BIOMASS RESEARCH & DEVELOPMENT INITIATIVE

Increasing Feedstock Production for Biofuels

Economic Drivers, Environmental Implications, and the Role of Research

National Agricultural Library Cataloging Record:

Increasing feedstock production for biofuels: economic drivers, environmental implications, and the role of research.

1. Biomass energy—Economic aspects—United States.
2. Biomass energy—Research—United States.
3. Feedstock—United States—Costs.
4. Corn—Yields—United States.
5. Forest biomass—United States.
6. Alcohol as fuel.
7. Biodiesel fuels—United States.

I. Biomass Research and Development Board (U.S.).

HD9502.5.B543

Photos credits for front cover:

Top photos ©Comstock and Agricultural Research Service, U.S. Department of Agriculture (USDA).

Bottom photos ©JupiterImages and Natural Resources Conservation Service, USDA.

About the Biomass Research and Development Board

The Biomass Research and Development Board (Board) was created by the Biomass Research and Development Act of 2000, as amended. The Board's mission is to coordinate Federal research and development activities relating to biobased fuels, power, and products. The Board is currently focused on addressing challenges and offering solutions to the President's 20-in-10 plan and the biofuels aspects of the Energy Independence and Security Act (EISA), specifically Section 202. Additional information about the Board and the Biomass Research and Development Initiative is available on the website (www.brdisolutions.com).

Membership

- Department of Agriculture (USDA)
- Department of Energy (DOE)
- National Science Foundation (NSF)
- Environmental Protection Agency (EPA)
- Department of the Interior (DOI)
- Office of Science and Technology Policy (OSTP)
- Office of the Federal Environmental Executive
- Department of Transportation (DOT)
- Department of Commerce
- Department of the Treasury (Treasury)
- Department of Defense (DOD)

Agency representatives to the Biomass Research and Development Board

Co-Chairs

Dr. Gale Buchanan, Under Secretary for Research, Education and Economics, USDA

John Mizroch, Acting Assistant Secretary, Energy Efficiency and Renewable Energy, DOE

Thomas C. Dorr (former co-chair), Under Secretary for Rural Development, USDA

Andrew Karsner (former co-chair), Assistant Secretary, Energy Efficiency and Renewable Energy, DOE

Members

C. Stephen Allred, Assistant Secretary, Land and Minerals Management, DOI

Vice Admiral Thomas J. Barrett, Deputy Secretary, DOT

Alex Beehler, Assistant Deputy Under Secretary for Environment, Safety & Occupational Health, DOD

Dr. Arden Bement, Director, NSF

Joseph Cascio, Federal Environmental Executive, Office of the Federal Environmental Executive

Dr. George Gray, Assistant Administrator for Research and Development, Science Advisor, EPA

Dr. Sharon Hays, Associate Director and Deputy Director for Science, OSTP

Dr. Raymond Orbach, Under Secretary for Science, DOE

Phillip Swagel, Assistant Secretary for Economic Policy, Treasury

James Turner, Deputy Director, National Institute of Standards and Technology

About This Document

The Biomass Research and Development Board (Board) commissioned an economic analysis of feedstocks to produce biofuels. The Board seeks to inform investments in research and development needed to expand biofuel production. This analysis focuses on feedstocks; other interagency teams have projects underway for other parts of the biofuel sector (e.g., logistics). The analysis encompasses feedstocks for both conventional and advanced biofuels from agriculture and forestry sources.

This analysis of greater use of biofuel feedstocks should not be construed in any way as an analysis of the Renewable Fuels Standard required by EISA 2007 or its impacts, nor used to pre-judge the outcome of the regulatory process. EPA is responsible for implementing this program and is currently developing a rulemaking document that will include an analysis of the environmental impacts, including on air and water quality, of the new renewable fuel standard. EPA's analytical efforts are being conducted in conjunction with the USDA and DOE. The scope of this report, key assumptions, and constraints may lead to different results than those reported in EPA's rulemaking.

Acknowledgments

The Board members thank the Interagency Feedstocks Team for preparing this report. Three committees comprise the Feedstocks Team: Economics, Sustainability, and Greenhouse Gas. The committees worked closely together, and the Board as well as the team members believe that building relationships across departments and agencies has been a major benefit of the research that produced this report.

The Co-Chairs thank the entire Board for their input into the design of the study and for support throughout its development. Dr. Gale Buchanan, Under Secretary for Research, Education, and Economics at USDA, provided invaluable advice and moral support to the Feedstocks Team. Critical to the completion of the report was a group—Robert Perlack, Scott Malcolm, Bryce Stokes, Jan Lewandrowski, and Zia Haq—that cut across all three committees and oversaw the modeling that underpins this report. The authors of the cellulosic section want to acknowledge those who supported the forestry analysis: Robert Hugget, Kevin McCullough, Jamie Barbour, Jim Perdue, Don Riemenschneider, Ed Gee, and Robert Rummer of the Forest Service; Daniel Cassidy of CSREES; Tim Volk of SUNY-ESF, and; Tim Rials of University of Tennessee. The Co-Chairs would also like to thank David O'Toole and Chad Haynes from Booz Allen Hamilton for their contributions.

The report's development, writing, and review process reflects the input of the members of all three committees. A few individuals took the lead in writing different parts of the report. The major contributing authors are Joseph Cooper (Chapters 2 and 9), Erik Dohlman (Chapter 3), Alison Goss Eng (Chapter 8), Paul Heisey (Chapter 4), Jan Lewandrowski (Chapter 7), Scott Malcolm (Chapters 4 and 5), Steve Ogle (Chapter 7), Bob Perlack (Chapter 6), Kathryn Quanbeck (Chapter 2), Bryce Stokes (Chapters 6 and 8), Marca Weinberg (Chapters 1-3), and David Widawsky (Chapter 8).

Dale Simms and Tom McDonald of the Economic Research Service (USDA) greatly improved the report through their editing. The authors are especially grateful to Wynnice Pointer-Napper, ERS, for patiently, diligently, and quickly designing the charts and formatting and laying out the report. Thanks also to Cynthia A. Ray (ERS) for cover design.

Economics

Co-Chairs: John Ferrell (DOE) and Mary Bohman (Economic Research Service, USDA, Chair of Feedstocks Team)

Joseph Cooper, Erik Dohlman, Paul Heisey, Scott Malcolm, Greg Pompelli, Kathryn Quanbeck, Marca Weinberg (Economic Research Service, USDA)

Chuck Zelek (Natural Resources Conservation Service, USDA)

Zia Haq, Alison Goss Eng (Energy Efficiency and Renewable Energy, Department of Energy)

Bob Perlack, Anthony Turhollow, Anna Shamey (ORNL)

Chad Hellwinckel and Daniel De La Torre Ugarte (Agricultural Policy Analysis Center, University of Tennessee at Knoxville)

Bryce Stokes, Marilyn Buford, Kenneth Skog, Dennis Dykstra, Patricia Lebow, and Patrick Miles (Forest Service, USDA)

Simon Mui, Sharyn Lie (EPA)

Robert Fireovid, Jeffrey Steiner (Agricultural Research Service, USDA)

Harry Baumes, Hosein Shapouri (Office of Energy Policy and New Uses, USDA)

Greenhouse Gas (GHG)

Co-Chairs: William Hohenstein (Global Change Program, USDA) and Dina Kruger (EPA)

Jan Lewandrowski (Global Change Program, USDA)

Steve Ogle (National Resources Ecology Laboratory, Colorado State University)

Sustainability

Co-Chairs: John Houghton (Office of Research, DOE), Donna Perla (EPA), and Bryce Stokes (Forest Service)

Alison Goss Eng (DOE)

Bob Perlack (ORNL)

Tim Johnson, Rebecca Dodder, Herbert Fredrickson, David Solan, Rebecca White, David Widawsky (EPA)

Marilyn Buford (Forest Service)

Jeffrey Steiner (Agricultural Research Service, USDA)

Robbin Shoemaker, Scott Malcolm (Economic Research Service, USDA)

Jill Auburn, William Goldner (CSREES, USDA)

Jan Lewandrowski (Global Change Program, USDA)

Paul Zebe (Department of Transportation)

Bobbie Lippiatt (NIST)

John Stewart (Department of Interior)

Bruce Rodan (OSTP)

Karen Laughlin (Foreign Agricultural Service, USDA)

Judy Raper (NSF)

Peer Review

The report was reviewed by the entire feedstock team as well as the external reviewers listed below. In addition, the report was significantly improved by comments provided during the Office of Management and Budget (OMB) review process and we would like to thank Kristi Kubista-Hovis, who coordinated the review. We thank all reviewers for their invaluable comments, and responsibility for any remaining errors rests with the feedstock team.

Alex Barbarika and Richard Iovanna, Farm Service Agency, USDA.

Randall J.F. Bruins, Senior Environmental Scientist, Ecological Exposure Research Division, National Exposure Research Laboratory, Office of Research and Development, EPA

Bruce Dale, Professor of Chemical Engineering and Materials Science, Michigan State University

Fred Deneke, National Forestry Programs Coordinator, National Association of Conservation Districts, USDA Forest Service (retired)

Brenda Groskinsky, Science Policy Advisor & Office of Research and Development Science Liaison for Region 7, U.S. EPA

William F. Hagy, III, Deputy Administrator, Rural Development, USDA

Bruce Hamilton, Program Director, Division of Chemical, Bioengineering, Environmental and Transport Systems and Office of Emerging Frontiers in Research and Innovation, NSF

Robert Larson, Deputy Division Director of the Transportation and Climate Division, Office of Transportation and Air Quality, Office of Air and Radiation, U.S. EPA.

Doug Lawrence, Director of the Resource Economics and Social Sciences Division, Natural Resource Conservation Service, USDA

Alan Lucier, Senior Vice President, National Council on Air and Stream Improvement

Bruce McCarl, Professor of Agricultural Economics, Texas A&M University

Peter Nagelhout, Economist, Office of Policy, Economics, and Innovation National Center for Environment Economics, U.S. EPA

Diane Okamuro, Program Director, Plant Genome Research Program, Division of Biological Infrastructure, NSF

Roberta Parry, Senior Agricultural Advisor, Office of Water, U.S. EPA

Phil Robertson, Professor of Ecosystem Science, Michigan State University

Chris Soares, Office of Economic Policy, Department of the Treasury

Wallace Tyner, Professor of Agricultural Economics, Purdue University

Michael Wang, Section Manager, Center for Transportation Research, Argonne National Laboratory

Paul Westcott, Senior Economist, Economic Research Service, USDA

Contents

Increasing Feedstock Production for Biofuels

Economic Drivers, Environmental Implications, and the Role of Research

Executive Summary

A large expansion in ethanol production, along with research and innovation to develop second-generation biofuels, is underway in the United States, spurred by volatile oil prices and energy policies. This increased focus on ethanol and other biofuels is an important element of U.S. economic, energy, environmental, and national security policies. A series of policies have supported development of biofuels, including the Biomass Research and Development Act of 2000, the Energy Policy Act of 2005 (which mandated increasing domestic use of renewable fuels to 7.5 billion gallons in 2012), the Energy Independence and Security Act (EISA) of 2007 (which established a 36-billion-gallon mandate for biofuels by 2022), and the 2002 and 2008 Farm Bills. Meeting these goals will require that technical, economic, and research challenges are met. The availability of biomass feedstocks is a critical part of the challenge. The National Biofuels Action Plan identified two general barriers to providing sustainable quantities of feedstocks: a lack of biomass production capacity and the high relative costs of production, recovery, and transportation for feedstocks.

The goal of this report is to inform research recommendations to address the constraints surrounding availability of biomass feedstocks. To meet this goal, an economic assessment, which links to an analysis of the consequences for greenhouse gas emissions and sustainability, has been developed that encompasses feedstock production from agriculture and forestry sources. The boundaries of the analysis—a domestic focus on feedstocks and up to the farmgate or forest roadside—circumscribe the findings. Uncertainty about the conversion of feedstocks to biofuels, transportation of both, international effects, and consideration of displaced petroleum fuels are beyond the scope of this study. Four questions guide the analysis:

- What feedstocks and at what price?
- What is the regional distribution of feedstock production?
- What are the effects of alternative investments in research on feedstocks?
- What are the consequences for sustainability and greenhouse gases related to feedstock production?

This report uses the renewable fuel volumes contained in EISA as the basis for modeling scenarios. These scenarios are not predictions of what will occur under EISA, but a starting point for assessing potential impacts on domestic feedstock production. However, this analysis of greater use of biofuel feedstocks should not to be construed in any way as an analysis of the Renewable Fuels Standard required by EISA 2007 or its impacts, nor used to pre-judge the outcome of the regulatory process. EPA is responsible for developing and implementing the RFS program as required by EISA and is currently developing a rulemaking that will include a more comprehensive analysis of the new renewable fuel standard. EPA's analysis will include a comprehensive assessment of the economic and environmental impacts of the RFS program, including a cost and benefit analysis and the development and application of the lifecycle greenhouse gas (GHG) emission estimates for each fuel type as mandated by the Act. These lifecycle GHG emission estimates will be used to determine compliance with the program standards.

Our analysis draws on a coordinated modeling approach. A conceptual framework describes the relationship between feedstocks for biofuels and the overall market for each feedstock, including how higher yields for specific feedstocks (e.g., resulting from investments in research) affect feedstock and biofuel markets. First-generation feedstocks are those currently being used to produce biofuels for commercial sale. Second-generation feedstocks are those with the potential to produce biofuels, including cellulosic biofuels, for commercial sale. Two comprehensive models of U.S. agriculture that provide information by U.S. region are used in tandem. The Regional Environment and Agriculture Programming (REAP) model analyzes the feedstocks associated with producing first-generation biofuels. The Policy Analysis System (POLYSYS) model solves for the optimal production of feedstocks for second-generation biofuels. A forest sector model derives the supply of multiple sources of wood products for cellulosic biofuels and is linked to the POLYSYS model results through prices for feedstocks. Urban wood waste sources of feedstocks are exogenous in the analysis.

The scenario analysis uses as a point of departure the U.S. Department of Agriculture (USDA) baseline for 2007, which provides projections to 2016. The 2007 baseline was the latest available when the report's modeling was completed and has the advantage of representing policies and markets before new mandates were established. Current market prices are volatile and have risen beyond levels used in the baseline. However, the analysis in this report should not be affected by those short-term fluctuations as it starts with a longer-term projection of prices and production levels and then focuses on the changes in indicators and the pattern of changes (versus precise values).

Results are reported as changes from the baseline for the final year of the scenarios. The scenarios analyzed include changes in productivity, input costs, carbon prices, and biofuel imports.

- The **2007 baseline in 2016** assumes 12 billion gallons of corn-based ethanol and 700 million gallons of biodiesel.
- The **reference case for 2016** represents a total biofuel target of 16 billion gallons, with 15 billion gallons of corn-based ethanol and 1 billion gallons of biodiesel.
- The **increased corn productivity scenario for 2016** increases the rate of growth in corn yield by 50 percent using the same inputs.
- The **high input cost scenario for 2016** increases energy-dependent input costs by 50 percent.

- The **positive carbon price scenario for 2016** builds in a value for sequestering carbon and a cost for producing carbon equal to $25 per ton of carbon dioxide.
- A **combination scenario for 2016** combines the increased corn productivity, high input cost, and positive carbon price scenarios for 2016.
- The **cellulosic reference scenarios for 2022** include the same first-generation targets as for 2016 plus 20 billion gallons of second-generation biofuels, with 3 cases that vary by the allocation of second-generation biofuel sources.
- The **increased productivity cellulosic scenarios for 2022** double the growth rate of corn productivity and increase energy crop productivity by 1.5 percent annually starting in 2012.

Economics of Feedstocks

Ethanol is a standardized commodity and producers must compete based on price and seek the lowest cost combination of feedstocks, logistics, and conversion technology. Differences in ethanol production costs across feedstocks will determine the amount of each feedstock devoted to ethanol production or other biofuels. There may be some quality differences among biodiesel fuels that could be reflected in minor market price differences. Similarly, differences in production costs will largely determine the amount of each feedstock devoted to biodiesel production.

Feedstocks must meet two profitability tests for use in biofuel production: first, profitability for the grower and second, profitability for biofuel producers.

First-Generation Feedstocks

Satisfying a 3-billion-gallon increase in biofuels from baseline to reference (2016) requires a 3.6-percent increase in corn production over the baseline, with a 4.6-percent increase in corn prices. Prices for other crops—especially soybeans, which compete directly with corn for land—increase. Comparing the reference case to the baseline in 2016, the price of soybeans is 3.2 percent higher while the prices of other major crops increase by less than 1 percent.

The additional corn for ethanol in the reference case for 2016 (over the baseline) comes from a combination of additional acreage and reduced non-ethanol corn use in response to higher prices. Corn acreage increases by 3.7 million acres (a 4.1-percent increase). Total crop acreage increases 4.4 million acres (a 1-percent increase). The price increase for corn leads to reduced use in other markets, with non-ethanol use declining by 5.2 percent and exports falling by 7.7 percent.

Corn acreage to produce an additional 3 billion gallons of ethanol is found in the regions that already produce corn: the Corn Belt, Northern Plains, and Lake States. Eighty percent of the 4.1-percent increase in national corn acreage (when comparing the baseline to the reference case for 2016) comes from these three regions. The most efficient outcome occurs when crops are located where they are best suited to the local resource conditions.

Higher yielding corn (e.g., from additional investment in research and development) reduces the pressures on the agricultural sector associated with producing 15 billion gallons of ethanol. A 50-percent increase in the rate of corn productivity growth increases total production by 2.6 percent and reduces prices by 6.3 percent compared to the reference case for the identical quantity of 15 billion gallons of ethanol. Each additional 5 bushels per acre increases production by 1.3 percent and lowers corn prices by $0.11 per bushel.

Research to enhance productivity provides multiple benefits for markets, sustainability, and carbon reduction. Higher productivity not only reduces the price of feedstocks, but also reduces their footprint on the land. The reductions in land use improve soil and water quality and lower carbon emissions. One caveat is that biofuel demand is assumed to be fixed and not linked to corn prices. Further research is needed to analyze the degree to which lower corn prices would increase demand for biofuels, and thus for feedstocks, which could lead to greater overall land use.

Changes in input market conditions and other policies, such as a carbon tax, could offset land pressures associated with increases in biofuel production. Total crop acres equal 317 million acres in the baseline and increase to 321 million acres in the reference scenario. Total acres fall below the baseline level in the high input cost, positive carbon price, and combination scenarios. Total acres in the high corn productivity scenario fall from the reference case, but not below total acres in the baseline.

Second-Generation Feedstocks

If feedstocks from cropland only—agricultural residues and energy crops—are used to produce cellulosic ethanol, then prices reach over $60/dry ton to produce 20 billion gallons of ethanol in the cellulosic reference scenario for 2022. Estimated farmgate prices needed to secure sufficient feedstocks are about $45/dry ton under a cropland production scenario of 16 billion gallons, which assumes that biomass from forest sources contributes 4 billion gallons. Estimated farmgate prices are about $40/dry ton under a scenario requiring only 12 billion gallons of advanced fuels produced from cropland, with 4 billion gallons from forest sources and 4 billion gallons from imports.

The share of energy crops relative to crop residues increases as the total volume of biofuels from cropland falls. To produce 20 billion gallons from cropland, only 36 percent of the required feedstock would come from some combination of energy crops, such as switchgrass and poplar. The remainder comes from crop residues, with corn stover accounting for about 70 percent of the total residue. Under the 16-billion-gallon scenario, energy crops account for about 40 percent of the total, and their share is over half when cropland feedstock requirements are reduced to 12 billion gallons. This trend toward an increasing share of energy crops is due primarily to the imposed constraint that limits the amount of residue that can be removed to sustain soil productivity, making recovery of small per-acre quantities expensive relative to the production of dedicated energy crops.

The amount of land planted to energy crops varies between 16 and 19 million acres for cellulosic scenarios requiring feedstocks to produce 12 to 20 billion gallons of biofuels. Most of the change in acres involves shifting of cropland in pasture to energy crops and hay to make up for the lost forage, as well as the conversion of some marginal cropland to energy crops.

The regional distribution of feedstocks to produce 20 billion gallons of biofuels from cropland shows that the Corn Belt and Lake States dominate production of corn stover; the Northern Plains, Mountain States, and Pacific region lead in the production of straw; and the Delta, Appalachian, Corn Belt, and Southeast regions lead in the production of energy crops. This regional distribution does change as the amount of feedstock required from cropland is lowered. Particularly evident is the disappearance of crop residue from the Northern Plains, Mountain States, and Southern Plains. Again, the key factor in this trend is the imposed constraint on residue removal, which makes recovery of small per-acre quantities expensive relative to the production of dedicated energy crops.

The increased productivity cellulosic scenarios for 2022 result in lower farmgate prices with a narrower range: $43, $42, and $40/dry ton for the 20-, 16-, and 12-billion gallon scenarios, respectively. The proportion of energy crops is higher across all three scenarios in year 2022. For any given scenario, the high-yield case shows a much higher percentage shift of cropland (used to grow crops) to energy crops. This result follows from the imposed model constraints that restrict the amount of residue removed to no more than 34 percent of available corn stover and 50 percent of wheat straw. Allowing for more residue removal would lower collection costs and improve the profitability of residue collection relative to the production of energy crops.

Contributions from forestland are assumed to provide sufficient feedstock to produce 4 billion gallons of second-generation and other renewable fuels. This biomass feedstock contribution is based on an examination of aggregated supply curves for forest residues and what could be available at forest roadside prices ranging from roughly $40 to $46 per dry ton. The price is derived from the POLYSYS model results for scenarios requiring cropland feedstock sufficient to produce 12 to 16 billion gallons of ethanol. Available forestland resources include logging residues, other removal residues, thinnings from timberland and other forestland, primary mill residues, urban wood waste, and conventionally sourced wood. The amounts of forestland biomass needed from each of these resources were exogenously determined. Wood grown under short rotations on cropland dedicated to biofuels production is excluded as these woody crops are an integral part of the energy crop mix, which is estimated in POLYSYS.

What Consequences for Greenhouse Gas Emissions?

Much of the current interest in expanding U.S. production and use of biofuels stems from the view that biofuels offer significant opportunities to enhance energy security and independence while reducing greenhouse gas (GHG) emissions. Conceptually, increasing the use of biofuels replaces fossil fuels that continuously add carbon dioxide (CO_2) to the atmosphere with fuels that recycle CO_2 between the atmosphere and terrestrial systems. In reality, the GHG footprint of biofuels is more complex. For example, the processes of producing ethanol and biodiesel involve a number of steps—including the production of feedstocks—that produce GHG emissions. Moreover, there are many places in these processes—including those that take place on the farm—where the GHG footprint of the final fuel products can be affected by management decisions. And if increased demand for feedstock crops results in new lands being brought into production, there will be additional emissions associated with land-use changes. This analysis includes the U.S. agricultural sector (not international land use) up to the farmgate (not transportation or conversion of feedstocks, or use of biofuels).

When assessing only the impact of increased domestic crop production, increasing corn ethanol production from 12 to 15 billion gallons per year results in an increase of less than 10 million metric tons of CO_2 equivalent GHG emissions. In the REAP analysis, moving from the USDA baseline scenario to the reference scenario, total GHG emissions from domestic crop production activities increase 7.95 million metric tons CO_2 equivalent. Compared to current agricultural emissions, this would be an increase of about 1.8 percent. This GHG assessment considers the emissions impact within the United States only and does not include changes in agricultural production in other countries, nor does it include the secondary agricultural impacts on the livestock sector, substitution in the feed market, or impacts of petroleum fuel replacement. Therefore, this estimate of GHG emissions does not capture the full lifecycle impacts of increased biofuel production.

Carbon markets could be an effective approach to simultaneously increasing biofuels production and improving the GHG footprint of these fuels. Among the alternative scenarios analyzed, the introduction of a carbon price of $25 per mt CO_2 equivalent resulted in the largest decrease in GHG emissions relative to the reference case.

A comprehensive approach to reducing the farm-sector share of GHG emissions related to biofuel production could include a broad set of incentives targeting a variety of farm sector activities and management decisions. The changes in farm sector activities that result in the largest reductions in GHG emissions differ across the alternative scenarios. In the high corn productivity scenario, changes in farm inputs account for over 75 percent of total reduction in GHG emissions (relative to the reference case). In the high input cost and the positive carbon price scenarios, the main sources of emission reductions are, respectively, land-use change (96 percent) and changes in tillage (87 percent).

With respect to increasing our understanding of the GHG implications of biofuels, three potentially fruitful research areas are raising crop productivity without additional use of fossil fuel inputs, reducing uncertainties in N_2O emissions associated with nitrogen fertilizer use, and upgrading the capabilities of USDA's in-house economic models to analyze the GHG implications of changes in various programs, policies, and market conditions.

What Consequences for Sustainability?

For bioenergy to become fully integrated into the U.S. economy, it must be economically, environmentally, and socially sustainable. Sustainability depends on ensuring the long-term provision of an adequate food, feed, and fiber supply; water yield and quality; abundance and diversity of flora and fauna; energy; and other resources. And it recognizes the value and validity of human actions and inputs. Information about the sustainability of much higher domestic production of biofuels can help guide Federal and local policies concerning energy, the environment, and agriculture. It can also help set priorities for research programs and improve the operation of the biofuel energy sector. The potential consequences of biofuel production are far ranging in size because the technologies are changing rapidly and impacts are likely to grow as the scale of the industry increases.

Implications for sustainability that can be drawn from the REAP and POLYSYS modeling activities were limited as these two models are not designed to provide information on variables that measure sustainability directly. Nonetheless, the models show that environmental and other impacts of the patterns of ethanol production are generally more favorable for the high corn productivity and high input cost scenarios than for the reference case.

Combinations of different perennial crops (e.g., grasses and woody crops) can provide more diversity for species and habitat than do monocultures. If nitrogen and pesticide movement are managed efficiently, these crops can provide shelterbelts, riparian strips, and windbreaks. Having continuous cover with grasses and almost continuous cover with trees provides protection and diversity. To meet the feedstock needs designated by the 2022 goals, 16-19 million acres of perennial crops are needed, resulting in total land-use changes of about 20-23 million acres as other land transitions to forage and hay.

The amount of sustainably harvestable crop residues for a specific location varies, depending on factors like climate, soil texture, and production practices used. The amount of residue needed to maintain soil organic carbon to avoid decreased crop productivity is generally greater than the residue requirements to avoid soil erosion. Crop residue above the amount needed to address these services could be removed for feedstock use.

Implications for Research

This report addresses the uncertainty surrounding the use of additional feedstocks to meet the Nation's biofuels goals—namely, what types of feedstocks and at what prices, grown where, and with what implications for greenhouse gases and sustainability. The investigation is conducted through an analysis of scenarios for specific biofuel targets, and with alternative assumptions about key variables like crop productivity and input prices.

Each section of the report draws on the analysis to identify implications and priorities for further research. The most obvious finding is that new technologies resulting from research and development are the linchpin to developing a sustainable biofuel industry that meets national targets. These technologies include enhanced production systems; sustainable management tools; better data, models, and decision tools; and the integration of feedstock production with conversion and use.

The report's analysis supports recommendations about research investments, conditional on the scope of the research and specific assumptions. Given available models and data, the analysis uses quantitative targets for biofuel production and is not able to estimate a fully functioning set of markets and policies for both feedstocks and biofuels. Nevertheless, the following areas emerge as priorities for future research efforts:

Research on feedstocks that reduces pressure on cropland. Research options consistent with the analysis include increasing yields for existing feedstocks, developing new feedstocks that can be sustainably produced outside of cropland, and enhancing the sustainable use of byproducts.

Research on a broad portfolio of feedstocks. No single agricultural commodity, byproduct, or forest product can supply sufficient feedstocks to meet national biofuel targets. Constraints on land suitable for any single feedstock and competing demands from other markets (e.g., food, feed, wood products) preclude such a research or production focus. A wide array of feedstocks will lead to more geographic diversity, less resource pressure on any one location, and greater resilience to drought, pests, and other production shocks.

Research that targets sustainability and GHG emission reductions. Increasing production of existing crops has negative consequences for the environment, which can be offset by research that increases yields, develops sustainable alternative feedstocks, or devises more sustainable production practices and systems.

Research that leads to feedstocks that are profitable for farmers and forest managers to produce. The cellulosic scenarios indicate that the share of energy crops in total feedstocks depends on their productivity and profitability. Research to raise the value of byproducts also increases profitability as the refiner can pay more for feedstocks and the farmer has an additional revenue stream.

The Federal Government, universities and the private sector have alread invested billions of dollars in research to improve feedstock productivity andimprove the conversion of feedstocks. Reflecting the diverse geography of potential feedstocks, research projects span the United States and encompass a large variety of feedstock sources. The Department of Energy supports multiple projects to investigate alternative conversion technologies with a wide variety of feedstocks, at various scales to spur fi nancial interest. The Department of Agriculture supports an array of activities related to biofuel feedstocks including the development of new bioenergy crop varieties and hybrids in conjunction with systems to increase energy yields per acre, maximize net energy effi ciency, and minimize greenhouse gas emissions. The National Science Foundation has an extensive plant genomics program, with implications for feedstock improvement.

Other recommendations based on the analysis relate to investments in data and modeling. The recommendations focus on the models available within the Federal Government, but also reflect more general needs. Priorities include:

Integrated models across agricultural, forestry, and energy markets. Separate models were used to analyze agricultural feedstocks for first-generation biofuels, agricultural feedstocks for second-generation biofuels, and feedstocks from forest products. The models also do not include energy markets and government policies that support biofuel markets directly (e.g., blenders' tax credits). Also, the models used hold constant the quantity of biofuels and do not allow for interactions between feedstock and biofuel markets.

Data for second-generation feedstocks. Second-generation biofuels remain a nascent industry, with data and information available mainly from experimental research and expert judgment. Investments are also needed in data and models to assess sustainability and GHG emissions.

Research and models to analyze global land-use changes. This report uses regional models to provide a sharp U.S. focus, with environmental indicators. This should inform investments in domestic research, but does not include environmental effects for production decisions and land-use changes in other countries.

Research and models to analyze the effect of variability over time in weather and other exogenous variables. The current analysis compares scenarios at fixed points in time and under baseline assumptions about weather, income, demographics, and other variables.

The research implications address only the needs identified through the report's economic analysis and do not account for the scientific uncertainties or costs of the research. This report is intended to help the Federal Government prioritize research setting in conjunction with scientific experts. Finally, decisions about research funding are occurring in an era of scarce resources and potential policy tradeoffs. For example, expanding research on corn yields could limit research to develop feedstocks for second-generation biofuels.

Key Modeling Assumptions

The quantitative analysis of the effects of biofuel feedstocks on agricultural and forestry markets, as well as greenhouse gas (GHG) emissions and sustainability indicators, requires assumptions about the scope of markets analyzed and the timeframe of comparisons. The choices made reflect the objectives: analyzing constraints and associated research priorities for U.S. feedstock production by region. Tight deadlines necessitated the use of models and data available at the beginning of 2008.

This report uses the renewable fuel volumes contained in EISA as the basis for modeling scenarios. These scenarios are not predictions of what will occur under EISA, but a starting point for assessing potential impacts on domestic feedstock production. This analysis should not to be construed in any way as an analysis of the Renewable Fuels Standard required by EISA 2007 or its impacts, nor used to pre-judge the outcome of the regulatory process. EPA is responsible for developing and implementing the RFS program as required by EISA and is currently developing a rulemaking that will include a more comprehensive analysis of the new renewable fuel standard. This work will include a comprehensive assessment of the economic and environmental impacts of the RFS program, including a cost and benefit analysis and the development and application of the lifecycle GHG emission estimates for each fuel type as mandated by the Act. These lifecycle GHG emission estimates will be used to determine compliance with the program standards.

The scenario analysis uses as a point of departure USDA's baseline for 2007, which provides projections to 2016. The USDA baseline for 2007 was the latest available when the report's modeling was completed and has the advantage of representing policies and markets before new mandates were established. Current market prices are volatile and have risen beyond levels used in the baseline. However, the analysis in this report should not be affected by those short-term fluctuations as it starts with a longer-term projection of prices and production levels and then focuses on the changes in indicators and the pattern of changes (versus precise values).

The amount of ethanol produced from corn in 2016 is set at 15 billion gallons. Ideally, the quantity of corn-based ethanol produced and its price would be determined by the supply and demand that clears the market, with due consideration of producer and consumer incentives, such as subsidies and tax credits. However, we have no ability to explicitly model changes in ethanol demand, nor basis upon which to select another level. And evidence suggests that the 15-billion-gallon standard is likely to be binding in 2016.

Quantitative modeling for sustainability and GHG emission changes are conducted only for first-generation biofuels in 2016. The REAP model permits detailed environmental analysis, but does not include second-generation feedstocks. The POLYSYS model includes second-generation feedstocks but is not capable of detailed environmental assessments.

The GHG assessment considers the emissions impact within the United States only and does not include changes in agricultural production in other countries, nor does it include the secondary agricultural impacts on the livestock sector, substitution in the feed market, or impacts of petroleum fuel replacement. Therefore, this estimate of GHG emissions does not capture the full lifecycle impacts of increased biofuel production.

International markets are considered only through total exports and imports resulting from changes in market conditions. The analysis does not consider land-use changes outside the United States resulting from biofuel policy-induced changes in prices.

The analysis compares results of scenarios at the same point in time (a comparative static analysis). It does not assess the economic viability of biofuels or the costs and benefits of biofuels to consumers. A series of scenarios departing from the baseline form the core of the quantitative assessment.

- The high productivity scenario represents an increase over baseline productivity levels—which assume yield growth based on recent and long-term trends—of 50 percent, achieved without additional input use. This scenario results in a yield of about 180 bushels of corn per harvested acre in 2016, and is similar to an "increased yield" scenario presented by the National Corn Growers Association (2006). This would reflect a 55-percent acceleration in trend yield growth if the base is 2.0 bushels per year (the assumption of the baseline model). Such an acceleration could be explained as the application of currently available biotechnology, such as stacked traits, or other technologies in the pipeline.
- The high input cost scenario represents an increase in the cost of energy-intensive inputs of 50 percent from baseline assumptions to investigate the implications of higher production costs.
- A price of $25 is assumed for the positive carbon price scenario. Regulated carbon markets that include agriculture as a source of offsets do not exist in the United States. However, the value of $25 is a reasonable assumption based on existing carbon markets in other countries and potential costs of producing agriculture-based offsets.

The research implications address only the options identified through the report's economic analysis and do not account for scientific uncertainties or costs of the research. This report is intended to help the Federal Government prioritize research setting in conjunction with scientific experts.

Chapter 1

Introduction

A large expansion in ethanol production, along with research and innovation to develop second-generation biofuels, is underway in the United States, spurred by high oil prices and energy policies. This increased focus on ethanol and other biofuels is an important element of U.S. economic, energy, environmental, and national security policies. A series of policies have supported development of biofuels, including the Biomass Research and Development Act of 2000, the Energy Policy Act of 2005 (which mandated increasing domestic use of renewable fuels to 7.5 billion gallons in 2012), the Energy Independence and Security Act (EISA) of 2007 (which established a 36-billion-gallon mandate for biofuels by 2022), and the 2002 and 2008 Farm Bills. Meeting these goals will require that technical, economic, and research challenges are met. The availability of biomass feedstocks is a critical part of the challenge. The National Biofuels Action Plan identified two general barriers to providing sustainable quantities of feedstocks: a lack of biomass production capacity and the high relative costs of production, recovery, and transportation for feedstocks.

This report provides a comprehensive assessment of feedstock production options. Four questions guide the analysis:

- What feedstocks will be produced and at what price?
- What is the regional distribution of feedstock production?
- What are the benefits of investments in research on feedstocks?
- What are the consequences for sustainability and greenhouse gas emissions related to feedstock production?

The growth of biofuels is likely to be constrained by competition for limited land resources, so technology will be critical in widening the role of biofuels. If the energy from abundant cellulosic materials could be economically harnessed and ethanol per acre of feedstock increased, land requirements would be significantly reduced. But this will require innovation and diffusion of new conversion technologies and genetic advances.

A Portfolio of Feedstocks… and Complex Interactions

Understanding the barriers to acquiring an adequate supply of multiple feedstocks is a challenge because of the simultaneous and ongoing interactions between energy markets and feedstock production on the one hand and feedstock, food/fiber, and wood product sectors on the other.

Corn is the primary feedstock used to produce ethanol in the United States today, but market adjustments from ethanol expansion extend beyond the corn sector. The growth of U.S. ethanol production is reverberating through the field crop and livestock sectors, and is affecting farm income, government payments, and food prices. Natural resource concerns have also arisen over ethanol expansion and changes in farmers' cropping choices.

Energy Independence and Security Act (EISA): Motivations and Mandates

In addition to increases in the cost of oil, a number of other drivers may have prompted Congress to pass the Energy Independence and Security Act of 2007 and its ambitious Renewable Fuel Standard:

- U.S. energy consumption is expected to grow 50 percent by 2030, with transportation one of the largest energy-consuming sectors. Biofuels are one of the alternatives to traditional petroleum-based transportation fuels.
- The use of biofuels diversifies our Nation's energy portfolio, leading to increased energy security.
- Biofuels can be produced domestically, making the U.S. less vulnerable to international disruptions in energy supply.
- Producing and using most biofuels results in fewer greenhouse gas emissions than petroleum fuel counterparts.

EISA requires increased biofuel production and additional funds to promote cellulosic and advanced biofuel production. The Renewable Fuel Standard (RFS) increases to 36 billion gallons by 2022. The mandate includes specific allocations, including:

- 21 billion gallons of *advanced biofuels*—essentially renewable fuels other than ethanol derived from corn starch that meet certain GHG emission reductions;
  - ➢ Of the 21 billion gallons of advanced biofuels, at least 16 billion gallons must be from c*ellulosic biofuel*;
  - ➢ Of the 21 billion gallons of advanced biofuels, at least 1 billion gallons must be from *biomass-based diese*l; and
- The remaining 15 billion gallons may be met with additional advanced biofuels or conventional biofuels such as corn ethanol.

Understanding the economics of biomass feedstocks requires a familiarity with potential sources ranging from starch-based feedstocks like corn to forest and crop residues to dedicated energy crops like switchgrass or poplars. Biodiesel from soybeans is also expanding. Each of these potential feedstocks has its own biological characteristics, resource requirements, costs of production, and delivery considerations, as is detailed in chapter 2.

Research that increases the viability of alternative feedstocks may alleviate pressures on existing feedstock markets, but new tradeoffs may emerge. For example, agricultural residues such as corn stalks and wheat straw offer a large and readily available biomass resource for cellulosic ethanol, but sustainability and conservation constraints exist. Removing too much residue can worsen soil erosion and deplete the soil of needed nutrients and organic matter. Similarly, sustainable forest residue harvests for biomass would need to factor in soil nutrient management for long-term soil productivity.

Earlier feedstock studies have made important contributions to understanding the cost structure and supply for some individual feedstocks. This report complements those studies by providing a comprehensive nationally disaggregate assessment of links in food/fiber and feedstock markets that policymakers need to make fully informed decisions. Ultimately, each farmer and forester will decide how much to produce of each feedstock and food/fiber product depending on projected net benefits and resource needs. A breakthrough rendering a new feedstock economically viable may have no market consequences if landowners favor a different feedstock or economic opportunity.

To illustrate the complex set of interactions in feedstock markets, this report provides a sector-level analysis that examines production options simultaneously, allows prices to rise and fall with market responses, and provides a roadmap for research priorities. A sampling of market interactions and their implications include:

Feedstocks compete with other uses for land. One feature most feedstock options share is their land intensity. The supply of land in agriculture is relatively constant, so allocating cropland to biofuel feedstocks means less land devoted to other products. High prices for food, feed, and fuel crops could prompt conversion of pasture and forest lands, but substantial changes could threaten sustainability and pressure Conservation Reserve Program (CRP) lands and other native habitat. Further, land that is currently not cultivated for crops (pasture or marginal lands) is also likely to be less productive than existing cropland due to climatic and agronomic factors. An overview of U.S. land use presented in chapter 2 provides context for assessing the role of land constraints in feedstock markets.

Biofuel production raises crop farm income. Demand for ethanol directly increases the price and production of corn. Additional corn production tends to be taken out of acreage in other crops, raising those prices as well. Producers of many U.S. crops have seen record revenues, in part, from the increased demand for corn ethanol. Increased gross revenues, however, are tempered by increases in production costs. Cropland values and rents will increase in response to the higher crop prices. Prices of inputs like fertilizer are likely to rise due both to an increase in the demand for inputs used in corn production and to higher energy prices.

Some farmers and sectors may experience decreased profits. While many farmers gain from the demand for biofuels, food consumers and food processors lose from the biofuel-induced increase in crop prices. Corn is a major feedgrain for livestock (traditionally the largest user of corn), and the increase in meat production costs due to increased feed costs is absorbed by both consumers and livestock producers. The impact of higher corn prices and feed costs is partially offset by the greater availability of distillers' grains (from ethanol production) as a substitute feed. However, that benefit will vary by livestock species; distillers' grains primarily benefit beef and dairy producers because only limited amounts can be included in the rations of monogastric animals like hogs and poultry (Westcott, 2007). Depending on market characteristics, these increased costs could be passed on to consumers in the form of higher prices for animal products. Whether the demand for biofuels increases the net returns to livestock producers and farmers of commodities not grown for biofuels depends on whether their revenues increase more than their operating costs. Quantitative methods such as the simulation models used in this report can help sort out the direction and magnitude of the change in net farm income of these farmers.

Scope of the Study: Spotlight on Market for Feedstocks

Whether, and to what extent, market interactions will increase or decrease various prices and quantities of inputs and outputs are empirical questions, addressed in this report qualitatively (in chapters 2 and 3) and quantitatively (in chapters 5 and 6, for corn-based and cellulosic ethanol, respectively). The policy context for the simulation analysis is drawn from the biofuel mandate incorporated in EISA. Greenhouse gas and sustainability issues associated with biofuel production are addressed briefly in the context of market interactions and modeling, and in more detail in chapters 7 and 8. The potential for investments in R&D to reduce costs and increase opportunities is addressed in every chapter.

The agriculture and forest sector models introduced in chapters 5 and 6 solve for optimal responses at a regional level, given individual production opportunities, intrasector relationships (e.g., links between crop and livestock sectors), variation in underlying resource conditions, and historic decisions about land use and land management. This analysis considers a range of the most well developed feedstock types, including:

- Corn for ethanol,
- Herbaceous feedstocks (e.g., switchgrass, Miscanthus, alfalfa, other grasses),
- Agricultural residues (corn stover, wheat straw), and
- Woody crops (e.g., willows, poplars) and forest residues.

Scenarios (described in chapter 4) for the quantitative analysis include a reference case that describes the optimal (least-cost) solution to meeting biofuel mandates. Results describe sectoral adjustments and costs, location/mix of different types of feedstocks, and changes in environmental indicators, relative to a scenario that replicates the 2007 USDA baseline for 2016-2017. Alternative scenarios represent potential effects of investments in R&D that enhance feedstock productivity, as well as changes in input costs and carbon prices.

The geographic scope of the study is national, but feedstock supply is inherently regional. The distribution of biomass feedstocks and comparative advantage of one type over another varies with local conditions. Thus, the study addresses feedstock availability and cost at a regional level.

Beyond the Scope

This report provides an economic analysis of domestic biofuel feedstock production opportunities, costs, and challenges. It has been developed in response to a fairly narrow request—to inform domestic research and development investments in feedstocks—and on a tight timeline. The models selected for this analysis are well suited to meeting this charge. They capture the complex interactions driving commodity prices, land-use change, and the supply of corn for ethanol and a few cellulosic feedstocks, and model it at a regional scale, allowing us to consider the pattern of production within the U.S. In addition, one of the models solves for a wide range of crop rotations, production practices, and associated levels of environmental indicators. However, the care taken with model parameters necessary to carefully examine our primary questions inherently circumscribes the analysis, and many factors that are important on a global scale are beyond the scope of this analysis. For example, the study does *not* provide empirical analysis of:

- ***Global production and land use.*** Though feedstock, biofuel, and energy production all occur globally, the focus here is on domestic production. The one exception is the role of international biofuel markets—imports and exports—and their influence on the U.S. market, which is discussed qualitatively in chapter 3. Similarly, global land-use implications and feedbacks into international feedstock production are critical drivers in global solutions, but are outside the scope of this report.
- ***Energy market implications for biofuel demand***. Energy prices that are high enough, relative to the cost of producing biofuels, *could* induce a level of biofuel production and, thus, feedstock demand, that exceeds the levels implied by mandates. Whether or not biofuel demand *would* increase with increased energy prices depends on the manner in which biofuels interact with other liquid fuels (e.g., as a substitute or an additive used in fixed proportions) and on the difference between the level of biofuel demand and the mandate. An increase in biofuel demand could simply make a mandate less binding. The conceptual analysis in chapter 3 explicitly considers these interactions, but the empirical analysis assumes that biofuel production meets mandate levels exactly. Energy markets and policy interactions are extremely complex, and incorporating them would divert attention from the study's objectives.
- ***Comprehensive sustainability implications or lifecycle analysis.*** Carbon emissions/sequestration and sustainability issues are examined in chapters 7 and 8, but only within the context of feedstock production. A comprehensive analysis would require assessing environmental, economic, and social sustainability indicators throughout the entire biofuel production stream and lifecycle analyses of carbon and other greenhouse gas emissions. The scope and timing of the analysis precluded such an assessment.
- ***Transportation and infrastructure logistics.*** A key determinant for biomass supply is an infrastructure that ensures economically viable feedstock logistics and handling from farm to plant. Other determining factors include regional demand, local resources (water), and enabling infrastructure (e.g., storage facilities, roads, rails, and barges for feedstocks and pipelines for liquid fuels). The conceptual discussion in chapters 2 and 3 do address the role of logistics costs, but the models are only able to solve for feedstock production at the "edge of field" or roadside.
- ***Food prices.*** Food prices will adjust as feedstock demand reverberates through the market. Increases in global and domestic food prices

in early 2008 garnered substantial attention. Increased use of corn for ethanol is part of the story, but other factors have put upward pressure on food prices, including the declining value of the U.S. dollar, rising input prices, increasing agricultural costs of production, adverse weather conditions in 2006 and 2007 affecting global production levels, and some countries' curbing of commodity exports to mitigate their own food price inflation.

The complex global interactions driving food prices are discussed in chapter 3, but the focus of the report—on domestic feedstock production and the potential role of research—circumscribes our analysis. Interactions between crop price changes (which are examined in chapter 5) and food prices are not examined empirically. The omission of this analysis is not an indication that it is not important; rather, its omission reflects the complexity of an issue best undertaken by experts in the field and with models explicitly designed for that purpose.

Finally, other types of feedstocks—including starches (other than corn) and sugar-based ethanol, other residues (e.g., rice straw), urban wastes, and emerging options such as algae—may gain or lose prominence. These options are identified in chapter 2, but limited information on prices and production scope, processes, and costs preclude including them in the models. Given the rapid advances in cellulosic and other advanced conversion technologies, it is difficult to predict what the feedstock market will look like in 2022. 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.

Overview of Potential Feedstocks

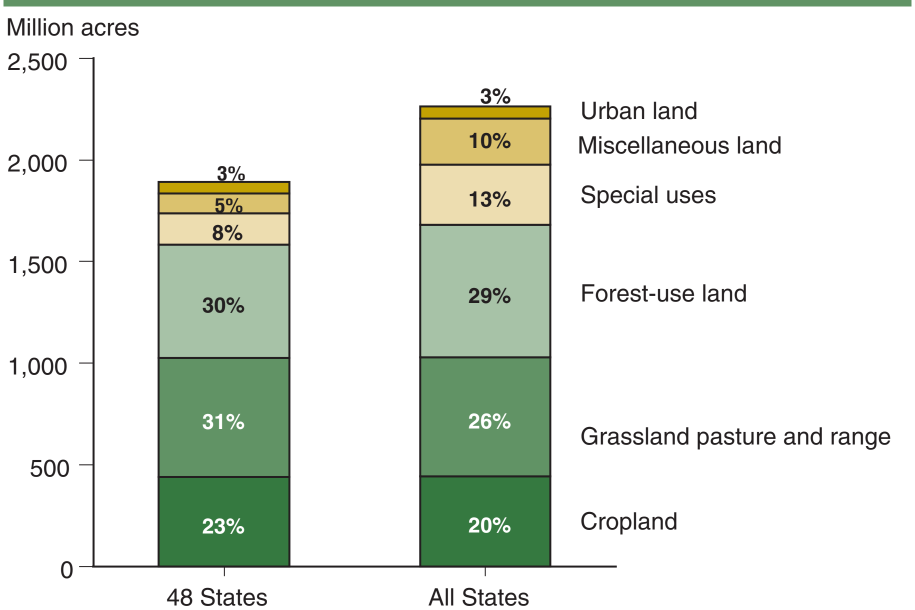
This chapter provides an overview of alternative feedstocks for biofuels. The foundation of the feedstock market, literally and figuratively, is the underlying land base. Additional options for emerging feedstocks would reduce pressures on land, either because they are jointly produced with other products (e.g., crop or wood residues) or because their production could be concentrated in a limited area. However, because most feedstocks are land-based and the amount of land in agriculture is relatively constant, allocating more land to growing feedstocks may mean less land is allocated to other uses. The manner in which that tradeoff is resolved has implications for feedstocks as well as food/fiber markets. This chapter addresses the economics of land market competition, surveys existing and emerging feedstocks, and considers Federal research efforts that could influence the market dynamics for alternative feedstocks.

The Competition for Land

The United States has a land area of about 2.3 billion acres, the largest shares of which are allocated to forest use, grassland pasture and range, and cropland. Land classified as cropland totaled about 442 million acres in 2002 (fig. 2.1). This total represents all land in crop rotation, including cropland used for pasture. Cropland used for crops—cropland harvested, cropland failure, and cultivated summer fallow—totaled 340 million acres, or 77 percent of total cropland acreage (Lubowski et al., 2006).

The most consistent trends in major uses of land (1945-2002) have been an upward trend in special-use and urban areas and a downward trend in total

Figure 2.1
Major uses of land in the United States, 2002



Note: Land for special use includes roads, parks, and recreational areas.
Source: USDA/ERS Major Land Uses database.

grazing lands. Forest-use area generally declined from 1949 to 1997, but increased by about 1 percent between 1997 and 2002 (the latest year for which such data are available). Total cropland area has declined, but has not done so consistently (fig. 2.2).

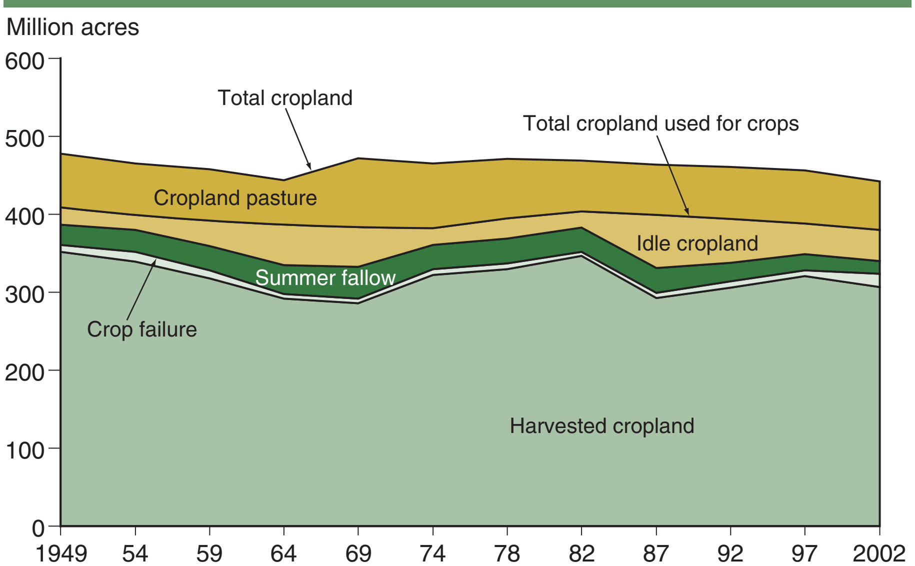
While individual agricultural markets (e.g., corn) have proven very responsive to new sources of demand, substantial increases in the production of one crop generally come at the expense of another. Additional corn acreage tends not to come from uncultivated or marginal land (Hart, 2006). Growers may also switch rotation patterns, growing corn 2 or more years in a row on a given field rather than alternating crops, such as between corn and soybeans, on an annual basis.

Bringing more land into cultivation could allow more production of each crop, but that land would have to come from another use. One source for new lands for crop and feedstock production is existing pasture and rangelands. Another source of land is acreage enrolled in the Conservation Reserve Program (CRP) (see box). While bringing more land into production could reduce upward pressure on commodity and feedstock prices, converting CRP land, native grasslands, and other lands in less intensive uses could reduce wildlife habitat and increase delivery of sediment, nutrients, and pesticides to water bodies. Moreover, land that is not currently cultivated for crops (e.g., CRP, pasture, or marginal lands) is likely to be less productive than existing cropland due to climate and agronomic factors; converting those lands to crop production is not likely to generate a commensurate increase in production levels.

Economic Factors Behind Production of Alternative Feedstocks

Just as with other goods, the quantity of any particular feedstock produced—and the price that feedstock commands—is determined by the interplay of supply and demand factors, and thus, decisions made by producers and

Figure 2.2
Major uses of U.S. cropland



Source: USDA/ERS Major Land Uses database.

The Conservation Reserve Program

Under the voluntary Conservation Reserve Program (CRP), the U.S. Department of Agriculture (USDA) establishes contracts with agricultural producers to retire highly erodible and other environmentally sensitive cropland and pasture. During the 10- to 15-year CRP contract period, farmland is converted or maintained in grass, trees, wildlife cover, or other conservation uses providing environmental benefits. Such benefits include improvement of water and air quality, creation of wildlife habitat, restoration of wetlands, carbon sequestration, preservation of soil productivity, protection of groundwater, and reduction of offsite wind erosion damages. The program also assists farmers by providing a dependable source of income.

As of April 2008, CRP enrollment stood at 34.7 million acres. USDA provides participants with annual rental payments during the contract period and half the cost of establishing conservation covers. Farmers and ranchers can participate in the CRP via general signups and continuous signups. Continuous signup includes the Conservation Reserve Enhancement Program (CREP) and the Farmable Wetlands Pilot Program.

General Signup. Landowners and operators with eligible lands compete nationally for acceptance based on an environmental benefits index (EBI) during specified enrollment periods. Producers may submit offers below soil-specific maximum rental rates to increase their EBI ranking.

Continuous Signup. Landowners and operators with eligible lands may enroll certain high-priority conservation practices, such as filter strips and riparian buffers, at any time without competition. CREP is a Federal-State effort under which landowners and operators implement projects designed to address specific environmental objectives.

Recent Developments

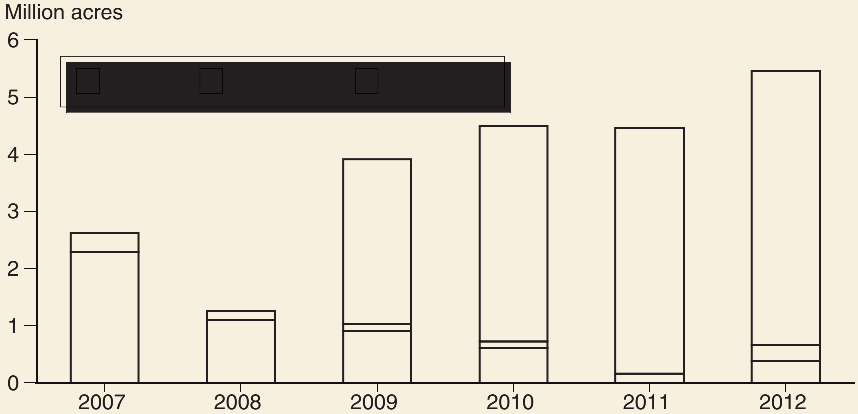
Re-enrollment and extension of contracts in 2007-2010. In 2006, USDA offered holders of general signup contracts set to expire between 2007 and 2010 (28 million acres) the opportunity to re-enroll or extend their contracts. USDA divided expiring contracts into five quintiles based on EBI scores of the land under contract. Land owners in the quintile with the highest EBI scores were offered new 10- or 15-year contracts. Those in the 2nd highest quintile were offered 5-year contract extensions, those in the 3rd highest were offered 4-year extensions, and so forth. Holders of over four-fifths of expiring contract acres accepted the extensions.

Near-term projected enrollment changes: The Food, Conservation, and Energy Act of 2008 imposes a 32-million-acre maximum for CRP starting October 2009, by which date contracts covering about 5 million acres of CRP land will expire. Taking into account these expirations, and assuming steady enrollment in continuous signups, CRP acreage would be about 30.5 million acres on October 1, 2009—about 1.5 million acres below the cap—if USDA holds no general signups and offers no further contract extensions.

Continued on page 10

Continued from page 9.

Near-term CRP expirations



Note: These are just contract expirations. Some lands may be re-enrolled and new lands could be enrolled, so net enrollement changes over time are uncertain.

Source: USDA, Farm Service Agency, *Conservation Reserve Program: Summary and Enrollment Statistics, 2007*. http://www.fsa.usda.gov/Internet/FSA_File/annual_consv_2007.

Longer term prospects. The longer term prospects for the CRP depend on commodity price trends and on changes to USDA's payment policy for CRP. The high signup rates under the extension program, as well as the infrequency of landowners breaking contracts[1], suggests satisfaction with the program. This enthusiasm may stem from a conservation ethic or from the CRP offering higher net profit than commodity production. Commodity returns that eclipse CRP payments may lead to a smaller pool of potential enrollees.

A smaller pool of applicants would have two broad impacts. First, competition for enrollment would be reduced, so land accepted into program would on average be both more expensive and have fewer critical environmental attributes. Second, if the pool of applicants shrinks substantially, the number of acres offered could be insufficient to meet future enrollment goals. The impacts on continuous and general signups are likely to be different. Average per-acre payments for continuous signup are over twice the average for general signup. While this may reflect differences in land quality, it also reflects the incentive payments offered in the continuous program. Thus, it is likely that the continuous program will be less affected by rising commodity prices.

Finally, USDA's payment schedule for the CRP will determine the future of the program. If payments keep up with commodity prices, it is much more likely that the program will be unaffected. Of course, this means that total program costs could increase, perhaps substantially. It also means that land that could relieve pressures on cropland demand might be retained in the CRP.

[1]For example, a survey of FSA offices in April 2008 showed landowners broke contracts on only 131,300 acres in this fiscal year.

consumers. When deciding how much corn to produce, for example, farmers weigh the price they expect to receive for their crop against the anticipated costs of producing that crop, and determine what quantity of corn provides the greatest possible return compared to decisions on other cropping alternatives.

Like any market, the market for a given feedstock is also directly influenced by the availability of substitutes (which would reduce demand) and by alternative uses (which would increase demand). For example, demand for corn comes from a variety of sources; farmers can sell their corn for feed, can export it, and can sell it to ethanol producers. Total corn demand, then, aggregates alternative markets and each new source of demand (or increased demand for a given source) shifts the aggregate demand curve out, increasing the price farmers receive for each bushel of corn produced. On the other hand, demand for corn for ethanol would decrease (shift inward) if alternative feedstocks (e.g., switchgrass) were commercially viable. While economic theory can predict the direction of the shift, the size of the shift and the resulting implications for market-clearing prices and quantities is an empirical question that will depend on a variety of factors, including the production economics for each feedstock and the extent to which they are substitutes or complements. (See box, "Market Mechanisms Determine Feedstock Prices and Quantities.")

The ethanol feedstock market is characterized by alternative feedstocks that may be physically interchangeable. Fuel ethanol is not a readily differentiable product. To a blender or consumer, a gallon of ethanol is a gallon of ethanol, regardless of who supplies it or what it is made from. Therefore, relative prices of alternative feedstocks and their conversion costs are critical in determining the mix of feedstock used to produce ethanol. At the same time, biofuel mandates might affect the mix of feedstocks if they differentiate production targets by type of feedstock.

In contrast to ethanol, biodiesel may exhibit some scope for product differentiation among biodiesel fuels (Carriquiry, 2007). While an ethanol molecule does not vary depending on its source, biodiesel from different feedstocks may have ester fuels with different chain lengths, resulting in different fuel quality characteristics. As such, differences across diesel feedstocks may be reflected in biodiesel prices, and can complicate the economic analysis of biodiesel markets and biodiesel feedstock markets relative to ethanol markets. Nonetheless, differences in production costs among biodiesel alternatives are likely to determine the quantities produced of each alternative feedstock.

Toward a Portfolio of Feedstocks

Land managers will chose to produce what is profitable. If the number of acres needed to produce a given level of biofuel from one feedstock versus another was the same regardless of the amount produced, basic economic principles suggest that only one of the feedstocks will be used—the cheapest one to grow and convert to biofuel. Consistent with that premise, the predominant source of conventional ethanol in the United States is corn. Given the competing demands for corn, using corn as a feedstock for fuel is not without economic impacts within and beyond the farm sector.

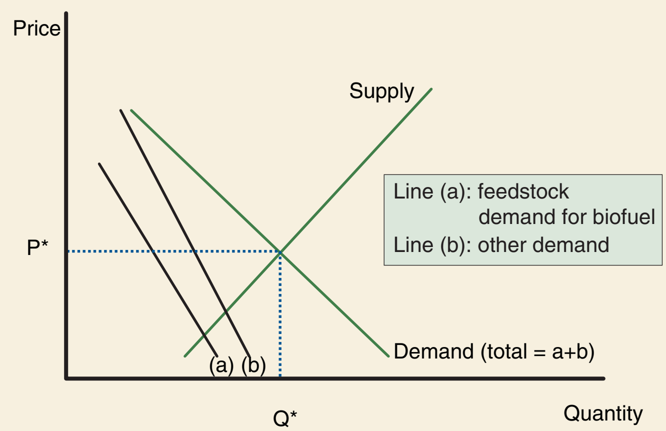
Market Mechanisms Determine Feedstock Prices and Quantities

A simple diagram depicting supply and demand is useful for exploring the market mechanisms driving feedstock production. In the figure, the supply curve represents the quantity of corn that producers are willing to supply to the market at any given price level. The supply curve is upward sloping because production costs increase with increases in aggregate production levels and producers are willing to incur additional costs to produce more only if the expected price exceeds the additional costs of production. For example, a corn producer may be willing to use less productive lands or engage in more intensive use of fertilizers, pesticides, and irrigation to boost yields if the price of corn outweighs the additional (marginal) costs. Hence, the per-unit costs to supply corn rise as corn production expands. In the case of feedstocks, competition for land resources is a key factor determining the steepness of the supply curve.

Consumers represent the other side of the equation that ultimately determines the amount of corn produced, and the price at which it is sold. Most potential feedstocks, including corn, have multiple uses, so the market demand curve is actually an aggregate of the demand of different types of consumers. Each use of corn—ethanol, livestock, and sweeteners, for example—has its own demand curve. Two such curves are denoted as (a) and (b) in the figure. Ethanol producers' willingness to pay for a feedstock is represented by the downward sloping demand curve (a). High feedstock prices attract a relatively low level of demand because producers would have to sell the resulting ethanol at a higher price, and fewer consumers would be willing to purchase it at that higher price. Conversely, lower prices attract more demand. The demand curves for the various uses of corn are aggregated to form the market demand curve for corn.

The point at which the market supply and demand curves intersect determines the actual price (P*) and quantity (Q*) purchased during any given time span. This price and quantity remains stable (in "equilibrium") unless some other factor causes the supply or demand curve to shift inward or outward—changing the quantity producers are willing to supply, or consumers willing to buy, at any given price. In general, demand shifts can be caused by changes in wealth, population, tastes, or prices of substitute or complementary goods, and government policy. For example, the location and shape of the demand curve for corn for ethanol depends on the availability of other feedstocks; at high prices for corn, other feedstocks might become more attractive and ethanol producers could substitute away from corn, reducing demand. Supply shifts can be caused by changes in technology, input costs, government policy, or the number of producers in the market. For convenience, and because it is currently so dominant, we use corn as an example in this discussion, but the same principles would apply to any feedstock with more than one use. Chapter 3 addresses these supply and demand factors in depth.

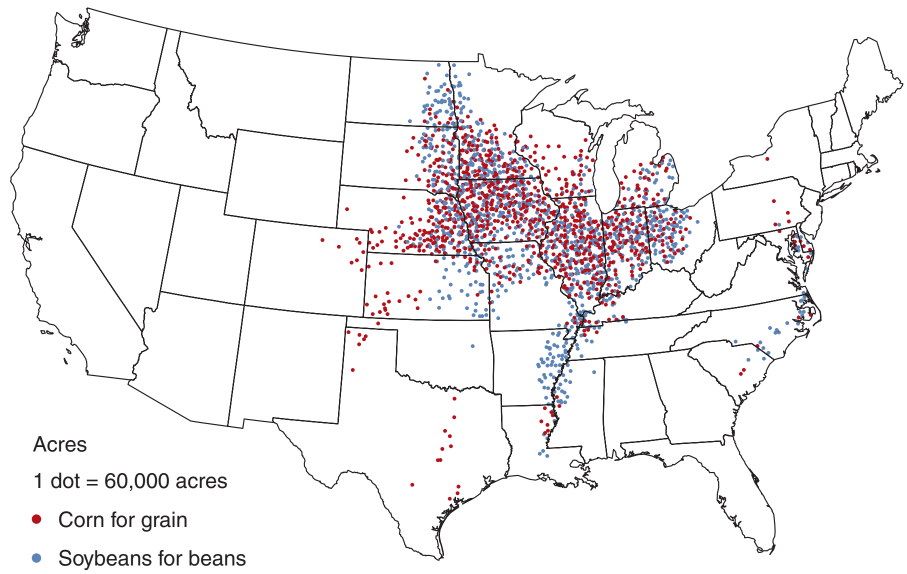
The market mechanism determines prices and quantities for inputs with multiple uses



Dependency on one feedstock, corn, makes food and biofuel prices particularly vulnerable to yield shocks for that commodity. Most U.S. corn is produced in the Corn Belt (fig. 2.3). A drought in the Midwest could significantly increase corn prices (McPhail and Babcock, 2008). Commercialization of geographically diverse biofuel feedstocks could make biofuel prices less sensitive to weather shocks, pest infestations, and other yield-reducing shocks that tend to vary by region.

The feedstock with the highest ethanol output per acre is not necessarily the one that receives the most widespread use. For instance, if one feedstock is cheaper under ideal growing conditions but has a limited geographic range (sugarcane in the U.S., for example), a less productive feedstock could generate higher net benefits under conditions that are marginal for the first feedstock. Changes in the relative costs of converting other feedstocks into

Figure 2.3
Corn and soybean acres



Source: USDA/NASS, 2002 Agricultural Census.

ethanol, or increases in the demand for ethanol, could facilitate commercialization of more sources of ethanol. If the number of acres needed to achieve the fuel production level from one feedstock versus another changes along with the number of acres of each feedstock needed, then the market will likely use both feedstocks. In addition, the relative quantities of two feedstocks could change with changes in the cost of converting the feedstock to biofuel or with changes in the amount of biofuel demanded.

Table 2.1 summarizes key cost and conversion characteristics of feedstock alternatives at the farm level. Included are per-acre production costs, feedstock yields, and fuel yields.[1] The estimates provided are averages, abstracted from regional, local, and even farm-level heterogeneity likely to be reflected in different farmgate net benefits. Further, farm-level costs are sensitive to input costs such as fuel and fertilizer, which generally follow energy (in particular, natural gas) prices. Given the recent increases in fuel prices, farm-level cost estimates from studies published in 2006 or earlier may not reflect energy prices after that period. In turn, biorefinery costs are sensitive to both energy and feedstock costs. Clearly, the assessment would benefit from more research to refine these figures, particularly for emerging alternatives. Nonetheless, the data allow for a ready comparison of costs and technical conversion parameters across feedstock alternatives at the farm level for fixed input prices. For some values in table 2.1, a range of estimates is presented. Studies can vary in their modeling assumptions and may examine different geographic regions, across which costs or yields can vary.

[1]Agriculture is a land-intensive activity, and as such the cost of land is an important part of total production costs. Thus, for feedstocks other than residues, the “total feedstocks production cost” values in table 2.1 include the opportunity cost of land, which is measured as the average cash rental rate for land producing the commodity in the regions producing that feedstock. Many farmers rent at least a portion of the land they farm. For those farmers, land costs are a direct outlay. For farmers and foresters who own the land they manage, land rents represent a return to their asset. .

Several patterns are apparent. Key variables demonstrate a large range of values across feedstocks. For example, USDA projections for yield gains are highest for feedstocks with the highest commercial demand—corn and soybeans (table 2.1). Sugar crops can yield the most ethanol per acre (the highest fuel yield) but, for sugarbeets in the U.S., they also have the highest production costs. While total feedstock production costs for herbaceous and forest crops are generally not

Table 2.1

U.S. field-level cost and conversion characteristics of feedstock alternatives

Feedstock	Total feedstock production costs (including harvest cost)	Yield per acre	Total output[5]	2016 baseline projected annual yield growth rate[8]	Harvesting and collection costs	Fuel yield
	$/acre	*Tons/ac/yr*	*Mil. tons/yr*	*Percent*	*$/planted acre*	*Gal/ac*
First-generation feedstocks*						
Corn	417[1]	4.2[3]	355.2[6]	1.23	101[10]	388-418[11]
Grain sorghum	261[1]	1.8[3]	12.4[6]	0.65	89[10]	168-181[11]
Barley	272[1]	1.5[3]	5.7[6]	0.89	78[10]	138-161[11]
Sugarcane	n/a	32.7[3,4]	30.1[4]	0.32[9]	n/a	638[12]
Sugarbeets	986[2]	23.8[2,3]	31.2[4]	0.82[9]	n/a	590[12]
Soybeans	278[1]	1.3[1,3]	92[7]	1.04	65[10]	64[13]
Second-generation feedstocks*						
Corn stover	n/a[28]	3[16]	254[17]	1.23[15]	7-11[19]	240-270[20]
Wheat straw	n/a[28]	1[16]	58[18]	n/a	17[16]	80-90[21]
Switchgrass	133-329[14]	4.2-10.3[20]	n/a	n/a	33-129[14]	336-924[21]
	$/dry ton	*Dry tons/ac/yr*	*Mil. dry tons/yr*		*$/dry ton*	*Mil. gal/yr*[23]
Short-rotation woody crops	39-58[24]	5-12[23]	n/a	n/a	17-29[24]	393
Forest residues and thinnings	37-92[27]	n/a	101[22]	n/a	35-87[26]	9,040
Conventionally sourced wood	48-71[27]	n/a	15[27]	n/a	32-43[27]	1,335
Primary mill residues	n/a[28]	n/a	1.3[27]	n/a	n/a	116
Municipal solid waste	n/a[28]	n/a	14[27]	n/a	n/a	1,253

*First-generation feedstocks are those currently being used to produce biofuels for commercial sale. Second-generation feedstocks are those with the potential to produce biofuels for commercial sale. The data shown for noncommercial feedstocks are from test plots, field studies, and research conducted by both the public and private sector. Production and harvest costs depend on fuel prices, which may have increased since those estimates were produced. Except for residues, feedstock production costs include land charges, which vary by region. Land charges represent an opportunity cost for landowners who manage their own land.

[1]USDA/ERS, 2007; USDA/ERS, 2008a, 2008c, 2008d. Values shown are an average of 2005-2007.
[2]USDA/ERS, 2007. USDA, National Agricultural Statistics Service (USDA/NASS), 2008. Values shown are an average of 2005-2007.
[3]USDA/NASS, 2008. Yield/acre is calculated using an "Olympic Average" for 2003 through 2007, excluding the lowest and highest values in the 5 year period.
[4]USDA/ERS. 2008e. USDA/NASS. 2008. Sugarcane yields are for sugarcane for sugar only, not sugarcane for sugar and seed.
[5]Total production shown is calculated as yield per acre (2003-2007, "Olympic Average") x total acres planted (2005-2007, average).
[6]USDA/ERS. 2008a. Values shown are an average of 2005-2007.
[7]USDA/ERS. 2008. Values shown are an average of 2005-2007.
[8]Westcott, 2008.
[9]Time frame is FY09-FY18.
[10]Foreman et al., 2007.
[11] Dhuyvetter et al., 2005. Assuming 2.6 - 2.8 gallons of ethanol per 56-lb bushel of corn and sorghum. Assumes 2.2-2.6 gal per 48-lb bu for barley (Berkke, 2005).
[12]Shapouri, 2006.
[13]Bain, 2007. Assuming 0.183 lbs soyoil per 1 pound of soybeans and 0.135 gallons of biodiesel per pound of soyoil.
[14]Duffy, 2008. Perrin et al., 2008. The Duffy study covers Iowa, representing the higher end of the range and the Perrin study covers North and South Dakota and Nebraska, representing the lower end of the range.
[15]Assuming same rate of growth for corn stover as corn.
[16]Gallagher et al., 2003. Assuming a removal rate of 47-82% depending on feedstock, region, soil type and environmental constraints.
[17]Corn stover yield per acre x corn acres planted (2005-2007 average). Values are dry tons/acre/year.
[18]Wheat straw yield per acre x wheat acres planted. USDA/ERS, 2008f. Values are dry tons/acre/year.
[19]Brechbill & Tyner, 2008. Harvesting costs depend on removal rates, which ranged from 38% to 70% for this Indiana study. These are custom harvest costs.
[20]McLaughlin and Kszos, 2005. Range based on average yields reported in McLaughlin and Kszos for field trials in 14 States, with the highest value representing test plots in Alabama and the lowest representing test plots in Kansas. See also Dobbins et al, 1990; Farrell et al., 2006.
[21]Bain, 2007; Aden et al., 2002. Assuming a conversion rate of 80.1 (thermochemical conversion)- 89.7 (biochemical conversion) gallons/dry ton.
[22]Perlack et al., 2005.
[23]Adegbidi et al., 2001; Volk et al., 2006.
[24]Tharakan et al., 2005; Eaton, 2007.
[25]Stumpage value, or payment to the landowner for the biomass, assumes production costs are offset by higher value products generated in the harvest.
[26]USDA/FS, 2005.
[27]Chapter 6, this report.
[28]This feedstock has no direct production costs, other than harvest costs, but a payment to the owner of this feedstock may be necessary for acquiring it. For crop residues, the payment would be a function of the value of nutrient and organic matter of the removed residues, as well as values the removed residues may have on subsequent field operations (e.g., reduced tillage and herbicide use) and on crop production (Perlack and Turhollow, 2008). Charges for primary mill residues would never exceed stumpage prices for pulpwood. For MSW feedstock, the payment may be in the form of a reduced fee for removing the MSW from the site.

available, estimates for switchgrass suggest that some cellulosic crops may be cost competitive with the starch crops, at least prior to processing.

Total feedstock production costs per acre indicate the average minimum that growers would be willing to accept in order to plant the crop. Omitted are the costs incurred in the processing of the feedstocks at the biofuel plant. These costs can vary substantially across feedstocks. The costs of commercial conversion of cellulosic feedstocks are unknown, but they are not currently competitive with conversion costs for starch-based feedstocks. Comparison across feedstocks of the total costs of producing ethanol from each would require that all processing and distribution costs be available.

Corn provides a greater ratio of fuel yield to farm-level production costs (per acre) than other crops that are in current commercial use (for which cost data are available, table 2.1). Hence, it is not surprising that corn dominates ethanol production in the U.S. However, with increased demand for biofuels and/or technical advances that reduce costs in converting alternative feedstocks to biofuel, other feedstocks may come to challenge corn's dominance. Research on technologies to reduce conversion and processing (including transportation) costs may lead to significant decreases in these costs.

The attractiveness of one feedstock over another will also be determined by the cost of delivering that feedstock from "root to refinery." That cost will be a function of harvesting and collection costs, which vary with the weight and bulk of the feedstock, and distance to the biofuel plant. Transportation costs are a major issue for ethanol producers. The ethanol industry is characterized by many plants, geographically dispersed so as to be near the feedstock source; most ethanol plants are in the Midwest, given that the U.S. ethanol industry is primarily corn-based.

To provide an overview of alternative feedstocks for U.S biofuels, this chapter divides them (and their associated production processes) into three categories based on the maturity of their production processes: (1) first generation, (2) second generation, and (3) other long term options. The first category represents production processes that are relatively mature: future cost savings due to technique refinements are likely to be marginal. Currently, all commercial production of biofuels, including corn ethanol and biodiesel, falls into category (1). The second category represents production processes that are emerging, with significant potential for reducing production costs. The second generation of biofuels are those from feedstocks without a food use, such as agricultural residues or urban wood waste. Category (3) represents longer-term prospects for commercialization. The bulk of our analysis is devoted to the first two categories, given data availability and current production or near-term prospects.

First-Generation Feedstocks

In principle, any starch or sugar crop (basically, the edible portion of most crops intended for food) can be fermented and converted to ethanol using the current generation of technologies. Sugar crops can most easily be converted to ethanol, essentially squeezing the sugar juice out of the crop and fermenting it. Converting starches into ethanol requires that they first be broken down into sugars, which are fermented. Vegetable oils and animal fats can also be turned into biofuels (biodiesel), but use different processes than for ethanol. In either case, the first-generation technologies discussed in this section are mature and include those that are commercially viable at current prices. Diversifying ethanol and biodiesel production toward a wider suite of sugar and starch crops would likely do little to reduce the competition for land, but may reduce the potential impact of weather shocks on fuel prices by expanding the geographic scope of production.

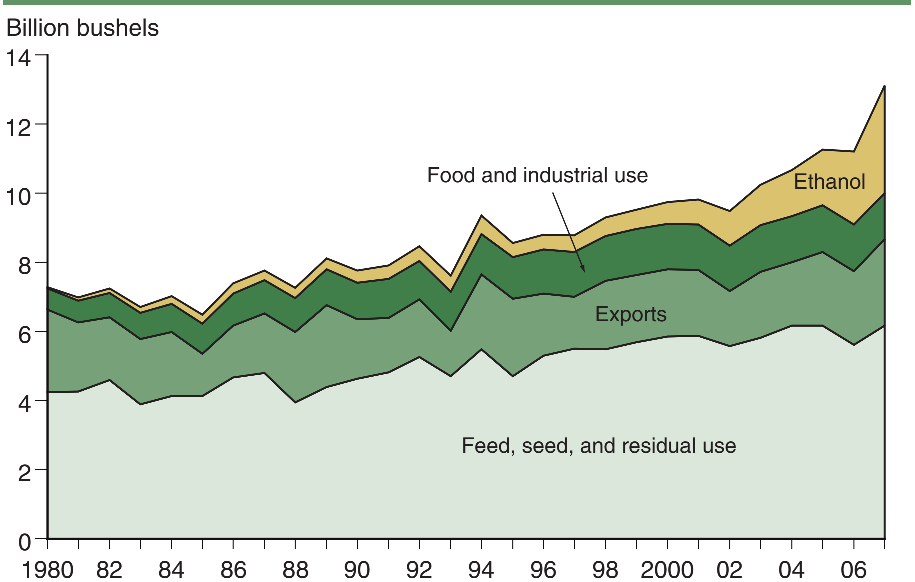
Ethanol Production From Starch Crops

Very little U.S. ethanol is produced from feedstocks other than corn. Corn is also the most widely produced feed grain in the United States—around 94 million acres were planted to corn for grain in 2007 (ERS, 2008a).

The vast majority of the U.S. corn crop is used for livestock and poultry feed (fig. 2.4). In 1980, less than 1 percent of U.S. corn was used to produce ethanol. Since 2001, total corn production has increased rapidly (from 9.5 billion bushels to 13 billion bushels in 2007) and the share of corn used for ethanol has jumped from 7 percent to 24 percent.

Corn's prominence as an ethanol feedstock may stem from its dominance in U.S. feedgrain production—extensive infrastructure and physical and human capital (farmers are familiar with production practices) already exist for corn. But in the U.S., corn also has an advantage over other feedstocks in economic efficiency of conversion into ethanol. Corn's fuel yield (gallons per acre) is more than 2.6 times higher than barley's and 2.3 times higher than sorghum's based on the midpoint of the ranges in fuel yields (table 2.1). Production costs are approximately 1.6 times higher for corn than for grain sorghum and 1.5 times higher than for barley.

Figure 2.4
Ethanol accounts for a growing share of corn use



Source: USDA/ERS, Feed Grains Database, accessed April 28, 2008.

Two basic processes are used in the United States to produce ethanol from starch crops: dry milling and wet milling. Dry milling is the most common form of ethanol production; most existing grain ethanol plants and all U.S. plants under construction that will use grain as feedstocks currently are dry mill. Total U.S. ethanol refining capacity is 8.522 billion gallons per year as of March 2008 (RFA, 2008). Converting corn into ethanol also produces coproducts, including distillers dried grains (DDGs) from dry milling and corn oil from wet milling, that can serve as a portion of livestock feed rations (Aines et al., 1986).

While corn dwarfs all other starch crops in ethanol production, other starch crops are used for commercial ethanol. Eight U.S. ethanol plants use grain sorghum (milo) as a feedstock (RFA, 2008). Grain sorghum is grown primarily in the Central Plains (Kansas, Nebraska, Missouri) and Southern Plains (Texas, Oklahoma, Arkansas). Approximately 15 percent of U.S. grain sorghum is being used for ethanol (NSP, 2008). Grain sorghum produces roughly the same amount of ethanol per bushel as corn, but the sorghum yield (bushels per acre) is lower than for corn (table 2.1). Grain sorghum also yields DDGs, and is completely interchangeable with corn in the ethanol production process—plants can seamlessly switch between sorghum and corn as an ethanol feedstock (NSP, 2008). Approximately 7.7 million acres were planted to sorghum in 2007, with a total output of almost 505 million bushels (USDA/NASS, 2008). Barley is also being used in three U.S. ethanol plants (RFA, 2008). Research is underway on hulless barley varieties that should increase ethanol output per bushel of barley relative to conventional barley varieties, and thus could make this feedstock more attractive.

Ethanol Production From Sugar Crops

Crops high in sugar content (like sugarcane and sugarbeets) are easier to process into ethanol than starch crops since the sugar required by fermentation is already present. Fermenting and distilling ethanol from these crops is not much different than rum or brandy production. However, for the most part, the United States does not have a comparative advantage in the production of these crops (USDA/OCE, 2006). The U.S. sugar program is designed to assist domestic producers of sugarcane and sugarbeets by maintaining domestic sugar prices above world levels (ERS, 2008b).

Even though ethanol production is not competitive with sugar production at current prices (for sugar destined for human consumption), production of ethanol from industrial-use sugarcane is being pursued in Hawaii, Florida, and Louisiana (Christiansen, 2008). One ton of sugarcane produces about 19.3 gallons of ethanol, a greater ethanol output per acre than for corn (table 2.1). In 2007, around 880,000 acres of U.S. sugarcane were harvested (USDA/NASS, 2008), which is less than 1 percent of total acres devoted to corn. According to USDA data for 2006, 27 counties in Florida, Louisiana, Hawaii, and Texas produced sugarcane, with 1 Florida county accounting for 40 percent of total production.

Sugarbeets are grown primarily in the upper Midwest. Current conversion technologies yield an ethanol output per acre that is close to that of sugarcane (table 2.1). However, sugarbeets are a high-cost input for biofuel production at present and are not used for that purpose (USDA/OCE, 2006).

Sweet sorghum, which contains carbohydrates in fractions of both sugar and starch, is another feedstock candidate. Research has been conducted on sweet sorghum as an ethanol feedstock in warmer regions like Hawaii, Florida and Texas, but little of the crop is currently grown (Lau et al., 2006). Another alternative in the research phase is energy cane, a breed of sugarcane that produces high amounts of sugar and stalk for ethanol conversion.

Oil Crops as Feedstocks for Biodiesel

Many different types of oils—such as vegetable oil, fryer oil, tallow, and fats—can be converted to biodiesel, but the most common U.S. feedstock is soybean oil. Soybeans are commonly grown in rotation with corn, and more than 80 percent of soybean acreage is in the upper Midwest, followed by the Delta and Southeast (fig. 2.3 and USDA/ERS, 2008c).

Like production of ethanol from sugar and starch crops, the conversion process is relatively simple. "Turnkey" processors, which can process animal and vegetable oils into biodiesel fuel that can be used in unmodified diesel engines, can be bought on the open market but the quality of the output may not be as consistent as from large-scale biodiesel plants (Eidman, 2007). About 1.5 gallons of biodiesel can be produced from a bushel of soybeans (Gray, 2006). Biodiesel production yields glycerin as a coproduct, which has a variety of marketable industrial uses.

Today, the biodiesel sector is characterized by local or regional markets, with no dominant producer except on a very local basis. Production varies widely from 50,000 gallons to 80 million gallons per facility, with most plants producing less than 30 million gallons (Biomass Research and Development Board, 2008).[2] As of March 2008, the National Biodiesel Board reports 171 plants either in operation or under construction, with an estimated production capacity of 2.44 billion gallons per year. However, in 2007, most U.S. biodiesel plants could not cover their operating expenses (Carriquiry and Babcock, 2008). As a consequence, the 2007 biodiesel production was only about 450 million gallons. Feedstock accounts for 80 percent of the cost of a gallon of biodiesel, the highest ratio of feedstock cost to total production costs for any of the feedstocks considered in table 2.1 (Carriquiry and Babcock, 2008). Much of biofuel plants' difficulty in covering their operating expenses is the high price of oilseeds relative to the price of biodiesel.

Another technically feasible feedstock for biodiesel—if not commercially economic at current prices—is tallow (animal fat). With a large beef industry in the United States, tallow could serve as a low-cost biodiesel feedstock. Yellow grease, the cooking grease left over from restaurants, is another alternative.

Jatropha has also received some attention as a feedstock crop for biodiesel. It can be grown on low-quality soil, needs little water, and has relatively high oil yields (University of Florida, 2007). Currently, jatropha is grown primarily in Southeast Asia, as well as parts of Africa and Latin America. Some jatropha varieties are native to certain Southern States, but may be considered invasive species (a threat to desirable vegetation) if introduced to other U.S. regions (USDA/NRCS, 2008).

[2] Commercial biodiesel is manufactured through trans-esterification of plant oils or animal fats with methanol, catalyzed by inorganic bases or acids such as sulfuric acid. It should not be confused with the direct use of vegetable oils in diesel engines. The latter is technically feasible, although high concentrations of vegetable oils in the diesel fuel blend require the engine to be modified. The long-term impacts of vegetable oil use on engine maintenance is also uncertain. Biodiesel has similar properties, such as viscosity levels, to diesel fuel, making it a more direct substitute for diesel fuel.

While rapeseed oil (canola) is the favored biodiesel feedstock in Europe, it receives little attention in the United States given traditional preference for soybean production. Currently, only one U.S. biodiesel plant, in North Dakota, produces biodiesel from rapeseed on a commercial basis.

Second-Generation Feedstocks

This second generation of biofuels are those made from feedstocks without a food use. A wide array of feedstocks can be used, including agricultural residues like corn stover, herbaceous energy crops like switchgrass, and short-rotation woody crops like hybrid poplar and willow. Plentiful stocks and the potential for high yields per acre and low resource demands have generated substantial enthusiasm for cellulosic ethanol options. However, ethanol production based on cellulosic feedstocks does not currently exist on a commercial basis. The current difficulty in converting these feedstocks into ethanol is that the cellulosic material in these plants needs to be broken down before it can be converted to ethanol. The growth and expansion of cellulosic ethanol technology will hinge on continued research and development (R&D) to reduce costs, and/or increases in fuel prices and the prices of other feedstocks sufficient to induce commercial cellulosic production.

Agricultural Residues

Agricultural crop residues are the biomass that remains in the field after harvest. The most common residues include corn stover (stalks, leaves, and/or cobs), and straw associated with wheat, rice, barley, or oat production. Because of their immediate availability, agricultural residues are expected to play an early role in the development of the cellulosic ethanol industry.

The eight leading U.S. crops can produce more than 450 million tons of residues each year (Perlack et al., 2005). A sizeable portion of this is corn stover. Assuming a 1:1 ratio of stover to grain, in the last 5 years the United States has produced, on average, almost 360 million tons of corn stover per year (USDA, ERS, 2008a). Given current conditions, only a fraction of those residues will be available for use in fuel or energy production due to technological feasibility, economic feasibility, and environmental concerns. However, R&D investments leading to improvements in technology and management practices may make more residues available in the future. In addition to major residue producing crops like corn and wheat, other crops such as rice and sugarcane, which face residue disposal issues, might also contribute biomass for fuel in the future (DiPardo, 2000; Wilhelm et al., 2004). Crop residues can be found throughout the United States, but are primarily in the Midwest because of corn stover's preeminence.

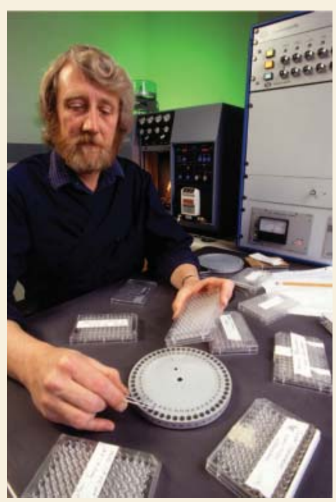
The percentage of residue that growers will be willing and able to remove from their fields is unknown. A farmer will only collect, bundle, and store bulky stover and other crop residues if revenues outweigh the costs. Also, the quantity of residue that can be removed without increasing soil erosion and reducing soil fertility will vary by field and region and is the subject of ongoing research. The total yield figures in table 2.1 are sensitive to assumptions about residue removal rates. For example, addressing concerns about productivity impacts of residue removal due to reduced soil carbon may

When Producing Ethanol, Some Stover Needs To Be Left in the Field

Stover refers to the corn stalks, leaves, and cobs that remain on fields after grain harvest. Stover is not waste material because farmers leave it on their fields to revitalize the soil, thereby maintaining soil productivity, and to prevent erosion. Thanks to scientific and technological advances that can turn stover into ethanol, farmers may soon harvest corn stover for cellulosic sugars that can be fermented into ethanol. On the one hand, harvesting stover for sugars to make ethanol may lessen U.S. dependence on crude oil imports. On the other hand, leaving stover in place may help reduce soil erosion caused by strong winds or intense rainfall. It also replaces carbon in the soil, lessening carbon dioxide accumulation in the atmosphere as a greenhouse gas and its contribution to global climate change. Research efforts are underway to understand how much corn stover can be sustainably removed from fields so that renewable biofuels can be produced and soil, water, and air natural resources are protected.

Bales of corn stover have been collected to conduct a research project that will determine the amounts that need to be left in the field to protect the soil.

Photo courtesy of USDA Agricultural Research Service.



Soil samples collected from the field are loaded into a carbon/nitrogen analyzer-mass spectrometer carousel to measure how much carbon plants have pulled from atmospheric carbon dioxide and stored in soil organic matter.

Photos courtesy of USDA Agricultural Research Service.

reduce total available residues (Wilhelm et al., 2007; Banowetz et al., 2008) (see box, "When Producing Ethanol..." and chapter 8 for more discussion of this subject).

While the collection of residues, particularly corn stover, may be feasible once a market exists, new infrastructure for the collection and processing of these feedstocks will need to be created. For example, machinery designed to collect corn and corn stover in a single pass is currently being developed. Transportation and storage costs of this bulky feedstock are likely to be a significant portion of ethanol costs.

Forest Residues

Forest-based resources could also be used to provide bioenergy and biofuel feedstocks. Prices offered for the residues and removal costs determine the economic practicality of hauling this material to the roadside. Other factors, including sustainability concerns and particular language in biofuel mandates, may circumscribe the location and extent of woody feedstocks. For example, the renewable fuels standard in EISA excludes certain forests (e.g., those on Federal lands, old-growth forests, those ranked as imperiled) from being considered for feedstocks.

Forest health may be jeopardized by fire, pests, and invasive species. A buildup of excessive woody biomass has raised forest susceptibility to epidemic outbreaks of insects and disease. Utilizing biomass for biofuels provides market-driven opportunities for prescriptive and restorative treatments. A current forest practice for treating small-diameter trees is to burn the material in the woods, contributing to unsafe particulate levels and releasing greenhouse gases (especially methane) (Ammann et al., 2001; Bonnicksen, 2008). Using this material to produce biofuels can improve air quality and reduce emissions. Applying best management practices and technologies when harvesting and recovering this material reduces site impacts and protects soil quality and site productivity.

Logging Residues—The U.S. timber industry harvests over 235 million dry tons annually (Smith et al., 2004), leaving substantial nonmerchantable wood and residues onsite that could be used as bioenergy feedstock. Logging residues of about 67 million dry tons/year are produced during conventional harvest operations, forest management activities, and clearing operations (Smith et al., 2004; USDA Forest Service, 2004; Johnson, 2001).

Other Removal Residues—A significant increase in removals of other residues—such as unutilized wood from cut or otherwise killed growing stock, precommercial thinnings, and timberland clearing—is likely to occur in response to insect and disease epidemics. Also, land being cleared for other uses, primarily urban expansion, generates much wood that is currently wasted (WFLC, 2007).

Thinnings From Timberland—Another source of forest biomass is the material generated from fuel treatment operations and thinnings designed to reduce the risk of loss from wildfire on timberlands.[3] These lands occur throughout the United States.

[3]Timberland is forestland that is capable of producing in excess of 20 cubic feet per acre per year of industrial products in natural stands and is not withdrawn from timber use by statute or administrative regulation.

Thinnings From Other Forest Land—Forest lands other than commercial timberlands may have wood volumes in excess of prescribed or recommended stocking densities that require some form of treatment or thinning operation to reduce fire hazard or to achieve other land management objectives such as controlling invasive species. Examples include pinyon-juniper and mesquite woodlands.

Primary Mill Residues—The Forest Service classifies primary mill residues into three categories: bark, coarse residues (chunks and slabs), and fine residues (shavings and sawdust). These mill residues tend to be clean, uniform, concentrated, dry, and already located near a processing facility. These traits make them excellent feedstocks for cellulosic ethanol. However, demand for these residues as an ethanol feedstock will compete with current uses such as fuel (burned to generate heat) and mulch, for which they are also well suited.

Urban Wood Waste—Urban wood wastes include wood (discarded furniture, pallets, containers, packaging materials, and lumber scraps), yard and tree trimmings, and construction/demolition wood. This can be a significant source of bioenergy feedstock depending on location and concentration; type of material; and acquisition, transport, and processing costs.

Conventionally Sourced Wood—Depending on local market conditions, wood that can be merchantable at lower size and quality specifications for conventional wood products (e.g., round pulpwood) could move between the wood products and energy markets. Some fraction of this resource may be available for bioenergy purposes, especially when pulpwood prices are low.

Short-Rotation Woody Crops—Short-rotation woody crops (SRWC) include crops such as willow, poplar, cottonwoods, sycamore, and southern pines that grow quickly in a plantation environment and can be utilized when the trees are small. A wide variety of species can be grown in many different locations, making SRWC a highly adaptable feedstock. In many parts of the country, plantations of willow, poplar, pines, and cottonwood have already been established and are being commercially harvested, primarily for pulpwood and other smallwood products.

Biorefinery Sugars—The hemicellulosic component of wood used for pulp and paper is another biofuel feedstock. Currently, about one-third of the 115 million dry tons harvested annually is used for pulp (FRA, 2005). Extracting a portion of the hemicellulose from the wood prior to pulping allows those sugars to be converted to ethanol and other chemicals. Similar opportunities exist for composite wood product manufacturing plants. However, the conversion technology is immature.

Spent Pulping Liquors (Black Liquor)—Pulping produces spent chemicals containing 35 percent of the original energy in the wood that could be used to produce liquid fuels. However, spent pulping liquors are used almost exclusively to produce heat and power for the pulping process and the feedstock may not be available for biofuels for the foreseeable future.

Dedicated Energy Crops

Residues are not the only source for cellulosic feedstocks. Certain annual or perennial crops can be dedicated as ethanol feedstocks. However, some of these potential dedicated cellulosic feedstocks are also food/feed crops, and as such would compete with food uses for agricultural land. For example, forage sorghum, which grows 6 to 12 feet tall and produces more dry matter tonnage than grain sorghum, is currently used for silage (NSP, 2008). The potential of dedicated energy crops to increase farm profits and/or decrease the variability of profits will largely dictate the extent to which farmers will plant dedicated energy crops.

A steady supply of uniform and consistent-quality biomass feedstock is necessary for large-scale viability of cellulosic ethanol production. Various perennial plants have been investigated as possible sources of dedicated cellulosic feedstocks. These include herbaceous crops such as switchgrass, Miscanthus, and hybrid poplar and willow trees. Switchgrass is currently at the center of considerable attention and research (see box, Switchgrass: A New Biofuel Crop).

Switchgrass can be cultivated on lands that are economically marginal for growing field crops, such as land in dry regions or with otherwise low-valued economic uses. A prairie grass that is native to some U.S. regions, switchgrass is well adapted to the Midwest, Southeast, and Great Plains. Several factors could favor adoption of switchgrass, including environmental benefits (carbon balances, improved soil nutrients and quality) and use of existing hay production techniques to grow and harvest the crop. Factors working against switchgrass adoption include lack of crop rotation potential; farmers' aversion to growing new crops for which they lack information and know-how; yield uncertainty; the 2- to 3-year lag—relative to annual crops—before perennial crops (in the case of switchgrass) become economically productive; and the potential to be a weedy or invasive species in some U.S. regions (USDA/NRCS, 2006; CAST, 2008). Prevailing patterns of land tenure, with farmers leasing large portions of land, could compound the economic disadvantage of the transition period and long-term investment associated with perennials.

Conversion of switchgrass into cellulosic ethanol takes place in a handful of small demonstration or pilot-scale ethanol plants. Switchgrass yields on these experimental plots vary substantially by region and growing condition—averaging about 4 to 10 dry tons/acre/year (table 2.1), though the actual range may be even wider. Switchgrass yields have been highest in the Southern and midlatitude U.S. due to long growing seasons and use of high-yielding varieties. For example, test plots in Tennessee have shown average yields at the high end of the range, while test plots in southern Iowa have shown average yields of 1 to 4 dry tons per acre (Iowa State University, 2007). Expected conversion ratios also vary substantially and are a key research focus. Table 2.1 assumes 80 to 90 gallons of ethanol can be made from 1 dry ton of switchgrass (though the theoretical maximum is 110 gallons/dry ton). The economic lifespan of a switchgrass crop is about 10 years.

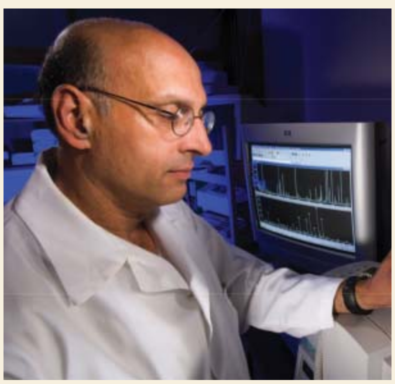
In the long run, the viability of energy crops like switchgrass or Miscanthus hinges on continued reductions in both cellulosic ethanol conversion costs and transportation/storage costs (energy crops are bulky in relation to their energy content). (Khanna (2008) provides further insights into these factors

Switchgrass: A New Biofuel Crop

Switchgrass is a promising biofuel crop because it can be grown across a wide range of conditions, can yield great amounts of biomass, establishes deep roots to store carbon in the soil and does well on marginal lands. Switchgrass is a native prairie grass long used for conservation planting and cattle feed in the United States. Interest in switchgrass for ethanol has intensified recently as the Federal Government and perhaps producers gain confidence in its potential as a bioenergy crop. With current varieties, farmers can expect switchgrass yields in the northern Plains to produce 200 to 500 gallons of ethanol per acre. Scientists are using a wide range of innovative tools to further improve switchgrass and help bring ethanol production from biomass closer to economic reality.

Switchgrass can yield almost twice as much ethanol as corn. Genetic and breeding research will improve its biomass yield and its ability to recycle carbon as a renewable energy crop

Photo courtesy of USDA Agricultural Research Service.



Chemically treated switchgrass cell wall samples are prepared for analysis of lignin content by gas chromatography-mass spectrometry. The information will be used to identify elite switchgrass plants for improved ethanol yield through plant breeding.

Photo courtesy of USDA Agricultural Research Service.

in an Illinois case study.) In addition, increasing switchgrass yields through breeding, biotechnology, and agronomic research could increase the economic viability of energy crops.

Other Long-Term Options

A wide range of carbon-containing wastes can be used to produce "advanced" biofuels, including construction and demolition debris, animal wastes, and sewage sludge. Some municipal solid wastes (MSW) have the potential to be converted directly into liquid fuels through cellulosic ethanol or other technologies. Likewise, MSW can be used to generate power at biorefineries, significantly reducing the greenhouse gas footprint and operating costs over the lifecycle of the biofuels supply chain. Currently, MSW is not being used as a feedstock for biofuels, so accurate cost-of-production data are unavailable.

One long-term possibility that would likely make minimal use of land resources is the direct production of ethanol by algae.[4] However, the conversion technologies are still in the early stages and costs are prohibitive at current energy prices (Rotman, 2008).

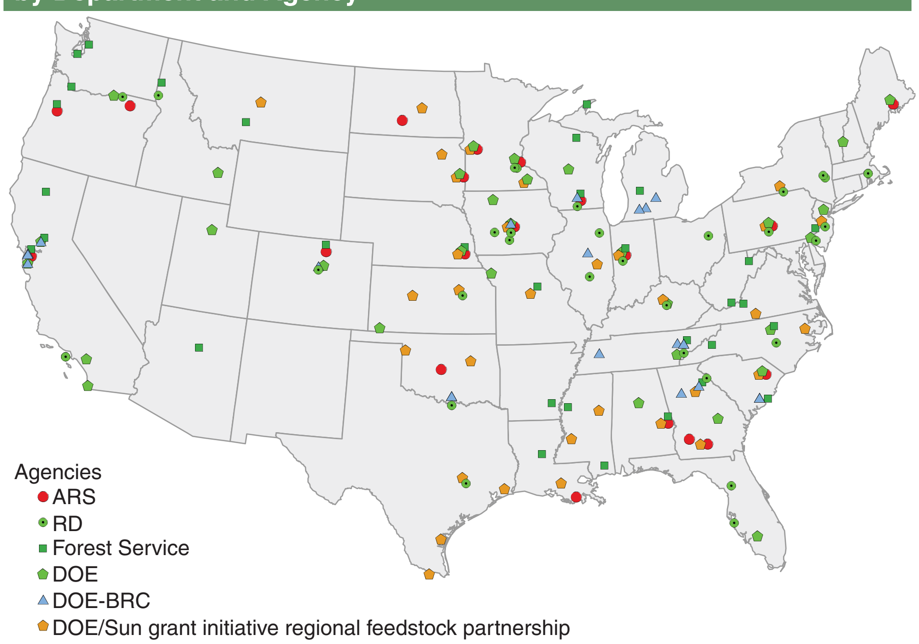
[4] http://www.renewableenergyworld.com/rea/news/ate/story?id=49831

Research Investments in Feedstocks for Biofuels

The Federal Government is investing billions of dollars in research to improve feedstock productivity and boost the efficiency of conversion to biofuels. The investments are coordinated through a variety of departments and agencies, and include collaborations with university and private sector partners, including several national laboratories. Reflecting the diverse geographic opportunities for feedstocks, the location of DOE and USDA research projects span the United States (see figures 2.5 and 2.6). In addition, the National Science Foundation has an extensive plant genomics program, with implications for feedstock improvement. And its MUSES (Materials Use: Science, Engineering, and Society) program supports projects that address biofuels sustainability.

The ***Department of Energy*** supports multiple projects to investigate alternative conversion technologies with a wide variety of feedstocks, at various scales to spur financial interest. In 2007, DOE selected six commercial biorefinery projects under section 932 of the Energy Policy Act of 2005, which made funds available for the development of six full-scale biorefineries. At present, four of the selectees have moved past the negotiation phase and have signed cooperation agreements with the DOE. Other DOE initiatives support development of small-scale biorefineries and projects to develop commercially viable cellulosic production. Core feedstock research and development goals for DOE

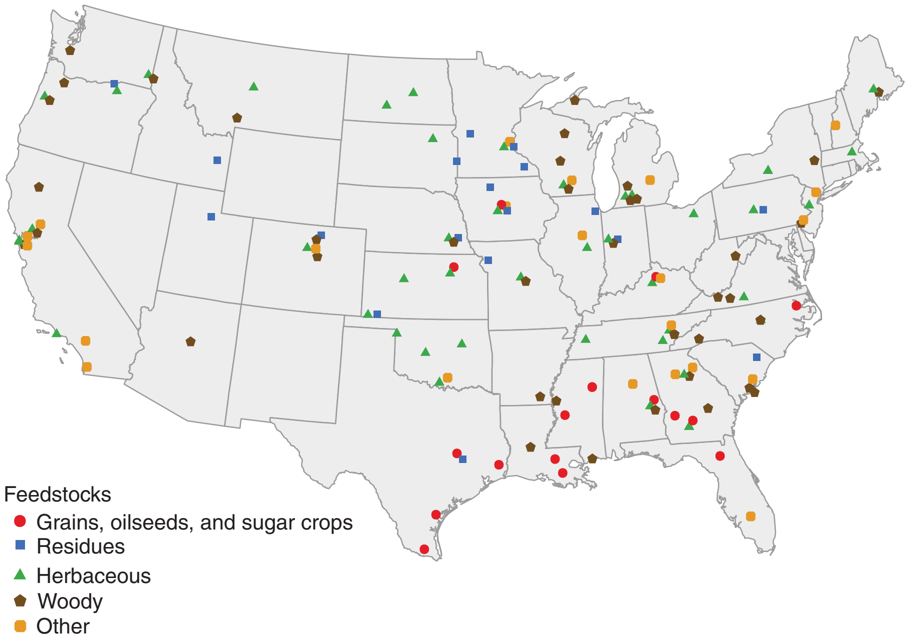
Figure 2.5
USDA and DOE research sites with a focus on biofuel feedstocks, by Department and Agency



Note: Common sites were offset slightly so they would be visible.
In many cases, this reflects cooperative efforts in the same locations.

Source: USDA and DOE, 2008.

Figure 2.6
USDA and DOE research sites with a focus on biofuel feedstocks, by feedstock



Note: Common sites were offset slightly so they would be visible. In many cases, this reflects cooperative efforts in the same locations.

Source: USDA and DOE, 2008.

include reducing production processing costs for dry herbaceous ethanol feedstocks (including harvest, storage, preprocessing, and transport) from 72 cents per gallon in 2007 to 37 cents in 2012 and 32 cents in 2017.

The ***Department of Energy*** also partners with other research organizations, universities, and the private sector to conduct cutting-edge bioenergy research:

- ***The DOE/Sun Grant Initiative Regional Feedstock Partnership*** provides support for developing the feedstock resource base identified through assessment efforts. This work includes analysis of past and existing resource development efforts and the establishment of new replicated field trials. The field trials are used to collect data on a variety of factors, including the impacts of agricultural residue removal from the field, as well as the establishment of herbaceous and woody energy crops. In 2008, 38 herbaceous crop and corn stover removal trials were initiated, with woody crop trials being added in 2009. For more information on these trials, please see http://www.sungrant.org/Feedstock+Partnerships/.

- ***Bioenergy Research Centers and Partners*** include three centers—one in the Southeast, one in the Midwest, and one on the West Coast—with partners across the Nation. Each center represents a multidisciplinary partnership with expertise spanning the physical and biological sciences, including genomics, microbial and plant biology, analytical chemistry, computational biology and bioinformatics, and engineering. Institutional partners include DOE's national laboratories, universities, private companies, and nonprofit organizations.

The ***Department of Agriculture*** supports an array of activities promoting the development of biofuel feedstocks through intramural research and partnerships with educational and other research institutions. Much of the research and support takes place within USDA's Research, Education, and Economics (REE) mission area, and through the Forest Service and office of Rural Development. USDA is developing new bioenergy crop varieties and hybrids in conjunction with improved feedstock production systems to increase energy yields per acre, maximize net energy efficiency, and minimize greenhouse gas emissions. The recently enacted 2008 Food, Conservation, and Energy Act (www.ers.usda.gov/farmbill/2008) contains numerous provisions within the Research and Energy titles that provide competitive grants and funding for feedstock development and production, pilot and demonstration plants for advanced biofuels, database development, and such programs as the Biomass Research and Development and Biomass Crop Assistance programs.

- The ***Agricultural Research Service*** (USDA/ARS), through its labs and partners develops new germplasm, parental stocks, and cultivars with value-added traits to enhance biomass yields and conversion efficiency. USDA-ARS also conducts research determining the amount of biomass feedstocks that can be produced and sustainably harvested in different U.S. regions, without disrupting agricultural diversity or compromising natural resource quality. ARS plant scientists nationwide are collaborating with ARS engineers and scientists at four major laboratories to develop the best plant varieties, crop production practices, and biorefining systems for producing bioenergy from cellulosic feedstocks. Molecular geneticists are mapping the genomes of switchgrass and model grasses so that the breeding of superior energy crops can be greatly accelerated. Biorefining or conversion research at ARS focuses on systems for onfarm power and fuel production, generating power or fuels from agricultural wastes, recycling byproducts and nutrients onfarm, and producing value-added coproducts (http://www.ars.usda.gov/research/programs/programs.htm?NP_CODE=307).

- The ***Cooperative State Research, Education, and Extension Service*** (USDA/CSREES) seeks to build a scientific knowledge base from which to use agricultural and forestry materials more effectively in nonfood products, including biofuels. Through its unique partnership with the land grant university system, CSREES is addressing the challenges of the emerging biofuels industry with grant programs that support research, development, demonstration, and pre-commercialization activities. Extension programs in bioenergy are providing outreach and formal training to encourage development and implementation of biobased technologies (http://www.csrees.usda.gov/newsroom/briefs/renewable_energy.html).

- The ***Forest Service*** (USDA/FS) executes research on forest-based feedstocks, management options, harvesting, logistics, and conversion technologies through its research stations and partnerships. Currently, the Forest Service supports research and development of bioenergy and biobased products using woody feedstocks in 33 locations in 23 States. Research activities include feedstock development, sustaining soil productivity, short-rotation woody crops, sustainable forest feedstock management systems, and feedstock harvest, collection, and delivery.

- ***Rural Development*** (USDA/RD), in conjunction with the ***Department of Energy*** operates the **Biomass Research and Development Initiative grant program**. The Initiative provides financial assistance to eligible entities to carry out research on and development/demonstration of biofuels and biobased products and practices in three areas: (1) feedstock development; (2) biofuels and biobased products; and (3) biofuels development analysis to improve sustainability and environmental quality, cost effectiveness, security, and rural economic development. USDA participation has made available over $71 million between FY 2003 and FY 2007 to 70 projects (http://www.rurdev.usda.gov/or/biz/FY07Awards9008.pdf). Future research funding under this initiative will be managed by the Research, Education, and Economics Mission Area at USDA.

The public and private sectors have long supported research on increasing the productivity of starch and sugar crops. This section highlighted the cellulosic feedstock research being supported by the Department of Agriculture and Department of Energy. Much of this research is being conducted at universities, agency research stations and labs, and national laboratories. Biomass feedstock researchers and technologists are improving feedstock quality and quantity and reducing the amount of inputs needed. Improvements in computational sciences and high-throughput systems should accelerate the development of these newer, largely nondomesticated feedstocks. Sustainable, cost-effective management systems for feedstock production are also being developed.

A number of companies previously involved in the development of traditional agricultural commodity crops and forest trees are now engaged in cellulosic feedstock development. Some companies are collaborating with universities, oil companies, private foundations, and individual States through various initiatives. Some have partnered with agency scientists and Federal national laboratories, or received funding through competitive Federal solicitations. Research is aimed at producing higher yields, improving feedstock quality and resistance to environmental stressors such as drought and pests, and devising sustainable growing methods. In some cases, yield estimates from this work exceed those presented in this report's scenarios. Success in these efforts can reduce the risks and costs of providing cellulosic feedstocks for future use.

Conclusions

This chapter surveyed the variables that markets use—for example, production costs and energy content—in determining production levels for feedstock alternatives. The wide variety of biofuel feedstocks available creates both opportunities and challenges for the biofuels industry. On the one hand, multiple feedstocks allow for biofuels to be produced in regions ranging from the rich soils of the Midwest to the dry grasslands of the Plains. On the other hand, as most of these feedstocks are of unknown economic viability, producers and processors may be hesitant to invest in technologies dedicated to a single feedstock that may become obsolete. Prior establishment in the marketplace may be one reason that "corn is king" in biofuels. Corn is deeply entrenched in U.S. agriculture, with proven yields, and years of research devoted to its growth and use. In time, other feedstocks may gain in popularity as biofuel sources, while others will prove to be cost prohibitive.

Feedstock and Biofuel Market Interactions

Policy mandates and energy prices are key factors guiding the pace at which biofuels are adopted in the domestic market. However, biofuels production—and consequently the cost and availability of feedstocks—will be influenced by a wide range of market and other policy factors. In addition to developments in energy markets and energy policies, potential policies related to carbon emissions, feedstock productivity, and conversion efficiency could influence biofuel and feedstock production incentives. Imports of biofuels, the value of biofuel and feedstock coproducts, and logistics (e.g., storage and transportation) costs are other important determinants.

Because of the inherent connection between biofuels and their source feedstocks, market changes ripple through feedstock production and prices, with implications for producer income, biofuel production costs, and demand by alternative uses for feedstocks (e.g., corn demand by livestock producers, exports). Assessing the future cost and availability of feedstocks for biofuel production therefore requires evaluation of multiple factors, and recognition of the many potential interactions between biofuels and feedstocks. This chapter underscores several main points:

- Biofuel production is influenced by a wide range of market and policy factors, each with different implications for the production and price of biofuels and feedstocks.
- Some factors (e.g., mandates, higher energy prices) that could encourage production of biofuels are also associated with higher prices for both biofuels and feedstocks.
- Factors that lower the price of biofuels and feedstocks include yield growth, improved conversion efficiency, biofuel imports, and reduced logistics costs.
- Factors that simultaneously raise biofuel/feedstock production levels and lower prices for both are yield growth and reduced logistics costs. Improved conversion efficiency would lower prices of both feedstocks and biofuels and reduce feedstock demand and production.
- A carbon price could have varied impacts on biofuel and feedstock markets, depending on the GHG profile of individual feedstocks and whether a price to curb carbon emissions would raise or lower incentives to grow that crop.

Overview of Biofuel and Feedstock Relationships

Many factors affect biofuel production, and they have numerous pathways by which they affect the cost and availability of feedstocks. Each factor is discussed separately to illustrate the distinct role that mandates or feedstock productivity, for example, play in creating incentives to produce and convert feedstocks into renewable fuels. However, biofuel and feedstock production are jointly determined by factors that influence demand and those that affect supply, and these variables will work in concert to guide outcomes.

Factors affecting the quantity demanded and the price blenders and consumers will pay for biofuels include energy policies, prices of energy substitutes, and, potentially, carbon policies (fig 3.1a). Incentives to supply biofuels depend largely on the relationship between biofuel prices and costs associated with procuring feedstocks (production, harvest, storage, transportation), as well as other input costs and conversion efficiency. Trade in biofuels could also affect domestic biofuel production if price differences between foreign and domestic markets are large enough to induce either exports or imports.

Feedstock demand, in turn, reflects developments in the biofuels markets. But just as biofuels production is affected by an array of factors, feedstock markets balance competing demands with the resources available for production. For example, increased demand for biofuel feedstocks reverberates through the feedstock sector as biofuels compete for inputs ([1] in fig. 3.1b), as well as competing against nonbiofuel uses for feedstocks ([2] in fig. 3.1b). Increased demand for feedstocks currently used in biofuel production (primarily corn and soybean oil)—for increased biofuel production or for alternative uses, such as corn for animal feed or export—will result in higher prices for all consumers of that feedstock. Feedstock yield gains, improved biofuel conversion efficiency, and development of technologies that can utilize different feedstocks could lessen this competition.

These simple relationships are key drivers, but belie the full scope of these interactions. As demand for biofuel feedstocks increases, agricultural producers may grow more biofuel feedstocks and less of other crops. But even if feedstock production rises, higher demand-induced prices and increased production work their way back into the supply side of the biofuel market—by increasing feedstock production costs or affecting the value of coproducts (which can alter production incentives) ([3] in fig. 3.1b).

Market dynamics, research, and policies cause the supply and demand for biofuels and feedstocks to expand or contract over time. But some factors that directly boost demand for biofuels—such as higher energy prices or policies to limit carbon emissions—could actually reduce incentives to supply feedstocks, even as demand for them increases. For example, higher petroleum prices should stimulate biofuels demand, but can reduce supply at any given biofuels price by raising the costs of feedstock production, transportation, and conversion. Similarly, a carbon policy placing an explicit value on carbon storage or abatement may raise the relative value of biofuels that have lower carbon emissions, but may also affect feedstock production by promoting conservation practices (e.g., no-till, reduced energy and fertilizer use) that could restrain yield growth or raise the cost of feedstock production. Recognizing these interactions can help to clarify tradeoffs, anticipate outcomes, and indicate research and development priorities.

Figure 3.1a
Biofuel market

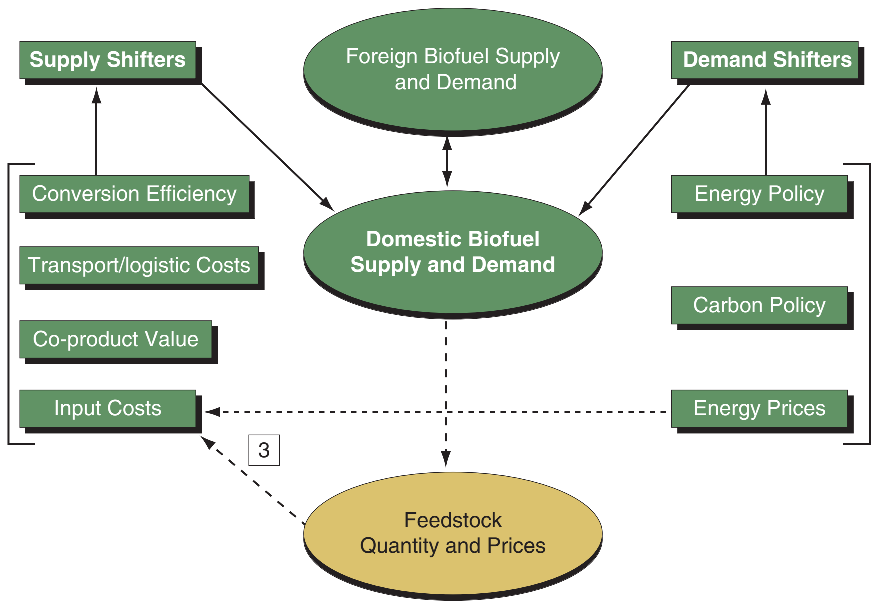
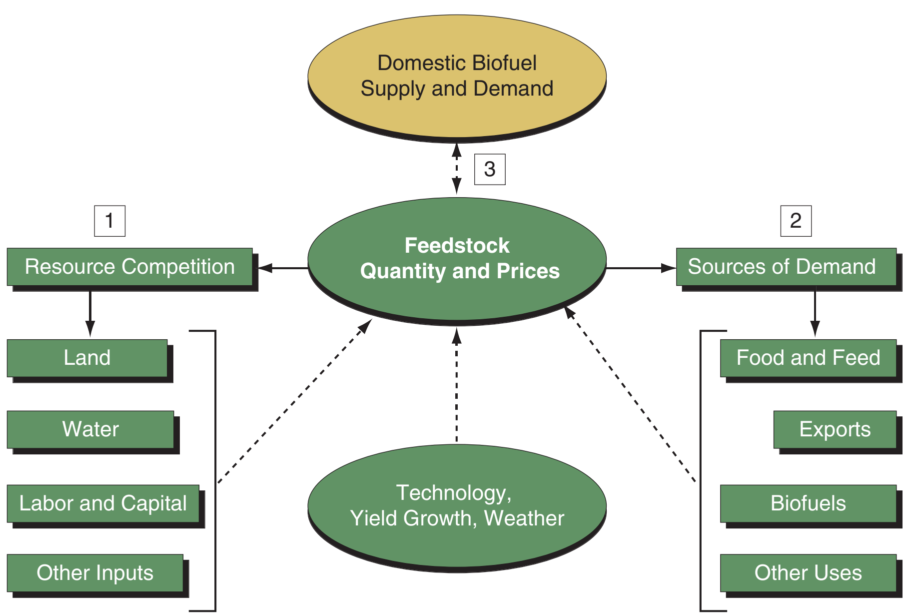


Figure 3.1b
Feedstock market



Biofuels Compete for Resources and Draw Feedstocks From Other Uses

In contrast to finite petroleum resources, biofuel feedstocks such as agricultural crops, dedicated energy crops, and crop residues are attractive, in part, because they are renewable. At the same time, the availability of these renewable feedstocks relies on resources that are fixed or limited, including land, irrigation water, labor, and capital (both physical and financial). Increased demand for these resources [(1) in fig 3.1b] raises the cost of producing feedstocks which, in turn, affects input costs for biofuels producers.

Feedstocks are also in demand for other uses. For conventional first-generation biofuel feedstocks such as corn and soybean oil, production and prices have traditionally been governed by domestic demand for livestock feeding, direct food consumption, and demand from foreign buyers [(2) in fig 3.1b]. Enhanced biofuel demand and competition for feedstocks has already had tangible impacts on agricultural markets—raising the price of traditional feedstock supplies and shifting the allocation of cropland toward biofuel feedstocks ([3] in fig. 3.1a and 3.1b).

Biofuel Mandates and Impacts on Feedstock Prices

The market for biofuel feedstock alternatives can be affected by government legislation specifying the overall volume and type of renewable fuels. Hence, simply meeting feedstock-specific mandates may drive some of the relative demand among certain feedstocks.

If the mandate for biofuels is binding (that is, the mandate is set at a level that exceeds the amount of biofuels that would be used in the absence of a mandate), the fuel blender will have to pay whatever price is necessary to induce refiners and feedstock providers to supply the level needed to meet the mandate. This increase in demand will, thus, increase both the domestic price and quantity of feedstocks, assuming no other changes such as productivity growth or increased imports (see box, “Market Mechanisms and Biofuel Mandates”). A mandate is more likely to be binding, and to affect the market equilibrium, at lower fossil fuel energy prices, higher feedstock prices, and in the absence of other production inducements such as the Volumetric Ethanol Excise Tax Credit.[1]

Feedstock costs are the largest component of biofuel production costs, and biofuels account for a growing share of U.S. feedstock demand. As feedstock demand increases, supply growth may not be able to keep pace, which places upward pressure on prices—both for biofuel crops and for all other crops that vie for land and other resources. Consequently, biofuels production affects the entire agricultural system, causing adjustments to the allocation of production and prices across multiple commodities.

The Benefits of Research: Feedstock Productivity Growth and Use of New Feedstocks

At the broadest level, research aimed at improving technologies used in feedstock production and conversion could increase feedstock availability and reduce the quantity needed to achieve any biofuels target, lowering feedstock prices and making more available for other uses. For example, research supporting higher yield growth or technologies to extract more biofuels from a given amount of feedstocks can reduce per-unit production costs and bolster supply at any given price for biofuels. For a given quantity of biofuels, higher yields and improved conversion processes could simultaneously increase the overall availability of feedstocks and reduce the share required by biofuels producers. In general, this would mitigate competition between biofuel and nonbiofuel uses of feedstocks.

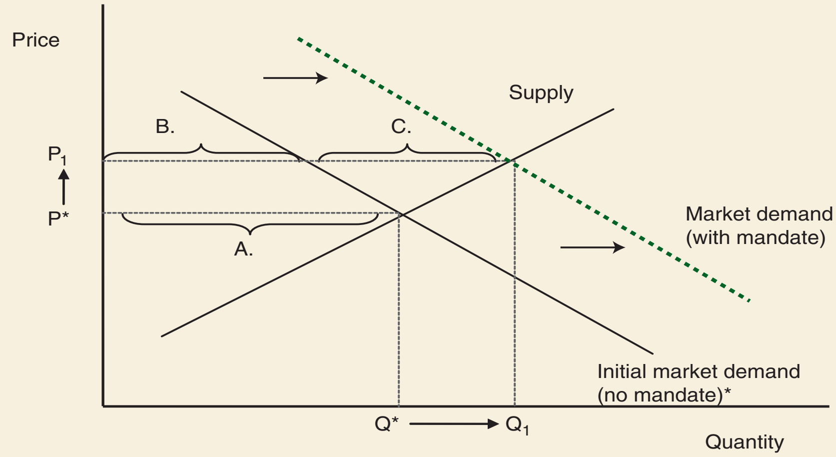
[1] The Volumetric Ethanol Excise Tax Credit (VEETC) is currently $0.51/gallon, but the 2008 Farm Bill lowers that rate to $0.45/gallon in the first calendar year after annual production or importation of ethanol reaches 7.5 billion gallons. Ethanol use is on pace to approach 9 billion gallons for 2008, so the VEETC is expected to fall in 2009.

Market Mechanisms and Biofuel Mandates

A policy mandate dictating increased biofuel use causes the quantity demanded for biofuels at any given price to increase. Taking the market mechanism for a representative feedstock with alternative uses as a starting point (see box in chapter 2), the demand from existing feedstock users (e.g., corn for livestock feed) is then supplemented with new demand from biofuel producers (e.g., corn for ethanol) to shift the overall feedstock demand curve to the right. Thus, the distance between the two demand curves represents the quantity of feedstock required to meet the mandate. (To better illustrate the aggregate effect, demand curves for each individual use, depicted in chapter 2, are omitted from this figure, but do underlie the framework. The chart assumes no demand for the feedstock from biofuels producers until the mandate is enacted.) This rightward shift in the demand curve increases prices. Feedstock producers respond to the higher price by increasing production to Q_1 from Q*, and this movement up the supply curve means production gets more expensive (perhaps because of increased fertilizer use or production on land less suitable for the feedstock). At the new equilibrium, prices are higher for all consumers of the feedstock. If the policy mandate is binding (manufacturers are producing to satisfy the mandate), biofuel producers will outcompete other users of the feedstock, purchasing a quantity of C—even at the higher prices. Other consumers will also pay a higher price, but purchase less than if the mandate did not exist (quantity B instead of quantity A).

This discussion assumes that the biofuel mandate is binding over the range of prices shown. Also, the mandate does not require that the entire output be used for biofuels (e.g., some portion would always go to other uses). Relaxing either assumption would generate a kink in the demand curve. This figure represents a single feedstock with multiple uses, not a dedicated biofuel feedstock such as switchgrass. A mandate-induced shift in demand for a dedicated feedstock would also result in increased quantities and higher prices for that feedstock as a new demand curve materializes, but the figure would look different (not depicted). The market demand and biofuel demand curves would be the same. Biofuel producers using the dedicated feedstock would not compete directly with other users, but the new demand would still force adjustments—such as reduced supplies and higher price—in other markets that compete for land and other resources. Above a certain price, the demand curve could be kinked, with a steeper (less price responsive) section at a quantity sufficient to comply with the mandate.

Impact of biofuel mandate on the market for a feedstock with multiple uses



*Assumes no pre-existing biofuels production.

Like any other forecasting exercise, forecasting crop yields is very imprecise. Crop yields may increase because of increased input use or technological change. Technological change, in turn, can come about through increased genetic yield potential; greater resistance to pests, diseases, or drought; or through management innovations. These sources of increased crop yields can be interrelated, as when genetic improvement leads to varieties that are more responsive to fertilizer application.

Substantial precedent for productivity growth exists. Much of the growth in U.S. agricultural productivity since the 1930s is due to a series of biological innovations embodied in major crop seeds—in particular, corn, cotton, soybeans, and wheat (Fernandez-Cornejo, 2004). These innovations resulted from investments in crop variety research and development (R&D) in both the public and private sector. Just as in traditional commercial agriculture, biofuel feedstock productivity gains could offset some of the feedstock price impacts of increased demand and help overcome resource constraints. Research focusing on yield growth, development of feedstocks that can grow on marginal lands, or the development of crop varieties allowing more intensive use of existing land (e.g., double-cropping) could mitigate price pressure by increasing the overall supply of feedstocks and lowering costs for biofuels producers. Research gains could also offset the effects of demand shifts, such as from a binding biofuels mandate (see box, "Market Mechanisms and Productivity Gains").

Likewise, research on energy efficiency in feedstock production and biofuel conversion, and on feedstock traits that enhance yields such as drought tolerance and improved fertilizer uptake, could lessen the need for energy using inputs and temper the impact of higher energy prices on feedstock and biofuel production costs.

A variety of economic studies have found that returns to agricultural research are high. These returns include benefits not only to the farm sector, but also to the food industry and consumers in the form of more abundant commodities at lower prices. Based on a sample of 27 studies that estimated economic returns to public agricultural research in the United States, the median rate of return was 45 percent per year (Fuglie and Heisey, 2007). In comparison, the real rate of return on government securities in recent years has been 3-4 percent, and even lower in 2008.

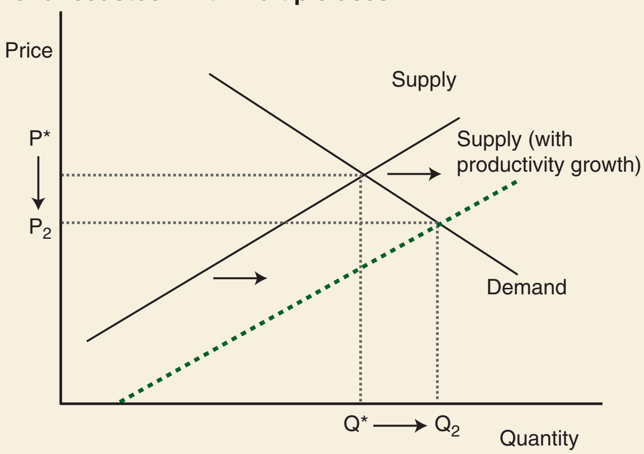
This conceptual analysis illustrates the potential benefits of research. The magnitude of potential shifts is an empirical question, which ultimately will determine the returns to research investment. The nature of research is such that those investments must be made well before their (uncertain) gains are fully realized. Substantial public investment in biofuel research and development is underway across a broad spectrum of the Executive Branch (see chapter 2). In addition, though R&D investment can have uncertain outcomes, the potential gains are enough to spur private investment. Private R&D investment can already be seen in conversion technologies, but may not be as strong for feedstocks with less established markets or with benefits that are difficult for the innovator to capture.

Market Mechanisms and Productivity Gains

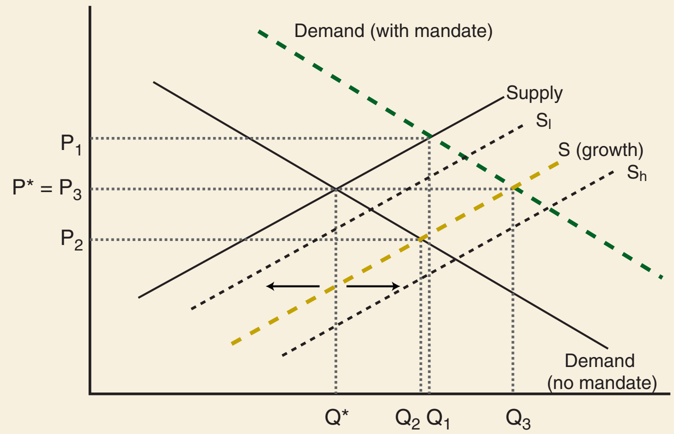
Investment in research and development leading to technologies that enhance feedstock yields without increased land and resource use would unequivocally reduce prices and increase feedstock production, all else constant. When combined with other adjustments, the outcome could be a bit more complicated. Increased productivity would shift the entire feedstock supply curve to the right (see first figure). Market adjustments would result in an increased quantity of feedstocks at any given price and a lower equilibrium per-unit price (equilibrium quantity shifts from Q* to Q_2, and equilibrium price drops from P* to P_2).

If a policy-led demand shift, e.g., due to a binding biofuel mandate, is combined with a productivity-induced supply shift, the quantity of feedstock supplied to the market would increase beyond the level realized under either shift in isolation (see second figure). The equilibrium feedstock price would be lower than with the mandate alone, and higher than with the productivity growth shift alone, but could be either higher, lower, or the same as the original equilibrium price (P*), depending on the size of the shift and the price responsiveness of the market supply and demand curves. The productivity growth-induced supply shift depicted as S (growth), combined with the mandate-induced demand shift would leave price untouched (P_3 = P*), but a greater quantity (Q_3) would be available at that price. A lower productivity increase (resulting in the supply curve labeled S_l) would lead to a higher price than P* and a higher productivity increase (S_h) would lead to a lower price than P*.

Impact of feedstock productivity growth on the market for a feedstock with multiple uses



Impact of productivity growth combined with mandate on the market for a feedstock with multiple uses



P*, Q* = baseline equilibrium
P_1, Q_1 = equilibrium with mandate
P_2, Q_2 = equilibrium with productivity growth
P_3, Q_3 = equilibrium with productivity growth and mandate

S_l = supply with low productivity growth
S (growth) = supply with moderate productivity growth
S_h = supply with high productivity growth

Successful R&D efforts could also improve conversion efficiency, decreasing the amount of feedstock needed to produce a gallon of biofuel. The effect of improved conversion efficiency would be opposite to that of a new biofuels mandate, with the feedstock demand curve shifting back toward its original location, thus lowering the price even as the quantity of feedstocks declines (the reverse of the shift illustrated above).

Note: Similar to the previous box, the charts depict a feedstock with multiple uses (e.g., biofuels and livestock feed). In the price range shown, the mandate is binding and the feedstock is allocated between the uses based on shifts in supply and demand.

The Value of Research: Conversion Efficiency

Conversion efficiency is an important determinant of the cost of biofuels production (fig 3.1a). Conversion efficiency will vary with the technology used to transform a feedstock to a liquid renewable fuel, and by feedstock type. For any feedstock, efficiency gains can be measured simply as improved extraction of biofuel from each unit of input at a given cost.

By increasing the conversion efficiency of existing (e.g., corn) or potential feedstocks (e.g., corn stover, switchgrass), the quantity required to meet any particular biofuel production goal is reduced. The impact of improved conversion efficiency would be opposite to that of a binding biofuels mandate, lowering both feedstock prices and the quantity of feedstocks used to produce biofuels. This would reduce price pressures and raise the quantity available for nonfuel uses of feedstocks, alleviate pressures on natural resources, and potentially resolve some of the logistical challenges associated with feedstock transportation and storage. Consumers and biofuel producers would benefit, but farmers could see profits decline with the price reductions.

As an example, converting corn to ethanol typically produces about 2.6 to 2.8 gallons of ethanol from 1 bushel of corn. Improved technologies or different processes could theoretically be used to extract additional fermentable material from the corn kernel, and breeding corn for a higher carbohydrate content could raise ethanol output per bushel of corn above current rates. Research to improve the quality traits of existing biofuel feedstocks could work in tandem with yield improvements to reduce the quantity of feedstocks required by the biofuel sector and lower feedstock prices.

Petroleum Prices, Biofuel Demand, and Feedstock Input Costs

Petroleum prices are another vital determinant of biofuel supply and demand. As substitutes or additives to conventional gasoline and diesel, biofuel demand is directly enhanced by higher oil prices (assuming biofuel demand is determined primarily by market forces rather than a mandate). While this relationship is relatively straightforward, other complex interactions exist between energy markets and feedstock markets.

Increased biofuel production affects feedstock production and raises prices by competing for resources and vying with other users. Higher oil prices (and, consequently, higher biofuel prices)[2] help biofuel producers accommodate these higher costs, but indirectly affect supply by raising input and transportation costs for biofuel feedstock producers (depicted in fig. 3.1a by a dashed arrow between energy prices and input costs).

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 fertilizers, also contribute meaningfully to operating expenses (e.g., natural gas accounts for a large share of nitrogen fertilizer costs) for some crops. Increased production costs would result in a higher equilibrium price and a lower quantity of feedstock. (This interaction would be represented in a supply/demand figure by a shift in the supply curve to the left, reducing the quantity supplied at any given feedstock price; this is the inverse of the figure in the box depicting the effect of productivity growth).

The impacts of higher energy prices vary by type of feedstock. The impact depends on the energy intensity (the share of energy costs in total operating costs) of the feedstock being produced, as well as the volume and mass of the feedstock being delivered because bulkier and heavier feedstocks are more expensive to transport.

[2]The higher biofuels price assumes that biofuels are a substitute for petroleum fuels. If higher petroleum prices are the result of reduced supplies, biofuel prices could decline if biofuels are used only as an additive in fixed proportion to petroleum fuels.

For example, energy costs account for roughly half of operating costs for crops such as wheat, corn, and sorghum, but less than one-quarter of operating costs for soybeans and cotton. Consequently, rising energy prices, by themselves, would normally induce a switch from energy-intensive crops such as corn to less energy-intensive crops like soybeans. Higher energy prices would also reduce incentives to use fertilizers and irrigation, perhaps lowering yields, but feedstock producers may be willing to invest in improved irrigation technology or adopt new management practices (e.g., soil nutrient testing) if the returns outweighed the costs. Higher energy prices may also hasten the production of dedicated energy crops (e.g., switchgrass) if their production and handling costs are less energy intensive.

Carbon (Greenhouse Gas) Emissions and the Value of Biofuels

The emission of carbon and other greenhouse gases (GHGs) may have adverse effects on the environment or other attributes (e.g., health) that may not be reflected in market prices. Carbon policies can be used to reduce these effects by establishing a price to be paid on these emissions. Carbon policies, if enacted, would be another potential demand driver for biofuels that may also indirectly affect feedstock production incentives.

For example, policies that create incentives to use fuels with a more favorable GHG profile may raise biofuel demand by changing the price relationship between biofuels and petroleum fuels. Or a carbon policy that discourages the use of any GHG-emitting fuel may reduce overall demand for all transportation fuels, including biofuels, even if the proportion supplied by biofuels increases. A carbon price may also affect feedstock production by penalizing energy- (and hence carbon-) intensive crop production practices, or by encouraging land-use decisions that sequester carbon. The extent to which a carbon market would affect these decisions depends on a number of factors, including the carbon price, the policy mechanism (e.g., a "cap and trade" system or carbon tax), the lifecycle reduction in GHGs associated with biofuels made from different feedstocks, and how strongly input costs and incentives to sequester carbon affect feedstock production decisions.

Currently, there is no U.S. policy-mandated system such as a carbon tax or "cap and trade" system that places an explicit value on GHG reductions, but voluntary markets for practices that reduce emissions or sequester carbon—carbon "offsets"—have emerged in the United States and Europe. Under a "cap and trade" system, entities required to cap their emissions at a certain level may be allowed to purchase "offsets" from others outside of the "cap and trade" system, potentially including agricultural producers, to meet some of their emission-reducing commitments. Or a carbon price could be imposed as a tax on all fuels or carbon-intensive practices that release carbon into the atmosphere.

For the biofuel producer, a carbon price can support production incentives if it creates demand for a lower-emission biofuel from blenders, retailers, or consumers who have a financial incentive to substitute biofuels for conventional fuels. Higher carbon prices or biofuels with a greater reduction in lifecycle carbon emissions would presumably amplify any such incentives, but the net impact on biofuel demand would depend on how carbon prices affect overall transportation fuel use (and the extent to which biofuels can substitute for petroleum fuels).

As with higher energy prices, a carbon price would affect feedstock production decisions and prices. For feedstock producers, there are two ways to reduce GHG emissions: through changes in farm operations, such as reduced fertilizer use or lower energy use in field operations (planting, harvesting); and through changes in tillage (no-till) and other land-use practices (e.g., fallow, planting trees) that sequester carbon. If a carbon policy creates incentives for agricultural producers to adopt either strategy, feedstock producers would weigh the benefits of potential carbon “offset” payments against increased costs or forgone production due to lower input (energy) use, reduced cultivation, and altering other management practices that produce GHGs. This could reduce production and raise prices of conventional feedstocks—particularly among crops that use a lot of energy, such as corn—but may spur growth of cellulosic feedstocks (e.g., switchgrass, forestry) if they sequester carbon and the value of this sequestration is marketable.

Consequently, many uncertainties surround the impact of a carbon price on feedstock production and prices, and the supply effects could vary by feedstock. Market prices and quantity purchased will also depend on how demand for individual feedstocks evolves. If demand changes outweigh supply effects, then higher demand will raise both prices and production and lower demand will do the opposite. The many factors that must be taken into account make it difficult to predict the impact of carbon prices on feedstock prices and quantities. Again, any research that would improve energy efficiency, yield growth, and conversion efficiency would help biofuel and feedstock producers adjust to carbon prices.

Global Biofuel Supply and Import Restraints

Although the United States is the world’s leading producer of biofuels, global production and foreign demand could interact with the domestic biofuels market if price relationships make exporting or importing biofuels economically attractive. Strong foreign demand and high foreign prices could stimulate U.S. exports. However, continued rapid growth in domestic renewable fuels demand suggests that U.S. prices may be sufficiently strong to attract additional imports from foreign producers, if their production costs and demand situation result in lower prices (see box, “Overview of Biofuels Trade”). To compete in the U.S. market, the price of foreign biofuels would have to be low enough to more than cover the costs of transportation and any tariff (currently 54 cents per gallon of ethanol for most countries) imposed on U.S. imports.

If imports become more economically viable, they would reduce demand and lower prices for domestically produced biofuels, resulting in a lower level of production than would have occurred without imports. However, lower prices would stimulate an increase in the total quantity consumed. Imports would also affect domestic feedstock markets by reducing demand and prices for feedstocks used in the domestic production of biofuels. This would ease price pressures on U.S. feedstocks. The amount of biofuel imports and how they affect U.S. feedstock markets may also hinge on the extent to which a binding mandate that varies by type of feedstock creates distinct markets for corn-based ethanol, biomass-based biodiesel, other advanced biofuels, and cellulosic biofuels.

Overview of Biofuels Trade

Currently, biofuels trade accounts for 10-15 percent of total global production. Leading producers generally face strong internal demand, and ethanol (which represents over 80 percent of global biofuels production) faces high tariffs in most countries. In 2007, the United States accounted for roughly 45 percent (7 billion gallons) of global biofuel production, with the European Union (EU) and Brazil accounting for most of the remainder. Brazil—with its low-cost sugar-based production of ethanol—is the only country that exports a meaningful quantity of ethanol, exporting roughly 900 million gallons in 2007, or about 50 percent of world exports. The U.S. is the world's leading importer of ethanol.

Different countries use a wide variety of feedstocks in biofuel production, reflecting domestic availability of feedstocks and policy goals. While initially relying on corn as a feedstock for ethanol production, China—the world's fourth leading ethanol producer—has shifted focus to cassava and sorghum to limit the use of corn for nonfeed purposes (Coyle, 2007). Feedstocks such as wheat, palm oil, cassava, and jatropha are also being adopted in various countries, including India, Malaysia, and Indonesia.

In the United States, renewable fuel imports have usually—with temporary exceptions—comprised a relatively small share of domestic consumption. This is because the tariff-inclusive cost of importing ethanol has generally exceeded domestic ethanol prices. Since the 1980s, the U.S. has maintained as part of its energy policy a tariff on ethanol from most countries, which currently stands at 54 cents per gallon (scheduled to expire in January 2009).[1] Under NAFTA, imports from Canada and Mexico enter duty free, but renewable fuel production in those countries is very limited. A separate trade agreement permits countries of the Caribbean Basin Initiative (CBI) to supply up to 7 percent of U.S. ethanol consumption duty-free. Much of the ethanol imported into the United States comes directly from Brazil or is routed through the CBI countries to avoid the tariff. In 2000, the U.S. imported 68 million gallons of fuel ethanol. Imports rose to a record 659 million gallons in 2006 before declining to 441 million gallons in 2007 (about half of which came from the CBI).

[1]The ethanol tariff was instituted shortly after tax credits were implemented for ethanol blending in the early 1980s. The current (2008) 51-cent-per-gallon volumetric ethanol excise tax credit applies to all ethanol regardless of whether it is produced domestically or imported.

As the United States is the world's leading producer and exporter of corn, foreign corn-based ethanol is unlikely to emerge as a viable competitor to U.S. corn-based ethanol production. It is difficult to anticipate how rapidly technologies and costs of cellulosic biofuel conversion will evolve abroad, but investment to enhance cellulosic feedstock yields, improve quality traits, and maximize conversion efficiency are vital to domestic cellulosic biofuel prospects. If research and development advances and the large quantity of potential feedstocks make the United States the low-cost producer of cellulosic biofuel, imports of these renewable fuels would be unlikely.

On the other hand, sugar-based ethanol from Brazil and other countries may fill more of the U.S. demand for biofuels if domestic feedstock costs are high. Similarly, the goal of 1 billion gallons of biodiesel starting in 2012 could be met partly by increased imports of biodiesel, which faces a small tariff, or by increased imports of vegetable oils as a feedstock (the U.S. is a net exporter of soybean oil but a net importer of all vegetable oils).[3] Whatever the level or type of biofuel, increased imports (holding other factors constant) would reduce the quantity of domestically produced biofuels, which would reduce demand for biofuel feedstocks. This would lower feedstock prices for all feedstock consumers, and raise the share consumed by nonbiofuel feedstock users.

Biofuel legislation in a biofuel exporting country may limit its total potential for exports. For instance, if legislation in another country requires that all domestically sold automotive fuels be blended with some proportion of ethanol, then fuel blenders in that country will likely act to keep sufficient ethanol on hand to meet their own minimum blending requirements.

Value of Biofuel Coproducts

Creating new uses or enhancing the demand for coproducts raises the returns to any particular production activity, and makes increased production more attractive even if the price of the primary product remains the same. The value of coproducts can have a substantial impact on the economic viability of renewable fuels production (fig. 3.1a). For biofuels, the price of coproducts associated with both feedstock production and conversion affect economic incentives by changing the quantity of the primary product (e.g., ethanol) producers are willing to supply at any given price. If the coproduct value is associated with agricultural production, the producer will adjust production up or down to reflect the changing price of the coproduct (a feedstock supply shift). If the coproduct comes from the conversion process, an increase in its value is reflected back to the feedstock producer as a demand shift for the biofuel feedstock. Either way, a coproduct with increased market value raises the quantity of the feedstock produced, but the feedstock price will go up if the coproduct is produced by the biofuel facility and down if the value of the coproduct is captured directly by the agricultural producer.

Dried distillers' grains (DDGs), an animal feed that can substitute for corn in some livestock rations, is a coproduct of dry-mill corn ethanol production. Despite nutritional characteristics that limit its use for some livestock and some marketing issues, higher corn prices and increased DDGs availability have established a market for this product, and the price of DDGs is an integral part of the profit calculation for an ethanol producer. Improved quality, consistency, and the development of export markets could further increase the value of DDGs and support ethanol production incentives. The ethanol producer is willing to purchase more corn and produce more ethanol if the price of DDGs climbs, thus raising the demand for corn.

Other examples of coproducts of biofuel feedstocks include soybean meal (a coproduct of soybean oil processing used as an animal feed) and crop residues (e.g., corn stover). Coproducts of the renewable fuel conversion process include carbon dioxide (for beverage and other uses) from dry-mill corn ethanol production, glycerin (for cosmetics and other uses) from biodiesel production, and lignin (for cofiring or chemicals) from cellulosic ethanol production.

[3] The United States is currently a net exporter of biodiesel, but much of it is imported from Malaysia, Indonesia, and Argentina, and then re-exported after blending with petroleum diesel. Until October 2008, these exports were eligible for the same $1-per-gallon tax credit available for biodiesel blended for domestic use. Legislation (HR-1424) enacted in October 2008 clarified that the credit does not apply to biodiesel produced and used outside the United States.

If corn stover (or other crop residues) becomes a marketable feedstock for cellulosic ethanol production, this coproduct of corn production could expand the incentive to produce corn since it adds value to the farm enterprise. The price of corn grain may decline if corn stover replaces some of the feedstock demand for corn, but overall returns to the corn sector will likely improve. Similar arguments apply for potential uses of other coproducts, but in some cases increased biofuel production has significantly decreased the value of existing coproducts. For example, glycerin prices have slumped as new supplies have saturated the market. Some biofuel companies are attempting to increase the value of coproducts through branding (e.g., DDGs) and the development of niche markets (e.g., kosher glycerin).

Logistics and Transportation Issues

One of the fundamental challenges to the increased production and distribution of biofuels is managing the increased demands on the feedstock transportation and storage infrastructure, and developing more efficient modes of distribution for biofuels. If logistical improvements make biofuel feedstocks less expensive to deliver and store, feedstock supply would shift out (to the right), which would lead to increased availability of feedstocks and lower prices. This is particularly relevant for feedstocks of nascent biofuels such as corn stover, dedicated energy crops, or forestry resources, which have not yet established a harvest, transportation, and storage infrastructure for biofuels use. If these issues are resolved, improved marketability would allow feedstock producers to achieve higher returns.

Logistical Issues for Conventional First-Generation Feedstocks

Because biofuel facilities can reduce per-unit conversion costs by operating at a large scale, they tend to draw feedstocks from up to 50-75 miles away, which causes the cost of transporting those feedstocks to rise. And because of their large capital costs, biofuel facilities require year-round supply to operate continuously, which introduces feedstock storage capacity and quality retention issues.

The existing infrastructure for corn grain and soybeans (oil) is well-established—with harvesting, storage, and distribution systems that have evolved over decades—and ethanol producers are typically located within corn production regions. Transportation of corn to the ethanol facility is usually via the "just-in-time" delivery model, and drying allows for stable storage. Corn is also relatively dense, which reduces the number of trips and delivered cost (per unit of weight). Corn also benefits from well-established grading and quality criteria, and easily accessible public information on production, prices, and stock levels. For corn ethanol, the primary logistical issues in the near term will be adding storage capacity for increased corn production and accommodating increased truckload requirements to ethanol plants.

Unique Challenges for Second-Generation Ethanol

The logistics and transport of cellulosic biomass is more challenging than for corn. Crop residues and dedicated energy crops are bulkier, more expensive to transport, harder to dry and store, and lacking in established quality standards and sources of market information. Crop residues and herbaceous energy crops can be handled like hay, but storage and transportation issues are more challenging if the feedstocks are destined for a large, centralized biofuel facility. Research in this area may focus on developing bulk harvest and handling systems that allow economic handling, storage, and transport—for example, using multiple feedstocks with differing harvest windows, extending single-crop harvest windows, or moving feedstock processing forward in the supply chain from the conversion facility to areas nearer feedstock production.

Biofuel Distribution Issues

Most ethanol is currently produced in the Nation's interior, but 80 percent of the U.S. population (and implied ethanol demand) lives along its coastlines. Developing an infrastructure to transport biofuels from production facilities to end-users at a lower cost would increase the supply of biofuels at any given price, and consequently raise the demand for feedstocks. Distribution by pipeline is the most economical way to transport liquid fuels, but compatibility issues between existing fuel pipelines and ethanol require that most ethanol be transported by rail or truck operations, which are more expensive. If ethanol is produced from cellulosic feedstocks (which will probably be more geographically dispersed than corn ethanol production), the geographical balance between ethanol production and demand would probably improve. The development of dedicated ethanol pipelines or overcoming current compatibility issues could lower distribution costs.

Implications for Food and Feed Prices

Food prices have risen globally and domestically, driven by a variety of factors. The extent to which biofuel demand for feedstocks is driving food expenditures is a matter of debate. As noted, corn prices have increased, and higher corn prices increase animal feed and ingredient costs for farmers and food manufacturers. However, those price increases pass through to U.S. retail prices at a rate less than 10 percent of the change in corn price. Given that foods using corn as an ingredient make up less than a third of retail food spending, overall retail food prices would rise less than 1 percentage point per year above the normal rate of food price inflation when corn prices increase by 50 percent. Even this increase may be partially tempered by changes to corn use in food production (Leibtag, 2008). Overall, the Consumer Price Index (CPI) for all food is forecast by USDA to increase 5 to 6 percent in 2008 as higher commodity and energy costs continue to be reflected in retail prices to consumers (http://www.ers.usda.gov/Briefing/CPIFoodAndExpenditures/ updated October 24, 2008).

Increased U.S. demand for corn ethanol also has global impacts. The United States typically accounts for 60-70 percent of world corn exports (Westcott, 2007), so increases in U.S. domestic demand for corn will increase international corn prices. And overseas demand for U.S. corn exports (primarily for use as livestock feed) is currently strong, due in part to fast growing Asian economies (FAO, 2008).[4]

Increases in the world price of corn and other crops is particularly significant for food consumers in developing countries—whether due to biofuel

[4]Part of the strong export demand for U.S. corn is also due to the depreciation of the U.S. dollar.

demand in the U.S. and other developed countries or to other factors such as increased energy prices, changes in global food consumption patterns, exchange rate adjustments, or local supply disruptions (Trostle, 2008). In these countries, food tends to be a larger portion of household expenditures than in developed countries. On the other hand, foreign crop producers can generally benefit from the increase in world crop prices. In summary, the effects of higher crops prices filter through many sectors, both domestically and globally.

Conclusions

This chapter provides an analytical overview, with some brief examples, of how a range of factors influence economic incentives to produce, transport, and convert feedstocks into renewable fuels. These factors include government policy, technologies for feedstock production and conversion, and energy prices. Table 3.1 summarizes the expected impacts of these and other variables on biofuel and feedstock quantities and prices ("↑" indicates an increase, "↓ " a decline, and "↕" an indeterminate effect). To isolate the effects of each individual factor, all other factors are assumed to be unchanged.

The main point to be drawn from the table is that factors affecting biofuel production have attendant (and predictable) impacts on biofuel prices, feedstock prices, feedstock production, and the distribution of feedstock consumption between biofuel and nonbiofuel uses. Consequently, these impacts often entail tradeoffs between the interests of different groups. For example, some individual factors that stimulate biofuels production (e.g., biofuels mandate, higher energy prices) are associated with both higher biofuel and feedstock prices. However, a research thrust supporting feedstock yield and productivity growth, conversion efficiency, and improved feedstock logistics could simultaneously lower feedstock prices, increase the availability for nonbiofuel users, and facilitate increased biofuel production. Higher prices for the coproducts of biofuel production would lower the price and increase the quantity of biofuels, but would raise feedstock prices and reduce the quantity available to nonbiofuel users. The effects of a carbon price and biofuel imports on prices and quantitites are mixed, but the interpretation of their impacts would likely be balanced by other criteria, such as environmental goals or energy independence. Knowledge of these tradeoffs can inform decisionmaking by anticipating and clarifying the relationship between objectives and consequences for any particular group.

This chapter relies on basic economic principles to discuss how various factors can affect biofuels and feedstock production; it does not depict the magnitude of effects or, for the most part, potential interactions between the variables. Those interactions are captured in the empirical analyses presented in ensuing chapters. Those chapters explore in detail the specific relationships that feedstock productivity growth, higher input costs associated with increased energy prices, and carbon pricing would have on feedstock production, the agricultural sector, and environmental indicators related to crop production.

Table 3.1

Summarizing the price and quantity impacts of supply and demand shifters

	Impact on biofuels		Impact on feedstocks[1]			
			Biofuels use	Nonbiofuels use	Total	
Changes caused by:	Price	Quantity (domestic)	Quantity	Quantity	Quantity	Price
Increased biofuels mandate[2]	↑	↑	↑	↓	↑	↑
Higher yield growth[3]	↓	↑	↑	↑	↑	↓
Higher energy prices[4]	↑	↑	↑	↓	↕	↑
Improved conversion efficiency	↓	↑	↓	↑	↓	↓
Carbon price[5]	↕	↕	↕	↕	↕	↕
Increased biofuel imports[6]	↓	↓	↓	↑	↓	↓
Higher coproduct value[7]	↓	↑	↑	↓	↑	↑
Reduced logistics costs[8]	↓	↑	↑	↑	↑	↓

Note: The up arrow (↑) indicates that the price or quantity variable is moving up in response to the source of the change. For example, higher energy prices would be associated with both a higher biofuels price and increased quantity. A down arrow (↓) indicates the reverse. For example, higher yield growth would reduce the price of biofuels. An arrow going in both directions (↕) indicates that variable could increase or decrease. The effects shown in each row are assumed to be independent of one another, holding all other factors unchanged.

[1] For simplicity, this table assumes one generic market for feedstocks, serving biofuel and nonbiofuel markets. Depending on the factor being evaluated, the impact on feedstock quantity purchased for biofuel and nonbiofuel purposes may differ, but the price impacts will always be the same for both groups.

[2] Assumes the binding mandate is imposed on consumption, which acts as a rightward demand shift for biofuels. The biofuels price refers to that received by the producer.

[3] The impacts of yield growth assume market interactions, and not a mandate, are the determining factor.

[4] The impact of total feedstock quantity is ↕ because the rightward demand shift for biofuel feedstocks may be offset by a leftward supply shift of feedstocks due to higher input costs. The impact of higher energy prices on biofuel prices and quantity assumes that biofuels are a substitute for petroleum fuel and that a market exists for discretionary blending.

[5] As discussed in the text, the impacts of a carbon price on biofuel and feedstock prices and quantities are indeterminate, and are likely to vary by feedstock. A carbon price could cause the feedstock price to rise and the quantity to decline, or the opposite, depending on how it affects feedstock input costs, the market value of carbon sequestered in feedstock production, the overall demand for transportation fuels (petroleum and renewables), and the proportion that is supplied by biofuels.

[6] The impact of increased biofuel imports on domestic biofuel production is negative, but the total quantity consumed (domestic plus imports) would increase.

[7] Refers to positively priced coproducts of the biofuel conversion process (e.g., dried distillers' grains). An increase in the value of a coproduct from agricultural production (e.g., corn stover) could cause the price of the primary feedstock (e.g., corn) to go down.

[8] Refers to the impact of feedstock transportation or storage (not biofuels distribution). The impact on feedstock prices refers to the delivered cost and not the producer price, which may go up as a result of lower marketing costs.

Feedstock Sources – Scenarios for the Future

The anticipated increases in demand for corn and other biomass may transform the agricultural landscape as cropping choices change and production practices adapt. While conversion based on corn is a proven technology, cellulosic technologies are expected to come online only after several years of development. EISA specifies target production levels for ethanol from each major feedstock category. In 2015, the projected 15-billion-gallon target for corn-based ethanol is reached, with the cellulosic ethanol target low enough not to require significant additional agricultural resources. This is supplemented by 1 billion gallons of biomass-based diesel fuel. In 2022, the terminal year of the act, corn-based ethanol remains at 15 billion gallons and biodiesel remains at 1 billion gallons, with cellulosic feedstocks required to contribute a minimum of 16 billion gallons. Two complementary analyses are conducted here. One analysis focuses on the expected consequences from a bioenergy system supplied mainly by corn (the 2016 projection), and a second analysis includes the input from cellulosic feedstocks (2022). Each analysis is anchored to the USDA baseline projections.

To analyze the effect of increased ethanol use on feedstock availability and consequences to the environment, the 15-billion-gallon corn-based ethanol and 1-billion-gallon biodiesel scenario (the reference scenario) is compared to the "business as usual" outcome defined by the USDA baseline (see box, "Why Fix Ethanol Production at 15 Billion Gallons?"). The baseline provides projections for prices and quantities of major agricultural products, and is determined by a combination of model results and expert judgment (see box, "USDA Baseline Agricultural Projections"). The latest year for which baseline estimates were available at the time of modeling was 2016, when EISA requires 15 billion gallons of corn-based ethanol and 1 billion gallons of biodiesel. The baseline is developed from conditions and assumptions regarding the future, which cannot be predicted with perfect accuracy. The focus of this analysis is on the relative changes in prices and quantities compared to the baseline, and not on the absolute values. To augment the analysis, alternative scenarios are defined that reflect possible deviations from the conditions of the reference case. In each scenario (including the reference case), corn-based ethanol demand is fixed at 15 billion gallons and biodiesel is fixed at 1 billion gallons.

Production Scenarios for 2016: Corn as the Predominant Feedstock

To assess the economic and environmental outcomes associated with feedstock supply, the analysis must establish a point of reference for biofuel production with which to make comparisons. Figure 4.1 shows the evolution of projected biofuel production under the 2007 USDA baseline, and under EISA. The target for corn-based ethanol is also shown. For the corn ethanol analysis of 2016, the implications of the 15-billion-gallon target under the analysis scenarios are compared to the USDA baseline projection for 2016 of 12 billion gallons, illustrated by point 1 in the figure. The reference case is represented by point 2 in the figure. The high corn productivity, high input price, and positive carbon price scenarios take point 2 as the point of

Why Fix Ethanol Production at 15 Billion Gallons?

The goal of this analysis is not to forecast feedstock supply at some point in the future but rather to assess the consequences to agricultural production, markets, and the environment of higher ethanol production. For illustration, corn starch-based ethanol production is assumed to be 15 billion gallons in 2016. Although this is a simplification of linkages from the energy market to the agricultural sector, it allows a focus on impacts in the farm economy.

In a more fully modeled system, the quantity of corn-based ethanol produced and its price would be determined by the supply and demand that clears both the corn market and the ethanol market, with due consideration of producer and consumer incentives, such as subsidies, tax credits, and mandates. Unfortunately, while long-term energy forecasting models exist, none are integrated with comprehensive agricultural models capable of meeting the objectives of this study. Energy prices are included in the cost of production in our analysis, but they are an input parameter and not determined by the model. Implicit in the 15-billion-gallon scenario is the assumption that market-driven production levels are too low and the mandate is binding or that energy prices are high enough relative to the cost of producing biofuels to induce that level of biofuel production (and associated feedstock demand), but not so high as to induce an even greater level of production.

Evidence suggests that the 15-billion-gallon standard is likely to be binding in 2016. Ultimately, whether or not corn-based ethanol production would increase to or beyond 15 billion gallons by 2016 depends on a variety of factors, including energy prices, ethanol plant capacity, the status of cellulosic conversion technologies and supporting infrastructure, changes in biofuel policies and, possibly, policy responses to higher food prices and potential scarcity.

- The effect of energy prices on biofuel demand will depend on the manner in which biofuels interact with other liquid fuels (e.g., as a substitute or as an additive used in fixed proportions). Energy prices could also fall.
- The effect of factors potentially increasing demand for biofuels depends on the difference between the level of biofuel demand and the mandate. An increase in biofuel demand could simply make a mandate less binding.
- Given current and planned ethanol plant capacity, and the lag time involved in bringing new plants online, the 15-billion-gallon level may well be the upper limit to U.S. corn starch-based production. Much of the dramatic increase in ethanol plant capacity over the past few years was motivated by a perfect storm of high energy prices, low corn prices, and energy/environmental policy shifts. As the market has adjusted to increased feedstock demand, profit margins have narrowed and the incentive to expand (absent the mandate) may be diminishing. Further, 15 billion gallons is the maximum that conventional, corn starch-based ethanol can contribute to the Renewable Fuel Standard.

Corn-based ethanol production may also wind up at less than 15 billion gallons if, for example, a cellulosic production technology came on line in sufficient quantities and at a low enough cost to suppress demand for corn ethanol.

USDA Baseline Agricultural Projections

The February 2007 baseline provides long-term projections for the agricultural sector through 2016. Projections cover agricultural commodities, agricultural trade, and aggregate indicators of the sector, such as farm income and food prices. The projections are based on specific assumptions regarding macroeconomic conditions, policy, weather, and international developments. The projections assume that there are no shocks due to abnormal weather, further 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 are one representative scenario for the agricultural sector over the next decade. As such, the long-term projections provide a point of departure for discussion of alternative farm sector outcomes that could result under different assumptions. The projections reflect a composite of model results and judgment-based analyses.

Longrun developments for global agriculture reflect increased demand for biofuels, particularly in the United States and the European Union (EU). U.S. agricultural projections reflect increases in corn-based ethanol production, which affects production, use, and prices of farm commodities throughout the sector. Expansion of biodiesel use in the EU raises demand for vegetable oils in global markets. Additionally, steady domestic and international economic growth in the projection supports gains in consumption, trade, and prices. Although export competition is projected to continue, global economic growth, particularly in developing countries, provides a foundation for gains in world trade and U.S. agricultural exports. Combined with increases in domestic demand, particularly related to growth in ethanol production, the results generally show higher market prices and cash receipts compared to today. Corn prices initially rise in the near term as increased ethanol production strengthens corn demand. As corn-based ethanol expansion slows, stocks rebuild and corn prices decline. In the longer run, corn stocks-to-use ratios fall slowly as gains in corn used for ethanol and moderate export growth outpace increases in production. Consequently, corn prices resume moderate growth and remain historically high. The documentation of the baseline process is available at http://www.ers.usda.gov/Briefing/Baseline/.

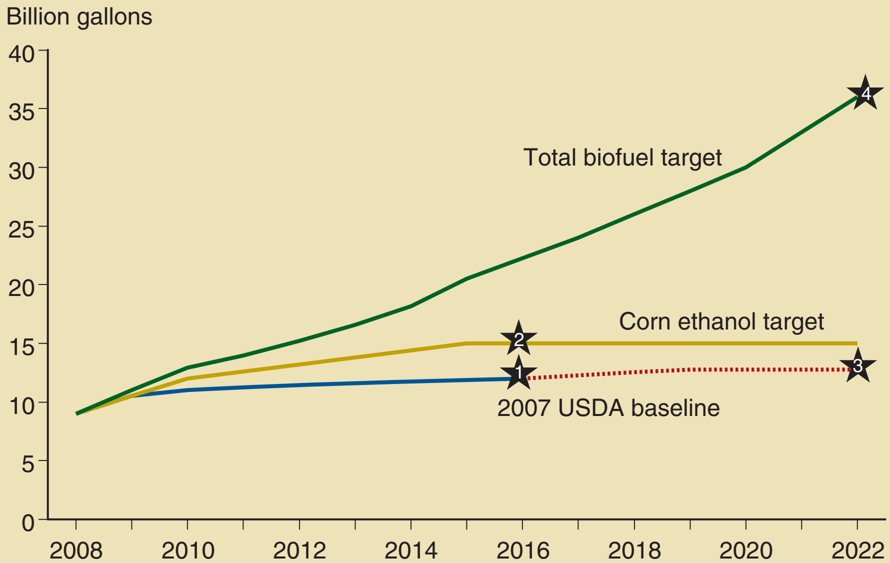
departure. In 2016, the influence of cellulosic ethanol is not analyzed. The 2007 USDA baseline ends its projection in 2016. For the cellulosic biofuel analysis, the USDA baseline has been extended to 2022. The analysis focuses on the supply implications of the cellulosic target of 20 billion gallons plus the 15-billion-gallon corn ethanol target. The assessment of the cellulosic scenarios is represented by the difference between the points labeled 3 and 4.

- **Baseline for 2016 marketing year**

The USDA baseline scenario represents the "business as usual" case. The USDA baseline projects 12.0 billion gallons of corn-based ethanol and 700 million gallons of biodiesel in 2016, the final year projected by the baseline. The USDA baseline was developed before recent legislation, and reflects production and market conditions anticipated to prevail over the projection period.[1] Energy prices correspond to estimates provided by the Energy Information Administration (EIA).

[1]USDA Long-Term Agricultural Projections, February 2007, table 1, http://usda.mannlib.cornell.edu/usda/ers/94005/2007/.

Figure 4.1
Biofuel production targets to 2022



Sources: USDA Agricultural Projections to 2016 and the Energy Independence and Security Act of 2007.

- **Reference case for 2016**

The reference case applies the same economic and production assumptions used by the USDA baseline, with corn-based ethanol production raised to 15 billion gallons and soybean-based biodiesel raised from 700 million to 1 billion gallons. In 2016, ethanol production from cellulosic feedstocks is not explicitly analyzed, as the amount needed is relatively small (4.25 billion gallons), and likely to be satisfied by residues from existing crops. Cellulosic-sourced biofuel becomes a significant contributor to the overall total by 2022, and is covered in a separate analysis.

- **Increased corn productivity scenario for 2016**

Research to improve the productivity of corn is ongoing, both in the private and public sectors. Technological advances in corn productivity would allow production of the needed corn on fewer acres than if historical yield growth prevailed, effectively freeing up land for other crops. Annual growth in corn yield over 1960-2007 has been 1.9 bushels per harvested acre (see box, "Factors Contributing to Historical U.S. Corn Yield Growth"). The USDA baseline assumes that average corn yield will increase 14.5 percent from 2005 to 2016. The increased corn productivity scenario raises this figure by 50 percent, which leads to a 20.7-percent increase in average yield from 2005 to 2016 (see box, "Prospects for Growth in U.S. Corn Yield"). The increase is applied uniformly to corn production across all regions, rotations, and tillage. Yields for other crops remain at the levels used in the USDA baseline.

- **High input cost scenario for 2016**

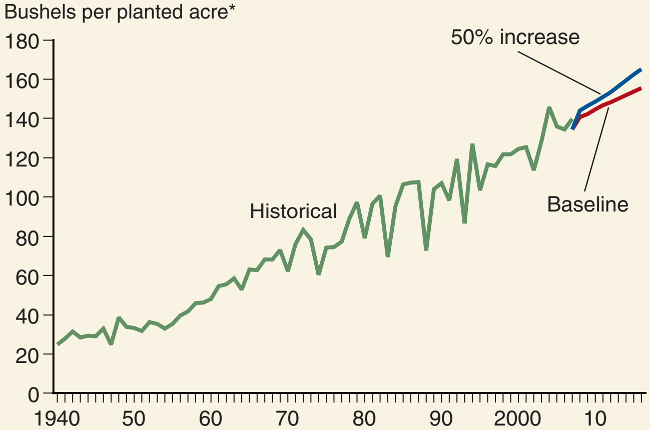
The high input cost scenario reflects the possibility that the relative cost of energy-intensive inputs to crop production will be higher than that assumed by the baseline. The main contributor to rising input costs is the cost of energy. High input prices raise the cost of production, shifting the supply curve and thereby

Factors Contributing to Historical U.S. Corn Yield Growth

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

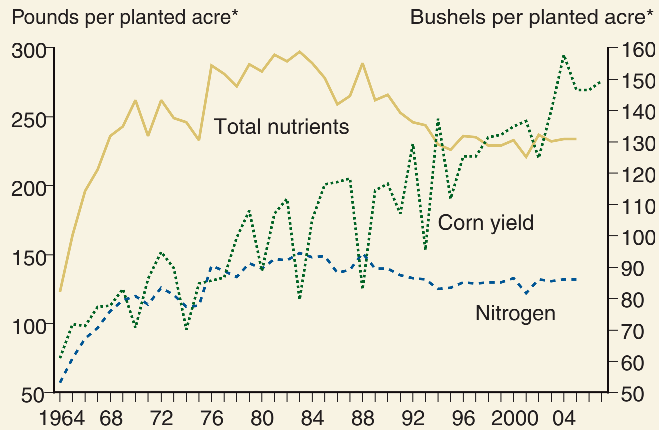
Cardwell (1982), in a decomposition of Minnesota corn yields between 1930 and 1979, estimated that the change from open-pollinated to hybrid corn—along with genetic improvements--contributed 58 percent of the yield increase, while commercial nitrogen increased yields by 47 percent. Other major contributors to increased yield were herbicide use and increases in plant population. (Cardwell's analysis included not only factors with positive influence on corn yield, but also those with negative effects, so positive percentages add to greater than 100.) However, Cardwell estimated that reduced manure use and loss of soil organic matter lowered corn yields by 28 percent. In essence, commercial nitrogen applications offset the loss of benefits from manure and soil organic matter; the net nitrogen effect was 19 percent.

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



*Denominator includes silage acreage.
Source: USDA, National Agricultural Statistics Service model projections.

Corn yield and fertilizer applied to corn, U.S., 1964-2007



*Excluding silage acreage.
Source: USDA, National Agricultural Statistics Service.

Cardwell's analysis concluded just before the peak level of corn fertilization in the early 1980s. It is likely that the level of commercial fertilizer applied since that time has been necessary to maintain yields, but has not contributed nearly as much to increasing them. Cardwell's analysis also separated out "genetic gains in yield" from increases in plant population. In fact, genetic factors may also enhance the ability to tolerate higher density planting, and this form of stress tolerance may have continued as an important factor in corn yield gains into at least the 1990s (Duvick and Cassman, 1999).

[1] Yield trends in the figure 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 uses planted area rather than harvested area because the objective is to model producer expectations when they plant. However, much of our discussion will be in terms of yields per harvested acre, which is what the literature on yield trends usually considers.

[2] In the second figure, silage acreage is excluded from the denominator in both the yield and fertilizer application rate calculations. This was done to make the yield denominator consistent with the denominator used in the available fertilizer series.

Table 4.1
Key parameters for 2016 corn feedstock scenarios

		USDA baseline	Reference case	High corn productivity	High input costs	Carbon price	Combination scenario
Corn-based ethanol	*Billion gallons*	12	15	15	15	15	15
Biodiesel	*Billion gallons*	0.7	1	1	1	1	1
Corn yield	*Bushels per acre*	156	156	166	156	156	166
Input cost multiplier		1	1	1	1.1-1.8[1]	1	1.1-1.8[1]
Carbon price	*\$/ton CO_2*	0	0	0	0	25	25

[1] Varies by crop, tillage practice, and region.

Prospects for Growth in U.S. Corn Yields

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 in (Illinois) corn yields: from about 1 bushel per year from 1940 to 1959 to 1.7 bushels from 1960 onward. They ascribe this acceleration in yield to widespread adoption of fertilizer and herbicides, while others (Sleper and Poehlman, 2006) have cited 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 bushel corn" by 2030, would be completely unprecedented.

Results from the National Corn Growers Yield Contest have also been used as a proxy for potential corn yields. However, documented yields of 360-370 bushels per acre (Elmore and Abendroth, 2007) are contingent on optimal environment and particular management strategies. For example, the highest yields are often obtained in the irrigated classes, where moisture is probably not a limiting factor. And the level of inputs and time spent in 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 work against high aggregate growth rates for corn yields. If higher corn prices encourage area expansion into less productive areas, the net effect could be a downward drag on yield increases. The REAP model includes region-specific yields, not included in the analysis here, that aggregate up to the national average. For the national average to reach the levels discussed here, some regions (e.g., in Corn Belt States such as Iowa and Illinois) would have to far eclipse national-average yields.

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 170 bushels per acre by 2016, which is equivalent to the reported figure of yields per planted acre of about 156 bushels per acre. Two bushels per year is slightly higher than long-term trends in yields, but consistent with a possible slight acceleration in recent years.

The "50-percent yield increase" scenario results in a yield of about 180 bushels per harvested acre in 2016. This is similar to the "increased yield" scenario presented by the National Corn Growers Association (2006), and would be equivalent to about 169 bushels per planted acre in 2016. It would require an increase in yields per harvested acre of about 3.1 bushels per year, a 55-percent acceleration in trend yield growth if the base is 2.0 bushels per year (the assumption of the baseline model), or a 68-percent 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 biotechnology, 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.

raising prices to the consumer. Demand, and therefore production, is reduced. Since the effects of higher input costs apply to all commodities, there is a general contraction in agricultural activity. Variable costs for each production activity may be broken down into non-energy (labor, overhead) and energy-dependent (fuel, fertilizer) categories. The energy-dependent costs for each activity are increased by 50 percent to reflect the Energy Information Administration high-energy-cost outlook for 2016. The demand-side effects of high energy costs are not considered, although higher than expected energy prices might lead to greater demand for corn, mitigating the effects of higher production costs.

- **Positive carbon price scenario for 2016**

The carbon price scenario builds in a value for sequestering carbon and a cost for producing carbon. Encouraging use of reduced- and no-till production systems captures the value. The cost is implemented by adding an amount to the price of carbon-producing inputs (energy and fertilizer) that corresponds to the carbon output of those factors. The price of carbon is taken to be $25 per ton of carbon dioxide. This value was selected based on a review of previous studies that have analyzed the potential impact of carbon markets on agriculture and forestry, including Schneider and Kumar (2008), Sohngen and Sedjo (2006), U.S. Environmental Protection Agency (2005), and Lewandrowski et al. (2004).[2] In these studies, $25 per metric ton of carbon dioxide was within the range of carbon prices analyzed, and, the results suggest the value would be sufficient to elicit some response by the farm and forestry sectors in the present analysis.

[2] In addition, Lewandrowski et al (2004) review several studies that were published prior to 2004.

- **Combination scenario for 2016**

The combination scenario combines the three alternative scenarios to examine how the different driving forces might compound the effects of increased ethanol production on agricultural production and markets.

To assess the contribution of an increase in corn-based ethanol over the 2005 Renewable Fuel Standard, the reference case is compared to the USDA base-line. To assess the changes from applying the differing assumptions of the high corn productivity, high input price, and positive carbon price scenarios, the output of these scenarios will be compared to the reference case. This distinction is made to separate expected changes due to the higher biofuel target from the changes that alternative assumptions may have on how the agricultural market might respond.

Production Scenarios for 2022: Cellulosic Feedstocks Gain Prominence

- **Extended USDA baseline to 2022**

POLYSYS is initially anchored to the 2007 USDA baseline, which contains projections for agricultural variables from 2007 through the year 2016. Because the time horizon of the study goes to 2022, the USDA baseline is extended by exogenously estimating three sets of variables. These variables are exports, crop yields, and population. Exports and yields beyond 2016 are determined by extending the trend in the final 3 years of the USDA baseline outward. Population of the U.S. is extended using U.S. Census Bureau estimates. Population estimates affect food demand and therefore crop prices and production.

Table 4.2
Key parameters for 2022 cellulosic feedstock scenarios

	Cropland biomass source only		Cropland + forestland biomass source		Cropland + forestland biomass + imports source	
	Reference (1)	High yield	Reference (2)	High yield	Reference (3)	High yield
	Dry tons per acre					
Corn-based ethanol	15	15	15	15	15	15
Cellulosic ethanol from cropland	20	20	16	16	12	12
Cellulosic ethanol from forestland	0	0	4	4	4	4
Cellulosic ethanol from imports	0	0	0	0	4	4
Cellulosic yield	4.6	5.2	4.6	5.2	4.7	5.4

- **Cellulosic reference scenarios for 2022**

The cellulosic reference case is split into three scenarios, each considering a different allocation of cellulosic ethanol feedstock source. Each scenario has 15 billion gallons of corn-based ethanol, 1 billion gallons of soy-based biodiesel, and 20 billion gallons of other advanced biofuels produced from a combination of forestland biomass and imports. The scenarios allocate advanced biofuel sources as follows:

(1) 20 billion gallons from cropland, 0 billion gallons from forestland, 0 billion gallons from imports;

(2) 16 billion gallons from cropland, 4 billion gallons from forestland, 0 billion gallons from imports;

(3) 12 billion gallons from cropland, 4 billion gallons from forestland, 4 billion gallons from imports.

- **Increased productivity cellulosic scenarios for 2022**

The increased productivity scenarios are the 2022 cellulosic reference scenarios under increased corn productivity (doubling the growth rate of corn productivity) and increased energy crop productivity. Energy crop productivity is assumed to increase by an annual rate of 1.5 percent starting in 2012, the year when large-scale plantings of energy crops are projected to take place. The 1.5-percent annual increase is attributable to breeding gains and selection of superior varieties and clones.

Implications for Research Advances

The scenarios are used to illustrate a range of outcomes that may result under differing assumptions regarding the production environment. The extent to which research in crop productivity can contribute to enhanced feedstock availability is further investigated by sensitivity analysis of the corn productivity scenario. Changes in planted acreage, production, and farm returns are measured for a range of increases in corn yield (25, 50, 75, and 100 percent over the projected yield increase of 13.8 percent).

Corn-Based Ethanol and the Changing Agricultural Landscape

An increase to 15 billion gallons of ethanol by 2016 over the 12 billion gallons projected by the 2007 USDA baseline will stimulate agricultural producers to respond to the greater demand for corn. New corn production will come from a number of sources: land planted to other crops, land not in production, and land enrolled in the Conservation Reserve Program (see box, "Changes to the Conservation Reserve Program"). The anticipation of greater demand for, and therefore greater production of, corn 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 not only changes to the national crop mix, but also the crop mixes in different parts of the country. Demand for all agricultural commodities will need to adjust to the new price signals, leading to changes in consumption. Also, regional changes in cropping activity and production practices, coupled with differences in soil characteristics, will have consequences for the environment. A quantitative, integrated agricultural sector model is employed to illustrate how greater ethanol demand will affect production and the market for farm products (see box, "Key Assumptions in REAP Scenario Analysis").

Commodity Markets Respond to the Changing Signals

Commodity prices rise across the board in the reference case compared with the USDA baseline, but the results are mixed in the alternative scenarios (see box, "Interpretation of Results," p. 56). The mandated level of 15 billion gallons of corn-based ethanol over the 12-billion-gallon level assumed in the USDA baseline indicates a greater use of corn for ethanol over and above corn used for feed and food.[1] The increased demand for corn raises corn prices and gives farmers incentive to plant corn at the expense of other crops. The degree to which other crops are displaced is mitigated by the fact that supply reduction drives the prices of the other crops higher as well, making them competitive with corn. This outcome is reflected in the reference case, where a 3.6-percent increase in corn production (table 5.1) is accompa-

[1] These results assume economically recoverable crop residue along with some low-cost accessible forestry materials would provide the bulk of the feedstock needed to produce the 4.25 billion gallons of cellulosic ethanol mandated in 2016. (In total, slightly more than 53 million dry tons of cellulosic material converted at 80 gallons per dry ton would be required.). The total amount of crop residue available in 2016 is predicted to exceed 200 million tons, although transportation and other logistics costs would keep much of this residue from the market. However, much more low-cost crop residue is available than needed for this level of cellulosic ethanol production, so crop residue production is not likely to impact other crop markets. Further, any dedicated energy crop production in 2016 will likely be limited and also not affect crop markets.

Changes to the Conservation Reserve Program

The Farm Act of 2007 has changed the amount of acreage that can be enrolled in the Conservation Reserve Program. The new cap is set at 32 million acres, which is lower than the current enrolled acreage. The USDA baseline projected that the previous cap, 39.2 million acres, would be reached by 2016. In our model, CRP is fixed at 39.2 million acres, with regional allocations allowed to change. For the reference case, about 1 million acres of CRP land move from the Corn Belt into the Mountain region (compared to the baseline distribution). Reducing the CRP limit to 32 million acres would likely prompt larger reductions in CRP acreage in the Corn Belt, Lake States, and Northern Plains than in the other regions. This would free up more acreage in the main crop producing regions, although this newly available area would be distributed across all crops. The additional land would contribute to small price drops and small production increases across all crops.

Key Assumptions in REAP Scenario Analysis

- All demands for agricultural commodities are national, except for regional livestock feed demand. Transportation and marketing costs are not considered.
- Crop rotation acreages are allocated proportionally; for 1 million acres in a two-crop rotation, 500,000 acres are allocated to each crop.
- Crop yields for each region are fixed at average values, and do not adjust for price-induced effects.
- Yields for all crops are calibrated to the 2007 USDA baseline for 2016, which includes growth in yield for all crops from the present to 2016. Corn yields in the high corn productivity scenario increase an additional 0.9 bushels/acre each year. Yield increases assume no corresponding increase in inputs.
- Crop production and the Conservation Reserve Program compete for land based on an upward-sloping supply function.
- Total CRP land is fixed, but is allowed to reallocate among regions.
- Energy and other input costs for crop production reflect historical regional variations.
- A corn-based ethanol target of 15 billion gallons for 2016 is fixed in all scenarios except the baseline, which assumes 12 billion gallons.

nied by a 4.6-percent increase in price (table 5.2) over the USDA baseline. The price of soybeans is 3.2 percent higher, while the prices of other crops increase by less than 1 percent (except for sorghum, which is widely used as a substitute for corn in livestock feed).

While ethanol production is one source of demand, food, feed, and exports also compete for product. The increase of corn-based ethanol production from 12 billion gallons to 15 billion gallons will require an additional 1 billion bushels of corn for ethanol. The price increase of corn leads to a reduction in quantity demanded for these other markets, with domestic non-ethanol corn use declining by 5.2 percent and exports (table 5.3) declining by 7.7 percent. Net returns (table 5.4) increase by 10.4 percent for corn and by 3.5 percent for other crops. Returns for livestock producers decline by 0.8 percent, mainly due to increased feed costs.

In the high corn productivity scenario, the price and production effects on other crops are mostly mitigated. For corn, however, a 50-percent increase in yield growth leads to a 6.3-percent decline in price compared to the reference case with a corresponding 2.6-percent increase in production. Domestic use and exports increase by a similar amount. In this scenario, net returns for corn producers decline by 2.7 percent compared to the reference case. Net returns decline 1.8 percent for other producers. The lower price of corn lifts returns for livestock producers by 1.4 percent.

Table 5.1

Commodity production under the alternative scenarios in 2016

		Baseline	Reference	Reference change from baseline	High corn productivity	High input costs	Positive carbon price	Combination scenario
				Percent	*Change from reference (percent)*			
Corn	*(Mil. bu)*	14,095.0	14,596.0	3.6	2.6	-1.2	-1.3	-0.2
Sorghum	*(Mil. bu)*	320.0	349.0	9.1	-0.2	-17.0	-21.5	-39.4
Barley	*(Mil. bu)*	210.0	208.2	-0.9	0.2	-7.5	-6.3	-12.7
Oats	*(Mil. bu)*	269.7	268.9	-0.3	0.7	-1.0	-3.2	-4.8
Wheat	*(Mil. bu)*	2,245.0	2,208.2	-1.6	0.3	-4.3	-1.5	-5.3
Rice	*(Mil. cwt)*	230.1	223.8	-2.8	0.7	-16.9	-12.0	-21.9
Soybeans	*(Mil. bu)*	3,085.0	3,150.2	2.1	1.3	-0.5	-0.3	0.7
Cotton	*(Mil. bales)*	22.8	22.7	-0.6	-0.8	-9.8	-6.9	-18.5

Table 5.2

Commodity prices under the alternative scenarios in 2016

		Baseline	Reference	Reference change from baseline	High corn productivity	High input costs	Positive carbon price	Combination scenario
				Percent	*Change from reference (percent)*			
Corn	*($/bu)*	3.30	3.45	4.6	-6.3	2.8	2.3	-0.1
Sorghum	*($/bu)*	3.05	3.14	3.0	0.0	3.9	4.9	7.2
Barley	*($/bu)*	3.15	3.17	0.6	-0.1	5.4	4.5	9.1
Oats	*($/bu)*	2.10	2.11	0.7	-1.7	2.4	7.5	11.9
Wheat	*($/bu)*	4.55	4.58	0.8	-0.1	2.0	0.7	2.4
Rice	*($/bu)*	9.83	9.85	0.2	0.0	0.9	0.7	1.2
Soybeans	*($/bu)*	6.75	6.97	3.2	-1.0	0.4	0.2	-0.6

Table 5.3

Exports under the alternative scenarios in 2016

		Baseline	Reference	Reference change from baseline	High corn productivity	High input costs	Positive carbon price	Combination scenario
				Percent	*Change from reference (percent)*			
Corn	*(Mil. bu)*	2,250.0	2,075.9	-7.7	12.2	-5.4	-4.3	0.1
Sorghum	*(Mil. bu)*	150.0	105.6	-29.6	-0.6	-55.3	-69.9	-100.0
Barley	*(Mil. bu)*	20.0	18.8	-6.0	1.5	-56.3	-47.1	-95.1
Oats	*(Mil. bu)*	3.0	2.8	-6.8	17.8	-25.5	-78.9	-100.0
Wheat	*(Mil. bu)*	1,125.0	1,089.8	-3.1	0.5	-8.3	-2.9	-10.3
Rice	*(Mil. cwt)*	117.5	111.2	-5.3	1.4	-33.8	-23.9	-43.7
Soybeans	*(Mil. bu)*	875.0	848.9	-3.0	1.0	-0.4	-0.2	0.6
Cotton	*(Mil. bales)*	18.1	18.0	-0.7	-0.9	-11.1	-7.8	-21.0

Table 5.4

Net returns to agricultural producers in 2016

	Baseline	Reference	Reference change from baseline	High corn productivity	High input costs	Positive carbon price	Combination scenario
	$ Million		*Percent*	*Change from reference (percent)*			
Corn	29,761.2	32,860.8	10.4	-2.7	3.5	-1.6	1.6
Other crops	20,987.9	21,712.7	3.5	-1.8	4.8	-6.0	-4.0
Livestock	41,739.7	41,391.8	-0.8	1.4	-0.9	0.4	0.8

Interpretation of Results

The REAP model provides measures of the magnitude and direction of change in an output value from a given set of conditions (such as the USDA baseline projections for 2016) for a wide array of production and environmental indicators. It estimates output when a large number of input factors (production, demand, and macroeconomic/policy conditions) are at play. The model uses values that reflect expected or average behavior in the future. Inputs such as labor, energy, and machinery are modeled as fixed factors that are independent from the agriculture sector, with no explicit market built into the model. The market for land is affected only by competing agricultural uses; other forces that influence land use such as urban development or recreation are not included. Input factors have been selected from the best available data sources and correspond to justifiable estimates of likely future conditions. While large changes to several fixed model inputs may change output values, small random deviations from the base values are likely to "cancel out" and preserve the direction and magnitude of change from the starting point. While a model of this type cannot provide confidence intervals or measures of statistical significance, it does show how various agricultural production systems might interact in response to a set of given conditions.

As an example, consider the price and production increases between the reference case and the USDA baseline. The 3-billion-gallon increase in corn ethanol production called for in the reference case stimulates production of corn and increases demand. The baseline price for corn in 2016 is lower than prevailing prices today, reflecting a belief that domestic and international demand, storage, and production will adapt to higher demand. Since corn competes with other commodities for land, the additional demand in the reference case also affects the markets for other crops. The actual price (or other output) generated by the model is not a prediction, but an indication of likely responses to additional corn demand. Our focus is whether the added demand puts upward, downward, or negligible pressure on any given value. And if the value is different, is it considerably different from the original value or from comparable values for other crops or regions?

As another example, consider the 3-million-acre decline in corn area from the reference case to the high corn productivity scenario. This scenario measures the sectorwide impact of a 50-percent increase in corn yield, with all other factors held constant. With fewer acres of corn needed to meet a given demand, the entire production system adjusts, resulting in a different distribution of crop acres planted, with different prices and production from the reference case. Overall acreage declines by only 1.6 million acres from the reference case, indicating that an additional 1.4 million acres are freed to be planted to other crops.

The negative impact of increased corn yields on net returns to corn producers is somewhat counterintuitive, and is the outcome of the complicated set of interactions described in chapter 3. In particular, a projected decline in corn price reduces gross receipts by more than higher production levels increase receipts. Also, the increase in corn yield motivates farmers to bring less productive land into corn production, bringing with it lower net returns than on average corn land. Thus, net returns to a given corn producer farming traditional corn land may increase, while average returns fall nationally. Further, this is not a predetermined result. For example, corn prices fall, production increases, and net returns to corn producers increase relative to the baseline case (see box, "Market Mechanisms and Productivity Gains," p. 35, for more discussion of factors driving these results).

For the high input cost scenario, energy-related input costs are increased by 50 percent over the reference case, potentially reducing returns to crop production. Energy-related inputs vary by crop and region, so the change in returns to production will also vary. The higher input costs are transmitted to the prices of all commodities. The price increases over the reference case range from a 0.4-percent increase in the price of soybeans, which use little inputs relative to other crops, to a 5.4-percent increase in the price of barley. Corn price increases 2.8 percent. High input costs further dampen exports and domestic demand relative to the reference case. The higher price for corn makes up for the increased cost, as net returns for corn production increase by 3.5 percent over the reference case. Returns increase 4.8 percent for other crops and decrease 0.9 percent for livestock producers.

With a carbon price of $25 per ton of carbon dioxide, costs of energy and fertilizer increase, encouraging less use and a move from conventional tillage to reduced- and no-till systems. Overall, higher carbon (energy and fertilizer) prices offset the benefits of switching to conservation tillage, leading to commodity price increases ranging from 0.2 to 7.5 percent. Returns to production decline 1.6 percent for corn producers and 6 percent for producers of other crops. Returns to livestock production increase slightly.

In the combination scenario, the stimulation to production induced by higher corn yields is balanced by the drag induced by higher input costs, with mixed implications across commodities. Prices for corn and soybeans decline; prices for sorghum, barley, oats, wheat, rice, and hay increase. This is partly due to corn, sorghum, soybeans, and oats being in competition as substitutes in livestock feed. Net returns for corn, relative to the reference case, increase 1.6 percent while livestock returns increase by 0.8 percent. Returns for other crops are 4 percent lower than in the reference case, though acreage and costs are lower as well.

Corn-Producing Regions Show Gains in Agricultural Production

The major corn-producing regions show increases in total acreage, mostly due to corn plantings, while other regions see less of an increase, with corn being planted at the expense of other crops. Variations in crop returns caused by the assumptions of the scenarios will induce changes to the crop mix planted in each region. The expected increase in planted acreage in 2016 amounts to 4.4 million acres over the USDA baseline (table 5.5). A 3.7-million-acre expansion in corn acreage (table 5.6) is complemented by 700,000 additional acres in other crops, driven by higher commodity prices. While the overall increase is large and each region exhibits an increase of 3 to 7 percent in corn acres, most of the new corn acres are in only a few regions. The Corn Belt and Northern Plains show increases of 1.2 million acres, and the Lake States show an increase of 600,000 acres. The remainder is distributed across the other regions. Acreage of other crops contracts, with wheat declining by close to 900,000 acres.

Table 5.5

Total acreage planted to major crops in each alternative scenario in 2016

Total acreage	Baseline	Reference	High corn productivity	High input costs	Positive carbon price	Combination scenario
			Million acres			
Northeast	15.05	15.24	15.24	14.71	15.16	14.55
Lake States	40.00	40.51	40.40	39.40	39.43	37.87
Corn Belt	100.99	102.57	102.01	101.88	102.51	101.18
Northern Plains	63.14	64.65	64.43	60.48	63.81	58.43
Appalachian	18.29	18.61	18.24	17.92	18.46	17.44
Southeast	7.54	7.63	7.44	7.15	7.15	6.79
Delta	15.88	16.43	16.33	15.63	16.19	15.88
Southern Plains	27.57	27.70	27.36	23.01	24.98	19.73
Mountain	20.81	20.33	20.57	18.70	20.04	18.47
Pacific	7.73	7.73	7.74	6.46	7.24	6.33
United States	316.99	321.41	319.77	305.34	314.96	296.67

Table 5.6

Regional acres planted to corn in each alternative scenario in 2016

Corn acreage	Baseline	Reference	High corn productivity	High input costs	Positive carbon price	Combination scenario
			Million acres			
Northeast	3.88	4.09	4.09	4.01	4.06	3.95
Lake States	14.45	15.05	14.21	14.73	14.55	13.23
Corn Belt	44.63	45.90	44.47	45.81	45.71	44.30
Northern Plains	16.50	17.64	17.07	16.95	17.12	15.55
Appalachian	4.76	4.96	4.77	4.84	4.86	4.58
Southeast	2.34	2.43	2.41	2.34	2.35	2.26
Delta	0.71	0.75	0.81	0.76	0.75	0.85
Southern Plains	1.15	1.22	1.24	1.20	1.20	1.15
Mountain	1.24	1.29	1.25	1.27	1.26	1.19
Pacific	0.34	0.35	0.35	0.33	0.34	0.32
United States	90.00	93.68	90.66	92.24	92.21	87.39

An important potential source of agricultural land is land enrolled in the Conservation Reserve Program (CRP). In this analysis, the total amount of CRP land is held constant at the program level of 39.2 million acres. However, land enrolled in CRP is free to reallocate among regions. The additional corn-growing land in the Corn Belt absorbs about 1 million CRP acres, with CRP acres in the Mountain region (not suited for growing large amounts of corn and having the lowest CRP payment rate) increasing by 1 million acres.

In the high corn productivity scenario, there is less pressure on the land base to meet the expanded demand from ethanol. Total planted acreage is 1.6 million acres less than the reference case, implying less land will be needed if technological advances in corn yield are realized. Fewer corn acres are planted nationally (3.0 million fewer acres than the reference case). Most of these acres come out of the corn-producing States, which show declines of 6 to 9 percent. Other regions show modest declines in corn acreage, with the exception of the Delta region (150,000-acre increase, about 1 percent of total planted acreage). Acreage changes for other crops vary. Wheat acreage declines by 900,000 acres, with the largest share coming from the Northern Plains. Soybean acreage increases by 2.4 million acres, with the largest share going to the Lake States.

Figure 5.1 shows total acreage change in each region under each alternative scenario. Figures 5.2 to 5.5 show the acreage changes from the reference case for major crops in the Corn Belt, Northern Plains, Southern Plains, and Lake States. The high input cost scenario shows a large decline in planted acres (14.7 million acres) relative to the reference case. The scenario has corn acres declining in all regions, along with a small decline from the reference case in corn acres nationally. Wheat production is energy intensive relative to corn; wheat acres drop by 2.7 million, with the largest share coming from the Southern Plains (800,000 acres). Wheat acres show very small declines in the corn-producing regions. Soybean acres increase nationally by 1.5 million acres relative to the reference case, with 1 million additional acres in the Delta. A 2-million-acre decline in cotton acres, mostly from the Southern Plains, results from the high input costs associated with irrigation. High input costs amplify the movement of CRP acres out of the Corn Belt.

Figure 5.1
Regional change in corn acres from reference case in 2016

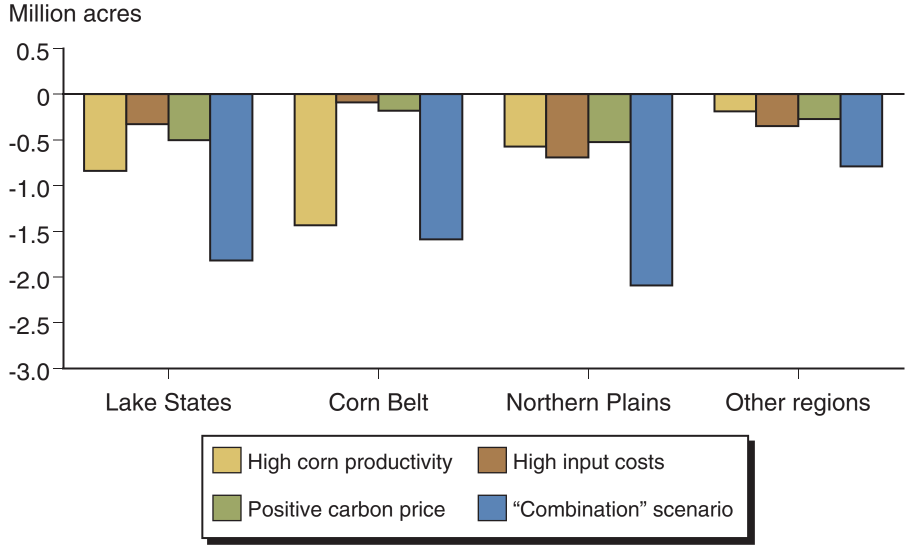


Figure 5.2
Change in acreage from reference case in 2016, Corn Belt

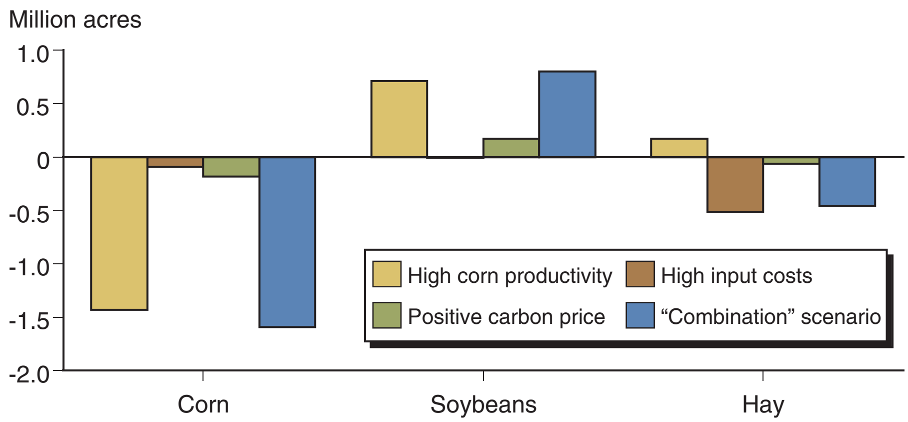


Figure 5.3
Change in acreage from reference case in 2016, Northern Plains

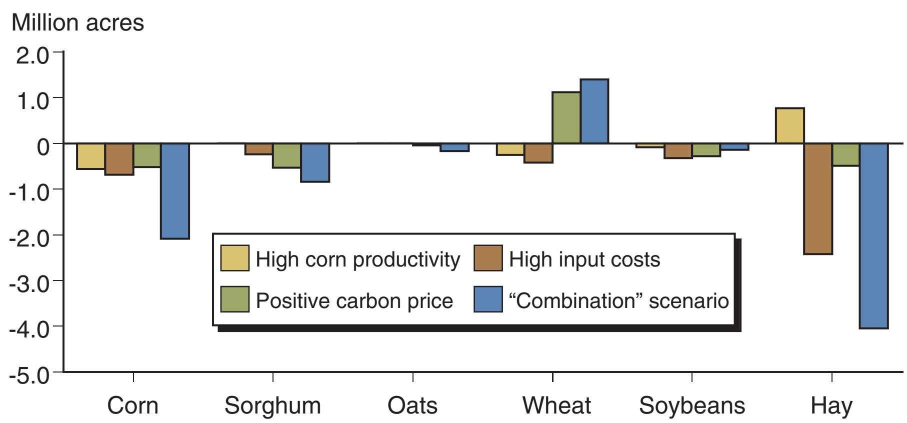


Figure 5.4
Change in acreage from reference case in 2016, Southern Plains

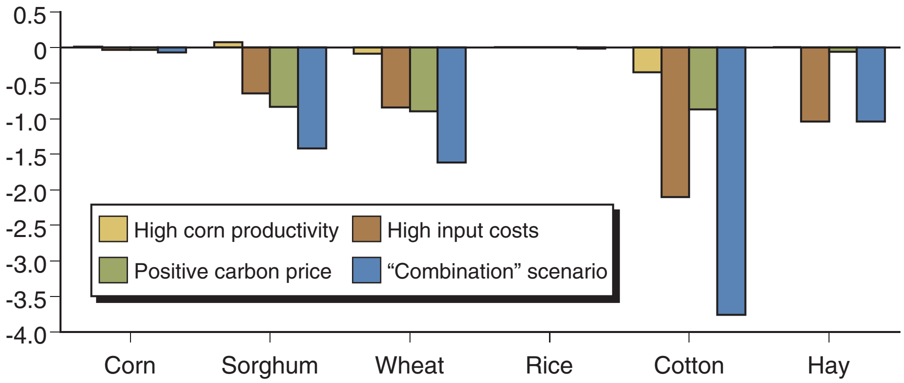
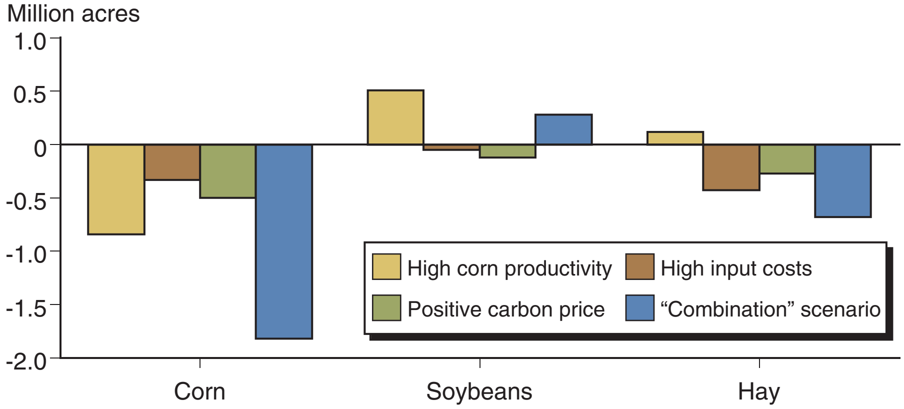


Figure 5.5
Change in acreage from reference case in 2016, Lake States



Corn plantings in the carbon price scenario decline by 1.5 million acres from the reference case (table 5.6). Soybean acres increase nationally by 1.5 million acres, with increases in every region. Due to the incentive provided by the carbon price for not converting uncultivated land, fewer CRP acres switch regions.

The combination scenario compounds the acreage-reducing effects of high input costs with those introduced by higher corn yields. Nationally, planted acreage is reduced to 296.7 million acres (24.7 million acres fewer than in the reference case). There are large acreage reductions in all crops except for soybeans, which hold at the reference case level. More than half of the acreage comes out of the Northern Plains (6.2 million acres) and the Southern Plains (8.0 million acres). In the Northern Plains, the acreage lost is roughly proportionally divided among the crops planted, whereas in the Southern Plains most of the reduction comes from cotton and hay.

Research Reduces Needed Acreage

Scenarios described above consider the implications of a 50-percent increase in annual yield growth. Here, we provide more perspective on those results by considering yield improvements ranging from a 25-percent to a 100-percent increase over baseline growth rates. Each 25-percent yield increment is equivalent to a national average increase of 5 bushels per acre.

Table 5.7 summarizes the percentage changes (from the reference case) to different outputs for each level of corn yield growth. Each 5-bushel-per-acre increase in yield reduces corn plantings approximately 1.5 million acres and reduces total land planted to crops by nearly as much. The pressure on the land base would abate at increasing rates if greater yield improvements were realized; the 50-percent increase in yield growth leads to a 1.6-million-acre (0.5 percent) decrease in planted acres, while a 100-percent increase in yield growth would reduce planted acres by 5.2 million acres, or 1.6 percent.

Corn prices decline by approximately $0.11 per bushel for each additional 5 bushels per acre, with a corresponding increase in production of 1-2 percent. The price decline is greater than the production increase. As a consequence, net returns to corn farming decline by an average of 1.2 percent for each 5-bushel-per-acre yield increase. Reduction in farm returns is more than made up for by benefits to corn consumers. Returns to livestock production increase 0.7 percent, on average, with each increase in corn yield of 5 bushels per acre.

Because the distribution of corn production is not uniform across regions, the effects of higher corn productivity relative to other crops are felt more strongly in some regions. Of the total reductions in corn planted, the majority comes out of continuous corn rotations in the Corn Belt. Much of the reduction in land devoted to corn is replaced by soybeans in corn-soybean rotations. While over 90 percent of the changes in corn acres are in the primary corn producing areas—the Corn Belt, Lake States, and Northern Plains—those regions account for only about half of the change in total planted acres. Some regions see no decline in total acreage (e.g., Northeast and Pacific), with most of the decline in national acreage occurring in the Corn Belt, Northern Plains, Appalachian, and Southeast regions.

The regional shifts become more pronounced as yield growth increases. For example, with yield growth 50 percent higher than baseline levels, total planted acres in the Delta fall by just under 100,000 acres (0.6 percent). If corn yield growth were 100 percent over baseline levels, total planted acres in the Delta

Table 5.7
Changes from reference case under alternative yield growth assumptions in 2016

	Corn yield growth			
	25%	50%	75%	100%
	Percent			
Corn acreage	-1.6	-3.2	-4.6	-5.9
Total acreage	-0.2	-0.5	-0.9	-1.6
Corn production	1.3	2.6	4.3	6.1
Corn price	-3.1	-6.3	-9.4	-12.3
Net returns:				
Corn	-1.2	-2.7	-3.9	-4.9
Livestock	0.7	1.4	2.2	2.9

would fall by an additional 700,000 acres. This is because increased corn-soybean rotations in the corn producing States puts pressure on soybeans in the Delta region, leading to greater reallocation of acreage there.

This analysis has focused, in part, on yield improvements for corn. In general, improvement in corn yield beyond that assumed in the baseline reduces the pressure on agricultural land by producing the corn needed on fewer acres. Complementary research on reducing inputs to crop production, such as fertilizer and pesticides, and improving the efficiency of land management would also have implications for production by reducing the cost per acre, thereby changing returns to production. While not addressed directly by the model, increases in yields of crops other than corn would likely have similar effects on crop markets and the agricultural land base.

Appendix: The Modeling Framework for REAP

To assess the production, market and environmental consequences of increased feedstock needs, a quantitative economic model is used. The Regional Environment and Agriculture Programming Model (REAP) is a mathematical optimization model that quantifies agricultural production and its associated environmental outcomes for 50 regions in the United States. The regions are defined by the intersection of USDA's Farm Production Regions (10 groups of States with similar agri-economic characteristics) and the Land Resource Regions (defined by predominant soil type and geography) as formulated by USDA's Natural Resources Conservation Service. Regional production levels are determined for 10 crops and 13 livestock categories, and national production levels are determined for 20 processed products. Import supply and export demand functions capture international markets.

REAP explicitly models regional differences in crop rotations, tillage practices, and input use such as fertilizer and pesticides. Input use and national prices are determined endogenously. REAP employs regional data (derived from USDA's Agricultural Resource and Management Survey (ARMS), and the Environmental Productivity and Integrated Climate (EPIC) model) on crop yields, input requirements, costs and returns, and environmental parameters to estimate longrun equilibrium outcomes. For this analysis, the model is calibrated to prices and quantities contained in the year 2016 of the 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 (consult the REAP documentation for references.)

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) set 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 a solution away from "corner points", thus introducing a realistic level of variety into the solution. The model is calibrated to production levels given by the USDA baseline by the Positive Math Programming method. This method introduces the baseline levels as calibration constraints, and the resulting marginal costs are used to modify the objective function to adjust the discrepancy 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 additions of or changes 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 anticipated differences from the baseline. markets will respond to shocks created by policy or technology on both the supply and demand sides.

REAP holds unchanging many factors 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 produce produce markets will respond to shocks created by policy or technology on both the supply and demand sides. See Johansson et al. (2007) for more detail on the model.

Cellulosic-Based Ethanol and the Contribution from Agriculture and Forestry

The cellulosic feedstocks (see chapter 2) needed to produce 20 billion gallons per year (BGY) of second-generation and other renewable fuels can come from a wide variety of cropland and forestland sources, including imports. The impact of producing these biofuels on U.S. agriculture and forestry will very much depend on the relative proportions of cropland- and forestland-derived feedstocks and the extent to which imports are used to meet the mandate. To meet the 2022 target, upwards of 240 million dry tons of feedstock would be needed from U.S. croplands if no forest-sourced biomass or imported biofuels are used. Much less cropland-derived feedstock would be needed if forest biomass and imports are used.

An agricultural policy simulation model was used to identify how production of dedicated energy crops and collection of crop residues, the major sources of cropland-derived biomass, could affect the regional and national mix of crops and overall land use. A separate analysis assesses the contributions from forestland and imports. This chapter describes results from this modeling effort under three different sets of assumptions about the contributions from cropland, forestland, and imports by 2022.

Scenarios

Three alternative scenarios—with varying contributions from cropland, forestland, and imports, and under baseline and high yields—were used to assess the impacts of producing 36 BGY of renewable fuels on agricultural markets and land use. The foundation for each scenario is USDA's baseline for 2016, extended to 2022. These scenarios are as follows:

- 16 BGY first-generation biofuel scenario for 2016, as discussed previously, but extended to 2022 with corn-based ethanol of 15 billion gallons per year (BGY) and soybean oil biodiesel of 1 BGY.
- 36 BGY biofuel scenario with corn-based ethanol of 15 BGY, soybean diesel of 1 BGY, and 20 BGY of second-generation and other biofuels produced from combinations of cropland biomass, forestland biomass, and imports, as follows:
  - ➢ 20 BGY from cropland, 0 BGY from forestland, 0 BGY from imports;
  - ➢ 16 BGY from cropland, 4 BGY from forestland, 0 BGY from imports;
  - ➢ 12 BGY from cropland, 4 BGY from forestland, 4 BGY from imports.
- 36 BGY biofuel scenario (same as above) under increased corn productivity and increased energy crop productivity. In this scenario, corn productivity was assumed to be double the rate in the USDA baseline in 2022 to account for possible technological advances in molecular

breeding and biotechnology. Energy crop productivity is assumed to increase by an annual rate of 1.5 percent starting in 2012, the year when large-scale plantings of energy crops are projected to occur.[1] The higher energy crop productivity accounts for possible technological advances attributable to breeding gains and selection of superior varieties and clones. The purpose of this scenario is to explore how the upper limits of productivity advances, which would imply fewer acres needed to produce 36 billion gallons of biofuels, affect land-use decisions.

Cropland Cellulosic Modeling Methods

An agricultural policy simulation model of the U.S. agricultural sector, POLYSYS, was used to assess the impacts of cellulosic feedstock production in year 2022. The REAP model was not used because it currently does not have the capability to assess energy crops and the collection of crop residues. However, like the REAP model, POLYSYS is anchored to published baseline projections for the agricultural sector and simulates deviations from the baseline. To simulate year 2022, the 2007 10-year USDA baseline for all crop prices, yields, and supplies was extended to 2022 based on extrapolation of trends in the final 3 years of the USDA baseline.[2]

The POLYSYS model includes national demand, regional supply, livestock, and aggregate income modules (De la Torre Ugarte et al., 1998; De la Torre Ugarte and Ray, 2000; POLYSYS, 2006). The model contains the eight major crops (corn, grain sorghum, oats, barley, wheat, soybeans, cotton, and rice), as well as dedicated energy crops and hay (alfalfa and other hay). Corn and wheat residue costs and returns are added to the corresponding crop returns, if profitable. POLYSYS is structured as a system of interdependent modules of crop supply, livestock supply, crop demand, livestock demand, and agricultural income. The supply modules are solved first, then crop and livestock demand are solved simultaneously, followed by the agricultural income module.

There are 938 million acres within the United States that are either owned or managed by agricultural producers. The 2002 Census of Agriculture determined that 434 million acres can be classified as cropland, while 395 million acres are classified as pastureland or rangeland. Of the 434 million cropland acres, POLYSYS includes 307 million acres available for the 8 major crops and for hay in the current-year (2007) baseline. Additionally, cropland used as pasture (61 million acres) can enter into production of energy crops if the loss of regional pasture can be made up with additional hay production. The objective of the model is to produce 36 BGY of renewable fuels from corn grain, soybeans, energy crops, and crop residue supplies, and to estimate the impacts on production, prices, acreage, government payments, and net returns of all model crops and livestock. In all scenarios, forestland biomass and imports are modeled within POLYSYS as reduced demands for cellulosic ethanol production.

[1]The Sun Grant Initiative is working with the Department of Energy- Energy Efficiency and Renewable Energy Office of Biomass Program on a Regional Biomass Partnership to address barriers associated with the development of a sustainable and predictable supply of biomass feedstocks. Currently, there are over 30 planned trial plantings of bioenergy crops covering a wide geographic area. Private companies have also announced plans to undertake large-scale planting of switchgrass, sorghum, and other energy crops. For these reasons, a 2012 start date was selected.

[2]POLYSYS economic results are in nominal dollars when reported within the 10-year USDA baseline projection. When POLYSYS is extended beyond the 10-year baseline, results are in real or constant dollars of the last year of the USDA baseline. That is, year 2022 results are in year 2016 dollars.

Consequences for Crop Markets and Land-Use Change

To assess the impacts of cellulosic feedstock production, scenarios reflecting the use of advanced cellulosic biofuels are compared to the 16 BGY first-generation biofuel scenario. The 16 BGY first-generation biofuel scenario uses the same set of economic and technical assumptions as the USDA baseline except corn-based ethanol production is increased to 15 BGY and soybean biodiesel is increased to 1 BGY. These production levels are held constant through 2022. A range of cropland biomass production levels appropriate for producing 12 to 20 BGY of ethanol was evaluated, with forest-land biomass and imported biofuels making up any difference needed to produce 36 BGY of renewable fuel. In the analysis, the domestic expansion to meet the mandate was assumed to be cellulosic ethanol. While there are many other advanced alternatives, cellulosic ethanol has the potential to be a major biofuel. This assessment was repeated under an increased productivity scenario for both corn and energy crops, with the general effect of requiring less land to produce the needed feedstock.

Two major cellulosic feedstock sources—crop residues (corn stover and wheat straw) and energy crops—were modeled to produce 36 BGY of renewable fuels. The amount of crop residues produced is calculated as a function of assumed crop yields, the ratio of residue to grain, and the weight and moisture content of the grain. The amount of residue that can be sustainably removed depends on tillage patterns (e.g., no-till versus conventional till), crop rotations, and constraints related to preventing soil erosion from water and wind. The model explicitly considers all of these factors. However, it does not allow tillage patterns to change in response to increasing demand for cellulosic ethanol feedstocks. Furthermore, the model is constrained to remove no more than 34 percent of available corn stover and 50 percent of wheat straw. These percentages reflect the operational limits of today's collection equipment, but do not take into account future advancements in technology. The modeled constraints generally ensure that sufficient residue is left on the field to maintain soil organic matter.

The energy crops are modeled generically and would likely represent a combination of perennial grasses, such as switchgrass; short-rotation woody crops, such as hybrid poplar and willow; and annual energy crops, such as sweet sorghum.[3] Energy crops will displace cropland currently used as pasture and some conventional crops as they come into production.[4] The model excludes the 584 million acres classified as grassland, pasture, and range (Lubowski et al., 2006), as well as land currently enrolled in the Conservation Reserve Program. In the model, cropland used as pasture can be converted into energy crops provided the following conditions are met: net returns to energy crops are more than regional rental rates for pasture, energy crops are the most profitable alternative use of pasture in the region, and regional hay production can offset the lost forage from the removal of pasture.

Productivity is a critical assumption in assessing the potential supply of cellulosic feedstocks such as crop residues and dedicated energy crops. It affects (1) the amount of crop residue potentially available and its collec-

[3] For each POLYSYS region (i.e., agricultural statistical district), a comparison was made among crop yields for woody crops and perennial grasses. The highest yielding crop was assumed for any given district. Generally, woody crops are more dominant in the Lake States, Northeast, Northwest, and parts of the South.

[4] It is possible to grow energy crops on land other than cropland, such as grassland, pastureland, and forestland, but this possibility was not modeled.

tion cost, (2) the costs of producing energy crops, and (3) the economics of crop residue collection versus energy crop production and, thus, changes in land use. A lowering of corn productivity to levels used in chapter 5 (i.e., a 50-percent increase in yield growth for 2016) and a concomitant lowering of expected breeding gains for energy crops would result in slightly higher corn prices, perhaps slightly more corn stover, and slightly lower shares for energy crops (relative to the results with 100-percent growth in productivity, see table 6.1). Complicating the assessment of crop residue and energy crop supply is the uncertainty of how much residue can be removed, given environmental sustainability and collection equipment constraints. Any changes that allow more residue to be sustainably collected improve the economics of crop residue collection relative to energy crop production.

Results from the different cellulosic model simulations are summarized in figure 6.1, with each chart representing a different combination of cropland, forest biomass, and imports to produce 36 BGY of renewable fuels. (A detailed regional breakdown of the proportions of crop residues and energy crops is provided in table 6.1.) The top chart (no forestland/imports) shows the farmgate feedstock price (red line and left axis) needed to get sufficient crop residues and energy crops into production to produce 36 BGY of renewable fuels. Prices reach over $60/dry ton in 2022 (in 2016 dollars) when all feedstocks come from cropland. In 2022, about 36 percent of the required feedstock, or about 85 million dry tons, would come from perennial grasses, woody crops, and annual energy crops (blue line and right axis). The remainder of about 152 million dry tons comes from crop residues, mainly corn stover.

The middle and bottom charts in figure 6.1 show scenarios requiring less feedstock from cropland. Estimated farmgate prices needed to secure sufficient feedstock are about $15/dry ton less under a cropland production scenario of 16 BGY and about $20/dry ton less under a production scenario requiring only 12 BGY of advanced biofuels produced from cropland. There are larger shares of energy crops relative to crop residues than in the scenario requiring 20 BGY from cropland. Under the 16 BGY scenario, about 40 percent of total feedstock requirements come from energy crops. Energy crops' share is over half when cropland feedstock requirements are reduced to 12 BGY. This trend toward an increasing share of energy crops to crop residue is due primarily to the imposed constraint that limits the amount of residue that can be removed. Relaxing this removal constraint to account for more advanced collection systems, such as a single-pass harvester, or improved preservation of soil carbon levels through the use of more no-till cultivation would increase the profitability of residue collection and increase the proportion of residue to energy crops.[5]

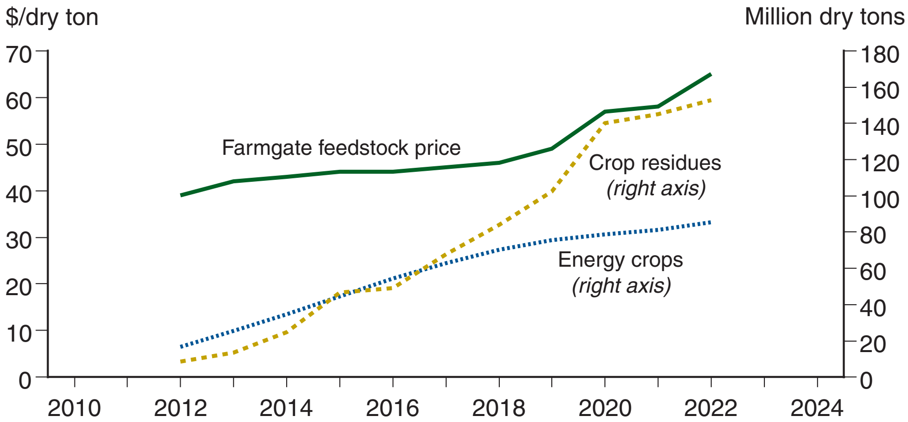
These scenarios requiring 12 to 20 BGY of biofuel from cropland feedstock were evaluated under a case where yield growth for corn is doubled and yield growth for energy crops is increased by 1.5 percent annually. A doubling of the baseline-projected increase in corn yield is higher than that assumed in the high-yield scenario for corn-based ethanol (chapter 5), but within the levels of documented high yields (see chapter 4). For energy crops under this high-yield scenario, it was assumed that productivity would increase in subsequent plantings or as the technology deploys to account for breeding gains and the use of improved varieties and clones. In these higher yield

[5]The modeled residue availability analysis assumes the combined use of conventional tillage, mulch tillage, and no-till. In the analysis, the proportions of mulch tillage and no-till increase over time relative to conventional tillage, which reflects the general trends in tillage practices regardless of the change in renewable fuels policy. More crop residue can be removed sustainably with an increase in the number of acres under no-till cultivation. Although not modeled, increasing the amount of no-till acres above current trends would make more residue available for removal. The use of winter cover crops would also allow considerably more residue to be removed sustainably.

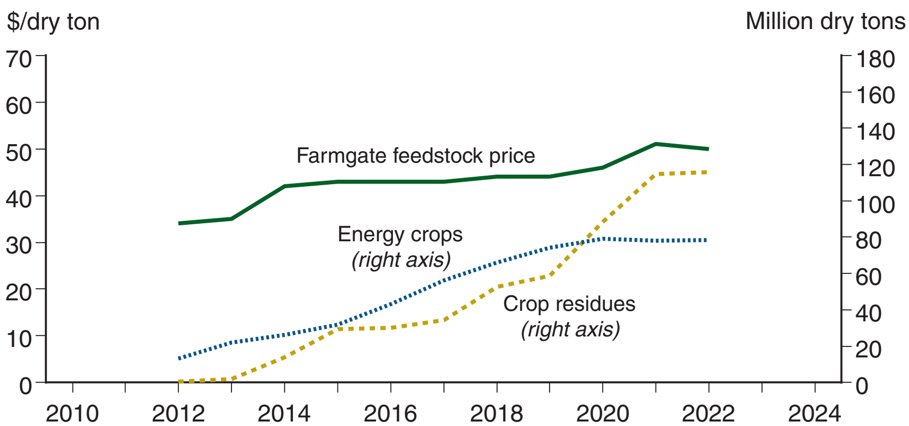
Figure 6.1

Summary of estimated prices and feedstock quantities required to produce 36 BGY of renewable fuels

Cellulosic scenario - 20 BGY from cropland, 0 BGY from forestland, and 0 BGY from imports



Cellulosic scenario - 16 BGY from cropland, 4 BGY from forestland, and 0 BGY from imports



Cellulosic scenario - 12 BGY from cropland, 4 BGY from forestland, and 4 BGY from imports

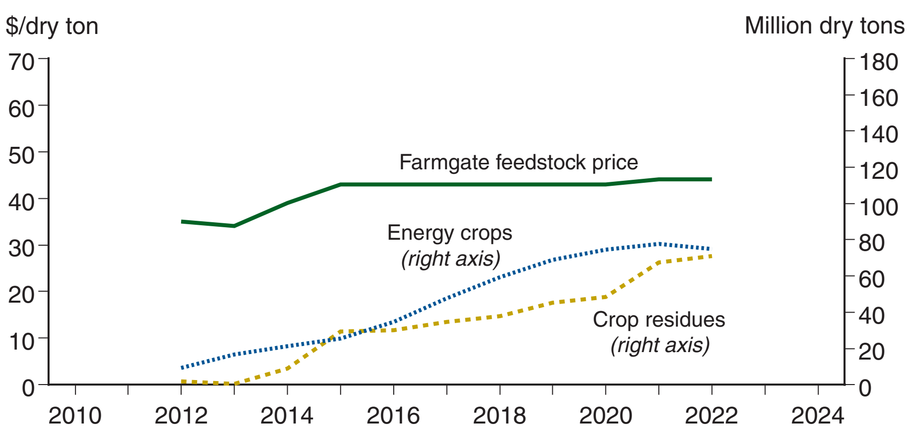


Table 6.1

Summary of regional feedstock requirements to produce 36 BGY of renewable fuels in 2022

	20 BGY from cropland biomass; 0 BGY from forestland biomass; 0 BGY from imports		16 BGY from cropland biomass; 4 BGY from forestland biomass; 0 BGY from imports		12 BGY from cropland biomass; 4 BGY from forestland biomass; 4 BGY from imports	
Feedstock/region	Reference w/ cropland cellulosics meeting 20 BGY	Reference w/ cropland cellulosics meeting 20 BGY - high yield	Reference w/ cropland cellulosics meeting 16 BGY	Reference w/ cropland cellulosics meeting 16 BGY - high yield	Reference w/ cropland cellulosics meeting 12 BGY	Reference w/ cropland cellulosics meeting 12 BGY - high yield
	Million dry tons					
Stover:						
Northeast	2.6	0.0	1.0	0.0	0.0	0.0
Lake States	22.2	19.0	20.6	14.8	4.6	3.9
Corn Belt	62.5	67.2	56.4	57.3	44.7	17.8
Northern Plains	14.1	0.0	1.2	0.0	0.0	0.0
Appalachian	2.6	1.5	1.7	1.5	1.2	0.4
Southeast	1.0	0.2	0.4	0.2	0.1	0.1
Delta	0.9	0.3	0.4	0.3	0.2	0.2
Southern Plains	1.8	2.0	1.6	0.0	0.0	0.0
Mountain	0.4	0.0	0.1	0.0	0.0	0.0
Pacific	1.0	0.0	0.5	0.0	0.0	0.0
U.S. total	**109.1**	**90.2**	**83.8**	**74.0**	**50.8**	**22.4**
Straw:						
Northeast	1.0	1.1	1.1	0.9	1.0	0.8
Lake States	4.9	5.2	4.9	5.0	4.7	2.5
Corn Belt	5.6	5.3	5.2	5.1	4.8	4.7
Northern Plains	12.5	0.0	5.8	0.0	0.2	0.0
Appalachian	2.1	1.8	2.0	1.7	1.8	1.6
Southeast	0.6	0.5	0.6	0.5	0.5	0.4
Delta	2.0	1.8	1.9	1.7	1.8	1.7
Southern Plains	0.7	0.0	0.1	0.0	0.0	0.0
Mountain	7.6	2.0	3.9	1.1	3.6	0.5
Pacific	6.9	1.4	6.4	0.9	1.5	0.8
U.S. total	**43.8**	**18.9**	**31.8**	**17.0**	**20.0**	**13.2**
Perennial energy crops:						
Northeast	2.8	6.1	2.6	3.6	2.6	3.4
Lake States	3.5	4.4	3.0	3.0	2.9	2.8
Corn Belt	16.0	21.5	15.1	20.2	13.4	19.1
Northern Plains	5.1	6.9	3.6	6.6	3.1	6.5
Appalachian	17.0	25.1	17.4	23.0	17.6	22.6
Southeast	7.7	12.8	8.3	11.8	7.9	10.9
Delta	27.2	41.7	25.6	39.3	26.2	39.5
Southern Plains	4.7	7.0	1.5	3.9	0.0	3.3
Mountain	0.0	0.0	0.0	0.0	0.0	0.0
Pacific	1.4	1.2	1.3	1.1	1.3	1.0
U.S. total	**85.3**	**126.9**	**78.5**	**112.5**	**74.9**	**109.2**

--continued

Table 6.1
Summary of regional feedstock requirements to produce 36 BGY of renewable fuels in 2022—Continued

	20 BGY from cropland biomass; 0 BGY from forestland biomass; 0 BGY from imports		16 BGY from cropland biomass; 4 BGY from forestland biomass; 0 BGY from imports		12 BGY from cropland biomass; 4 BGY from forestland biomass; 4 BGY from imports	
Feedstock/region	Reference w/ cropland cellulosics meeting 20 BGY	Reference w/ cropland cellulosics meeting 20 BGY - high yield	Reference w/ cropland cellulosics meeting 16 BGY	Reference w/ cropland cellulosics meeting 16 BGY - high yield	Reference w/ cropland cellulosics meeting 12 BGY	Reference w/ cropland cellulosics meeting 12 BGY - high yield
	Million dry tons					
All residues and energy crops:						
Northeast	6.4	7.2	4.6	4.5	3.6	4.2
Lake States	30.6	28.6	28.5	22.8	12.2	9.3
Corn Belt	84.2	94.1	76.7	82.6	62.9	41.6
Northern Plains	31.7	6.9	10.6	6.6	3.3	6.5
Appalachian	21.6	28.4	21.0	26.2	20.6	24.6
Southeast	9.3	13.5	9.3	12.5	8.5	11.5
Delta	30.1	43.7	27.8	41.3	28.2	41.4
Southern Plains	7.1	9.0	3.2	3.9	0.0	3.3
Mountain	8.0	2.0	4.0	1.1	3.6	0.5
Pacific	9.3	2.6	8.2	2.0	2.9	1.9
U.S. total	**238.2**	**236.0**	**194.1**	**203.5**	**145.7**	**144.8**

Note: All scenarios assume reference level of 15 BGY of corn-based ethanol and 1 BGY of biobased diesel.

scenarios, national farmgate prices are in a much narrower range ($43, $42, and $40/dry ton for the 20 BGY, 16 BGY, and 12 BGY scenarios, respectively). The proportion of energy crops is higher across all three scenarios in year 2022, reflecting the greater profitability of energy crops (due to the higher yields) versus stover and straw.

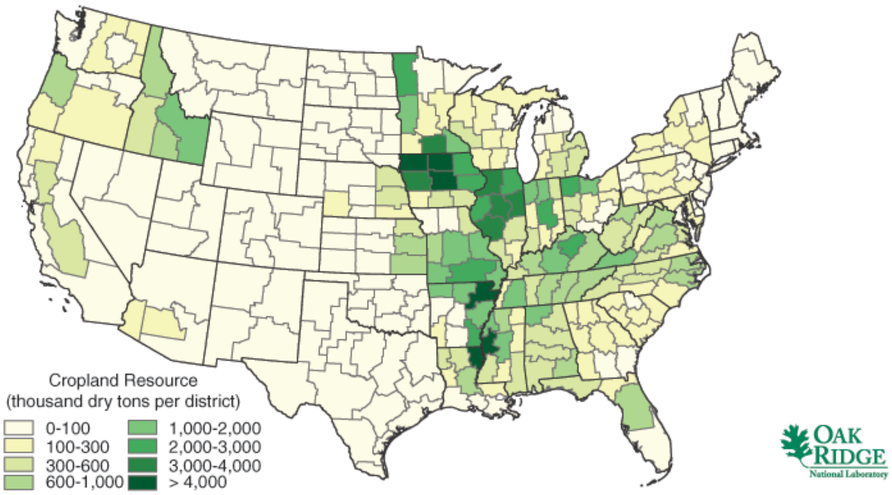
The regional breakdown of the feedstock requirements needed to produce 20 BGY of advanced biofuels from cropland (table 6.1) shows, as expected, the Corn Belt and Lake States dominant in the production of corn stover; the Northern Plains, Mountain States, and Pacific region tops in the production of straw; and the Delta, Appalachian, Corn Belt, and Southeast regions leading in the production of energy crops. This regional distribution does change as the amount of feedstock required from cropland is lowered to account for the availability of forest residues and imported biofuel (fig. 6.2). Particularly evident is the disappearance of crop residue from the Northern Plains, Mountain States, and Southern Plains as less feedstock is required from cropland (table 6.1). Again, the key factor in this trend is the imposed constraint on residue removal, which makes recovery of small per-acre quantities expensive relative to the production of dedicated energy crops.

Depending on the scenario, the amount of land needed to accommodate energy crops varies between 15.9 and 18.6 million acres for cellulosic scenarios requiring feedstocks to produce 12 to 20 BGY. Figure 6.3 summarizes the distribution of acres among major uses of cropland (crops, hayland, cropland pasture, and energy crops) and changes in land use to accommodate energy crops. Most of the acreage change involves the shifting of cropland

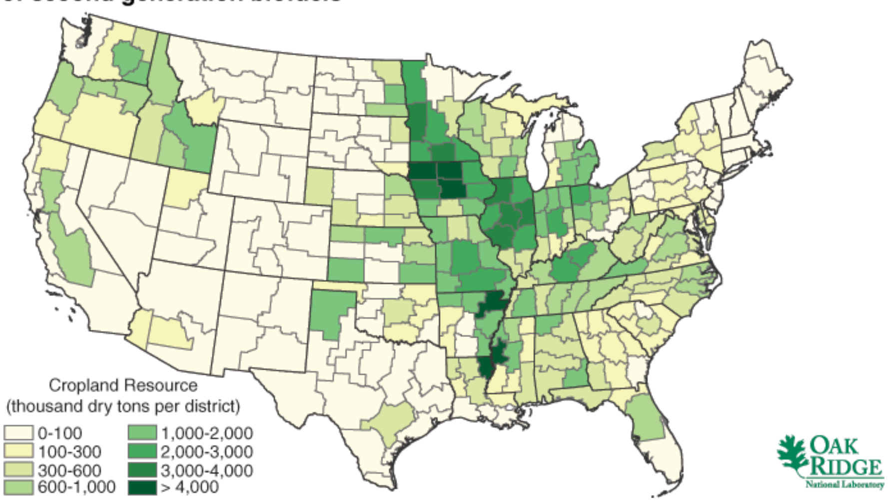
Figure 6.2

Location of cropland resources for the production of second generation biofuels in 2022

Location of cropland resources for production of 12 BGY of second generation biofuels



Location of cropland resources for production of 16 BGY of second generation biofuels



Location of cropland resources for production of 20 BGY of second generation biofuels

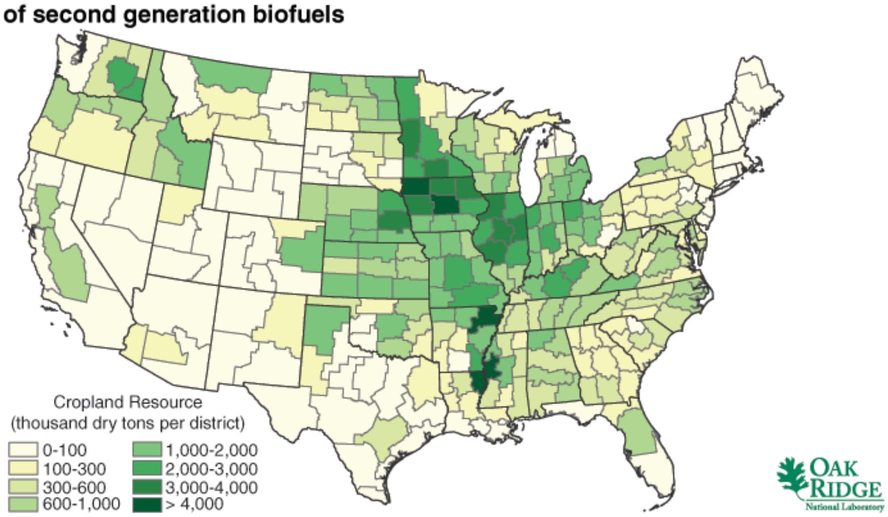


Figure 6.3a
Distribution of acres among major categories of land use in 2022

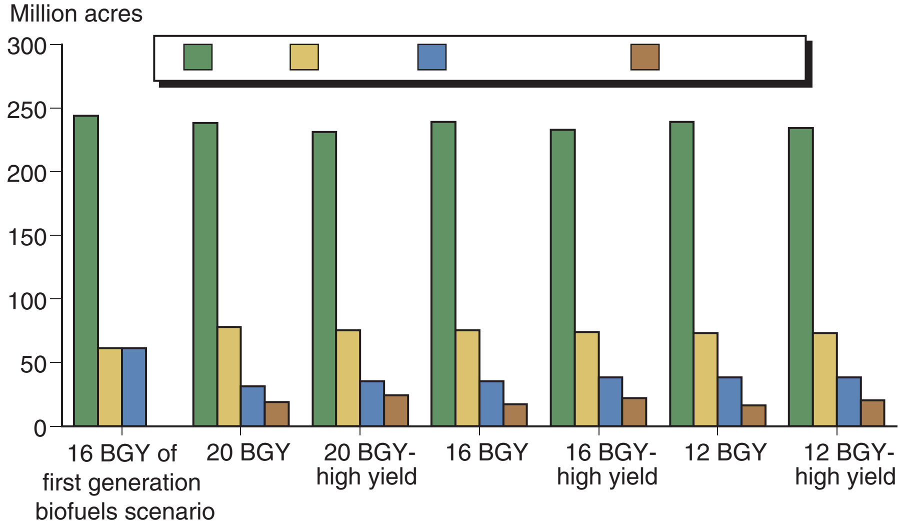
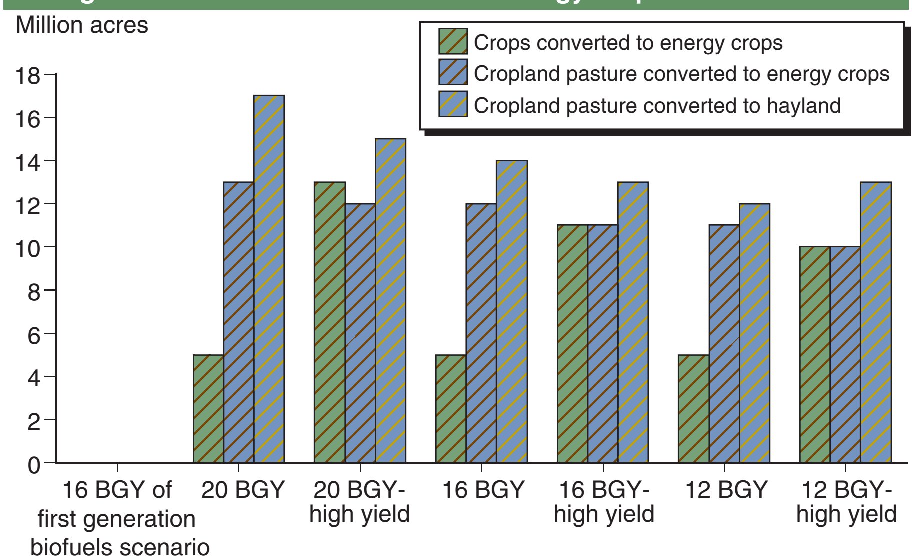


Figure 6.3b
Changes in land use to accommodate energy crops in 2022



pasture to energy crops and hay to make up for the lost forage, as well as conversion of some marginal cropland to energy crops.

The largest land-use changes are associated with the scenario requiring all of the biomass to come from cropland to produce 20 BGY of ethanol. In this scenario, there is a shift of about 2.5 percent of cropland to energy crops. Under the high yields for corn and energy crops, there is a shift of about 5.3 percent of cropland to energy crops. Lesser shifts in land use are associated with the scenarios requiring less biomass from cropland. For any given scenario, the high-yield case shows a much higher percentage shift of cropland (used to grow crops) to energy crops. For example, the quantity of energy crops in the 12 to 20 BGY scenarios ranges from 75 to 85 million dry tons. That is, a 40-percent reduction in the required contribution from cropland reduces the required contribution from energy crops by about 12 percent. This indicates that energy crops are more profitable relative to the collection of crop residues. This result is due to imposed model constraints that restrict the amount of removed residue to no more than 34 percent of available corn stover and 50 percent of wheat straw. Allowing for more residue removal would lower collection costs and improve the profitability of residue collection relative to the production of energy crops.

For the most part, analysis results suggest a significant amount of cropland used as pasture is planted to energy crops and hay to make up for the lost forage. This represents an increase in the use intensity of cropland pasture. The amount of cropland used as pasture brought back into production of hay and energy crops ranges from 23 million acres when feedstock for only 12 BGY is required to nearly 30 million acres under the highest cropland biomass scenario (20 BGY) (fig. 6.3). In all of these scenarios, the amount of cropland pasture converted to hay to make up for lost forage could be reduced with a successful R&D effort to increase hay productivity. Higher production from existing hayland could make additional cropland (pasture) available for energy crops.

Small amounts of crops convert to energy crops in all regions—with the exception of the Delta—across all scenarios. In the Delta, nearly 2.0 million acres of cotton, 1.6 million acres of soybeans, and 500,000 acres of rice are converted to energy crops (fig. 6.4). When lower amounts of biofuels are required from cropland resources (12 and 16 BGY), results show a loss of about 500,000 acres of corn in the Northern Plains, with some additional plantings of soybeans in the Corn Belt and to a lesser extent in the Northern Plains and Lake States.

Land allocated to energy crops increases under the high-yield scenarios owing to the higher net returns from energy crops relative to corn and wheat with residue removal. Under higher assumed yields for energy crops, there is more displacement of cropland used for crops with energy crops and less conversion of cropland used as pasture. The amount of land used for energy crops increases from about 20.3 million acres for the 12 BGY scenario to 23.8 million acres for the 20 BGY scenarios. The scenario with the lowest cropland feedstock requirements (12 BGY) and higher yields would shift 10 million acres of land currently in major crops to energy crops, nearly 10 million acres of pasture to energy crops, and over 12 million acres of pasture to hay to make up for the lost forage.

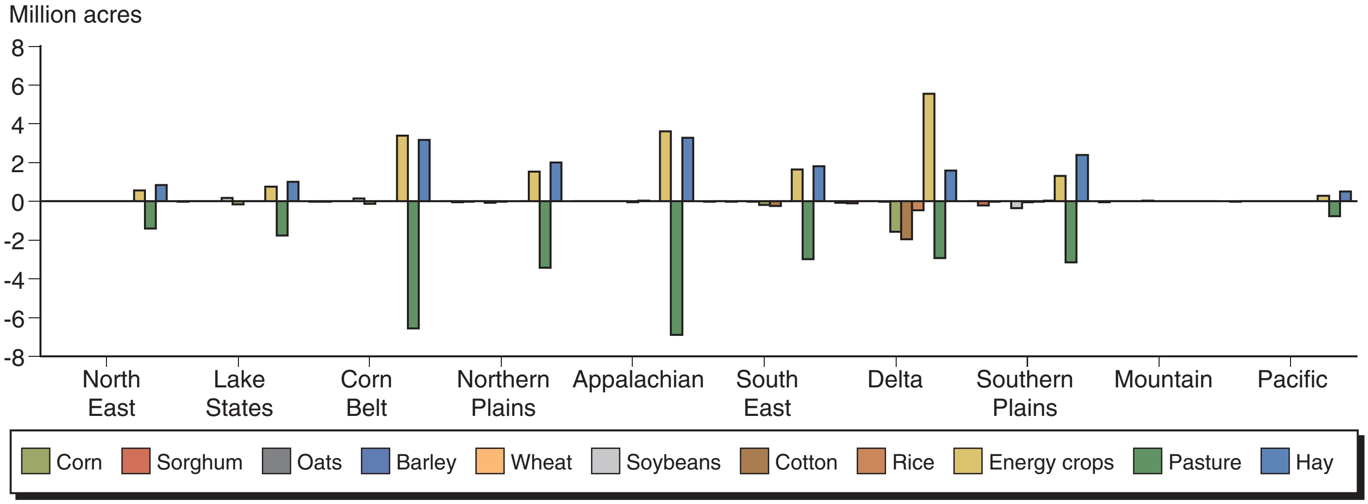
Contributions From Forestlands

Contributions from forestland are assumed to provide sufficient feedstock to produce 4 BGY of second-generation and other renewable fuels. This biomass feedstock contribution is based on an examination of aggregated supply curves for forest residues and what could be available at forest roadside prices ranging from roughly $40 to $46 per dry ton. This price is derived from POLYSYS model results for scenarios requiring cropland feedstock sufficient to produce 12 to 16 BGY of ethanol. The *Billion-Ton Report* (Perlack et al., 2005) estimated a current unexploited potential feedstock sufficient to produce 12 BGY of renewable fuels, excluding any contributions from conventionally sourced wood and wood currently being used for relatively low-value uses. The 4 BGY of second-generation and other renew-

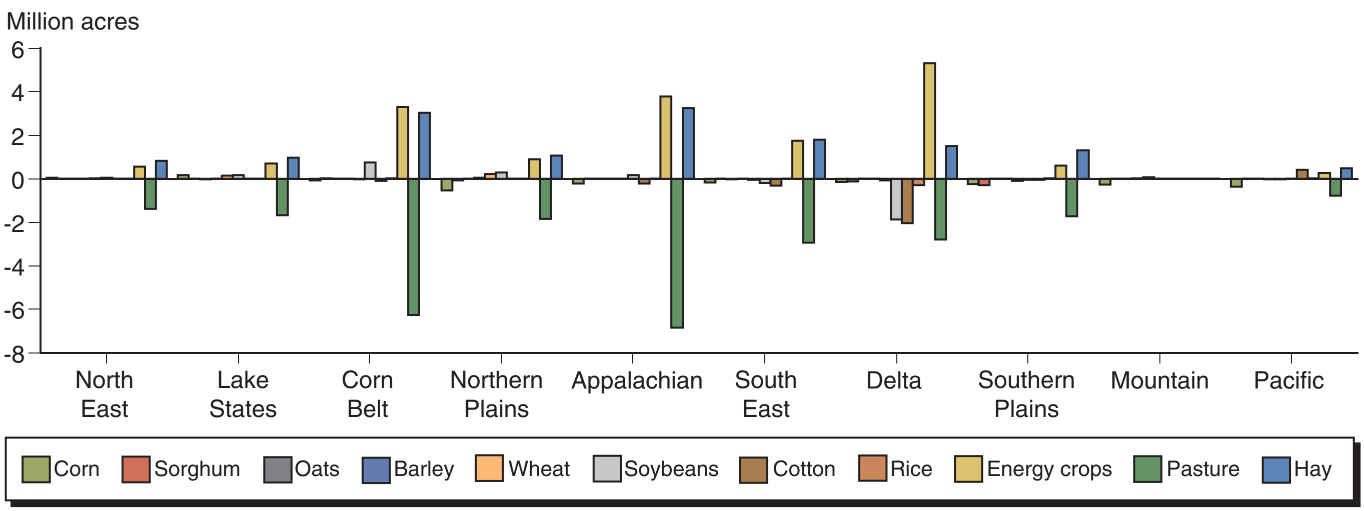
Figure 6.4

Summary of estimated land use change required to produce 36 BGY of renewable fuels in 2022

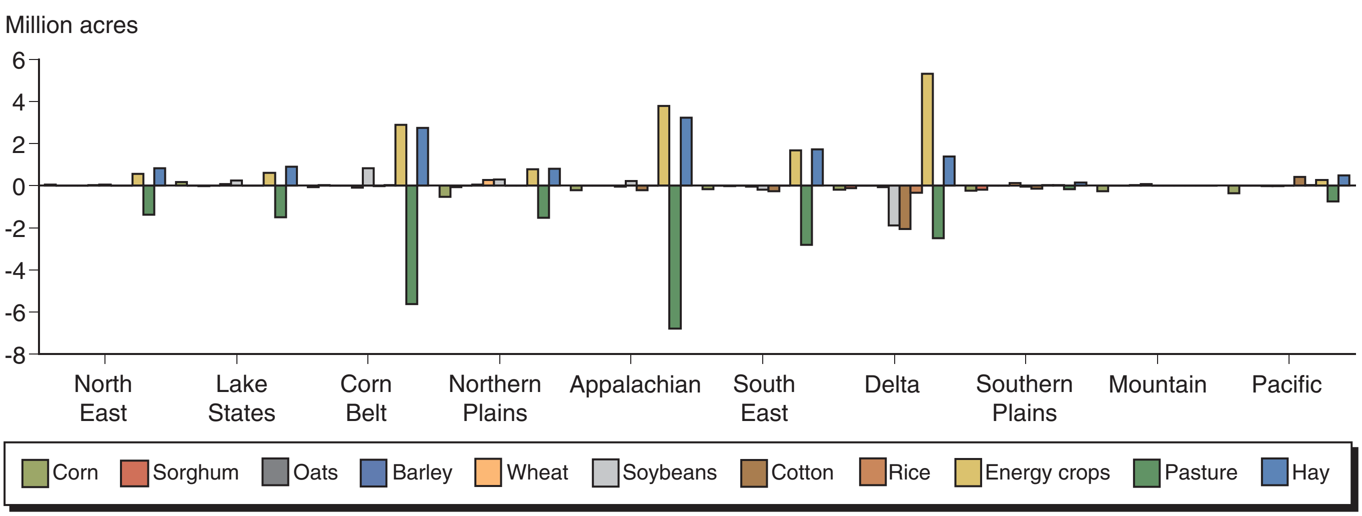
Cellulosic scenario - 20 BGY from cropland, 0 BGY from forestland, 0 BGY from imports



Cellulosic scenario - 16 BGY from cropland, 4 BGY from forestland, 0 BGY from imports



Cellulosic scenario - 12 BGY from cropland, 4 BGY from forestland, 4 BGY from imports



able fuels is thus a relatively conservative estimate of the potential contribution from forestlands.

The forestland resources available for cellulosic biofuel production are varied and include logging residues, other removal residues, thinnings from timberland and other forestland, primary mill residues, urban wood waste, and conventionally sourced wood (see chapter 2). Excluded here is wood grown under short rotations on cropland and dedicated to biofuels production. These woody crops are an integral part of the energy crop mix under cropland resources, which account for 75 to 85 million dry tons across scenarios. A substantial share of energy crops will likely be woody crops, especially in the Lake States, Northeast, Northwest, and South.[6]

[6]The analysis did not attempt to evaluate the potential of woody crops grown on timberland, grassland, or any land not currently classified as cropland. To be sure, the potential exists to grow short-rotation woody crops on forestland and grassland. Since woody crops are modeled as a generic energy crop, no attempt was made to reclassify any cropland used to grow woody crops as forestland.

Some other potential forestry feedstocks were not included. For example, the pulp and paper industry generates large amounts of pulping liquors. Although heat and power are currently generated as a byproduct in the recovery of valuable chemicals from these liquors, innovative gasification technologies could be used to convert these pulping liquors into a number of advanced biofuels.

There are about 749 million acres of forestland in the contiguous United States, with about two-thirds classified as timberland—the source of most conventional wood products. Slightly more than 20 percent of this forestland is classified by the USDA's Forest Service as "other" and is generally not productive enough for commercial operations owing to poor soils, lack of moisture, high elevation, or rockiness. Other forestlands tend to be used for livestock grazing and extraction of some non-industrial wood products. The remaining 10 percent of forestland acres are reserved from harvesting and are dedicated to a variety of nontimber uses, such as parks and wilderness.

U.S. forestlands have considerable potential to provide biomass from two primary sources: residues associated with the harvesting and management of commercial timberlands for the extraction of sawlogs, pulpwood, veneer logs, and other conventional products; and currently nonmerchantable biomass associated with the standing forest inventory. The nonmerchantable biomass includes rough and rotten wood not suitable for conventional forest products and excess small-diameter trees in overstocked forests. Much of this forest material has been identified by the Forest Service as needing to be removed (i.e., thinnings) to improve forest health and to reduce fire hazard risks (USDA-FS, 2003).

[7]The FIA program has been in continuous operation since 1928. It collects, analyzes, and reports information on the status and trends of America's forests: how much forest exists, where it exists, who owns it, and how it is changing. The latest technologies are used to acquire a consistent core set of ecological data about forests through remote sensing and field measurements. The data in this report are summarized from 125,000 permanent field plots in the United States.

The primary data for estimating biomass from thinning of timberland were plot-level data compiled by the Forest Inventory and Analysis Program (FIA)[7] of USDA's Forest Service (Smith et al., 2004). The plot data indicate current stand conditions on all U.S. timberland.[8] Data on logging residues, other removals, and mill residues are available from the FIA Timber Product Output (TPO) Database Retrieval System (USDA-FS, 2004). Data for urban wood waste are from the *Billion-Ton Report* and are based on supporting analyses from McKeever (2004) and EPA (2003).

[8]Analyses are based on the interim updated FIA inventory of the 2000 Resources Planning Act (RPA) projections (USDA Forest Service, 2007).

In this analysis of the forestland contribution to producing 20 BGY of second-generation and other renewable fuels, removal of biomass from thinnings for fuel treatment operations is annualized, assuming that the excess biomass currently available in densely stocked stands would be removed in stages over 30 years. This same assumption was used to estimate biomass from forest thinnings for the *Billion-Ton Repor*t (Perlack et al., 2005). All non-Federal timberland with Fire Regime Condition Classes (FRCC) 1, 2, or 3 are assumed to be available for treatment.[9] Biomass from federally owned lands was excluded since this biomass does not qualify toward meeting the Renewable Fuel Standard. Only biomass directly removed from non-Federal lands is included. Primary mill residues and urban wood waste are an exception because the origin is generally unknown.

Plots were selected for thinning treatments if their stand density index (SDI)[10] was greater than 30 percent of the maximum SDI for their forest type and ecoregion (Shepperd, 2007). Potential removal volumes were identified based on prescriptions that would remove trees across the diameter distribution using the SDI criterion. This treatment method is the same as the one used to estimate biomass from forest thinnings for the *Billion-Ton Report*, except that FRCC 1 was added. Since this class is not generally overstocked, few acres in this fire condition class meet the stand density requirements that permit thinning.

It is assumed that trees 1-5 inches in diameter at breast height (dbh) and the tops and branches of larger trees will be available for use as biomass. It is assumed that all of the small-tree biomass can be extracted to roadside, but that only 80 percent of the volume in tops and branches of larger tress will make it to roadside due to breakage. Wood from the main stems of trees 5-9 inches dbh in the West or 5-7 inches dbh in the East is assumed to be available for use as pulpwood. Wood from the main stem of trees greater than 9 inches in the West or 7 inches in the East is assumed to be available for use as sawlogs, and thus not available as biofuels feedstock.

Two types of costs were estimated—stumpage (landowner payment) and harvesting to roadside. Harvesting costs are estimated for wood removed from each FIA plot using an adaptation of the Fuel Reduction Cost Simulator (FRCS) model (Fight et al., 2006). The original FRCS model was designed to simulate harvests in the interior West. It was substantially revised for this study, with new harvesting procedures designed to simulate harvests in the North (North-Central and Northeast), South, and wetter areas of the West. In addition, all cost data were updated. For this study, FRCS is used to estimate the costs of providing biomass at roadside using any of three alternative harvesting systems—ground-based, whole-tree harvesting with mechanized felling; ground-based, whole-tree harvesting with manual felling; or cable yarding of whole trees that have been manually felled.

Stumpage prices were estimated from published information with regional, historical, and projection analyses. Stumpage costs are very dynamic and location-specific. For this analysis, it was assumed that low levels of wood biomass use would incur an average stumpage price of $4 per dry ton for tops/branches, logging residue, and mill residues. As the level of top, branch and small tree removal increases on forest land—in association with harvest for conventional products such as sawlogs—the stumpage price for wood biomass was assumed to increase up to 90 percent of recent pulpwood prices at the current level of sawlog harvest.

[9]Fire Regime Condition Class designation for forest inventory plots were obtained from the Forest Service Landfire Project – Rapid Assessment Products – Fire Regime Condition Classes. See http://www.landfire.gov/ra3.php

[10]SDI (Reineke 1933) is a long-established, science-based forest stocking guide for even-aged stands that can be adapted to uneven-aged stands (Long and Daniel, 1990) using data available from broad-scale inventories.

Biomass supply curves were derived by using the biomass harvest cost for each FIA plot, estimated as the weighted-average cost to remove and chip trees 1-5 inches dbh and to chip the tops and branches of larger trees at roadside. Sawlog supply curves were derived by using the sawlog harvest cost for each FIA plot, estimated as the weighted-average cost to remove trees 9 inches dbh or larger in the West and 7 inches dbh or larger in the East. In each State, biomass supply from tops/branches and small trees is limited so the associated sawlog supply does not exceed projected sawlog supply in 2022. It was assumed that 1/30th of the constrained biomass supply will be available for harvesting each year.

Logging residues, other removal residues, and primary mill residues are reported annually in the Timber Product Output (TPO) database. Costs were developed for these feedstocks based on empirical studies and reported information. For logging residues, the cost included just the additional costs of primary processing (i.e., chipping at roadside). For mill residues, only handling and storage costs were included since they are byproducts of forest product processing. Other removal residues are very site- and stand-specific. An average cost was assumed for this operation based on published information.

All the wood is assumed to be residues or byproducts, lacking a higher value than energy wood except for the conventionally sourced wood. Wood that would normally be used in higher value products (e.g., pulpwood, posts, piling, etc.) could be used for biofuels when prices for alternate uses are low. Also, within the lower merchantable limits, small-diameter material can easily shift between conventional, commercial uses and biofuel feedstocks, depending on prices and other factors.

The modeled scenarios assume that feedstock sufficient to produce 4 BGY of second-generation and other renewable fuels can be derived from forestland wood resources. Since woody biomass was modeled within POLYSYS as reduced demands for cropland cellulosic feedstocks, POLYSYS was used to establish farmgate prices for nonwoody, cellulosic feedstocks. This cost, approximately $44 per dry ton, was used to determine available woody volumes for each of the forestland feedstock resources. This price target became the upper bound for available wood quantities needed to produce 4 billion gallons of biofuel annually.

In total, about 45 million dry tons of forest biomass are needed nationally to produce 4 BGY (table 6.2).[11] About 45 percent of the feedstock comes from logging residues, with another 14 percent from other removals at a forest roadside cost of about $44/dry ton. Thinnings on timberlands account for nearly a quarter of the forestland contribution, or about 1 BGY. Primary mill residues from forest product mills and urban wood wastes combined contribute an estimated 9 percent of the requirement from forestlands. Finally, conventionally sourced wood is conservatively assumed to account for 8 percent of the total.

The Southeast, Delta, and Appalachian regions are the largest sources of forestland biomass, followed by the Lake States, Northeast, and Pacific regions (fig. 6.5). The spatial distribution of forestland resources generally parallels major logging activities and areas with an excess of thinnings from overstocked forest stands (fig. 6.6). Feedstock sufficient to produce 20 BGY

[11]A number of assumptions were used in the compilation of the forestland biomass resources. These assumptions are noted in table 6.2.

Table 6.2
Annual forestland biomass availability

Source	2022 reference scenario portion	Upper bound
	Million dry tons[1]	*Million dry tons*[2]
Logging residues[3]	20.1	40.1[4]
Other removal residues[3]	6.1	12.2
Thinnings from timberland[3]	10.9	20.8[4]
Thinnings from other forestland[3]	0[5]	0[5]
Primary mill residues	1.3	1.3[6]
Urban wood residues[7]	2.8[8]	14.0[9]
Conventionally sourced wood	3.5[10]	15.0[11]
Total	44.7[12]	102.8

Notes:

[1]Since the upper bound is constrained by physical availability and estimated cost at $44 per dry ton at roadside (same as farmgate cost), and since only 45 million dry tons are to be used from the forestry sector (based on relative proportions in the billion-ton report), the sources were apportioned by using half of the upper bound, except for mill residues, which are the most readily available, low-cost source (used 100% of upper bound) and for urban wood residues, which are the most difficult to estimate.

[2]Constrained by physical availability and estimated cost of $44 per dry ton at roadside.

[3]Biomass from Federal land is removed per Subtitle A, Section 201 (I)(iv) for the Renewable Fuel Standard under the Energy Independence and Security Act of 2007.

[4]Recovery of logging residue and recovery of biomass from thinnings from timberland may become mutually exclusive in the future. In the past analyses, logging residues were reported separately as the wastes from conventional forest operations and thinnings were reported as additional harvest operations with fuel treatments as the major goal. Currently, logging residues are not generally recovered. In the future, there will likely be fewer residues generated by conventional logging operations as recovery of the wood for energy will become more integrated with logging for conventional products. Therefore, by 2022, it is expected that logging residues and the thinnings from timberland may become more duplicative and are not really additive. This concern is handled by a 50-percent reduction in the logging residue quantity estimate for 2022.

[5]The projected cost for thinning other forest land—i.e., usually low-volume trees or stands—is higher than the $44 per dry ton threshold, but is included here to indicate that technology or other incentives (such as controlling invasive species) may allow this to be a viable option. The current estimate is that 8.7 million dry tons would be available from non-Federal lands, but at a cost greater than $44 per dry ton at roadside.

[6]These 1.3 million dry tons are the unused fraction. There are 13 million dry tons that are currently used for miscellaneous byproducts. About 35 and 37 million dry tons are currently used for fiber products and energy, respectively. Some of the used material could move into fuel production.

[7]The *Billion-Ton Report* without any updated analysis.

[8]Only 10 percent of the potential urban wood residue resources identified in the *Billion-Ton Report* was used to make the 45-million-dry-ton goal because of lack of reliable cost information on this source.

[9]Only half of the available unexploited resource potential identified in the *Billion-Ton Report* used as the upper bound because of lack of reliable cost information.

[10]Less than 4 million dry tons are needed from this source to meet the goal.

[11]Conventional forest crops (e.g., pulpwood) could be used for biofuels if priced competitively with other end-use markets. Pulp and paper plant receipts of pulpwood declined by about 15 million dry tons over the past decade because of U.S. markets and capacity. The resource has not declined. It was assumed that 5 dry tons of the 15 million dry tons would be available at the cost limit.

[12]The amount of woody cellulosic feedstock needed to produce 4 BGY of biofuel is 44.7 million dry tons, based on a conversion yield of 89.5 gallons per dry ton.

Figure 6.5
Production and costs for forestland wood

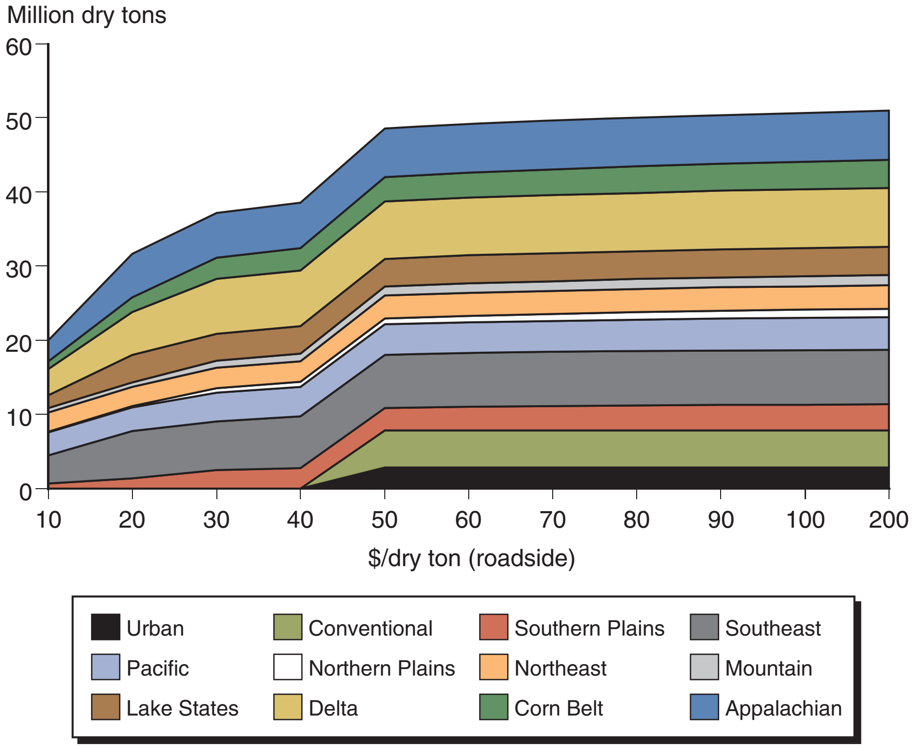


Figure 6.6
Forestland biomass resources

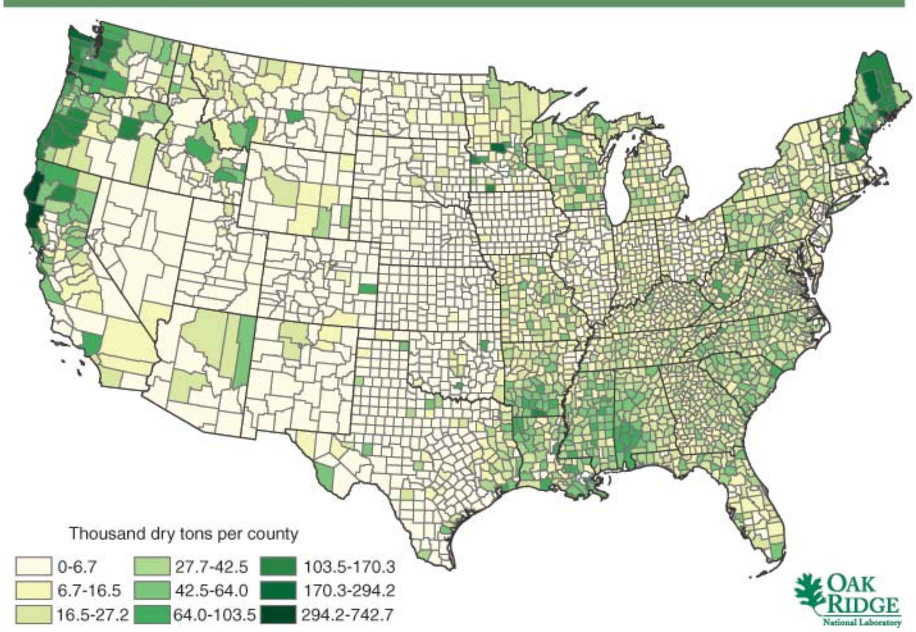
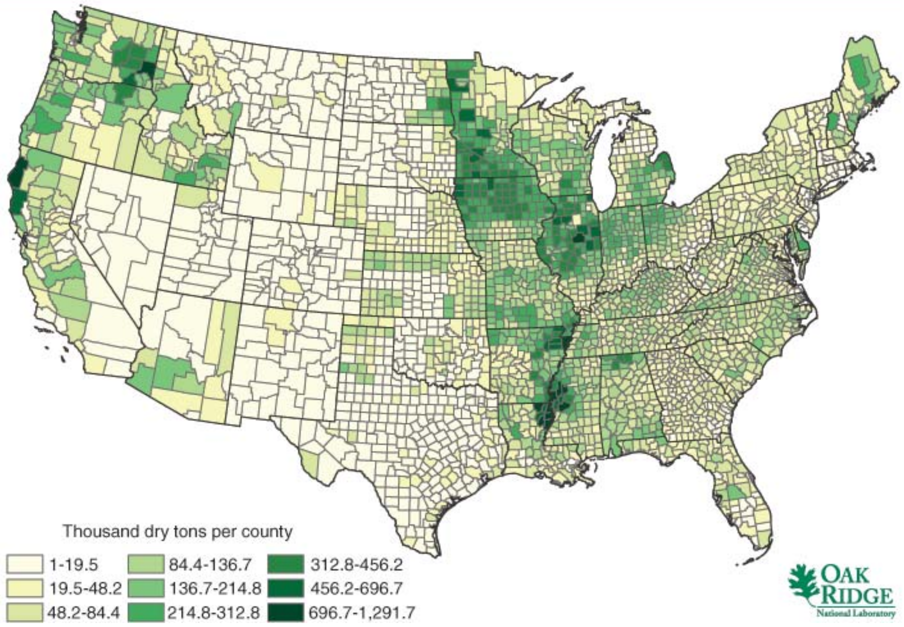


Figure 6.7
Cropland and forestland biomass resources



of ethanol or other advanced biofuels is shown in figure 6.7. Spatial coverage is rather complete across the United States, except for some of the interior West where resources are limited to fuel treatment thinnings.

Contributions From Imports

Global production of fuel ethanol for 2008 is about 18 billion gallons. Just over half of this is U.S. corn-based ethanol. Another third (36 percent) is sugarcane ethanol production from Brazil (Trostle, 2008). The remainder is production from other countries using a variety of feedstocks, such as wheat, barley, cassava, sugarcane and sugar beets. DOE's Office of Policy and International Affairs recently examined market and policy scenarios for future biofuels production and concluded that advanced ethanol production using cellulosic feedstocks could expand significantly with higher conversion efficiencies and more rapid reduction in costs (DOE, 2008). In 2020, global biofuel and biodiesel production was projected to be around 54 BGY, increasing to 83 BGY by 2030. The assumed level of imported biofuels (4 BGY) in the assessed scenarios is reasonable given these projections.

Implications for Future Research

This chapter attempted to assess the potential cellulosic feedstock contribution from croplands and forestlands to produce 20 billion gallons of second-generation and other renewable fuels by 2022. An agricultural policy simulation model was used to identify the potential contribution from crop residues and energy crops and how this contribution could affect the regional and national mix of crops, prices, and overall land use. A separate analysis was used to assess the contributions from forestlands and imports. Findings from this analysis suggest further research aimed at improving the quality of data and for improving and integrating cellulosic feedstock modeling.

Model findings are sensitive to assumptions about the amount of crop residue that must remain in the field in order to maintain soil quality, organic matter, and limit erosion from water and wind. Generally, the amount of residue that needs to remain is a function of many variables, including tillage, crop rotations, and many location-specific variables such as soil type and field slope. To ensure the collection of crop residue would be sustainable, the amount of residue removal was limited to no more than 34 percent of available corn stover and 50 percent of wheat straw. These constraints may be conservative in situations where no-till cultivation is practiced and/or the local physical attributes of the soil permit larger quantities of residue removal. Allowing for a larger fraction of residue removal would lower the collection costs and increase the profitability of residue collection. Thus, additional research is needed to quantify appropriate levels of sustainable residue removal at a regional and county level for use in the POLYSYS model.

The relative profitability of crop residue collection and the production of energy crops depend on what one assumes about residue removal, as just discussed, and what one assumes about energy crop productivity. Energy crops are not currently planted commercially. Data used in the POLYSYS model are based on small-scale research plots and expert opinion. Additional research is needed to assess energy crop productivity in commercial-scale plantings and at many more locations in order to validate yield assumptions currently assumed in the POLYSYS model.

Dedicated energy crops were modeled in POLYSYS rather generically. Each of the 305 regions in the model had 1 generic energy crop choice that could compete for land with the major crops or cropland in pasture. Ideally, the POLYSYS model should have the capability to assess the competitiveness of a much larger range of cellulosic feedstocks as well as regionally relevant feedstocks, such as energy cane. At a minimum this should include each major type of energy crop—short-rotation woody crops, perennial grasses, and annual energy crops (e.g., sweet sorghum)—within each region. This detail would provide for a more robust assessment of the potential of energy crops within a region and would provide further detail needed to evaluate GHG implications and feedstock sustainability criteria more rigorously.

Finally, the assessment of the feedstock potential from croplands, forestlands, and exports was done independently. There is a need to develop a version of the POLYSYS model that includes a forestland module so that land competition issues and a full set of second-generation and other renewable fuels can be evaluated under differing biofuel feedstock scenarios. This would require the development of a forest supply component accounting for the supply of woody biomass (i.e., logging residues, fuel treatment thinnings, mill residues, etc.) and forest product demand. Integrating forestland into POLYSYS would thus provide an opportunity to conduct economic analyses of both cropland and forestland resources as well as allow the evaluation of potential tradeoffs between the two sectors.

Greenhouse Gas Implications

Introduction

Much of the interest in expanding the domestic production and use of biofuels stems from the view that these fuels can simultaneously enhance energy security and lower greenhouse gas (GHG) emissions. This chapter examines the farm-sector GHG implications of moving to a world in which domestic production of ethanol and biodiesel are significantly higher than today. The objectives are to examine how increased demand for biofuels might affect the GHG emissions associated with the production of feedstock crops, highlight opportunities where farm-level decisions can affect changes in the GHG emissions associated with feedstock production, and identify areas where additional research could most improve our understanding of the GHG profiles of feedstock crops.

Conceptually, biofuels offer the opportunity to replace fossil fuels, which when combusted continuously add carbon dioxide (CO_2) to the atmosphere, with fuels that recycle CO_2 between the atmosphere and plant material in agriculture and forest systems. That is, CO_2 is emitted when ethanol is used in place of gasoline, biodiesel in place of petroleum diesel, or biomass in place of coal in electricity generation, but an equivalent amount of CO_2 is removed from the atmosphere when the next rotation of the feedstock crop is produced.

In assessing the GHG impacts of using biofuels in place of fossil fuels, some have assumed that biofuels are GHG neutral. From this perspective, the use of biofuels results in a reduction in GHG emissions equal to the GHGs that would have been emitted if fossil fuels had been used in their place. For example, the Technical Guidelines of the Department of Energy's revised Voluntary Greenhouse Gas Reporting Program (U.S. Department of Energy, 2007) instruct entities not to report any emissions associated with biofuels used in transportation vehicles (Part 1.D.4).

In reality, the GHG footprints of biofuels are more complex. First, the production and use of a given quantity of biofuel may result in a less than energy-equivalent reduction in the use of fossil fuel. If so, the effect would be a more modest reduction in GHG emissions attributable to the biofuel's displacement of fossil fuel. Second, there are a number of steps in the production of both biofuels and fossil fuels that produce GHG emissions. To estimate the GHG emissions associated with the production and use of various biofuels and to compare those emissions with the emissions associated with the use of fossil fuels, an extensive scientific literature has developed the lifecycle analysis (LCA) framework.[1] While direct comparisons of GHG benefits reported in LCA studies can be complicated by differences in methodologies (e.g., how coproducts are treated), scope of study, key parameter values, and metrics used to present results, some general findings of past studies are consistent.[2]

- Among biofuels, corn ethanol has relatively modest GHG benefits. Compared to gasoline, Wang et al. (2007) estimate the average reduction

[1]The first studies employing LCA analyses were done in the late 1970s and focused on estimating the net energy balance of corn ethanol. For reviews of these studies, see Shapouri et al. (2002) and Hammerschlag (2006). Later studies applied the LCA framework to other biofuels and extended it to include comparisons of GHG emissions associated with biofuels and their fossil fuel counterparts [see USDA and U.S. DOE (1998), Wang (1999 and 2005), and Adler et al. (2007)]. For a review of lifecycle analyses of liquid biofuels for transportation uses, see Larson (2006).

[2]The GHG analysis conducted for this report does not take into account the full lifecycle analysis of GHG emissions, which EPA is undertaking as part of the regulatory analysis required by EISA 2007.

in GHG emissions for corn ethanol produced in the United States at 19 percent. The reduction in GHG emissions can be as high as 52 percent if the refinery process is powered by biomass and can increase GHG emissions if the refinery process is powered by coal.

- The GHG benefits for biodiesel, sugar ethanol, and cellulosic ethanol are potentially much larger than for corn ethanol. Relative to their petroleum counterparts, USDA and DOE (1998) estimate the reduction in GHG emissions for soybean biodiesel (i.e., B100) at 78.45 percent. Wang et al. (2008) estimate the reduction in GHG emissions for sugar ethanol in Brazil at 78.4 percent. Schmer et al. (2008) estimate the reduction in GHG emissions from switchgrass versus ethanol at 94 percent.
- A promising opportunity to achieve significant GHG benefits with biofuels is in the substitution of biomass for coal in operating power plants. Relative to coal, Adler et al. (2007) estimate the reduction in GHG emissions associated with using switchgrass, reed canary grass, and hybrid poplar to generate electricity at 85-93 percent. These benefits could be significantly higher if the lands used to produce the feedstocks have a higher average carbon stock (i.e., carbon stored in vegetation and soils) in feedstock production than in their previous use.

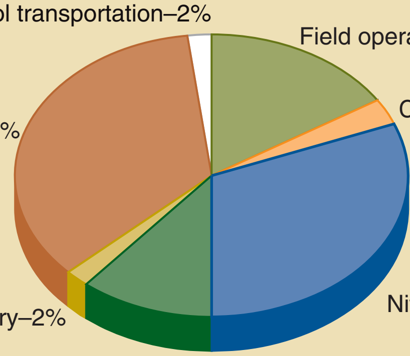
A potentially important source of GHG emissions related to the production of biofuel feedstocks, which to date has not been thoroughly modeled in the context of biofuel lifecycle analysis, are the emissions related to land-use changes (Searchinger et al., 2008). These include direct emissions related to bringing new land into production for feedstock crops, and indirect emissions related to bringing new land into production to maintain supplies of traditional food, forage, and fiber commodities. Emissions related to land-use change could occur domestically or internationally as a result of U.S. and world commodity markets adjusting to higher levels of U.S. demand for liquid biofuels.

To date, emissions related to land-use change have not been considered a problem in GHG lifecycle analyses. It has been assumed that U.S. production of ethanol (and biodiesel) did not affect commodity prices so as to drive conversions of new lands—nationally or internationally—into production of feedstock crops or production of crops for food, fiber, or forage. As U.S. production of corn ethanol ramps up to more than double the 2007 level and as production of cellulosic ethanol and other advanced biofuels becomes economically viable, the issue of biofuel demand driving land-use changes—and thus GHG emissions from land-use change—will need to be examined more rigorously. This fact was recognized by the EISA legislation, which specified that EPA consider indirect emissions, such as significant emissions from land-use changes, in the lifecycle analysis of biofuels under the act. Accordingly, EPA is developing a lifecycle analysis of biofuels that captures these and other secondary effects.

Figure 7.1 illustrates the GHG emissions for a gallon of corn-based ethanol, disaggregated to show the share of emissions attributable to different activities. The shares and total emissions shown are from Argonne National Laboratory's GREET model and do not include emissions related to land-use change or emissions due to secondary agriucultural sector effects. For

Figure 7.1
Shares of GHG emission for corn-based ethanol, by source

Total of 5,795 grams/gallon (with coproduct credits)



Source: GREET Model, Argonne National Laboratory.

purposes of this report, it is helpful to distinguish between the activities and emissions that occur "before" versus "after the farmgate." Emissions related to farm machinery, use of nitrogen and other chemicals, and field operations all occur before the farmgate and account for 60 percent of the emissions depicted in figure 7.1.[3] Emissions that occur in the transportation of the feedstocks from the farm to the refinery, the refining of the biofuels, and the delivery of the biofuels to the final consumer occur after the farmgate. Since the purpose of this report is to assess the impacts of increasing liquid biofuel production on the U.S. feedstock sector, this chapter will focus on the emissions that occur before the farmgate as well as the emissions related to domestic land-use change (direct and indirect). Emissions related to land-use changes in foreign countries are beyond the scope of this report and will not be examined.

Farm-Level Actions Affecting GHG Profile of Feedstock Production

GHG emissions related to feedstock production include CO_2, nitrous oxide (N_2O), and methane (CH_4) emissions.[4] The farm management decisions discussed in this section can influence the magnitude of these emissions as well as the quantity of carbon sequestered in soils and biomass.[5]

Land-Use Change

Land-use change is arguably the least well quantified of all management decisions in past analyses of GHG emissions related to biofuel production. Converting land into crop production will influence both biomass and soil carbon pools due to vegetation removal and soil disturbance. In turn, changes in the carbon pools affect the flux of CO_2 between the atmosphere and farm. Converting forestland into crop production generally entails clearing of woody biomass and loss of carbon from the site. Carbon losses to the atmosphere can be reduced if the wood is incorporated into products (Skog and

[3]This 60-percent share assumes current feedstock production patterns in the U.S. Factoring in changes to cropping patterns and exports could result in a different profile than shown in figure 7.1.

[4]CH_4 emissions are mostly driven by livestock enteric fermentation and manure management, which will not be considered in this report, but may be important if biofuel feedstock production is influencing the number of livestock or feed quality.

[5]Appendix table 7.1 presents estimates from scientific studies describing the potential of changes in selected land uses and production practices to sequester carbon.

Nicholson, 1998). On the other hand, burning the wood onsite leads to loss of the carbon and also generates non-CO_2 GHG emissions. In addition to biomass, CO_2 is typically emitted from soils. The conversion of forests or grasslands into annual cropland (Davidson and Ackerman, 1993) can lead to soil carbon losses ranging from 70 to 80 percent in temperate regions and 60 to 70 percent in tropical regions (Ogle et al., 2005).

Land Management Practices

The net emissions associated with land-use change will also depend on the management of land after conversion. For example, no-till can limit the loss of carbon following conversion by reducing erosion and maintaining soil structure (Six et al., 2000). No-till use on former CRP lands has been found to reduce loss of soil organic matter compared with using conventional tillage (Gilley et al., 1997). However, no-till may also have less of an effect on carbon storage in cropland soils than originally thought because of reduced root growth deeper in the soil profile than under conventional tillage (Baker et al., 2007; Blanco-Canqui and Lal, 2008)). More research is needed to confirm the generality of this finding.

No-till can also reduce N_2O emissions relative to conventional tillage even with the same fertilizer rates. However, the effect is thought to be ephemeral and eventually evens out with N_2O emission rates under conventional tillage management (Six et al., 2006). For corn-soybean rotations in the Midwest, N_2O emissions were nearly equal under no-till and conventional tillage after about 10 years (Parkin and Kaspar, 2006).

Farmers can also increase carbon (C) inputs to soils through a variety of practices, and thus limit losses of soil C following land-use change, or stimulate an increase in soil C for lands under long-term cultivation (CAST, 2004). For example, increasing the use of fertilizers, irrigation, lime, organic amendments, and cover crops typically results in higher soil carbon levels. Similarly, the choice of feedstock crop, crop variety, and crop rotation can affect soil C stocks. This is particularly true when land is converted from annual crops to a perennial feedstock such as short-rotation poplar or switchgrass (Adler et al., 2007).

Fertilizer Management

Recent research has raised questions about the accuracy of N_2O emission factors used to estimate GHG emissions from nitrogen fertilizer applications in the production of biofuel feedstocks (Crutzen et al., 2007). N_2O is emitted both directly and indirectly from cropland soils, and emissions are largely controlled by nitrogen management practices, including the amount and timing of mineral N fertilization, seeding legumes, and applying manures and other organic fertilizers (Mosier et al., 1998). It is generally accepted that approximately 1 percent of mineral N added to soils is directly emitted as N_2O (Bouwman et al., 2002; IPCC, 2006), but rates vary largely due to climatic conditions. In contrast, indirect N_2O emissions occur offsite with gaseous losses of N that are redeposited on soils and N loss in groundwater or overland water flow. Indirect emissions of N_2O are highly uncertain, but may be considerably higher than originally thought (Crutzen et al., 2007). More research is needed to resolve this issue.

Several management options can reduce both direct and indirect N_2O emissions. The timing and amount of mineral and organic fertilization are two key management decisions. Avoiding overfertilization and applying fertilizer during peak plant demand will limit direct N_2O emissions, and reducing nitrogen application rates will limit indirect N_2O emissions. Nitrification inhibitors may also limit direct N_2O emissions (Bremner, 1997).

Energy Use

Management also influences CO_2 emissions associated with energy use on farms, such as combustion of fossil fuels in farm machinery (West and Marland, 2002). Management decisions have direct implications for emissions associated with the production of fertilizers and herbicides that are applied to feedstock crops. For example, fuel-associated emissions decline with conversion from conventional tillage to no-till (West and Marland, 2002). Liming also leads to emissions of CO_2 from soils (West and McBride, 2005). Moreover, lower GHG emissions from reduced energy use or liming can be sustained as long as the practice continues. Carbon sequestration in soils will reach an equilibrium limit over a finite period of time.

Methodological Issues Affecting Estimates of GHG Emissions

Assessing the GHG implications within the feedstock sector of any policy or scenario that contemplates large increases in the production of biofuel feedstocks requires that several key methodological issues be addressed. Understanding these issues is important because alternative treatments are available and conceptually defendable, and because the approach chosen can significantly affect the magnitude and, in some cases, the direction of the GHG impacts that follow. This section briefly discusses four such methodological issues relevant to the current analysis.

Choice of Baseline

To estimate how GHG emissions related to feedstock production will change as the result of a given policy or scenario, there must be a point of reference. The choice of baseline determines the starting point for counting impacts and also helps determine what impacts are counted.

Two common choices for baselines are a previous "point in time" or historic baseline, and a "business as usual" (BAU) or projected description of the future. For example, a "point in time" baseline would compare absolute changes in GHG emissions associated with biofuel production between two different years. A BAU baseline might use the official USDA baseline—with its assumed trends in biofuel production and other variables as well as policy expectations—to assess the additional impacts of an alternative biofuel scenario in a future year. In contrast to "point in time" baselines, BAU baselines can incorporate anticipated trends in key variables as well as the effects of existing policies and expected policy changes. By comparing an alternative scenario with a BAU scenario, one can assess the additional impacts from the alternative over and above what is thought would have happened anyway.

The analysis for this report uses the 2007 USDA baseline, which assumes that U.S. production of ethanol from corn will be 12 billion gallons per year by the end of 2016. Actual production of corn ethanol in 2007 was about 6.5 billion gallons. Hence, while increasing corn ethanol production to 15 billion gallons a year by 2016 (i.e., the level considered in this report) represents an 8.5-billion gallon increase relative to 2007, it represents a 3-billion-gallon increase relative to the baseline.

Scope or System Boundaries

Another key methodological issue in assessing the GHG impacts of a given policy or scenario is the choice of boundaries for the analysis. Conceptually, the boundaries can be thought of as a "fence" where activities or impacts that occur inside the fence are counted and those that occur outside the fence are not. Typical boundaries in GHG analyses focus on a set of key gases, specific activities and/or sectors, a particular geographic area, and designated time period. In practice, it is often difficult to specify a set of boundaries that contain the complete set of GHG implications of a given policy or scenario. That is, impacts often occur inside the boundaries of an analysis that will have GHG implications outside of the boundaries. However, the goal is to minimize effects outside the boundaries to the extent possible so that the analysis provides a robust estimate of the GHG emissions associated with the issue being examined—in this case, changes in feedstock production for corn ethanol.

The distinction between the impacts that occur inside and outside of the boundaries is critical because they may have counteracting effects on the policy goals. To illustrate, defining the boundaries to be the U.S. farm sector, farmers may significantly reduce the use of nitrogen fertilizers in response to a financial incentive aimed at lowering farm sector N_2O emissions. If as a result the price of fertilizers decrease and homeowners—who are outside the boundaries—respond by applying more nitrogen fertilizer to residential properties, then the increased emissions from residential applications will partially offset the decrease in farm sector emissions. As a result, a portion of the GHG benefits accounted for in the analysis would be offset by related actions outside the boundaries. Another example is the effect of increased U.S. corn production on globally traded commodities such as soybeans. U.S. soybean production may decline due to higher returns on corn production for biofuel needs. This may lead to greater production of soybeans in other countries such as Brazil, and potentially more deforestation to meet the supply gap created by changing production trends in the United States (Searchinger et al., 2008). These phenomena are generally referred to as "leakage" in the GHG literature.

As with baselines, the choice of boundaries affects which impacts are included in an analysis. In this study, the boundaries include the U.S. agricultural sector as modeled in REAP (see chapter 4). As such, the study does not address leakage associated with other economic sectors or regions outside of the United States. Therefore, the analysis cannot address issues related to the overall carbon footprint of corn ethanol. For example, the focus on agricultural producers means that GHG impacts of ethanol-related activities that occur beyond the farm are not counted.[6] Similarly, the study cannot assess the optimal mix of biofuel feedstocks in the farm sector. The

[6]Wang et al. (2007) illustrate the potential to affect the GHG footprint of corn ethanol at the refining stage. They analyze the lifecycle GHG emissions associated with a unit of ethanol relative to the lifecycle emissions for an energy-equivalent quantity of gasoline for 10 alternative refinery technologies. On average, ethanol reduces GHG emissions relative to gasoline by 19 percent, but the range across technologies varies from a reduction of 52 percent for biomass-fired plants to a 3.0-percent increase in emissions for coal-fired plants.

focus on ethanol as a transportation fuel precludes consideration of using agricultural lands to produce feedstocks for other biofuels such as biomass for power generation.

Timing of Emissions From Land-Use Change

A third methodological issue is the treatment of carbon losses from terrestrial sinks when new lands are brought into agricultural production. Bringing new lands into production—directly for the production of feedstock crops or indirectly to produce crops that have been replaced by feedstock crops elsewhere—leads to carbon losses from vegetation and soils. Carbon losses from vegetation can be viewed as one-time events that typically occur when lands first shift from pasture, grasslands, or forests into crop production. Carbon losses from soils occur over a longer time period. Once converted, lands are likely to remain in crop production for years or even decades. Several options exist for emissions accounting related to land-use change, including (but not limited to):

(1) Count the emissions related to land-use change in the year of conversion;

(2) Count emissions changes at the time that they occur, which would differ for vegetation and soils (e.g., 1-3 years);

(3) Average the entire loss of carbon from soils and biomass over a period of time, such as the number of years the land would be used to produce biofuel feedstocks.

In the first approach, it is likely that in the first year emissions related to biofuels will be much higher than those related to the fossil fuels they replace. In subsequent years, the reverse will be true. Thus, the focus is on how long the land must stay in feedstock production to offset the initial carbon loss and generate net GHG benefits. The second approach would have a similar focus, but with less bias in the first year. Because the timepath of emissions is crucial to the analysis of GHG impacts in both of these approaches, they are most appropriate for use with dynamic modeling frameworks.

The REAP model is a static framework, meaning it assesses changes in market and other conditions for a given point in time—in this analysis, comparisons are made between USDA baseline conditions in 2016 (published in 2007) and a set of alternative conditions in 2016. To properly reflect emissions related to land-use changes in this framework, an approach is required that is independent of the emissions timepath. This analysis, then, uses the third approach—emissions related to land-use changes are modeled as the average annual emissions over an assumed lifetime of the biofuel production system.

Dealing With Uncertainty

The last methodological issue is the treatment of uncertainty. It is important to understand the potential role of uncertainty in assessing the GHG implications of farm sector activities for three reasons. First, the GHG emissions associated with many activities such as applying nitrogen fertilizer, shifting tillage practices, or bringing new lands into crop production can vary significantly depending on such factors as climate and edaphic characteristics, current management practices, management history, and a variety of other site-specific environmental characteristics such as topography. As a result, there is often no single number that can be used to assign an emissions level to a given activity or land-use change. Second, considerable scientific uncertainty still surrounds the magnitude of emissions associated with several key agricultural sources. Crutzen et al. (2007), for example, argue that the indirect N_2O emissions from nitrogen fertilizer applications on croplands may be higher than the levels obtained from the most commonly used estimation method. They point out that for biodiesel from rapeseed and ethanol from corn, the higher N_2O emissions could offset the GHG benefits related to lower fossil fuel use. Finally, even for activities and land uses where relatively precise measures of emissions or sequestration are possible, obtaining them may be prohibitively expensive and resource intensive. In these cases, the only cost-effective options may be to rely on less precise but simple emission coefficients, or in some cases more rigorous process-based models such as USDA's COMET-VR, which provides field-level estimates of soil carbon changes for agricultural lands in the United States (Brenner et al. 2004: http://www.cometvr.colostate.edu/).

In empirical work, three options for dealing with uncertainty are to (1) develop representative point estimates of emission levels from published studies, (2) develop error bounds for likely high and low emission levels from published studies and/or expert knowledge that are considered "representative" of the activities and land-use changes, or (3) develop probability distribution functions if there are a sufficient number of published studies on the activity or land-use change. The analysis presented below uses the first approach. One consequence of using this approach is that we cannot address any uncertainties associated with the point estimates themselves.

GHG Implications of Modeled Scenarios

The REAP and POLYSYS models have been used in this report to assess the economic implications for the U.S. farm sector of increased feedstock production for liquid biofuels. In this section, we focus on the REAP model to further consider the GHG implications of the scenarios analyzed.

The biofuel target examined in the REAP scenarios is to increase domestic production of corn-based ethanol to 15 billion gallons and biodiesel to 1 billion gallons per year by 2016. While this reflects the target specified in Title II of EISA, the analysis presented here is limited in scope and does not represent a complete GHG analysis of the EISA fuel volumes.[7] One important limitation is that the REAP runs focus on corn ethanol, which is only one of the liquid biofuels for which EISA specifies targets and timetables out to 2022. A second important limitation is that the analysis does not look at international land-use changes that might be directly or indirectly driven by world markets responding to increased U.S. demand for biofuels and their feedstocks. As noted earlier, this could be an important source of GHG emissions as biofuel production increases and would need to be accounted for in a complete assessment. This analysis also does not account for secondary GHG impacts in domestic agricultural markets—such as changes in livestock

[7]EPA is conducting a comprehensive GHG analysis of the EISA fuel volume requirements as part of its rulemaking analysis.

sector emissions related to changes in the prices and quantities of feed grains. Again, these impacts would need to be assessed in a complete GHG assessment of EISA.

In REAP, the allocation of land to alternative uses (including commodity production, idle land, and conservation uses), the choice of tillage system (i.e., conventional, reduced, or no-till systems), and the application of nitrogen fertilizers are all endogenous variables. Changes in these activities and land uses will be the principal sources of agricultural sector GHG emissions associated with increased production of liquid biofuels. GHG emissions associated with land use and production decisions listed below are estimated in REAP using coefficients obtained from a variety of sources (see appendix table 7.1). Estimates include:

(1) CO_2 emissions related to changes in regional and national land use patterns (i.e., bringing new land into crop production);

(2) CO_2 emissions/sequestration related to changes in the regional and national mixes of tillage practices;

(3) GHG emissions related to nitrogen fertilizer use; and

(4) GHG emissions related to the use of farm machinery, other chemicals, and field operations in corn ethanol production.

Summary results describing the aggregate U.S. farm-sector GHG implications of the five REAP scenarios are presented in table 7.1.[8] From these results, three broad conclusions can be highlighted. First, the farm-sector GHG implications of increasing corn ethanol production from 12 to 15 billion gallons a year (i.e., from the level specified in the USDA baseline to the level specified in the reference scenario) are likely to be modest. Total farm-sector GHG emissions are 7.95 million metric tons CO_2 equivalent (MMT CO_2 eq) higher in the reference case than in the USDA baseline case. For perspective, the 2006 edition of EPA's *Inventory of U.S. Greenhouse Gas Emissions and Sinks* estimates total methane and nitrous oxide emissions from all agricultural sources in 2004 at 440.2 MMT CO_2 equivalent (EPA, 2006a). Compared to current agricultural sector emissions then, an additional 7.95 MMT CO_2 would represent an increase of about 1.8 percent.

The farm-sector GHG implications of increasing corn ethanol production from 12 to 15 billion gallons per year would be very sensitive to changes in either corn productivity or input costs associated with increased energy prices. In REAP, increasing the rate of growth in corn productivity by 50 percent relative to the reference scenario reduces GHG emissions relative to that scenario by 7.7 million metric tons (i.e., almost offsetting the increase in emissions observed in the reference scenario).[9] Increasing energy-related input costs 50 percent relative to the reference scenario has a similar effect, but the magnitude is larger (i.e., the reduction in emissions relative to the reference scenario is 13.67 million metric tons). Another key parameter that would affect GHG emissions of U.S. crops is assumed export response under the two scenarios. If more of the additional feedstock needed for ethanol production came from exports, emission effects would derive more from international than from domestic crop changes.

[8]The sources, and in most cases the values of the emissions coefficients used to calculate the GHG impacts are detailed in appendix table 7.2.

[9]For this REAP scenario it is assumed that corn productivity increases 6.9 percent relative to the reference scenario. This reduces the GHG emissions associated with machinery, farm operations, other chemicals, and nitrogen fertilizer. To account for this, the GHG emissions for these categories shown in figure 7.1 (i.e., in terms of grams of CO_2 per gallon) were decreased 6.9 percent. These changes resulted in productivity-adjusted emissions per acre for each REAP region.

Table 7.1

Change from reference case in agricultural sector GHG emissions in 2016, by REAP scenario

	Reference[1]	High corn productivity	High input costs	Positive carbon price	Combi-nation
	Million metric tons				
Total change in GHG emissions	7.95	-7.70	-13.67	-22.07	-44.48

[1] Value for reference case reflects changes relative to the USDA baseline; values for all other scenarios reflect changes relative to the reference scenario.

Finally, of the three variables examined in the alternative scenarios, the introduction of a carbon price of $25 per mt CO_2 eq. results in the largest decrease in GHG emissions (22.07 MMT CO_2 relative to the reference case). (The value of $25 per mt is explained on p. 51.) To put this result in context, it should be emphasized that the set of carbon incentives included in the scenario were a subset of the incentives that would be included in a broader program to mitigate GHG emissions in agriculture systems. Most importantly, the incentives did not include carbon payments for shifting croplands and pasture to forest. This was done to keep the scenario focused on the implications of changes in demand for biofuel feedstocks.

A 2005 study by EPA used the FASOMGHG model to assess the potential to mitigate GHG emissions in the U.S. forestry and agriculture sectors (U.S. EPA, 2005). This study looked at the period 2010-2110 and included incentives for afforestation, forest management, carbon sequestration in agricultural soils, agricultural mitigation of CH_4 and N_2O, fossil fuel mitigation in crop production, and biofuel offsets (primarily for power generation). For a carbon price of $30 per mt CO_2, the EPA study estimated that 125 million acres of cropland would shift to conservation tillage (almost all no-till) by 2015, resulting in annual carbon sequestration of close to 200 MMT CO_2 annually. The results of the EPA study suggest the REAP GHG results for the positive carbon price are both conservative and not representative of what would occur under a comprehensive GHG mitigation program. Even with these qualifications, the results of this scenario suggest that the development of viable carbon markets could be a promising policy option to simultaneously increase biofuels production and improve the GHG footprint of these fuels.

Table 7.2 disaggregates the changes in U.S. farm-sector emissions by activity and land-use change. It also provides the associated changes in total acres for each activity and land use. The changes in farm-sector activities that result in the largest emission reductions differ across the alternative scenarios. In the high corn productivity scenario, changes in farm input use (nitrogen, other chemicals, and field operations) account for almost 80 percent of the total reduction in GHG emissions (relative to the reference case). In the high input cost and positive carbon price scenarios, the main sources of emission reductions are, respectively, land-use change (78 percent) and changes in tillage (73 percent). These results suggest there are a broad set of options available to reduce the GHG emissions associated with increased feedstock production. Additionally, when the changes

Table 7.2
REAP impacts by activity and land-use change in 2016

Activity	Baseline	Reference	High corn productivity	High input costs	Positive carbon price	Combination scenario
New cropland (land-use change)						
Acres in crop production (million)						
U.S. total	316.99	321.41	319.77	305.34	314.96	296.67
Change from reference[1]		4.42	-1.64	-16.07	-6.45	-24.74
GHG impact: Change in soil carbon (million mt CO_2)						
Change from reference[2]		3.75	-1.30	-10.67	-4.24	-16.51
Changes in tillage						
Conventional tillage (million acres)						
U.S. total	232.09	234.81	233.13	215.99	192.01	170.02
Change from reference		2.72	-1.68	-18.82	-42.80	-64.79
Conservation tillage (million acres)						
U.S. total	51.02	51.70	51.58	53.06	69.41	71.30
Change from reference		0.68	-0.12	1.36	17.71	19.60
No till						
U.S. total	33.88	34.90	35.06	36.30	53.53	55.35
Change from reference		1.02	0.16	1.40	18.64	20.46
GHG emissions due to changes in tillage systems (million mt CO_2)						
U.S. total						
Change from reference[2,3]		-0.69	-0.04	-1.28	-16.00	-17.90
Changes in corn production						
Acres (million)						
U.S. total acres in corn	90.00	93.68	90.66	92.24	92.21	87.39
Change from reference		3.68	-3.02	-1.44	-1.47	-6.29
GHG Impacts (million mt CO_2)						
Machinery						
U.S. total	4.57	4.74	4.52	4.68	4.68	4.40
Change from reference		0.16	-0.21	-0.06	-0.06	-0.34
Farm operations						
U.S. total	36.59	37.89	36.20	37.44	37.41	35.21
Change from reference		1.30	-1.70	-0.46	-0.49	-2.68
Other chemicals						
U.S. total	25.16	26.05	24.89	25.74	25.72	24.21
Change from reference		0.89	-1.17	-0.31	-0.33	-1.85
Nitrogen fertilizers						
U.S. total	70.90	73.42	70.14	72.54	72.48	68.22
Change from reference		2.52	-3.28	-0.89	-0.94	-5.20

[1] Values for reference case reflect changes relative to the USDA baseline; values for all other scenarios reflect changes relative to the reference case.
[2] Negative numbers imply positive net carbon sequestration. Positive numbers inply net CO_2 emissions from soils.
[3] Numbers reflect changes in emissions due ONLY to changes in tillage. Changes in emissions related to associated land-use changes (e.g., starting tillage on new cropland or stopping tillage on lands being retired) are included in the land-use change category. This is done to avoid double counting.

in corn productivity, energy prices, and a carbon price are combined into one REAP scenario, farm-sector emissions decrease 44.48 MMT CO_2 below the reference scenario. This suggests GHG impacts associated with changes in the three key variables examined are relatively distinct and that a comprehensive approach to reducing farm-sector GHG emissions related to biofuel feedstock production could include a broad set of incentives targeting different GHG sources.

Returning to the reference scenario, nitrogen fertilizer use and farm operations are the second and third most important activities driving the increase in GHG emissions. Together with land-use change, these three sources account for over 95 percent of the increase in GHG emissions between the baseline and reference scenarios. Changes in tillage practices, farm machinery, and use of other chemicals are relatively minor emissions sources (accounting for less than 1 MMT CO_2 equivalent each).

Table 7.3 presents regional GHG impacts for the five REAP scenarios. As expected, regional GHG impacts are directly related to changes in land use and commodity production. Across scenarios, changes in land use and corn production are most pronounced in the Corn Belt. Focusing on the reference and baseline scenarios, the Corn Belt accounts for 34.5 percent of the 3.68 million acres of new corn production, 41 percent of the increase in emissions related to farm operations, and 41 percent of the higher emissions associated with increased use of nitrogen fertilizers.

After the Corn Belt, the GHG impacts are most pronounced in the Lake States and the Northern Plains. Large parts of these regions are suitable for growing corn but under baseline conditions are more suited to other crops. Again, comparing the reference scenario to the baseline scenario, these two regions account for 47 percent of the emissions associated with bringing new land into production, 41 percent of the emissions associated with farm operations, and 41 percent of the emissions associated with additional use of nitrogen fertilizers. In general, the GHG impacts in the other six REAP regions are much smaller.

Finally, while the total amount of land enrolled in USDA's Conservation Reserve Program (CRP) was held fixed at 39.2 million acres (the level specified in the 2007 USDA baseline), the REAP model results suggest that increasing biofuel production could lead to shifts in the management of conservation lands that would result in net losses of soil carbon. This possibility is inferred from the regional redistribution of land in the Conservation Reserve Program as modeled in the REAP analysis. In the reference scenario, for example, CRP enrollment in the Corn Belt decreases by slightly more than 1 million acres relative to the baseline scenario. At the same time, CRP enrollment in the Mountain region increases by about 1 million acres.[10] On a per-acre basis, the release of soil carbon from former CRP lands coming into production in the Corn Belt would be significantly higher than the accumulation of carbon in the soils of new CRP lands in the Mountain States (see appendix table 7.1). Moreover, the loss of soil carbon in the Corn Belt would occur at a faster rate than the gains in soil carbon in the Mountain States.

[10]For the other eight REAP regions, the changes in CRP acres are much smaller.

Table 7.3
Regional GHG impacts for corn acres only, by REAP scenario in 2016

Region	Baseline	Reference	Reference minus baseline	High corn productivity	High input costs	Positive carbon price	Combination scenario
				Change from reference			
				Million acres			
North East	3.88	4.09	0.21	-0.01	-0.08	-0.03	-0.14
Lake States	14.45	15.05	0.60	-0.84	-0.33	-0.50	-1.82
Corn Belt	44.63	45.90	1.27	-1.43	-0.09	-0.18	-1.59
Northern Plains	16.50	17.64	1.14	-0.57	-0.69	-0.52	-2.09
Appalachian	4.76	4.96	0.20	-0.19	-0.11	-0.09	-0.38
Southeast	2.34	2.43	0.09	-0.03	-0.09	-0.08	-0.17
Delta	0.71	0.75	0.04	0.06	0.00	0.00	0.09
Southern Plains	1.15	1.22	0.08	0.01	-0.03	-0.03	-0.07
Mountain	1.24	1.29	0.04	-0.04	-0.02	-0.03	-0.10
Pacific	0.34	0.35	0.01	0.00	-0.02	-0.01	-0.03
United States	90.00	93.68	3.68	-3.02	-1.44	-1.47	-6.29
				GHG emissions (*million mt CO_2*)			
Machinery							
North East	0.16	0.17	0.01	-0.01	0.00	0.00	-0.01
Lake States	0.60	0.63	0.02	-0.04	-0.01	-0.01	-0.06
Corn Belt	2.48	2.54	0.07	-0.10	0.00	-0.01	-0.10
Northern Plains	0.85	0.89	0.05	-0.05	-0.03	-0.02	-0.12
Appalachian	0.21	0.22	0.01	-0.01	0.00	0.00	-0.02
Southeast	0.08	0.09	0.00	0.00	0.00	0.00	-0.01
Delta	0.03	0.03	0.00	0.00	0.00	0.00	0.00
Southern Plains	0.06	0.07	0.00	0.00	0.00	0.00	0.00
Mountain	0.08	0.08	0.00	-0.01	0.00	0.00	-0.01
Pacific	0.02	0.03	0.00	0.00	0.00	0.00	0.00
United States	4.57	4.74	0.16	-0.21	-0.06	-0.06	-0.34
Farm Operations							
North East	1.30	1.36	0.06	-0.06	-0.02	-0.02	-0.11
Lake States	4.83	5.00	0.17	-0.28	-0.07	-0.11	-0.49
Corn Belt	19.80	20.34	0.54	-0.77	-0.03	-0.08	-0.82
Northern Plains	6.78	7.15	0.36	-0.41	-0.25	-0.19	-0.95
Appalachian	1.69	1.76	0.07	-0.09	-0.03	-0.03	-0.14
Southeast	0.66	0.69	0.03	-0.02	-0.03	-0.03	-0.07
Delta	0.22	0.23	0.01	0.01	0.00	0.00	0.02
Southern Plains	0.51	0.54	0.03	-0.01	-0.01	-0.01	-0.03
Mountain	0.62	0.64	0.02	-0.06	-0.01	-0.01	-0.09
Pacific	0.20	0.20	0.00	0.00	-0.01	-0.01	-0.02
United States	36.59	37.89	1.30	-1.70	-0.46	-0.49	-2.68

—*continued*

Table 7.3
Regional GHG impacts for corn acres only by REAP scenario in 2016—Continued

Region	Baseline	Reference	Reference minus baseline	High corn productivity	High input costs	Positive carbon price	Combination scenario
				Change from reference			
				GHG emissions (*million mt* CO_2)			
Other Chemicals							
North East	0.89	0.94	0.04	-0.04	-0.01	-0.01	-0.07
Lake States	3.32	3.44	0.12	-0.19	-0.05	-0.07	-0.33
Corn Belt	13.61	13.98	0.37	-0.53	-0.02	-0.06	-0.56
Northern Plains	4.66	4.91	0.25	-0.28	-0.17	-0.13	-0.65
Appalachian	1.16	1.21	0.05	-0.06	-0.02	-0.02	-0.10
Southeast	0.45	0.47	0.02	-0.01	-0.02	-0.02	-0.04
Delta	0.15	0.16	0.01	0.00	0.00	0.00	0.01
Southern Plains	0.35	0.37	0.02	-0.01	0.00	0.00	-0.02
Mountain	0.42	0.44	0.01	-0.04	-0.01	-0.01	-0.06
Pacific	0.14	0.14	0.00	0.00	-0.01	0.00	-0.01
United States	25.16	26.05	0.89	-1.17	-0.31	-0.33	-1.85
Nitrogen							
North East	2.51	2.64	0.12	-0.12	-0.03	-0.03	-0.21
Lake States	9.36	9.69	0.33	-0.55	-0.14	-0.21	-0.94
Corn Belt	38.36	39.40	1.04	-1.49	-0.05	-0.16	-1.58
Northern Plains	13.14	13.85	0.71	-0.80	-0.48	-0.38	-1.84
Appalachian	3.27	3.41	0.14	-0.17	-0.06	-0.06	-0.28
Southeast	1.28	1.34	0.06	-0.04	-0.06	-0.06	-0.13
Delta	0.42	0.44	0.02	0.01	0.00	0.00	0.03
Southern Plains	0.98	1.04	0.06	-0.02	-0.01	-0.01	-0.06
Mountain	1.19	1.23	0.04	-0.12	-0.02	-0.03	-0.17
Pacific	0.38	0.39	0.01	0.00	-0.03	-0.01	-0.03
United States	70.90	73.42	2.52	-3.28	-0.89	-0.94	-5.20

As with general trends in GHG emissions, the redistribution of CRP lands is relatively sensitive to changes in the key variables reflected in the alternative scenarios. In the high corn productivity scenario, the Corn Belt recovers about 40 percent of the decrease in CRP land that had occurred in the reference scenario. However, in the high input cost scenario, another 1.66 million acres are lost from the CRP in the Corn Belt (i.e., relative to the reference scenario). In the positive carbon price scenario, enrollment in the Northern Plains decreases by 1.8 million acres while enrollment in the Southern Plains, Lake States, Southeast, and Pacific increase by 2 million acres altogether.

Implications for Future Research

The material presented in this chapter points to several areas where additional research could significantly improve USDA's ability to assess the GHG implications of farm sector activities and programs generally and biofuel-related activities and programs in particular.

First, the reduction in GHG emissions associated with the high corn productivity scenario almost completely offsets the increase in emissions in the reference scenario. This suggests research aimed at achieving increases in corn productivity—and by implication, crop productivity generally—that are not tied to the additional use of fossil fuel inputs offers a promising approach to simultaneously enhancing food and energy security and lowering GHG emissions associated with crop production.

Second, if USDA is to have the inhouse ability to analyze the GHG implications of changes in programs, policies, or market conditions, the capabilities of economic models like REAP and POLYSYS to capture and track the GHG impacts need to be upgraded and expanded. While REAP has some capabilities, its results often differ from those obtained using more comprehensive farm and forest sector models like FASOMGHG. These differences need to be better understood, and if necessary, addressed. POLYSYS can quantify the amount of land that changes uses. For GHG assessments, a better definition of feedstocks associated with the land-use changes and the ability to assign and track GHG emissions associated with alternative production decisions would greatly improve utility. More ambitious would be to link REAP and POLYSYS to a forest sector model. The agriculture and forest sectors compete for land and other resources. Analyzing the GHG implications of policies or events that could shift significant areas of land between these sectors requires a model that captures the competition for land between them. And research is starting to focus on the GHG implications of international land-use changes related to increasing biofuel production. Assessing these implications will require a global computable general equilibrium framework.

Third, estimates of the GHG emissions associated with the production of feedstock crops—and crops in general—depend critically on the coefficients used for N_2O emissions related to nitrogen fertilizer use. At present, estimates of N_2O emissions related to nitrogen use are highly uncertain—both at the field and more aggregate levels. Additionally, it appears that significant decreases in N_2O emissions could be achieved either by applying less nitrogen to the field or by changing the way current applications are managed (e.g., when nitrogen is applied). Decreasing the uncertainties associated with N_2O emissions from nitrogen fertilizers is a major research priority to better understanding the GHG profile of feedstock production systems (and crop production systems generally).

Finally, one promising opportunity for significant biofuel-related GHG benefits is the substitution of biomass for coal in electricity generation. The feedstocks that would be utilized to produce this electricity are largely the same feedstocks that would provide cellulosic ethanol (i.e., switchgrass, short-rotation woody crops, and agricultural residues). An assessment of the feedstock sector implications of expanding biofuel use in electricity generation, both at present and in the context of a growing cellulosic ethanol industry, would prove useful.

Conclusions

This chapter has analyzed the farm-sector GHG implications of increasing corn ethanol production from 12 to 15 billion gallons per year. The key conclusions are:

- Farm-sector GHG impacts are likely to be modest. In moving from the 2007 USDA baseline scenario to the reference scenario, total farm-sector GHG emissions increase 7.95 million metric tons (MMT) CO_2 equivalent. Compared to current agricultural emissions, this would be an increase of a little more than 1.8 percent.[11]

- Among the alternative scenarios analyzed, the introduction of a carbon price of $25 per mt CO_2 equnivalent resulted in the largest decrease in GHG emissions (relative to the reference case). This suggests that the development of a viable carbon market could be an effective approach to simultaneously increasing biofuels production and improving the GHG footprint of these fuels.

- The changes in farm-sector activities that result in the largest reductions in GHG emissions differ across alternative scenarios. In the high corn productivity scenario, changes in farm inputs account for 80 percent of total reduction in GHG emissions (relative to the reference case). In the high input cost and the positive carbon price scenarios, the main sources of emission reductions are, respectively, land-use change (78 percent) and changes in tillage (73 percent). This suggests that a comprehensive approach to reducing the farm-sector share of GHG emissions related to biofuel production could include a broad set of incentives targeting a variety of farm-sector activities and management decisions.

- Two research goals likely to advance our understanding of the GHG implications of biofuels policies are (1) developing better estimates of N_2O emissions associated with nitrogen fertilizer use, and (2) enhancing USDA economic models with more capability to analyze the GHG implications of changes in various programs, policies, and market conditions. Additionally, research leading to increases in crop productivity that are not tied to the additional use of fossil fuel inputs has the potential to significantly decrease the GHG emissions associated with the production of biofuel feedstocks.

[11]Again, this finding is an implication of the analysis. Aggregate GHG impacts would likely be different if the analysis had included emissions related to international land-use change and secondary agricultural sector impacts.

Appendix table 7.1

Estimated potential annual carbon sequestration by land-use change and production practice in U.S. agriculture

Land use or management practice	Estimated per-acre sequestration	Total potential sequestration
	Metric tons	*Million metric tons*
Cropland – Land-use change:		
Afforestation of cropland	0.79-1.72	83-181
Croplands shifted to perennial grasses	0.25-0.51	26-54, 26*
Conservation buffers	0.13-0.25	1-2
Restoration of wetlands	0.10	5, 16*
Cropland - Production practice changes:		
Conservation tillage and residue management	0.09-0.18	35-107, 23*
Improved crop rotations and winter cover crops	0.04-0.12	5-15
Elimination of summer fallow	0.08	1-3, 1*
Improved fertilizer management	0.02-0.06	6-18
Use of organic manure and byproducts	0.20-0.50	3-9
Improved crop rotations with hay or pasture		38*
Improved irrigation management	0.04	5-11
Grazing land:		
Afforestation of pasture	0.73-2.09	8-22
Rangeland management	0.05-0.15	5-16
Pasture management:		
Improved use of fertilizers	0.10-0.20	2-4
Use of organic manure	0.20-0.50	3-9
Planting of improved species	0.10-0.30	1-3
Grazing management	0.30-1.30	5-20

Source: For sources of estimates, see Lewandrowski et al. (2004), except those with an asterisk (*), which are annualized projections from the 1990-2005 USDA Greenhouse Gas Inventory Report (USDA, 2005), assuming a 50% adoption rate.

Appendix table 7.2

Derivation of GHG coefficients used with REAP scenarios

Annual rates of soil C loss for land shifting into cropland

REAP values for soil carbon losses associated with land shifting into cropland are based on estimates provided by Eve at al. (2002) (Table 5, page 202). Values from Eve, et al, used in the REAP analysis are:

REAP region	Continuous crop to CRP
	(mt C/ha)
Appalachia	0.46
Corn Belt	0.62
Delta States	0.74
Lake States	0.51
Mountain	0.29
Northeast	0.47
Northern Plains	0.46
Pacific	0.35
Southeast	0.28
Southern Plains	0.44

These regional values are divided by 2.47 to convert the units to metric tons of carbon per acre and then multiplied by 3.66 to convert carbon to carbon dioxide. In addition, Eve et al provide estimates for land moving *out* of cropland, so those values were multiplied by -1 to reflect shifting new land *into* crop production.

Annual rates of soil carbon loss for changes in tillage systems

Emissions coefficients associated with changes in tillage practices were derived using methods described in the Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories (IPCC, 1997). The derivation of the coefficients is described in Lewandrowski et al. (2004) pp. 23-25.

Farm-level GHG emissions related to corn ethanol production

Estimates for greenhouse gas emissions other than that specifically related to land use or tillage were developed using coefficients from the GREET model (Argonne National Laboratory). Estimates are derived from fuel-cycle GHG emission shares for corn-based ethanol assuming co-product credits. Values are:

Activity	Grams CO_2 per gallon
Farm machinery	115.9
Nitrogen	1,796.5
Other chemicals	637.5
Corn farming	927.2

These values are then converted to emissions per acre by region using the regional per acre corn yields in REAP and assuming 1 bushel of corn yields 2.8 gallons of ethanol.

Sustainability and Criteria for Biofuels

For bioenergy to become fully integrated into the U.S. economy, it must be economically, environmentally, and socially sustainable. This chapter focuses only on the environmental sustainability of feedstock production, covering agricultural crops and residues, forest sources, and wood from urban wastes for the selected scenarios. Economics is addressed in other chapters; greenhouse gas emissions are evaluated in chapter 7.

This chapter (1) briefly introduces general concepts and criteria for economic, environmental and social sustainability; (2) discusses practices related to environmentally sustainable feedstock production; (3) evaluates whether the potential feedstock production scenarios developed in Chapter 4 and analyzed in chapters 5 and 6 provide adequate information to understand environmental sustainability of production practices; and (4) identifies future research needed to better understand, develop, and implement sustainable biofuel feedstock production systems.

Criteria for Sustainable Biofuels

The common use of the term "sustainability" began with the 1987 publication of the World Commission on Environment and Development report, *Our Common Future,* which defined sustainable development as "development that meets the needs of the present generation without compromising the ability of future generations to meet their own needs."

Ideally, determining whether feedstock production is sustainable requires an understanding of a wide array of direct and indirect benefits, impacts, and costs associated with its production. A first step is to define sustainability criteria and then develop an accounting method of measurable indicators to determine whether established criteria are met.

Sustainable renewable energy production, conversion, and delivery systems must not only be productive, but also environmentally, economically, and socially viable now and for future generations. A variety of national and international discussions are considering how to describe sustainable biomass production. Currently, there is little consensus on which criteria or indicators should be used to assess biomass sustainability for trade or environmental protection purposes. Many commonly used criteria apply to the lifecycle of a biofuel's production and use. First, the biofuel should reduce energy consumption and enhance energy security through reduced use of petroleum-based products. Second, it should have environmental benefits, such as reducing greenhouse gas emissions, preserving varied land use, and maintining soil productivity, water quality/quantity, and biodiversity. Third, it should enhance other ecosystem services and not unduly reduce supplies of food and other resources. Fourth, it should be economically competitive, and fifth, it should contribute more energy than is required to produce it (Hill et al., 2006).

To determine if the above criteria are met, ideally one would evaluate a set of sustainable biofuels criteria over the full lifecycle of the biofuels system to determine all the costs, benefits (both market and nonmarket), and environmental effects. This analysis would also account for the choices that producers and consumers make, which reflect potential substitutions among energy sources, technologies, and relative prices, and which lead to a new set of equilibrium prices and energy uses.

Analyzing the various economic, social, and environmental aspects of biofuels is challenging. Sustainability indicators can guide decisionmaking and can be used to evaluate the performance and progress of biofuel production systems. A rigorous, science-based set of indicators provides firm analytical underpinnings to inform policy and decisionmaking. Science-based indicators also facilitate comparison across biofuels and biomass production systems. Sustainability indicators can provide useful information regarding policy and research options, and can help determine which biomass production methods are consistent with long-term environmental and economic goals.

As stated in the Executive Summary, this report focuses on the feedstock production portion of the supply chain for both conventional and advanced biofuels. It does not look at other components of the supply chain, such as conversion technologies, distribution infrastructures, and end uses. Additionally, although all the criteria mentioned above must be considered across the lifecycle of biofuels to determine sustainability, this chapter only explores the sustainability of feedstock production, and only evaluates trends resulting from the modeled scenarios for a limited number of environmental indicators, as described in chapters 4, 5, and 6. The analysis does not allow conclusive statements or extensive discussion on the sustainability of feedstock production practices. These scenarios must also be understood in the context of model sensitivity analyses for the purpose of R&D prioritization, and do not represent predictive analyses of actual future conditions. Hence, the focus is on the effect of different scenario input changes on future outcomes, rather than on a comparison of current versus expected future conditions. What research might be required for understanding sustainability is summarized at the end of this chapter.

Within the context of agricultural production, Congress defined sustainability as an integrated system of plant and animal production practices having a site-specific application that in the long term will:

- Satisfy human food and fiber needs;
- Enhance environmental quality and the natural resource base upon which the agricultural economy depends;
- Make the most efficient use of nonrenewable resources and onfarm resources and integrate, where appropriate, natural biological cycles and controls;
- Sustain the economic viability of farm operations; and
- Enhance the quality of life for farmers and society as a whole.

Environmental sustainability of agricultural production is a critically important consideration, and is the primary focus of this chapter. The models (i.e., REAP and POLYSYS) described in previous chapters focus on onfarm inputs and outputs of feedstock production driven by behavioral choice models reflecting economic considerations. In addition to environmental impacts and sustainability at the "edge of the field," there are other environmental impacts and sustainability concerns beyond the farm's edge, potentially extending across regional, national, and global boundaries. Given the constraints of the models used, this chapter does not discuss sustainability in this broader geographic context and focuses only on edge-of-field environmental sustainability criteria and indicators.

A broader discussion of economic, social, and environmental sustainability indicators across the lifecycle of biofuels production and use is being developed by a separate Sustainability Team under the Biomass Research and Development Board.

Environmental Benefits

The production of crops and crop residues for use as bioenergy feedstocks involves soil cultivation; application of fertilizer, pesticides, and other chemicals; and irrigation, all of which can impact soil, water quality and quantity, air quality, site productivity, and greenhouse gas emissions. Activities and management practices can be evaluated on the degree to which they enhance overall environmental attributes while mitigating negative environmental impacts. The principles for determining the sustainability of practices in this chapter focus on whether the land can continue to provide goods and services (e.g., wood, water, food, feed, habitat supporting biodiversity, fiber, energy) over the long term and conform to water quality and other environmental standards. To determine whether feedstock production practices lead to sustainable outcomes beyond the farm would require more comprehensive analyses of off-farm releases and outcomes. The models used in this analysis do not look at environmental implications beyond the edge of the farm or forest.

Some environmental outcomes and benefits that should be considered when evaluating the sustainability of biomass production include:

- **Reduced greenhouse gas emissions** (discussed in chapter 7)—The net carbon load and greenhouse gases released in production and consumption of the biofuel should not exceed the amounts released in producing and using a like amount of fossil fuel energy.
- **Water**—Biomass feedstock production systems can be evaluated regarding the degree to which they prevent or avoid adverse impacts on water resources. Water and nutrient use efficiency can be included when developing sustainability indicators.
- **Site productivity**—Long-term site productivity is a concern when large volumes of organic material are removed, especially material that would have remained on the field to cover the soil and recycle nutrients. Crop and management systems should maintain or enhance soil productivity.

Environmental Sustainability Indicators

Indicators are well established for measuring certain environmental changes, although not all these measures are related to sustainability. Much work has gone into monitoring environmental changes of our natural resources. This is an important safeguard for all production systems. For biofuel feedstock production, current mandates stipulate that the EPA provide reports to Congress to assess current and future impacts of biofuels on air quality, water, soil, ecosystem health/biodiversity, and invasive plants. It is crucial to identify which resource systems may be impacted by environmental changes and to understand when those changes impair function. However, monitoring environmental changes is not adequate for assessing sustainability of systems. Future research needs to improve our ability to evaluate sustainable outcomes are discussed at the end of this chapter.

Different scenarios of agricultural and forestry production imply different inputs of land, water, pesticides, nutrients, soil, cultivation, energy, and other factors, depending on the crops and characteristics of the land. These different inputs result in different environmental outcomes. In general, the models attempt to minimize the cost of biofuels production and to meet supply constraints. In addition, society expects (and sometimes regulates or provides incentives) that activities and management practices are performed so as to enhance positive environmental attributes while minimizing or mitigating negative environmental impacts.

Net Energy Balance

Net energy benefit, in general, may be useful as an indicator for sustainability only if it estimates the overall lifecycle reduction in fossil fuel use (and associated GHG emissions) due to increased biofuel use and decreased petroleum fuel use. Estimating the net energy balance or energy efficiency associated with the renewable fuel itself is not an adequate indicator of sustainability. Even in cases where the net energy balance of a renewable fuel is negative or has less energy efficiency than fossil fuels, fossil fuel replacement benefits may still prevail.

Carbon and Greenhouse Gases

Assessing the carbon impact of biofuel production and greenhouse gas emissions is likewise important (see chapter 7).

Water Quantity

As feedstock production increases, water supply may become a limiting factor in some locations. Water is used to irrigate feedstocks and to convert feedstocks to biofuels. To ensure water availability for societal purposes, advances in sustainable feedstock practices are needed to optimize efficient water use through crop development, production, use, and management; conservation practices; and water purification, reuse, and distribution technologies.

Water Quality

Maintenance and enhancement of water quality is essential to ensure safe drinking water, fishable and swimmable waters, agricultural production, and manufacturing and other economic activities. Sedimentation, nutrient flow, and pesticide runoff have the potential to degrade both water quality and aquatic habitat (National Academies, 2007). Attenuation of sediment and chemical inputs will depend on the soil type, season, crop, and farm management practices. Additional work is needed in assessing, understanding, and modeling cumulative water quality impacts from feedstock production over broad spatial scales, especially in accumulative water systems and as a gauge for sustainability. As biofuels production becomes more geographically dispersed, it will become more important to mitigate cumulative effects on larger bodies of water. Some work has already begun, such as modifying the SPARROW model to estimate such effects.

Land-Use Change

Pertinent land-use categories include land already in production (for food, fuel, or fiber) and uncultivated land. Land-use shifts among categories have the potential for economic, social, and environmental benefits and/or impacts. Chapters 5 and 6 report changes in land use. Shifting from one crop to another or one crop production system to another can affect availability of the displaced crop and/or productivity of the land. These shifts can affect crop prices, labor, and resources, with potential adverse or beneficial economic and environmental effects. Bringing uncultivated land into production may change the function of that land relative to goods and services. To achieve sustainability, one must understand the complex relationships of land use and the goods and services provided by the land.

Soil Productivity

Soil productivity (and its enhancement) is a central, fundamental resource for biomass production, and is often considered a nonrenewable resource. Soil loss through erosion is the most obvious environmental indicator of a sustainability concern. Soil structure and compaction, soil organic matter, and soil microbial communities all influence soil productivity and, more generally, long-term soil tilth. Such soil attributes also influence the ability of soil to provide essential environmental services, such as adsorbing and assimilating mobile nutrients and sequestering carbon. Tracking soil characteristics having a robust relationship to sustainability would provide useful measures related to soil productivity.

Sustainability Assessment Approach

This section introduces an approach for assessing the sustainability of feedstock production, and evaluates environmental indicators from the production models in chapters 5 and 6, with some inference beyond the modeled outputs. Many challenges, highlighted below, remain to translate sustainability principles into effective, quantifiable, verifiable indicators. Additionally, although extensive environmental monitoring data exist, there are still significant gaps in data and measures for water quality and quantity, land use, air quality, and soil productivity.

Economic and biophysical simulation models provide estimates of production choices that result from combinations of prices, biophysical production relationships, and the influence of particular policies. These endogenous choices include such things as planting particular crops in particular regions, crop irrigation, fertilizer application rate and timing, and crop rotations. These and other production decisions influence environmental outcomes that can be measured using specific quantitative environmental indicators.

In this report, indicators of these environmental criteria are generated within the REAP and POLYSYS modeling activities described below, but provide only a preliminary snapshot of environmental sustainability. A more complete understanding of environmental sustainability can be developed by integrating these results with additional research on environmental quality stressors. This is particularly important considering the potential for large-scale biofuel production.

Ultimately, sustainable practices must meet the needs of the present generation without compromising the ability of future generations to meet their own needs. In evaluating environmental sustainability, this could be rephrased as ensuring that natural systems (e.g., land, water, ecosystems, air) provide and can continue to provide goods and services that society values such as clean water, food, fiber, and fuel nutrient cycling; soil formation and conservation; climate change mitigation; flood moderation; water purification; and vector-borne disease mitigation.

These functions encompass a broad set of market and nonmarket services. Market services can include production of tradeable agricultural commodities, but can also include recreation (through payment to participate), water quality (e.g., investments to improve water quality), and water quantity (e.g., irrigation water). Nonmarket services might include recreation, habitat diversity, and biodiversity. The ability of the resource base to provide goods and environmental services is influenced by factors already mentioned as well as others such as land continuity (and/or fragmentation), maintenance of buffers and refuges, and resource management goals and activities.

The key to a complete discussion of environmental sustainability for biofuels is being able to translate environmental outputs (e.g., from REAP and POLYSYS analyses) to indicators of environmental outcomes, and thence to environmental services.[1] Ultimately, we would like to have data describing the status of environmental conditions at both a micro and macro level—are conditions improving, deteriorating, or holding steady? In cases where indicators suggest possible changes in environmental conditions, a key challenge is to use experiments, data, and models to identify which elements of the entire production system might be most influential in these changes, to effectively monitor them, and to develop practices and systems that mitigate or reverse undesired impacts.

[1]Currently, there is no consensus on which indicators represent the highest priority for further study.

Advances in environmental science and monitoring have provided many robust techniques for measuring and describing environmental indicators (e.g., changes in chemical concentrations in air, land, water). At the same time, environmental scientists are continually refining environmental assessments—analyses of biophysical relationships and subsequent outcomes resulting from environmental changes—that underlie concepts of sustainability. Moreover, the ability to monitor environmental changes and assess their outcomes depends on data that are available, of appropriate scale and representation, and of reliable quality. Such data are not always easily obtained. So, although extensive environmental monitoring data sets exist, there are still significant data gaps on water quality and quantity, land use, air quality, and soil quality.

Given the state of science, data availability, and our evolving understanding of natural system resiliency, we must currently rely on a limited set of environmental indicators to represent environmental sustainability.

This approach, therefore, attempts to (1) understand the relationship between economic drivers and environmental performance, (2) identify key practices in agricultural production systems that can impact environmental outcomes, (3) identify quantitative indicators of when these practices may become environmental stressors, and (4) determine whether these stressors threaten environmental sustainability.

Sustainability Assessment Frameworks

Many worldwide biomass certification systems are being developed that quantify sustainable production of biomass feedstocks. Two models relevant to U.S. interests are discussed below—one for forestry, the other related to agriculture. Many other systems are summarized elsewhere (Van Dam et al., 2008). While these two models are not designed to provide information on the full range of environmental services, they do incorporate several of the key concepts for sustainability indicators noted earlier, and serve as illustrative examples of tools that may be helpful to a broader approach to sustainability.

The first example comes from forestry. Forest certification in the U.S. uses a voluntary approach that includes third-party evaluation of forest management practices and labeling of products from certified forest management operations.[2] In addition, formal global deliberations produced the Montreal Process Criteria and Indicators (C&I), which apply to broad geographic areas, such as states or countries, and enable trend analysis at the national level using data produced by the U.S. Forest Service and partners.

[2]The two primary certification programs in the U.S. are the Forest Stewardship Council (FSC) and the American Forest and Paper Association's Sustainable Forestry Initiative (SFI).

The forestry systems represent a set of practices and indicators of sustainability. Labeling and third-party certification programs are based on production practices oriented around sustainability issues. Regional (and national) measures of sustainable forestry practices were developed through international collaboration and agreement. As such, these provide examples of the potential for clear, detailed, measurable, and verifiable indicators of sustainability in the forestry sectors, indicators that can be used for both domestic policy and international negotiations and can be linked to other accepted environmental models of forest sustainability.

The second example, for bio-based products from agriculture, was developed for an entirely different purpose: to provide an environmentally sound lifecycle assessment of products in order to document the cradle-to-grave (or cradle-to-cradle) environmental "footprint"of a specific set of products. The Building for Environmental and Economic Sustainability (BEES) model has been used, with support from the U.S. Department of Agriculture, to assess the economic and environmental performance of bio-based products available through the "BioPreferred" Federal purchasing program. Analyses have been done to assess products from eight feedstocks (soybeans, corn, wheat, canola, rice, potatoes, cotton, and wool).

Although originally developed for assessments of building and construction materials, BEES is a flexible analytical platform that can use appropriate process models and data to estimate lifecycle impacts for a wide range of products and services. While BEES, like most other lifecycle models, has its limitations, it is notable in taking a lifecycle approach to an entire set of bio-products. Some other examples of sustainability metrics for agriculture and the food industry (e.g., USDA-certified organic products) document practices consistent with concepts of sustainability, but rarely take the step of conducting lifecycle assessments for these products.

The next section describes the results of the sustainability analysis that was conducted for this report, which shares some similarities with both the BEES example (in providing some feedstock-specific data) and the forestry example (in providing data on specific practices), but still has a long way to go in providing broader insights into concepts of sustainable biomass production.

Analysis of the REAP and POLYSYS Models for Sustainability Implications

An ideal assessment of sustainability in biomass production for biofuels would include a suite of monitoring and modeling results, and describe how production conditions and choices influence environmental goods and services. This section presents the results of modeling exercises used for this report—representing model sensitivity analyses to provide insights into factors influencing sustainability. The results described in the following sections focus on a limited set of indicators for soil loss (erosion) and chemical loss from farms to water bodies. The scope and direction of these indicators can help prioritize further research that will be needed to move toward a more robust understanding of sustainability (research needs are listed at the end of this chapter). All scenario results and comparisons are modeled for the year 2016, including baseline and reference scenarios, and are not intended as comparisons across time to contemporary sustainability data.

Two economic models were used to assess the economic and land-use aspects, and some of the environmental sustainability aspects, of increased biofuels production. REAP was limited to starch crop production, and POLYSYS was used for cellulosic feedstocks. Only REAP has environmental indicators.

REAP Model

The Regional Environment and Agriculture Programming model (REAP) contains several environmental indicators that can be used to assess the environmental impact of the biomass production scenarios described in chapter 4 (see p. 56 for a more thorough description of REAP). This model is able to simulate changes in production practices and the resulting environmental outcomes within the agricultural sector in response to policy directives.

While land use, crop mix, crop rotations, tillage practices, and fertilizer application rates are endogenous to the model, the environmental impacts of these agronomic practices were estimated by 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 several environmental parameters under different tillage, crop rotation, soil management, and weather scenarios at a daily timestep. In addition to the effects of production practices on yields, EPIC is used to compute edge-of-field environmental indicators such as nitrogen loss and greenhouse gas emissions per acre for each REAP crop system.

Limitations of REAP Model Used To Evaluate Sustainability

Although REAP reports at the environmental indicator level, it provides no information regarding corresponding potential environmental impacts. For example, while nitrogen runoff levels are included in REAP, there is no indication from the model of how this output (in tons) influences the concentration in local waterways or the potential risk to plants and animals downstream.

REAP provides only a static view of the environmental impacts of a given scenario, with no information regarding expected future change if the scenario were to persist. To assess environmental sustainability, one must understand the implied trends; only then can one make a logical assessment of the sustainability of the system over the long term. But such calculations are beyond the scope of the REAP model.

Thus, extensions of REAP would be needed to analyze the environmental services provided by the impacted ecosystems, in order to assess environmental sustainability. One approach would be to model the impact of changes in water quality due to runoff against the ability to continue current uses of the water.

REAP can model loading into estuaries and other surface-water bodies, but analysis of such output is beyond the scope of this report. The results section of this chapter presents selected environmental outputs of each scenario. However, more information is needed to evaluate the sustainability of the scenarios as a whole.

REAP modeling comparisons were limited to the changes expected from the various scenarios, modeled and compared in 2016. Although comparison is possible to contemporary sustainability data in the model, such an analysis has not been undertaken because the principal purpose of this sensitivity exercise is to identify where R&D efforts on biofuel feedstocks would be most beneficial, i.e., what factors can assist in improving implementation of the existing EISA mandates. Chronological comparisons across time to model real-world predictions would require additional validation of the exogenous inputs to the REAP model structure, such as anticipated commodity price changes. Also, the scenario impacts of interest would need to be separated from background changes common to all scenarios across time.

POLYSYS Model

The Policy Analysis System (POLYSYS) model provides detailed information on land-use change, including energy crop (cellulosic) contributions, and models EISA requirements out to 2022. Environmental factors are determined indirectly. The representation of the forest sector's role in meeting the renewable fuel standard is modeled through POLYSYS as a partial displacement, i.e., the reduction of cropland needed for biofuels production from the agricultural sector. Then the model results at the reduced amounts were used for the agricultural components and the forestry component was analyzed exogenously. (For more information on the POLYSYS model, see chapter 6.)

Results

The environmental output of the REAP and POLYSYS models were evaluated across the scenarios described in chapter 4. The 2016 baseline is 12 billion gallons of ethanol from corn by 2016; the reference case has 15 billion gallons of ethanol from corn by 2016. The REAP model was used to evaluate the environmental indicator changes (between the baseline and the reference case) resulting from an additional 3 billion gallons of ethanol from corn. There was an increase in land and other resources needed to support increased biofuels production. This increase in demand resulted in more acres in corn production and therefore greater potential for fertilizers and pesticides to leach into soil and water resources, as well as for erosion.

Table 8.1 shows selected environmental variables and their changes from the 2016 reference case across the high corn productivity, high input cost, and positive carbon price scenarios. Table 8.2 has detailed analysis of the differences between the baseline and the reference case for selected regional environmental indicators.

In nearly all cases, the environmental indicators from REAP represented a greater negative impact under increased production than the 2016 baseline. Figures 8.1-8.22 show the implications for selected environmental variables under the scenarios of high corn productivity, high input costs, and positive carbon prices. In general, increased productivity, high input costs, or a carbon price would motivate a reduction in input use, especially nitrogen and pesticides, and reduce risks to water quality. Likewise, reducing soil erosion and acres in production lessens risks to the environment.

Generally, more land in the production of corn implies greater potential environmental impacts; the same with inputs of nitrogen and pesticides. More tillage, especially conventional tillage, can result in more erosion, which leads to impaired water quality and site productivity. Model results suggest that farmers might respond to the incentives analyzed by shifting production to areas of less potential environmental impact.

The scenarios that build from the 2016 reference case provide a sense of the range of environmental costs and benefits that come from meeting the biofuels production targets. The high corn productivity scenario reduced the number of corn acres needed for production relative to the reference case, so overall fertilizer and pesticide use was less. The high input cost scenario reduced acres in production because some land became unprofitable to produce crops on. The positive carbon price scenario (carbon priced at $25 per ton) promoted agronomic practices that conserve carbon, such as increasing no-till by 18.6 million acres.

Starch-Based Feedstocks

Most of the model runs produced results that were intuitive and consistent with the descriptions above. Under the high corn productivity scenario, most of the U.S. had less erosion, lower pesticide and fertilizer applications, and less leaching of farm chemicals into water supplies compared to the 2016 reference scenario. The same was true for the high input cost scenario. The

Table 8.1

REAP output: Deviation from reference scenario

Indicator	High corn productivity	High input costs	Positive carbon price	Sustainability implication
Nitrogen leaching:				
Tons in groundwater	↓↓	↓↓↓	↓↓	Less risk to water quality, aquatic ecosystems, soil productivity
Tons in solution	↓	↓↓	↓↓	
Tons in sediment	*	↓↓	↓	
Pesticides applied	↓	↓↓	↓↓	Less risk to water quality, aquatic ecosystems, biodiversity
Pesticide leaching:				
Tons in groundwater	↓	↓	↓	Less risk to surface- and ground-water quality, aquatic ecosystems, soil productivity (soil biota)
Tons in solution	*	↓↓	↓	
Tons in sediment	↓	↓↓	↓↓	
Soil erosion	↓	↓↓↓	↓↓	Improved soil productivity; improved water quality; fewer chemical inputs required
Cropland acres in production	↓↓	↓↓↓	↓	Reduces the potential for chemical leaching and other environmental impacts of production
Tillage practices:				
Conventional	↓	↓↓	↓↓↓	Movement toward conservation and no-till systems improves soil productivity over the long term, reduces erosion, and can reduce the need for fertilizer inputs; however, such a shift can increase pesticide inputs
Conservation	*	↑	↑↑↑	
No-till	↑	↑↑	↑↑↑	
Cropland:				
Corn	↓↓	↓	*	Corn is nutrient-intensive compared to many of the crops it is replacing; a reduction in corn acres often reduces fertilizer applied

Difference from reference

↕ Small	↕↕ Medium	↕↕↕ Large

*The difference from the reference was less than 0.5%.).

positive carbon price scenario prompted reductions in erosion and nutrient indicators that were similar to those exhibited under the high input cost scenario. As expected, the combination scenario showed the greatest deviations from the reference case for both nitrogen and phosphorus.

Potential Environmental Benefits and Impacts of Increased Biofuels Production

The keys to understanding the sustainability impacts of each scenario are the change in total land in production, amount of inputs used, and tillage practices. By comparing the USDA 2016 baseline to the 2016 reference case, one can assess the impact of an increase in demand for biofuel feedstocks on these metrics. The total number of planted acres increased by approximately 4 million (1 percent) from the baseline to the reference case, with most of the increase in the Corn Belt (1.7 million acres) and Northern Plains (1.2 million). The number of corn acres increased by 3.7 million, which caused the modeled agronomic practices to change and potential environmental impacts to grow. Total fertilizer applications were larger for the reference than the 2016 baseline (2.4 percent more nitrogen and 1 percent more phosphorus)—nearly 230,000 tons more of nitrogen were applied. As a result, approximately 125,000 tons more nitrogen leached into groundwater, sediment, and surface water. Pesticide applications were almost 3 percent (10 million tons) higher in the reference than the 2016 baseline. Pesticide loss from fields was approximately 240,000 tons greater due to the increase in crop acreage. Similarly, sheet and rill erosion was almost 22 million tons greater under the reference case than the USDA 2016 baseline.

Erosion Declines With Reduction in Cropland Acreage and Use of Conservation Tillage

The system used to produce biofuel feedstocks can affect erosion potential through the tillage practices used and soil properties. The extent of the impact depends on geography and the physical characteristics of the farm. Expanded corn production can include either conventional tillage or some form of conservation tillage, including no till. The farmer's choice of tillage practice depends on many factors such as available equipment, fuel prices, or incentives. As more acres of corn are grown for biofuels, use of conventional tillage incurs greater erosion potential.

Across the U.S., erosion was less in the high productivity growth, high input cost, carbon price, and combination scenarios than in the 2016 reference case. The greatest reduction was with the combination scenario at almost 80 million tons (8 percent) less sheet and rill erosion and over 60 tons (23 percent) less wind erosion. Most of the acreage that shifted out of production in the four scenarios was highly erodible land—REAP shifts production to areas of less potential impact (see discussion in chapter 5)—which is one reason for less erosion compared with the reference case.

Table 8.2

Regional environmental indicators by REAP scenario, in 2016

	USDA Baseline	Reference	Reference minus baseline	High corn productivity		High input costs		Positive carbon price		"Combination" scenario	
	Million tons	*Million tons*	*Million tons*	*Million tons*	*Percent*	*Million tons*	*Percent*	*Million tons*	*Percent*	*Million tons*	*Percent*
					Change from reference						
Erosion											
Sheet and rill											
Northeast	49.75	50.46	0.71	0.01	-0.01	-1.41	-2.79	-1.08	-2.14	-2.40	-4.76
Lake States	97.22	98.46	1.24	-0.57	-0.58	-2.71	-2.75	-3.59	-3.65	-7.26	-7.37
Corn Belt	437.04	444.28	7.24	-5.08	-1.14	-4.90	-1.10	-12.03	-2.71	-21.91	-4.94
Northern Plains	147.18	153.77	6.59	4.77	3.10	-12.56	-8.17	-6.46	-4.20	-17.00	-11.05
Appalachian	72.01	73.73	1.73	-2.57	-3.48	-2.86	-3.88	-2.88	-3.91	-7.74	-10.50
Southeast	48.80	49.42	0.61	-1.29	-2.62	-2.88	-5.83	-2.93	-5.93	-5.30	-10.72
Delta	83.32	86.69	3.38	-0.61	-0.70	-3.71	-4.28	1.67	1.92	0.55	0.63
Southern Plains	64.95	66.00	1.06	-0.17	-0.25	-12.65	19.16	-5.22	-7.90	-16.75	-25.38
Mountain	30.21	29.57	-0.64	0.29	-0.99	-2.11	-7.15	0.44	-1.49	-2.03	-6.86
Pacific	3.92	3.92	0.00	0.01	0.24	0.04	0.97	-0.35	-8.83	-0.10	-2.53
United States	1,034.39	1,056.30	21.91	-5.22	-0.49	-45.76	-4.33	-33.30	-3.15	-79.94	-7.57
Winds											
Northeast	0.02	0.02	0.00	0.00	-1.66	0.00	-6.35	0.00	-3.98	0.00	-12.62
Lake States	2.06	2.02	-0.04	0.08	3.81	-0.20	-10.11	-0.29	-14.54	-0.46	-22.56
Corn Belt	34.22	34.95	0.73	-0.27	-0.78	-1.05	-3.01	-2.10	-6.02	-3.43	-9.82
Northern Plains	57.52	59.91	2.39	-0.42	-0.71	-4.21	-7.02	-3.50	-5.85	-8.24	-13.75
Appalachian	0.00	0.00	0.00	0.00	-0.13	0.00	-2.02	0.00	-7.41	0.00	-9.94
Southeast	0.10	0.11	0.00	0.00	-2.54	-0.01	-6.31	-0.01	-6.38	-0.01	-11.73
Delta	0.14	0.15	0.00	0.00	1.16	-0.02	-10.39	-0.02	-13.63	-0.03	-17.80
Southern Plains	144.77	146.18	1.41	-0.77	-0.53	-23.23	-15.89	-10.27	-7.03	-43.96	-30.09
Mountain	16.40	16.13	-0.27	0.11	0.69	-3.89	-24.11	-3.15	-19.51	-4.67	-28.94
Pacific	0.04	0.04	0.00	0.00	-0.10	-0.03	-88.96	0.00	0.17	-0.03	-89.23
United States	255.29	259.51	4.23	-1.28	-0.50	-32.64	-12.58	-19.35	-7.46	-60.83	-23.45
Nitrogen applied											
Northeast	0.28	0.29	0.01	0.00	-0.93	-0.02	-6.56	-0.01	-4.30	-0.04	-13.76
Lake States	1.03	1.05	0.03	-0.06	-5.29	-0.03	-2.90	-0.03	-3.01	-0.13	-12.06
Corn Belt	3.58	3.66	0.08	-0.12	-3.39	-0.03	-0.82	-0.13	-3.48	-0.28	-7.58
Northern Plains	1.74	1.81	0.06	-0.08	-4.20	-0.08	-4.45	-0.07	-4.06	-0.23	-12.65
Appalachian	0.53	0.55	0.02	-0.02	-3.46	-0.03	-4.95	-0.01	-2.54	-0.06	-10.58
Southeast	0.22	0.23	0.01	0.00	0.29	-0.02	-8.51	-0.02	-8.79	-0.03	-11.47
Delta	0.46	0.46	0.00	0.01	2.12	-0.07	-15.02	-0.02	-4.48	-0.05	-10.15
Southern Plains	1.02	1.04	0.02	-0.01	-0.59	-0.23	-22.31	-0.18	-17.72	-0.43	-40.95
Mountain	0.36	0.36	-0.01	0.00	0.95	-0.04	-10.83	-0.03	-7.93	-0.06	-17.91
Pacific	0.16	0.16	0.00	0.00	0.29	-0.02	-10.19	-0.02	-13.58	-0.02	-12.77
United States	9.37	9.60	0.23	-0.27	-2.80	-0.56	-5.85	-0.53	-5.56	-1.31	-13.68

—continued

Table 8.2

Regional environmental indicators by REAP scenario, in 2016—Continued

	USDA Baseline	Reference	Reference minus baseline	High corn productivity		High input costs		Positive carbon price		"Combination" scenario	
	Million tons				Percent	Million tons	Percent	Million tons	Percent	Million tons	Percent
				Change from reference							
Phosphorus applied											
Northeast	0.21	0.21	0.00	0.00	-0.24	-0.01	-3.38	0.01	4.98	0.00	0.54
Lake States	0.53	0.54	0.01	0.00	-0.27	-0.02	-2.82	0.01	2.72	-0.01	-1.48
Corn Belt	1.37	1.39	0.02	-0.01	-0.51	-0.01	-0.66	0.08	5.58	0.06	4.25
Northern Plains	0.91	0.92	0.01	0.00	-0.27	-0.05	-5.63	0.07	7.11	-0.01	-0.62
Appalachian	0.25	0.25	0.00	-0.01	-2.30	-0.01	-3.45	0.01	4.75	0.00	-0.83
Southeast	0.10	0.10	0.00	0.00	-3.26	-0.01	-5.29	0.00	0.17	0.00	-4.62
Delta	0.21	0.22	0.01	0.00	-0.62	-0.01	-4.44	0.01	4.50	0.01	2.53
Southern Plains	0.38	0.38	0.00	0.00	-0.86	-0.06	-15.04	-0.01	-2.12	-0.08	-19.90
Mountain	0.34	0.33	-0.01	0.01	1.68	-0.03	-8.68	0.01	4.43	-0.02	-5.62
Pacific	0.12	0.12	0.00	0.00	0.12	-0.01	-11.09	0.00	0.39	-0.01	-8.56
United States	4.42	4.47	0.04	-0.02	-0.44	-0.21	-4.62	0.20	4.42	-0.06	-1.32
Nitrogen fate											
Leached to groundwater											
Northeast	0.07	0.07	0.00	0.00	1.01	-0.01	-11.45	0.00	-3.72	-0.01	-17.72
Lake States	0.20	0.21	0.01	-0.02	-10.80	-0.01	-4.71	-0.01	-5.69	-0.05	-24.52
Corn Belt	0.14	0.14	0.00	0.00	-1.61	0.00	-2.01	0.00	-0.14	-0.01	-5.13
Northern Plains	0.07	0.07	0.00	-0.01	-9.54	-0.01	-7.71	0.00	-2.72	-0.02	-25.69
Appalachian	0.20	0.20	0.00	0.00	-1.90	-0.01	-4.15	0.00	-1.42	-0.02	-7.45
Southeast	0.09	0.09	0.00	0.00	-0.71	-0.01	-7.79	-0.01	-7.99	-0.01	-10.43
Delta	0.11	0.11	0.00	0.00	1.97	-0.01	-6.24	0.00	0.62	0.00	-1.88
Southern Plains	0.03	0.03	0.00	0.00	0.67	0.00	-12.98	-0.01	-19.63	-0.01	-27.45
Mountain	0.02	0.02	0.00	0.00	1.31	0.00	-8.42	0.00	-7.35	0.00	-19.01
Pacific	0.02	0.02	0.00	0.00	0.86	-0.01	-53.70	-0.01	-52.98	-0.01	-54.88
United States	0.95	0.98	0.02	-0.03	-3.37	-0.07	-6.94	-0.05	-4.84	-0.14	-14.62
Lost in solution											
Northeast	0.04	0.04	0.00	0.00	0.25	0.00	-3.76	0.00	-1.65	0.00	-6.08
Lake States	0.16	0.17	0.00	0.00	-1.77	0.00	-2.06	0.00	-1.78	-0.01	-6.92
Corn Belt	0.44	0.45	0.01	-0.01	-2.12	0.00	-0.46	0.00	0.12	-0.01	-2.58
Northern Plains	0.32	0.33	0.01	-0.01	-2.98	-0.01	-4.26	-0.02	-4.83	-0.04	-11.71
Appalachian	0.07	0.07	0.00	0.00	-3.12	0.00	-3.96	0.00	-0.46	0.00	-6.96
Southeast	0.03	0.03	0.00	0.00	-4.34	0.00	-4.95	0.00	-5.15	0.00	-11.64
Delta	0.24	0.25	0.01	0.00	-0.13	-0.02	-7.25	-0.01	-2.13	-0.01	-4.83
Southern Plains	0.26	0.27	0.00	0.00	-0.57	-0.04	-16.53	-0.04	-13.52	-0.09	-32.39
Mountain	0.08	0.08	0.00	0.00	0.92	0.00	-6.37	0.00	-4.24	-0.01	-10.76
Pacific	0.05	0.05	0.00	0.00	0.10	0.00	-7.46	0.00	-1.35	0.00	-7.93
United States	1.69	1.72	0.03	-0.03	-1.54	-0.10	-5.58	-0.07	-3.85	-0.18	-10.63

—continued

Table 8.2
Regional environmental indicators by REAP scenario, in 2016—Continued

	USDA Baseline	Reference	Reference minus baseline	High corn productivity		High input costs		Positive carbon price		“Combination” scenario	
	Million tons	*Million tons*	*Million tons*	*Million tons*	*Percent*	*Million tons*	*Percent*	*Million tons*	*Percent*	*Million tons*	*Percent*
				Change from reference							
Lost in sediment											
Northeast	0.14	0.14	0.00	0.00	0.69	0.00	-2.53	0.00	-0.99	0.00	-2.58
Lake States	0.11	0.11	0.00	0.00	0.06	0.00	-3.12	0.00	-2.16	-0.01	-5.95
Corn Belt	1.36	1.39	0.03	-0.01	-0.51	-0.01	-0.52	0.00	-0.02	-0.01	-1.07
Northern Plains	0.58	0.60	0.03	0.01	1.26	-0.04	-6.40	-0.03	-4.33	-0.06	-10.40
Appalachian	0.21	0.21	0.01	-0.01	-2.61	-0.01	-3.58	0.00	-1.52	-0.02	-7.31
Southeast	0.05	0.05	0.00	0.00	-3.48	0.00	-5.74	0.00	-5.85	-0.01	-11.01
Delta	0.16	0.17	0.01	0.00	-0.78	-0.01	-3.80	0.00	0.28	0.00	-0.43
Southern Plains	0.19	0.19	0.00	0.00	-1.39	-0.04	-21.80	-0.03	-15.27	-0.08	-40.39
Mountain	0.05	0.04	0.00	0.00	1.66	-0.01	-14.14	0.00	-3.49	-0.01	-13.55
Pacific	0.01	0.01	0.00	0.00	0.16	0.00	4.74	0.00	-3.41	0.00	-1.40
United States	2.85	2.91	0.07	-0.01	-0.31	-0.12	-4.03	-0.07	-2.29	-0.19	-6.63
Pesticides applied											
Northeast	12.90	13.19	0.29	-0.16	-1.24	-0.68	-5.19	-0.25	-1.93	-1.23	-9.35
Lake States	44.77	46.00	1.23	-0.94	-2.04	-1.41	-3.07	-2.04	-4.43	-5.14	-11.18
Corn Belt	143.18	146.70	3.52	-2.59	-1.76	-1.01	-0.69	-2.11	-1.44	-5.69	-3.88
Northern Plains	47.99	51.38	3.39	-0.64	-1.24	-3.98	-7.74	-2.93	-5.71	-9.19	-17.89
Appalachian	28.32	29.70	1.38	-2.31	-7.76	-1.56	-5.26	-1.32	-4.43	-4.55	-15.34
Southeast	11.87	11.97	0.09	-0.70	-5.86	-0.57	-4.76	-0.65	-5.47	-1.54	-12.83
Delta	47.36	47.52	0.16	0.47	0.99	-3.15	-6.63	-1.87	-3.93	-3.57	-7.51
Southern Plains	15.11	15.48	0.37	-0.30	-1.95	-4.25	-27.44	-2.87	-18.53	-7.96	-51.44
Mountain	8.87	8.82	-0.05	0.02	0.26	-0.67	-7.59	0.02	0.25	-0.35	-4.02
Pacific	8.01	8.06	0.05	0.02	0.29	-1.74	-21.58	-1.32	-16.34	-1.84	-22.84
United States	368.40	378.83	10.44	-7.12	-1.88	-19.03	-5.02	-15.34	-4.05	-41.08	-10.84
Pesticide fate											
Leached to groundwater											
Northeast	0.02	0.02	0.00	0.00	-0.78	0.00	-5.34	0.00	6.82	0.00	-0.75
Lake States	0.04	0.04	0.00	0.00	0.90	0.00	-4.62	0.00	-6.28	0.00	-10.34
Corn Belt	0.01	0.01	0.00	0.00	1.69	0.00	3.35	0.00	15.58	0.00	20.27
Northern Plains	0.00	0.00	0.00	0.00	5.22	0.00	0.07	0.00	5.93	0.00	12.74
Appalachian	0.07	0.07	0.00	0.00	-2.03	0.00	-2.23	0.00	-6.08	-0.01	-10.16
Southeast	0.08	0.08	0.00	0.00	-5.29	0.00	-3.05	0.00	-2.94	-0.01	-10.50
Delta	0.01	0.01	0.00	0.00	11.08	0.00	-6.47	0.00	4.40	0.00	14.20
Southern Plains	0.00	0.00	0.00	0.00	1.59	0.00	-5.48	0.00	-19.93	0.00	-20.33
Mountain	0.00	0.00	0.00	0.00	-0.97	0.00	-5.43	0.00	-5.41	0.00	-9.26
Pacific	0.00	0.00	0.00	0.00	0.00	0.00	-2.36	0.00	-2.24	0.00	-7.39
United States	0.22	0.23	0.01	0.00	-1.75	-0.01	-2.92	-0.01	-2.40	-0.02	-6.74

—continued

Table 8.2
Regional environmental indicators by REAP scenario, in 2016—Continued

	USDA Baseline	Reference	Reference minus baseline	High corn productivity		High input costs		Positive carbon price		"Combination" scenario	
	Million tons				Percent	Million tons	Percent	Million tons	Percent	Million tons	Percent
				Change from reference							
Lost in sediment											
Northeast	0.02	0.02	0.00	0.00	1.28	0.00	-8.23	0.00	-4.98	0.00	-13.19
Lake States	0.04	0.04	0.00	0.00	-0.30	0.00	-8.23	0.00	-2.27	0.00	-8.93
Corn Belt	0.62	0.64	0.02	-0.01	-1.78	0.00	-8.23	0.00	-0.09	-0.02	-2.37
Northern Plains	0.14	0.15	0.01	-0.01	-4.21	-0.01	-8.23	-0.01	-9.30	-0.03	-19.56
Appalachian	0.11	0.12	0.00	0.00	-1.92	0.00	-8.23	0.01	6.53	0.00	2.94
Southeast	0.02	0.02	0.00	0.00	-3.65	0.00	-8.23	0.00	-8.93	0.00	-10.05
Delta	0.13	0.13	0.00	0.00	-0.11	0.00	-8.23	0.00	-3.50	0.00	-3.45
Southern Plains	0.09	0.09	0.00	0.00	-5.07	-0.03	-8.23	-0.01	-11.56	-0.05	-58.84
Mountain	0.00	0.00	0.00	0.00	-0.89	0.00	-8.23	0.00	-15.48	0.00	-18.68
Pacific	0.00	0.00	0.00	0.00	-0.03	0.00	-8.23	0.00	-2.65	0.00	-7.92
United States	1.18	1.21	0.03	-0.03	-2.08	-0.06	-8.23	-0.03	-2.16	-0.11	-8.73
Lost in surface runoff											
Northeast	0.13	0.13	0.00	-0.01	-3.86	0.00	-2.81	0.00	2.18	-0.01	-4.49
Lake States	0.57	0.58	0.01	0.00	0.37	-0.01	-2.26	-0.02	-4.17	-0.05	-7.71
Corn Belt	1.90	1.95	0.05	0.00	0.17	0.00	-0.13	0.01	0.61	0.01	0.55
Northern Plains	1.58	1.64	0.06	0.01	0.84	-0.06	-3.67	-0.10	-6.21	-0.17	-10.34
Appalachian	0.22	0.23	0.02	-0.03	-13.55	-0.02	-6.79	-0.02	-7.13	-0.05	-22.61
Southeast	0.08	0.08	0.00	0.00	-5.74	0.00	-3.72	0.00	-3.94	-0.01	-11.25
Delta	0.53	0.55	0.02	0.01	1.13	-0.03	-4.56	0.04	7.50	0.04	7.18
Southern Plains	0.48	0.50	0.02	0.03	5.59	-0.02	-3.75	-0.07	-14.39	-0.07	-13.47
Mountain	0.73	0.74	0.01	-0.01	-1.10	-0.02	-2.95	-0.01	-1.59	-0.04	-5.55
Pacific	0.34	0.34	0.00	0.00	-0.03	-0.06	-18.33	0.00	0.07	-0.06	-17.41
United States	6.55	6.74	0.20	0.00	0.06	-0.23	-3.36	-0.17	-2.57	-0.40	-5.93

Note: "USDA Baseline" refers to REAP model runs calibrated to the USDA agricultural projections for 2016 (or the 2016/2017 crop year) that were released in February 2007 (see USDA, OCE, 2007).

Figure 8.1
Sheet and rill erosion

Change from reference (million tons)

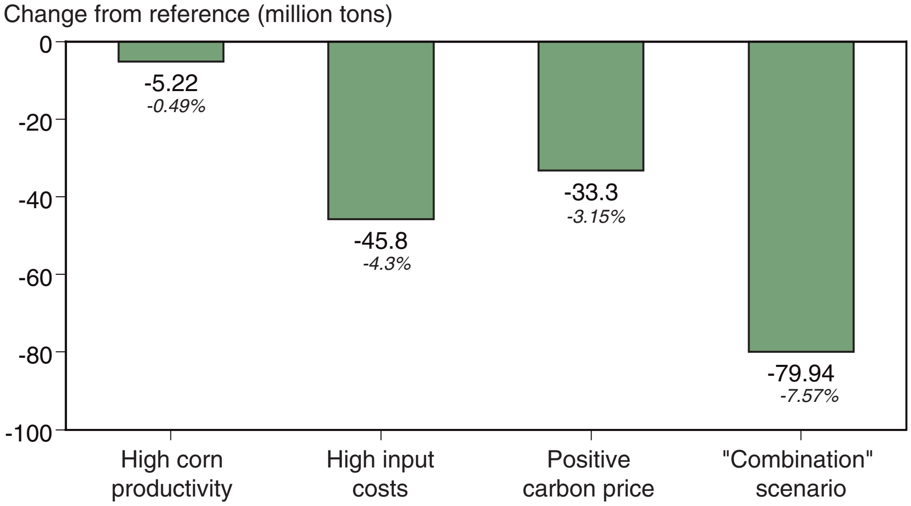


Figure 8.2

Wind erosion

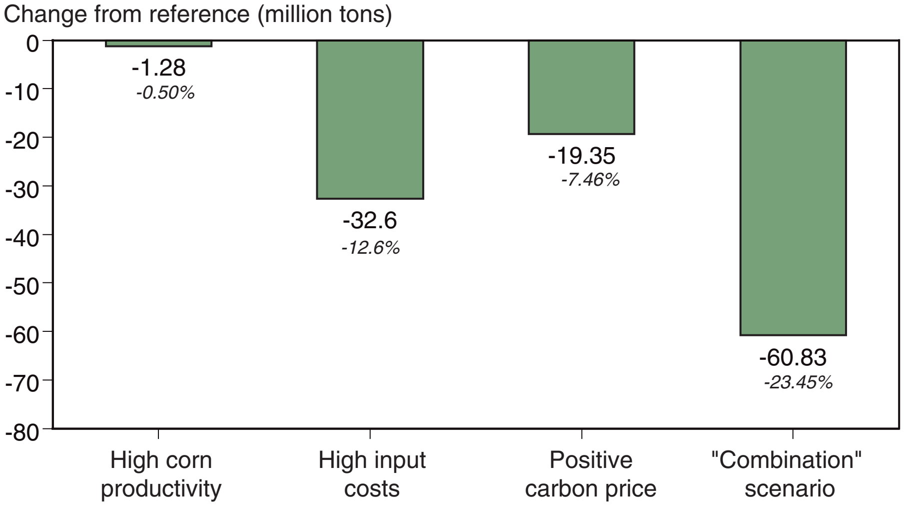


Figure 8.3

Northern Plains—Sheet and rill erosion

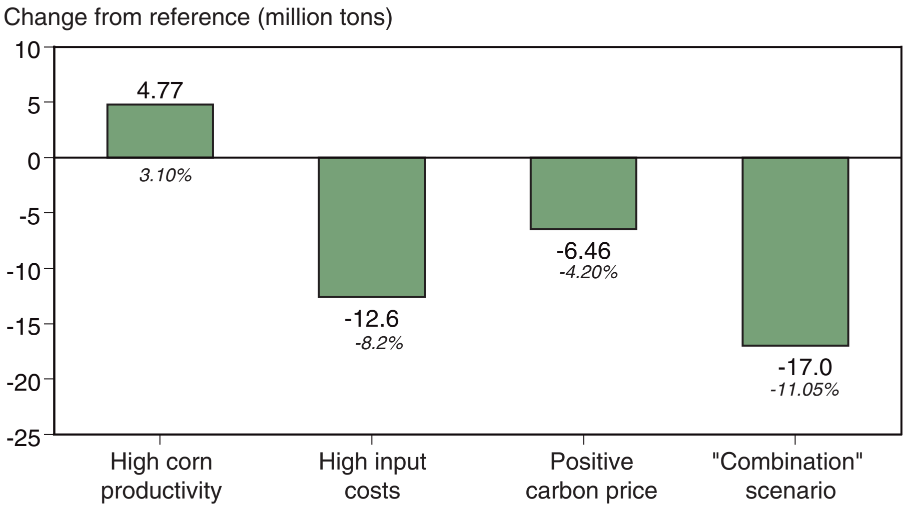


Figure 8.4

Southern Plains—Wind erosion

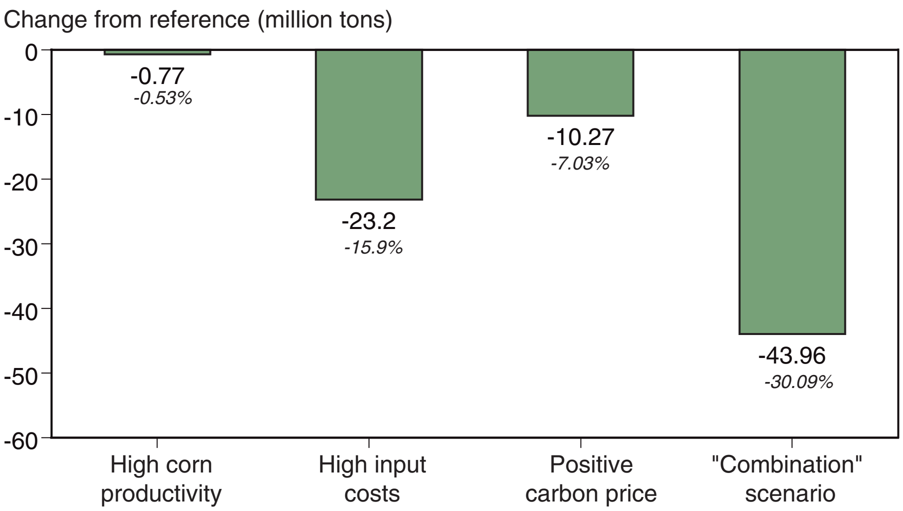


Figure 8.5
Nitrogen fertilizer applied

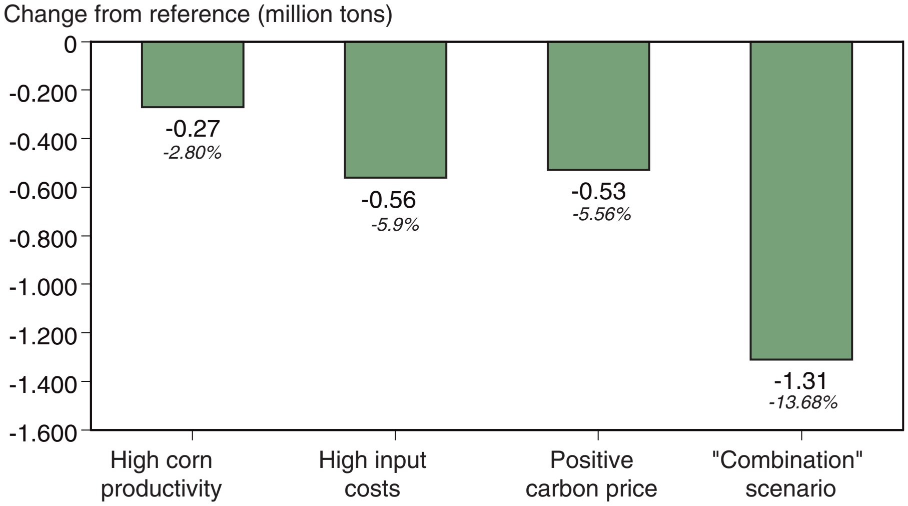


Figure 8.6
Phosphorus fertilizer applied

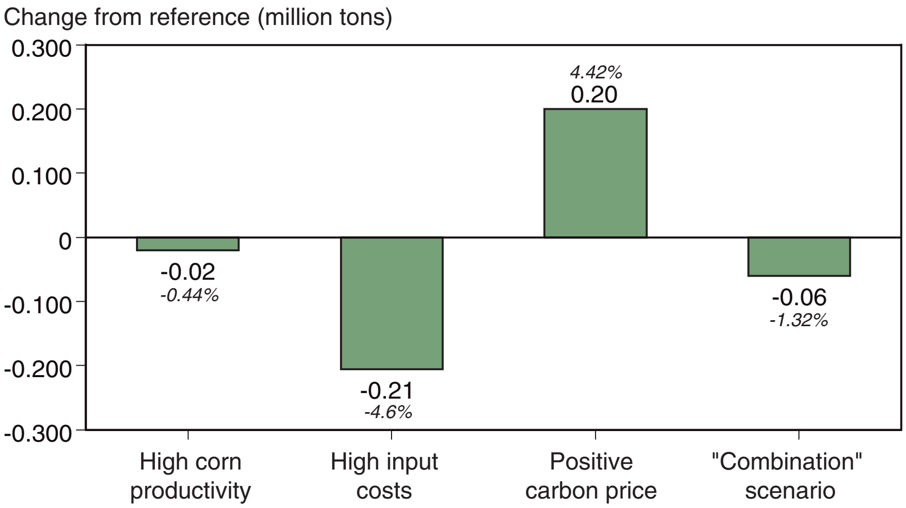


Figure 8.7
Southern Plains—Nitrogen fertilizer applied

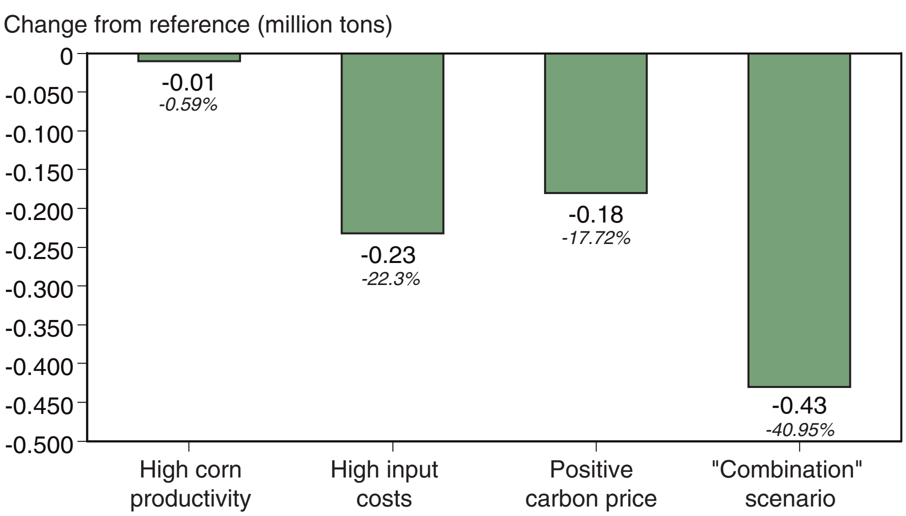


Figure 8.8

Southern Plains—Phosphorus fertilizer applied

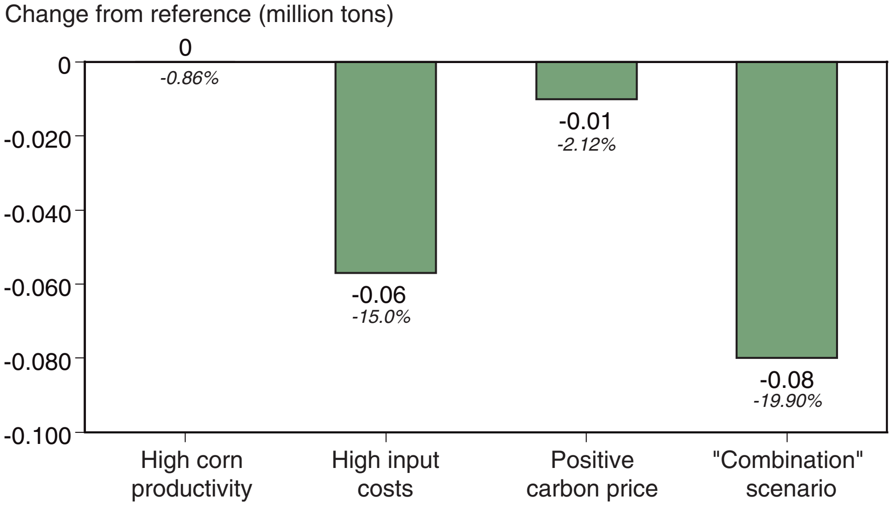


Figure 8.9

Nitrogen leached to groundwater

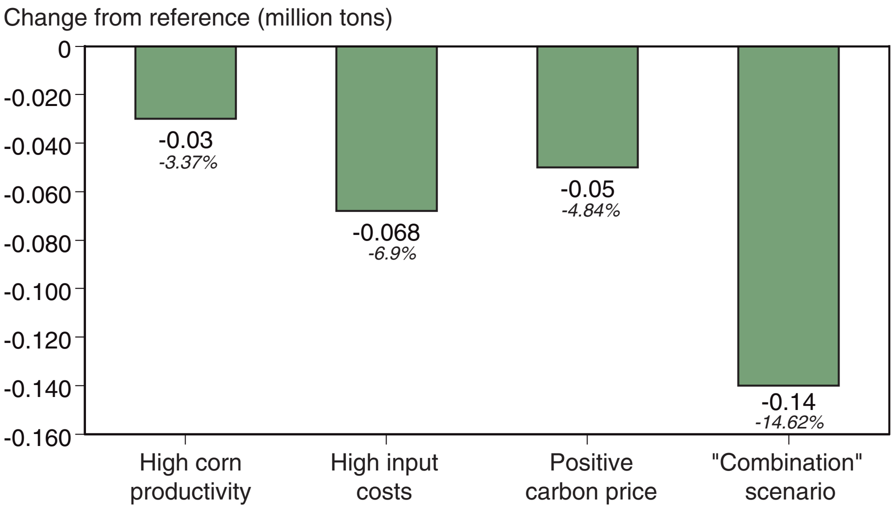


Figure 8.10

Lake States—Nitrogen leached to groundwater

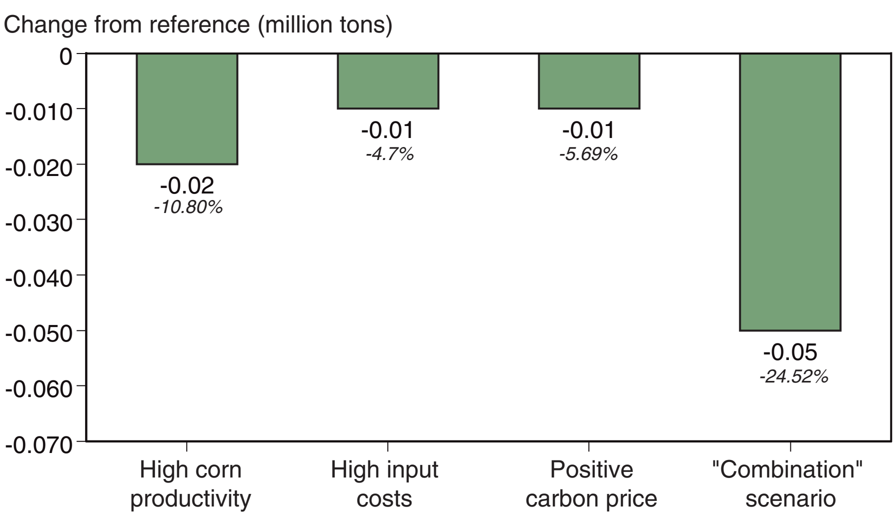


Figure 8.11

Nitrogen lost in solution

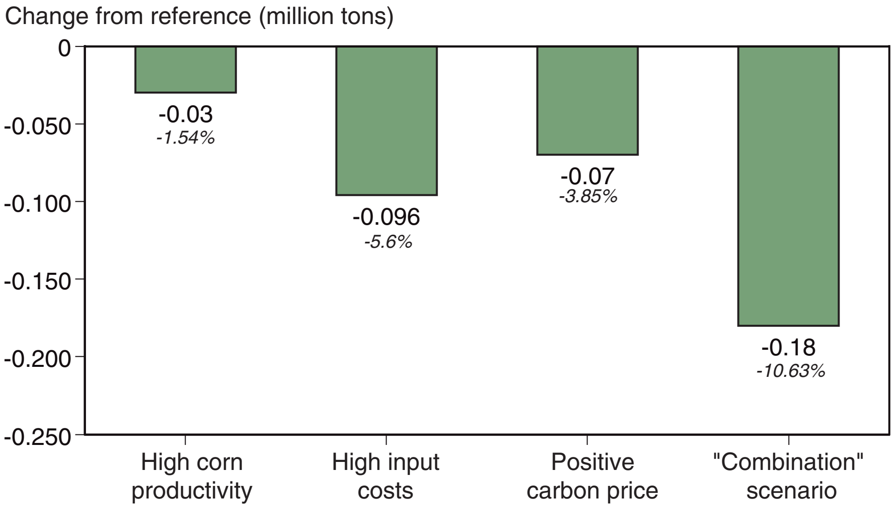


Figure 8.12

Southern Plains—Nitrogen lost in solution

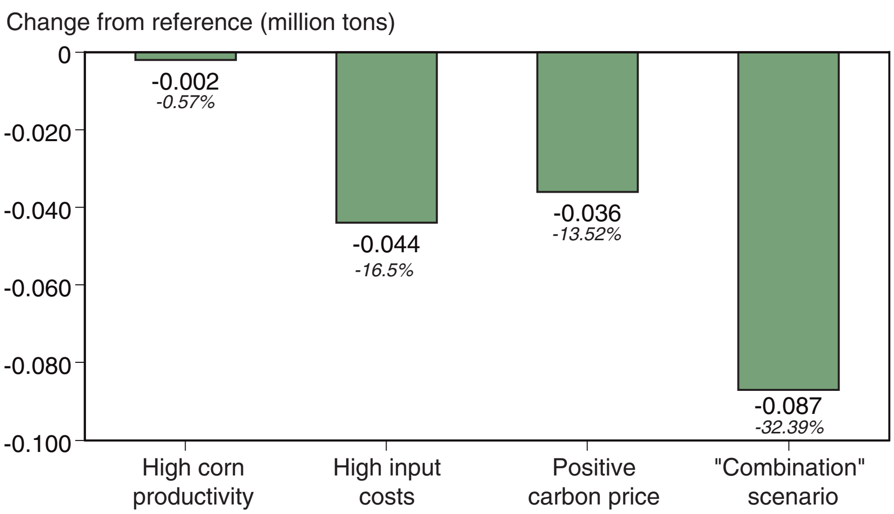


Figure 8.13

Nitrogen in sediment

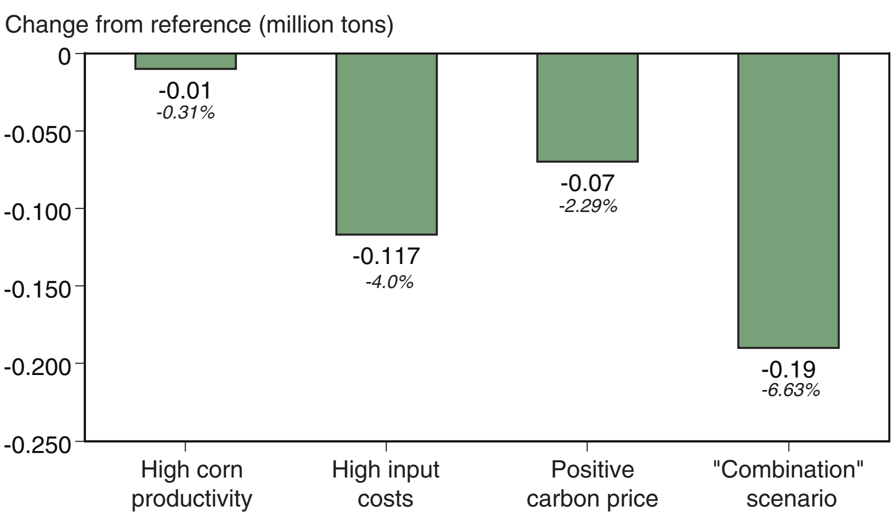


Figure 8.14
Northern Plains—Nitrogen in sediment

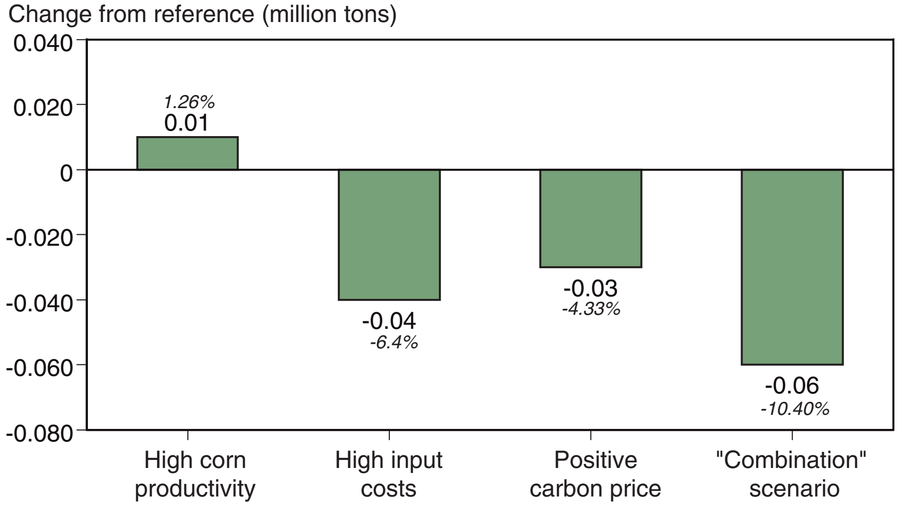


Figure 8.15
Pesticides applied

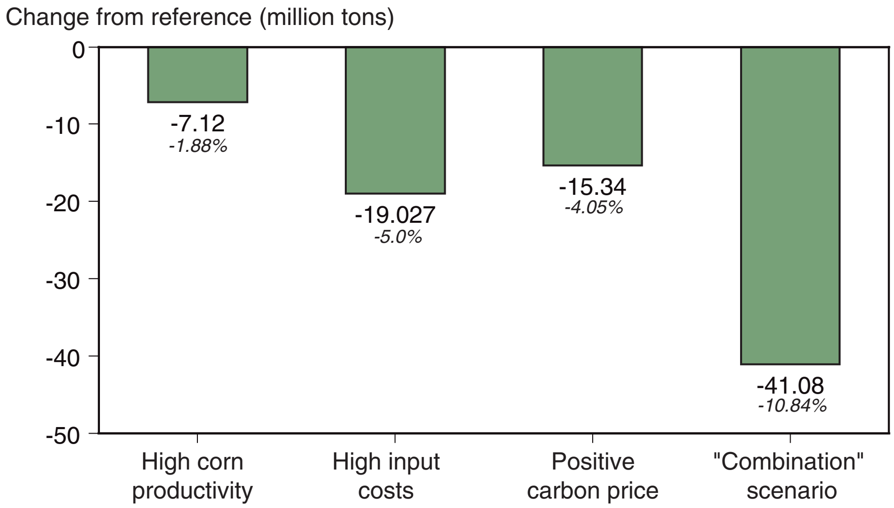


Figure 8.16
Pesticides leached to groundwater

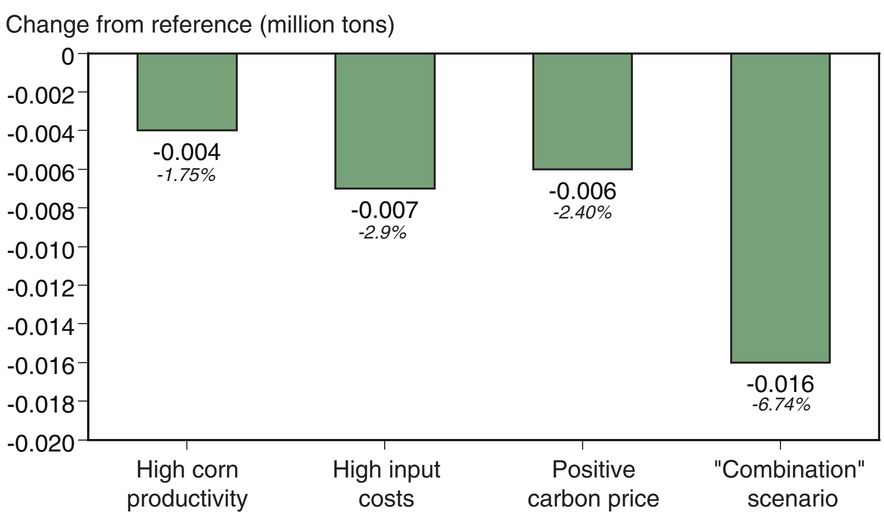


Figure 8.17

Pesticides in sediment

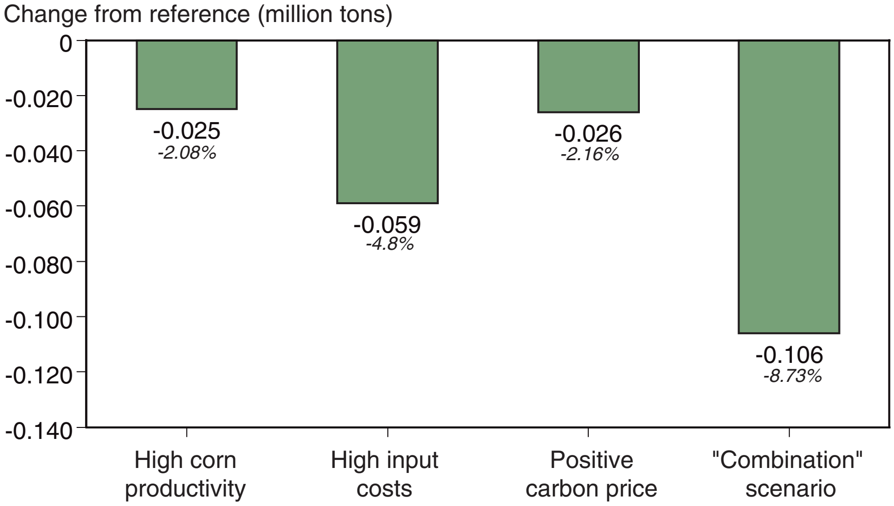


Figure 8.18

Pesticides in surface runoff

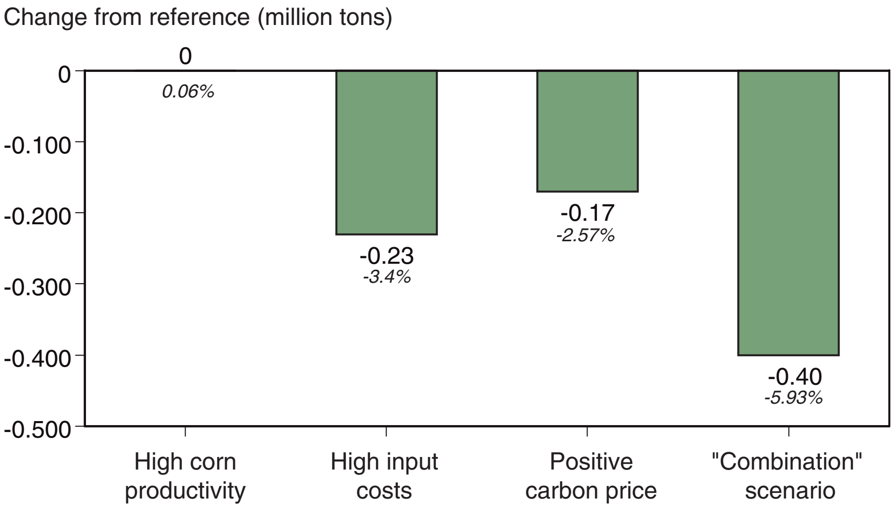


Figure 8.19

Northern Plains—Pesticides applied

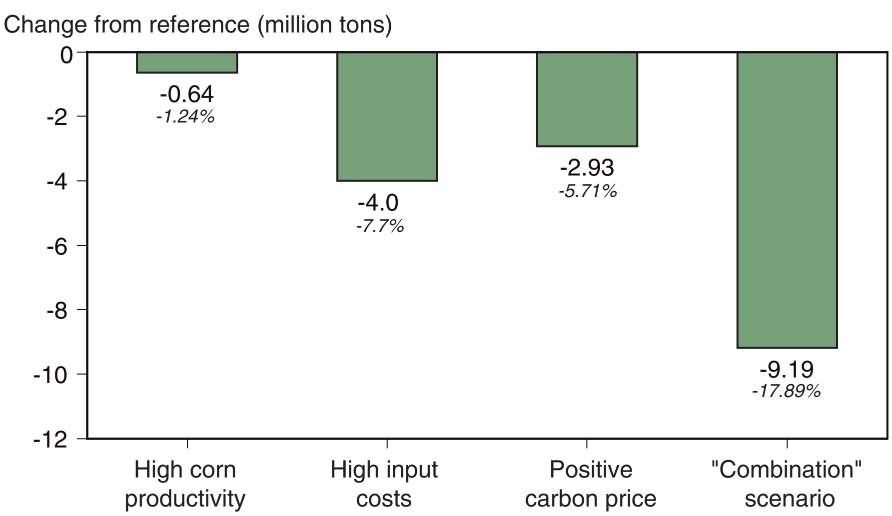


Figure 8.20

Southeast—Pesticides leached to groundwater

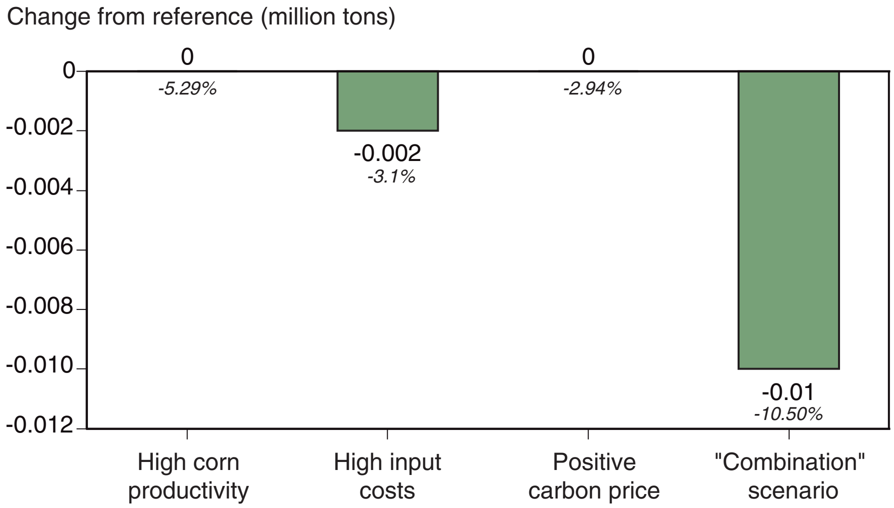


Figure 8.21

Southern Plains—Pesticides in sediment

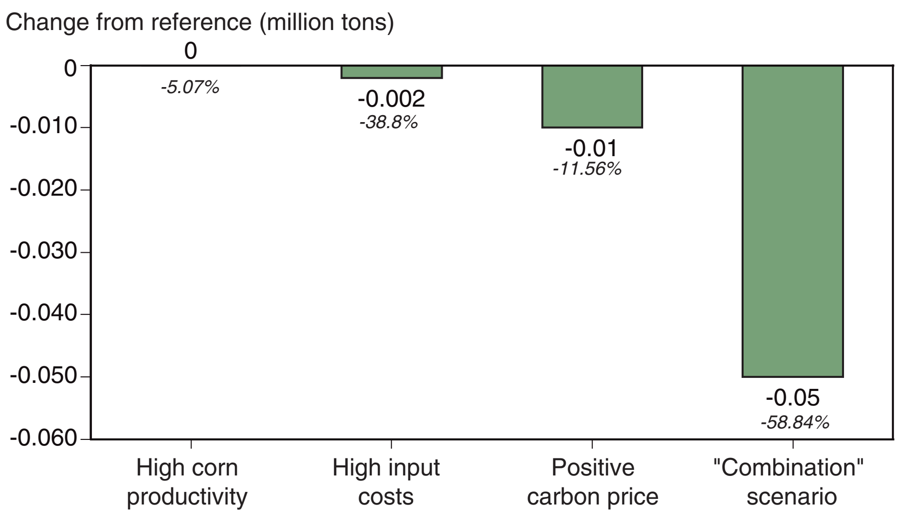
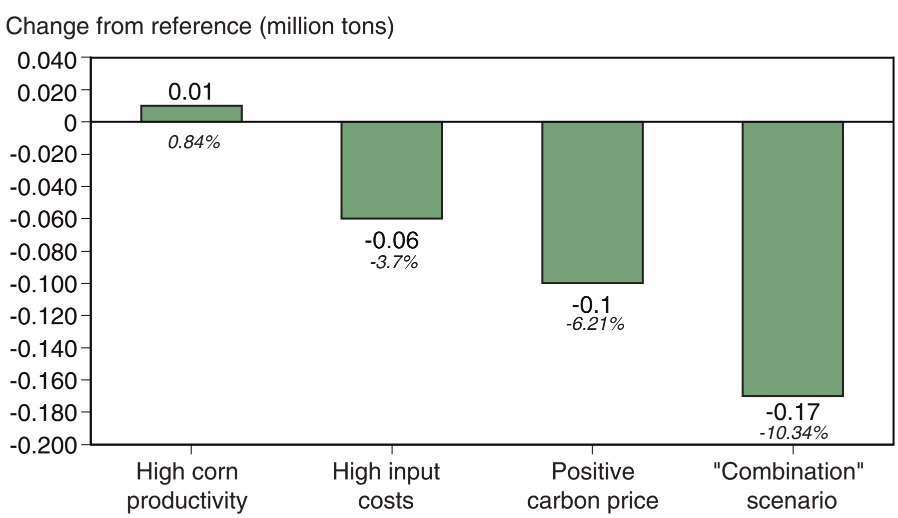


Figure 8.22

Northern Plains—Pesticides in surface runoff



Fertilizer Applications Reduced by Shifts in Cropland Acreage

Fertilizer applications were generally lower across the U.S. in each of the alternative scenarios than in the reference case. The combination scenario used approximately 14 percent less nitrogen and 1 percent less phosphorus than the reference case. The positive carbon price scenario had approximately 6 percent less nitrogen (530,000 tons) but 4 percent more phosphorus (200,000 tons). The price of carbon is reflected in higher fertilizer prices, which leads to changes in farmers' nutrient application rates.

When examining fertilizer applications generally, the regional differences were greatest in the Southern Plains, and each scenario showed lower values than the reference case. The high productivity scenario led to only slight changes, but the high input cost, carbon price, and combination scenarios reduced nitrogen use more significantly. Nitrogen use in the Southern Plains was reduced by roughly 230,000, 180,000 and 425,000 tons respectively (22, 18, and 41 percent lower than the reference), while phosphorus use was reduced by 60,000, 10,000, and 80,000 tons (15, 2, and 20 percent lower than the reference).

Many of the changes in fertilizer applications can be attributed to changes in cropland acreage across the U.S. Changes in tillage practices have much less effect on fertilizer applications than do shifts in acreage. The Southern Plains had fewer acres in production in each of the scenarios, so total fertilizer applications nationally were lower.

Nitrogen Leaching Lower With Change in Tillage Practices and Soil Type

The amount of nitrogen leaving fields in solution, in groundwater, and in sediment was lower in every scenario nationwide than in the reference case. Of the three scenarios isolating an effect, the largest reductions relative to the reference were in the high input cost scenario. The high productivity scenario showed the smallest changes. The combination scenario resulted in 7 to 15 percent less nitrogen loss than in the reference case.

Changes to the amount of nitrogen fertilizer applied are an indicator of the amount of nitrogen leached to groundwater and lost in solution. For example, in the high corn productivity scenario, 2.8 percent less nitrogen was applied across the U.S. and 3.4 percent less was leached. The proportionality does not hold for nitrogen lost to sediment (approximately 0.3 percent less), indicating some shift in the application rates across the regions from one soil type to another.

Most of the differences among scenarios are due to a shift from no-till, which is generally associated with a decline in chemical leaching (see table 7.2 for changes in tillage). The Lake States, however, exhibited more leaching for corn grown with no-till due to predominant soil type.

Pesticide Applications and Leaching Reduced by Shift in Regional Production

Pesticides in REAP follow the same pattern as many other environmental indicators—all the scenarios have less leaching than the reference case, and the largest differences are with the combination scenario. Pesticides applied were approximately 11 percent less, while pesticides leaving the field through leaching, in sediment, and in surface runoff were 6-9 percent less. This discrepancy indicates a shift in the regional applications of pesticides, rather than evenly reduced applications across the U.S.

The differences across scenarios were primarily due to a reduction in corn acreage. Corn requires more pesticides than the crops that replace it in the scenarios. With less corn acreage, pesticide applications (and consequent leaching) were lower.

Cellulosic-Based Feedstocks

As reported in chapter 6, various levels of cellulosic-based feedstock mixtures from cropland, forestland, and imports were used to meet increased biofuel needs in the reference case and other production scenarios. Feedstocks included corn stover, wheat straw, perennial crops (grasses and trees), and wood—under high corn productivity and high energy crop productivity scenarios.

Sustainability considerations for cellulosic feedstock production are basically the same as in starch-based feedstock production and therefore involve the same general criteria. However, in cellulosic-based feedstock production systems, much more of the plant material is removed than in starch-based systems. The missing plant biomass would otherwise help maintain soil organic matter or protect against erosion. Cellulosic-based resources must be properly managed to avoid negative environmental impacts. On the other hand, many of the cellulosic feedstocks are residues from crop harvest, forest harvest and thinning, and mill/urban wastes. Using these kinds of feedstocks requires no additional cropland, fertilizer, pesticides, or water. Perennial crops can have a beneficial environmental effect when properly managed, especially when planted on poor or marginal cropland.

Perennial Crops

Today's agricultural landscape is often characterized by large fields of annual crops with only narrow patches of perennial trees and grasses along streams and roads. These annual crops require tillage and cultivation every year, and the fields lie barren for most of the year. Perennial crops such as grasses require little tillage—just to establish the crop in the beginning and then every few years to refresh it. Woody crops can require some initial establishment tillage and some cultivation during the first few years. Perennial crops bring many positive environmental attributes to the production of feedstocks for biofuels.

Woody crops and grasses, especially in combination, can provide more habitat diversity for plant and animal species. These crops can reduce runoff of nitrogen and pesticides and can provide shelterbelts, riparian strips, and windbreaks.

The 2022 biofuel goals could be met with 16-19 million acres of perennial crops providing the feedstock needed. Total land changes of 20-23 million acres would be involved as other land uses change to provide forage and hay (see chapter 6). For example, in one scenario, nearly 11 million acres of pasture shift to energy crops, and 12 million acres of pasture shift to hay production to make up for the lost forage.

Residue Removal

Corn stover and straw are the residue materials left in fields after the crops are harvested for grain. These residues have been considered by some to be trash, with no value. However, these materials help prevent water and wind erosion of soil, replace soil organic carbon lost to the atmosphere due to cultivation, enhance soil structure, return inorganic nutrients to the soil, sustain microbial life in the soil, and increase water filtration through the soil. Residues also help maintain the soil's organic carbon levels to support crop productivity. The amount of residue needed to maintain soil organic carbon and crop productivity is generally greater than the residue needed simply to avoid soil erosion. Crop residue beyond that needed to sustain the land's productivity could be removed and used for biofuel feedstock.

The amounts of sustainably harvestable residues for a specific location will vary depending upon climate, soil texture, and the production practices used. Corn produced with conventional tillage requires that more residues be left in the field than corn produced in no-tillage systems. Similarly, corn grown in rotation with soybeans requires more remaining residue than continuous corn because soybeans produce less residue than corn. Crops grown in higher rainfall areas or under irrigation produce more biomass than crops grown in areas with less precipitation or without irrigation.

Knowing how much of the residue that can be removed sustainably is still being refined through additional research and technology development (Graham et al, 2007; Wilhelm et al., 2007).

Land-Use Change

The demand for cellulosic feedstocks may require large losses in pastureland—in some cases, more than 23 million acres. This degree of land-use change may amplify impacts to local and regional ecosystems. Typically, when pastureland undergoes agricultural intensification, fertilizer and pesticide applications increase, as does erosion due to increased cultivation. Also, the water requirements for pasture can be less than for many cellulosic energy crops; and planting new crops or installing irrigation systems on pastureland can alter local water cycling and land drainage patterns.

With most of the projected loss in pasture area occurring in the Corn Belt and Appalachian regions, irrigation will probably not increase with shifts out of pasture. However, if the energy crops that replace pasture in these regions are woody, such as hybrid poplar or other short-rotation crops, impacts to water, soil, and nutrient cycling could be larger than with perennial grasses due to differences in agronomic practices.

The cellulosic reference case requires some major land-use changes in cropland as well. Corn acreage increases to provide additional corn stover residues as the market develops. This additional cropland will come primarily from cultivated farmland currently used for other crops, so this shift is expected to involve minimal environmental changes. In the high corn productivity scenario, less acreage is required and less corn stover becomes available, requiring slightly more perennial cropland than in the cellulosic reference case.

Forest and Wood Feedstocks

In all 2022 scenarios involving wood, wood is stipulated to provide about 20 percent of cellulosic feedstocks. This proportion was based on the *Billion Ton Report* (Perlack et al., 2005) and is the equivalent of about 45 million dry tons annually, or about 4 billion gallons of biofuels. Some assumptions and estimates were made concerning which wood feedstocks would make up the needed component (chapter 6). Neither REAP nor POLYSYS are able to model either the economics or sustainability criteria for the forestry sector. Thus, these analyses were completed exogenously to these models using other models and tools (Fight et al., 2006; Biesecker and Right, 2006).

Generally, forestry sustainability is achieved through either the application of best management practices (BMPs) that are either voluntary or statutory (regulated by States) or through formal forest certification programs. In all cases, these practices are science-based and have the goals of protecting ecological function and minimizing negative environmental impacts. Many versions of forest sustainability criteria exist because of the various approaches to applying BMPs or certification. Most include core ecological and environmental aspects, with additional considerations for economic and social implications. Forestry sustainability criteria usually have these basic elements:

- Conservation of biological diversity,
- Maintenance of productive capacity,
- Maintenance of forest ecosystem health and vitality,
- Conservation and maintenance of soil and water resources,
- Maintenance of forest contribution to global carbon cycles,
- Maintenance and enhancement of long-term multiple socioeconomic benefits, and
- Legal, institutional, and economic framework for forest conservation and sustainable management.

For this analysis, some inferences can be made about the woody biomass component of the scenarios.

- **General harvest activities—**Logging, when properly applied under BMPs, regulations, or certification, does not have significant negative ecological and environmental impacts. In the U.S., much effort has gone into educating timber-harvesting operators and designing equipment to minimize ecological impacts. Cautionary actions are taken to minimize soil disturbance, to prevent soil or machine fluids from entering streams and other water bodies, and to meet prescribed biodiversity/habitat requirements, like leaving downed/standing dead trees, protecting sensitive areas, and using retention trees.
  - ➢ ***Removing residues—***Logging slash, the unmerchantable trees and tree components, can be removed so as not to accelerate erosion or

degrade the site. Studies have shown how to minimize such impacts through use of buffer zones, leaving adequate biomass residue, and nutrient management programs.

- ➢ ***Thinnings—***Thinnings leave some stand structure to provide continuous cover, erosion control, and habitat. Under correct prescriptions and harvesting operations, thinning enhances forest health and vitality by removing excess biomass.

- **Mill and urban wastes—**Generally, it is more sustainable to use waste material than to dispose of it. This is even more important with urban wastes, especially if the only disposal option is landfills. Most mill wastes are being utilized for energy and other products.

Currently, about 278 million dry tons of timber are harvested in the U.S. annually. According to Smith and others (2003), timber growth has exceeded removals since the first national statistics were reported in 1952. For example, in 2001, growth exceeded removals in all regions of the country: by 49 percent in the North, 12 percent in the South, 74 percent in the Rocky Mountain region, and 47 percent in the Pacific Coast region. An additional 45 million dry tons of removals, mostly waste, from forests will have little impact nationally. That level of removals represents about 6.5 million acres spread over nearly three-quarters of a billion acres of forestland. Through the use of BMPs and certification programs already in place, specific forest land, watersheds, and landscapes should not experience significant environmental effects. More research is still needed to understand and verify ecological function and management under more intensive biomass removal regimes.

The current state of forest health is jeopardized by fire, pests, and invasive species. A buildup of excessive woody biomass has led to these hazards and raised forest susceptibility to epidemic outbreaks of insects and disease. Utilizing biomass for biofuels will provide market-driven opportunities for prescriptive and restorative forest management treatments.

Needs for Future Research On Sustainability

This chapter started with a definition of sustainability based on meeting the needs of the current generation while not compromising the ability of future generations to meet their own needs. Applied to biomass production for biofuels, this concept was framed in the context of economic, environmental, and social sustainability. Feedstock production sustainability includes natural resource management and stewardship, and sustained provision of environmental services. As the data, analyses, and modeling limitations of this chapter have shown, current analytical efforts to use quantifiable indicators are very elementary and need a great deal of work, especially when assessing large volumes of biomass production.

The existing REAP and POLYSYS models provide limited information about environmental conditions. Greater insight into sustainability will require a substantial investment in new research. This chapter described a number of areas where additional research would help improve our understanding, including additional monitoring, appropriate experiments, more comprehensive data, more integrated production and environmental modeling, improved analysis tools, greater range of scalability, and enhanced economic and lifecycle analysis.

Experimentation and Additional Data

Environmental monitoring data, particularly in growth areas for biomass production, are needed to support basic conclusions about environmental conditions. For example, REAP/EPIC results estimate farm chemical runoff (nitrogen, phosphorus, pesticides), but do not estimate concentrations in water bodies. Extensive systems of water quality monitoring (i.e., NAWQS program at USGS), forest inventory and health monitoring, and agriculture monitoring are in place, but may need enhancements to ensure continuity. Additional monitoring will be important relative to expected land-use and management changes. In addition to physiochemical monitoring data, indicator flora and fauna (aquatic, terrestrial, avian) species might be monitored to provide information on environmental conditions affected by areas of increasing biomass production for biofuels.

Experiments are needed to understand and quantify underlying ecological, physical, and chemical processes in order to provide sustainable management systems. More targeted research is critical to developing comprehensive data sets, reliable models, and robust predictions, estimates, and tools.

Experimental data are needed to supplement monitoring data to calibrate behavioral, lifecycle, and biophysical models associated with biofuels production systems, and integrated models of environmental effects. For example, the SPARROW model is a framework for estimating nutrient loadings in water systems. If the SPARROW model were integrated with the REAP or POLYSYS models (per modeling research recommendations, below), specialized data may be necessary to ensure that the model is generating accurate results. Particularly needed are applied experimental data to understand and quantify the (agricultural, environmental, and socioeconomic) sustainability characteristics of biofuel feedstocks and their variants (eg., till vesus no-till). These data should include impacts pertinent to the farmer and farmland, such as soil carbon loss in relation to rates of corn stover removal, as well as impacts on the offsite environment such as nitrate and phosphate runoff. The potential sustainability benefits of nontraditional biofuel feedstocks like native prairie grasses may warrant exploration as to economic and environmental parameters.

Climate modeling data could provide a more accurate estimate of future environmental effects of biomass production. The EPIC model generates estimates of environmental phenomena based on historical (daily) patterns of weather. Applying estimates of production decisions to detailed soil, topographical, and weather data generates the EPIC results within REAP. Farm chemical runoff and erosion occur disproportionately during extreme weather events. Climate research already suggests climate instability is increasing, and it is unlikely that the next 30 years' weather patterns will mirror the past 30 years. Using current climate research to generate new series of weather data, and rerunning the models, might provide new insights into sustainability.

Modeling Research

This chapter has discussed numerous instances where behavioral and biophysical **models could be refined or updated** to improve the robustness of the results. Static models of environmental conditions could be made dynamic; agricultural production models could include more information on the timing of production practices, as timing of biophysical processes is critical to environmental conditions (especially for fallow/conservation land that may come into production). Research could also help inform which options and opportunities for refining existing models merit the most attention, given the potential for these modeling refinements to reflect changing environmental conditions.

Integrating existing environmental process models into existing behavioral models could generate a wealth of information on the sustainability of biomass production systems. Much as EPIC was incorporated into REAP and SPARROW might offer more refined estimates of water quality, many other environmental process models could be integrated into a modeling platform to provide insight into environmental conditions and services affected by biomass production.[3]

[3]Environmental services and benefits, and modeling research opportunities, are summarized in EPA's Ecological Benefits Assessment Strategic Plan (EPA, 2006b).

Another example of research on model integration is incorporating models that include choices in biomass conversion technologies into biomass production choice models. Different conversion platforms (e.g., flexible biochemical fermentation, pyrolytic, thermochemical, and combined biochemical/thermochemical conversion processes) are optimized for different types of biomass. Thus, if demand for biomass is a derived demand, the estimates of biomass production models could be improved by endogenizing the conversion platform as alternative platforms become technically and economically feasible.

Creating new models of ecosystem services has received only limited research attention, particularly for perennial grasses and woody biomass cropping systems. For example, some preliminary research has been conducted to suggest how switchgrass production might influence water quality (vis a vis nutrient translocation) or wildlife habitat, but there is limited research to demonstrate how large-scale production would perform in generating these environmental services.

Another research area receiving a great deal of interest is the modeling of international markets for biomass production. International trade models for commodities exist, but there are few examples of robust international models to estimate the effect of biofuel markets on biomass production and resulting environmental conditions.

Improving Estimation or Modeling Results

In the course of producing this report, five REAP and POLYSYS scenarios were evaluated. Although these scenarios generated preliminary estimates for a limited set of environmental indicators, there are a large number of exogenous policy, behavioral, and biophysical parameters in the model. Many other values of underlying parameters could be explored to investigate the impact on environmental indicators. An improvement with additional data and model capability would have been a systematic set of sensitivity analyses on the indicators. It would have been useful to determine which parameters were most influential in determining environmental outcomes, and across what range of those parameters the greatest mitigation or exacerbation occurred.

More robust uncertainty analysis would facilitate inferences available from the models. An area of critical research is to identify the major uncertainties associated with each of the components of the sustainability assessments. Such an analysis would indicate specific research that could help mitigate the uncertainties.

Scale

The influence of spatial scale may be profound for biomass production decisions, and the sustainability outcomes associated with those decisions are similarly influenced by scale. Production decisions can be highly heterogeneous with respect to **local spatial scale.** Preliminary research on cellulosic biofuel markets raises questions about market integration due to the high cost of transporting biomass to conversion facilities. This has implications for sustainability, particularly if other spatial factors (proximity to major transportation corridors) influence the intensity of biomass production.

Regional scale effects are of great interest, particularly because watersheds and water basins are affected by aggregate decisions at the regional level. Moreover, landscape and habitat continuity (or fragmentation) at the regional level often determines the sustainable provision of environmental services. For example, additional research is needed to assess, understand, and model cumulative water quality impacts from feedstock production over broad spatial scales, especially in accumulative water systems and as a gauge for sustainability.

National and international scale effects require a different set of research tools, and there are a number of areas where additional research would improve our understanding of sustainable biomass production. Greenhouse gas production and carbon sequestration can be profoundly influenced by which biomass sources are used, where they are grown, and how they are produced. Large water bodies of national importance (e.g., Great Lakes, Gulf of Mexico) will also be influenced by large-scale biomass production. As the scale of biofuels production increases locally and regionally, it will become more important to mitigate cumulative effects on these larger bodies of water, and doing so will require dedicated research on data, models, and uncertainty.

Fundamental Research

The sustainability of biofuels production is a relatively new topic, and much basic research is needed to better understand the underlying mechanisms and processes. As just one example, soil fertility and other characteristics are a critical component of sustainability. Local soil and climate effects are important and highly variable, especially as sources of nitrous oxide emissions (Kim and Dale, 2008). A better understanding of the underlying processes will help predict and guide, for example, the sustainability of agricultural management practices. A recent USDA/DOE workshop on research and other needs for biofuels sustainability documents some of the important topics (http://www.csrees.usda.gov/about/white_papers/pdfs/usda_doe_discussion_paper.pdf).

Conclusions

Information about the sustainability of much larger levels of domestic production of biofuels will help guide Federal and local policies on energy, the environment, and agriculture. It will also help set priorities for research programs and improve the operation of the biofuel sector. However, the concept of sustainability is still relatively new and incomplete. Many of the impacts of expanded biofuel production are uncertain because the technologies will be changing rapidly, and the possible scale of production is significantly larger than the current scale. The sustainability of agricultural production for biofuels is a complex and nascent field, and this chapter discusses many of the issues in only an introductory way.

In addition to this chapter's overview of sustainability criteria and indicators for biofuels, the chapter also discusses inferences that can be drawn from the REAP and POLYSYS modeling activities presented elsewhere in this report. These two models were not designed to provide information on variables that measure sustainability directly, so the implications for sustainability were limited. For example, the models provide estimates of nitrogen in water runoff but provide no information about the impacts of nitrogen on stream quality and the estimated rates of denitrification in the stream.

Feedstock production for the high corn productivity and high input cost scenarios have more favorable environmental impacts than the 2016 reference case. Higher corn productivity leads to a smaller footprint, less intensive cultivation, and reduced quantities of fertilizer, pesticide, water, and other inputs—even though each acre might require higher inputs. The high input cost scenario lessens environmental impacts as well, but the cause is more indirect. Farmer practices are affected by higher fertilizer and diesel costs, so they apply less fertilizer and employ conservation tillage at higher rates. The carbon price scenario changed the environmental impact little, simply because the price of carbon was too low to cause substantial changes in farmer practices. At $25 per ton of carbon, the economic benefit of reducing the carbon footprint of feedstock production was less than the economic cost for much of the U.S.

There is still much to be learned about how sustainability applies to biofuel crops. More is known about the processes that take place on the farm or in the forest than about impacts distant from the source. A full lifecycle analysis would predict not only what measurable impacts occur offsite, but also how other systems, such as unmanaged ecosystems, react to the changes. Even lifecycle analyses may not be comprehensive enough. For example, a concern about biofuels is the potential for undesirable land-use changes due to pressure on land availability. This consequence is only indirectly associated with biofuels.

Currently, the ecological processes that occur at the farm field or forest stand level are better understood than their aggregate effects across the landscape. The potential for intentional carbon storage in soil is uncertain, as are the societal impacts of bioenergy production. But more research effort is underway. The Federal Government, through the Biomass R&D Board and other venues, is developing research agendas, identifying criteria and indicators, and investing resources to better understand sustainability so that the biofuels sector can grow responsibly.

Chapter 9

Prioritizing Research and Its Dividends

Increasing the production of biofuels to meet multiple policy objectives requires technological advances at every stage of the production chain. The analysis in this report assumes the policy-driven biofuel targets of 15 billion gallons of corn-based ethanol and 1 billion gallons of biodiesel in 2016 and an additional 20 billion gallons of advanced biofuels by 2022. Achieving these production levels has both market and environmental impacts. For example, a production surge in conventional biofuels results in a net expansion in land planted to conventional crops, with corn acres increasing at the expense of other major crops. Consequently, crop prices increase, which benefits crop producers and increases expenses for consumers. Greenhouse gas emissions increase and other sustainability indicators (e.g., increased fertilizer application) suffer.

The undesirable outcomes of achieving targeted biofuel levels could be mitigated through technological advances in the provision of feedstocks. This report examines the market and environmental impacts of meeting reference biofuel targets with increased corn productivity (chapters 4 and 7), and with both increased corn and cellulosic productivity (chapter 5). Increased productivity—greater yield per unit of inputs applied—can improve several indicators.

Table 9.1 summarizes research outcomes from this report. Biofuel production is fixed at the "reference" level, so all environment impacts stemming from research and development (R&D) are due solely to market responses and shifts in use among resources. For some indicators, the expected general direction of the R&D impact—an increase denoted by ↑ or decrease denoted by ↓—is suggested by basic economic principles. Due to complex interactions, other impacts can be assessed only through specific assumptions about parameter values or through empirical analysis. The "↕" arrow denotes that the direction of the expected change in the indicator depends upon the assumptions used in the model, and thus suggests that more research is needed to determine the general direction of the change.

Each numbered row in table 9.1 refers to an outcome of an R&D focus (e.g., increased productivity of energy crops), holding all other research outcomes constant. The first column identifies the research focus and the second column provides a brief explanation of the general economic impact(s). The 3rd and 4th columns denote the general change in price per unit and in total quantity (output) of the targeted feedstock (e.g., energy crops, forest residues, or feedstocks generally in the case of conversion efficiency). Columns 5 and 6 address the change in national acreage of the commodity targeted for R&D and in total acreage of all feedstock commodities. The last four columns are changes in four key environmental indicators: greenhouse gas (GHG) emissions, nitrogen use, pesticide use, and soil erosion. Uncertainty in the direction of change is more frequent for these indicators because many interactions come into play.

The outcomes in table 9.1 would change if biofuel production levels were determined by the market (and not fixed by policy targets) . For example, if the level of biofuel production was market determined, increasing corn productivity (holding everything else constant) would likely increase the amount of land planted to corn destined for biofuels, the opposite outcome from that indicated in the table. This could occur if biofuel producers increase output in response to productivity-induced reductions in corn prices.

Increasing Efficiency in the Provision of First-Generation Feedstocks

Given current technologies, corn is the dominant ethanol feedstock in the U.S., and will remain so for some time. Research to increase corn productivity (table 9.1, row 1) benefits all consumers (lower price) and producers of corn. Higher corn productivity (that is, yield for a given amount of inputs) reduces pressure on land use, enabling lower GHG emissions and improvements in other sustainability indicators. On the other hand, simply increasing corn yields by increasing the application of inputs could have the opposite effect.

The analysis in this report assumes that yield increases are attained through R&D-driven increases in productivity. In the high corn productivity scenario, production of corn ethanol increases 3 billion gallons/year relative to the baseline, but without commensurate increases in GHG emissions. For example, $C0_2$ emissions are just 0.25 MMT higher than in the baseline, and 7.7 MMT lower than in the reference case, where the ethanol increase is achieved under baseline productivity growth. Thus, research aimed at achieving increases in corn productivity—and crop productivity generally—that are not tied to the additional use of fossil fuel inputs may simultaneously enhance food/energy security and lower GHG emissions. Of course, opportunity costs are associated with resources devoted to any area of research. For example, additional research funding for first-generation biofuels could compete with funding for second-generation biofuels (with potentially lower GHG emissions).

Toward A Portfolio of Feedstocks

Rows 2-4 in table 9.1 cover new technologies to support advanced biofuels: energy crops, crop residues, and nonagricultural feedstocks. In general, one might expect that a broader portfolio of feedstocks would relieve pressure on land use and result in improvements in GHG and sustainability indicators. However, many complex interactions are at play, and empirical studies are needed to sort out the impacts. For instance, the effects of more productive energy crops (row 2) on total land use depend on the required agronomic conditions for the crops. Energy crops under development (switchgrass, short-rotation woody crops) will compete more with pasture than cropland. While not analyzed explicitly in this report, a larger portfolio of feedstocks will mitigate the effects of weather or crop diseases/pests through diversification of sources and extending feedstocks geographically.

More research is needed on the GHG and sustainability impacts of increasing the share of residues recovered as inputs into biofuel production. For example, how much residue can be recovered before soil erosion increases? Row 3 presumes that research leads to an increased share of residues that are

Table 9.1

Research outcomes and effects on commodities that serve as feedstocks for biofuels, with each row isolating one change

(outcomes are relative to the “reference scenarios” for first-generation and advanced biofuel production targets)[1]

		Market for targeted feedstock		Land use		GHG-emissions[2]	Other sustainability indicators (national level)		
Research & development investment focus	Explanation of general economic impact	Price	Quantity	Targeted feedstock	All feedstock		Nitrogen use	Pesticide use	Soil Erosion
1) Increase productivity of a conventional crop (e.g., corn)[3,4,5]	Higher yield per acre due to more efficient use of inputs (e.g., fertilizer) decreases total acres needed to meet biofuel demand. More supply (but from less acres) results in lower overall market price. Less acres in all feedstocks are needed to achieve biofuel production targets. Decreased environmental impacts as less land, fertilizer, and pesticide inputs are needed to achieve biofuel targets.	↓	↑	↓	↓	↓	↓	↓	↓
2) Increase productivity of an energy crop (e.g., switchgrass, woody crops, conventional-sourced wood)[5]	As in row (1), higher yield per acre decreases total acres needed to meet biofuel demand. Energy crops under development compete more with pasture than cropland, making impacts on the environmental variables sensitive to modeling assumptions.	↓	↑	↓	↓	↕	↕	↕	↕
3) Increase share of residues sustainably recovered	Ability to use the residue coproduct in the production of a marketable starch crop results in more planted acres in the targeted crop than in the reference scenario.	↓	↑	↑	↓	↓[6]	↓	↓	↓
4) Develop nonagricultural sources of feedstocks	New sources, e.g., byproducts such as forestry residues and municipal solid waste (MSW). Their value increases due to the new use being found for them.	↑[7]	↑	N.A.[8]	↓	↓	↓	↓	↕[9]
5) Increase coproduct values at refinery	Refiner will pay higher price for feedstock given that the total return from biofuels and the coproduct is higher, leading to greater production of the feedstock. Acreage in other feedstocks may decrease by a proportionally smaller amount than the increase in the targeted feedstock.	↑	↑	↑	↕	↕	↕	↕	↕
6) Increase logistics (e.g., transportation and storage) efficiency	The effect of decreasing the costs of handling feedstocks from the farm gate to the biofuel processor is similar to increasing supply of the targeted feedstock.	↓[10]	↑	↑	↓	↕	↕	↕	↕
7) Increase conversion efficiency	Less feedstock required to meet biofuel mandate.	↓	↓	↓	↓	↓	↓	↓	↓

Note: The “↓” arrows means a decrease in the expected level of the indicator and “↑” means an increase; “↕” denotes that direction of the expected change in the indicator depends upon the assumptions used in the model, and that research is needed to determine even the general direction of change.

[1]The “reference scenario” represents the biofuel targets of 16 billion gallons of conventional biofuels in 2016 and, for 2022, the same conventional targets plus 20 billion gallons of advanced biofuels (see chapter 4).

[2]Change in GHG emissions that occur before the farmgate as well as emissions related to domestic land-use change.

[3]Increased productivity means greater yield per unit of inputs applied.

[4]The arrows in this row summarize the empirical results for the higher corn productivity scenario in chapters 5 and 7.

[5]The analysis in the row assumes a constant level of input use.

[6]Assuming that the residues are sustainably recovered.

[7]Many nonagricultural resources, such as logging residues, have low acquisition costs (i.e., stumpage prices). These prices are likely to increase as uses and markets develop. The price increase could be in the form of a decrease in the fees charged for removing MSW from a site.

[8]This row assumes that the feedstocks in question are byproducts incidental to the production of a primary marketed good, and that no additional primary product is being developed.

[9]Sustainability criteria are likely to improve if these non-ag sources displace biomass grown on cropland. Increased use of some non-ag resources could worsen sustainability criteria (e.g., increased sedimentation from the removal of logging residues).

[10]Delivered cost of the feedstock for the biofuel processor decreases, even if the price at the farm gate increases.

sustainably recovered, hence producing benefits in all the sustainability indicators in the table.

The movement of indicators related to the development of nonagricultural feedstocks (row 4) like solid waste or forest resideues can be predicted from general economic principles. (The feedstocks are assumed to be byproducts of a primary marketed good, with no additional production taking place.) Sustainability indicators are likely to improve if these nonagricultural sources displace biomass grown on cropland. However, increased use of some nonagricultural resources could worsen sustainability criteria (e.g., increased sedimentation from the removal of logging residues).

Biofuels processing can yield marketable coproducts like dried distillers' grains. Research that leads to an increase in coproduct values (row 5) will enable the refiner to pay more for feedstocks if the total return from biofuels and coproducts is raised by productivity gains in the latter. This can lead to greater production of the feedstock, though the net impact on the environment depends on how land is allocated among other feedstocks.

Feedstocks for biofuels are often bulky, and many nascent feedstocks lack an established distribution chain. Therefore, research to ease production logistics—reducing the cost of feedstock transportation and storage (row 6)—can have the same effect as increasing supply of the targeted feedstock. Lower delivered cost of any feedstock to the biofuel processor will tend to increase acreage devoted to it, and thus decrease land in other feedstocks. Environmental impacts will depend on which feedstock benefits from the logistics research.

This analysis stops at the farmgate or forest roadside in order to focus on feedstocks. However, investments further down the production chain cycle back to feedstock markets. For example, more efficient conversion of feedstocks to biofuel (row 7) reduces the feedstock requirements to produce a given quantity of biofuels. In such a case, all the indicators in table 9.1 are likely to decrease. Similar to the case with higher feedstock productivity, the findings are sensitive to the assumption of constant biofuel quantities.

Implications For Research Investments

The research implications address only the needs identified through the report's economic analysis and do not account for the scientific uncertainties or costs of the research. This report is intended to help the Federal Government prioritize research setting in conjunction with scientific experts. Decisions about research funding are occurring in an era of scarce resources and potential policy tradeoffs. For example, expanding research on corn yields could limit research to develop feedstocks for second-generation biofuels.

Additional research would help improve our understanding of biofuel markets in a number of areas: fundamental research, appropriate experiments, targeted monitoring, more comprehensive data, production and environmental modeling that is better integrated, improved analysis tools, and enhanced economic and lifecycle analysis. Experiments are needed to understand and quantify underlying ecological, physical, and chemical processes in order to provide sustainable management systems. Targeted monitoring and analysis can help to more efficiently identify trends in environmental, economic, and social variables. More targeted research is critical to developing comprehensive datasets, reliable models, and robust predictions, estimates, and tools.

The Federal Government, universities, and the private sector have already invested billions of dollars in research to improve feedstock productivity and improve the conversion of feedstocks. Reflecting the diverse geography of potential feedstocks, research projects span the United States and encompass a large variety of feedstock sources. The Department of Energy supports multiple projects to investigate alternative conversion technologies with a wide variety of feedstocks, at various scales to spur financial interest. The Department of Agriculture supports an array of activities related to biofuel feedstocks, including the development of new bioenergy crop varieties and hybrids in conjunction with systems to increase energy yields per acre, maximize net energy efficiency, and minimize greenhouse gas emissions. The National Science Foundation has an extensive plant genomics program, with implications for feedstock improvement. Chapter 2 provides additional information on current research priorities.

Environmental Effects

Biofuels offer the opportunity to replace fossil fuels, which increase GHG emissions, with fuels that reduce GHG emissions or are at least neutral in GHG emissions. In reality, the GHG footprints of biofuels and their associated production processes are complex. Models might be enhanced to better address GHG emissions by:

- More accurately determining nitrogen emissions from cropland soils;
- Exploring the extent to which GHG emissions can be reduced if biorefineries and/or power plants are powered by biomass;
- Developing probability distributions of GHG emissions.

The environmental impacts of biofuel production are wide ranging and likely to change as the scale of the industry increases. Information about the sustainability of much higher domestic production of biofuels can help guide Federal and local policies concerning energy, the environment, and agriculture. Further research in assessing environmental impacts of biofuels production might:

- Quantify appropriate levels of sustainable residue removal at a regional and county level.
- Assess energy crop productivity in commercial-scale plantings and at many more locations in order to validate modeled yield assumptions.
- Model changes in nutrient and chemical runoff beyond the farm and their impacts on the ecosystem.

Forestry

Contributions from forestland are assumed to provide sufficient feedstock to produce 4 billion gallons per year of second-generation and other renewable fuels. However, much research is still needed in modeling both the economics and sustainability criteria of the forestry sector. Capturing the potential of forest biomass resources will not happen without addressing some major challenges such as reliability and sustainability of feedstock supply, land-use change and competition, and logistics of growing, recovering, and transporting feedstocks.

Critical areas of research include developing production systems for forest feedstocks and residues (variously from thinning treatments, production forests, and short-rotation woody cropping systems) so that bioenergy can be integrated into everyday management. This work includes silviculture, genetics, genomics, soil, and forest operations research. Further research in assessing sustainability encompasses designed experiments, analysis, and modeling, and includes:

- Developing and testing forestry best-management practices integrating expanded biomass removal;
- Developing new varieties of woody crops that are fast-growing, disease- and pest-resistant, and water- and nutrient-use efficient;
- Improving harvest and transportation systems for forest biomass;
- Refining cost and equipment information for field processing to improve efficiency and mitigate impacts;
- Quantifying sustainability criteria for forest bioenergy feedstocks.

Economic Modeling and Data

The modeling framework in this report analyzes both economic and environmental impacts of meeting the reference scenario for conventional biofuels (chapter 5). For example, it shows how the markets for field crops other than corn respond to meeting increased demand for conventional biofuels, and measures changes in some key environmental indicators. The modeling also provides a first cut at assessing the potential cellulosic feedstock contribution from croplands and forestlands (chapter 6). However, while the empirical models used have accounted for a wide range of interactions between key variables, they are still limited in scope. For example, research is needed to:

- Model relationships across sectors, in particular the agricultural and energy sectors. To more fully account for how biofuel policies affect social welfare, impacts of policy changes need to be assessed in both sectors.
- Model links between countries to capture trade-related impacts of meeting biofuel demand. The current models assume no international responses to domestic policy changes. Other models have this ability but lack the ability to anlyze regional and environmental issues. A protocol to integrate models is needed.

- Integrate models to allow for competition between land uses. The current assessment of feedstock potential from cropland, forestland, and exports was done independently for each of these categories.
- Incorporate uncertainty about factors that influence planting decisions and the markets for agricultural commodities. For example, weather and pest conditions are assumed to be average for the growing season, but in fact their variability affects planting decisions.
- Incorporate into the models a full set of second-generation and other renewable fuels that can be evaluated under differing biofuel feedstock scenarios.
- Evaluate the impacts of meeting biofuel production targets over time. The current models are static, and cannot address how changes in one period may affect the next.

As demonstrated in this report, a variety of economic tools are available to analyze problems that vary in scale and scope depending on the main analytical focus. However, significant gaps exist in our knowledge base, especially when it comes to the analysis of advanced feedstocks, of the economic and environmental interactions between conventional and advanced feedstocks, and of the relationship between agricultural and energy markets. The end goal is not necessarily to achieve one "super-model," but ultimately, a set of tools that provide a full economic and environmental analysis of alternative paths to meeting future biofuel demand.

References

Adegbidi, H.G., T.A. Volk, E.H. White, L.P. Abrahamson, R.D. Briggs, and D.H. Bickelhaupt. 2001. "Biomass and nutrient removal by willow clones in experimental bioenergy plantations in New York State," *Biomass and Bioenergy* 20 (6):399-411.

Aden, A., M. Ruth, K. Ibsen, J. Jerchura, K. Neeves, J. Sheehan, B. Wallace, L. Montague, A. Slayton, and J. Lukas. 2002. *Lignocellulosic Biomass To Ethanol Process Design and Economics Utilizing Co-Current Dilute Acid Prehydrolysis and Enzymatic Hydrolysis for Corn Stover*. Rep NRE L/TP-510-32438. National Renewable Energy Laboratory, Golden, CO.

Adler, P.R., S.J. Del Grosso, and W.J. Parton. 2007. "Life-cycle assessment of net greenhouse-gas flux for bioenergy cropping systems," *Ecological Applications* 17:675-691.

Aines, Glen, Terry Klopfenstein, and Rick Stock. 1986. "Distillers Grains" Nebraska Cooperative Extension MP51. University of Nebraska, Lincoln, NE. http://ianrpubs.unl.edu/fieldcrops/mp51.htm

Ammann, Harriet, Robert Blaisdell, Michael Lipsett, Susan Lyon Stone, and Shannon Therriault. 2001. "Wildfire Smoke: A Guide for Public Health Officials," California Air Resources Board. http://www.arb.ca.gov/smp/progdev/pubeduc/wfgv8.pdf (accessed 06/02/08).

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

Baker, J.M., T.E. Ochsner, R.T. Venterea, and T.S. Griffis. 2007. "Tillage and soil carbon sequestration – What do we really know?" *Agriculture, Ecosystems and Environment* 118:1-5.

Banowetz, G.M., A. Boatang, J.J. Steiner, S.M. Griffith, V. Sethi, and H. El-Nashaar. 2008. "Assessment of straw biomass feedstock resources in the Pacific Northwest," *Biomass & Bioenergy.*

Berkke, Kirstin. 2005. "Beyond corn: Alternative feedstocks for ethanol production," *Ethanol Today*, April, www.ksgrains.com/ethanol/Altfeedstocks.pdf

Biesecker, Robin L., and Roger D. Right. 2006. *My Fuel Treatment Planner: A User Guide*. Gen. Tech. Rep. PNW-GTR-663. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. Portland, OR.

Biomass Research and Development Board. 2008. *The Economics of Biomass Feedstocks in the United States: A Review of the Literature*. Occasional Paper #1. October. http://www.brdisolutions.com/default.aspx?rdr=http://www.brdisolutions.com/initiative/default.aspx

Blanco-Canqui, H., and R. Lal. 2008. “No-tillage and Soil-Profile Carbon Sequestration: An On-Farm Assessment,” *Soil Science Society of America Journal*. Vol. 72, No. 3 May-June.

Bonnicksen, T.M. 2008. “Greenhouse gas emissions from four California wildfires: opportunities to prevent and reverse environmental and climate impacts.” FCEM Report 2, The Forest Foundation, Auburn, CA. http://www.calforestfoundation.org/pdf/FCEM-2.pdf (accessed 4/22/08).

Bouwman, A.F., L.J.M. Boumans, and N.H. Batjes. 2002. “Modeling global annual N_2O and NO emissions from fertilized fields,” *Global Biogeochemical Cycles* 16, Paper No. 1080.

Brechbill, Sarah C., and Wallace E. Tyner. 2008. “The Economics of Biomass Collection, Transportation, and Supply to Indiana Cellulosic and Electric Utility Facilities.” Working Paper #08-03, Dept. of Agricultural Economics, Purdue University. April.

Bremner, J.M. 1997. “Sources of nitrous oxide in soils.” *Nutrient Cycling in Agroecosystems* 49:7-16.

Brenner, J., K. Paustian, M. Easter, K. Killian, A. Swan, S. Williams, and S. Ogle. 2004. “Final Report to US Department of Energy-Energy Information Agency 1605(b) Agriculture Greenhouse Gas Emissions and Sequestration-National Land Resource Region Carbon Study.” U.S. Department of Agriculture, Natural Resources Conservation Service.

Cardwell, V.B. 1982. “Fifty Years of Minnesota Corn Production: Sources of Yield Increase,” *Agronomy Journal* 74: 984-990.

Carriquiry, M. 2007. “U.S. Biodiesel Production: Recent Developments and Prospects,” *Iowa Ag Review*, Vol. 13. No. 2, Spring. http://www.card.iastate.edu/iowa_ag_review/spring_07/article4.aspx

Carriquiry, M., and B. Babcock. 2008. “A Billion Gallons of Biodiesel: Who Benefits?” *Iowa Ag Review*, Vol. 14. No. 1, Winter. http://www.card.iastate.edu/iowa_ag_review/winter_08/article3.aspx

Christiansen, Ryan. 2008. “U.S. sugarcane-to-ethanol projects underway,” *Ethanol Producer Magazine*, Oct. http://ethanolproducer.com/article.jsp?article_id=4778&q=sugarcane%20to%20ethanol%20underway&category_id=27.

Council for Agricultural Science and Technology (CAST). 2008. “Biofuel Feedstocks: The Risk of Future Invasions,” QTA2007-1, Council for Agricultural Science and Technology, Ames, IA, Nov. http://www.castscience.org/websiteUploads/publicationPDFs/Biofuels%20Commentary%20Web%20version%20with%20color%20%207927146.pdf

Council for Agricultural Science and Technology (CAST). 2004. *Climate Change And Greenhouse Gas Mitigation: Challenges And Opportunities For Agriculture*. Ames, IA.

Coyle, William. 2007. "The Future of Biofuels: A Global Perspective," *Amber Waves*, U.S. Department of Agriculture, Economic Research Service. Nov. http://www.ers.usda.gov/AmberWaves/November07/Features/Biofuels.htm

Crutzen, P.J., A.R. Mosier, K.A. Smith, and W. Winiwarter. 2007. "N_2O release from agro-biofuel production negates global warming reduction by replacing fossil fuels," *Atmospheric Chemistry and Physics Discussions*. Vol. 7. pp. 11191-11205. http://www.atmos-chem-phys-discuss.net/7/11191/2007/acpd-7-11191-2007.pdf.

Davidson, E.A., and I.L. Ackerman. 1993. "Changes in soil carbon inventories following cultivation of previously untilled soils," *Biogeochemistry* 20:161-193.

De la Torre Ugarte, D., D.E. Ray, and K.H. Tiller. 1998. "Using POLYSYS Modeling Framework to Evaluate Environmental Impacts in Agriculture," *Evaluating Natural Resource Use in Agriculture*. T. Robertson, B.C. English, and R.R. Alexander (eds.). Iowa State Press, Ames, IA.

De la Torre Ugarte, Daniel G., and Darrell E. Ray. 2000. "Biomass and Bioenergy Applications of the POLYSYS Modeling Framework," *Biomass and Bioenergy* 4(3):1-18, May.

Dhuyvetter, K., T. Kastens, and T Schroeder. 2005. "The U.S. Ethanol Industry: Where will it be located in the future?" Agricultural Issues Center, University of California, Davis. Nov. www.aic.ucdavis.edu.

DiPardo, J. 2000. "Outlook for Biomass Ethanol Production and Demand." U.S. Energy Information Administration. www.eia.doe.gov/oiaf/analysispaper/pdf/biomass.pdf.

Dobbins, C.L., P. Preckel, A. Mdrafi, J. Lowenburg-DeBoer, and D. Stucky. 1990. *Evaluation of Potential Herbaceous Biomass Crops on Marginal Crop Lands: 2) Economic Potential. Final Report*. ORNL/Sub/85-27412/5&P2. Oak Ridge National Laboratory, Oakridge, TN.

Duffy, M. 2008. "Estimated Costs for Production, Storage and Transportation of Switchgrass." NEP: New Economics Papers Agricultural Economics. April.

Duvick, D.N., and K.G. Cassman. 1999. "Post-Green Revolution Trends in Yield Potential of Temperate Maize in the North-Central United States," *Crop Science* 39: 1622-1630.

Eaton, J. 2007. *Opportunities for Poplar Bioenergy Farms in North America*. IEA Task 30 Task Report. http://www.shortrotationcrops.org/PDFs/Eaton_Jake.pdf

Eidman, V. 2007. "Economic Parameters for Corn Ethanol and Biodiesel Production," *Journal of Agricultural and Applied Economics*, Vol. 39, No. 2 (Aug.): 345-356.

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

Eve, M.D., M. Sperow, K. Howerton, K. Paustian, and R.F. Follet. 2000. “Predicted impact of management changes on soil carbon storage for each cropland region of the conterminous United States.” *Journal of Soil and Water Conservation*. Vol. 57, No. 4.

Farrell, Alexander E., Richard J. Plevin, Brian T. Turner, Andrew D. Jones, Michael O’Hare, and Daniel M. Kammen. 2006. “Ethanol Can Contribute to Energy and Environmental Goals,” *Science* 311:506-508.

Fernandez-Cornejo, Jorge. 2004. *The Seed Industry in U.S. Agriculture: An Exploration of Data and Information on Crop Seed Markets, Regulation, Industry Structure, and Research and Development*. AIB-786. U.S. Department of Agriculture, Economic Research Service, Feb.

Fight, Roger D., Bruce R. Hartsough, and Peter Noordijk. 2006. *Users guide for FRCS: fuel reduction cost simulator software*. Gen. Tech. Rep. PNW-GTR- 668. U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station, Portland, OR. http://www.fs.fed.us/pnw/pubs/pnw_gtr668.pdf see also http://www.fs.fed.us/pnw/data/frcs/frcs_home.htm

Foreman, L., Mir Ali, Janet Livezey, and Robert Dismukes. 2007. “Estimation of the Preplanting and Planting Costs by Crop.” Draft Final Report to the Risk Management Agency. U.S. Department of Agriculture, Economic Research Service. May.

Forest Resources Association (FRA). 2005. “Annual Pulpwood Statistics summary report, 2001-2005,” Rockville, MD.

Fuglie, Keith O., and Paul W. Heisey. 2007. *Economic Returns to Public Agricultural Research*, EB-10, U.S. Department of Agriculture, Economic Research Service. Sept. www.ers.usda.gov/publications/eb10/eb10.pdf

Gallagher, P., M. Dikeman, J. Fritz, E. Wailes, W. Gauthier, and H. Shapouri. 2003. *Biomass from Crop Residues: Cost and Supply Estimates,* AER-819. U.S. Department of Agriculture, Office of Energy Policy and New Uses. Feb.

Gilley, J.E., J.W. Doran, D.L. Karlen, and T.C. Kaspar. 1997. “Runoff, erosion, and soil quality characteristics of a former Conservation Reserve Program site.” *Journal of Soil and Water Conservation* 52:189-193.

Gray, Allan. 2006. “Is Biodiesel as Attractive an Economic Alternative as Ethanol?” Purdue Extension Paper ID-341, Department of Agricultural Economics, Purdue University, Dec. http://www.ces.purdue.edu/extmedia/ID/ID-341.pdf

Hammerschlag, R. 2006. "Ethanol's Energy Return on Investment: A Survey of the Literature 1990-Present," *Environmental Science and Technology*. Vol. 40, No. 6.

Hart, Chad. 2006. "Feeding The Ethanol Boom: Where Will the Corn Come From?" *Iowa Ag Review*. Vol. 12, No. 4, Fall. Center for Agricultural and Rural Development, Iowa State University.

Hill, Jason, Erik Nelson, David Tilman, Stephen Polasky, and Douglas Tiffany. 2006, *Environmental, Economic, And Energetic Costs And Benefits of Biodiesel and Ethanol Biofuels*, Proceedings of the National Academy of Sciences. July 12.

Intergovernmental Panel on Climate Change (IPCC)/UNEP/WMO. 2006. "2006 IPCC Guidelines for National Greenhouse Gas Inventories." S. Eggleston, L. Buendia, K. Miwa, T. Ngara, and K. Tanabe (eds.). Hayama, Japan.

Intergovernmental Panel on Climate Change (IPCC). 1997. *Revised 1996 IPCC Guidelines for National Greenhouse Gas Inventories Reference Manual, Volume 3*. Houghton, J.T., L.G. Meria Filho, B. Lim, K. Treanton, I. Mamaty, Y. Bonduki, D.J. Griggs, and G.A. Callender (eds.).

Iowa State University, Department of Agronomy. 2007. "Switchgrass." March. http://www.extension.iastate.edu/Publications/AG200.pdf.

Johansson, Robert, Mark Peters, and Robert House. 2007. *Regional Environment and Agriculture Programming Model (REAP)*. TB-1916. U.S. Department of Agriculture, Economic Research Service, March.

Johnson, Tony G. 2001. *United States Timber Industry - An Assessment of Timber Product Output and Use, 1996*. General Technical Report SRS-45, Sept. U.S. Department of Agriculture, Forest Service, Southern Research Station, Asheville, NC.

Khanna, Madhu. 2008. "Cellulosic Biofuels: Are They Economically Viable and Environmentally Sustainable?" in *Choices* 23(3), http://www.choices-magazine.org/magazine/article.php?article=40.

Larson, E.D. 2006. "A review of life-cycle analysis studies on liquid biofuel systems for the transportation sector," *Energy for Sustainable Development*. Vol. X. No 2.

Lau, Michael, James Richardson, Joe Outlaw, Mark Holtzapple, and Rene Ochoa. 2006. "The Economics of Ethanol from Sweet Sorghum Using the MixAlco Process." AFPC Research Report 06-2. Aug. 11. Texas A&M University. http://www.afpc.tamu.edu/pubs/2/446/RR%2006-2.pdf

Leibtag, E. 2008. "Corn Prices Near Record High, But What About Food Costs?" *Amber Waves*, Feb. http://www.ers.usda.gov/AmberWaves/February08/Features/CornPrices.htm

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*. TB-1909, U.S. Department of Agriculture, Economic Research Service, April.

Long, J.N., and T.W. Daniel. 1990. "Assessment of growing stock in uneven-aged stands," *Western Journal of Applied Forestry* 5(3): 93-96.

Lubowski, R., M. Vesterby, S. Bucholtz, A. Baez, and M. Roberts. 2006. *Major Uses of Land in the United States, 2002*. EIB-14. U.S. Department of Agriculture, Economic Research Service.

McKeever, D. 2004. "Inventories of woody residues and solid wood waste in the United States 2002." Ninth International Conference, Inorganic-Bonded Composite Materials. Vancouver, British Columbia. Oct. 10-13.

McLaughlin, Samuel B., and Lynn Adams Kszos. 2005. "Development of Switchgrass (*panicum virgatum*) as a Bioenergy Feedstock in the United States," *Biomass and Bioenergy* 28.

McPhail, L., and B. Babcock. 2008. "Ethanol, Mandates, and Drought: Insights from a Stochastic Equilibrium Model of the U.S. Corn Market," Working Paper 08-WP 464, Center for Agricultural and Rural Development, Iowa State University, March. http://www.card.iastate.edu/publications/DBS/PDFFiles/08wp464.pdf

Mosier, A.R., J.M. Duxbury, J.R. Freney, O. Heinemeyer, and K. Minami. 1998. "Assessing and mitigating N_2O emissions from agricultural soils," *Climatic Change* 40:7-38.

National Academies. 2007. *Water Implications of Biofuels Production in the United States.* http://dels.nas.edu/dels/rpt_briefs/biofuels_brief_final.pdf

National Corn Growers Association. 2006. "How Much Ethanol Can Come from Corn?" www.ncga.com/ethanol/pdfs/2006/HowMuchEthanolCan%20ComeFromCorn.v.2.pdf

National Sorghum Producers (NSP). www.sorghumgrowers.com, Accessed April 2008.

Ogle, S.M., F.J. Breidt, and K. Paustian. 2005. "Agricultural Management Impacts on Soil Organic Carbon Storage under Moist and Dry Climatic Conditions of Temperate and Tropical Regions," *Biogeochemistry* 72:87-121.

Parkin, T.B., and T.C. Kaspar. 2006. "Nitrous oxide emissions for corn-soybean systems in the Midwest," *Journal of Environmental Quality* 35:1496-1506.

Perlack, R.D., and A. F. Turhollow. 2008. *Analysis of Grower Payments for Agricultural Crop Residues*. Environmental Science Division, Oak Ridge National Laboratory, Oak Ridge, TN.

Perlack, Robert D., Lynn L. Wright, Anthony F. Turhollow, Robin L. Graham, Bryce J. Stokes, and Donald C. Erbach. 2005. *Biomass As Feedstock For A Bioenergy And Bioproducts Industry: The Technical Feasibility of a Billion-Ton Annual Supply*. DOE/GO-102005-2135 and ORNL/TM-2005/66. U.S. Department of Energy, Oak Ridge National Laboratory, Oak Ridge, TN.

Perrin, R.K., K.P. Vogel, M.R. Schmer, and R.B. Mitchell. 2008. "Farm-scale production cost of switchgrass for biomass," *Bionergy Research* 1:91-97. http://www.springerlink.com/content/f85977006m871205/

POLYSYS (2006). Policy Analysis System Documentation. http://apacweb.ag.utk.edu/polysys.html

Reineke, L.H. 1933. "Perfecting a stand density index for even-aged forests," *Journal of Agricultural Research* 46: 627-638.

Renewable Fuels Association (RFA). www.ethanolrfa.org. Accessed April 2008.

Rotman, D. 2008. "The Price of Biofuels," *Technology Review*, Jan./Feb.

Searchinger, T., R. Heimlich, R.A. Houghton, F. Dong, A. Elobeid, J. Fabiosa, S. Tokgoz, D. Hayes, and T-H. Yu. 2008. "Use of U.S. Croplands for Biofuels Increases Greenhouse Gases Through Emissions from Land-Use Change," *Sciencexpress*. Published online 7 Feb.

Schmer, M.R., K.P. Vogel, R.B. Mitchell, and R.K. Perrin. 2008. "Net energy of cellulosic ethanol from switchgrass." Proceedings of the National Academy of Sciences,Vol. 105, No. 2, pp. 464-469.

Schneider, U.A., and P. Kumar. 2008. "Greenhouse Gas Mitigation through Agriculture," *Choices* 1st Quarter, 23(1): 19-23.

Shapouri, H. 2006. "The Economic Feasibility of Ethanol Production from Sugar in the United States." U.S. Department of Agriculture, July.

Shapouri, H., J.A. Duffield, and M. Wang. 2002. *The Energy Balance of Corn Ethanol: An Update*. AER-814, U.S. Department of Agriculture, Office of the Chief Economist, July.

Shepperd, W.D. 2007. "SDI-Flex: a new technique of allocating growing stock for developing treatment prescriptions in uneven-aged forest stands," *Restoring Fire-Adapted Ecosystems: Proceedings of the 2005 National Silviculture Workshop*, Robert F. Powers (ed.). Gen. Tech. Rep. PSW-GTR-203, U.S. Department of Agriculture, Forest Service, Pacific Southwest Research Station, Albany, CA. http://www.fs.fed.us/psw/publications/documents/psw_gtr203/psw_gtr203_001afm_toc.pdf

Six, J., K. Paustian, E.T. Elliott, and C. Combrink. 2000. "Soil structure and organic matter: I. Distribution of aggregate-size classes and aggregate-associated carbon," *Soil Science Society of America Journal* 64: 681-689.

Skog, K.E., and G.A. Nicholson. 1998. "Carbon cycling through wood products: the role of wood and paper products in carbon sequestration," *Forest Products Journal* 48:75-83.

Sleper, D.A., and J.M. Poehlman. 2006. *Breeding Field Crops*. Ames, IA: Blackwell. Fifth edition.

Smith, W. Brad, Patrick D. Miles, John S. Vissage, and Scott A. Pugh. 2004. "Forest Resources of the United States, 2002." General Technical Report NC-241, U.S. Department of Agriculture, Forest Service, North Central Research Station, St. Paul, MN. http://www.treesearch.fs.fed.us/pubs/11987

Sohngen, B., and R. Sedjo. 2006. "Carbon Sequestration in Global Forests Under Different Carbon Price Regimes," *The Energy Journal*, Vol. 27, pp. 109-126.

Tannura, M., S. Irwin, and D. Good. 2008. "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, Feb. 20.

Tharakan P.J., T.A. Volk, C.A. Lindsey, L.P. Abrahamson, and E.H. White. 2005. "Evaluating the impact of three incentive programs on cofiring willow biomass with coal in New York State," *Energy Policy* 33(3):337–47.

Trostle, Ronald. 2008. *Global Agricultural Supply and Demand: Factors Contributing to the Recent Increase in Food Commodity Prices.* U.S. Department of Agriculture, Economic Research Service, WRS-0801, May (revised July 2008).

Turhollow, A.F., J.W. Johnson, and J.H. Cushman. 1988. "Linking Energy Crop Production to Conversion: The case of herbaceous lignocellulosic crops to ethanol," *RERIC International Energy Journal* 10(2):41-49.

United Nations, Food and Agriculture Organization (FAO). 2008. *Crop Prospects and Food Situation*, Report No. 2, April. http://www.fao.org/giews/english/cpfs/index.htm

U.S. Department of Agriculture, Economic Research Service. 2008a. "Feed Grains Database," April 15, update. http://www.ers.usda.gov/Data/feedgrains/ (accessed 06/01/08).

U.S. Department of Agriculture, Economic Research Service 2008b. "Sugar and Sweeteners: Policy," Briefing Room, March 3. http://www.ers.usda.gov/Briefing/Sugar/Policy.htm

U.S. Department of Agriculture, Economic Research Service 2008c. "Soybeans Briefing Room," April. http://www.ers.usda.gov/Briefing/SoybeansOilcrops/background.htm

U.S. Department of Agriculture, Economic Research Service. 2008d. *2008 Oil Crops Yearbook*. Accessed June 1, 2008. http://usda.mannlib.cornell.edu/MannUsda/viewDocumentInfo.do?documentID=1290.

U.S. Department of Agriculture, Economic Research Service. 2008e. Sugar and Sweetener Yearbook Tables, U.S. Sugarcane Supply and Use. Accessed June 1, 2008. http://www.ers.usda.gov/Briefing/Sugar/Data.htm

U.S. Department of Agriculture, Economic Research Service. 2008f. Wheat Yearbook Tables, Table 1. Accessed June 1, 2008. http://www.ers.usda.gov/Data/Wheat/YBtable01.asp

U.S. Department of Agriculture, Economic Research Service. 2007. Commodity Costs and Returns: U.S. and Regional Cost and Return Data. Accessed June 1, 2008. http://www.ers.usda.gov/Data/CostsAndReturns/

U.S. Department of Agriculture, Farm Service Agency. 2007. *Conservation Reserve Program: Summary and Enrollment Statistics, Fiscal Year 2007*. http://www.fsa.usda.gov/Internet/FSA_File/annual_consv_2007.pdf

U.S. Department of Agriculture, Forest Service. 2007. *Interim Update of the 2000 Renewable Resource Planning Act Assessment*. FS-874. http://www.fs.fed.us/research/rpa/2005rpa/RPA_Interim_Update_April2007_low_resolution.pdf

U.S. Department of Agriculture, Forest Service. 2005. *A Strategic Assessment of Forest Biomass and Fuel Reduction Treatments in Western States.* Gen. Tech. Rep. RMRS-GTR-149. Rocky Mountain Research Station, Fort Collins, CO.

U.S. Department of Agriculture, Forest Service. 2004. "Timber Products Output Mapmaker Version 1.0," http://ncrs2.fs.fed.us/4801/fiadb/rpa_tpo/wc_rpa_tpo.ASP

U.S. Department of Agriculture, Forest Service. 2003. "A Strategic Assessment of Forest Biomass and Fuel Reduction Treatments in Western States." http://www.fs.fed.us/research/infocenter.htm.

U.S. Department of Agriculture, National Agricultural Statistics Service. 2008. "Data and Statistics: Quick Stats." http://www.nass.usda.gov/Data_and_Statistics/Quick_Stats/index.asp (accessed May 2008).

U.S. Department of Agriculture, Natural Resources Conservation Service. 2008. "Invasive and Noxious Weeds." http://plants.usda.gov/java/introduced?startChar=&queryParam=&sort=sciname&format=Print (accessed 04/24/08).

U.S. Department of Agriculture, Natural Resources Conservation Service. 2006. "Plant Fact Sheet: Switchgrass-*Panicum virgatum L.*" http://plants.usda.gov/factsheet/pdf/fs_pavi2.pdf (accessed 4/15/08).

U.S. Department of Agriculture, Office of the Chief Economist. 2007. *Agricultural Projections to 2016*. OCE-2007-1. Feb.

U.S. Department of Agriculture, Office of the Chief Economist. 2006. *The Economic Feasibility of Ethanol Production From Sugar In The United States*. July. http://www.usda.gov/oce/EthanolSugarFeasibilityReport3.pdf

U.S. Department of Energy, Office of Policy and International Affairs. 2008. *World Biofuels Study*.

U.S. Department of Energy. 2007. Technical Guidelines Voluntary Reporting of Greenhouse Gases (1605(b)) Program. Jan. http://www.pi.energy.gov/enhancingGHGregistry/technicalguidelines.html

U.S. Department of Energy and U.S. Department of Agriculture. 1998. *Life Cycle Inventory of Biodiesel and Petroleum Diesel for Use in an Urban Bus.* Prepared by the National Renewable Energy Laboratory. NREL/SR-508-24089.

U.S. Environmental Protection Agency. 2006a. *Inventory of U.S. Greenhouse Gas Emissions and Sinks: 1990-2004*. EPA 430-R-06-002.

U.S. Environmental Protection Agency. 2006b. *Ecological Benefits Assessment Strategic Plan*. EPA-240-R-06-001. Office of the Administrator. http://www.epa.gov/economics/.

U.S. Environmental Protection Agency. 2005. *Greenhouse Gas Mitigation Potential in U.S. Forestry and Agriculture*. EPA 430-R-05-006.

U.S. Environmental Protection Agency. 2003. "Basic Facts: Municipal Solid Waste." Office of Solid Waste and Emergency Response, Washington, DC. Oct. http://www.epa.gov/epaoswer/non-hw/muncpl/facts.htm.

University of Florida. 2007. "Jatropha tree could be a biodiesel boon for Florida farmers, UN researcher says," Aug. http://news.ufl.edu/2007/08/29/fuel-plant/

van Dam, Jinke, Martin Junginger, André Faaij, Ingmar Jürgensb, Gustavo Best, Uwe Fritsche. 2008. "Overview of recent developments in sustainable biomass certification." Accepted for publication in *Biomass and Bioenergy*. http://www.lowcvp.org.uk/assets/reports/van%20Dam%20et%20al%20%20certification%20paper%2015.11.07%20final.pdf (accessed 3/3108).

Volk, T.A., L.P. Abrahamson, C.A. Nowak, L.B. Smart, P.J. Tharakan, and E.H. White. 2006. "The Development of Short-Rotation Willow in the Northeastern United States for Bioenergy and Bioproducts, Agroforestry and Phytoremediation," *Biomass and Bioenergy* 30:715-727.

Wang, M. 1999. *Effects of Fuel Ethanol Use on Fuel Cycle Energy and Greenhouse Gas Emissions*. Transportation Technology R&D Center, Argonne National Laboratory.

Wang, M. 2005. "Updated Energy and Greenhouse Gas Emission Results of Fuel Ethanol." Presented at the 15th International Symposium on Alcohol Fuels. San Diego, CA. Sept. 26-28.

Wang, M., M. Wu, H. Huo, and J. Liu. 2008. "Life-Cycle Energy Use and Greenhouse Gas Emission Implications of Brazilian Sugarcane Ethanol Simulated with the GREET Model," *International Sugar Journal*.

Wang, M., M. Wu, and H. Ho. 2007. "Life-cycle energy and greenhouse gas emission impacts of different corn ethanol plant types," *Environmental Research Letters*. No. 2.

Westcott, Paul. 2008. "USDA Agricultural Projections to 2017," U.S. Department of Agriculture, Economic Research Service. Feb.

Westcott, P. 2007. "U.S. Ethanol Expansion Driving Changes Throughout the Agricultural Sector," *Amber Waves*, Vol. 5, No. 4, Sept. http://www.ers.usda.gov/AmberWaves/September07/PDF/Ethanol.pdf

West, T.O., and G. Marland. 2002. "A synthesis of carbon sequestration, carbon emissions, and net carbon flux in agriculture: comparing tillage practices in the United States," *Agriculture, Ecosystems and Environment* 91:217-232.

West, T.O., and A. C. McBride. 2005. "The contribution of agricultural lime to carbon dioxide emission in the United States: dissolution, transport, and net emissions," *Agriculture, Ecosystems and Environment* 108:145-154.

Western Forestry Leadership Coalition (WFLC). 2007. *Western Bark Beetle Assessment: A Framework for Cooperative Forest Stewardship*. http://www.wflccenter.org/news_pdf/222_pdf.pdf

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

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