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Ethanol and a Changing Agricultural Landscape

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Abstract

The Energy Independence and Security Act (EISA) of 2007 established specific targets for the production of biofuel in the United States. Until advanced technologies become commercially viable, meeting these targets will increase demand for traditional agricultural commodities used to produce ethanol, resulting in land-use, production, and price changes throughout the farm sector. This report summarizes the estimated effects of meeting the EISA targets for 2015 on regional agricultural production and the environment. Meeting EISA targets for ethanol production is estimated to expand U.S. cropped acreage by nearly 5 million acres by 2015, an increase of 1.6 percent over what would otherwise be expected. Much of the growth comes from corn acreage, which increases by 3.5 percent over baseline projections. Water quality and soil carbon will also be affected, in some cases by greater percentages than suggested by changes in the amount of cropped land. The economic and environmental implications of displacing a portion of corn ethanol production with ethanol produced from crop residues are also estimated.

Keywords: Biofuels, corn ethanol, regional crop mix, regional environmental effects, water quality, water use, cellulosic ethanol, crop residues, livestock, Regional Environment and Agriculture Programming (REAP) Model, renewable fuel standard

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Contents

Summary

U.S. policy to expand the production of biofuel for domestic energy use has significant implications for agriculture and resource use. While ongoing research and development investment may radically alter the way biofuel is produced in the future, for now, corn-based ethanol continues to account for most biofuel production. As corn ethanol production increases, so does the production of corn. The effect on agricultural commodity markets has been national, but commodity production adjustments, and resulting environmental consequences, vary across regions. Changes in the crop sector have also affected the cost of feed for livestock producers. As the Nation demands more biofuel production, and markets for new biofuel feedstocks, such as crop residues, emerge, the agricultural landscape will be further transformed.

What Is the Issue?

The Energy Independence and Security Act of 2007 (EISA) specifies a minimum total amount of U.S. biofuel production through 2022, and also sets target levels for fuels produced from specific feedstock categories. Together with volatile energy prices, this and earlier Federal legislation supporting biofuel processing have increased demand for biofuels and the agricultural feedstocks used to produce them. Greater demand for biofuel increases pressure on the agricultural land base as more land is put into production and/or more inputs, such as fertilizer, water, and pesticides, are applied to cropland. Rising demand for corn, the principal biofuel feedstock in the United States, changes the profitability of growing corn and other “energy crops”. Farmers respond by changing their planting decisions, which alter crop mix, land use, and use of inputs, such as fertilizer, which then influence water quality, soil erosion, and other environmental indicators. The environmental consequences of shifts in agricultural production vary by region.

This report also looks at the economic and environmental implications should crop residues, such as corn stover and wheat straw, become commercially viable as biofuel feedstocks. Widespread harvesting of crop residues as an alternative biofuel feedstock has implications for input use, nutrient runoff, erosion control, and soil productivity.

What Did the Study Find?

Land for new biofuel feedstock production comes from two main sources: acreage not currently in production and acreage shifted from other crops. The amount of additional land and displaced crops associated with increased biofuel production differs by region. If the RFS targets are met, total cropland is projected to increase by 1.6 percent over baseline conditions by 2015, with corn acreage expanding by 3.5 percent and accounting for most of the cropland increase. While corn acreage expands in every region, traditional corn-growing areas would likely see the largest increases—up 8.6 percent in the Northern Plains, 1.7 percent in the Corn Belt, and 2.8 percent in Lake States. Prices are expected to increase slightly for most crops compared with the baseline, although the price increase could be reduced if corn yields increase at a faster rate than expected.

Corn is a heavy user of nitrogen fertilizer. Given the RFS targets, the resulting increase in fertilizer use and shift from corn-soybean rotations to continuous corn production leads to deterioration of key environmental performance measures. Nitrogen losses to surface water and groundwater increase by 1.7 and 2.8 percent, respectively, while soil runoff increases by 1.6 percent from the baseline. Differences in geography, soil type, and prevailing agricultural production activities lead to considerable variation in environmental effects among regions. The increases in leaching to groundwater are greatest in the Lake States and Southeast, while increases in runoff to surface water are greatest in the Corn Belt and Northern Plains.

As energy feedstocks that are also used as animal feed move more toward biofuel use, higher costs of animal feed reduce returns to animal production. Production of livestock declines slightly by 2015 relative to the baseline—0.6 percent for farm-fed cattle and 0.5 percent for poultry—which may result in reduced manure nutrient runoff and leaching in some areas.

Technical advances in biofuel production may soon allow other plant material to be used as energy feedstock. One of the most readily available sources of "cellulosic" feedstock is crop residues. Increased use of residue could reduce demand for corn, reducing requirements for most agricultural inputs. But replacing corn-based ethanol with biofuel created from crop residues could have mixed results on environmental quality. Removal of large amounts of crop residues requires replacement of nutrients through increased application of fertilizer and increases runoff and soil erosion. Replacing 3 billion gallons of corn ethanol with crop residue ethanol could increase nitrogen runoff and leaching in the Corn Belt, although reduced corn plantings in other regions cause these measures to decline in much of the United States.

How Was the Study Conducted?

A regionalized agricultural sector mathematical programming model with linked environmental process models was used to simultaneously estimate profit-maximizing decisions on land use, livestock production, crop mix, crop rotations, tillage practices, and fertilizer application rates. In essence, we compare the market equilibrium prior to EISA's passage with the market equilibrium expected if the new RFS production targets are met in 2015, the year that the corn-ethanol target peaks. The environmental impacts of land use and agronomic practices were estimated by applying coefficients derived from a crop biophysical simulation model that incorporates soil, weather, and management information to estimate crop yields, erosion, and chemical (pesticide and fertilizer) discharges to the environment under various crop rotation and soil management regimes. Changes to U.S. agriculture and environmental outputs from meeting EISA's biofuel production targets for 2015 were evaluated against a baseline case that reflects 2007 U.S. Department of Agriculture (USDA) projections for biofuel demand in 2015 (developed just prior to EISA's passage).

Introduction

The prospect of expanded biofuel use to meet U.S domestic energy needs has ushered in a new era of promise and uncertainty for U.S agriculture. Volatile energy markets, U.S. dependence on oil imports, greenhouse gas emissions from fossil-based fuels, and the search for new uses for agricultural commodities have combined to stimulate the development of agriculturally based biofuels. Broad support for biofuel development is reflected in an aggressive Government response in the form of ethanol production mandates, processing cost subsidies, and fuel-blending requirements. Meanwhile, biofuel-related research and development is underway in both the public and private sectors. The agriculture community has responded, in turn, with significant shifts of cropland resources to energy crops—primarily corn for ethanol production—to meet increasing biofuel demands. Market adjustments from corn ethanol expansion have reverberated through the field crop and livestock sectors, raising concerns for farm income, Government payments, and food prices. Natural resource concerns have also arisen with changes in land use and management as producers adapt to market shifts.

While ethanol can be produced from a variety of crops, corn has served as the predominant feedstock over the initial history of U.S. domestic biofuel production. Conversion of corn-based ethanol is a proven technology, and a production and distribution system has already evolved to service the national corn grain market. Other technologies that convert cellulosic biomass to ethanol are expected to come online at a commercial scale, but only after technological and economic hurdles are overcome. Until recently, ethanol was a small market for corn producers. The share of domestic corn production supplying the ethanol market, however, has grown substantially—from 7.5 percent (705 million bushels) in 2001 to 23.2 percent (3,049 million bushels) in 2008 (USDA-WASDE, 2009). To meet the growing demand for corn-based ethanol, U.S. cropland planted to corn increased to 93.5 million acres in 2007 (USDA-WASDE, 2009), the highest level since 1944, before declining to 86 million acres in 2008.

Recent Federal legislation marks a significant long-term commitment to expand agricultural biofuels. The renewable fuel standard (RFS), passed as part of the Energy Independence and Security Act of 2007 (EISA), specifies not just the total level of biofuels to be used until 2022, but also target levels for fuels produced from major feedstock categories. Corn-based ethanol production will likely remain a major component of the biofuel portfolio for most of EISA's lifespan. Corn-based ethanol production will continue to increase, with as much as 15 billion gallons counting toward the 2015 RFS (more than 60 percent above the 2008 production level of 9 billion gallons), and hold at that level for the remainder of the act's duration, unless replaced with ethanol from advanced feedstocks, such as crop residues, forest residue, or dedicated energy crops (cellulosic feedstocks). To meet the RFS, roughly 35 percent of domestic corn production will be needed to produce the 15 billion gallons of ethanol. The share of U.S. ethanol production supplied by cellulosic feedstocks will increase as new conversion technologies come online, with the RFS for cellulosic and other advanced biofuels set to reach 20 billion gallons by 2022.

While increased demand for corn and other commodities has expanded the market for agricultural products, growth in biofuel feedstock production puts more pressure on the agricultural land base and raises costs for crop and livestock producers as well as consumers. At the same time, rapid expansion in agricultural land devoted to biofuels has raised environmental concerns. Biofuels have been seen as an environmentally preferred alternative to fossil-based fuels and, in the energy use sector, this is well supported. Broader effects, however, include expansion in cultivated land with accompanying shifts in regional cropping patterns, production practices, and input use that affect the environment in various ways outside of the energy sector. The expansion of corn acreage is a particular agri-environmental concern, due to the high fertilizer use associated with corn production and its effects on other product markets.

The effect of national biofuel targets will vary across regions, depending on the distribution of crop expansion and related adjustments in the agricultural sector. Environmental outcomes, in turn, will reflect regional differences in climate, soil, and predominant practices. Environmental consequences may be driven by an increase in the number of acres planted in some regions, whereas changes to crop mix or management regime may be the main driver for others. Future demand for cellulosic feedstocks, including crop residues and new dedicated energy crops, will further transform the agricultural landscape as regional crop distribution changes and production practices adapt.

While significant expansion of U.S. biofuel production undoubtedly has broad implications for the agricultural sector, our understanding of the nature and magnitude of these effects remains incomplete. Agricultural sector adjustments reflect the complexity of linkages across supply and demand markets for farm commodities. Commodity market adjustments, in turn, will drive changes in resource use and environmental quality that are both complex and uncertain. As we implement ambitious targets for biofuel production, a better understanding of potential market, resource, and environmental outcomes can help inform policy to support agriculture's expanding role in energy.

Research Objectives

To gain insight into the complex set of market and environmental interactions associated with increasing demand for biofuel feedstocks in the United States, we report on an agricultural sector-level analysis of producer adaptations under new Federal policy directives for biofuels. The analysis draws on an Economic Research Service (ERS) modeling framework of the U.S. farm sector to examine adjustments in prices and production and resulting changes in resource use and environmental indicators. The analysis is intended to address the following questions:

- How will increased demand for biofuel feedstocks affect regional crop patterns and livestock production?
- What are the likely environmental impacts and how will they be distributed regionally?
- Will recent changes in acreage, agricultural markets, and environmental indicators persist as corn-based ethanol production levels off and cellulosic ethanol production expands?

- How sensitive are reported changes in the agricultural system to key production factors, such as input costs and crop yields, and the adoption of cellulosic conversion technology?

The scenarios (described in this section, "Assessing Changes to the Agricultural Landscape") for the quantitative analysis represent economic (welfare) maximizing solutions to meet biofuel targets established by the 2007 EISA. Results describe sectoral adjustments and costs, location/mix of different crops ("Expanding Corn Acreage Drives Market and Environmental Outcomes") and livestock ("Biofuel Impacts on the Livestock Sector and Implications for the Environment"), and changes in environmental indicators under Federal mandates, relative to a scenario that replicates the official 2008 USDA baseline projections for 2015. Alternative scenarios demonstrate the potential effects of investments in research and development that enhance biofuel feedstock productivity and conversion efficiency, as well as changes in input costs. The emergence of cellulosic ethanol production is examined based on the role crop residues might play as new technologies develop ("Crop Residues and the Introduction of Cellulosic Ethanol"). The geographic scope of the study is national, but agricultural production is inherently regional. Thus, the study addresses agricultural production and cost and the associated resource impacts at a regional level.

Finally, this analysis focuses on potential implications in 2015, the year the RFS target for corn-based ethanol production peaks but before large-scale cellulosic ethanol comes online. Beyond this time, other types of feedstocks—including starches (other than corn) and sugar-based ethanol, dedicated energy crops (e.g., switchgrass or short-rotation woody crops), other crop residues (e.g., rice straw), urban wastes, and emerging options like algae—may gain or lose prominence. Many technological and economic factors will influence future biofuel markets, and future analysis incorporating new information from biological, physical, and economic research will be necessary to keep pace with these emerging technologies.

Beyond the Scope

In spite of the careful modeling used to examine the primary research questions, several issues were not addressed by the analysis, and many important factors on a cross-sector or global scale were beyond the study scope. For example, the study does not analyze:

- ***Energy market implications for biofuel demand.*** High energy prices, relative to the cost of producing biofuels, could induce a level of biofuel production and, thus, feedstock demand, that exceeds the mandates. Whether biofuel demand would increase with higher energy prices depends on how biofuels interact with other liquid fuels (e.g., as a substitute or an additive used in fixed proportions) and on the difference between biofuel demand and the biofuel mandate.
- ***Comprehensive assessment of sustainability.*** Carbon emissions and other environmental indicators are examined only within the context of agricultural production. A comprehensive sustainability analysis would require an assessment of environmental, economic, and social sustainability indicators throughout the biofuel production stream, including

lifecycle analyses of carbon and other greenhouse gas (GHG) emissions. The U.S. Environmental Protection Agency (EPA), however, is responsible for implementing the RFS under EISA and is currently developing policies that support a comprehensive analysis of environmental impacts, including effects on air and water quality.

- ***Transportation and infrastructure.*** An efficient biomass supply depends on an infrastructure that ensures economically viable handling and delivery of feedstocks from farm to plant. Other determining factors include regional biofuel feedstock demand, local resource endowments (land and water), and a capital infrastructure with storage facilities, roads, rails, and barges for feedstocks and pipelines for liquid fuels. The model only solves for feedstock production, however, as opposed to ethanol production, and assumes that infrastructure is in place to produce and deliver the targeted volume of ethanol.

- ***Food prices.*** Food prices will adjust as demand for biofuel feedstocks reverberates through the market. Increases in global and domestic food prices in early 2008 garnered substantial attention. Expanded use of corn for ethanol is part of the story, but other factors have placed upward pressure on food prices, including a decline in the U.S. dollar, high input prices and agricultural production costs, adverse weather conditions in 2006 and 2007 that affected global production levels, and a hold on commodity exports to allow some countries to mitigate food price inflation. Interactions between crop price changes (see the section, "Expanding Corn Acreage Drives Market and Environmental Outcomes") and food prices are not examined empirically. Omitting food price effects from the analysis is not an indication that the issue is not important, but rather that an issue this complex is best undertaken by experts in the field using models explicitly designed for that purpose.

- ***Global production and land use.*** Though crop, biofuel, and energy production operate within global markets, the focus here is on U.S. domestic production. Global land-use implications and how land-use changes affect international feedstock markets are critical drivers in global policy initiatives. While global land use and market effects may influence the domestic market for biofuel feedstocks, tracking these effects is outside the scope of this report. The section on research and policy options delves into concerns about indirect land-use change, with a focus on developing estimates that demonstrate how such a change may occur.

Exploring the Links: Implications of Increased Biofuel Demand on the Environment

The impact of biofuel demand on the agricultural landscape will ultimately be determined by individual producer decisions and shaped by a complex and dynamic set of price incentives, resource constraints, and market forces that will be felt throughout the agricultural sector. Fundamental economic principles provide a context for understanding market responses; an increase in the demand for corn ethanol will lead to higher corn prices and an increased corn supply. The processes behind this seemingly simple relationship are complex, and its implications for a sector as interlinked as U.S. agriculture are often uncertain. Figure 1 provides a stylized illustration of linkages involving product markets, their effect on land and resource management decisions, and implications for environmental quality.

Increased Demand For Biofuel Feedstocks Motivates Adjustments Within Crop Markets…

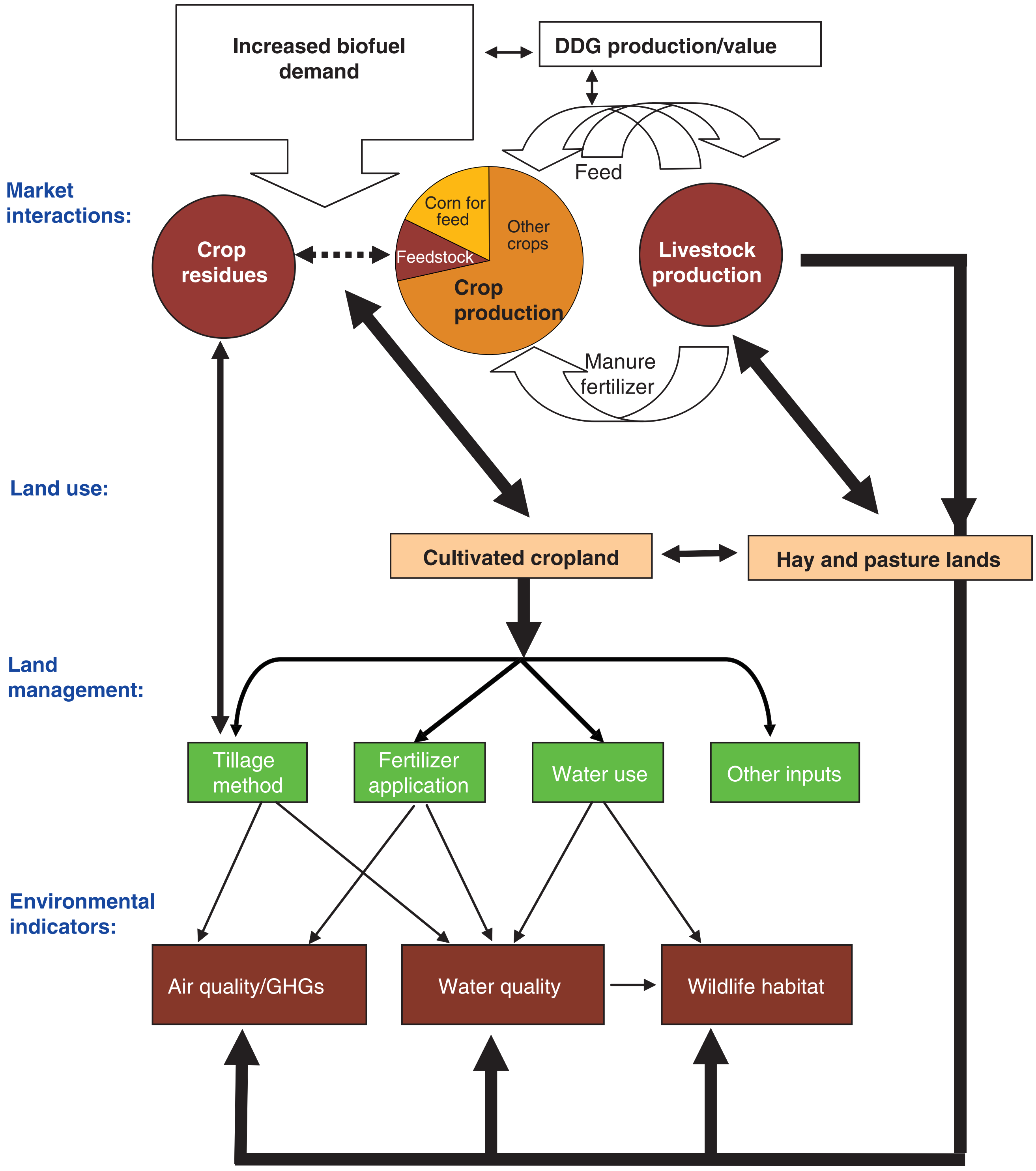
Increased demand for biofuel feedstocks reverberates through the agricultural sector as biofuel crops compete against nonbiofuel crops for land and other inputs (fig. 1). The ultimate mix of crop prices and production levels depends on an equilibration of the aggregate response to the joint set of prices and demand shift relationships.

If the demand for corn for ethanol outstrips increases in corn supply, constrained availability will lead to higher prices for alternative uses, such as processed foods and livestock feed. Higher corn prices, in turn, change incentives to produce and purchase other crops through shifts in both demand and supply. Higher corn prices make other corn substitute crops more attractive to consumers (e.g., sugar for corn fructose in processed foods, sorghum for corn grain in livestock feed). Higher corn prices in the domestic market will also dampen demand for corn abroad. Simultaneously, farmers may respond to higher corn prices by producing corn on fields otherwise used to produce alternative crops, such as soybeans or wheat. Increasing demand for corn substitutes, coupled with a potential reduction in supply due to competition for land, results in price increases for noncorn crops. These price increases could, in turn, motivate farmers to moderate the shift toward corn.

As cellulosic ethanol production comes online, residues produced as a byproduct of crop production, such as corn stover and wheat straw, will also increase in value. Although residues left on the field reduce loss of soil, nutrients, moisture, and carbon, and thus have value to farmers, residues are currently a “free good” produced in quantities that exceed their economic value. Increased values for residues used in ethanol production would feed back into crop production decisions by increasing the total value of the crop—farmers would receive revenues for both the crop (e.g., corn) and the residue (e.g., stover)—although revenues for the primary crop may be reduced as crop feedstock demand declines.

Figure 1

Increased biofuel demand affects land use, land management, and the environment through a series of complex agricultural interactions



DDG = Distiller's dried grains.
GHG = Greenhouse gas.

Source: USDA, Economic Research Service.

…As Well as Adjustments Between Crop and Livestock Markets

Livestock farmers' response to changing feed prices loops back to the crop sector along several pathways. In general, livestock producers will respond to an increase in feed prices by reducing animal production, which could then lessen the upward pressure on feed prices. Different animal species, however, have different feed requirements, as well as differing relationships between total feed costs and bottom-line profits. Thus, a hog farmer may respond differently than a dairy farmer, and they both may respond differently than a poultry producer. This relationship is further complicated by the availability of distiller's grains, a byproduct of the ethanol distilling process that can be fed in limited quantities depending on the animal. Distiller's grains become more plentiful as corn ethanol production expands, providing additional revenue for ethanol processors (see box, "Distiller's Grains: An Important Coproduct of Corn Ethanol"). If distiller's grains can be worked into feed rations, producers can moderate the impact of increased feed prices (Stillman et al., 2009).

Livestock and crop production are also linked through animal waste. Environmental concerns about waste production from large livestock operations, and subsequent rules governing the disposal of manure and other wastes to protect water quality, have increased the demand for cropland where livestock producers can spread their manure (so that manure nutrients can be used by crops rather than becoming runoff into water bodies). Likewise, higher fertilizer prices (associated with volatile energy prices) increase demand by crop producers for manure as a relatively cheap source of nutrients.

Changes in the Crop and Livestock Sectors Influence, and Are Influenced by, Land-Use Choices

The rapid expansion of biofuel feedstock production has placed significant demands on the agricultural land base, raising concerns about resource sustainability and environmental quality. While individual agricultural markets (e.g., corn) have proven responsive to new sources of demand, substantial increases in the production of one crop generally come at the expense of another. Growers may switch rotation patterns annually, growing corn 2 or more years in a row on a given field rather than alternating crops, such as between corn and soybeans.

Higher prices for corn and other crops may provide incentives to expand the cropland base. That land, however, would have to come from other land uses. One source of new land for crop and feedstock production is cropland pasture. Another potential source is idled cropland, including acreage enrolled in the Conservation Reserve Program (CRP), which may be available for production as multiyear contracts expire. While bringing more land into production can reduce upward pressure on commodity and feedstock prices, land that is not currently cultivated for crops may be less productive than other land in the region and be less likely to generate a commensurate production increase. Converting CRP land, cropland pasture, and other lands

Distiller's Grains: An Important Coproduct of Corn Ethanol

Distiller's grains are a primary coproduct in corn ethanol production. During the dry milling process, starches from corn are converted to ethanol through fermentation and distillation. The resulting residual product—distiller's grains—comprised of protein, minerals, fat, and fiber, has increasingly been used as a high-quality animal feed supplement. Distiller's grains can best be used as a feed for ruminant animals, such as beef cattle and dairy cows. Monogastric animals, such as hogs and poultry, have a limited ability to digest distiller's grains, but distiller's grains are increasingly being used in rations for those species as well.

Two forms of distiller's grains may be derived from ethanol processing. Distiller's wet grains (DWG), with a moisture content in excess of 50 percent, are used primarily as feed supplements for beef and dairy cattle. Due to the water weight of the product, wet distiller's grains generally serve local markets near the processing facility. Distiller's dry grains (DDG), often blended with liquid residues (solubles), are dried to a moisture content of roughly 10 to 15 percent. Drying increases production costs, but increases the shelf life of the material and reduces the costs of hauling. Distiller's dry grains with solubles (DDGS) may also be modified for use in swine and poultry feed, in addition to beef and dairy. Distiller's dry grains are often shipped significant distances from the processing facility, serving broader regional and export markets.

Distiller's grains account for roughly 20 percent of returns to ethanol production (Dhuyvetter et al., 2005). While the concentration of biofuel processing capacity in the upper Midwest is attributable primarily to the availability of lower cost corn, proximity to confined livestock operations, which can absorb distiller's grains, is likely a contributing factor. Livestock producers, in turn, have recognized the value of distiller's grains, particularly DWG used in beef cattle rations. While marketing challenges remain due to variability in nutrient composition, product storage and transport, and food safety concerns, animal feed rations are being modified to make use of this resource.

to more intensive uses could also reduce wildlife habitat, while increasing delivery of sediment, nutrients, and pesticides to local water bodies.

Land Allocation Decisions Affect Changes in Practices and Input Use…

Higher commodity prices due to biofuel demand may also result in farm-level resource management changes. How production regimes respond will depend on the crop produced, field characteristics, local resource conditions, and producer incentives to reduce environmental impacts. Several important resource management decisions involve tillage systems, applied nutrients and pesticides, and irrigation use.

Tillage and residue management. Tillage of cropland soils is used for a variety of beneficial purposes: soil loosening/aeration, incorporation of nutrients and plant residues, weed control, seedbed preparation, and soil and water conservation. Field tillage, however, can have adverse impacts on soil quality (e.g., structure, depth, soil organic carbon, and moisture/nutrient retention) and soil erosion rates. Tillage management systems vary in their frequency and intensity. A key factor used to assess the soil erosion potential of a tillage regime is the amount of crop residue left on the field after planting. Tillage systems are classified according to residue cover (Sandretto and Payne, 2006):

- Conservation tillage (>30 percent residue remaining)
    - No-till
    - Ridge-till
    - Mulch-till
- Reduced-till (15-30 percent residue remaining)
- Conventional or intensive-till (<15 percent residue remaining)

Once cellulosic technologies become commercially viable, residue removal for cellulosic biofuels may further affect environmental outcomes. As cellulosic ethanol conversion plants come online, crop residues already widely available—including corn stover and wheat straw—may play a major role in this transition. Beyond their value as an ethanol feedstock, however, crop residues left on the field help maintain soil nutrients, erosion, and carbon levels. Therefore, an important policy consideration in implementing residue-based cellulosic conversion is the amount of crop residue that can be harvested, while also maintaining soil quality and soil productivity as determined by tillage regime and other factors.

Nutrient and chemical use. Increasing biofuels' demand for feedstocks may result in increased use of nutrients and pesticides as cultivated land and corn acreage expand. Average rates of nitrogen use in U.S. corn production (138 pounds/acre) (USDA-NASS, 2006), for example, are greater than application rates for crops that may be displaced—including soybeans and wheat (16 and 66 pounds/acre, respectively) (USDA-NASS, 2007). Pesticide use also tends to be relatively intensive in U.S. corn production. Higher prices for corn and other crops may also increase the intensity of chemical input use.

Water use. Expansion of biofuel feedstock production has the potential to increase water demand due to ethanol processing requirements and, more significantly, changes in irrigation. Potential demand for irrigation water will depend on changes in total acreage irrigated, the crops being irrigated, and water applied per acre. In the long term, cellulosic biofuel production is likely to expand, although little is known about water requirements for cellulosic production on more marginal lands. While expansion of ethanol production may occur in areas not traditionally irrigated, large new surface water and groundwater withdrawals may be limited by physical supply availability, legal constraints, and economic considerations. The net effect of biofuels on agricultural water withdrawals is uncertain and may vary both regionally and over time, depending on future spatial patterns of biofuel processing facilities, primary feedstock sources, consumptive requirements of displaced irrigated crops, and local water institutions.

…Which Contribute to Changes in Environmental Quality

Environmental outcomes will reflect the interaction of changing land use, crop choice, and resource management decisions made for complex biophysical systems across a diverse landscape. Moreover, the potential environmental consequences of biofuel production will change rapidly as technologies evolve and the scale and distribution of production shifts. This report addresses three important measures of environmental sustainability: soil erosion, nitrogen loss, and GHG emissions.

Soil erosion. Soil erosion on agricultural lands is a significant national concern. In 2003, the latest year for which data are available, approximately 971 million tons of cropland soil were lost to water (sheet and rill) erosion, with an additional 776 million tons lost to wind erosion. (USDA-NRCS, 2003). Deterioration of the soil structure due to erosion can reduce the long-term productivity of cropland soils. Cropland soil erosion can also cause significant environmental damage, including water-quality degradation (e.g., turbidity and sedimentation) and air-quality impairment (e.g., suspended particulates). Fields vulnerable to erosion reflect the inherent erodibility of the field (e.g., soil characteristics and slope), tillage and erosion control practices (e.g., cover crops and residue management), and the amount and intensity of rainfall and wind. The potential for biofuel demand to expand production of row crops, such as corn, on erodible croplands has raised concerns over soil loss.

Nutrient loss. Nutrient loss from applied chemical fertilizers and animal manure on cropland—primarily nitrogen and phosphorus—is a major source of water-quality impairment. Primary pathways for nutrient transport include field runoff of nitrogen and phosphorus to surface water and nitrogen leaching below the crop root zone to groundwater. Runoff and leaching of agricultural pesticides, herbicides, and other applied chemicals contribute to further water-quality degradation. The potential for agricultural pollutant nutrient loads and other applied chemicals is highly site-specific and depends on several factors, such as crop type and land cover, soil and topography, management regimes for nutrients and pesticides, irrigation use, and proximity to water. Increased fertilizer and pesticide runoff in the Mississippi River Basin, where much of the ethanol feedstock production is concentrated, has raised concerns about worsening hypoxia (oxygen deprivation) in the Gulf of Mexico (National Research Council, 2008).

GHG emissions. Expanding domestic production and the use of biofuels can both enhance energy security and lower GHG emissions due to reduced fossil fuel combustion. The various phases of corn feedstock and ethanol production, however, also contribute to GHG emissions, including carbon dioxide (CO_2), nitrous oxide (N_2O), and methane (CH_4). Corn is an energy-intensive crop due to high energy and fertilizer requirements. At the same time, conversion of idled cropland and pastureland to crop production releases stored carbon once the vegetation is removed and the soil disturbed. Consequently, a given quantity of biofuel that displaces the use of fossil fuel may result in only a modest reduction or possibly an increase in net GHG emissions. Commodity price changes due to biofuel policies, and the resulting indirect effects on domestic and international land use and land management, are an important consideration in assessing the net effect of GHG emissions.

Assessing Changes to the Agricultural Landscape

We employed a national agricultural sector model with regional specificity in production and resource allocation to evaluate changes in the U.S. farm sector in response to accelerated biofuel demand. Regional differentiation in production and resource endowments allows us to examine adjustments in key environmental indicators across regions and determine whether changes are the result of adjustments in planted acreage, cropping patterns, input use, management practices, such as tillage, or a combination of factors.

The Regional Environment and Agriculture Programming (REAP) model is a quantitative, economics-based model used to evaluate market and policy impacts on U.S. agriculture. A comprehensive description of REAP is provided in Appendix A. Production quantities, prices, and land allocations were determined by the model, subject to baseline assumptions on yields, technology, costs, and targets for corn- and cellulosic-based ethanol (see box, "Key Assumptions in REAP Analysis"). In addition to determining market and production outcomes, REAP simulates resource and environmental consequences of Government policies on the agricultural sector. REAP computes several environmental indicators to assess the impact of biomass production scenarios. Indicators examined in this study include nutrient and pesticide runoff and leaching, soil erosion, and GHG emissions.

Key Assumption in REAP Analysis

- All demands for crop commodities are national, while demands for livestock production are regional. Transportation and marketing costs are not considered.
- Acres of individual crops in multicrop rotations are allocated proportionally; thus, for 1 million acres in a two-crop rotation, 500,000 acres are allocated to each crop.
- Crop yields are fixed at average values per region and do not adjust for price-induced effects.
- Crop production and the Conservation Reserve Program (CRP) compete for land based on an upward-sloping supply function.
- Demands for final agricultural products (crops, livestock, and processed goods) are modeled using linear functions.
- Yields for all crops are calibrated to the USDA baseline for 2015, which includes yield growth for all crops from the present to 2015. Corn yields in the "high corn-productivity" scenario increase an additional 1 bushel/year. Yield increases assume no corresponding increase in inputs.
- The corn-based ethanol target of 15 billion gallons (RFS15) is fixed in all scenarios except the baseline, which assumes 13.3 billion gallons, and in the cellulosic scenario, where corn-based ethanol is allowed to vary.
- The 1-billion-gallon biodiesel standard is met entirely from soybeans.

Production decision variables—including land use, crop mix, crop rotations, tillage practices, and fertilizer application rates—and livestock production were determined simultaneously in the model. The environmental impacts of land use and agronomic practices were estimated, in turn, by applying coefficients derived from the Environmental Policy Integrated Climate (EPIC) model—a crop biophysical simulation model. EPIC incorporates soil, weather, and management information to estimate crop yields, erosion, and chemical (pesticide and fertilizer) discharges to the environment. EPIC calculates crop yields and input use under different tillage, crop rotation, soil management, and weather scenarios at a daily time step.

The USDA's agricultural projections (referred to as the USDA baseline) reflect 10-year projections for U.S. agriculture and provide a useful benchmark to evaluate changes to the agricultural sector associated with alternative policy scenarios (see box, "Choosing a Baseline"). The 2008 USDA baseline, incorporated into the REAP model, provides projections for the agricultural sector through 2017[1] (USDA, 2008). Projections cover agricultural commodity markets, agricultural trade, and economic indicators, such as farm income and food prices.

The 2008 USDA baseline projects national biofuel production at 13.3 billion gallons of conventional ethanol and 700 million gallons of biodiesel in 2015. The 2008 USDA baseline, developed before passage of EISA, reflects production and market conditions envisioned over the projection period in the absence of a revised RFS. Thus, the baseline depicts a possible outcome that follows a "business as usual" biofuel policy without accelerated Federal mandates. The 2008 USDA baseline scenario for 2015 will be denoted "baseline" in the following analysis.

Figure 2 shows the evolution of projected biofuel production under the 2008 USDA baseline and with the new RFS. Point 1 represents the 15-billion gallon RFS scenarios and 77 percent of the total ethanol production for 2015. Point 2 is the total RFS for 2015 of 20.5 billion gallons, including 15 billion gallons of conventional ethanol, 3 billion gallons of cellulosic biofuel, 1.5 billion gallons of noncellulosic advanced biofuel, and 1 billion gallons of biomass-based diesel.

Conventional Ethanol Production and Agriculture

The baseline projections for commodity markets and biofuel demands are based on assumptions—supported by USDA empirical analysis—of macroeconomic conditions, policy, weather, and international developments. The 2008 USDA baseline projections assume that there are no significant shocks due to abnormal weather, outbreaks of plant or animal diseases, or other factors affecting global supply and demand. The Farm Security and Rural Investment Act of 2002, the Energy Policy Act of 2005, and the Agricultural Reconciliation Act of 2005 are assumed to remain in effect through the projection period. The projections represent a scenario for anticipated changes in the agricultural sector over the next decade. As such, the projections provide a point of departure for discussion of alternative farm sector outcomes that could result under different assumptions.

[1] The USDA publishes 10-year projections, which in 2008 went out to 2017; 2015 is the year we chose from the baseline for our analysis.

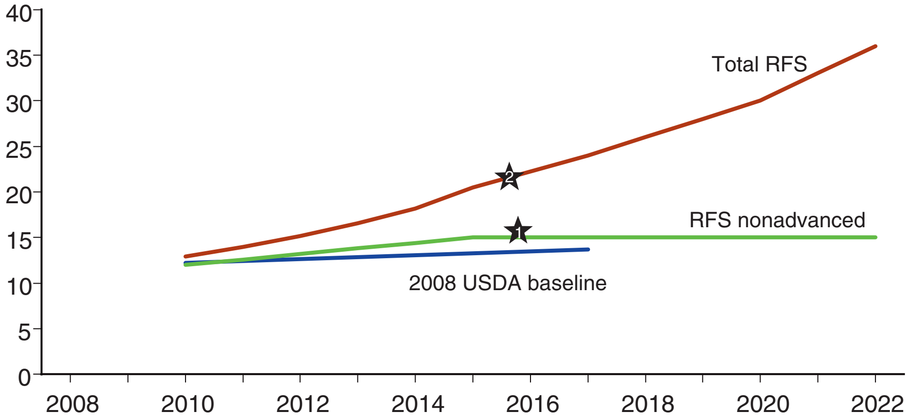
Choosing a Baseline

Consequences of a policy on crop and livestock markets and environmental outcomes are evaluated relative to a point of reference or baseline. Two common choices for baselines are a previous "historical reference" and a projected "business as usual" situation. A "point in time" baseline would compare absolute changes in parameters of interest between the 2 different years. "Historical reference" baselines measure the combined effects of all policies on agriculture over the timespan. A "business as usual" baseline assesses the impacts of a policy over and above what may have happened in absence of the policy. We employed USDA agricultural projections—a "business as usual" baseline—to assess the differential effects of increased biofuel production beyond the current trend.

Figure 2

Ethanol production projections, 2008-22

Billion gallons



RFS = Renewale fuel standard.

Source: USDA, Economic Research Service.

To assess how production patterns and environmental indicators may change relative to projected baseline outcomes, the model was run using the 15-billion-gallon RFS level for 2015 (RFS15). The year 2015 represents the first year that the RFS permits as much as 15 billion gallons of corn-based ethanol to count toward the overall mandate. After 2015, the corn-based biofuel target remains at 15 billion gallons, while the target level for advanced biofuel production continues to increase. Since increases in crop productivity are anticipated to continue, 2015 might be the year of greatest potential impact from corn-based ethanol. The cellulosic biofuel target for 2015 is 3 billion gallons, a level that may be satisfied by crop residue and other available cellulosic feedstocks without displacing existing crop acreage with significant plantings of new dedicated energy crops. While some planting of dedicated energy crops may occur on cropland or pastureland by 2015, REAP does not take this into account.

Additional scenarios assess the robustness of model results relative to key factors that influence production decisions, including higher projected corn yield (HCY), higher ethanol conversion rates (HCE), and higher input costs (HIC). The first two scenarios reflect areas of ongoing research and development, and the third recognizes the importance of agricultural production costs that are driven mainly by volatile energy prices. For simplicity, each scenario assumes a fixed demand of 15 billion gallons of corn-based ethanol and 1 billion gallons of biodiesel supplied by soybeans. While we understand that scenario-induced changes in relative prices and feedstock demands may alter ethanol demand, the modeling framework precludes a full assessment of U.S. energy market adjustments. For each case, we make a comparison between the scenario, which includes the 15-billion-gallon ethanol demand, with the baseline. The conditions described in the scenarios could apply to the baseline in the absence of higher biofuel demand. The purpose, however, is to measure, relative to the baseline, the scenarios' influence on the response to higher ethanol demand, regardless of whether those responses might be mitigated by the scenarios. Moreover, increased demand for ethanol, and associated price increases, may induce innovation (by making it more profitable) in yields and conversion rates. Likewise, increased crop production may increase the demand for key inputs, thus raising their prices. We cannot assess the extent to which biofuel policies may lead to scenario shifts, but we do find the analysis of the shift implications informative.

Research to improve corn productivity is underway in both the private and public sectors. Technological advances in corn productivity that increase yield growth beyond historic trends would allow corn feedstock production to meet Federal targets on fewer acres, effectively freeing up land for other crops. Average annual growth in corn yield over 1960-2007 has been about 1.9 bushels per harvested acre (1.9 percent per year). The USDA baseline assumes that average corn yield will increase 9 percent from 2008 to 2015. The "high corn-productivity" growth scenario (RFS15+HCY) raises this figure by 50 percent, which leads to a 13.5-percent increase in average annual yield from 2008 to 2015 (see box, "Prospective Growth in U.S. Corn Yield"). The corn-yield increase is applied uniformly to corn production across all regions, rotations, and tillage. Yields for other crops remain at the levels assumed in the USDA baseline.

Increasing corn supply through higher yield productivity is one way to reduce competition for land due to corn feedstock production. Another strategy is to reduce the demand for corn feedstocks by improving the efficiency of the ethanol conversion process. Corn-based ethanol production has increased from 2.4 gallons per bushel in the 1980s to 2.8 gallons (nondenatured, before the addition of gasoline) per bushel in today's state-of-the-art facilities. Our analysis assumes an average conversion rate of 2.8 gallons per bushel through 2015. Technological advances that improve the efficiency of starch collection and fermentation could increase this to a theoretical maximum level of 3 (nondenatured) gallons per bushel. The conversion rate realized depends on the starch content of the corn, which may vary considerably by genetic trait, from region to region, from harvest to harvest, by the fraction of starch that is extracted, and by the ability of the fermentation process to utilize the available starch (McAloon et al., 2000). Corn varieties bred for highly fermentable starch content could be employed on a wider scale, but this study does not assume any differentiation in the corn supply. More efficient conversion of corn would require less corn to produce the same amount of ethanol, thereby reducing the amount of land planted to corn. To measure the impact on outcomes of a high ethanol conversion efficiency scenario (RFS15+HCE), we apply a value of 2.9 gallons per bushel. This value indicates an improvement in the industrywide conversion rate that still accounts for variation between highly efficient plants and plants operating at less efficient levels. The key difference between the high corn-productivity growth scenario and the high ethanol-conversion scenario is that the former shifts the *supply* of corn and the latter shifts the *demand* for corn.

Higher energy prices raise the cost of producing and delivering feedstocks because fuel and electricity for planting, harvesting, tillage, drying, and irrigation often account for a substantial share of farm operating costs. Expenses from indirect energy use, such as energy for fertilizer production, also contribute to operating expenses (e.g., natural gas accounts for a large share of nitrogen fertilizer costs) for some crops. The high input-cost scenario reflects the possibility that the relative cost of energy-intensive inputs to crop production will be higher than that assumed by the baseline. As the energy-dependent component of production costs varies by crops, region, and management practices, the change in relative crop returns will depend on the energy intensity of the crop. Variable costs for each production activity may be broken down into nonenergy (e.g., labor and overhead) and energy-dependent (e.g., fuel and fertilizer) categories. Reflecting the high energy-cost scenario of the Energy Information Agency projections, the 'high input-cost' scenario (RFS15+HIC) incorporates a 50-percent premium to energy-dependent costs. High energy costs would also affect the market for biofuels. Since we model a fixed ethanol demand, however, market-based effects, such as increased demand for biofuels if oil prices were significantly higher, are not captured.

The Introduction of Cellulosic Ethanol

Emerging biofuel production technologies that derive fermentable material from plant cellulosic matter, such as crop residues, forest residues, and grasses, will develop new markets for agricultural products. Whether these products can compete with traditional crops for land and other resources will depend on the type and location of cellulosic feedstock sources. As new technologies emerge, corn may remain the predominant feedstock for ethanol production in the near future. Different cellulosic feedstocks, however, will compete to supply the growing demand for cellulosic-based ethanol. These new sources, while critical for the long-term growth and sustainability of biofuel production, are not yet commercially viable and may play a minor role in the initial wave of cellulosic ethanol production.

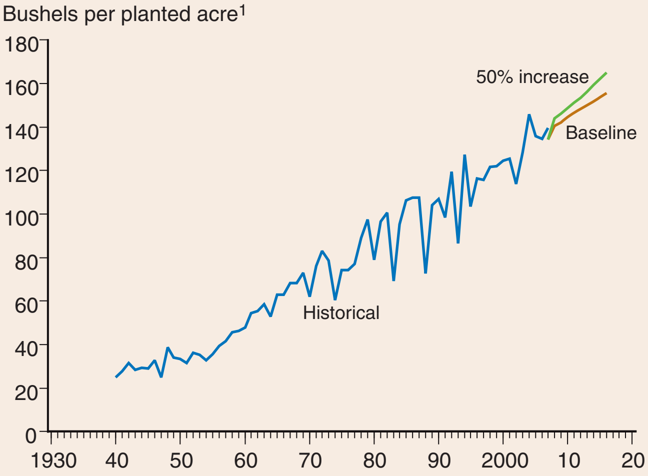
This analysis looks at projected effects on the agricultural sector where crop residues serve as the primary cellulosic feedstock. Although significant markets for residues do not currently exist, crop residues, such as corn stover and wheat straw, are widely available. Crop residues, however, play an important role in restricting nutrient loss and erosion and maintaining soil carbon levels. The amount of residue that can be harvested and still maintain soil productivity, which depends on tillage regime and other factors, is an important policy concern (USDA-NRCS, 2006). Switchgrass and other perennial grasses represent high-yield feedstock alternatives to crop residues. While they show promise in field trials, these grasses are not yet grown on a commercial scale, with minor exceptions, and issues of seed availability, production systems and farmer adoption, storage and transport logistics, and market institutions will need to be resolved before large-scale production becomes viable. Short-rotation woody crops, such as willow and poplar, are

Prospective Growth in U.S. Corn Yield

Following the introduction of commercial corn hybrids in the 1930s, U.S. corn yields have trended upward dramatically.[1] For a long time, increased yields were also supported by increasing input use, such as chemical fertilizers. But since about 1980, corn yields have continued to increase even as fertilizer application rates leveled off or declined.[2]

Extrapolating past yield trends may help to forecast crop yield growth, but trends differ based on starting point and are not necessarily linear over time. Tannura et al. (2008) note a particular shift in trend growth rates for corn yields (Illinois): from about 1 bushel per year during 1940-1959 to 1.7 bushels from 1960 onward. They ascribe this yield acceleration to widespread adoption of fertilizer and herbicides, while others (Sleper and Poehlman, 2006) cite adoption of single cross corn hybrids. Tannura et al. conclude that increases in trend yield growth of up to 70-75 percent (e.g., from 2 to 3.5 bushels per year) could be consistent with historical experience, but increases of 6 bushels or more per year, necessary to reach the widely publicized goal of 300 bushels of corn by 2030, would be unprecedented.

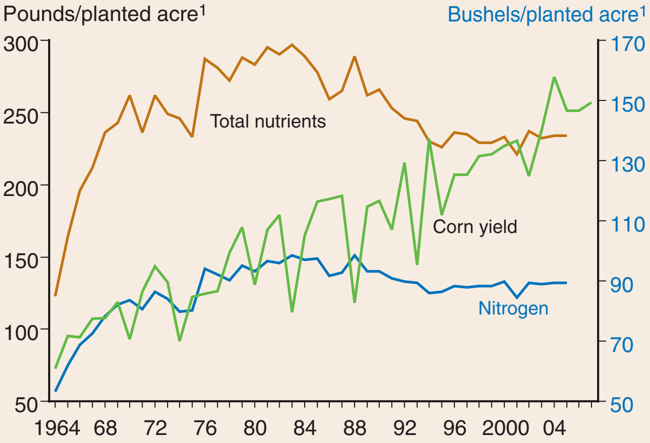
Historical and projected U.S. corn yield growth, 1940-2016



1Denominator includes silage acreage.

Source: USDA, National Agricultural Statistics Service model projections.

Corn yield and fertilizer applied to corn, United States, 1964-2007



1Excluding silage acreage.

Source: USDA, National Agricultural Statistics Service.

Results from the National Corn Growers Association's Corn Yield Contest have also been used as a proxy for potential corn yields. Documented yields of 360-370 bushels per acre,[3] however, (Elmore and Abendroth, 2007) are contingent on optimal growing conditions and particular management strategies. For example, the highest yields are often obtained in the irrigated classes, where moisture can be more carefully regulated than under dry land farming conditions. The level of inputs and time spent managing contest plots may be far above the economic optimum in a commercial situation. Thus, contest yields are more of an indication of yield potential than of a likely national average across a wide range of conditions. Top yields for both State or nationwide irrigated classes have fluctuated widely around a constant mean for the past 20 years or more (Duvick and Cassman, 1999; Elmore and Abendroth, 2007).

Other factors may work against high aggregate growth rates for corn yields. While higher corn prices may encourage expanded irrigation and fertilizer input use, corn area expansion into less productive areas could pose a downward

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[1] Yield trends are presented in terms of yields per planted acre—in this case, corn planted for all purposes—consistent with the presentation in the modeling exercises. The REAP model used here analyzes planted area rather than harvested area because the objective is to model producer expectations when they plant. Much of our discussion will be in terms of yields per harvested acre, which is what the literature on yield trends usually considers.

[2] Silage acreage is excluded from the denominator in both the yield and fertilizer application rate calculations to make the yield denominator consistent with the denominator used in the available fertilizer series.

[3] These represent exceptional yields from the Yield Contest, and while it is physically possible to achieve considerably higher yields, to do so would be uneconomical on a national scale.

Continued on page 17

Continued from page 16

drag on yield increases. The REAP model includes region-specific yields that aggregate up to the national average. For the national average to reach projected levels, some regions (e.g., Corn Belt States, such as Iowa and Illinois) would have to eclipse national-average baseline yields to offset lower yields in other corn-producing areas.

The baseline model used in the agricultural projections includes a jump in yields from 2007 to 2008, primarily to put yields back on the apparent trend line, and then an increase of about 2 bushels per year in yields per harvested acre. This results in an aggregate national corn yield per *harvested* acre of about 171 bushels annually by 2015, which is equivalent to the reported figure of yields per *planted* acre of about 156 bushels per acre per year. Two bushels per year is slightly higher than the long-term yield trend, but is consistent with a recent slight acceleration in yield growth.

The "50-percent yield increase" scenario results in a yield of about 175 bushels per harvested acre in 2015. This is similar to the "increased yield" scenario presented by the National Corn Growers Association (2009) and would be equivalent to about 161 bushels per planted acre in 2015. It would require an increase in yields per harvested acre of over 3 bushels per year, a more than 50-percent acceleration in trend yield growth if the base is 2.0 bushels per year (the assumption of the baseline model), or a more than two-thirds acceleration if the base is 1.85 bushels per year (our linear estimate based on aggregate data for 1960-2007). Such an acceleration could occur as currently available biotechnologies, such as stacked traits, or other imminent technologies are applied. Most of the yield growth would result from investments in research that have already been made, not in investments to be made over the next 10 years.

another feedstock option. These fast-growing trees, which produce sufficient biomass for harvest in a few years rather than the decades common in traditional forestry, are also not currently grown on a large scale. Forest-based residues from logging, timberland clearing, and fire control could also be another biomass source. While it is impossible to forecast the supply of each feedstock with certainty, it is reasonable to assume that crop residues will factor prominently in the early phases of cellulosic ethanol production.

The total ethanol RFS for 2015 is 19.5 billion gallons—with at least 4.5 billion gallons of advanced biofuel (3 billion gallons is from cellulosic feedstock) and the remainder from conventional sources. Actual feedstock shares, however, may vary depending on the relative costs and production capacity of conventional and cellulosic sources. The discrepancy in shares may be especially true if cost-effective cellulosic conversion technology advances at a rapid pace. In this case, cellulosic ethanol might substitute for corn ethanol, reducing demand for corn. To measure the effects of an increasing share of cellulosic ethanol in the analysis, crop residue-based ethanol production is varied from 3 billion gallons to 6 billion gallons, with corn-based ethanol making up the difference (i.e., ranging from 15 billion gallons down to 12 billion gallons). The remaining 1.5 billion gallons of advanced biofuel is assumed to be derived from nonagricultural sources like urban waste. This scenario is meant to illustrate the possible tradeoffs between producing ethanol from corn or from cellulosic residue. The scenario is not meant as a projection or a likely outcome. It does, however, represent some of the issues that may emerge as production of cellulosic ethanol, and consequently demand for cellulosic feedstocks, increases. Table 1 summarizes the key parameter values for the baseline and increased ethanol production scenarios.

Table 1

Key parameters for 2015 ethanol production scenarios

Item	Baseline	RFS 15 billion gallons (RFS15)	RFS 15 billion gallons + High corn yield (RFS15+HCY)	RFS 15 billion gallons + High conversion efficiency (RFS15+HCE)	RFS 15 billion gallons + High input cost (RFS15+HIC)	RFS 15 billion gallons + Cellulosics (RFS15+CELL)
Corn ethanol (billion gallons)	13.3	15.0	15.0	15.0	15.0	12-15.0
Biodiesel (billion gallons)	0.7	1.0	1.0	1.0	1.0	1.0
Corn yield (bushels per planted acre)	156	156	161	156	156	156
Ethanol conversion (gallons per bushel)	2.8	2.8	2.8	2.9	2.8	2.8
Input cost multiplier	1	1	1	1	1.1-1.8	1
Cellulosic (billion gallons)	0	0	0	0	0	3.-6.

RFS=renewable fuel standard.

Note: Highlighted cells indicate parameters that differ from baseline parameter values. Biodiesel production is held at 1 billion gallons in all scenarios.

Source: Economic Research Service calculations based on Regional Environment and Agriculture Programming (REAP) model data.

Expanding Corn Acreage Drives Market and Environmental Outcomes

Greater U.S. demand for corn and the need for greater domestic production will create a new set of conditions under which farmers make planting, input use, and management decisions. Increased land planted to corn will mean either less land available for other crops or new land coming into production, affecting the economics of all crops. Shifts in the relative returns of different crops will cause changes in crop mix at the national level and across regions. Demand for all agricultural commodities will need to adjust to the new price signals, leading to changes in consumption. Environmental effects will vary across the landscape, reflecting regional differences in cropping activity and production practices and their interaction with soil and water resources on and off the farm.

An increase to 15 billion gallons of U.S. ethanol demand over the 13.3 billion gallons assumed in the baseline (year 2015) increases demand for corn, raising prices and stimulating an increase in land planted to corn. While some soybean acreage is displaced by corn, higher biodiesel demand leads to a net increase in acres planted to soybeans. As acres for corn crops expand, acres planted to other crops decrease. Much of the additional planted acres are offset by a reduction in land enrolled in the CRP. Domestic corn price increases also lead to a reduction in corn exports, which reduces pressure on the land base somewhat. Every region shows an increase in corn acreage, with the majority of additional acres concentrated in the traditional corn growing regions of the Corn Belt, Northern Plains, and Lake States.

Crop production involves various practices and inputs—soil cultivation; application of fertilizer, pesticides, and other chemicals; and irrigation—all of which can affect resource use and environmental quality. Increased acreage due to additional biofuel feedstock demand affects land management, with implications for soil productivity, water quality and quantity, air quality, and GHG emissions. Because regions differ in how crop production translates to environmental outcomes, the effect on environmental indicators (e.g., soil erosion, nutrient runoff, and GHG emissions) varies considerably by region. In some regions, the changes in environmental measures are greater than the change in acreage, indicating an intensification of input use and, possibly, expanded production on marginal lands.

Table 2 represents the magnitude and direction of the changes in market, land use, and environmental indicators for each of the RFS15 scenarios, relative to the baseline scenario. The arrow's direction denotes the direction of change; an up-arrow means an increase in the level of the indicator over the baseline and a down-arrow means a decrease in the level of the indicator below the baseline. The number of arrows denotes the magnitude of change relative to the baseline scenario, where a single arrow represents a percent change close to the change in acreage from the baseline to the reference. In all cases, with the exception of the high input-cost scenario (RFS15+HIC), acreage increases over the baseline. Under the RFS15 scenario, price, production, and returns to crop farmers all rise, while livestock returns decline. An improvement in corn yield (RFS15+HCY) is accompanied by a reduction in corn price and an increase in production, which benefits livestock producers through interactions with the feed market. Reduction of corn demand via improved ethanol

Table 2

Change in market and environmental indicators from USDA baseline, 2015

Indicator	RFS 15-billion gallons (RFS15)	+ High corn yield (HCY)	+ High conversion efficiency (HCE)	+ High input cost (HIC)
Market:				
Corn price	↑↑	↓↓	↑	↑↑↑
Corn production	↑↑	↑↑↑	↑	↑
Returns:				
Corn	↑↑↑	↑↑	↑↑	↑↑↑
Other crops	↑↑	↑↑	↑↑	↓↓
Livestock	↓	↑		↑
Cropland:				
Total acres in production	↑	↑	↑	↓↓↓
Corn	↑↑	↑	↑↑	↑
Continuous corn	↑↑↑	↑	↑↑	↓
Highly erodible cropland in production	↑	↑	↑	↓↓↓
Tillage:				
Conventional	↑	↑	↑	↓↓↓
Conservation	↑↑	↑↑	↑↑	↑↑↑
No-till	↑↑	↑↑	↑↑	↑↑↑
Soil erosion:				
Soil loss	↑	↑	↑	↓↓↓
Nutrient loss:				
Surface runoff – in sediment	↑	↑	↑	↓↓↓
Surface runoff – in solution	↑	↑	↑	↓↓↓
Groundwater leaching	↑↑	↑	↑↑	↓↓↓
Pesticide loss:				
Surface runoff – in sediment	↑↑	↑	↑↑	↓↓
Surface runoff – in solution	↑	↑	↑	↓↓
Groundwater leaching	↑↑	↑	↑↑	↓↓
Greenhouse gas:				
Greenhouse gas emissions	↑↑	↓	↑	↓↓↓

RFS=Renewable fuel standard.

Notes: Up-arrow indicates increases in 2015 relative to baseline projections; down-arrow indicates decreases. The number of arrows denotes relative magnitude of change: one arrow, less than 2 percent; two arrows, 2 percent to 4 percent; three arrows, greater than 4 percent.

Source: Economic Research Service calculations based on Regional Environment and Agriculture Programming (REAP) model data.

conversion mitigates price and production effects, but outcomes for resource and environmental quality are generally similar to the RFS15 case. High input costs (RFS15+HIC) lead to a large decrease in acres planted and an increase in price and returns to crop farmers. In all scenarios except the high input-cost scenario, environmental indicators worsen relative to the baseline due to increased acres planted and changes in cropland management. In the high input-cost case, the large decline in acres planted contributes to proportionally large reductions in environmental effects.

Crop Producers See Higher Returns

Cultivated U.S. cropland area is projected to expand in response to Federal biofuel targets as increased demand for corn drives prices higher across grain commodities. According to model projections, U.S. cropland in production for 2015 increases slightly over the 2008 USDA baseline, from 313.8 to 318.7 million acres (1.6 percent), with some growth in nearly all regions (table 3). Acreage adjustments lead to changes in production that reflect regional differences in yield (tables 4 and 5). The prices of corn and soybeans are higher relative to the baseline, while other crop prices hold steady (table 6). Crop producers realize higher returns as the increases in price and production over the baseline are greater than the increase in production costs necessary to achieve higher production levels (table 7). Corn producers see a greater increase in returns compared with producers of other crops.

Higher feed prices, however, lead to lower returns to the livestock sector and a small contraction in animal inventories. The high corn-yield and high ethanol-conversion rate scenarios also show higher returns to corn producers relative to the baseline. In the high ethanol-conversion scenario, the price of corn increases slightly because the higher demand for ethanol keeps corn production above the baseline. The price of corn declines in the high corn yield case, but production increases keep returns higher than the baseline scenario. Corn production increases in all regions, with greater increases where corn is most profitable. The high input-cost scenario raises returns to corn farmers due to the increase in price and production. Other agricultural producers see a reduction in net income because, even as prices rise, production is reduced by a larger percentage, lowering revenue compared with the baseline.

Land allocations shift considerably across regions, reflecting regional comparative advantage in first-generation biofuel feedstock production. Cropland acreage in production expands in all regions. The largest absolute acreage gains occur in the Northern Plains (up 2 million acres to 67.2 million

Table 3

Regional acreage planted, by scenario, 2015

Region	Baseline	RFS 15-billion gallons (RFS15)	+ High corn yield (HCY)	+ High conversion efficiency (HCE)	+ High input cost (HIC)
			Million acres		
Northeast	14.7	14.8	14.8	14.8	14.1
Lake States	39.4	39.9	39.7	39.8	37.3
Corn Belt	101.2	102.3	101.9	102.1	100.8
Northern Plains	65.2	67.2	65.8	66.7	57.1
Appalachian	18.1	18.5	18.4	18.4	17.5
Southeast	5.8	6.1	6.0	6.0	5.4
Delta	14.5	15.0	15.0	15.0	14.0
Southern Plains	25.7	25.8	25.7	25.8	20.1
Mountain	21.3	21.3	21.3	21.3	18.5
Pacific	7.7	7.8	7.8	7.8	6.1
United States	313.8	318.7	316.2	317.7	291.0

RFS=Renewable fuel standard.

Note: Totals may not sum due to rounding.

Source: Economic Research Service calculations based on Regional Environment and Agriculture Programming (REAP) model data.

Table 4

Acreage planted to major crops, by scenario, 2015

Ctop	Baseline	RFS 15-billion gallons (RFS15)	+ High corn yield (HCY)	+ High conversion efficiency (HCE)	+ High input cost (HIC)
			Million acres		
Corn	91.5	94.7	92.9	93.7	92.1
Sorghum	5.8	5.7	5.0	5.7	3.7
Barley	3.5	3.5	3.5	3.5	3.0
Oats	3.8	3.8	3.8	3.8	3.5
Wheat	56.0	56.0	56.0	56.0	49.5
Rice	3.2	3.1	3.1	3.1	2.6
Soybeans	68.0	69.9	69.9	69.9	68.5
Cotton	12.1	12.1	12.1	12.1	10.0
Silage and hay	69.9	69.9	70.0	69.9	58.1
Total	313.8	318.7	316.2	317.7	291.0

RFS=Renewable fuel standard. Note: Totals may not sum due to rounding.

Source: Economic Research Service calculations based on Regional Environment and Agriculture Programming (REAP) model data.

Table 5

Commodity production, by scenario, 2015

Crop	Baseline	RFS 15-billion gallons (RFS15)	+ High corn yield (HCY)	+ High conversion efficiency (HCE)	+ High input cost (HIC)
	Production	—— *Percent change from baseline* ——			
Corn (*million bushels)*	14,240	2.7	5.3	1.9	0.7
Sorghum *(million bushels)*	340	-2.0	-14.2	-1.6	-35.6
Barley *(million bushels)*	210	0.5	0.5	0.5	-9.4
Oats *(million bushels)*	249	-0.5	0.1	-0.2	-4.7
Wheat *(million bushels)*	2,125	-0.3	0.0	-0.2	-9.8
Rice *(million cwt)*	240	-2.3	-2.3	-2.3	-18.1
Soybeans *(million bushels)*	3,035	2.0	2.1	2.0	0.7
Cotton *(million bales)*	22	-0.2	-0.1	-0.2	-9.1

RFS=Renewable fuel standard.

Cwt = hundredweight.

Source: Economic Research Service calculations based on Regional Environment and Agriculture Programming (REAP) model data.

acres), Corn Belt (up 1.1 million acres to 102.3 million acres), and Lake States (up 490,000 acres to 39.9 million acres), accounting for almost three-quarters of the additional acres in crop cultivation. Higher corn yield and higher ethanol conversion both put downward pressure on cultivated acreage, but additional acres are still needed to achieve the higher biofuel production level. In contrast, high input costs dramatically reduce the number of acres in production to 291 million acres (down 22.8 million acres from baseline) as profit margins decline in many regions despite higher commodity prices.

Expansion in U.S corn acreage drives both increased cropland in production and regional crop pattern shifts. Corn acreage increases by 3.25 million acres over the baseline (3.5 percent), with substantial increases occurring in all U.S. regions (table 8). The greatest absolute increase occurs in the Northern Plains, with an additional 1.5 million acres in 2015 (8.6 percent). The Corn Belt adds 770,000 acres, although the gain over baseline levels (1.7

Table 6

Commodity prices, by scenario, 2015

Crop	Baseline	RFS 15-billion gallons (RFS15)	+ High corn yield (HCY)	+ High conversion efficiency (HCE)	+High input cost (HIC)
	Price	*—— Percent change from baseline ——*			
Corn *($/bushel)*	3.55	2.2	-3.0	1.6	6.8
Sorghum *($/bushel)*	3.30	0.3	-0.8	0.2	5.3
Barley ($/bushel)	3.85	-0.3	-0.3	-0.3	5.8
Oats *($/bushel)*	2.25	1.0	-0.2	0.5	10.1
Wheat *($/bushel)*	4.55	0.1	0.0	0.1	5.0
Rice *($/cwt)*	12.12	0.1	0.1	0.1	1.0
Soybeans *($/bushel)*	8.90	2.7	2.6	2.7	3.5
Cotton *($/pound)*	0.56	0.1	0.1	0.1	3.9

RFS=Renewable fuel standard.

Cwt = hundredweight.

Source: Economic Research Service calculations based on Regional Environment and Agriculture Programming (REAP) model data.

Table 7

Net returns to agricultural production, by scenario, 2015

Comnodity	Baseline	RFS 15-billion gallons (RFS15)	+ High corn yield (HCY)	+ High conversion efficiency (HCE)	+ High input cost (HIC)
	Net returns ($ billion)	*—— Percent change from baseline ——*			
Corn	31.5	5.4	2.4	3.8	6.4
Other crops	23.7	2.8	3.3	3.1	-4.0
Livestock	33.6	-0.3	0.5	-0.2	-1.3

RFS=Renewable fuel standard.

Source: Economic Research Service calculations based on Regional Environment and Agriculture Programming (REAP) model data.

Table 8

Regional acreage planted to corn, by scenario, 2015

Region	Baseline	RFS 15-billion gallons (RFS15)	+ High corn yield (HCY)	+ High conversion efficiency (HCE)	+ High input cost (HIC)
			Million acres		
Northeast	3.9	4.0	3.9	4.0	3.9
Lake States	14.7	15.1	14.8	14.9	14.4
Corn Belt	45.2	46.0	45.5	45.7	46.0
Northern Plains	17.8	19.3	18.4	18.8	17.9
Appalachian	4.6	4.7	4.7	4.7	4.6
Southeast	1.8	1.9	1.9	1.9	1.7
Delta	0.7	0.8	0.7	0.7	0.8
Southern Plains	1.2	1.3	1.2	1.2	1.2
Mountain	1.3	1.4	1.4	1.4	1.3
Pacific	0.3	0.4	0.3	0.3	0.3
United States	91.5	94.7	92.9	93.7	92.1

RFS=Renewable fuel standard.

Note: Totals may not sum due to rounding.

Source: Economic Research Service calculations based on Regional Environment and Agriculture Programming (REAP) model data.

percent) is comparatively small. In regions where corn is less predominant, corn acreage expansion is modest. In response to rising biodiesel demand, the Northern Plains and Delta regions add over 500,000 acres of soybeans as production shifts from the Corn Belt region. Total acreage in wheat does not change nationally. The Northern Plains region loses 180,000 acres of wheat in response to corn and soybean expansion, but makes up these losses by small gains in other regions.

Shifts in corn yield may have implications for acreages of other crops as well. In our analysis, the effect of corn yield on soybean area is mixed in terms of regional shifts and fairly small in magnitude. Corn acreage expansion appears more important than corn yield in influencing soybean acreage. Increases in projected corn yield, however, cause some significant shifts in wheat acreage, with large decreases in the Southeast and Northeast and comparatively large increases in the Appalachian and Lake States regions. Observed volatility outside major grain-producing areas may reflect a higher degree of crop switching due to shifts in relative crop returns.

Higher commodity prices will motivate producers to convert land currently idled through the CRP to crop production as contracts expire. The 2008 Farm Act lowered the amount of acreage that can be enrolled nationally in the CRP, from 39.2 million to 32 million acres. The 2008 USDA baseline, which was finalized prior to passage of the 2008 Farm Act, projected enrollment at 35.4 million acres in 2015, which is slightly above current enrollment. In our model, CRP enrollment declines from the baseline level of 35.4 million acres to 32.3 million acres under the RFS15 scenario. CRP acreage shifts west, with reduced acreage enrollment in the Corn Belt and Plains regions and a modest enrollment increase in the Mountain States. Results suggest that much of the additional acreage in production under the RFS15 scenario will come from CRP land as contracts expire, although not all of that land will be used to produce biofuel feedstock.

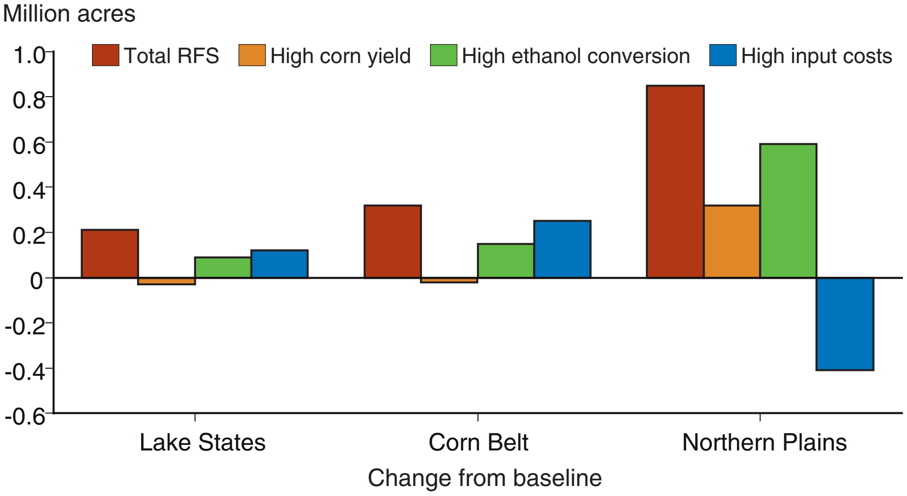
Production Intensifies

Expansion in U.S. corn acreage is attributable, in part, to an increase in continuous corn production—planting corn on the same field for at least 3 consecutive years—effectively reversing a trend that sees different crops planted on a given field in alternate years (e.g., corn in rotation with soybeans). Rotating crops can reduce soil loss and enhance soil productivity, while reducing the need for pesticides and fertilizers. Continuous planting accounts for about 30 percent of the corn produced under the baseline. Continuous planting, however, represents half of the corn acreage under the 15-billion-gallon biofuel scenario. Expansion of continuous corn production occurs in all regions (fig. 3), but is especially strong in the Northern Plains, where 56 percent of the additional corn acres are planted in continuous rotations. In the high input-cost scenario, continuous corn acres increase in the Corn Belt and Lake States, but decrease in the Northern Plains.

The shift to more intensive farming practices with continuous corn is mitigated somewhat by a shift from conventional soil tillage to conservation tillage methods. Tillage choice—the method used to prepare the soil for planting—is an important determinant of soil erosion control, as well as the fuel, machinery, and labor resources needed to manage the field. Conventional tillage, which

Figure 3

Change in continuous corn acres, by scenario, 2015



RFS = Renewable fuel standard.

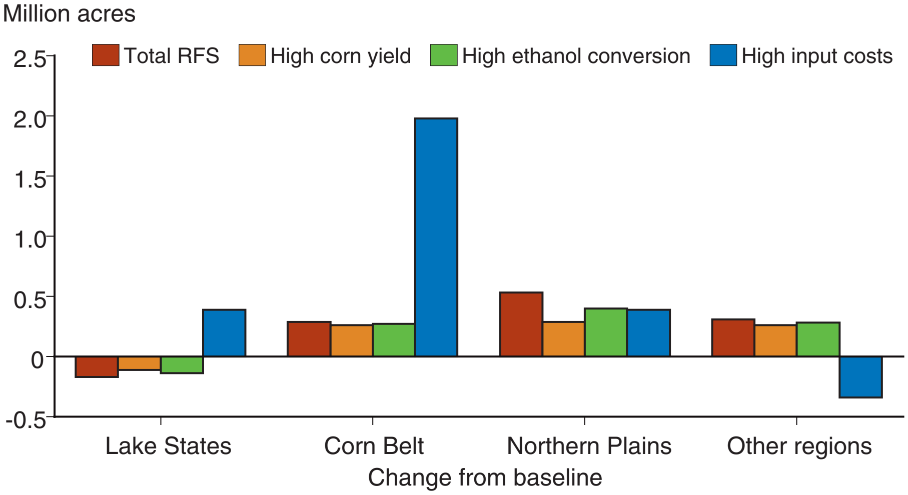
Source: USDA, Economic Research Service calculations based on Regional Environment and Agriculture Programming (REAP) model data.

accounts for 72 percent of all cropland under the baseline, remains the predominant system under the RFS15 scenario. No-till, which minimizes disturbance of the field, accounts for 11 percent of cropland. No-till acres increase in the Corn Belt and Northern Plains, but decrease in the Lake States (fig. 4). Of the 4.9 million additional acres under the RFS15 scenario, 23 percent are in no-till acres and 51 percent are conventionally tilled acres. The higher corn-yield growth scenario, while requiring fewer acres in corn than in the RFS15 scenario, shows that a third of the additional acres that are needed relative to the baseline go into no-till systems and only 20 percent into conventional tillage systems. Land that would have been planted to corn is planted to other crops where no-till is a profitable option. Even more interestingly, the high input-cost scenario, with a large overall decline in total crop acres, shows an increase in crops planted under no-till as producers respond to lower fuel and equipment costs associated with no-till systems.

The REAP model shows that U.S. nitrogen fertilizer use in 2015 will increase by 2 percent over the baseline. This change is greater than the 1.6 percent increase in planted acres, indicating more intensive farming with increased corn production and higher corn prices. Regional differences in crops planted and heterogeneity in soil and climate characteristics lead to regional variation in the change in fertilizer use. Nitrogen use in the Northern Plains increases by 3.6 percent from the baseline, compared with 0.8 percent in the Southern Plains. On a per-acre basis, modest increases in fertilizer applications are exhibited in the major crop-producing regions (fig. 5). A large shift into soybeans planted in rotation with other crops in the Delta leads to a large decline in fertilizer intensity. Increasing yield growth for corn—a fertilizer-intensive crop—reduces the need for fertilizer per unit of yield. It should be noted, however, that the increase in corn yield assumes no corresponding increase in nitrogen uptake. Any increases in nitrogen uptake required to support higher yields would counter the fertilizer adjustments reported here. High input costs significantly reduce the amount of fertilizer used nationally (down 6.5 percent from the baseline), but do not reduce the intensity of fertilizer use. The acreage reduction

Figure 4

Change in no-till acres from baseline, by scenario, 2015

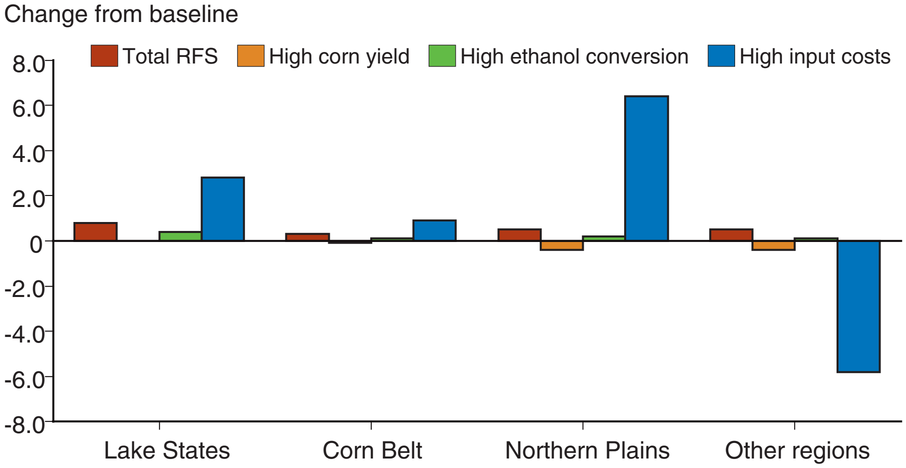


RFS = Renewable fuel standard.

Source: USDA, Economic Research Service calculations based on Regional Environment and Agriculture Programming (REAP) model data.

Figure 5

Change in nitrogen applied per acre, by scenario, 2015



RFS = Renewable fuel standard.

Source: USDA, Economic Research Service calculations based on Regional Environment and Agriculture Programming (REAP) model data.

under the high input-cost scenario (down 7.3 percent) more than offsets the reduction in fertilizer, resulting in increased fertilizer intensity in regions where corn production increases over the baseline. In regions where corn production declines, fertilizer intensity declines as well.

Water Quality Measures More Sensitive Than Change in Acreage

Ramping up corn production to satisfy biofuel production targets raises concerns about potential environmental impacts. Environmental effects reflect a shift in cropping patterns toward corn production, overall production intensification (as reflected by increased continuous corn and fertilizer use), and expansion of cropland acreage under production. Expanded use of conservation tillage systems may mitigate potential environmental impacts in some areas. Water quality impacts examined here include nitrogen runoff to surface water, nitrogen impacts on coastal estuaries, and nitrogen leaching to groundwater. While this report focuses primarily on potential effects of biofuels on water quality, water demands for irrigated feedstock production and ethanol processing will compete for limited water supplies in some areas (see box, "Water Use Impacts From Ethanol Production").

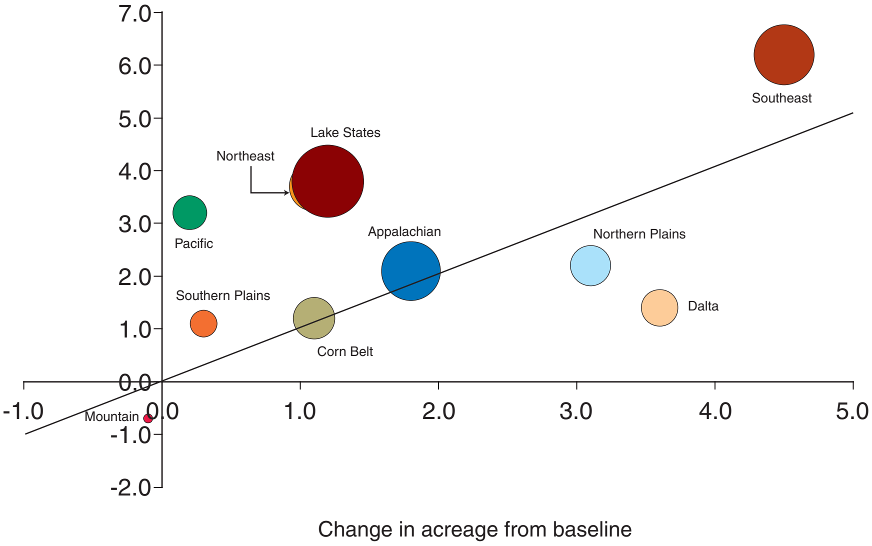
Nutrient Loss

Nitrogen leaching to groundwater in 2015 is estimated to increase by roughly 23,000 tons (2.8 percent) over baseline levels, reflecting the expansion of cropland acreage and increase in nitrogen application rates. This increase is substantially higher than the 1.6-percent increase in total acreage, driven mainly by large increases in the Lake States, Appalachian, and Southern regions. Figure 6 demonstrates the change in nitrogen leaching due to increased acreage planted and the amount attributed to shifts in cropland allocation and management that affect nutrient runoff. The size of the circle represents the absolute change in the indicator for a given region, demonstrating how much a region contributes to the national increase. The position of the region on the chart, relative to the diagonal line, indicates how much of the change in nitrogen leaching is caused by increases in total acreage and how much is influenced by changes in crop mix and management. A region positioned on or near the diagonal line, as seen for the Corn Belt and Appalachian regions, generally means that the increase in nitrogen leaching is driven by increased acreage, since the change in both acreage and leaching are equal along the line. A position

Figure 6

Change in nitrogen leached to groundwater, by region, 2015

Change in indicator from baseline



Notes: Size of circle represents the absolute change in the indicator, demonstrating how much a region contributes to the national increase. The circle's position, relative to the diagonal line, indicates how much of the change in nitrogen leaching is caused by increases in total acreage and how much is influenced by changes in crop mix and management.

Source: USDA, Economic Research Service calculations based on Regional Environment and Agriculture Programming (REAP) model data.

below the diagonal line, such as that of the Delta, indicates that the increase in acres is accompanied by shifts in crop mix and management that cause the increase in nitrogen leaching to be less than the change in acreage. A position above the diagonal line, such as for the Lake States and Southeast, means that the increase in acreage is accompanied by shifts in management that drive an increase in nitrogen leaching in excess of the increase in acreage. In some cases, conversion of marginal cropland acreage may explain high relative shifts in nitrogen leaching.

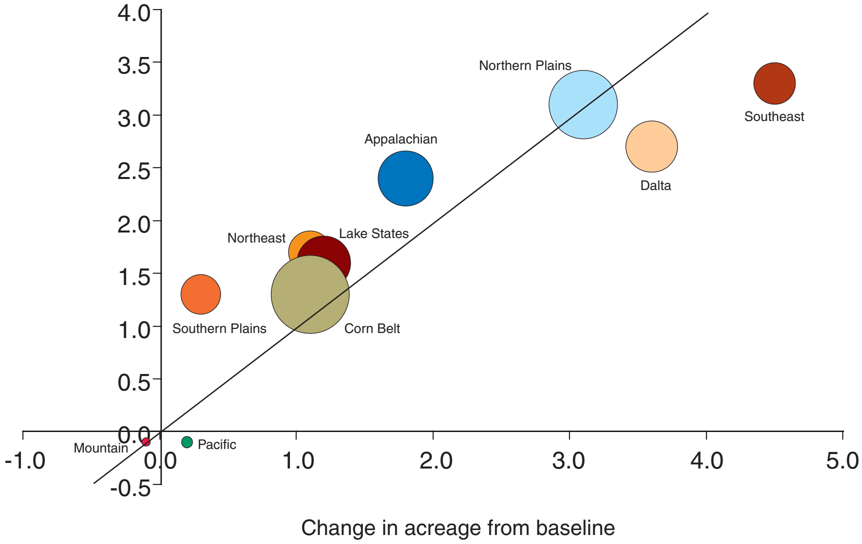
Nitrogen runoff to surface water increases by roughly 29,000 tons (1.7 percent) over baseline levels. Higher nitrogen loads reflect an expansion in U.S. cropland acreage in production, as well as higher nitrogen application rates per acre due to increased corn production. The change in nitrogen loads over the baseline, however, varies considerably by region (fig. 7). Nitrogen runoff from the Northern Plains increases by 3.1 percent, while nitrogen runoff from the Corn Belt—accounting for roughly 44 percent of U.S. nitrogen loadings to surface water from field crop production in 2006—increases by 1.3 percent. Increased productivity growth implies that the same amount of corn can be produced with less fertilizer per acre and with less land. Thus, much of the surface-water impact from meeting the increased biofuel demand is mitigated with high corn yield growth (scenario HCY). The increase over the baseline is limited to 13,600 tons (compared with 29,000 tons), mainly due to a large reduction of runoff in the Southern Plains under the HCY scenario compared with the baseline.

Nutrient loads, which reflect both the amount of nutrient field runoff and spatial proximity to coastal waters, have implications for water quality in

Figure 7

Change in nitrogen runoff to surface water, by region, 2015

Change in indicator from baseline



Notes: Size of circle represents the absolute change in the indicator, demonstrating how much a region contributes to the national increase. The circle's position, relative to the diagonal line, indicates how much of the change in nitrogen leaching is caused by increases in total acreage and how much is influenced by changes in crop mix and management.

Source: USDA, Economic Research Service calculations based on Regional Environment and Agriculture Programming (REAP) model data.

U.S. estuaries. Nationally, runoff to estuaries increases by 1.8 percent from the baseline. The largest contributor is the Corn Belt, with the Northeast, Lake States, Appalachian, and Delta regions also increasing runoff to estuaries (fig. 8). The increase in the Southern Plains, though small, is high in percentage terms. This indicates that further acreage expansion in the region may result in greater nutrient loads to the Gulf of Mexico. High corn yield growth (HCY) reduces the overall impact, as well as the amount of regional variation. Under this scenario, runoff from the Delta decreases only slightly with respect to the RFS15 scenario as a result the region's small dependence on corn and smaller-than-average acreage reduction.

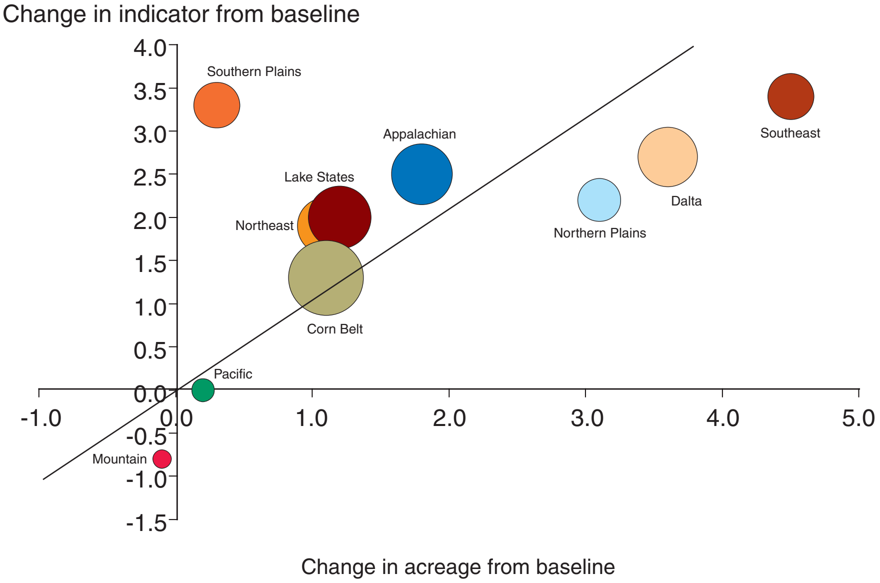
Soil Erosion

Soil erosion effects include both sheet (rainfall) and wind erosion. Soil erosion potential is affected by soil structure, slope of the field, and surface vegetation, among other factors. Crop residue management and vegetative cover crops can help minimize potential soil erosion by exposing less soil to wind and by reducing the impact of rainfall. The national increase in sheet erosion (1.7 percent from the baseline) in the RFS15 scenario mirrors the national increase in planted acreage (1.6 percent), with similar variation among regions (fig. 9). Sheet erosion levels higher than the national average occur in the Northern Plains, Appalachian, Delta, and Southeast regions. Most soil erosion occurs in the Corn Belt, with smaller amounts in the Northern Plains, Southeast, and Delta regions. For the most part, soil loss is driven by increases in planted acreage, which may be offset by shifts to conservation tillage.

Wind erosion increases 0.7 percent from the baseline in the RFS15 scenario, less than the national change in cropped land. Almost all the change occurs

Figure 8

Change in nitrogen runoff to estuaries, by region, 2015



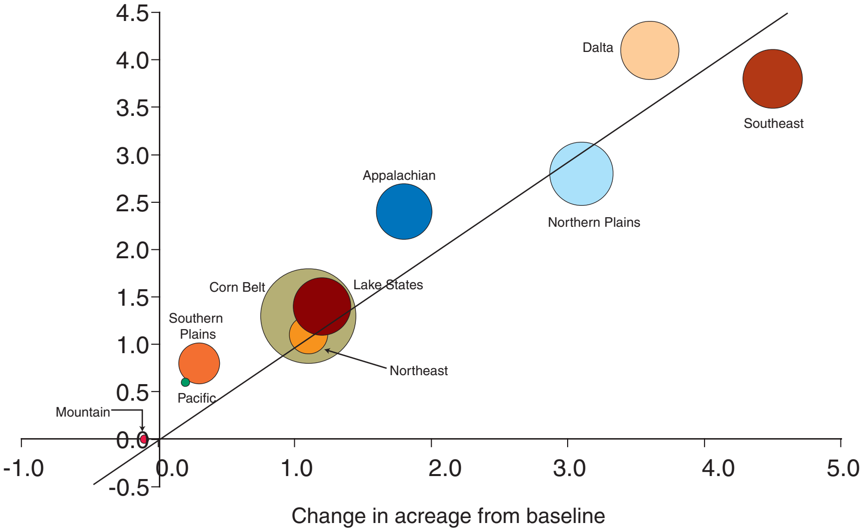
Notes: Size of circle represents the absolute change in the indicator, demonstrating how much a region contributes to the national increase. The circle's position, relative to the diagonal line, indicates how much of the change in nitrogen leaching is caused by increases in total acreage and how much is influenced by changes in crop mix and management.

Source: USDA, Economic Research Service calculations based on Regional Environment and Agriculture Programming (REAP) model data.

Figure 9

Change in sheet erosion, by region, 2015

Change in indicator from baseline



Notes: Size of circle represents the absolute change in the indicator, demonstrating how much a region contributes to the national increase. The circle's position, relative to the diagonal line, indicates how much of the change in erosion is caused by crop mix and management.

Source: USDA, Economic Research Service calculations based on Regional Environment and Agriculture Programming (REAP) model data.

in the Northern Plains and Corn Belt (fig. 10). In both regions, expanded acreage accounts for much of the change, with shifts to no-till reducing the effect of expanded acreage in the Northern Plains. The region most susceptible to wind erosion, the Southern Plains, does not see much change in acreage, so the impact on wind erosion is small. The high input-costs scenario reduces wind erosion by 20 percent.

GHG Emissions

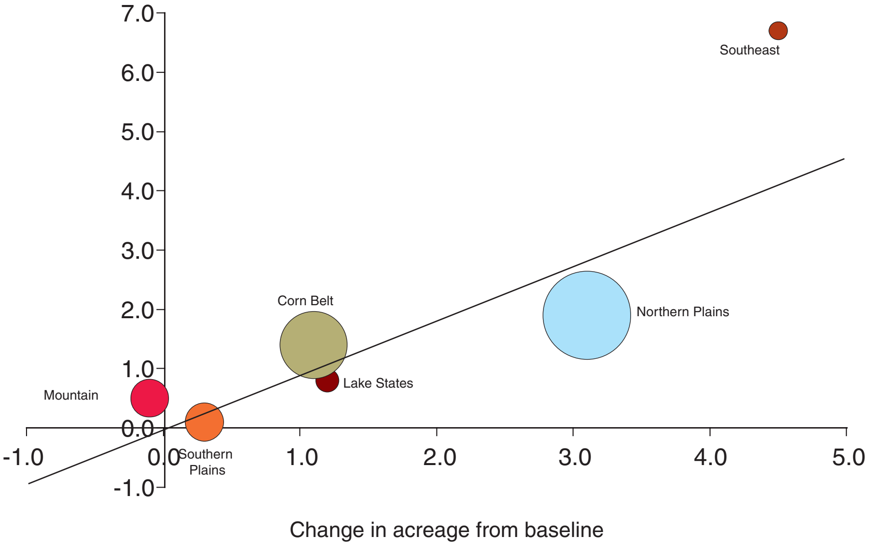
GHGs most closely associated with crop production include carbon dioxide (CO_2) and nitrous oxide (NO_x). These gases are produced by farm machinery and fertilizer inputs, as well as by processes that naturally occur in the soil. Converting land to crop production will reduce carbon sequestered in biomass as vegetation is removed, and soil disturbance will change soil carbon levels. Soil management also influences GHG emissions associated with energy use. For example, fuel-associated emissions decline with conversion from conventional tillage to reduced till or no-till. Increasing crop acreage leads to a small increase in GHG emissions from land-use change, which is partially offset by changes in land management (table 9). The EPA estimates that total U.S. GHG emissions for 2007 included 7.15 billion tons of CO_2 equivalent, 6 percent of which came from agriculture (EPA, 2009). The EPA further estimates that total annual carbon sequestration in U.S. cropland for 2007 was 19.7 million tons of CO_2 equivalent. If emission rates remain constant through 2015, the estimated 2.9-million-ton increase in emissions—3.8-million-ton decrease in sequestration due to the increase in capital, partially offset by 0.9-million-ton increase in sequestration due to increased no-till—would represent a 0.17-percent increase in U.S. emissions and a 15-percent reduction in agricultural sequestration. These emission changes are due to changes in agricultural land use and do not include the lifecycle emissions of the biofuel produced or offsets from less petroleum use.

Because of differences in inputs between crops, there will be some net change in GHG emissions not captured in this analysis. Net agricultural GHG emissions can be reduced in two ways: (1) through changes in farm operations that reduce direct and indirect emissions, such as lower energy use in field practices or reduced fertilizer use, and (2) through changes in tillage and other land-use practices that sequester carbon, such as creating grasslands and planting trees.

Figure 10

Change in wind erosion, by region, 2015

Change in indicator from baseline



Notes: Size of circle represents the absolute change in the indicator, demonstrating how much a region contributes to the national increase. The circle's position, relative to the diagonal line, indicates how much of the change in erosion is caused by crop mix and management.

Source: USDA, Economic Research Service calculations based on Regional Environment and Agriculture Programming (REAP) model data.

Table 9

Change from baseline in emissions due to land and tillage changes, 2015

Item	RFS 15-billion gallons (RFS15)	+ High corn yield (HCY)	+ High conversion efficiency (HCE)	+ High input cost (HIC)
	Million metric tons of CO_2 equivalent			
Change in land use	3.8	2.1	3.1	-14.8
Change in tillage system	-0.9	-0.8	-0.8	-2.8

RFS = Renewable fuel standard.

Source: Economic Research Service calculations based on Regional Environment and Agriculture Programming (REAP) model data.

Water Use Impacts From Ethanol Production

With projected expansion of the U.S. biofuels industry, increasing attention has focused on the implications for water demand:

- How much water will be required to support expansion in biofuels?
- How will emerging demands affect the allocation and sustainability of water supplies?
- To what extent will limited water supplies inhibit expansion of feedstock production?

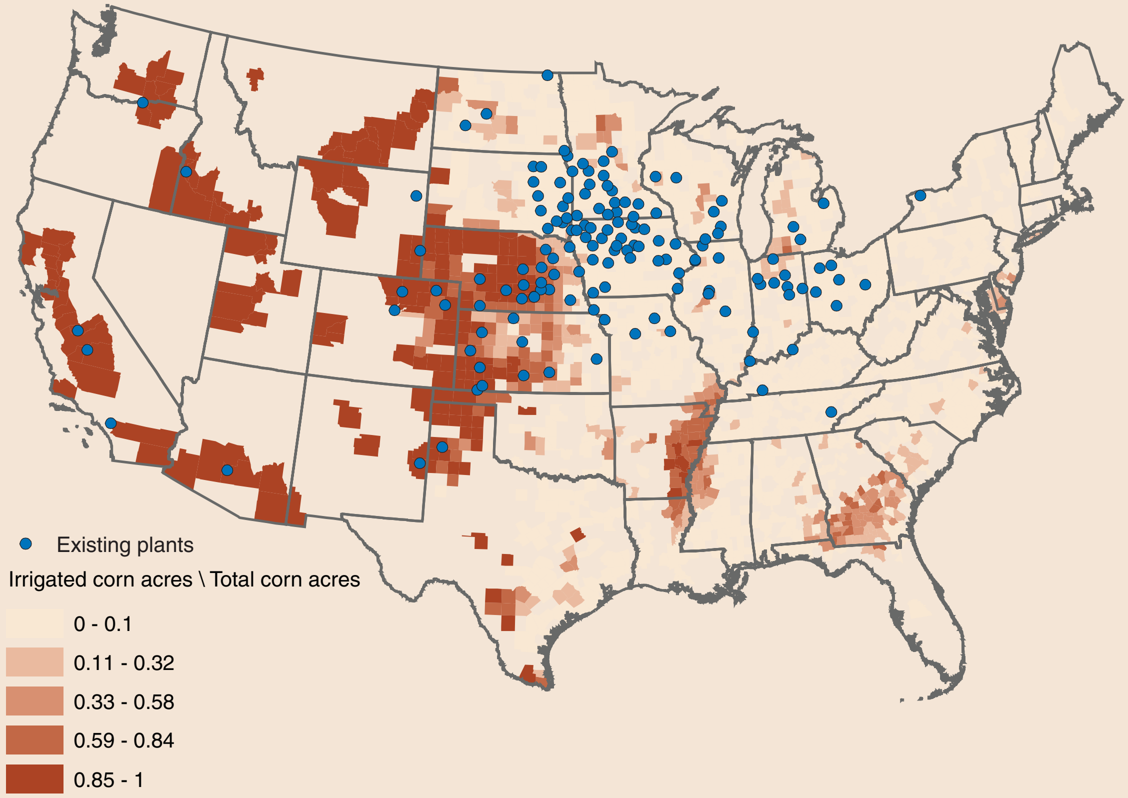
Most U.S. corn acreage is not irrigated. Irrigation is essential for corn production in much of the Western United States, where crop water requirements generally exceed natural soil moisture reserves. In the more humid Eastern States, supplemental irrigation may be applied to minimize the risk of production shortfalls due to below-normal precipitation. In 2002, 9.7 million acres of corn were irrigated nationally, accounting for about 14 percent of U.S. corn acres. Of the major corn-producing regions, irrigated corn production accounted for 55 percent of the irrigated land in the Northern Plains, 38 percent in the Corn Belt, and 14 percent in the Southern Plains (USDA-NASS, 2004a).

While it is unclear how much corn ethanol feedstock is produced under irrigation, the distribution of ethanol processing plants provides some indication (see map). Approximately 15 percent of current ethanol capacity is located in counties where more than half of the corn is irrigated. When considering both current and projected plant capacities, 20 percent of projected ethanol capacity is in counties where more than half of the corn is irrigated. The reliance on irrigation will reflect, in part, the share of feedstock supplied by locally grown corn and the share of local production that is irrigated.

Demand for Corn-Based Ethanol May Drive Changes in Agricultural Water Demand

The demand for biofuel feedstocks, and resulting increases in the price of corn and other grain commodities, may increase demand for agricultural water where irrigation expansion is feasible. The potential effect on water withdrawals will

Irrigated corn share and existing ethanol plant locations



Source: ERS calculations based on 2003 Census data and 2007 Renewable Fuels Association data.

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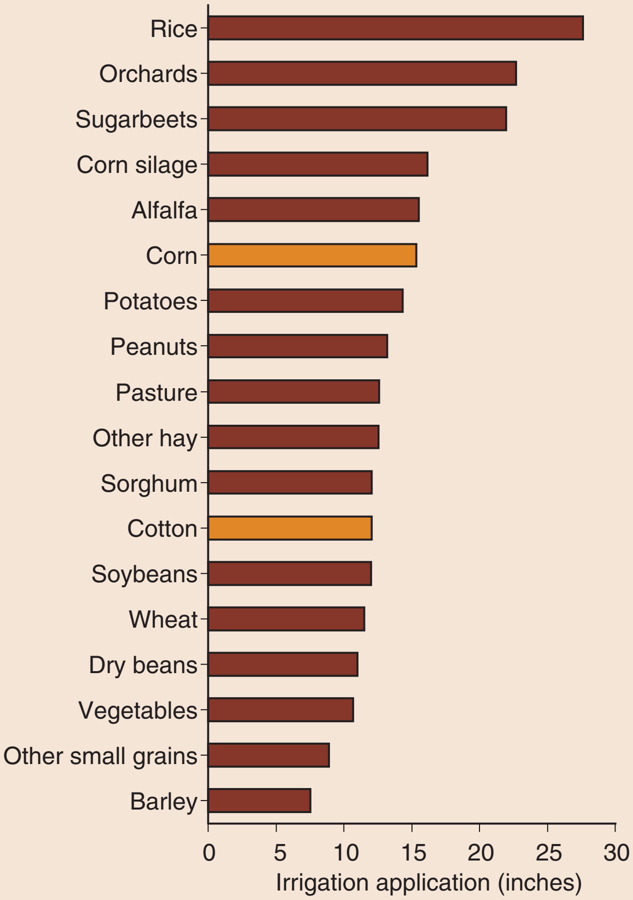
depend on changes in total irrigated acres, acreage by irrigated crop, and applied water per crop acre. The net effect on agricultural water withdrawals is uncertain and may vary both regionally and over time, depending on the distribution of biofuel processing facilities, feedstock sources, and institutions that govern water allocation.

In the short run, potential changes in water demand for feedstock production would largely be driven by an expansion of irrigated corn. In 2003, average applied water on irrigated corn acreage ranged from more than 20 inches in the West to less than 6 inches in the humid Eastern States (USDA, 2004a). Expressed in terms of average applied water per bushel of corn, more than 4,000 gallons of irrigation water were used per bushel produced in Mountain and Pacific regions, compared with 2,000-3,000 gallons in the Plains States and less than 1,000 gallons in the Eastern States. Assuming 2.7 gallons of ethanol can be produced per bushel of corn, irrigation water use per gallon of ethanol ranges from less than 400 gallons of applied water in the East to more than 1,500 gallons applied in the West. Estimates of water use per bushel of corn differ substantially across States and years due to variation in corn yields, natural precipitation, and other local production conditions.

The effect of a regional shift to irrigated corn on aggregate water demand depends, in part, on the water requirements of the crops displaced by corn. Available data suggest that increased corn acreage has displaced acreage in soybean production. Other potential sources of land for corn expansion include acreage in cotton and pasture, as well as fallow land on acreage in expiring Conservation Reserve Program (CRP) contracts (Westcott, 2007). In the Plains States, where much of the expansion in biofuel processing capacity is projected to occur, a shift from irrigated soybean or cotton production would likely result in a net increase in water use. Alternatively, a shift from more water-intensive crops, such as alfalfa hay or sugarbeets, could reduce water use in some areas. In the Southeast and Delta regions, where applied water in irrigated corn production is low relative to other irrigated crops, pressure on regional water supplies may be reduced.

Regional water demand could increase with expansion of irrigated acreage, through both reductions in fallowed land and conversion of nonirrigated cropland and pasture land. The effect of ethanol demand on the price of corn, and indirect price impacts on the profitability of other fieldcrop commodities, generally increases the demand for irrigated cropland and associated water. ERS model results indicating an expansion of cropland in the Plains States and other regions (see, table 3) suggest a potential for increased reliance on irrigation.

Water for corn production is higher than many crops, but lower than those that may be displaced, Plains States, 2003



Source: ERS calculations based on 2003 Census of Agriculture, Farm and Ranch Irrigation Survey (FRIS) data.

While corn is likely the primary feedstock source for ethanol production over the foreseeable future, other irrigated fieldcrops—including sorghum, small grains, and sugarbeets—may become increasingly important in noncorn-producing areas. Sorghum and small grains are generally less water-consumptive than corn, while sugarbeets generally use more water. In the longer term, cellulosic biofuel production is slated to expand. Although relatively little is known about water requirements for cellulosic crops produced on a commercial scale, native grasses (e.g., switchgrass) may use less water while trees (e.g., poplar) and other dedicated biomass crops may have greater water requirements. Potential irrigation demands will depend on the regional location of production, the reliance on marginal cropland soils, plant breeding advances, and evolving production technologies (NRC, 2007).

Water is an essential input in ethanol processing. Consumptive water use at ethanol processing facilities results largely from

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evaporation losses from cooling towers and evaporators during ethanol distillation following fermentation. Current estimates of consumptive water use from these facilities are approximately 4 gallons of water per gallon of ethanol produced. Thus, a plant producing 100 million gallons of ethanol per year would require approximately 400 million gallons of water per year. Total water withdrawals used in ethanol processing, however, are small relative to potential irrigation demands for feedstock production. Based on applied water for irrigated corn in Nebraska (USDA-NASS, 2004a), an estimated 780 gallons of irrigation water are used per gallon of ethanol produced—or roughly 200 times more water than is typically used for ethanol processing (NRC, 2007). But as water use for ethanol processing is concentrated in a smaller area, effects may be substantial at a local level.

Scarce Water Resources May Face Additional Pressure

Potential increases in water demand for energy crop production have raised concerns over the allocation and long-term sustainability of groundwater and surface water resources. Much of the current irrigated corn production in the Great Plains region relies on groundwater withdrawals from the Ogallala Aquifer. Groundwater withdrawals for agricultural and municipal uses have generally exceeded the natural recharge process of the aquifer, resulting in water table declination exceeding 100 feet over large portions of the region. Expansion of ethanol processing capacity in the Plains region, and increased irrigated feedstock production to supply these facilities, could accelerate withdrawals in some areas (Roberts et al., 2007). Moreover, as contracts expire for acreage idled under the CRP, some marginal cropland with potentially higher water requirements could return to irrigated production, placing additional pressures on groundwater resources. While corn production in the Corn Belt is largely rainfed, groundwater overdraft is a concern in areas of the upper Midwest where much of the current ethanol processing capacity is concentrated (NRC, 2007). In western irrigated regions that rely on surface-water withdrawals, emerging water demands for urban and environmental uses compete increasingly for agricultural water supplies. Expanding energy crop production has the potential to increase pressure on available water resources.

Under high prices for biofuel feedstocks, irrigation could potentially make corn economically profitable in some noncorn-producing areas. While biofuel feedstock production could conceivably expand in areas not traditionally irrigated, significant increases in surface and groundwater withdrawals may be limited by physical water-supply availability, storage and conveyance infrastructure, legal constraints, and economic considerations. Irrigation expansion often requires major capital investment in water-supply development, as well as assurances that potential economic gains (due to higher yields and reduced yield variability) will cover increased capital and operating costs. It is unclear whether biofuel markets would provide sufficient incentives for irrigation expansion in areas where irrigated fieldcrop production is not currently established.

At the national level, agricultural production to meet the demand for biofuels is not likely to greatly alter aggregate water withdrawals. Competing demands for limited water resources would restrict increases in the share of water allocated to the expansion of irrigated agriculture. While development of the biofuels industry has had a generally marginal impact on water supplies at the regional and local levels, future expansion and diversification of feedstock production could increase or decrease pressures where water resources are under stress, depending on shifts in cropping allocations. As biofuel production expands to meet national goals, the long-term sustainability of surface and groundwater resources used for feedstock production and ethanol processing may require policy attention.

Biofuel Impacts on the Livestock Sector and Implications for the Environment

While increasing biofuel demand has contributed to greater returns to U.S. crop production, the livestock industry faces higher feed costs. Greater concentrations in livestock production have increased both cost efficiencies and the relative importance of purchased feed. But biofuels also offer opportunities for livestock producers, as the sector adapts to changing market conditions and technologies. Shifts in animal production due to biofuel expansion could have positive implications for environmental quality.

Structural Change in the U.S. Livestock Sector

The U.S. animal sector has undergone significant structural change in recent decades. The number of farms with animals has declined, while farms accounting for most production are much larger. Production is generally more specialized, with farms usually raising a single species of animal. Operators often specialize in a specific stage of animal production, which is then linked to other stages of production and processing through formal contracts. Greater concentration of the industry has largely been driven by financial considerations. Larger operations are able to realize lower costs and higher returns, while tighter coordination among firms at different processing stages can reduce financial risks (MacDonald and McBride, 2009).

More animals on larger, specialized farms has been accompanied by regional shifts in livestock and poultry concentrations (Norton, 1998; Herath et al., 2005). Broiler production has increased in the Southeast and Delta regions. Swine production has shifted east and west from traditional hog-producing areas of the Midwest. Dairy production has expanded from the Midwest to the Western States, while the fed-cattle industry has consolidated in the Plains and Southwest. Factors motivating regional production shifts include lower costs for land and labor, availability of livestock support infrastructures, increased acceptance of contract production, and a strong local business environment (Herath et al., 2005).

Larger operations tend to rely more heavily on purchased feed than do smaller livestock operations. With greater concentrations in the livestock and poultry sector, the industry has shifted from reliance on grass forage to a grain-based diet under confined production conditions. The role of purchased feed has also increased as farm grain and forage production for animal feeding has declined and demand for feed supplements had expanded. While the animal industry has shifted location in recent decades, producers remain largely dependent on Midwestern feed grain supplies—primarily corn—which accounts for more than 90 percent of feedgrain use in the United States (USDA-ERS, 2008b).

Biofuel Demand Increases Costs for Livestock Producers

Feed grain costs increase with greater biofuel demand. As described in the section “Expanding Corn Acreage Drives Market and Environmental

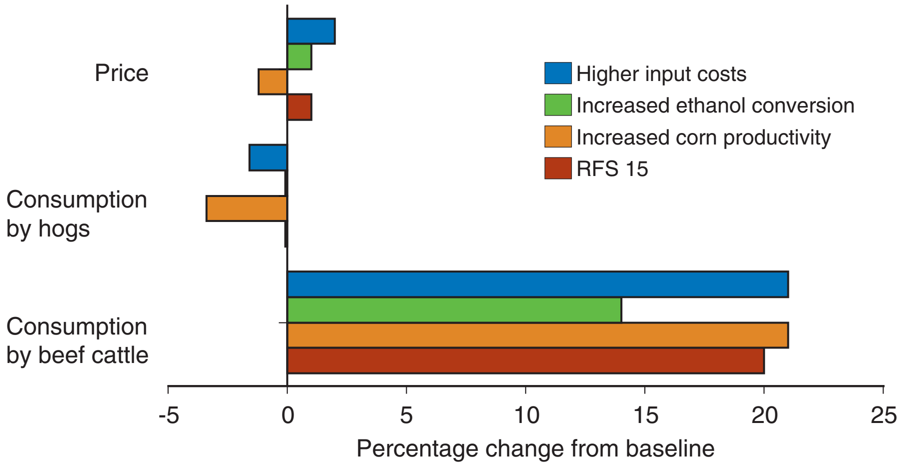
Outcomes," corn prices are predicted to increase by 2.2 percent due to the 1.7-billion-gallon increase in corn-based ethanol necessary to meet the 15-billion-gallon target (see table 5). Prices for soybean oil—another important input in animal feed rations—also increase. Soybean prices increase by 2.7 percent due to higher demand for soybean oil in biodiesel production and reduced soybean acreage due to competition with corn. Higher animal feed costs can reduce returns to animal production, as feed costs generally account for more than half of total variable expenditures in a given year (Becker, 2008). Reduced carryover stocks due to biofuel demand may also increase the variability of feed grain prices (Lawrence et al., 2008). Results suggest a reduction in average aggregate returns to livestock production of about 0.3 percent as biofuel production increases (see table 7). This effect occurs despite slight increases in livestock prices.

The use of corn ethanol coproducts, such as distiller's grains, in animal feed rations may offset higher feed grain costs (see box, "Prospective Growth in U.S. Corn Yield" p. 6). According to a 2006 survey of animal feeding operations in the Midwest and Plains States, approximately 14 percent of beef, dairy, and hog operations used biofuel coproducts, predominantly in the form of distiller's dried grains with solubles (DDGS) (USDA-NASS, 2007). Beef cattle and dairy account for a large share of consumption, although incorporation in swine and poultry diets is increasing.

Production of distiller's grains under the USDA baseline is projected to reach 41.5 million tons in 2015. Higher ethanol production under the RFS15 scenario would expand production of DDGS by an additional 12 percent, with the bulk of this increase consumed by the domestic cattle feeding sector (fig. 11). The increased demand for distiller's grains, associated with increased corn and soybean prices, results in higher prices for distiller's grains, despite increases from expanded ethanol production. As production of distiller's grains tracks closely with corn ethanol targets, changes in corn yields and input cost assumptions do not affect coproduct production appreciably.

Figure 11

Changes in price and selected uses of distiller's grains under alternative scenarios, 2015



RFS = Renewable fuel standard.
Source: USDA, Economic Research Service calculations based on Regional Environment and Agriculture Programming (REAP) model data.

Increases in ethanol conversion efficiency, however, could reduce the amount of distiller's grains available to livestock producers.

Productivity growth in corn yields would increase corn production and lower prices, offsetting the predicted effects of increased biofuel production. As a result, distiller's grains are priced 1.2 percent lower than the baseline scenario. On the other hand, combining increased biofuel production with improved ethanol conversion efficiencies leaves distiller's grain prices unchanged relative to the RFS15 scenario, but the reduced demand for corn-based ethanol leaves more corn available for feed and reduces the amount of distiller's grains fed to beef cattle by about a third. Higher corn productivity and increased consumption of distiller's grains by beef cattle displaces consumption in the hog sector; in contrast, increased conversion efficiency has a negligible effect on the hog sector. Higher ethanol conversion efficiency will lower production of distiller's grains since more of the starch is converted to ethanol and less is available for coproducts.

Higher Feed Costs May Reduce Livestock Inventories

In the short term, increased feed costs may result in financial losses to the U.S. livestock sector. As markets adjust over time, higher feed costs and reduced returns lead to decreases in production by livestock producers, raising prices for livestock products. In evaluating the increase in corn ethanol demand from 13.3 to 15 billion gallons in 2015 under the revised RFS, ERS projects that higher feed prices would lead to a slight contraction in livestock inventories (table 10). Animal inventories decline across all species, but declines are small, generally less than 0.5 percent.

A 50-percent increase in projected corn yield growth that occurs concurrently with biofuel expansion would offset the effect of the higher corn-ethanol target on livestock production levels due to feedgrain price reductions relative to biofuel expansion and absent increased yield growth. In contrast, higher

Table 10

Livestock and poultry inventories under alternative scenarios, 2015

Inventories	Baseline	RFS 15-billion gallons (RFS15)	+ High corn yield (HCY)	+ High conversion efficiency (HCE)	+ High input cost (HIC)
		Percent change from baseline			
Dairy *(million cows)*	9.0	-0.10	0.13	-0.07	-0.42
Hogs *(billion pounds)*	34.3	-0.14	0.33	-0.11	-1.72
Beef cow:					
Grazing *(million cows)*	29.3	-0.50	0.52	-0.36	-2.20
Farm fed *(million cwt)*	57.2	-0.62	0.80	-0.44	-2.87
Feedlot *(million cwt)*	300.2	-0.38	0.39	-0.28	-2.00
Stockers *(million cwt)*	114.7	-0.38	0.38	-0.28	-2.03
Poultry *(million pounds)*	38,771	-0.50	0.67	-0.36	-1.53

RFS = Renewable fuel standard.

Cwt = Hundredweight.

Source: Economic Research Service calculations based on Regional Environment and Agriculture Programming (REAP) model data.

ethanol conversion efficiencies have a small effect on feedgrain costs and livestock inventories. An increase in projected energy costs that raises the cost of feed grains and other livestock expenses, without a commensurate increase in productivity, results in further contraction of livestock production levels.

Small aggregate shifts in the livestock sector belie regional shifts in production in a few cases. Results suggest that small regional shifts would occur in the cattle and dairy industry. The size of dairy herds, for example, is fairly stable across much of the Western United States, while generally declining in the Corn Belt, Southeast, and Delta regions (table 11). Regional changes associated with RFS15 are small (less than 0.5 percent), but larger in many cases than the 0.1 percent aggregate decline for the United States as a whole. As with other variables, the largest changes would occur if increased biofuel demand coincides with higher energy-related input costs. Contraction in the feedlot-cattle sector mostly affects the Northern and Southern Plains. Regional shifts are also predicted for beef stocker production, with some growth in the Corn Belt and some contraction in the Southern Plains.

Biofuel Expansion Could Reduce Environmental Effects of Manure

Structural change in the U.S. animal sector has raised environmental concerns regarding animal waste. Larger operations concentrate animals in a limited area, and manure nutrients applied to land in excess of onfarm crop requirements contribute to air and water pollution. Under the Federal Clean Water Act, the EPA regulates animal waste on concentrated animal feeding operations (CAFOs), which generally include the largest operations. A CAFO rule was established in 2003 (and revised in 2008) that requires Nutrient Management Plans as a permit requirement for CAFOs that fall under the National Pollution Discharge Elimination System (NPDES) program (EPA,

Table 11

Regional shifts in dairy cows, 2015

Region	Baseline	RFS 15-billion gallons (RFS15)	+ High corn yield (HCY)	+ High conversion efficiency (HCE)	+ High input cost (HIC)
		Percent change from baseline			
Northeast	1.7	-0.1	0.1	0.0	-0.2
Lake States	2.1	0.0	0.0	0.0	-0.2
Corn Belt	0.9	-0.5	0.6	-0.3	-1.8
Northern Plains	0.3	0.0	0.0	0.0	-0.2
Appalachian	0.7	-0.1	0.2	-0.1	-0.5
Southeast	0.3	-0.4	0.6	-0.3	-1.1
Delta	0.2	-0.4	0.6	-0.3	-1.1
Southern Plains	0.4	-0.1	0.2	-0.1	-0.5
Mountain States	0.8	-0.1	0.2	-0.1	-0.5
Pacific	1.7	0.1	-0.1	0.1	0.0
United States	9.0	-0.1	0.1	-0.1	-0.4

RFS = Renewable fuel standard.

Note: Totals may not sum due to rounding.

Source: Economic Research Service calculations based on Regional Environment and Agriculture Programming (REAP) model data.

2008). Nutrient Management Plans restrict the rate of land-applied manure to the nutrient assimilative capacity of crops produced. States have also extended manure nutrient standards, in some cases, to operations not subject to Federal regulations. For livestock operations with a limited land base, much of the manure must be moved off the farm—often over long distances at considerable hauling cost—to land sufficient for manure application (Ribaudo et al., 2003).

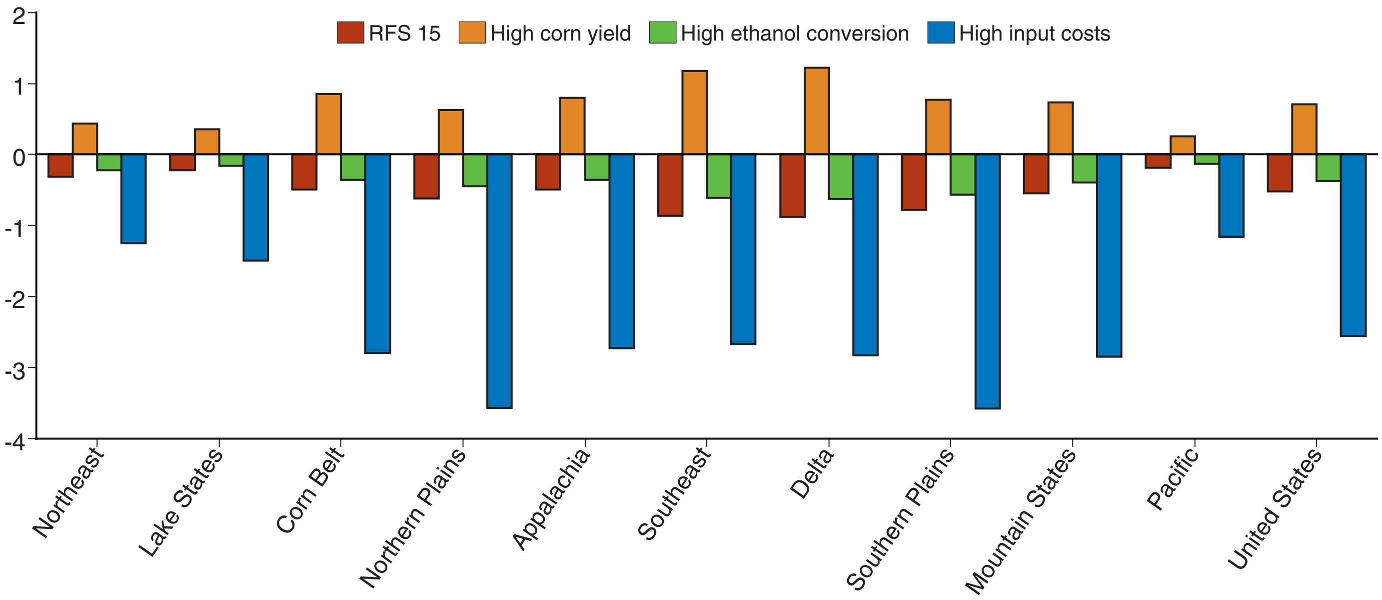
Expanding biofuel production may result in an indirect, if small, improvement in water quality due to reduced manure nutrient runoff and leaching. This effect is primarily due to reducing the volume of manure produced by reducing animal inventories. Findings suggest that expanding ethanol production from 13.3 to 15 billion gallons in 2015 (RFS15) would reduce recoverable manure production in confined animal operations by roughly 0.2 percent. The largest adjustments occur in the cattle and poultry sectors.

Reducing manure production translates to reductions of 7.9 million pounds of manure nitrogen and 4.5 million pounds of manure phosphorus. Total recoverable manure nutrients decline across all U.S. regions under the RFS15 target because potential reductions in recoverable manure are closely correlated with changes in animal inventories. Those changes, however, are all less than 1.0 percent. The most significant reductions occur in the Delta, Southeast, and Southern Plains, where manure nitrogen (fig. 12) and phosphorus decline from 0.7 percent to 0.9 percent. Declines in other regions range from 0.2 percent to 0.6 percent. Changing relative species' composition alters nitrogen and phosphorus availability.

Figure 12

Changes from baseline in available nitrogen from manure, by region and scenario, 2015

Percent change in available nitrogen



RFS = Renewable fuel standard.

Source: USDA, Economic Research Service calculations based on Regional Environment and Agriculture Programming (REAP) model data.

Projected manure nutrient levels are affected by modeling assumptions that influence corn production and feed costs. Declines in manure nitrogen will be lessened if increased biofuel demand is coupled with increased ethanol conversion rates (HCE), but will be even larger if input costs increase substantially (HIC). Notably, an increase in projected corn yields that lowers animal feed costs (HCY) will raise levels of recoverable manure nutrients, with the Delta and Southeast seeing the biggest increases.

Biofuel expansion may benefit confined feeding operations through increased demand for manure nutrients. Cropland expansion, increased cropland allocations to corn, and higher yields increase potential nutrient uptake. As a result, animal producers may have greater access to farm fields for manure spreading to comply with nutrient management provisions. Potential savings in hauling costs will depend on the willingness of local landowners to accept manure (Ribaudo et al., 2003). Water quality benefits will reflect the susceptibility of local water bodies to nutrient runoff and leaching, as well as the manure regime applied and the realized offsets in applied chemical fertilizers.

Animal production is also an increasing concern for air quality and GHG emissions (Aillery et al., 2005). Recommended guidelines for incorporating applied manure on corn feedstock acreage can limit emissions of volatilized ammonia and nitrogen. Methane gas from animal manure, collected from livestock holding areas and waste lagoons, has been used to generate electricity for confined livestock facilities. Recent interest has focused on methane as a supplemental power source for ethanol processing. Colocation of ethanol processing facilities with large feedlots and dairy operations can provide a significant share of an ethanol plant's energy needs (Hart and Carriquiry, 2007). Methane capture for power generation can also generate additional revenue for livestock producers through sale of carbon offsets in the emerging market for GHG emission reductions. Methane captured and filtered could also be integrated with the natural gas distribution system.

Implications For Expanding Ethanol Plant Capacity

Linkages between U.S. biofuel and livestock sectors will grow over time as competitiveness intensifies in the biofuels industry and markets expand for ethanol coproducts in animal feed. Ethanol producers may rely more on financial arrangements with livestock producers to capture cost efficiency gains as the industry evolves, further transforming the agricultural landscape.

With projected increases in energy costs, ethanol plant locations become more dependent on coproduct markets (Dhuyvetter et al., 2005). Higher costs for drying (typically with natural gas) provide an economic incentive to market distiller's grains in their wet form, while higher fuel costs increase the cost of shipment. Increased drying and transportation costs favor closer proximity of ethanol plants to animal concentrations to utilize wet distiller's grains. Rising costs may also encourage placement of ethanol plants near confined animal operations for methane power generation.

By placing ethanol production facilities away from farmer-owned cooperatives, integrated facilities become less spatially tied to corn-producing areas.

At the same time, the shift to larger capacity plants increases the need for access to reliable distiller's grains markets (Dhuyvetter et al., 2005). Expanding ethanol processing in the Southern High Plains,[2] in proximity to large cattle feedlot operations, indicates the growing importance of coproducts in plant siting decisions. Distiller's wet grains produced and fed to feedlot cattle can provide a reliable market outlet, as well as energy cost savings. A shift in the concentration of ethanol processing capacity from the Midwest will depend, in part, on the relative cost savings in local markets for distiller's grains versus the additional cost of feedstock transport from major corn-producing regions (Hart and Carriquiry, 2007).

Expanding the ethanol industry, in turn, may influence long-term trends in the livestock industry. Access to distiller's wet grains could spur increased concentrations of beef and dairy herds near ethanol processing facilities. Spreading manure on energy feedstock crops and potential use of animal waste for onsite power generation provide additional incentives for herd expansion near processing facilities. Ethanol's reliance on corn as the primary feedstock may adjust relative regional cost advantages in livestock production, potentially slowing or reversing the recent shift in animal concentrations from the Midwest.

In fact, current and planned ethanol production capacities appear to correlate strongly with the presence of livestock and, in particular, with livestock's capacity for distiller's grain consumption (fig. 13). Planned ethanol expansion into areas of Arizona and the Southern Plains, with high concentrations of confined livestock that can consume distiller's grains, is particularly striking. Certainly some outliers exist — strong DDG demand appears in Southern California without substantial ethanol capacity, while ethanol capacity in the Southeast and Eastern Corn Belt does not coincide with substantial DDG demand. The relationship could also be spurious, however, with livestock operations and ethanol plants independently located near corn production. It is clear that both the livestock and ethanol sectors are in flux. More research is needed to improve understanding of cause-and-effect linkages, if any, in livestock and ethanol location decisions, but also on likely implications for resource conditions.

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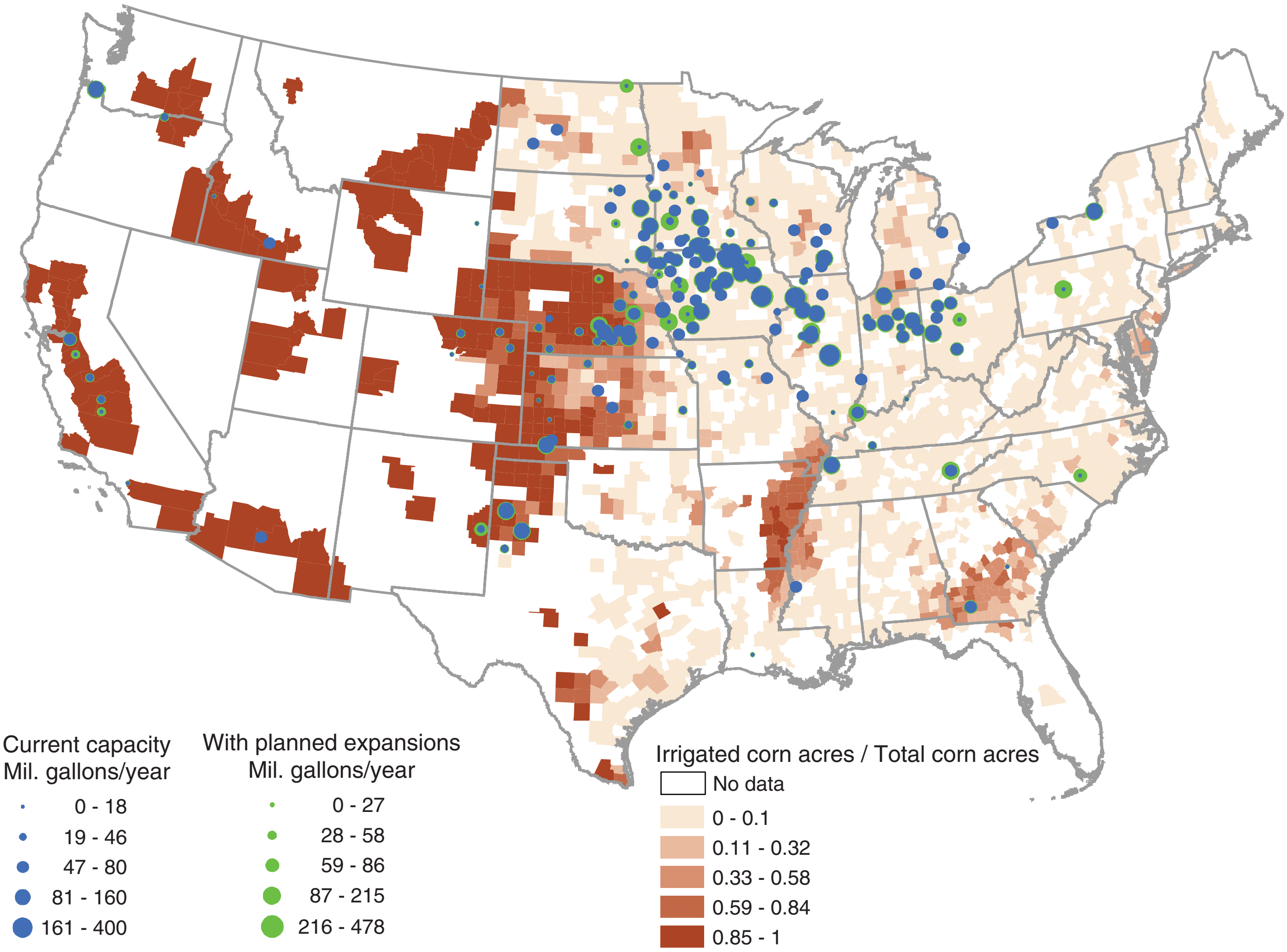
[2] Represents an area where ethanol production is expanding, but does not exactly correspond to regions cited previously; a smaller part of the Southern Plains (the panhandle of Texas and western Oklahoma).

Figure 13

Ethanol production capacity and corn acreage, 2002



Source: ERS calculations based on Renewable Fuels Association data, USDA's 2002 Agricultural Census, and Dhuyvetter, Kastens, and Boland (2005).

Crop Residues and the Introduction of Cellulosic Ethanol

Field residues from agricultural crop production represent a potential source of cellulosic feedstock to meet growing ethanol demand. Crop residues may be a particularly important feedstock in the coming years, as technologies and commercial markets continue to develop for cellulosic feedstocks. Crop residues may also provide an additional revenue source for crop farmers, although returns will depend on interactions in crop and residue markets. In this section, we evaluate potential sector impacts of crop residue harvest to meet policy targets for ethanol produced from cellulosic feedstocks and implications for resource use and environmental quality.

Crops that could provide above-ground crop residue for cellulosic ethanol production include corn, wheat, soybeans, barley, and oats. The quantity of residue produced per unit of yield varies by crop (table 12). The amount of sustainable residue that can be recovered from a field for a given crop is determined by harvest technology, soil nutrients, water availability, and erosion potential, among other factors. Crop residues provide soil nutrients and organic matter, but also prevent soil erosion and retain moisture. In this analysis, we assume that 50 percent of crop residues left on the fields can be harvested from fields that use no-till systems, 30 percent of the residues can be harvested from fields that use reduced tillage systems, and 10 percent of the residues can be harvested from fields that use conventional systems without adversely affecting soil productivity. These figures are intended only as a starting point and represent one possible residue collection scenario; future research will refine these values. Ongoing research analyzes how much residue can be harvested while maintaining soil productivity and crop yield, and removal rates used in this report may be higher than optimal given soil organic carbon requirements (Wilhelm et al., 2007). Because of erosion considerations, this analysis assumes that residue harvest is not permitted on land classified as highly erodible.

Residue harvest costs vary by region, crop, and the amount collected. In addition to the direct cost of collection, handling, and storage, harvest costs may also include the foregone value of nutrients, soil, and future yield lost. Typical nutrient content for crop residues are about 17 pounds of nitrogen and 4 pounds of phosphate per ton of corn residue and 11 pounds of nitrogen and 3 pounds of phosphate per ton of wheat residue (Wortmann et al., 2008).

Table 12

Residue-to-grain ratio for selected residue-producing crops

Crop	Residue-to-grain ratio (dry weight)
Corn	1.0
Soybeans	1.5
Wheat	1.3
Oats	1.4
Barley	1.5
Sorghum	1.0

Source: Graham et al., 2007.

Wortmann et al. place the value of nutrients lost per ton of corn residue at $17.93. Graham et al. (2007) provide a set of curves that estimate the collection cost as a function of stover collected per acre and collection method, including the cost of nutrient replacement (given as $6.50 per ton). For this analysis, we simplify the process by imposing a representative $40/ton cost of residue harvest across regions and crops. This value represents the midpoint of the curves in Graham et al., adjusted by the higher replacement cost of the Wortmann et al. analysis.

Effect of Crop Residue Feedstocks on Environmental Resources Is Mixed

To measure the effects of an increasing share of cellulosic ethanol in the analysis, crop residue-based ethanol production ranges from 3 billion gallons to 6 billion gallons, with corn-based ethanol making up the difference (i.e., 15 billion gallons down to 12 billion gallons). This scenario represents the possibility for accelerated development of cellulosic ethanol conversion technology, but keeps total ethanol demand constant. Below 6 billion gallons of cellulosic ethanol production, crop residue availability (after accounting for rate of removal by tillage system) exceeds demand by ethanol producers in most regions. At around 6 billion gallons of cellulosic production, all available crop residues are used in some regions, increasing the economic value of residue and causing primary crop production to increase, which puts downward pressure on the price of the primary crop. The higher price of crop residue would, in turn, provide production incentives for other sources of cellulosic feedstock that would also compete for land with the residue-producing crops. At 3 billion gallons of cellulosic production, the Northern Plains manufactures the most.

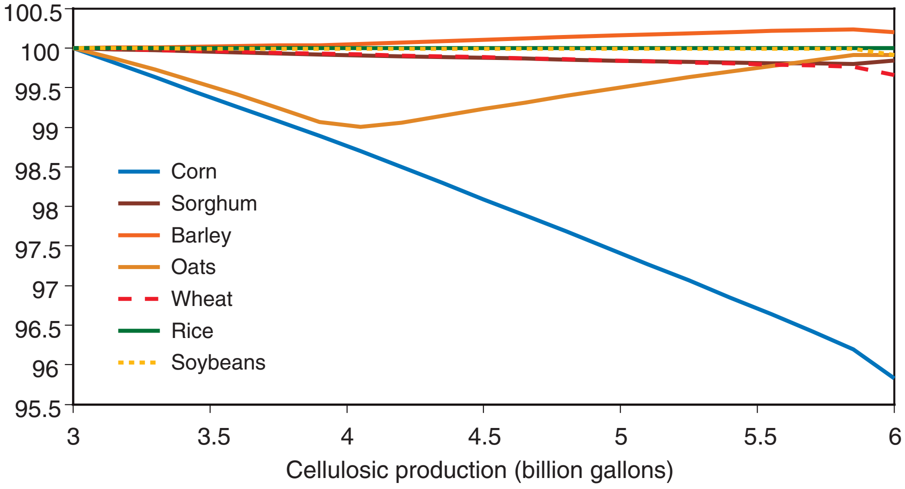
Crop prices relative to production levels, when 3 billion gallons of cellulosic ethanol replace corn ethanol in 2015 (i.e., corn ethanol production is reduced from 15 billion gallons to 12 billion gallons), are shown in figure 14. Prices for major crops vary considerably over the range of cellulosic production due to the different levels of assumed corn-based ethanol across the cellulosic scenarios. Corn shows the largest decline in price, dropping 4.2 percent as cellulosic production increases from 3 to 6 billion gallons, with steady price declines over the entire range. Less corn for ethanol and lower corn prices lead to more corn used for food and feed. In contrast, wheat prices decline only slightly over the whole range. The fraction of the corn crop used for ethanol declines from 37 percent to 31 percent as corn used for ethanol falls from 15 billion gallons to 12 billion gallons. The amount of corn used for food, feed, and exports increases from 9.3 billion bushels to 9.7 billion bushels.

Once the RFS15 target of 15 billion gallons of corn ethanol and 3 billion gallons of cellulosic ethanol is reached, total land planted to major crops will be 318.7 million acres. As crop residue-based cellulosic ethanol is substituted for increasing amounts of corn ethanol, less total land is planted to traditional crops. The decline in traditional planted crops is dominated by a large reduction in corn acreage, along with small reductions in soybeans and hay. Other crops show a slight increase in acreage as land is freed from corn production. The rate that acreage reduces as cellulosic production increases and corn ethanol production declines is about 1.7 million acres per billion-gallon reduction in corn ethanol. Acreage response varies across regions. Total planted acres decline in all major corn producing areas, as illustrated in figure 15, but at different rates. This decline is mainly driven by a greater reduction in corn acres in the Northern Plains, compared with other regions, as crop-residue demand increases. As crop residues gain economic value, the Northern Plains adds wheat acres, contributing to an increase in total cropped acreage in the region. Once over the 3 to 6 billion-gallons range in cellulosic production (and corresponding decrease in corn ethanol production), corn acres decrease by 5.8 percent, from 94.7 to 89.2 million acres. Reduced corn

Figure 14

Crop prices relative to 3 billion gallons of cellulosic ethanol production

Price index (3bg=100)

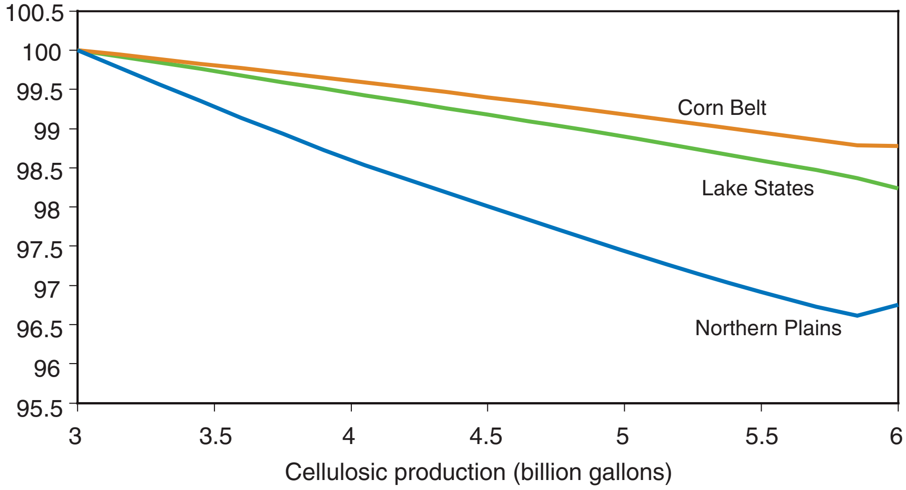


Source: USDA, Economic Research Service calculations based on Regional Environment and Agriculture Programming (REAP) model data.

Figure 15

Total acreage relative to 3 billion gallons of cellulosic ethanol production

Total acre index (3bg=100)



Source: USDA, Economic Research Service calculations based on Regional Environment and Agriculture Programming (REAP) model data.

area in the major corn-producing regions of the Corn Belt, Lake States, and Northern Plains drives the decline in overall acreage.

Although total acreage is reduced at higher levels of cellulosic ethanol production, aggregate environmental effects may not be reduced when additional fertilizer is applied to replace the nutrients removed with the harvested residue. We examined the response of four critical environmental measures:

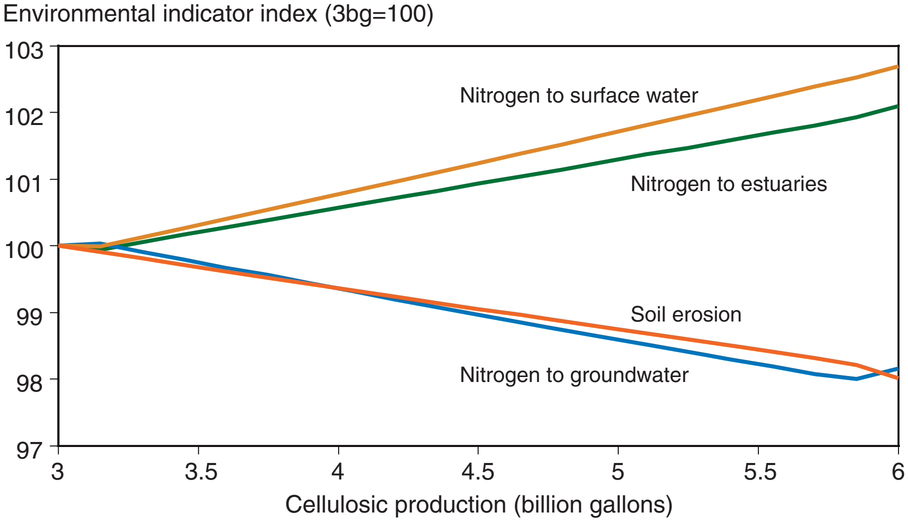
- Nitrogen leaching to groundwater;
- Nitrogen runoff to estuaries;
- Nitrogen runoff to surface water; and
- Soil erosion.

Figure 16 shows how these measures change relative to the baseline target across the range of cellulosic ethanol demand. To measure the effect of changes in production practices on environmental performance, independent of the direct effect of fewer acres planted, we divided the environmental impacts by the change in total acres for the given level of cellulosic production. In general, net levels of environmental impacts increase, even after accounting for the reduction in planted acres. Nitrogen leached to groundwater increased steadily up to 6 billion gallons of cellulosic ethanol production. Not all regions, however, exhibit an increase in all measures, as shown in figure 17 (also adjusted for changes in total acreage). High levels of runoff in the Corn Belt drive an increase in national levels of nitrogen lost to surface water. Reductions in leaching to groundwater in all other regions offset this high level of leaching in the Corn Belt, largely due to fertilizer replacement that compensates for the nutrient value of the harvested residue.

The potential for increased soil erosion from residue harvesting is an important policy concern. Findings suggest, however, that residue harvest could be

Figure 16

Changes in environmental indictors relative to 3 billion gallons of cellulosic ethanol production

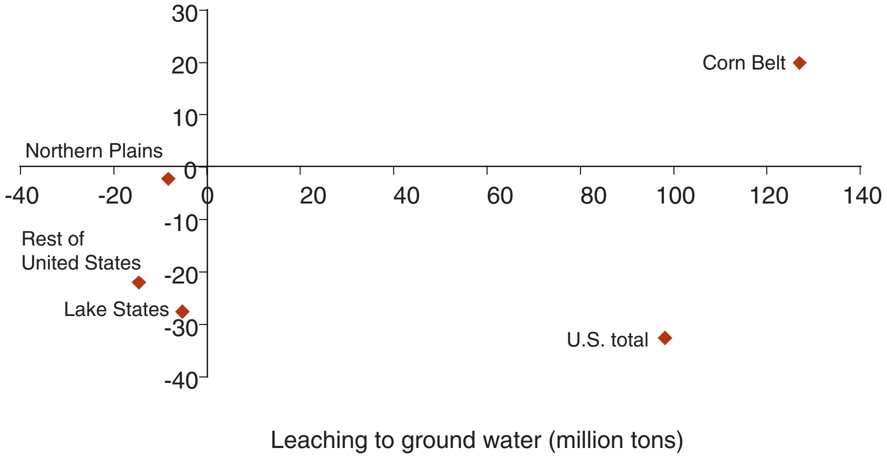


Source: USDA, Economic Research Service calculations based on Regional Environment and Agriculture Programming (REAP) model data.

Figure 17

Change in nitrogen leaching to groundwater and nitrogen runoff to surface water from an increase of 3 to 6 billion gallons of cellulosic ethanol production and a reduction of corn ethanol from 15 to 12 billion gallons, by region

Runoff to surface water (million tons)



Source: USDA, Economic Research Service calculations based on Regional Environment and Agriculture Programming (REAP) model data.

accompanied by changes in management regimes, contributing to a net reduction in soil erosion. As cellulosic production increases from 3 to 6 billion gallons and corn-based ethanol production falls from 15 to 12 billion gallons, acres planted to continuous corn decline, particularly in the Corn Belt, while the use of no-till systems expands. Use of no-till systems increases from 11 percent to 21 percent of national cropland in production, while use of conventional tillage systems declines from 72 percent to 53 percent. Wider adoption of no-till systems is driven by the economic value of crop residues, more of which can be harvested from no-till systems.

Production of feedstocks to supply the emerging cellulosic ethanol industry will become increasingly important to the agricultural landscape. The abundant supply of existing crop residues will play a large role, especially as dedicated energy crops begin to enter the picture. Harvesting crop residues as an ethanol feedstock, however, is not without consequences. Nutrients and organic matter left in the soil would need to be replaced if the residue was not harvested. Application of additional fertilizer has consequences to environmental measures, although the extent to which residues may be harvested while minimizing environmental effects is a topic of additional research.

Research and Policy Options To Mitigate the Impact of Biofuel Feedstock Production

Increased agricultural feedstock production to support the biofuels industry will reshape the U.S. farm sector through changes in commodity markets, land allocations, and production systems. As this study suggests, the implications for resource use and environmental quality are potentially far reaching. Technological advances at different stages of the biofuel production chain can improve the efficiency and cost-effectiveness of conventional and emerging technologies. At the same time, greater understanding of the complex biophysical and economic linkages may lessen the impact of unintended consequences on human and natural systems. Public and private research is underway on new technologies and the infrastructure needed to support an evolving biofuels sector. Research may inform policy design by improving our understanding of potential outcomes and tradeoffs for agriculture, energy, and the environment.

Increased Productivity Can Reduce Pressure on Land Resources

Rising demand for corn, the primary feedstock for ethanol processing under conventional technology, has increased competition for land resources in food and feed production. Research to increase corn productivity may reduce pressure on cropland by increasing ethanol output per acre of corn feedstock. Increased productivity supports both corn producers (through higher returns per unit yield) and consumers (through lower grain prices). Environmental indicators are also enhanced once higher corn yields can be achieved without commensurate increases in chemical and carbon-based inputs. Rates of yield growth will depend on the availability of higher yielding varieties (including new cultivars with higher starch content), the use and sustainability of irrigation and other yield-enhancing practices, and the distribution of new corn acreage across regions and land-quality classes. Additionally, improved crop-ethanol conversion efficiencies through updated fermentation and distillation technology or new crop varieties with higher starch content could also reduce cropland demand, although with differing impacts on product markets and resource use. Results suggest that increased productivity in the production and conversion of corn feedstock can enhance food and energy security, while lessening adverse effects on the environment.

Crop residues, such as corn stover and wheat straw, may serve as important feedstock sources to meet targets for cellulosic production. Crop residues are already widely available as biomass alternatives to corn feedstock, although significant markets and processing capacity do not currently exist. Once cellulosic technologies develop on a commercial scale, crop residues could provide an additional revenue source for grain producers. Residues, however, play an important role in managing soil erosion, nutrient loss, soil carbon, and soil moisture. Thus, residues are not “free”—there are costs associated with harvesting—and soil productivity and environmental quality could be adversely impacted. The amount of residue that can be harvested while maintaining productivity—based on the erodibility of the soil and tillage regime used—is an important policy concern and the focus of ongoing research (USDA-NRCS, 2006; Wilhelm et al., 2004).

Improved Assessment Capabilities Needed

As U.S. biofuel demand expands, many uncertainties remain regarding the implications of domestic production for resource use and environmental quality. Production of energy feedstock crops is projected to be much larger, while regional feedstock sources and technologies are still evolving. Basic research is needed to better understand the underlying mechanisms and processes that drive resource and environmental outcomes, both at the field level and at more aggregate regional scales. Linkages between agricultural economic sectors, the energy sector, and the broader economy are also complex, and the effects of market, technology, and infrastructure development are not clearly understood. Continuing research is needed to examine dynamic adjustments within the U.S. farm sector and their effect on ecologic processes and environmental outcomes across the agricultural landscape.

Improved assessment of biofuel sector impacts involves developing new analytic tools and supporting databases. Analysis at multiple scales—farm-level, watershed/regional, national, and international—would address the range of factors and outcomes likely to shape future biofuels policy. Linkages across agricultural and energy models are increasingly important as energy markets drive returns to agricultural feedstocks, with impacts across the farm economy. Assessment of the full range of resource impacts will depend on improved integration of bio-physical and economic models that capture dynamic linkages across human and natural systems. Comprehensive data on farm-level land use and resource management decisions under various agronomic conditions, and their impact on ecologic processes, is critical to assess environmental effects. Probability distributions for key model assumptions would help address uncertainty inherent in human and natural systems. Monitoring is also needed to support basic conclusions regarding environmental outcomes.

One facet of biofuels policy that has received considerable attention recently is the extent to which U.S biofuel policies influence land-use changes and the consequent changes in GHG emissions, both domestically and abroad. Accounting for international land-use change is beyond the scope of this study. Global land-use implications and feedbacks in international feedstock markets, however, remain an important unknown regarding the net benefits of biofuel policies.

Reducing GHG emissions, relative to the fossil fuels they are meant to replace, is an important part of current biofuel policy and a factor in determining which biofuels will qualify toward meeting the RFS. GHG emissions include those caused by growing, processing, and transporting the feedstock and production and transport of the biofuel itself. A major component of the GHG calculation is the additional land used to grow the feedstock. Land-use changes are often categorized into direct and indirect components. Although the distinction between direct and indirect land-use change blurs in a biofuel context, it is easiest to think of direct land use as the land used to produce the biofuel feedstock. This effect is mainly driven by the policy target, crop yield, and the ethanol conversion rate. Indirect land-use change results from land planted to other crops and conversion of pasture and forests that is induced—generally by price shifts—by the biofuel policy.

In this report, the additional 3.25 million acres of cropland devoted to corn production is considered direct land-use change and will factor into the direct GHG emissions calculation. The reduction in soybean acres for more corn acres could also be considered a direct land-use change. But, as illustrated in the section "Expanding Corn Acreage Drives Market and Environmental Outcomes," those production shifts lead to price shifts that echo through the crop and livestock sector, changing land use as farmers adjust to take advantage of price shifts. Those adjustments would be considered indirect land-use change. In a global economy, price and production shifts in the United States can also lead to indirect land-use change internationally. Indeed, two 2008 studies published in Science (Fargione et al., 2008; Searchinger et al., 2008) concluded that if GHG emissions from indirect land use changes were taken into account, GHG emissions from biofuel production could be far larger than previously estimated.

The Fargione and Searchinger articles effectively brought the potential implications of indirect land-use change into the public spotlight. Where, how much, and what type of land will be introduced into agriculture is a topic of considerable debate. Modeling the land-use change caused by agricultural policy requires projections about future values of parameters that cannot be known with certainty. Therefore, judgments and assumptions must be made about the likely values for this uncertain data. The bottom line of an integrated agriculture sector and GHG lifecycle model is, to a greater or lesser degree, sensitive to the values chosen and to the underlying structure of the model. Since the future cannot be measured, assumptions must be made regarding many factors, such as energy prices, rate of technological change, GHG policy (e.g., taxes, permit trading, offset markets, etc.), and macroeconomic indicators. Each assumption, whether made explicitly or implicitly in the structure and data of the model, will influence the outcome. Table 13 lists some modeling elements subject to uncertainty and how each element influences measurement of land-use change in agricultural sector models. Research leading to a better understanding and possible scientific consensus of these factors would improve analysis of climate change mitigation and adaptation policies.

Conservation Programs Can Reduce Potential Environmental Effects

Conservation programs can play an important role in mitigating the adverse environmental effects of biofuel feedstock production. USDA provides cost-sharing and technical assistance to those who adopt improved agricultural practices through the Environmental Quality Incentives Program (EQIP) and other conservation programs for working farms. Conservation practices widely used in fieldcrop production, and eligible for conservation payments, could be applied to corn production and other potential energy crops to enhance environmental stewardship, such as:

- Nutrient management measures, including soil testing, application regimes, and filter strips, can mitigate potential increases in nutrient runoff and leaching.

Table 13

Key uncertainties in measuring land-use change

Source of uncertainty	Impact on land use	Why is it uncertain?	Range of values
Productivity (yield) growth of corn—domestic and international	As productivity increases, less land is required to grow the same amount of crop.	Yield trends change over time with research innovations. Actual realized yields will be dependent on weather and soil quality, and thus will change with the location of converted lands.	Some studies assume yield growth high enough to eliminate land-use change impacts.
Displacement of corn-based feed by distiller's grains (DDGS)	Distiller's grains are a coproduct of corn-ethanol production and can partially substitute for corn as feed, reducing the demand for corn that goes directly to livestock feed.	The amount of displaced corn and soybeans in animal feed is subject to debate; availability and cost are partially dependent on proximity of livestock to ethanol plants. An animals' capacity for digesting DDGS varies.	Estimates range from a credit of 0.3 acre to 0.7 acre per acre of corn for biofuels.
Rate and cost of development, deployment, and conversion efficiency of cellulosic biofuel production	Higher yields (gallons/acre) are anticipated for cellulosic production, which would then require less land to produce the same amount of biofuel.	Cellulosic conversion technology is not yet operated on a commercial scale. Technologies with the greatest conversion potential may not be first to emerge.	Dependent on break-even cost of production estimates. Estimates range from $1 per gallon up to values considerably higher (not economical).
Amount of cropland shifting tillage practice (adopting or retaining conservation tillage)	Tillage affects carbon sequestration rates and GHG producing input use.	Incentives to switch tillage (carbon taxes, fuel and input prices) are subject to uncertainty.	Assumptions typically based on current practice. Some studies assume all new cropland is conventionally tilled.
Elasticity of supply and demand for biomass crops	More inelastic demand will require more land since there is less substitution by other commodities.	Imperfect knowledge of substitutes; technology changes over time that affect demand.	Usually not explicit in study, but implicit in the supply/demand structure of the model.
Yield and distribution of dedicated energy crops (switchgrass)	Growing energy crops will require conversion of cropland, pasture and/or forests, potentially diverting crop production.	Yields for energy crops are only beginning to be established in field trials—no production yet on a commercial scale. The land that will actually be used for production is unknown.	Values vary by region, but generally from 4-10 tons per acre. Fertilizer application and active management typically not factored in.

- Water-conserving technologies can enhance irrigation conveyance and field application efficiency, while water-supply enhancements, such as rainfall harvesting and wastewater reuse, can reduce demands on existing water resources.
- Conservation tillage systems can reduce erosion, while enhancing soil carbon, nutrients, and moisture.

Expanded use of crop residues as a biofuel feedstock would likely encourage conservation tillage systems, if guidelines can ensure sustainable residue-removal limits.

USDA conservation compliance provisions, which withhold Federal farm payments to producers who convert highly erodible soils or wetlands for cropland use, may limit cropland expansion on environmentally sensitive lands.

In some cases, production on highly erodible soils may be permitted with an approved conservation plan that limits potential erosion through conservation tillage and other measures. Conservation compliance provisions may be less useful in diverting second-generation energy crops from environmentally sensitive land, as these crops are not currently eligible for farm payments. The effectiveness of conservation compliance in providing environmental safeguards will depend on whether cellulosic feedstock producers receive Government payments through other farming enterprises.

References

Aillery, Marcel, Noel Gollehon, Robert Johansson, Jonathan Kaplan, Nigel Key, and Marc Ribaudo. *Managing Manure To Improve Air and Water Quality,* ERR-9, U.S. Department of Agriculture, Economic Research Service, September 2005, http://www.ers.usda.gov/Publications/ERR9/.

Bain, R.L. "World Biofuels Assessment. Worldwide Biomass Potential: Technology Characterizations," NREL/MP-510-42467, Golden, CO: National Renewable Energy Laboratory, U.S. Department of Energy, 2007.

Becker, Geoffrey S. *Livestock Feed Costs: Concerns and Options*, CRS Report for Congress, Congressional Research Service, Library of Congress, September 2008.

Dhuyvetter, Kevin C., Terry L. Kastens, and Michael Boland. *The U.S. Ethanol Industry: Where will it be located in the future?* Agricultural Issues Center, University of California, November 2005.

Duvick, D.N., and K.G. Cassman. "Post-Green Revolution Trends in Yield Potential of Temperate Maize in the North-Central United States," *Crop Science* 391622-1630, 1999.

Elmore, R., and L. Adendroth. "300 Bushels of Corn…When and How?" *Integrated Crop Management Extension Newsletter* IC-498(1), Ames, IA: Iowa State University, February 5, 2007.

Fargione, Joseph, Jason Hill, David Tilman, Steven Polasky, and Peter Hawthorne. "Land Clearing and the Biofuel Carbon Debt," *Science* (7 February 2008).

Graham, R.L., R. Nelson, J. Sheehan, R.D. Perlack, and L.L. Wright. "Current and Potential U.S. Corn Stover Supplies," *Agronomy Journal* 99:1-11, 2007.

Hart, Chad E., and Miguel Carriquiry. "Ethanol-Livestock Integration," *Agricultural Situation Spotlight*, Ames, IA: Iowa State University, Vol. 13, No. 1 (Winter 2007).

Herath, Deepananda, Alfons Weersink, and Chantal Line Carpentier. "Spatial Dynamics of the Livestock Sector in the United States: Do Environmental Regulations Matter?" *Journal of Agricultural and Resource Economics* 30(1):45-68, 2005.

Johannson, R.C., M. Peters, and R. House. "Regional Environment and Agriculture Programming Model (REAP)," Technical Bulletin 1916, U.S. Department of Agriculture, Economic Research Service, March 2007.

Lawrence, John D., James Mintert, John D. Anderson, and David P. Anderson. "Feed Grains and Livestock: Impacts on Meat Supplies and Prices," *Choices*, 2nd quarter, American Agricultural Economics Association, 2008.

MacDonald, James M., and William D. McBride. *The Transformation of U.S. Livestock Agriculture: Scale, Efficiency and Risks*, EIB-43, U.S. Department of Agriculture, Economic Research Service, January 2009.

McAloon, A., F. Taylor, W. Yee, K. Ibsen, and R. Wooley. *Determining the Cost of Producing Ethanol from Corn Starch and Lignocellulosic Feedstocks*, NREL/TP-580-28893, U.S. Department of Energy, National Renewable Energy Laboratory, 2000.

National Corn Growers Association. *Using Technology to Feed, Fuel the World*, 2009, http://ncga.com/files/pdf/UsingTechnology3-09.pdf.

National Research Council. *Water Implications of Biofuels Production in the United States*, Committee on Water Implications of Biofuels Production in the United States, Water Science and Technology Board, Washington, DC: The National Academies Press, 2008.

Norton, Jerry. *Transportation Implications of Structural Shifts in U.S. Agriculture*, U.S. Department of Agriculture, Agricultural Marketing Service, July 1998.

Ribaudo, Marc, Noel Gollehon, Marcel Aillery, Jonathan Kaplan, Robert Johansson, Jean Agapoff, Lee Christensen, Vince Breneman, and Mark Peters. *Manure Management for Water Quality: Costs to Animal Feeding Operations of Applying Manure Nutrients to Land*, AER-824, U.S. Department of Agriculture, Economic Research Service, June 2003, http://www.ers.usda.gov/Publications/AER824/.

Roberts, Martha G., Timothy D. Male, and Theodore P. Toombs. *Potential Impacts of Biofuels Expansion on Natural Resources – A Case Study of the Ogallala Aquifer Region*, Environmental Defense Fund, 2007.

Sandretto, Carmen, and James Payne. "Soil Management and Conservation," *Agricultural Resources and Environmental Indicators – 2006 Edition*, EIB-16, U.S. Department of Agriculture, Economic Research Service, July 2006, http://www.ers.usda.gov/publications/arei/eib16/eib16_4-2.pdf.

Searchinger, Timothy, Ralph Heimlich, R.A. Houghton, Fengxia Dong, Amani Elobeid, Jacinto Fabiosa, Simla Tokgoz, Dermot Hayes, and Tun-Hsiang Yu. "Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change," *Science* 319 (5867), 2008.

Sleper, D.A., and J.M. Poehlman. *Breeding Field Crops*, 5th edition, Blackwell Publishing, 2006.

Stillman, Richard, Mildred Haley, and Ken Mathews. "Grain Prices Impact Entire Livestock Production Cycle," *Amber Waves*, U.S. Department of Agriculture, Economic Research Service, September 2009, http://www.ers.usda.gov/AmberWaves/March09/Features/GrainPrices.htm.

Tannura, M., S. Irwin, and D. Good. *Are Corn Trend Yields Increasing at a Faster Rate?* Marketing and Outlook Brief 08-02, Department of

Agricultural and Consumer Economics, University of Illinois at Urbana-Champaign, February 20, 2008.

U.S. Department of Agriculture. *USDA Agricultural Projections to 2017*, OCE-2008-1, 2008.

U.S. Department of Agriculture, *World Supply and Demand Estimates*, August 12, 2009.

U.S. Department of Agriculture, Economic Research Service. *Farm Income and Costs: 2008 Farm Sector Income Forecast*, 2008a.

U.S. Department of Agriculture, Economic Research Service. *Feed Grains Database*, 2008b, http://www.ers.usda.gov/data/feedgrains/.

U.S. Department of Agriculture, National Agricultural Statistics Service. *Ethanol Co-Products Used for Livestock Feed*, study conducted jointly with the Nebraska Corn Development, Utilization and Marketing Board, 2007.

U.S. Department of Agriculture, National Agricultural Statistics Service. *Agricultural Chemical Usage – 2006 Field Crops Summary*, May 2007, http://usda.mannlib.cornell.edu/usda/nass/AgriChemUsFC//2000s/2007/AgriChemUsFC-05-16-2007_revision.pdf.

U.S. Department of Agriculture, National Agricultural Statistics Service. *Agricultural Chemical Usage – 2005 Field Crops Summary*, May 2006, http://usda.mannlib.cornell.edu/usda/nass/AgriChemUsFC/2000s/2006/AgriChemUsFC-05-17-2006.pdf.

U.S. Department of Agriculture, National Agricultural Statistics Service. *Farm and Ranch Irrigation Survey (2003), Special Studies—Part 1 of the 2002 Census of Agriculture*, AC-02-SS-1, Vol. 3, November 2004a, http://www.agcensus.usda.gov/Publications/2002/FRIS/index.asp.

U.S. Department of Agriculture, National Agricultural Statistics Service. *United States Census of Agriculture (2002)*, Summary and State Data, AC-02-A-51, Vol. 1, Part 51, June 2004b, http://www.agcensus.usda.gov/Publications/2002/USVolume104.pdf .

U.S. Department of Agriculture, Natural Resources Conservation Service. *Crop Residue Removal for Biomass Energy Production: Effects on Soils and Recommendations*, Technical Note No. 19, August 2006.

U.S. Department of Agriculture, Natural Resources Conservation Service. *National Resources Inventory – 2003 Annual NRI, 2003*, http://www.nrcs.usda.gov/Technical/nri/2003/nri03eros-mrb.html.

U.S. Environmental Protection Agency. 2*009 U.S. Greenhouse Gas Inventory Report*, 2009, http://epa.gov/climatechange/emissions/usinventoryreport.html.

U.S. Environmental Protection Agency, National Pollutant Discharge Elimination System (NPDES). CAFO Rule History, accessed on August 3, 2009, http://cfpub.epa.gov/npdes/afo/aforule.cfm.

Westcott, Paul. "U.S. Ethanol Expansion Driving Changes Throughout the Agricultural Sector," *Amber Waves*, U.S. Department of Agriculture, Economic Research Service, September 2007, http://www.ers.usda.gov/AmberWaves/September07/Features/Ethanol.htm.

Wilhelm, W.W., J.M.F. Johnson, J.L. Hatfield, W.B. Voorhees, and D.R. Linden. "Crop and Soil Productivity Response to Corn Residue Removal: A Literature Review," *Agronomy Journal* 96(1): 1 - 17, 2004.

Wilhelm, W.W., J.M.F. Johnson, D.L. Karlen, and D.T. Lightle. "Corn Stover to Sustain Soil Organic Carbon Further Constrains Biomass Supply," *Agronomy Journal* 99(6): 1665-1667, 2007.

Wortmann, C.S., R.N. Klein, W.W. Wilhelm, and C. Shapiro. *Harvesting Crop Residues*, University of Nebraska Extension Report, G1846, May 2008.

Appendix: The Modeling Framework

Empirical findings for this study are based on the Regional Environment and Agriculture Programming (REAP) model (Johansson et al., 2007). REAP is a mathematical optimization model that quantifies agricultural production and its associated environmental outcomes for 50 regions in the conterminous United States. The regions are defined by the intersection of the USDA's Farm Production Regions (10 groups of States with similar agri-economic characteristics[1]) and the Natural Resources Conservation Service's Land Resource Regions (defined by predominant soil type and geography).

Regional production levels are determined in the model for 10 crops and 13 livestock categories, with national production levels determined for 20 processed products. REAP explicitly models regional differences in crop rotations, tillage practices, and input use, such as fertilizer and pesticides. Commodity prices and input use are determined endogenously. REAP employs detailed data (derived from USDA's Agricultural Resource and Management Survey (ARMS) that is conducted by the National Agricultural Statistics Service and the Economic Research Service and the Environmental Productivity and Integrated Climate (EPIC) model) at the regional level on crop yields, input requirements, costs and returns, and environmental parameters to estimate long-run equilibrium outcomes.

For the analysis in this report, the model is calibrated to prices and quantities for 2015 of the 2008 USDA baseline. Changes in agricultural production from this baseline can be assessed for a wide range of policy, market, or environmental shocks. The model has been widely applied to address agri-environmental issues, such as soil conservation and environmental policy design, environmental credit trading, climate change mitigation policy, and regional effects of trade agreements (Johansson et al., 2007).

REAP is implemented as a nonlinear mathematical program using the General Algebraic Modeling System (GAMS) programming environment. The goal of the model is to find the competitive equilibrium (welfare-maximizing) of production levels subject to land constraints and processing and production balance requirements. Production activities for crops within a region (defined by crop rotation and tillage) behave according to a constant elasticity of transformation (CET) relationship. The CET specification allows for a solution away from “corner points,” thus allowing the solution to reflect a realistic variety of producer behavior.

The model is calibrated to national production levels given by the USDA baseline and the Positive Math Programming (PMP) method. This method introduces the baseline levels as calibration constraints, and the resulting marginal costs are used to modify the objective function that adjusts for discrepancies between the original model output and the baseline values. The modified model, without the calibration constraints, will solve to the precise levels specified by the baseline. Shocks based on policy, technical, or environmental scenarios can be introduced as adjustments to constraints, modifications of baseline data assumptions, addition of terms to the objective function, or a combination of approaches. This permits the model to evaluate deviations from the baseline.

[1] There are 10 Farm Production Regions; each consists of 3 to 11 States.

It should be noted that REAP holds many factors unchanged that influence planting decisions and the markets for agricultural commodities. Weather and pest conditions are assumed to be average for the growing season. REAP does, however, provide an economics-based framework for analyzing how agricultural markets respond to shocks to the production environment created by policy or technology on both the supply side and demand side.