



ISSUE BRIEF 13
**CLIMATE CHANGE
AND U.S. AGRICULTURE**

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SUMMARY

Despite its relatively small role in generating carbon dioxide (CO₂), agriculture is frequently discussed in the context of climate change—for several reasons. First, agriculture is one of the key sectors of the economy that may be strongly affected by climate change. Second, while relatively unimportant for CO₂ emissions, the agriculture sector is a major source of other greenhouse gas (GHG) emissions, notably nitrous oxide (N₂O) and methane (CH₄). Third, agricultural practices provide opportunities for soil-based carbon sequestration, potentially a relatively cheap mitigation option. Fourth, the recent biofuels boom is transforming U.S. agriculture in ways that have implications not only for GHG emissions and energy production, but also for agriculture and the food sector as a whole. This issue brief brings together each of these aspects of the connection between agriculture and climate change.¹

Effects of Climate Change on Agriculture

- Climate change is not expected to materially alter the overall ability of the United States to feed its population and remain a strong agricultural exporter. Generally, climate change is predicted to have overall positive but relatively modest consequences on agricultural production in the United States over the next 30 to 100 years. Longer term consequences are less well understood.

- At the regional level, however, projected effects on agriculture are considerable. Climate change is expected to reduce agricultural output in the South but increase production in northern regions, especially the Great Lakes.
- Predicting changes in precipitation patterns, extreme weather effects, pest populations, plant diseases, and other production risks is inherently difficult. Current assessments do not fully account for potential effects on agriculture from these climate impacts.

Agriculture as a Source of GHG Emissions

- The agricultural sector is responsible for roughly 8 percent of total U.S. GHG emissions.
- Agriculture is not a major source of CO₂ emissions, but it is the source of almost 30 percent of methane emissions and 80 percent of nitrous oxide emissions. On a CO₂-equivalent basis, these gases account for nearly 15 percent of all GHG emissions in the United States. Most agricultural nitrous oxide emissions stem from soil management; methane emissions come primarily from animal husbandry (specifically, enteric fermentation in the digestive systems of ruminant animals and manure management).
- While unlikely to be included in a mandatory policy, the agricultural sector is a potential source of low-cost emissions

¹ Broader issues such as overall energy demand, energy security, climate change agreements, and so forth, are outside the scope of this brief.

offsets. Though these offsets provide important GHG mitigation opportunities, incorporating them in a regulatory system presents challenges in terms of measuring, verifying, and assuring the permanence of claimed reductions.

- Cost-effective GHG mitigation opportunities in the agriculture sector include the use of soil management practices to reduce nitrous oxide emissions and increase carbon sequestration.
- Soil-based carbon sequestration, in particular, may represent an important near-term GHG mitigation option, and a means of keeping mitigation costs down until other emissions-reduction technologies develop.

Biofuels

- Corn-based ethanol production has skyrocketed in recent years, and this trend is likely to continue. Nationwide, nearly 130 ethanol biorefineries with total annual production capacity of 6.7 billion gallons are currently² in operation, making the United States the world's largest producer of ethanol.
- The almost 80 new plants currently under construction will approximately double current U.S. ethanol production capacity.
- With more than 13 billion gallons of annual production capacity either already in operation or under construction, domestic ethanol use is poised to far exceed the 7.5 billion gallon annual target established by the federal Renewable Fuels Standard (RFS) adopted in 2005 (the latter policy calls for 5 percent of total U.S. gasoline demand to be met using renewable fuels by 2012). Long-term projections taking into account cost, feedstock supply, and other constraints do not, however, foresee corn-based ethanol production exceeding 15–20 billion gallons annually.
- The current ethanol boom is affecting practically every aspect of U.S. agriculture. In 2007, the nation's farmers planted a record corn crop, increasing corn acreage by 19 percent. Additional land in corn production largely came from shifting acreage out of soybean production. As a result of strong demand, corn prices have not only remained high but are driving up prices for other commodity crops.

- Consumer food prices are not expected to be severely affected by high corn prices resulting from the current ethanol boom. Nevertheless, higher feed costs increase consumer prices for poultry, eggs, and red meats. This will likely cause overall retail food prices to rise somewhat faster than the general rate of inflation through the end of the decade (2008–2010). After these near-term price adjustments, however, consumer food prices are expected to rise more slowly than the general rate of inflation.
- Though corn-based ethanol replaces fossil fuels, its capacity to mitigate GHG emissions is limited. Taking into account the entire product life-cycle, the use of corn-based ethanol is estimated to reduce GHG emissions by roughly 10–20 percent relative to gasoline.³ Therefore, the foreseeable expansion of corn-based ethanol production can be expected to only marginally reduce total U.S. GHG emissions (by less than 0.5 percent).
- More substantial GHG reductions (up to 80–90 percent relative to gasoline) and significantly larger production volumes could be achieved through the successful commercialization of technologies for producing ethanol from cellulosic biomass. But large-scale expansion of this capability requires technological innovations.⁴

Effects of Climate Change on Agriculture

Agriculture, especially crop production, is fundamentally linked to climatic conditions, so any changes in climate will necessarily affect agriculture. Several assessments have scrutinized the effects of alternative climate-change scenarios on the U.S. agriculture sector, and although their predictions vary (in some cases widely), there is general agreement that climate change is unlikely to materially alter the ability of the United States to feed its population and remain a strong agricultural exporter.⁵

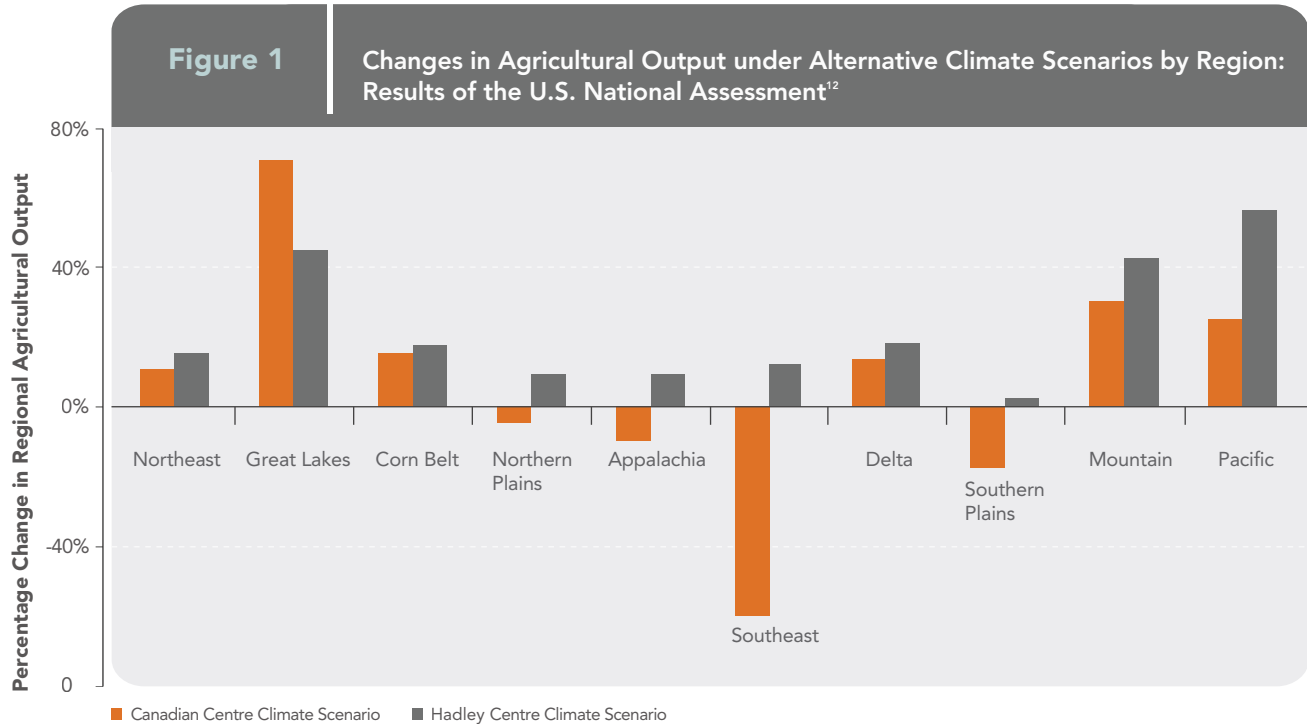
Generally, the predicted economic impacts from climate-related effects on agriculture are positive but moderate in aggregate over about the next 30–100 years. Though projected future growing conditions (temperature,

³ M. Wang, M. Wu, and H. Huo, "Life-cycle Energy and Greenhouse Gas Emission Impacts of Different Corn Ethanol Plant Types," *Environmental Research Letters* 2(2007):1–13; and K. Sanderson, "A Field in Ferment," *Nature* 444, Business Feature, 673–676, 7 December 2006.

⁴ M. Wang, M. Wu, and H. Huo, note above.

⁵ J. Reilly et al., "Agriculture: The Potential Consequences of Climate Variability and Change for the United States," in US Global Change Research Program, *US National Assessment of the Potential Consequences of Climate Variability and Change*, New York: Cambridge University Press, 2001; and R. Adams, R. Hurd, J. Reilly, *A Review of Impacts to U.S. Agricultural Resources*, Arlington, VA: Pew Center on Global Climate Change, 1999.

² As of August 22, 2007 (Renewable Fuels Association).



precipitation) would affect especially crop production and its regional distribution, market adjustments in production, consumption, and trade ensure that even substantial production changes would not become very costly overall. Longer-term agricultural effects of climate change are less well understood.

For example, the U.S. National Assessment⁶ examined the effects of alternative climate-change scenarios on agriculture. Depending on the adopted climate model,⁷ the results ranged from moderate costs to a few billion dollars of overall benefits in agriculture.⁸ Potential agricultural benefits from climate change stem from increasing temperatures and CO₂ levels, which boost crop yields.⁹ While increased crop yields generally count as a benefit, the fact that higher yields tend to lower crop prices means that farmers may not be any better off and could in fact suffer losses. Of course, lower crop and food prices are a plus for consumers.¹⁰ Targeted adaptation

efforts would tend to provide positive benefits to agriculture, while increasing pest populations and other production risks associated with climate change would have negative impacts.

Notwithstanding the fact that overall effects are predicted to be moderate, regional impacts can be large. Predicted changes in temperature and precipitation are least favorable to agriculture in the South and Great Plains, where the net effect of climate change is negative (see Figure 1). Predicted losses in agricultural output are especially large in the Southeast.¹¹ Northern areas, on the other hand—particularly the Great Lakes area—may benefit from more favorable climatic conditions.

Though different assessments project climate-related changes in agricultural production and land prices, these changes are moderate in the context of other trends in agriculture and food markets. For example, agricultural land prices declined roughly 50 percent between 1980 and 1983—a shift that is well beyond the projected effects of climate change. On the consumer side, a recent rise in retail food prices is likely to produce more noticeable impacts than any predicted effect from climate change. Similarly, changes in world markets for

6 Reilly et al. note above.

7 Two climate scenarios, the Canadian Climate Centre Model and Hadley Centre Model, were examined in the National Assessment. The Canadian model predicts significant warming in the South such that increases in the average temperature of about 9°F (5°C) are common by the year 2100. The Hadley model predicts more moderate temperature increases (Reilly et al. 2001, note 5 above).

8 See also C. Field et al. "North America", in *Climate Change 2007: Impacts, Adaptation and Vulnerability, Contribution of Working Group II to the Fourth Assessment Report of the Intergovernmental Panel on Climate Change*, M.L. Parry, et al. (Eds.), Cambridge University Press, Cambridge, UK, 617-652, 2007.

9 Higher atmospheric CO₂ concentrations generally enhance the rate of photosynthesis, which in turn improves crop yields.

10 Reilly et al. 2001, note 5 above.

11 The U.S. National Assessment defines agricultural output as aggregated crop and livestock production weighted by output prices.

agricultural products, trade and agricultural policies, farming technology, or competing uses for agricultural land are likely to impact this sector more dramatically than climate change over the next several decades.

Predictions about the effects of climate change on agriculture depend critically on underlying assumptions regarding technological change, adaptation to new climatic conditions and regulatory regimes, and alternative land uses. They also depend on international developments with respect to trade, food demand, and production (which in turn are also likely to be affected by climate change). Substantial changes in any of these modeling assumptions will alter and possibly overshadow predicted effects from climate change. For example, new crop varieties are continuously developed and crops today have broader suitable geographical ranges than just a few decades ago. This technological progress will continue and may even intensify in response to climate change. Opportunities to improve crop productivity and adapt to changing conditions are also vastly improved by biotechnology.

Besides temperature changes, the full effect of climate change will depend on other factors such as precipitation (total precipitation and its temporal distribution); extreme weather events (storms, droughts, etc.); changes in pest populations, plant diseases, and weeds; and so forth. These effects are poorly predicted by current climate-change models—different agricultural assessments emphasize inherent difficulties in properly accounting for them—and each may impose important costs on agriculture.

The difficulty of predicting net effects is illustrated by examining water availability—a critically important parameter—in irrigation-dependent areas where climate change is expected to alter both crop yields and water supply. The amount of water available for irrigation will change with both the timing and volume of annual water supply. Currently, much of the precipitation in many irrigation-dependent states occurs during the winter months, whereas demand for irrigation water peaks during the late spring and summer. Two types of water storage—man-made reservoirs and mountain snow pack—smooth this temporal discrepancy in precipitation and water demand. For example, in late April, the water preserved in the snow pack of California’s Sierra Nevada mountains currently just about matches what is stored by the state’s major reservoirs. According to current projections, rising temperatures may well reduce snow-pack storage capacity by one-third by the middle of the century.

This reduction in natural storage capacity would likely be replaceable, at least in part, by man-made storage, though at considerable cost. Without alternative storage capacity, agricultural producers in California would have to cope with a substantially reduced supply of water for irrigation.¹²

Agriculture as a Source of GHG Emissions

Emissions

Currently, the agricultural sector is responsible for about 8 percent of total U.S. GHG emissions (see Figure 2). Within the U.S. economy, emissions from agriculture rank considerably below those from the electric power industry (33 percent of total emissions), the transportation sector (28 percent of total emissions), and the industrial sector (19 percent of total emissions). The contribution from agriculture exceeds, however, the contribution from primary energy consumption in the commercial and residential sectors (6 percent and 5 percent of total emissions, respectively). In absolute terms, agricultural GHG emissions amount to about 595 million metric tons of CO₂-equivalent per year, whereas total annual U.S. emissions are about 7,260 million metric tons CO₂-equivalent.¹³

Although agriculture is not a major source of U.S. CO₂ emissions, it is the source of almost 30 percent of methane¹⁴ emissions and 80 percent of nitrous oxide emissions (see Figure 3). Together, these two gases, while not on par with CO₂, constitute almost 15 percent (on a CO₂-equivalent basis) of all GHG emissions in the United States.

Nitrous oxide emissions from agricultural soils account for almost two-thirds of overall GHG emissions from agriculture. These emissions originate primarily from the breakdown of manure and nitrogen fertilizers, but are also released from nitrogen-fixing crops (e.g. soybeans, alfalfa, and clover). Nitrous oxide emissions from soil management constitute roughly 5 percent of all U.S. GHG emissions.

Though GHG emissions have increased during the last

¹² Changes in the irrigation water supply undoubtedly will have considerable consequences on agriculture. Schlenker et al. examine projected climate-change scenarios for California and predict that declining water availability may reduce the value of farmland by as much as 40 percent (\$1,700 per acre). This effect is due solely to lost irrigation and does not include effects from changing temperature, which the study predicts will further reduce the value of farmland. (Schlenker, W., W. M. Hanemann, and A. Fisher, 2007, *Water Availability, Degree Days, and the Potential Impacts of Climate Change on Irrigated Agriculture in California*, *Climatic Change*, 2007 81:19-38.)

¹³ U.S. Environmental Protection Agency, “Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990–2005,” April 15, 2007.

¹⁴ The decomposition of livestock manure, under anaerobic conditions, produces methane. According to the U.S. Environmental Protection Agency, roughly 540 million CO₂-equivalent tons of methane were emitted from human-related activities in the United States in 2005 (EPA, note 14 above). Nearly one-third of these emissions originated in the animal husbandry industry, including enteric fermentation and manure management.

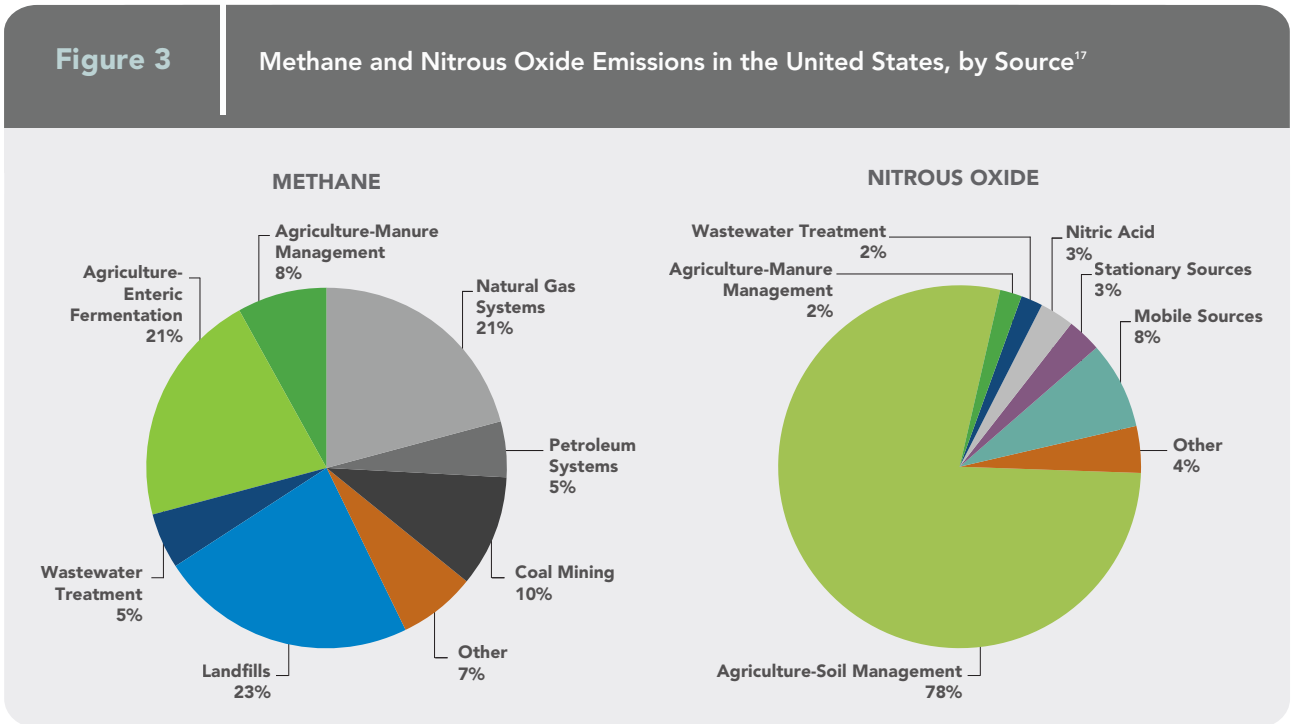
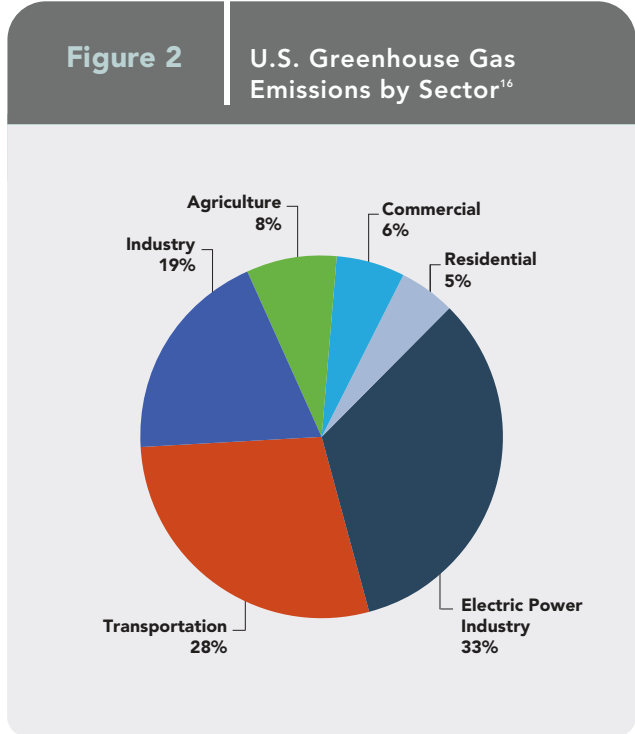
decade, emissions from agriculture have remained nearly constant. Methane from manure management is the main exception to this trend: methane emissions have increased by roughly one-third as livestock production has shifted to larger and larger concentrated animal feeding operations (CAFOs). On the other hand, large production units may facilitate future mitigation efforts by making investments in capital-intensive methane-reduction technologies, such as methane digesters, more cost-effective.

Potential for GHG mitigation and offsets

Collectively, the agriculture sector can contribute to GHG mitigation efforts in a number of ways, especially by increasing soil carbon sinks, reducing emissions of nitrous oxide and methane, and providing biomass-based alternatives to fossil-fuel use.¹⁵ Prominent GHG mitigation strategies in agriculture include the following:

1. Improved agricultural land management to increase soil carbon storage.
2. Enhanced livestock and manure management to reduce methane emissions.

15 See, for example, K. Paustian, J. M. Antle, J. Sheehan, and E. A. Paul, *Agriculture's Role in Greenhouse Gas Mitigation*, Arlington, VA: Pew Center on Climate Change, September 2006.



3. Development of new fertilizer application techniques to reduce nitrous oxide emissions.
4. Increased use of biomass energy crops to replace fossil fuels.

Improved agricultural land management to increase soil carbon storage

Changes in land use and agricultural practices can increase the amount of carbon stored in soils. Best management practices that increase soil sequestration include adopting conservation tillage, reducing fallow periods, including hay crops in annual rotations, and producing high-residue-yielding crops. Converting lands to conservation set-asides with trees (afforestation) or perennial grasses can produce larger changes in soil sequestration than changes in agricultural practices.¹⁶

Management practices that increase soil sequestration can be implemented relatively quickly and in many cases at low cost relative to other forms of emissions reductions. The amount of carbon storage that would be economically competitive with other mitigation opportunities, however, is less than the total technical potential for sequestration in agricultural soils. National-level studies suggest that as much as 70 million metric tons of soil-based carbon sequestration per year are available at a cost of \$50 per ton of carbon (\$13 per ton of CO₂) through best management practices, and another 270 million metric tons of carbon sequestration per year could be achieved by converting agricultural lands to forests.¹⁷

The profitability of alternative management techniques and the amount of carbon sequestration achievable at a given price vary widely across regions. The potential to increase soil carbon storage on agricultural lands generally ranges from 0.1 to 1 ton per hectare (0.04–0.4 tons per acre) per year due to differences in soil attributes. Most studies suggest that the Midwest and Great Plains regions are well suited for conservation tillage practices, while the Southeast may be better suited for the conversion of agricultural lands to forests.

Agricultural soils do not have an unlimited capacity to store carbon, and for any given management practice a saturation point will be reached over time. Complete carbon saturation is estimated to occur 20–30 years after changes in farm management practices and 70–150 years after afforestation, depending on the tree species used. Also, carbon stored in soils can be quickly released back into the atmosphere once a

Collectively, the agriculture sector can contribute to GHG mitigation efforts in a number of ways, especially by increasing soil carbon sinks, reducing emissions of nitrous oxide and methane, and providing biomass-based alternatives to fossil-fuel use.

farmer reverts back to traditional tilling practices. Thus, policies that provide offset credits for soil-based carbon sequestration in the context of a domestic CO₂ cap-and-trade program must be cognizant of permanence issues and of the potential for stored carbon to be released. Nevertheless, this option can provide immediate, low-cost GHG-mitigation benefits while more permanent solutions are developed.

Nitrous Oxide

Primary means of reducing nitrous oxide emissions focus on more efficient and moderate uses of manure and nitrogen fertilizers. This may be achieved by improving the timing and placement of fertilizers, testing soils to determine fertilization requirements, using nitrification additives, and incorporating fertilizers into soils. Technically, these practices could reduce nitrous oxide emissions from agriculture by up to 30–40 percent (reductions available at a competitive cost could be smaller). More efficient fertilizer applications would generate additional water-quality benefits by reducing nutrient runoff.

Methane

While enteric fermentation in the digestive systems of ruminant animals accounts for most agricultural methane emissions, manure management may offer greater opportunities

¹⁶ In 2005, U.S. agricultural soils were sequestering about 20 MMT of carbon per year with 36% of croplands applying some form of conservation tillage.

¹⁷ K. Paustian et al., note 18 above; and J. Lewandrowski et al., *Economics of Sequestering Carbon in the U.S. Agricultural Sector*, USDA Economic Research Service, 2004.

for mitigation.¹⁸ The main approach for controlling these emissions is to capture the methane and then burn the bio-gas to generate electricity. Other manure management options involve using manure-storage sheds, aeration processes, and lagoon storage systems with methane capture.

Using captured methane to generate electricity can reduce farm outlays for electricity and even provide surplus electricity for sale back to the grid. On-farm electricity generation produces CO₂ emissions but because of the higher global warming potential of methane, net GHG reductions—on a CO₂-equivalent basis—can approach 90 percent.¹⁹ In addition, the electricity generated from this activity replaces other forms of electricity generation, including generation using equally or more carbon-intensive fossil fuels. In that case, net reductions are achievable even in CO₂ emissions alone.

Over the last few years, interest in methane digesters for use in animal husbandry operations has increased noticeably. Most of the potential for applying this technology is concentrated in major dairy- and livestock-producing regions, such as California, Wisconsin, Iowa, Minnesota, North Carolina, and Texas. For example, California has initiated several programs, including the Dairy Power Production Program, the Self-Generation Incentive Program, and net-metering assembly bills, to encourage manure treatment with methane digesters. The Dairy Power Production and Self-Generation Incentive Programs provide cost-share funding for capital investments in new methane digesters.²⁰ Assembly Bills 2228 (signed into law in 2002) and 728 (signed into law in 2005) require the state's three largest investor-owned utilities (Pacific Gas & Electric, Southern California Edison, and San Diego Gas & Electric) to offer net metering to dairy farms that install methane digesters. Potential farm-level benefits from methane digestion are especially pronounced for relatively large operations, where the capital cost of installing digesters is least prohibitive, and in warm climates, where methane production potential is greatest.²¹

Total Mitigation Potential

The agriculture sector offers a wide range of mitigation opportunities. Therefore, the key question is how different

18 Over the past 20 years, methane-suppressing feed additives and more efficient feed rations have become commonplace, but these options have limited the potential to further curb emissions. However, improvements in the quality of grazing plants, nutritional supplements, animal genetics, and pasture management can lead to emissions reductions of up to 20 percent from beef cattle.

19 Burning 1 ton of methane (equivalent to 21 tons of CO₂ if allowed to vent) yields only 2.75 tons of CO₂. For more information on policy options for methane control in livestock operations, see "Air Emissions of Ammonia and Methane from Livestock Operations: Valuation and Policy Options," Shih, J.-S., D. Burtraw, K. Palmer, and J. Siikamäki. RFF Discussion Paper 06-11 (March 2006) at <http://www.rff.org/documents/RFF-DP-06-11.pdf>.

20 Some federal programs can also provide cost-share funding for methane digesters. Such programs include the Environmental Quality Incentives Program (EQIP), the Conservation Innovation Grants Program (CIG), and the Conservation Security Program (CSP) (NDESC 2005).

21 Shih, J.-S et al., note 22 above.

Table 1

National GHG Mitigation Total 2010-2110, Million Metric Tons CO₂ Equivalent, Annualized Averages by Activity (EPA 2005)

Activity	\$ per ton CO ₂ equivalent				
	\$1	\$5	\$15	\$30	\$50
Afforestation	0	2	137	435	823
Forest Management	25	105	219	314	385
Agricultural Soil Carbon Sequestration	62	123	168	162	131
Fossil Fuel Mitigation in Crop Production	21	32	53	78	96
Agricultural CH ₄ and N ₂ O Mitigation	9	15	32	67	110
Biofuels Offsets	0	0	57	375	561
All Activities	117	227	666	1,431	2,106

options compare in total mitigation potential and cost. This question is addressed in a recent EPA analysis; Table 1 summarizes the results.^{22,23} Though this issue brief focuses on agriculture, we also present results for forestry-related activities to highlight the relative potential of alternative mitigation options.

The total potential and relative cost of different mitigation activities vary considerably. At a low carbon price (\$1–\$5 per ton of CO₂), agricultural soil carbon sequestration is the dominant mitigation strategy. Another activity with considerable potential at low carbon prices involves managing forests for carbon sequestration. Afforestation (establishing trees on non-forested lands) and biofuels offsets (substituting biofuels for fossil fuels) offer only moderate mitigation potential at low carbon prices, but emerge as dominant mitigation activities once prices rise above \$30 per ton of CO₂-equivalent. Measures to reduce fossil-fuel use for crop production and agricultural methane and nitrous oxide emissions provide moderate mitigation capacity at all carbon prices, but their overall emissions-reduction potential is relatively small.

22 "Greenhouse Gas Mitigation Potential in U.S. Forestry and Agriculture", United States Environmental Protection Agency, Office of Atmospheric Programs, Washington, DC, Report EPA 430-R-05-006, November 2005.

23 The results of the EPA-study are by and large consistent with other studies, which have examined the cost of carbon sequestration, including (i) Lewandrowski, J., M. Peters, C. Jones, R. House, M. Sperow, M. Eve, and K. Paustian (2004) "Economics of Sequestering Carbon in the U.S. Agricultural Sector," Washington, DC: U.S. Department of Agriculture, ERS; (ii) Sedjo, R., B. Sohngen, and R. Mendelsohn (2001) "Estimating Carbon Supply Curves for Global Forests and Other Land Uses," Discussion Paper 01-19, Resources for the Future, Washington, DC.; and (iii) Stavins, R. N. (1999) "The Costs of Carbon Sequestration: A Revealed-Preference Approach," *American Economic Review* 89(4): 994-1009.

Overall, agricultural and forestry activities offer substantial GHG mitigation potential. Even at low carbon prices—from \$1 to \$5 per ton CO₂—these activities can provide annual net emission reductions ranging from 117 to 277 million metric tons CO₂. The cost-effective potential for emission reductions increases with carbon prices, reaching more than 2,000 million metric tons CO₂-equivalent emissions per year at a price of \$50 per ton CO₂. To put these estimates into perspective, current U.S. GHG emissions total about 6,500 million metric tons CO₂-equivalent per year.

The higher end of the carbon-price range shown in Table 1 is comparable to the range of global carbon prices thought to be necessary—based on current modeling analyses—to stabilize atmospheric CO₂ concentrations later this century. For example, it is estimated that stabilizing CO₂ concentrations in the 550 parts per million range will require carbon prices to reach \$5–\$30 per metric ton CO₂ by 2025, and about \$20–\$90 per metric ton by 2050.²⁴

Challenges

Agricultural emissions are unlikely to be included in binding programs to limit GHG emissions, such as a cap-and-trade program. Extending mandatory emissions-reduction requirements to agriculture would be hampered by several challenges. Agricultural GHG emissions are generally difficult to monitor and verify. Moreover, some types of mitigation—such as carbon sequestration through alternative soil management—may not be permanent.

Despite the likelihood that agriculture would be excluded from a mandatory regulatory program, the sector provides several potentially cost-effective opportunities for CO₂ offsets. Offsets, which are emissions credits generated by sources not covered under a cap-and-trade or other mandatory regulatory program, are attractive for their capacity to expand the pool of available, low-cost emissions-reduction options. However, many of the challenges associated with including agricultural sources in a mandatory regulatory program also apply to the measurement and verification of agricultural offsets. Common performance criteria for crediting offsets require that emissions reductions are real, additional, and permanent.²⁵ Each category of potential agricultural GHG-mitigation strategies faces difficulties in satisfying these criteria.

For example, the amount of carbon sequestered in agricultural soils is difficult to measure. Each soil type is different in its

capacity to absorb (or release) carbon, and different soils have different saturation points beyond which sequestering additional carbon is not possible or requires radical changes in land use (for example, afforestation). Carbon sequestration also raises questions about permanence; changes in soil management practices can quickly release the sequestered carbon back into the atmosphere. Leakage issues are also potentially difficult: if changing soil management practices to enhance sequestration in one field means that countervailing changes occur in another field, no net sequestration of carbon may result.

Similar challenges arise in the context of non-CO₂ agricultural emissions. For example, nitrous oxide emissions from agricultural soils are affected not only by soil management and fertilization, but also by natural processes—nitrification and denitrification—which can vary depending on the types of soils farmed and crops grown. Measuring changes in these emissions is therefore inherently difficult. Similar issues must be resolved when crediting offsets for methane control in manure management and livestock operations.

Present programs and proposals related to agricultural offsets

Several emissions-trading markets with distinct policies regarding agricultural offsets currently exist or are in the process of being developed. For example, the European Climate Exchange excludes any offsets from agricultural sinks. The Chicago Climate Exchange, the only voluntary emissions trading market in North America, includes the National Farmer's Union Carbon Credit Program, which allows farmers to aggregate marketable carbon credits for carbon sequestering practices.²⁶ The Northeast and Mid-Atlantic states' Regional Greenhouse Gas Initiative (RGGI), a first mandatory cap-and-trade program to limit power-sector CO₂ emissions in the United States, includes credits for methane mitigation from manure management practices.²⁷ The California legislature is developing a statewide cap-and-trade system under Assembly Bill 32 (passed in 2007) but has not yet set up a framework for GHG offsets.

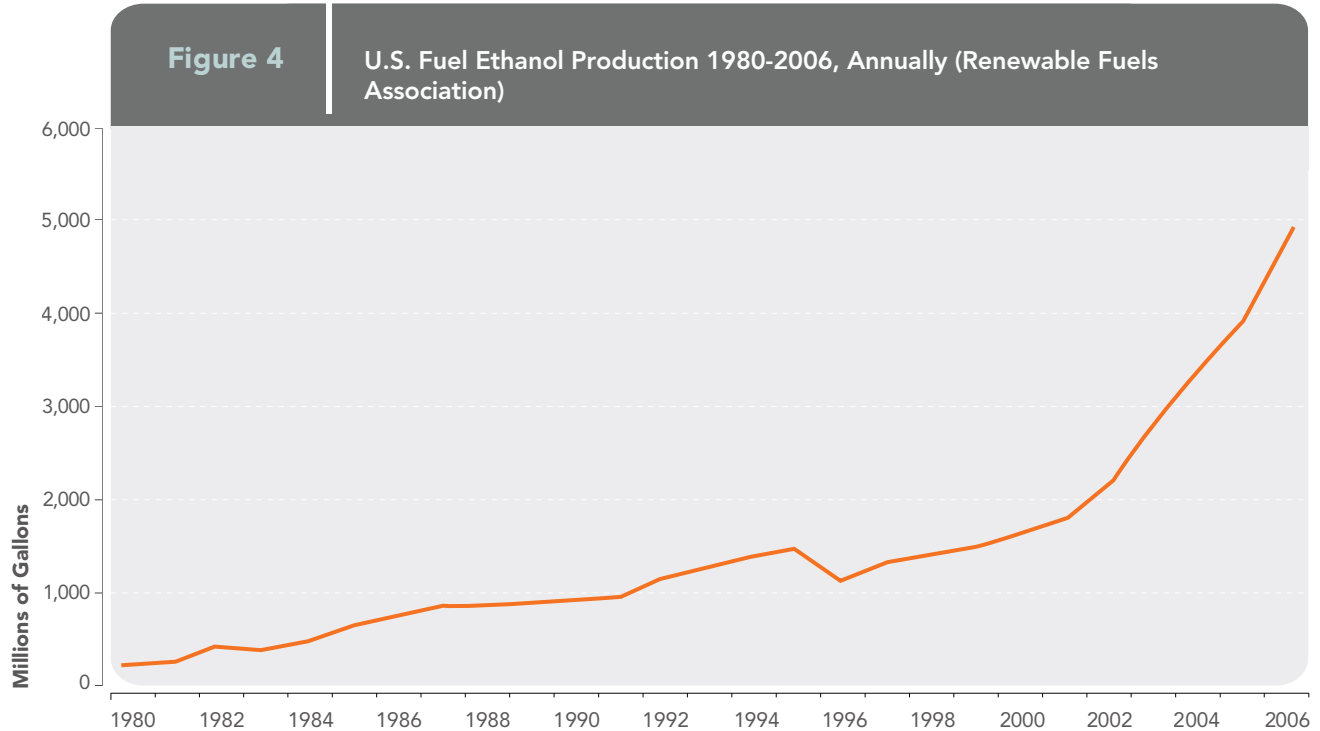
Some proposals for federal climate change legislation have included the agriculture sector. For example, the McCain-Lieberman "Climate Stewardship Act of 2005" and the Waxman "Safe Climate Act of 2006" both propose that emissions trading markets allow farmers to earn credits from

24 Recent studies of the carbon prices required for long-term stabilization of atmospheric CO₂ are summarized in Issue Brief #2 on stabilization scenarios.

25 For more discussion related to offsets, see Issue Brief #15.

26 National Farmer's Union, Carbon Credit Program, 2007 <http://www.nfu.org/issues/environment/carbon-credits/> (accessed July 12, 2007).

27 The Climate Trust, RGGI Eligible Sector 4: Avoided Methane Emissions from Agricultural Manure Management, 2007, http://climatetrust.org/solicitations_RGGI3.php (accessed July 12, 2007).



carbon storage in agricultural soils.²⁸ However, the amount of offsets permitted in these bills is limited, and no federal legislation has considered credits from agricultural activities that mitigate nitrous oxide or methane emissions.

Biofuels

U.S. production of ethanol has skyrocketed in recent years—approximately quadrupling since 2000/2001 (Figure 4)—and is poised to double again by the year 2008. According to the Renewable Fuels Association, nearly 130 ethanol biorefineries with total annual production capacity of 6.7 billion gallons nationwide were in operation as of late August 2007.²⁹ The nearly 80 additional biorefineries currently under construction are expected to approximately double present ethanol production capacity.³⁰ With the recent expansion of corn-based ethanol production, the United States has become the world's largest producer of ethanol, surpassing Brazil's sugarcane-based ethanol production.³¹

With more than 13 billion gallons of annual production capacity either already in operation or under construction, ethanol consumption in the United States is poised to far exceed the 7.5 billion gallon per year target established by the 2005 Renewable Fuels Standard (which calls for domestic renewable fuels to displace five percent of total U.S. gasoline demand by 2012).

Several factors have contributed to the rapid expansion of ethanol production in the United States. During the last year, relatively high oil prices combined with a 51-cent per gallon tax credit to make ethanol economically attractive; at the same time, demand for ethanol as a substitute for the fuel oxygenate MTBE was growing. More broadly, policymakers view increased use of biofuels as a means of enhancing America's energy security by reducing dependence on fossil fuels. Strongly increased demand for ethanol is almost fully supplied from domestic sources; overseas suppliers are deterred by a 54-cent per gallon tariff on ethanol imports.³²

Corn prices roughly doubled during the last year, yet demand for corn remains strong.³³ U.S. producers have responded

²⁸ Evan Branosky, WRI Policy Note 1, World Resources Institute, 1–6, 2006.

²⁹ <http://www.ethanolrfa.org/industry/locations/>

³⁰ U.S. production of biodiesel—another principal biofuel and a substitute for diesel—is small relative to ethanol. In 2006, about 250 million gallons of biodiesel were produced in the United States.

³¹ In 2006, the United States and Brazil produced more than 70% of world's total ethanol production (13.5 billion gallons). U.S. ethanol is corn based; Brazilian ethanol is derived from sugarcane.

³² However, ethanol imports from designated Central American and Caribbean countries are duty-free for up to 7% of the U.S. ethanol markets.

³³ See, for example, A. Baker, and S. Zahniser, *Ethanol Reshapes the Corn Market*, *Amber Waves*, Vol. 4,

Corn-based ethanol reduces GHG emissions, but not necessarily by much. Researchers recently estimated that corn ethanol, produced using current technology, reduces GHG emissions on average by 19 percent for every gallon of gasoline displaced.

to these new market conditions surprisingly swiftly; the 2007 corn crop is the largest corn crop planted in more than 60 years.³⁴ In acreage planted, the 2007 crop—at 92.9 million acres—exceeds the 2006 crop by 19 percent. The increase in corn acreage has been offset by shifting land out of soybean production; soybean acreage declined 15 percent from 2006 to the 2007 total of 64.1 million acres.³⁵ The recent, dramatic increase in corn acreage has somewhat reduced corn futures prices, though futures prices continue to reflect expectations of strong demand growth going forward. Market adjustments to the rapid expansion of corn-based ethanol production also extend beyond corn itself, trickling through the entire U.S. agricultural and food sectors.

Given current average yields of about 2.8 gallons of ethanol per bushel of corn and 150–160 bushels of corn per acre, every additional billion gallons of ethanol production implies about 2.2–2.4 million acres of additional land devoted to corn. Thus, increasing corn-ethanol production by another 6 billion gallons per year implies an additional land requirement of 13–14 million acres. Farmers' response this year (nearly 15 million

additional acres of corn) seems to roughly uphold the current demand-supply balance. The fact that farmers are planting mostly bioengineered corn (a 12 percent increase from 2006) will also help supply keep pace with demand.

Replacing fossil fuels with corn-based ethanol reduces GHG emissions, but not necessarily by much. After thoroughly examining life-cycle GHG emissions for gasoline and ethanol, researchers at Argonne National Laboratory³⁶ recently estimated that corn ethanol, produced using current technology, reduces GHG emissions on average by 19 percent for every gallon of gasoline displaced.³⁷ The study highlights the importance—from the standpoint of GHG emissions—of the process fuel used in ethanol production. Ethanol produced at plants that are fueled by natural gas can achieve GHG reductions of 28–39 percent compared to gasoline. Switching from natural gas to coal as the process fuel, however, may completely eradicate the GHG reduction benefits of ethanol. Although most current ethanol plants run on natural gas, this finding is important because high natural gas prices are encouraging developers to opt for a coal-fueled ethanol production process at new plants. Other well-known, but perhaps less inclusive assessments have suggested yet lower GHG reductions from corn-based ethanol—around 7–12 percent relative to gasoline.³⁸

Despite their slight differences, the results from available assessments all suggest that increasing corn-based ethanol usage to 12–14 billion gallons annually (enough to displace nearly 10 percent of U.S. gasoline demand) would reduce present GHG emissions only minimally—by merely a fraction of a percent. Until it becomes technologically and economically feasible to produce cellulosic ethanol, which has the potential to cut GHG emissions by 80–90 percent relative to gasoline, the current ethanol boom seems unlikely to provide significant climate benefits.³⁹

Specific provisions in the new U.S. Department of Agriculture (USDA) 2007 Farm Bill proposal would support further expansion of the domestic biofuels industry, including a total of \$1.6 billion directed toward renewable energy and

Issue 2, 2006 (updated May 2007), <http://www.ers.usda.gov/AmberWaves/May07SpecialIssue/Features/Ethanol.htm>.

34 National Agricultural Statistics Service, "U.S. Farmers Plant Largest Corn Crop in 63 Years," News Release, June 29, 2007, Washington, DC: U.S. Department of Agriculture.

35 Soybeans and corn are often planted in rotation. Recent increases in corn acreage often involves farmers shifting from corn-soybean rotation to corn-corn-soybean rotation.

36 M. Wang et al., note 3 above.

37 Cellulosic ethanol would offer more significant GHG emission reductions (up to 80–90 percent, similar to GHG reductions from the sugarcane-based ethanol in Brazil), but cellulosic ethanol production is currently not economically feasible.

38 A. E. Farrell, R. J. Plevin, B. T. Turner, A. D. Jones, M. O'Hare, and D. M. Kammen, "Ethanol Can Contribute to Energy and Environmental Goals," *Science* 311 (27 January 2006): 506–508; and J. Hill, E. Nelson, D. Tilman, S. Polasky, and D. Tiffany, "Environmental, Economic, and Energetic Costs and Benefits of Biodiesel and Ethanol Biofuels," *Proceedings of the National Academy of Sciences* 103, no. 30 (July 25, 2006): 11206–11210.

39 Studies by M. Wang et al. (note 3 above) and Farrell et al. (note 41 above) also address the long-standing dispute about whether the fossil-energy balance of corn ethanol is positive—that is, whether the use of corn ethanol results in a net reduction of fossil-fuel use, taking into account upstream fossil-fuel inputs to grow, harvest, and process corn into ethanol. For example, Wang et al. find that all current and potential future ethanol production processes achieve a positive fossil-energy balance. The energy balance of gasoline, on the other hand, is negative. Farrell et al. reaches similar conclusions.

cellulosic ethanol projects. Other measures in the 2007 Farm Bill proposal include \$500 million for bioenergy and biofuel research, \$500 million to support rural renewable energy systems, and \$210 million to support loan guarantees for cellulosic ethanol projects.

From farmers' perspective, the effects of the ethanol boom are somewhat mixed. Crop producers benefit: high prices and increased demand for corn strengthen other crop prices and agricultural land values. Livestock producers, however, face increased feed prices. Distiller grains, a byproduct of ethanol production, can be used as feed for beef cattle, but poultry and pork production are especially affected by rising corn costs. Nevertheless, USDA expects overall farm incomes to remain strong, in large part due to corn-based ethanol. Higher commodity prices also reduce budget expenses for price-dependent Farm Bill programs and allow agricultural producers to rely on the market for a greater share of their income.

Consumer prices are not expected to be severely affected by the expansion of corn-based ethanol production. Higher feed costs are projected to increase consumer prices for poultry, eggs, and red meats; hence, overall production of these agricultural products may decline slightly. Overall, USDA projects that retail food prices will rise between 2008 and 2010 at a rate moderately faster than the general inflation rate. After these near-term price adjustments, however, consumer food prices are expected to rise more slowly than the general rate of inflation.^{40, 41}

Notwithstanding the current boom, growth in the corn-ethanol industry is expected to slow down and then level off. Though annual ethanol production may soon exceed USDA's 10-year baseline projection of 12 billion gallons, long-term corn-ethanol production is not expected to rise beyond 15–20 billion gallons annually. At that level, land requirements for corn cultivation would approach 100 million acres, of which nearly half would be needed to supply corn for the ethanol industry.⁴²

An important issue is how the ethanol and agricultural commodity markets will respond to production shortfalls due to weather, pests, and other factors. Ethanol production, which is on track to account for more than 30 percent of U.S. corn consumption in the near future, is less responsive

to the price of corn than other major markets (e.g. for feed uses and exports). As a result, overall demand for corn is likely to become less responsive to prices and larger price changes are likely to follow market adjustments in case of production shortfalls. These effects are magnified by a decline in corn stocks, which have diminished due to strong demand and currently provide only a limited buffer for potential supply shocks. Therefore, the agricultural sector is likely to experience higher overall prices and increased market volatility.⁴³

Cellulosic ethanol, though not yet economically competitive, could substantially expand the potential of biofuels. For example, the "billion-ton" study by USDOE and USDA concluded that U.S. agricultural and forestry lands have the resource potential to produce more than one billion tons of biomass per year by the mid-21st century, assuming historically strong productivity improvements continue.⁴⁴ This represents potentially adequate feedstock to support 110 billions of gallons of cellulosic-ethanol production per year. Currently, the technical potential of agricultural biomass is about 194 million dry tons per year (enough to support 15 billion gallons of ethanol output). However, significant technological advances are needed to convert this technical potential to economically attractive production.

Finally, continued expansion of the biofuels industry and strong crop prices are bound to have a range of land-use consequences. For example, strong demand for corn has already raised concerns that environmentally sensitive lands in the Conservation Reserve Program (CRP)⁴⁵ will be returned to crop production. This, in turn, could have potentially adverse implications for soil conservation, carbon sequestration, and other environmental aspects of agriculture. Future expansion of cellulosic ethanol production may generate similar externalities, and may extend to forested areas.⁴⁶ On the other hand, crops such as alfalfa or switch grass, which require less intensive farming practices than corn and other cash crops, may provide feedstock for cellulosic ethanol production while also generating environmental benefits from, for example, reduced soil erosion.

43 Westcott, et al. note 44 above.

44 USDOE and USDA, "Biomass as a Feedstock for Bioenergy and Bioproducts Industry: The Technical Feasibility of a Billion-Ton Supply," U.S. Department of Energy and U.S. Department of Agriculture. Washington DC, April 2005.

45 The Conservation Reserve Program financially encourages farmers to convert highly erodible cropland or other environmentally sensitive land to vegetative cover, such as native grasses, trees, filterstrips, or riparian buffers. Farmers receive an annual rental payment for the term of the multi-year contract. CRP goals include reducing soil erosion, improving water quality, establishing wildlife habitat, and enhancing forest and wetland resources.

46 Sugar-based ethanol production in Brazil already has triggered concerns about increased deforestation. However, the productivity (gallons per acre) of Brazilian sugar-based ethanol production is high, and the acreage required for ethanol is lower than in the United States. Also, Amazonian rainforests, where deforestation is a major concern, are not fit for growing sugarcane. Therefore, ethanol-based deforestation, if any, would primarily be due to secondary effects such as overall increases in crop, feed, and land prices.

40 USDA Economic Research Service, *Agricultural Baseline Projections: U.S. Crops, 2007–2016*, Washington, DC: USDA, 2007.

41 Westcott, P. R. *Ethanol Expansion in the United States: How Will the Agricultural Sector Adjust?* USDA Economic Research Service, Washington, DC: USDA, 2007.

42 USDA Economic Research Service and The Office of Chief Economist, *An Analysis of the Effects of an Expansion in Biofuel Demand on U.S. Agriculture*. Washington DC: USDA May 2007.