranged widely, from a projected application rate of no nitrogen at all to a high of 336 kg/ha/year. To reduce the impact of "outlier" responses on the crop production patterns that emerged, these responses were standardized based on consultation with experts and additional information in the literature to a 10-year production cycle with an adjusted range of nitrogen applications and harvest methods. Final average annual nitrogen application rates used varied regionally from 45 to 120 kg/ha/year, while final average annual phosphorus applications ranged largely from 0 to 29.3 kg/ha/year.[4] For a comparison of switchgrass N application ranges with a sample of other crops in the model, see Table 1.

TABLE 1. Minimum and Maximum Nitrogen Applications (in kg/ha) by Crop and Production Region

Region		Corn	Sorghum	Switchgrass	Winter Wheat
Appalachia	Min	37.75	81.03	45.39	34.30
	Max	184.14	99.18	90.79	176.96
Corn Belt	Min	88.90	107.59	107.81	40.93
	Max	158.62	154.33	119.79	180.42
Delta States	Min	30.09	13.39	99.99	46.18
	Max	159.27	154.01	100.30	130.24
Lake States	Min	65.66	N/A	119.79	42.36
	Max	173.36	N/A	120.00	126.07
Mountain States	Min	115.75	20.49	74.86	24.82
	Max	210.46	93.44	75.23	145.14
North East	Min	83.70	N/A	67.50	26.07
	Max	217.79	N/A	75.00	106.80
Northern Plains	Min	32.44	9.61	80.74	25.74
	Max	246.21	181.66	90.00	128.22
Pacific States	Min	134.44	N/A	N/A	59.66
	Max	217.12	N/A	N/A	127.95
Southeast	Min	29.29	94.11	58.97	49.62
	Max	155.70	107.69	58.97	154.26
Southern Plains	Min	71.07	7.96	108.00	0.00
	Max	273.48	158.54	120.00	136.65

Switchgrass harvest is assumed to occur once a year, after the first establishment year, using a standard mow and round bale harvest method. Once production methods for each region were settled upon, switchgrass crop growth parameters were calibrated regionally to produce the yields shown in Table 2. These yield estimates were derived based on a variety of literature and data sources (Graham et al., 1996; Lemus et al., 2002; McLaughlin et al., 2006).[5] Those yields are assumed to be valid for the year 2008; for analysis of production in 2015, the productivity of switchgrass is assumed to increase at a rate of 2% per year over the yields given in Table 2.[6]

REAP was modified to include a market for switchgrass, and the switchgrass enterprises were allowed to compete with existing production enterprises in farmers' decision-making. In this analysis, switchgrass competes with existing crops solely on the basis of relative returns. Farmers decide, based on a comparison of returns, whether to use their acreage to produce more traditional commodity crops in existing rotations or to produce switchgrass using the introduced switchgrass

TABLE 2. Switchgrass Yields Used to Calibrate Crop Growth Parameters (2008)

Region	MT/ha	tons/acre
Appalachia	7.8-14.5	3.5-6.5
Corn Belt	11.6-14.3	5.16-6.4
Delta States	8.5-14.5	3.8-6.5
Lake States	10.1-13.3	4.5-6.0
Mountain States	6.73	3.0
Northern Plains	10.8-13.4	4.8-6.0
North East	7.2-13.9	3.2-6.2
Southern Plains	7.9-14.1	3.5-6.3
South East	9.8-14.6	4.4-6.5

production enterprises. Other farmer decision factors, such as a reluctance to adopt new, untested crops or the cash-flow issues associated with waiting for the switchgrass to establish itself before harvest, are not modeled in this analysis.

The baseline agricultural production scenario for our analysis uses USDA's 2008 projected baseline for crop production patterns in 2015 and USDA's estimated baseline corn-based ethanol production level of 13.3 billion gallons per year (BGY). Relative to that scenario, we explore how 2015 planting patterns respond to introduction of a switchgrass market at a range of prices for switchgrass.

RESULTS

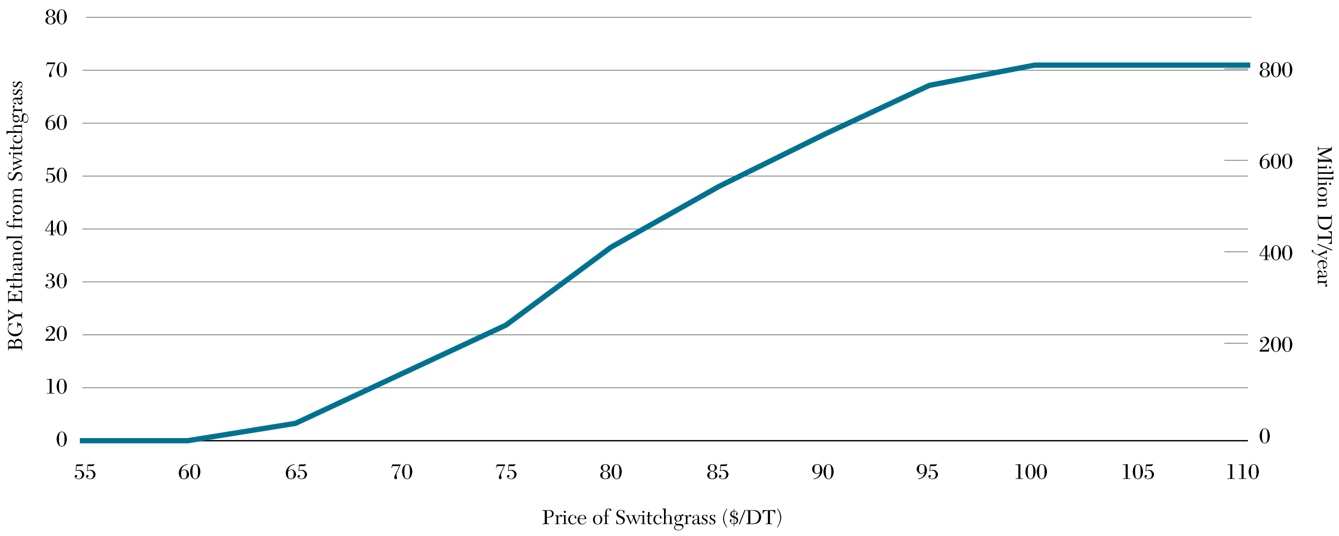
The following sections present graphs of projected impacts or behavior in 2015 as a result of introducing a market for switchgrass, with switchgrass selling at a range of prices as shown. High prices provide incentive for the production of substantial amounts of switchgrass, and thus substantial ethanol production potential. It would not be possible, however, for sufficient ethanol production capacity to exist in 2015 to absorb the levels of switchgrass production suggested at the higher end of the range; the necessary cellulosic conversion technology is not yet mature, and the logistics of the infrastructure required to support such an industry will take time to develop. The graphs are nevertheless illustrative of the underlying dynamics of farmer decision-making and the implications for production patterns, switchgrass supply and aggregate environmental impacts that could unfold over time as the industry develops. Such insights will be critical to informing responsible policy to guide the industry as it expands.

U.S. Switchgrass Supply

Our results suggest that farmgate prices greater than $60 per dry ton (DT) are required to jump-start switchgrass supply, but that supply increases rapidly beyond that point as price increases (Figure 1).[7]

At a price of $100/DT, enough switchgrass is supplied to support an ethanol industry of nearly 70 BGY. That level of production, however, requires a whopping 153 million acres

FIGURE 1 Switchgrass Supply and Ethanol Potential



of land to be brought into switchgrass production—almost twice the amount of land in corn production and half of the 330 million acres of land estimated to be used for crops in the United States in 2006.[8] The 2007 Renewable Fuel Standard calls for scaling up cellulosic ethanol production to 3 BGY by 2015; this analysis suggests that sufficient biomass would be available at a farmgate price of $65/dry ton to produce 3.5 BGY of ethanol and would require that 8 million acres of land be brought into switchgrass production.

Land allocated to switchgrass production comes from a combination of displacement of existing commodity crops, reduced CRP enrollment, reduced incidence of fallow in production rotations, and conversion of land from the "idle cropland" pool (Figure 2). The "idle cropland" pool is cropland that is designated by the USDA as either "idle" (then corrected for CRP acreage to avoid double-counting) or as "cropland used for pasture."[9] Our analysis suggests that at a switchgrass price of $90/DT, incentive exists for the conversion of 18.7 million acres of CRP land, 21 million acres of otherwise idle cropland, and 29 million acres of active crop acreage, together with the reduction of 3.9 million acres of fallow on active cropland. These acreages represent 26%, 29%, 40%, and 5% of the total switchgrass acreage of nearly 73 million acres at that price.

The total acreage accounted for in this analysis is 416 million acres in the combined pools of active and retired, or idle, cropland. Although there is also a possibility that land will be drawn out of forestry for conversion to cropland, that analysis is beyond the scope of the current study.

How switchgrass production is distributed regionally reflects a combination of factors, including productivity of the region for switchgrass production, the opportunity costs associated with displacing other land uses in that region, and the availability of idle or underutilized cropland.

Figure 3 gives a regional breakdown of switchgrass acreage at various biomass prices. Production in the Northern Plains dominates at all price levels. While not necessarily the most productive switchgrass production region (see Table 1), the Northern Plains emerges as the dominant production region because of the relatively lower value associated with existing crop production in the region, the high incidence of fallow in existing rotations, and other available opportunities for more intensive use of cropland that is currently idle or retired. At prices above $85/DT, substantial acreage is also brought into production in the Southern Plains. The Appalachian region and the Corn Belt follow a distant third and fourth, allocating 19.4 and 15.4 million acres, respectively, to switchgrass production at a price of $110/DT.

FIGURE 2 Projected Sources of New Land for Switchgrass Acreage

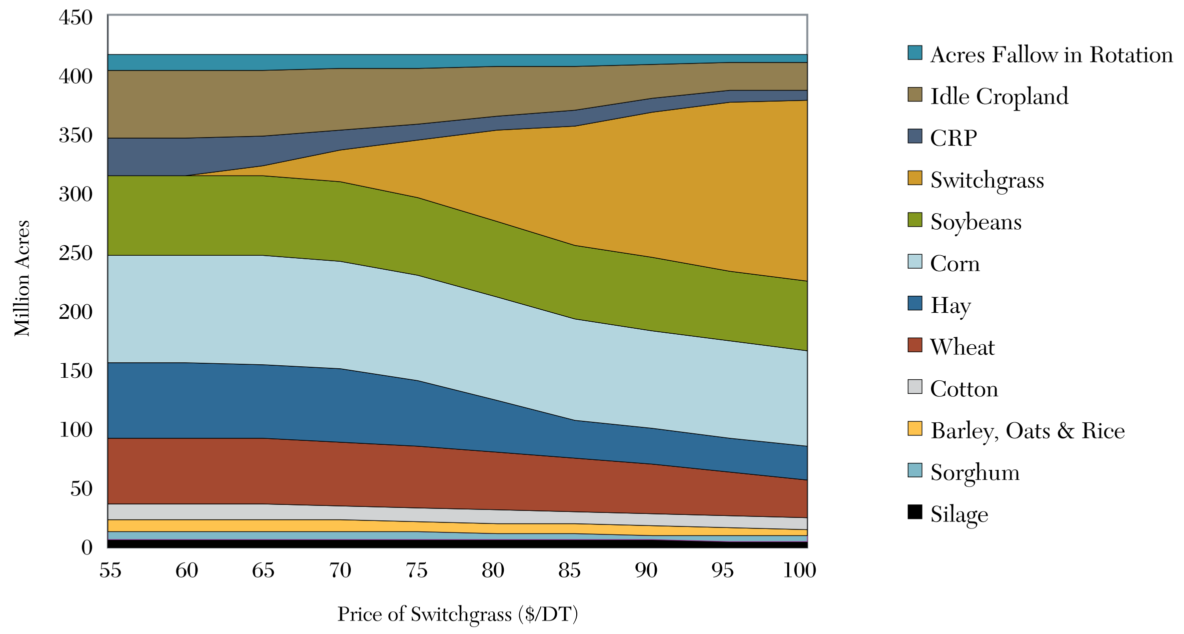
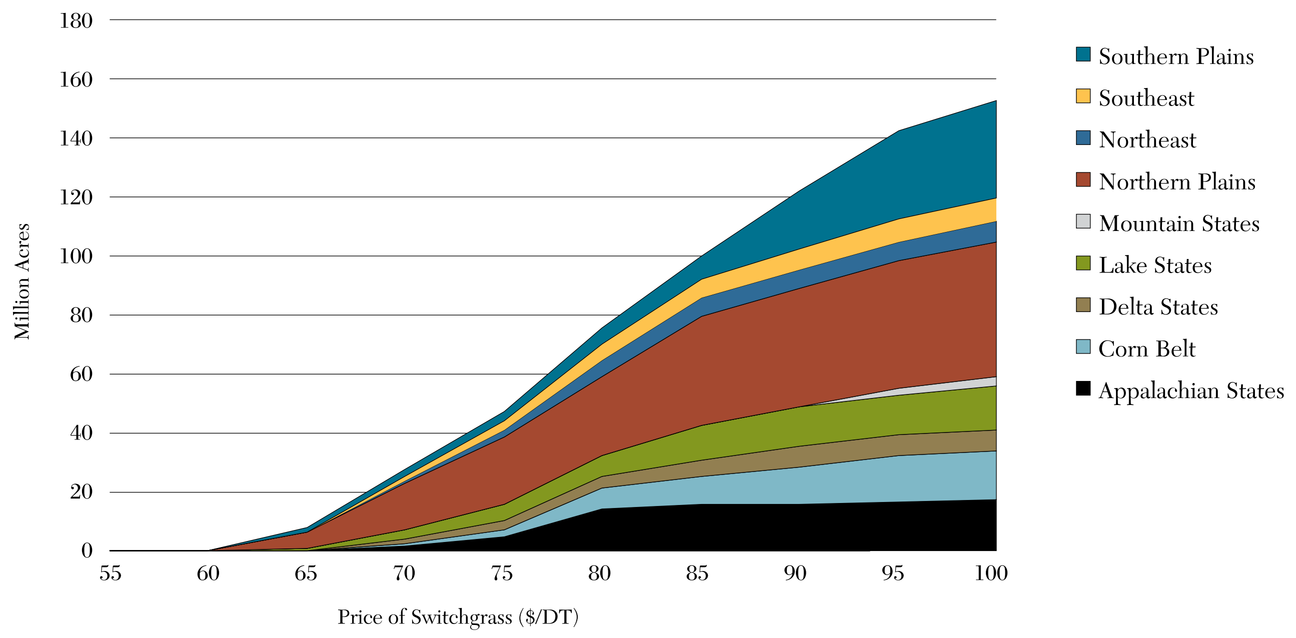


FIGURE 3 Regional Breakdown of Switchgrass Acreage



Market Impacts of Switchgrass Production

Switchgrass production results in market impacts when it displaces the existing production of crops; displacement generates a drop in supply and an increase in price of the displaced good. The impacts illustrated here reflect only the domestic price response to domestic changes in production; because most of these commodities are traded internationally, changes in price are likely to trigger international adjustments in production and supply that serve to mute the responses shown here. These impacts, nevertheless, reflect the relative strength of price pressure across commodities generated by allocating greater acreage to fuel, rather than food or feed, production.

FIGURE 4 Price Impacts on Agricultural Products

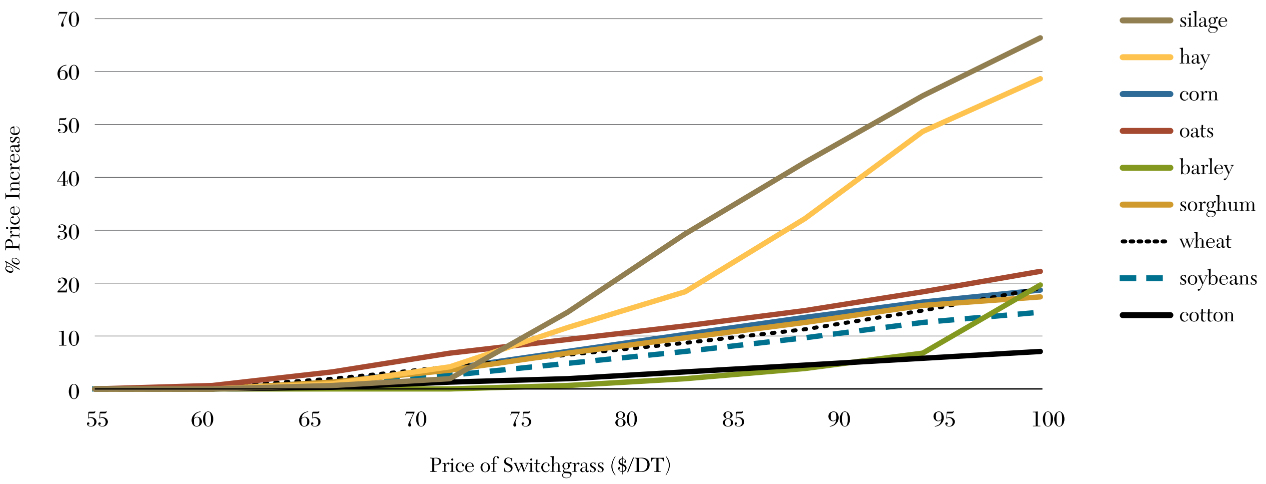


FIGURE 5 Impacts on Nutrient Application

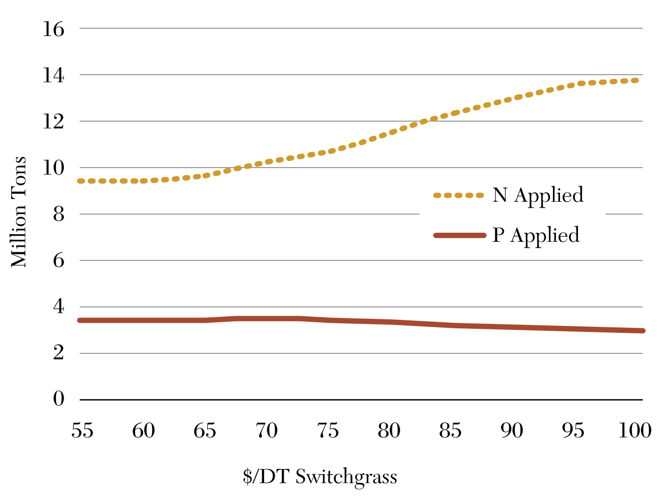
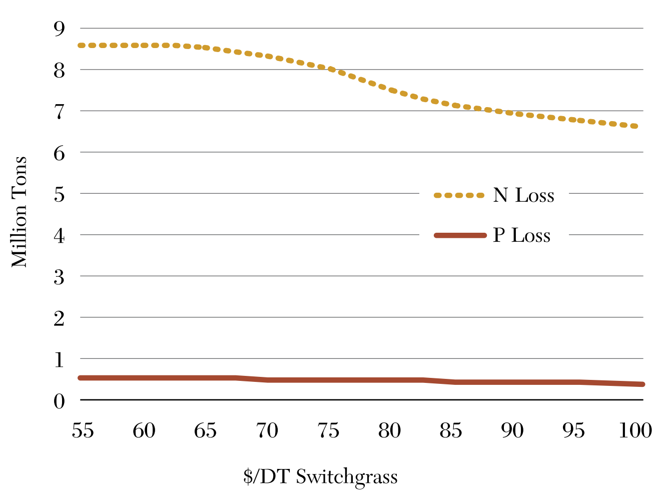


FIGURE 6 Impacts on Nutrient Losses from Field



Commodity price impacts in REAP are the result of complex interactions between projected supply and assumed demand in multiple markets, including livestock feed and other domestic processing markets as well as export markets. The model projects that the prices of hay and silage would be affected most drastically (Figure 4); at a switchgrass price of $100/DT, acreage in these commodities declines by 54% and 24%, respectively, but demand remains strong in domestic livestock markets. The price increase resulting from significant drops in corn, wheat, and barley acreage, in contrast, are moderated to a certain extent by drastic reductions in exports of those commodities; the kink in barley's price curve indicates the point at which exports drop to zero, beyond which prices begin to rise steeply. The international market and land-use implications of potential drops in exports have generated intense exploration into, and debate over, the indirect impacts of domestic biofuel production (Searchinger et al., 2008; Gibbs et al., 2008; Keeney and Hertel, 2009). This analysis suggests that the potential for significant indirect impacts exists; such impacts must be carefully considered in a comprehensive assessment of the social, market, and environmental implications of increased switchgrass production.

Domestic Environmental Impacts of Switchgrass Production

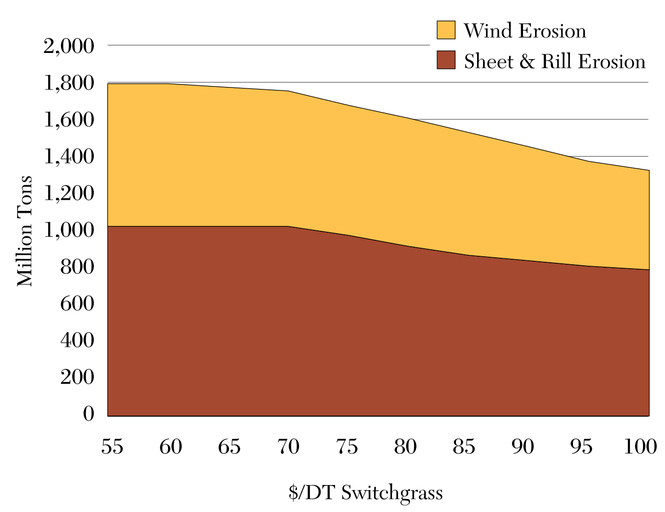
Despite switchgrass' reputation as a low-input crop, several of the production enterprises designed based on the NRCS field survey involved significant applications of nitrogen fertilizer.

Although switchgrass may grow at low input levels, it is rational for farmers to increase fertilizer application on crops with significant nitrogen response to maximize yields, particularly at high crop prices. The introduction of significant amounts of acreage into switchgrass production resulted in a sharp increase in the national application of nitrogen to cropland, from a baseline rate of 9.27 million tons/year to a high of 13.2 million tons/year (Figure 5).[10] This increase results from a combination of increased active farmland and from the substitution of relatively nitrogen-intensive switchgrass for less nitrogen-intensive crops such as soybeans. Simulated phosphorus application, on the other hand, drops slightly as a result of the change in production patterns, from 3.27 million tons/year to 3.11 million tons/year.

Production of nitrogen-intensive annual crops such as corn creates a nutrient pollution problem because the crops take up only a portion of the nitrogen and phosphorus applied and the remainder is flushed off the field through erosion, runoff, leaching, or drainage. Concentrated in surface water, nutrients contribute to the eutrophication, or nutrient over-enrichment, of rivers, streams, and lakes, reduced fish habitat, impaired drinking water, and development of hypoxic (oxygen-depleted) "dead" zones in coastal waters. Nutrient pollution is therefore a serious problem associated with fertilizer use in modern annual-crop-based agricultural systems.

Switchgrass, however, is a perennial crop that develops and maintains a healthy root system year round. Despite the substantial increase in nitrogen application as switchgrass produc-

FIGURE 7 Impacts on Erosion from Field



tion expands, Figure 6 illustrates that nutrient losses from cropland actually decline with that expansion. This analysis suggests that, from a water quality perspective, switchgrass is efficient enough at capturing nutrients before they are flushed from working lands to compensate for the increased nitrogen application necessary to support its production.

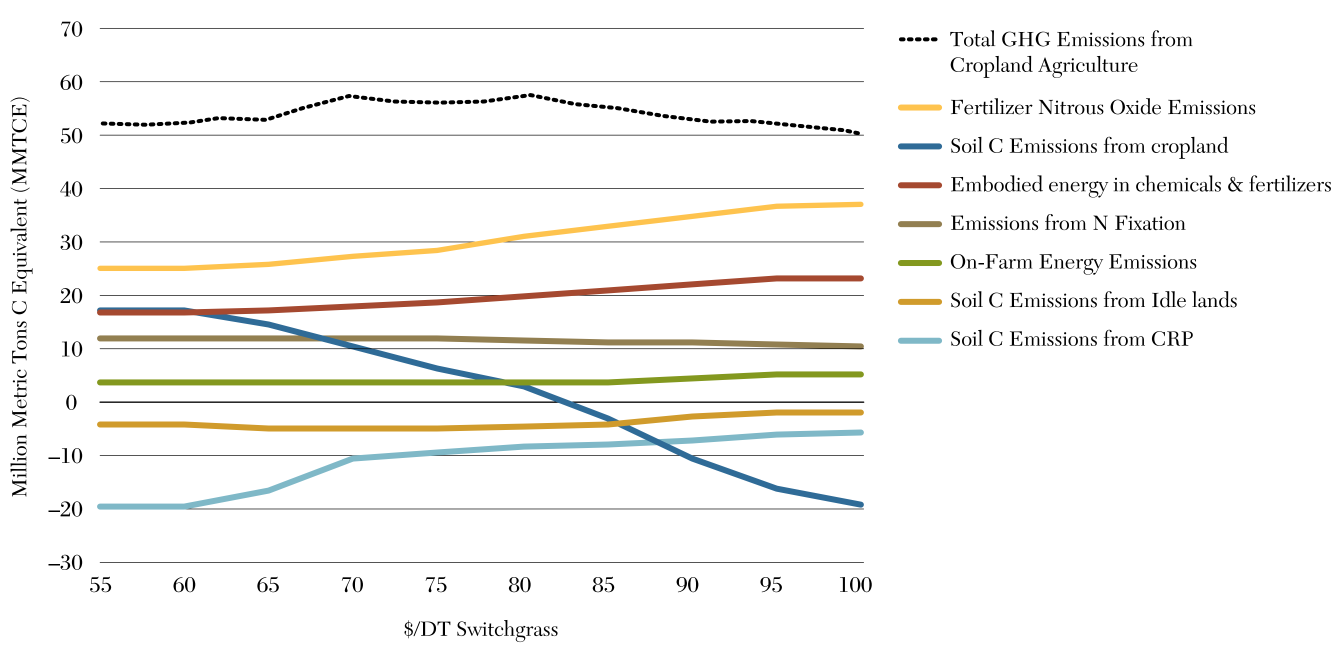
Aggregate cropland erosion also drops significantly as a result of the movement of acreage into perennial switchgrass. Acreage in CRP and pastureland generally has year-round cover and very low erosion rates to begin with, so most of the observed decline in erosion comes from the displacement of crops in highly erodible conventional annual systems and the reduction in winter fallow in crop production rotations. The reduction is roughly evenly split between wind erosion and water erosion (sheet and rill erosion) (Figure 7), and, relative to baseline erosion levels, is particularly significant in the Northern and Southern Plains and Appalachian states. Parts of these regions are particularly vulnerable to the wind and water erosion associated with existing annual crop production systems and are therefore benefited the most when a perennial cropping system displaces existing production.

Switchgrass' performance with respect to GHG emissions, on the other hand, is mixed. In our analysis, changes in GHG emissions from working cropland occur through two primary pathways: changes in soil carbon sequestration arising from new methods and patterns of production, and changes in nitrous oxide emissions arising from altered fertilizer application rates. Although soil carbon sequestration on working lands improves considerably when switchgrass production is introduced, much of the new land for switchgrass production comes from conservation reserve program land or pasture land, which was already providing soil carbon sequestration services. Net increases in soil carbon sequestration do occur, but until switchgrass displaces a substantial amount of existing crop production, those increases are not sufficient to compensate for the increases in nitrous oxide emissions arising from increased nitrogen fertilizer application for switchgrass production. Together with modest increases in on-farm energy use and in the energy use required for fertilizer production ("embedded energy"), the result is a significant net increase in GHG emissions from crop-based agriculture as switchgrass production is scaled up through a price range of $60-$80/DT (Figure 8).

Nitrous oxide emissions are therefore a potentially significant variable in the calculation of the GHG impacts of switchgrass production, but methods of estimating nitrous oxide emissions produce highly variable results (David et al., 2009). Although EPIC calculates rates of denitrification in modeled soils, it does not calculate the separation of denitrification products into nitrous oxide or nitrogen gas. Nitrous oxide emissions attributable to fertilizer application are therefore calculated using the IPCC emissions factors and then adjusted to calibrate to estimates of direct and indirect nitrous oxide emissions from synthetic fertilizer found in the 2007 EPA greenhouse gas inventory (EPA, 2007; IPCC, 2006). These estimates account for both the direct emissions attributable to increased soil nitrogen and the indirect emissions associated with volatization of applied fertilizer, surface run-off, and leaching. Aggregate IPCC emissions factors are, however, crude estimates that are unable to capture the impact of important variables such as weather, soil type, and tillage practice on the emission of nitrous oxides (DelGrosso et al., 2005). Adler et al. (2007) used a popular biogeochemical model called DAYCENT to estimate the nitrous oxide emissions associated with switchgrass production; they found that the IPCC emissions factors substantially underestimated switchgrass' direct emissions relative to their modeling results. Continued development of more robust estimation methods for nitrous oxide emissions will be a critical part of improved GHG impact measurement for biofuels and agricultural products more broadly.

The increases illustrated here represent only the domestic agricultural production portion of the life-cycle GHG emissions associated with switchgrass-based biofuel production and cannot be used in isolation to draw conclusions about the net GHG impacts associated with biofuels production and use.

FIGURE 8 Sources of GHG Emissions in U.S. Cropland Agriculture



The potential magnitude of the GHG impact within agriculture, however, suggests that detailed, disaggregated analyses of the behavior of the agricultural sector are a critical part of the full life-cycle analysis of the GHG emissions associated with biofuels.

CONCLUSIONS AND POLICY IMPLICATIONS

Second-generation cellulosic feedstocks such as switchgrass have the potential to provide benefits such as rural revitalization and improved energy security in the U.S. through increased production of domestic ethanol. However, to fully understand the environmental benefits or tradeoffs associated with relying more heavily on finite land supplies to provide fuel (on top of traditional demands for food and fiber), it is critical to develop a better understanding of several aspects of production: how patterns of land use will change as feedstock production scales up; what the environmental impacts of those changes are; what production methods would be used for newly commercialized feedstock crops; and how these production behaviors can be influenced by agricultural policy, biofuels support policy, or ag-relevant policy such as climate legislation.

The net domestic environmental impact of scaling up feedstock production is very dependent on what is displaced to make room for it, and how land-use patterns change to accommodate scaled-up switchgrass production. Switchgrass replacing high-biomass CRP lands, or pushing other domestically produced crops onto those lands, has a much different net impact than switchgrass replacing corn while total acreage in agriculture remains constant. Many of the projected environmental benefits of switchgrass production are illustrated relative to a more conventional, high-input annual crop system like corn. But high-intensity annual crop acreage is not the only land use lost when land is converted to biofuel production. In fact, an increasing amount of research suggests that a good portion of the demand for land for new agricultural products will be met through new land brought into agriculture, rather than through displacement of existing, high-intensity agricultural production. This analysis corroborates those findings; at switchgrass prices of $80/DT, for instance, 64% of the land going into switchgrass production is acreage coming into active agricultural use from idle or retired (CRP) land, while only 36% comes from land that is already in production.

In this analysis, available pools of new land are limited to idle or retired cropland, but a recent analysis by the California Air Resources Board suggests that North American forests may be vulnerable to agricultural expansion as well. In an exploration of land supply to support expanded corn ethanol production, the California Air Resources Board estimated that 30–40% of the increase in domestic agricultural acreage could come from forests.[11] Losing forest to agricultural production in response to an expansion in energy crop acreage would have net environmental impacts that go far beyond those covered in our analysis—including both carbon flux impacts from a reduction in above-ground biomass and impacts on biodiversity, habitat, and other landscape-scale environmental indicators that are not covered in our study. While continuing research is needed to reduce uncertainty and refine such land conversion estimates, the potential for such conversion at a significant scale must be an important part of the analysis of the domestic costs and benefits of biofuel expansion.

Even without considering the threat of high-carbon forest conversion, this analysis highlights the possibility of significant increases in agricultural GHG emissions arising from increased total nitrogen fertilizer use for switchgrass production. Commercial switchgrass production methods for the purposes of bioenergy production are still highly uncertain, and it is critical to understand the types of tradeoffs that may exist when fertilizer use is intensified to increase yield. Research on bioenergy crop yields should explicitly consider the sustainability implications of new varieties and production methods along multiple dimensions in order to ensure that unacceptable tradeoffs are not being exacerbated and embedded in yield-oriented production research.

Our results suggest that switchgrass has distinct water-quality advantages over traditional feedstocks such as corn and other cellulosic feedstocks such as corn stover (Marshall and Sugg, 2009); both nutrient loading and erosion are reduced by the conversion to a deep-rooted perennial cropping system. It is important to corroborate such findings with ongoing research as cropping methods for switchgrass evolve, particularly with long-term field trials to ground-truth simulation modeling results.

It is also critical to recognize that there may be environmental repercussions arising from displacing the production of existing commodities that are not reflected in domestic measures of agricultural impact. Domestic energy crop production is demonstrated to have significant potential impact on prices and exports for traditional commodity goods traded internationally. Such market impacts generate ripple effects in markets around the world. Farmers in other countries respond to reduced supplies of food and feed, or increased international prices, by expanding agricultural production to restore balance in food and feed markets around the world. The environmental impacts of that induced agricultural expansion—or indirect land use change—must also be accounted for in calculating the full environmental implications of expanded energy crop production in the United States.[12]

Further analyses are also required to address how land-owner and farmer decisions are likely to be affected by regional or federal climate change policies. Such policies could potentially increase the costs of inputs such as fertilizer and on-farm energy use, thereby providing an incentive for reduced use of energy-intensive inputs, but could also provide opportunities for farms and forests to contribute to national GHG reductions through emission offset markets. As demonstrated in this analysis, production patterns and practices affect agricultural GHG emissions through several different channels—nitrous oxide emissions, energy embedded in the chemicals and fertilizers used, and soil carbon sequestration, for instance. Effective offset markets must be carefully designed to accommodate how all channels may be affected by a change in practice or incentive. As demonstrated here, for instance, many of the expected GHG benefits associated with switching to no-till perennial switchgrass production are offset by other changes in production (e.g. increased fertilizer use) and by losses of the benefits already experienced on CRP lands and idle cropland when those lands are converted for agricultural production.

Biofuels are often presented in black and white—as entirely boon or boondoggle for the environment. The truth is that the impacts of production are very dependent on how, where, and what feedstocks are grown, and at what scale. Biofuel support policies, such as the 2007 Renewable Fuel Standard and the Volumetric Ethanol Excise Tax Credit, should acknowledge that distinction, and coax the growth of the industry along a more sustainable path, by making support contingent on achievement of a desired set of environmental performance measures. Environmental performance benefits, including better life-cycle GHG performance and more sustainable farming practices leading to cleaner water and healthier soils, must be incentivized through policy; they are not a predetermined outcome of biofuel production.

The limited set of sustainability criteria attached to the 2007 Renewable Fuel Standard, which include stipulations about what types of land feedstocks are grown on and the GHG intensity of biofuel production, are a promising start but should be expanded to include additional sustainability dimensions such as soil and water quality. Furthermore, it is imperative to maintain the integrity of those performance standards through the establishment of stringent quantification and measurement methodologies. Efforts to exclude emissions associated with indirect land use change from biofuel accounting methodologies, for instance, threaten to undermine the intent with which the GHG criteria were established in the first place.

This analysis contributes to the emerging understanding of the performance impacts of biofuel feedstocks, but it also highlights the need for continued refinement of estimation capacity and impact estimates through:

- collection of data on net returns to alternative land uses such as forestry to more fully understand landowner behavior with respect to conversion decisions;
- continued exploration of the impacts of commercial production methods as they evolve;
- expanded consideration of interactions among agricultural, climate, and energy policies in determining production behavior and the resulting environmental impacts of production; and
- more precise inventories of available pools of idle cropland in the United States.

Switchgrass is just one of many potential feedstocks for a next-generation ethanol industry, each of which has its own set of potential environmental benefits and costs. Appropriately designed biofuel policy based on scientific performance measurements is needed to ensure that the cellulosic industry that emerges over the next decade provides us with the environmental performance benefits that we hope to achieve from it.

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Notes

1. In one of the first comprehensive spatial analyses of abandoned agricultural land available for bioenergy production, Campbell et al. (2008) estimate that potential energy from biomass grown on 100% of the abandoned agricultural land for most countries in North America, Europe and Asia would satisfy less than 10% of the primary energy demand for those countries. They recommend further study of the potential of other types of marginal agricultural land and land areas degraded through wood harvest rather than agriculture.
2. Hsu (2008) estimates current yields of 63-72 gallons of ethanol per dry ton of biomass, depending on conversion technology used. Achieving a conversion yield of 85 gallons per dry ton by 2015 will therefore require moderate technological advances. A recent study by Sandia National Lab estimates a potential yield range in 2030 of 74-115 gallons of ethanol per dry ton of biomass based on projected maturation of conversion technologies (West et al., 2009).
3. For more information on the REAP model and how it has been used, see http://www.ers.usda.gov/publications/tb1916/tb1916.pdf.
4. One small sub-region of the Corn Belt applied 78 kg P/ha/year; this region never introduced switchgrass acreage, so the outlier application value did not affect results.
5. Ranges correspond to the yield values for subregions within each region.
6. This growth rate is higher than the ~1.2% that USDA uses in its baseline projections for corn production (see http://usda.mannlib.cornell.edu/usda/ers/94005/2010/Table18.xls), but lower than the more optimistic estimate of 3% annual growth in switchgrass yields used in a recent analysis by Sandia National Laboratory (West et al., 2009).
7. Farm-gate prices do not include the cost of delivery to the refinery. Because these costs are highly variable with distance, we restrict our analysis to the price offered for bales of switchgrass staged and ready for delivery on the farm.
8. "Cropland used for crops" data available as part of USDA/ERS's "Major Land Uses" data series at http://www.ers.usda.gov/Data/MajorLandUses/.
9. The amount of "idle cropland" available for conversions is constrained by USDA "Major Land Use" 2002 data by region.
10. The model is not able to reflect, however, the moderating influence likely to occur when increased nitrogen demand drives up nitrogen price.
11. See http://www.arb.ca.gov/fuels/lcfs/030409lcfs_isor_vol1.pdf, Table IV-10.
12. Also see http://www.wri.org/stories/2009/06/rules-fuels-biofuels-and-climate-change-impacts.

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