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The Economic Impacts of Bioenergy Crop Production on U.S. Agriculture

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Cover: Soil scientists Harry Pionke (left) and Ron Schnabel examine a switchgrass stand. If switchgrass were to become a major crop, it could add up to $5 billion to farmers' income and contribute to the reduction of the United States' dependence on oil imports.

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By Daniel G. De La Torre Ugarte, Marie E. Walsh, Hosein Shapouri, and Stephen P. Slinsky. U.S. Department of Agriculture, Office of the Chief Economist, Office of Energy Policy and New Uses. Agricultural Economic Report No. 816

Abstract

In response to energy security concerns, alternative energy programs such as biomass energy systems are being developed to provide energy in the 21st century. For the biomass industry to expand, a variety of feedstocks will need to be utilized. Large scale production of bioenergy crops could have significant impacts on the United States agricultural sector in terms of quantities, prices and production location of traditional crops as well as farm income. Though a number of scenarios were examined to study the impact of bioenergy crop production on the agricultural sector, two cropland scenarios are presented in this report. Under the wildlife management scenario, the analysis indicates that, at $30/dry ton (dt) for switchgrass, $31.74/dt for willow and $32.90 for poplar, an estimated 19.4 million acres of cropland (8.2 million from CRP) could be used to produce 96 million dry tons of bioenergy crops annually at a profit greater than the profit created by existing uses for the land. In this scenario, traditional crop prices increase from 3 percent to 9 percent (depending on crop) and net farm income increases by $2.8 billion annually. At $40/dt of switchgrass, $42.32/dt for willow and $43.87/dt for poplar and assuming the production management scenario, an estimated 41.9 million acres (12.9 million from CRP) could be used to produce 188 million dry tons of biomass annually. Under this scenario, traditional crop prices increase by 8 to 14 percent and net farm income increases by $6 billion annually.

Keywords: Alternative crops, bioenergy crops, biomass, Conservation Reserve Program, crop acreage shifts, crop budgeting, economic feasibility, economic impact, hybrid poplars, hybrid willow, POLYSYS, switchgrass

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Executive Summary

In response to energy security concerns, alternative energy programs such as biomass energy systems are being developed to provide energy in the 21st century. For the biomass industry to expand, a variety of feedstocks will need to be utilized. Producing bioenergy crops could significantly increase profits for the agricultural sector. Though this analysis focuses on switchgrass, hybrid poplar and willow, numerous herbaceous and woody crop species could be used as bioenergy crops. This report examines the potential for converting cropped, idle, and pasture acres, as well as Conservation Reserve Program acres, to bioenergy crop production. Though a number of scenarios were examined to study the impact of bioenergy crop production on the agricultural sector, just two cropland scenarios are presented in this report.

On cropped, idle, and pasture acres and assuming a farmgate price of $30/dry ton (dt) for switchgrass ($31.74/dt for willow and $32.90 for poplar) bioenergy crops offer a greater potential profit than existing uses on an estimated 11.2 million acres and produce 58 million dry tons of biomass. At a farmgate price of $40/dt of switchgrass ($42.32/dt for willow and $43.87/dt for poplar) an estimated 28.95 million cropped, idle, and pasture acres could be converted to bioenergy crop production producing 132 million dry tons.

Two bioenergy crop management practices were evaluated on Conservation Reserve Program Acres (CRP)–one to provide for high wildlife diversity, and the other to provide for high biomass production. Farmers forfeited 25 percent of their annual rental payment in exchange for the right to harvest and sell bioenergy crops. Management practices were designed to maintain the erosion and chemical runoff benefits of existing CRP acres included in the analysis. CRP acres deemed too environmentally sensitive or outside the geographic production range used for bioenergy crops in the analysis were excluded, leaving 16.9 million of the enrolled 29.8 million acres. Under the $30/dt switchgrass price ($31.74/dt for willow and $32.90/dt for hybrid poplar) and the wildlife scenario, an estimated 8.2 million acres producing 34 million dry tons of biomass could provide farmers with higher returns than the annual rental rate. Under the $40/dt switchgrass price and assuming the production management scenario, an estimated 12.9 million CRP acres producing 55.3 million dry tons of biomass could be converted to bioenergy production.

Under the $40/dt switchgrass price and the production scenario, nearly 42 million acres of cropped, idle, pasture, and CRP acres could be converted to bioenergy crop production resulting in an annual production level of 188 million dry tons. This number of acres is sufficient to make bioenergy crops the fourth largest crop produced by the United States behind corn, wheat and soybeans. Net farm income is estimated to increase by $2.8 billion annually ($30/dt switchgrass price; wildlife CRP management scenario; all cropped, idle, and pasture acres) to $6.0 billion annually ($40/dt switchgrass price; production CRP management scenario; all cropped, idle, and pasture acres). Conventional crop prices increase from 3 to 9 percent (above USDA 1999 baseline prices) under the $30/dry ton and CRP wildlife scenario and from 9 to 14 percent under the $40/dt and production scenario.

As a potential energy source, the 188 million dry tons of biomass produced under the $40/dt switchgrass price and the production CRP scenario is sufficient to provide 2.92 quadrillion Btus (Quads) of primary energy and produce 16.7 billion gallons of ethanol (current production is about 1.93 billion, or 7.3 percent of the electricity currently produced in the United States, assuming current conversion rates. Under the $30/dt switchgrass price and wildlife CRP scenario, the biomass produced is equivalent to 1.54 Quads of primary energy–sufficient to produce 8.51 billion gallons of ethanol or 3.8 percent of electricity use.

The analysis uses POLYSYS, an agricultural policy simulation model of the U.S. agricultural sector that includes national demand, regional supply, livestock, and aggregate income modules (De La Torre Ugarte and Ray, 2000). POLYSYS is anchored to published baseline projections for the agricultural sector and the model simulates deviations from the baseline. Typically, POLYSYS uses the USDA, Food and Agricultural Policy Research Institute (FAPRI) or Congressional Budget Office (CBO) baseline for U.S. agriculture.

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INTRODUCTION

The oil embargoes of the 1970s raised concerns about energy security. In response, programs to develop alternative energy sources were begun. While energy security still remains a concern, the potential threat of global climate change resulting from the use of fossil fuels has added new immediacy to the development of alternative energy systems. Biomass energy systems are among the alternatives being developed to provide energy into the 21st century. Life cycle assessments indicate that biomass energy systems can be energy efficient, may significantly reduce greenhouse gas emissions relative to fossil energy, and can provide other environmental benefits (DeLucchi, M.A.; Wang, M., Saricks, C., and Santini, D.; Mann, M.K., and Spath, P.L.).

Several biomass energy systems are nearing commercialization. Plans to build commercial cellulose to ethanol facilities are underway, but none are in operation yet. Pilot and demonstration facilities are operational, including a 24 mt/week facility in Canada. Advanced biomass gasification systems for electricity generation are being tested at two sites and co-firing tests (i.e., mixing biomass with coal in coal-fired electrical generation facilities) are being conducted at numerous sites throughout the United States. These early facilities will rely, predominantly, on waste biomass materials, such as logging residues, wood processing mill residues, urban wood wastes, and selected agricultural residues such as sugarcane bagasse and rice straw, as their biomass feedstock. However, these feedstocks are available in limited quantities. For the biomass industry to expand to represent a significant portion of the primary energy consumed in the United States, additional feedstocks will need to be utilized. Recognizing this fact, in 1978 the U.S. Department of Energy (DOE) established the Bioenergy Feedstock Development Program (BFDP) at the Oak Ridge National Laboratory (ORNL).

The BFDP is engaged in the development of new crops and cropping systems that can be used as dedicated bioenergy feedstocks. The program has screened numerous potential crop candidates to identify promising species. Research activities frequently involve collaborative efforts with university and United States Department of Agriculture (USDA) researchers. While numerous herbaceous and woody crop species could be used as bioenergy crops, this analysis focuses on switchgrass, hybrid poplar, and willow. The rationale for this focus includes the facts that these crops receive the greatest research funding and their management practices are similar to several of the other potential bioenergy crops being evaluated. Thus they can serve as a general model for many other potential bioenergy crops.

Switchgrass (*Panicum virgatum*) is a perennial warm-season grass. Its native range includes the United States east of the Rocky Mountains and extends into Mexico and Canada. It is a dominant species of the remnant tall grass prairies in the United States. Switchgrass is genetically diverse and includes both lowland and upland varieties. Currently, switchgrass is grown on limited acreage in the Conservation Reserve Program (CRP) and as a forage crop. Existing research plots have produced yields as high as 15 dry tons per acre per year (dt/ac/yr) and have averaged over 10 dt/ac/yr for 6 years. The potential to increase yields is viewed as high. Switchgrass can be planted, managed, and harvested in a manner similar to traditional hay crops using existing agricultural equipment.

Poplar (*Populus spp.*) is widely distributed throughout the United States and includes both aspen and cottonwood species. Many of the poplar varieties being developed for commercial use are crosses between two or more Populus species that provide hybrid vigor to the offspring. Currently, hybrid poplar is commercially produced on about 200,000 acres for use by the paper and pulp industry. In commercial stands in the Pacific Northwest, hybrid poplar trees have reached harvestable size (8 inch diameter breast height) in 6-7 years. At selected research sites, mean annual incremental yields of as high as 15 dt/ac/yr for a complete production cycle have been obtained using improved varieties. Hybrid poplar can be planted and managed with existing agricultural equipment and can be harvested with existing forestry equipment.

Willow (*Salix spp.*) can be grown throughout the eastern United States. However, suitable varieties and appropriate management practices required for large-scale commercial production in the Plains and Southern United States regions have not yet been developed. The willow plants used for energy production are hybrid shrubs, rather than the trees often associated with the species. Willow production is expected to involve a close-spaced, coppice system developed predominantly in Europe, where willow is being commercially produced for energy. Yields as high as 12 dt/ac/yr have been achieved in research plots

in the United States. Planting and harvesting of willow utilize specially designed machinery that is commercially available in Europe.

The production of switchgrass, hybrid poplar, and willow utilizes agricultural management practices that are similar to those used in traditional crop agriculture and forest plantations. In this study, production is assumed to occur on agricultural croplands. Thus, bioenergy crops must compete economically with traditional crops. As a result, large-scale production of bioenergy crops could have important implications for the agricultural sector in terms of crop prices and farm income. To address these issues, the DOE Office of Transportation Technologies and USDA, in collaboration with the University of Tennessee Agricultural Policy Analysis Center (APAC) and ORNL, have jointly evaluated the potential economic feasibility and ramifications of bioenergy crop production in the United States. For the study, an agricultural sector model (POLYSYS), which was developed and maintained by APAC and used by USDA's Economic Research Service (USDA-ERS), has been modified to include switchgrass, hybrid poplar, and willow. The analysis seeks, at a macroeconomic level, to:

- Estimate the farmgate price needed to make bioenergy crops economically competitive with alternative agricultural uses for cropland,
- Determine the regional distribution of bioenergy crop production,
- Estimate the potential impact of bioenergy crop production on traditional crop prices and quantities,
- Estimate the potential impact of bioenergy crop production on net farm income, and
- Evaluate the economic potential of a modified CRP to serve as a land resource for bioenergy crop production.

The CRP program has been suggested as a means to introduce bioenergy crops to the agricultural sector. The CRP contract length roughly corresponds to the production cycle of bioenergy crops. Production of bioenergy crops on CRP acres could potentially provide a stable supply of feedstocks to user facilities, and income to producers through continued receipt of partial rental payments and the sale of bioenergy crops, while potentially lowering the cost of the CRP program to the Federal Government. The partial support of bioenergy crops could help lower their price and improve their attractiveness to user facilities.

However, the CRP program is an environmental program. If it is to be used as a source of bioenergy crops, the production and harvest of these crops must be conducted in a manner that maintains the environmental benefits of the program. Criteria must be developed that identify acres suitable for bioenergy crop production. Management practices must be developed that minimize the loss of environmental benefits while still providing an economic incentive to producers. This study makes a first attempt at addressing these issues. The study eliminates the most environmentally sensitive CRP acres from consideration for bioenergy crop production, and analyzes the economic impacts of different bioenergy crop management strategies.

The following chapters describe the POLYSYS model, the modifications made to the POLYSYS model to accommodate inclusion of bioenergy crops, and the results of the analysis for two price and bioenergy crop management strategies. Appendices detail traditional crop management data sources and describe the management practices and estimated production costs assumed for bioenergy crops.

METHODOLOGY

The POLYSYS Model

The analysis uses POLYSYS, an agricultural policy simulation model of the U.S. agricultural sector that includes national demand, regional supply, livestock, and aggregate income modules (De La Torre Ugarte and Ray, 2000). POLYSYS is anchored to published baseline projections for the agricultural sector, and the model simulates deviations from the baseline. Typically POLYSYS uses the USDA, Food and Agriculture Policy Research Institute (FAPRI), or Congressional Budget Office (CBO) baseline for U.S. agriculture.

The regional crop supply module consists of independent linear programming models for each of the 305 geographic regions contained in POLYSYS corresponding to the 305 Agricultural Statistical Districts (ASD). Each ASD is characterized by relatively homogeneous production. The core POLYSYS model includes the eight major crops (corn, grain sorghum, oats, barley, wheat, soybeans, cotton, and rice) as well as some minor crops (peanuts, sugarcane, sugar beets, dry beans) and it can be modified to include additional crops or exclude some of the core commodities. As with all the other modules, the crop supply module is anchored to a national baseline which is disaggregated to a regional level based on historical crop production and supply patterns. Once the total acreage available for crop production in each ASD is determined (baseline acres and short- and long-term land retirement programs), the supply module allocates acres to competing crops using a linear programming model that maximizes expected returns using expected crop prices (to be described later). Production from each of the 305 ASDs is determined independently and aggregated to obtain national production. Allocation rules are utilized to limit the acreage that can be switched from production of one crop to another or removed from production in each ASD. These allocation rules prevent corner solutions and simulate the inelastic nature of agricultural supply.

The core POLYSYS model estimates expected returns in one of two ways: a weighted average of prices for the last 3 years or the previous year's price. Expected returns per acre for each crop include revenues, based on the expected prices and the baseline or hypothesized yield, and a range of expenditures, used to compute the variable and cash costs. The core model uses enterprise budgets for each crop in each ASD. Rotational budgets can be incorporated into any given study.

The crop supply module solves for the optimal allocation of cropping activities in each region, given the allocation rules established. The estimated supply quantity interacts with the crop demand module to estimate new prices, demand quantities, and carryover stocks for the current time period.

The livestock module is an econometric model that interacts with the crop supply and demand modules to estimate livestock production, feed use, and market prices. Livestock production levels are a function of lagged livestock and feed own and cross prices, as well as the baseline levels and exogenously determined variables such as livestock exports. The livestock sector is linked to the supply and demand modules principally through the feed grain component. Livestock quantities affect feed grain demand and price, and feed grain prices and supply affect livestock production decisions. Exports and imports of livestock products are exogenous to the model.

The crop demand module estimates national-level demand quantities and prices using elasticities and changes in baseline prices. Crop utilization is estimated for domestic demand (food, feed, and industrial uses), exports, and stock carryovers. Derivative products such as soybean oil and meal are also included. Demand quantities are estimated as a function of own and cross prices and selected non-price variables such as livestock production. The crop prices are estimated using price flexibilities, and stock carryovers are estimated as the residual element.

The income module uses information from the crop supply, crop demand, and livestock modules to estimate cash receipts, production expenses, government outlays, net returns, and net realized farm income.

To evaluate the economic potential of bioenergy crops, several modifications to the core POLYSYS model are made. Acres planted to alfalfa and other hay crops are incorporated into the model as are cropland acres currently enrolled in the CRP program and acres that are idled or in pasture. Geographic areas suitable for the production of bioenergy crops are identified, and production practices and yields for these crops are incorporated into the model. The land allocation rules in POLYSYS are modified to account for the potential production of bioenergy crops. In order to allow producers to include in their decision framework any anticipated price changes that might result from significant shifts of acres to bioenergy crops, a rational expectations price formulation is incorporated.

Cropland Categories

According to the 1997 Census of Agriculture, 431.4 million acres are identified as cropland in the United States. Seventy-three percent of these acres are currently in major crop production (including alfalfa and other hay). The remaining cropland acres are idled (4 percent), in pasture (14 percent), enrolled in the Conservation Reserve Pro-

Total United States Cropland = 431.4 million acres

Cropland in CRP
7%

Idle Cropland
4%

14%
Cropland in Pasture

73%
Cropland in Major Crops

2%

Cropland Not Considered in POLYSYS

Cropland Category
(Data Sources)

- 1999 USDA Baseline
- Land Enrolled in CRP (through October 1998 - Farm Service Agency)
- Idle Cropland (1997 Census of Agriculture)
- Cropland in Pasture (1997 Census of Agriculture)
- Difference between U.S. Census of Agriculture Cropland and Cropland Considered by POLYSYS

Figure 1. Cropland Categories

gram (7 percent), or in other uses such as in the production of fruits, vegetables, or other minor crops (2 percent) (figure 1). According to the 1999 USDA baseline, 254.5 million cropland acres are planted to the eight major crops. The 1999 FAPRI baseline estimates that 27.2 million cropland acres are planted to alfalfa and 33.2 million cropland acres are planted to other hay crops. A total of 29.8 million cropland acres are enrolled in the Conservation Reserve Program (Farm Service Agency, October 1, 1998). The 1997 Census of Agriculture estimates that 19.0 million cropland acres are idled with 60.3 million cropland acres planted to pasture. The version of POLYSYS used to evaluate bioenergy crops includes all of these cropland acres. POLYSYS does not include cropland acres allocated to fruits and vegetables and minor crops such as dry beans, sugarcane and sugar beets, tobacco, etc., which total 2 percent of all U.S. cropland.

The acres included in POLYSYS represent the cropland acres in the 48 contiguous States. Bioenergy crops can grow in all regions of the United States. However, for the purpose of this analysis, the geographic ranges where production can occur are limited to areas where bioenergy crops can be produced with high productivity under rainfed conditions and where sufficient research has been conducted to make informed decisions regarding suitable varieties, appropriate management practices, and expected

yields. The regions analyzed include those where sufficient knowledge of each bioenergy crop has been accumulated so one can reasonably expect that large-scale commercial production could begin during the timeframe considered in the analysis, 1999-2008. The production regions could be expanded in the future as research is conducted in other geographic regions. The switchgrass, hybrid poplar, and willow production regions used in this analysis are presented in figures 2 to 4.

With respect to the Conservation Reserve Program acres, geographic limitations reduce the number of acres from the enrolled 29.8 million acres (as of October 1, 1998) to 24.1 million acres. These acres are further restricted to remove from consideration for bioenergy production the most environmentally sensitive areas: (1) acres enrolled in buffer strips to protect water quality, (2) acres classified as wetlands, (3) acres critical to watershed management, and (4) critical habitat acres in Wildlife Conservation Priority Areas. These restrictions remove an additional 7.2 million CRP acres. Thus, for this analysis, 16.9 million CRP acres are identified as being potentially available for bioenergy crop production (figure 5).

A summary of the cropland, by category, that is included in POLYSYS is presented in table 1. The production of at least one of the bioenergy crops included in this analysis is assumed suitable on 368 million of the total 424

4
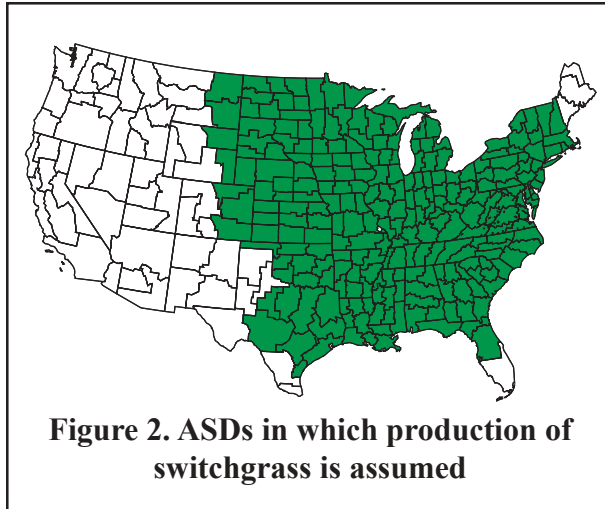
Figure 2. ASDs in which production of switchgrass is assumed
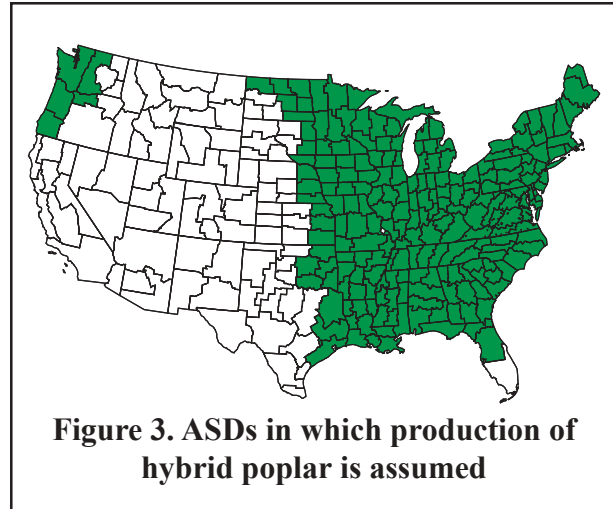
Figure 3. ASDs in which production of hybrid poplar is assumed
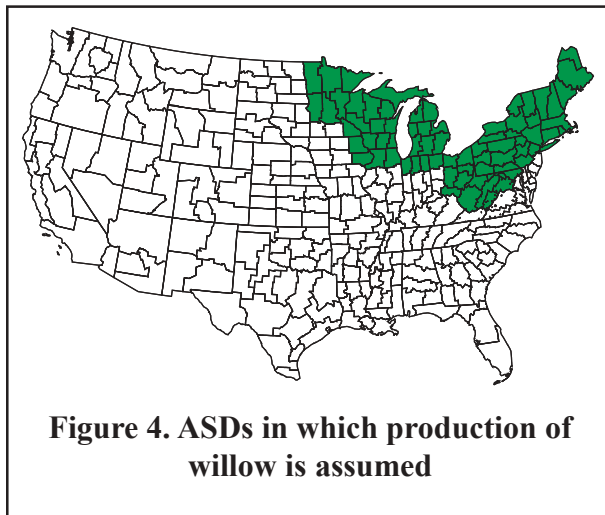
Figure 4. ASDs in which production of willow is assumed

Acres
- 469,000 to 1,430,000
- 235,000 to 469,000
- 119,000 to 235,000
- 54,000 to 119,000
- 0 to 54,000
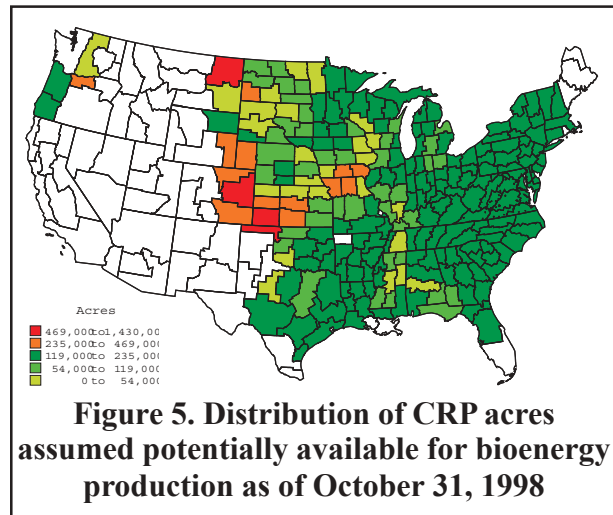
Figure 5. Distribution of CRP acres assumed potentially available for bioenergy production as of October 31, 1998

million acres included in POLYSYS.

Crop Production Costs

The bioenergy crops analyzed in this study are not currently produced as dedicated energy sources in the United States. However, about 200,000 acres of hybrid poplar are being commercially produced as a fiber source, and switchgrass is grown on some CRP acres and on hay acres as a forage crop. The lack of large-scale commercial production necessitates the use of research data and expert opinion to determine yields and management practices. Before beginning the analysis, experts from the U.S. Departments of Energy and Agriculture participated in a workshop (Appendix 1) where recommendations were made regarding:

- Geographic regions assumed for bioenergy crop production;
- Current and projected bioenergy crop yields by geographic region;
- Management practices appropriate for bioenergy crop production by land type and geographic region.

Geographic regions and yields are based chiefly on those contained in the Oak Ridge Energy Crop County Level Database (Graham, et al, 1996) and modified by the recommendations of the workshop participants. Bioenergy crop yields, by ASD, range from 2 dt/ac/yr to 6.75 dt/ac/yr depending on crop and location. Yields of bioenergy crops on idled and pasture acres are assumed to be 85 percent of those that can be obtained on acres in crop production. Bioenergy crop yields on CRP acres are adjusted by an index of traditional crop yields obtained on CRP acres prior to being enrolled in the CRP. Once planted, the expected yields for bioenergy crops remain fixed for the life of the production rotation. Research is ongoing to

improve yields. As a result, acres planted in later years could be assumed to have higher yields than those planted in earlier years.

Production costs for all crops considered in the analysis (i.e., traditional and bioenergy) are estimated using enterprise budgets. All production costs, except willow and hybrid poplar harvesting costs, are estimated using the APAC Budgeting System (ABS) (Slinsky and Tiller, 1999). ABS generates consistent enterprise and rotation budgets for each of the 305 ASDs contained in POLYSYS. Use of this budgeting system to estimate the costs of producing bioenergy crops as well as traditional crops ensures consistency across all crops in the analysis. ABS generates cost-of-production data based on operations schedules (i.e., field-level activities). The schedule of operations used for each traditional crop for each region is based on Agricultural Extension Service publications whenever possible. The resolution of information (State or substate level) provided in each budget varies according to the level at which particular information is available. Appendix 2 contains information regarding traditional crop management data sources.

Crop management practices for bioenergy crops produced on cropped, idle, and pasture acres are based on recommendations from the expert panel. These practices are presented in Appendices 3.1 and 3.2. Bioenergy crop management practices used on CRP acres were determined in subsequent discussions with USDA (Natural Resources Conservation Service and Farm Service Agency). Two CRP management practices were selected for use in the analysis: one to achieve high levels of biomass production (production management scenario), and one to achieve high levels of wildlife diversity (wildlife management scenario). These management practices are described in Appendix 3.3. Generally, the wildlife management scenario utilizes fewer fertilizer and chemical inputs than does the production management scenario. It also places significantly greater constraints on the harvest of switchgrass by restricting harvest to alternating halves of a field each year in contrast to the annual harvesting of the whole field in the production management scenario.

Estimated production costs for all crops include variable cash input costs (chemicals, fertilizers, seeds, cuttings, fuel and lubrication, machinery repair, hired labor, loan interest payments, etc.), producer's own labor, and machinery-related costs (such as depreciation, insurance, and non-land capital costs). Machinery-related costs are estimated by first defining all equipment needed to complete each field operation as specified by the management practices for each crop. Labor costs are estimated as a function of machinery hours. Machine costs per hour of operation are estimated using standard methodology (USDA, American Society of Agricultural Engineers) and multiplied by the hours per acre required to complete each operation to obtain the cost of the machinery per acre. Machinery prices and engineering performance parameters were obtained from the USDA (McBride) for all equipment except that used for harvesting hybrid poplar and willow. Those costs were estimated using BIOCOST, a budget generator model developed by Oak Ridge National Laboratory to estimate the cost of producing bioenergy crops (Walsh and Becker, 1996). BIOCOST is used to estimate hybrid poplar and willow harvesting costs because neither the USDA database nor ABS includes data on forest-harvesting equipment. The methodologies, input prices, and the cost categories used in BIOCOST are consistent with ABS.

The management practices used to estimate production costs are those that are typical for that ASD. They are not necessarily those used on every individual farm or soil type within a farm. Thus, the production costs used in the analysis are representative average costs for each ASD. Variation in production practices, yields, and labor and equipment constraints at an individual farm or field level within an ASD may occur which could alter the estimated costs of production for that site. These variations are not captured in the analysis.

Based on the assumed yield, management practices,

	POLYSYS Acreage (Mil. Acres)	Acres Assumed Suitable for Bioenergy Crop Production	
		(Mil. Acres)	(% of Total Acres)
Major Crops*	314.9	282.5	89.7%
CRP	29.8	16.9	56.7%
Idle	19.0	14.7	77.4%
Pasture	60.3	53.8	89.2%
TOTAL**	424.0	367.9	86.8%

* Includes corn, soybeans, sorghum, oats, barley, wheat, cotton, rice, alfalfa, and other hays.
** Excludes 7.4 million acres in other uses such as fruits, vegetables and other minor crops.

Table 1. Summary of Cropland in POLYSYS

	NE	APP	CB	LS	SE	SP	NP	PNW
Switchgrass								
Yield (dt/ac/yr)	4.87	5.84	5.98	4.80	5.49	4.30	3.47	-
Yield Range (dt/ac/yr)	3.50-5.50	4.36-6.62	4.95-6.73	3.50-6.00	3.40-6.45	2.55-5.98	2.00-5.49	-
Avg. Prod. Cost ($/ac)	983.14	969.50	975.75	863.10	929.73	847.37	714.25	-
Avg. Prod. Cost ($/dt)	22.53	18.53	18.21	20.07	18.90	21.99	22.97	-
Prod. Cost Range ($/dt)	21.38-25.10	17.21-20.89	17.63-18.76	18.91-23.32	17.87-23.70	16.87-29.44	18.73-36.20	-
Hybrid Poplar								
Yield (dt/ac/yr)	3.99	3.56	4.63	4.41	4.50	3.75	3.83	5.73
Yield Range (dt/ac/yr)	3.43-4.50	4.00-5.21	3.75-5.20	3.50-5.25	3.82-5.21	3.25-4.00	3.25 -4.31	5.50-6.00
Avg. Prod. Cost ($/ac)	920.38	967.56	917.26	892.82	967.57	928.78	900.74	1051.08
Avg. Prod. Cost ($/dt)	23.07	27.18	19.81	20.25	26.88	30.96	23.52	30.57
Prod. Cost Range ($/dt)	20.87-29.21	24.03-29.59	23.18-18.74	17.72-24.40	23.95-30.13	29.49-34.57	22.25-26.67	29.56-31.59
Willow								
Yield (dt/ac/yr)	4.90	4.50	4.70	4.60	-	-	-	-
Yield Range (dt/ac/yr)	3.15-5.77	4.50-4.50	4.50-5.08	4.05-5.25	-	-	-	-
Avg. Prod. Cost ($/ac)	2206.33	2163.74	2161.30	2154.30	-	-	-	-
Avg. Prod. Cost ($/dt)	20.47	21.86	20.90	21.29	-	-	-	-
Prod Cost Range ($/dt)	17.77-30.46	21.86-21.86	19.51-21.71	18.95-23.88	-	-	-	-

NE = CT, NH, NJ, NY, MA, ME, PA, RI, VT   APP = DE, KY, MD, NC, TN, VA, WV
CB = IA, IL, IN, MO, OH   LS = MI, MN, WI
SE = AL, AR, FL, GA, LA, MS, SC   SP = CO, KS, NE, OK, TX
NP = MT, ND, SD, WY   PNW = OR, WA
Yield = Mature Yield
Production Costs ($/ac & $/dt) = Present value cost over entire rotation

Table 2: Regional Bioenergy Crop Production Costs and Yields, Average and Range

and input costs used in the analysis, switchgrass is relatively the least expensive bioenergy crop to produce per dry ton yield for most ASDs. Hybrid poplar is next and willow is generally the most expensive. Table 2 contains the estimated regional average and range of production costs and yields for bioenergy crops.

The production costs are the present value cost (assuming a real discount rate of 6.5 percent) of producing the bioenergy crop (in dollars per acre and dollars per dry ton) for its entire production rotation. Production rotations are 10 years for switchgrass, 6 to 10 years for poplar, and 22 years for willow. The net present value framework is discussed in more detail in the following section. Production costs are those estimated for cropland acres currently planted to crops. Production costs for idle, pasture, and CRP acres are generally higher for each bioenergy crop.

Given that the estimated average per ton production costs for switchgrass are generally lower than for the tree crops in most ASDs, at similar market prices ($/dt) for the three bioenergy crops, switchgrass will be relatively more profitable than poplar and willow. As a result, POLYSYS allocates most of the bioenergy crop acres to switchgrass. Poplar and willow are generally more expensive to produce due to the higher establishment costs and the long period of time before returns from harvest are sufficient to pay for establishment. Those conditions require that interest payments be carried for several years. In a present value framework, costs incurred in the first few years are weighted more heavily than those incurred in later years. Appendix 4 contains a more detailed breakdown of the regional average bioenergy crop production costs.

Production Decision Issues

As annuals, traditional agricultural crops are planted and harvested each year. The bioenergy crops examined in this study are perennials that are planted in one year and remain in production for several years after planting. Harvest can occur annually during the production cycle (e.g., switchgrass), multiple times at defined intervals during a production cycle (e.g., willow), or once at the end of a production cycle (e.g., hybrid poplar). Due to the multi-year characteristics of bioenergy crops, a net present value (NPV) approach is used to decide which crop to produce. This differs from the original mechanism embodied in POLYSYS, which utilizes annual net returns to allocate acres among the traditional crops.

To evaluate whether a bioenergy crop should be planted in a particular region, its expected net present value profit is calculated and compared with the corresponding expected net present value profit for each of the traditional crops. Acreage is allocated to each crop (traditional as well as bioenergy crops) based on relative NPV profits subject to flexibility constraints described in the next section. Given that the three bioenergy crops examined in this study have production cycles of different time lengths, a common planning horizon is used to ensure comparability of discounted revenue streams. A total planning horizon of 40 years is set because, although not a minimum common denominator, it spans a long enough time period to consider insignificant the stream of net returns beyond this period. A real discount rate of 6.5 percent is assumed.

Production decisions on CRP, idle, and pasture acres require additional considerations to those made on cropland planted to traditional crops. On CRP acres, it is assumed either that existing contracts, upon expiration, can be renewed under the same conditions that were in effect upon initial enrollment in the program, or that the acres can be planted to bioenergy crops under a modified contract. This assumption greatly simplifies the analysis by not requiring development of a model to determine re-enrollment or initial enrollment requirements. In exchange for being allowed to produce and harvest bioenergy crops on CRP acres, 25 percent of the current rental rate on the acres is forfeited. Thus, the decision to allocate CRP acres to bioenergy crop production is reduced to a comparison of the net present value of producing bioenergy crops with the net present value of the foregone CRP rental payments.

Cropland acres that are idle or in pasture are assumed to be idled or in pasture for economic reasons—that is, given prices, costs of production, and yields, the most economic use of the land is either to not plant a crop or to dedicate it to pasture. To return these acres to production of the major crops or to plant bioenergy crops, the net present value returns of these crops must be higher than the most profitable crop under the baseline assumptions. Furthermore, to account for possible inertia to keep the land in its current use and/or the value of pasture land in livestock operations, the model assumes a premium of 10 percent above the baseline net present returns for idled acres and 15 percent for pasture acres is required.

Land Allocation Rules

To avoid corner solutions in the regional linear programming models, POLYSYS contains embedded flexibility constraints that limit the acreage that a given crop can lose or gain each year. To accommodate the addition of bioenergy crops, these allocation rules were modified to the following:

- If the net present value in years t, t-1, and t-2 is positive, the acreage of a crop can increase/decrease by up to 10 percent of the baseline acreage in year t, depending on its net present value relative to that of competing crops.
- If the net present value in years t and t-1 is negative and positive in year t-2, the acreage of a crop can increase/decrease by up to 30 percent of the baseline acreage in year t, depending on its net present value relative to that of competing crops.
- If the net present value in years t, t-1, and t-2 is negative, the acreage of a crop can increase/decrease by up to 50 percent of the baseline acreage in year t, depending on its net present value relative to that of competing crops.
- For crops comprising more than 20 percent of the total planted acres for all crops in an ASD, acres that can be gained or lost are limited to 20 percent of the baseline acreage of the crop.
- Idled and pasture acres that can be reallocated to agricultural production are limited to 40 percent and 25 percent, respectively, of the baseline acres in each ASD.
- Bioenergy crops can gain as much acreage as is available from other crops, given the above constraints.
- Once acreage is allocated to bioenergy crops, the acreage remains allocated to the bioenergy crop for the duration of its productive life cycle.

It is assumed that some type of contractual arrangement between farmers and bioenergy crop users exists which limits, for the duration of the bioenergy crop production cycle, the conversion of acres back to traditional crop production once they are allocated to bioenergy crops. Since the period of analysis for bioenergy crops is the years 2000-2008, which is less than the production cycle of the three bioenergy crops considered, land allocated to bioenergy crops remains in bioenergy crop production until the end period of the analysis.

Price Expectations

When dealing with traditional crops under a scenario of relative equilibrium, POLYSYS has historically calculated expected future prices using a naive price expectation hypothesis that utilizes a weighted average of prices in the previous three years. However, the introduction of bioenergy crops offers the possibility of significant shifts in the way agricultural cropland is allocated, which could potentially result in significant impacts on the prices of traditional agricultural crops. Thus POLYSYS has been modified to estimate future expected crop prices using a rational expectations approach.

Rational expectations are premised on the hypothesis that, in a given year, farmers will anticipate price changes resulting from significant shifts of acreage from traditional crops to bioenergy crops and will incorporate these price changes into their planting decisions. These changes in expected prices are estimated in POLYSYS through an iterative process. In the first step of the iteration, the supply module in POLYSYS allocates acres to traditional and bioenergy crops using naive price expectations for traditional crops (i.e., a weighted average of past prices) and assumed market prices for bioenergy crops. The supply of traditional crops resulting from the allocation interacts with the demand module in POLYSYS to estimate the changes in prices for traditional crops. These "new" prices for traditional crops are now used as the prices farmers expect to receive for these crops in the second step of the iteration process. Assuming the "new" market prices for traditional crops and the same prices for bioenergy crops assumed in the first step, the supply module in POLYSYS then reestimates the acres allocated to traditional and bioenergy crops. These new supply quantities interact with the demand module to once again estimate the "new" market prices for traditional crops. The two-step iteration is repeated until the changes in prices for traditional crops between the two iterations are less than a predetermined convergence factor.

Since there are no well-developed markets for the bioenergy crops, their prices are determined exogenously. To keep bioenergy crop prices consistent with each other, the price of switchgrass is used as the numeraire, and the prices of hybrid poplar and willow are adjusted based on their energy content (in Btu per dry ton).

Modeling Implications

The production and land allocation rules can be summarized in the following mathematical formulation, which indicates that for each time period (t) in each POLYSYS region (r), acres (x) are allocated based on the net present value for each crop (k), subject to land availability (X) in each land category (l) (cropland in major crops, cropland in CRP, cropland idle, and cropland in pasture), and subject to the upper (U) and lower limits (L) on the acreage planted to each crop.

The NPV includes any government payments on a per

$$Max_r^r \quad \sum_l \sum_k x_k^{l,t} NPV_k^{l,t}$$

$$subject\ to\ .$$

$$\sum_l \sum_k x_{l,k} \leq X_l$$

$$\sum_l \sum_k x_{l,k} \leq U_{l,k}$$

$$\sum_l \sum_k x_{l,k} \geq L_{l,k}$$

acre basis, such as the CRP rental rate, and is estimated using the price expectation formulation described previously.

ESTIMATED IMPACTS OF
BIOENERGY CROP PRODUCTION

A number of alternative scenarios were constructed and estimated. The results of just two scenarios are presented here, however, to keep the discussion focused on the economic feasibility and potential economic impacts of bioenergy crop production on the agricultural sector. These two scenarios, summarized in Table 3, were chosen because they serve to place boundaries around the discussion.

The wildlife diversity scenario assumes a bioenergy farmgate price (i.e., no transportation costs included) of $30/dry ton for switchgrass, $31.74/dt for willow, and $32.90/dt for hybrid poplar. (Because the energy density of the three bioenergy crops differs slightly, an equivalent energy price in $/MBtu results in slightly different $/dry ton prices. The $/MBtu value assumed for all three crops is $1.94). This scenario also assumes that wildlife management practices are employed on CRP acres and that farmers receive 75 percent of their rental rate in exchange for the right to harvest and sell bioenergy crops.

The production management scenario assumes a bioenergy farmgate price of $2.58/MBtu for each energy crop, which is equivalent to $40/dry ton for switchgrass, $42.32/dt for willow, and $43.87/dt for hybrid poplar. This scenario assumes that production management practices are employed on CRP acres and that farmers receive 75 percent of their current rental rate in exchange for the right to harvest and sell bioenergy crops.

Both scenarios use the 1999 USDA baseline for the eight major crops in the analysis (corn, grain sorghum, oats, barley, wheat, soybeans, cotton, and rice) and the 1999 FAPRI baseline for alfalfa and other hay, which are not included in the USDA baseline. CRP baseline acres and location are those prevailing on October 1, 1998. Idle and pasture baseline acres and location are obtained from the 1997 Census of Agriculture and are assumed to be representative of, and consistent with, the baseline information for the major crops.

Bioenergy crop production is assumed to begin in the year 2000, and the largest shift in land is estimated to occur in that year. Annual impacts for the period 2000-2008 are available for each scenario, but to facilitate the presentation of the results, only the results from the year 2008 are given. It is assumed that most of the initial shock resulting from the allocation of land to bioenergy crop production will have occurred by 2008 and that the agricultural production sector will have settled into a new long-run equilibrium.

Bioenergy crops compete not only with traditional crops for land, but with each other as well. Land is allocated to those bioenergy crops with the greatest average net returns. As discussed in previous sections, switchgrass is relatively the least expensive bioenergy crop to produce, and at similar market prices, switchgrass is relatively more profitable than poplar or willow. As a result, in most ASDs, switchgrass has higher average net returns for each price scenario examined in the analysis, and bioenergy crop acres are generally allocated to switchgrass production (see Appendix 4 for a detailed description of regional average costs and returns of bioenergy crops).

That observation does not imply that for any given field or soil type within an ASD, willow or poplar could not be produced more profitably than switchgrass or traditional crops. Rather, the analysis considers only average net present value returns for the entire ASD, given the assumed average yields and typical management practices for each bioenergy crop in each ASD. Variations in average returns

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Wildlife Management Scenario*		Production Management Scenario*	
Farmgate Crop Price	$1.94/MBtu	Farmgate Crop Price	$2.58/MBtu
• Switchgrass	$30.00/dt	• Switchgrass	$40.00/dt
• Willow	$31.74/dt	• Willow	$42.32/dt
• Hybrid Poplar	$32.90/dt	• Hybrid Poplar	$43.87/dt
Wildlife Management Practices on CRP land		Production Management Practices on CRP land	
• Fewer fertilizer and chemical inputs		• Standard fertilizer and chemical inputs	
• Annual switchgrass harvest is limited to alternating halves each year		• Annual switchgrass harvest of whole field	
Retain 75% CRP rental rate		Retain 75% CRP rental rate	
*For complete details on the two management practices see Appendix 3			

Table 3. Comparison between wildlife management scenario and production management scenario

between ASDs is accounted for in the model, but site-specific variations in returns within an ASD are not accounted for in the analysis.

At prices that are 20 percent higher than switchgrass (in $/MBtu), and keeping production costs and yields fixed, willow achieves a net present value return greater than switchgrass in many ASDs where both can be produced. Similarly, at a $/MBtu price that is 15 percent higher than switchgrass, poplar is relatively more profitable. Thus, combinations of yields, production costs, and market prices that provide a 15 percent to 20 percent differential in net present value returns between short-rotation woody crops and switchgrass would result in more acres being allocated to poplar and willow, over switchgrass (on acres for which the relative profitability of bioenergy crops exceeds those of traditional crops). A situation like this happens on CRP acres under the wildlife management scenario. The restrictions placed on the production and harvest of switchgrass relative to that of short-rotation woody crops, alter the relative profitability enough that significant acres of bioenergy crop production shift from switchgrass production (in the production management scenario) to hybrid poplar production. Willow, having the least average profitability, still does not enter the solution set in the analysis.

Thus, under the conditions and assumptions used in the analysis, switchgrass dominates the other two bioenergy crops under most scenarios considered. Under selected conditions, acres are also allocated to poplar but not to willow. The remaining discussion of the impacts of bioenergy crops production on the agricultural sector reflects these results.

Land Use Impacts

Estimated total national acres allocated to bioenergy crops under the two scenarios are presented in Table 4. Under the wildlife management scenario, 19.4 million acres of cropland are planted to bioenergy crops, with 10.4 million of those acres (54 percent) coming from land previously planted to traditional crops. An estimated 8.2 million CRP acres, 0.2 million idled acres, and 0.5 million pasture acres are converted to bioenergy crop production. For the production management scenario, an estimated 41.9 million acres are planted to bioenergy crops, with 23.4 million of those acres coming from land planted to traditional crops and 12.9 million acres coming from converted CRP acres. An estimated 2.1 million idled acres and 3.5 million pasture acres are also converted to bioenergy crop production.

Tables 5 and 6 present the shifts in acres from the major crops and cropland categories that result from the introduction of bioenergy crops. Total cropland area planted increases from the baseline 325.4 million acres to 335.9 million acres under the wildlife management scenario and to 346.8 million acres under the production management scenario. The additional acreage comes almost exclusively from CRP land in the wildlife management scenario and from CRP, idled, and pasture land in the production management scenario. Many traditional crops lose acres as a result of bioenergy crop production, but gain acres from production on idled and pasture acres. This effect occurs because the shift in acres resulting from the introduction of bioenergy crops results in lower production of traditional crops and thus higher traditional crop prices. The

Units in Million Acres	Wildlife Management Scenario				
	All Cropland	Major Crops	CRP	Idle	Pasture
Switchgrass	12.32	10.44	1.1	0.23	0.55
Hybrid Poplar	7.10	0	7.1	0	0
Willows	0	0	0	0	0
All Bioenergy	19.42	10.44	8.20	0.23	0.55
Units in Million Acres	Production Management Scenario				
	All Cropland	Major Crops	CRP	Idle	Pasture
Switchgrass	41.87	23.37	12.91	2.09	3.49
Hybrid Poplar	0	0	0	0	0
Willows	0	0	0	0	0
All Bioenergy	41.87	23.37	12.91	2.09	3.49

Table 4. Plantings of bioenergy crops, 2008

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Million Acres	USDA baseline (Feb. 1999)	WILDLIFE MANAGEMENT SCENARIO			
	1999 Acres	Effect on cropland in major crops	Acreage gained from idle & pasture	Net Change	2008 Acres
Corn	82.0	-2.2	0.8	-1.4	80.6
Sorghum	10.6	0.0	0.0	0.0	10.6
Oats	4.7	-0.1	0.0	-0.1	4.6
Barley	7.0	0.0	0.0	0.0	7.0
Wheat	73.1	-1.8	0.4	-1.4	71.7
Soybeans	71.8	-2.0	0.1	-1.9	69.9
Cotton	12.8	-0.8	0.3	-0.5	12.3
Rice	3.2	-0.1	0.0	-0.1	3.1
Alfalfa	27.1	-1.0	0.0	-1.0	26.1
Other Hay	33.1	-2.5	0.0	-2.5	30.6
Bioenergy	0.0	18.6	0.8	19.4	19.4
Total CRP	29.8	-8.2	0.0	-8.2	21.6
Total Planted	325.4	8.2	2.3	10.5	335.9
Idle and Pasture	79.3	-2.3	0.0	-2.3	77.0

Table 5. Cropland changes due to introduction of bioenergy crops, 2008
Wildlife management scenario

Million Acres	USDA baseline (Feb. 1999)	PRODUCTION MANAGEMENT SCENARIO			
	1999 Acres	Effect on cropland in major crops	Acreage gained from idle & pasture	Net Change	2008 Acres
Corn	82.0	-4.7	1.0	-3.7	78.3
Sorghum	10.6	-0.4	0.0	-0.4	10.2
Oats	4.7	-0.2	0.1	-0.1	4.6
Barley	7.0	0.0	0.0	0.0	7.0
Wheat	73.1	-7.4	1.2	-6.2	66.9
Soybeans	71.8	-3.5	0.1	-3.4	68.4
Cotton	12.8	-1.2	0.5	-0.7	12.1
Rice	3.2	-0.1	0.0	-0.1	3.1
Alfalfa	27.1	-2.2	0.0	-2.2	24.9
Other Hay	33.1	-3.7	0.0	-3.7	29.4
Bioenergy	0.0	41.2	0.7	41.9	41.9
Total CRP	29.8	-12.9	0.0	-12.9	16.9
Total Planted	325.4	17.8	3.6	21.4	346.8
Idle or Pasture	79.3	-8.5	0.0	-8.5	70.8

Table 6. Cropland changes due to introduction of bioenergy crops, 2008
Production management scenario

Crop	Million Acres	
	Bioenergy Crop Management Scenario	
	Wildlife	Production
Corn	0.237	0.277
Sorghum	0.003	0.000
Oats	0.005	0.000
Wheat	0.129	0.301
Soybeans	0.034	0.031
Cotton	0.249	0.454
Bioenergy	0.228	2.093
Total all crops	0.877	3.156

Table 7. Idle cropland brought back into crop production, 2008

Crop	Million Acres	
	Bioenergy Crop Management Scenario	
	Wildlife	Production33
Corn	0.595	0.712
Wheat	0.217	0.921
Soybeans	0.081	0.065
Bioenergy	0.548	3.485
Total all crops	1.441	5.183

Table 8. Cropland in pasture brought back into crop production, 2008

Crop	Acres
Corn	-965,908
Oats	+ 58,569
Soybeans	+904,671
Bioenergy	+ 2,667

Table 9. Changes in traditional crop production in Iowa resulting from the national introduction of bioenergy crops - production management scenario.

higher prices provide sufficient incentive to return some idled and pasture acres to traditional crop production. For example, under the production management scenario, corn loses 4.7 million acres as a result of bioenergy crop production but higher corn prices result in the conversion of 1 million idled and pasture acres to corn production, resulting in a net loss of 3.7 million corn acres.

Tables 7 and 8 detail the acres shifted to traditional crops and to bioenergy crops from idle and pasture acres under the two scenarios. In addition to changes in total crop acres allocated to each traditional crop on a national level, shifts of acres among traditional crops at a regional level may also occur. As an example, Iowa loses nearly 1 million acres of corn production (Table 9) under the production management scenario. However, fewer than 3,000 of these acres are shifted to bioenergy crop production. Rather, the changes in relative prices of traditional crops induce farmers to replace som of their corn acres with soybeans and, to a lesser extent, oats. Similar shifts in the allocation of traditional crop acres occur in other States as well, due to changes in the relative prices of traditional crops caused by the introduction of bioenergy crops.

As discussed previously, bioenergy crops compete for acreage not only with traditional crops, but with each other as well. Acreage from each ASD is allocated to each crop based on average NPV profit given the assumed yields, production costs, and land allocation rules described previously. In nearly every ASD, switchgrass is relatively more profitable than hybrid poplar, which is in turn relatively more profitable than willow. As a result, switchgrass dominates the other two bioenergy crops. Nearly 99 percent of the acres in traditional crops, idled, or in pasture that are shifted to bioenergy crop production are shifted to switchgrass production under both scenarios. In a few ASDs, hybrid poplar is the most profitable bioenergy crop and acres are allocated to it in these ASDs. Willow, being the least profitable of the three bioenergy crops, cannot compete for acres with the other two bioenergy crops and no acres are allocated to willow in the analysis.

The bioenergy crop produced on CRP acres depends on the scenario assumed (Table 10). The wildlife management scenario places substantial penalties on switchgrass in terms of yields and production costs relative to those of hybrid poplar and willow. As a result, for any given bioenergy crop price, the relative profitability of hybrid poplar exceeds that of switchgrass and willow on a substantial portion of the CRP acres allocated to bioenergy crops. On the remaining CRP acres allocated to bioenergy crops under the wildlife scenario, switchgrass is relatively more profitable than willow, and the acres are allocated to switchgrass. Under the production management scenario, switchgrass is the relatively more profitable crop, and the CRP acres are allocated to it. The results suggest that the interaction between environmental and economic benefits will require further delineation of management practices that provide a high level of both benefits.

Figures 6-12 present the regional distribution of bioenergy crop production by cropland type for the two scenarios. Figure 6 presents the location and range of acreage

| Crop	Million Acres	
	Wildlife Management Scenario	Production Management Scenario
Switchgrass	1.099	12.913
Poplar	7.097	0
All bioenergy	8.196	12.913
Bioenergy potential	16.925	16.925
Available CRP for bioenergy	22.608	22.608
All CRP through October 1998	29.788	29.788

**Table 10. CRP plantings, 2008**

of switchgrass production on all cropland acres (combined acres in crops, idled, in pasture, and in CRP). Figures 7 and 8 present the acres and location of switchgrass and hybrid poplar respectively on CRP acres under the wildlife management scenario. Under this scenario, switchgrass production on CRP acres occurs primarily in the southeastern United States. Hybrid poplar production on CRP acres occurs predominantly in the Midwest and Lake States. Figure 9 presents the location (in acres) of switchgrass production on all cropland acres. Figure 10 presents the location of

switchgrass production on CRP acres under the production management scenario. Under this scenario, switchgrass production occurs throughout the United States in nearly every ASD where production is permitted in the analysis. The highest concentration of acres occurs in the Northern and Southern Plains regions.

Figures 11 and 12 present the location of bioenergy crop production (in dry tons) under the two scenarios. Table 11 contains the quantities (in dry tons) of bioenergy crops available by State under the two scenarios. Total

Figure 6. Switchgrass plantings on all cropland, 2008

WILDLIFE MANAGEMENT SCENARIO

Acres

- ■ 469,000 to 1,430,000
- ■ 235,000 to   469,000
- ■ 119,000 to   235,000
- ■ 54,000 to   119,000
- ■   0 to   54,000
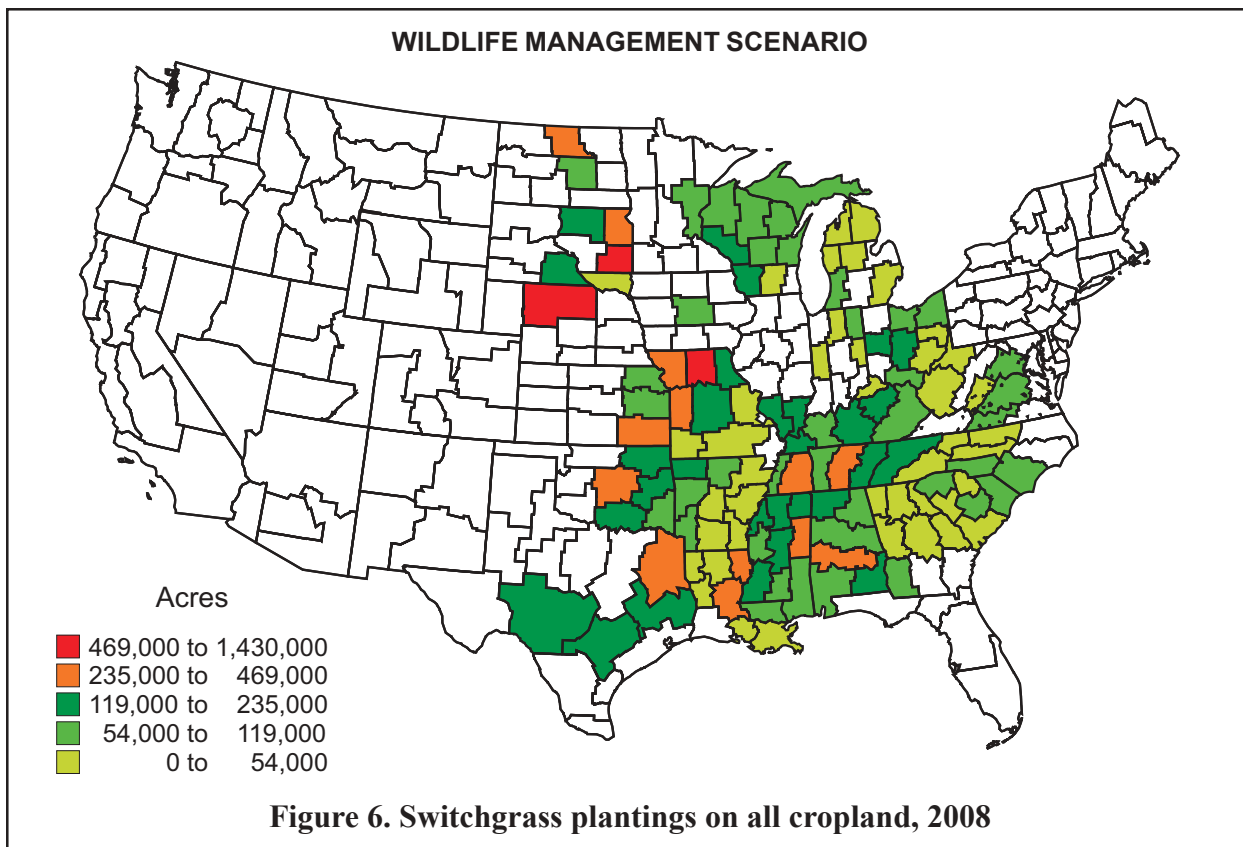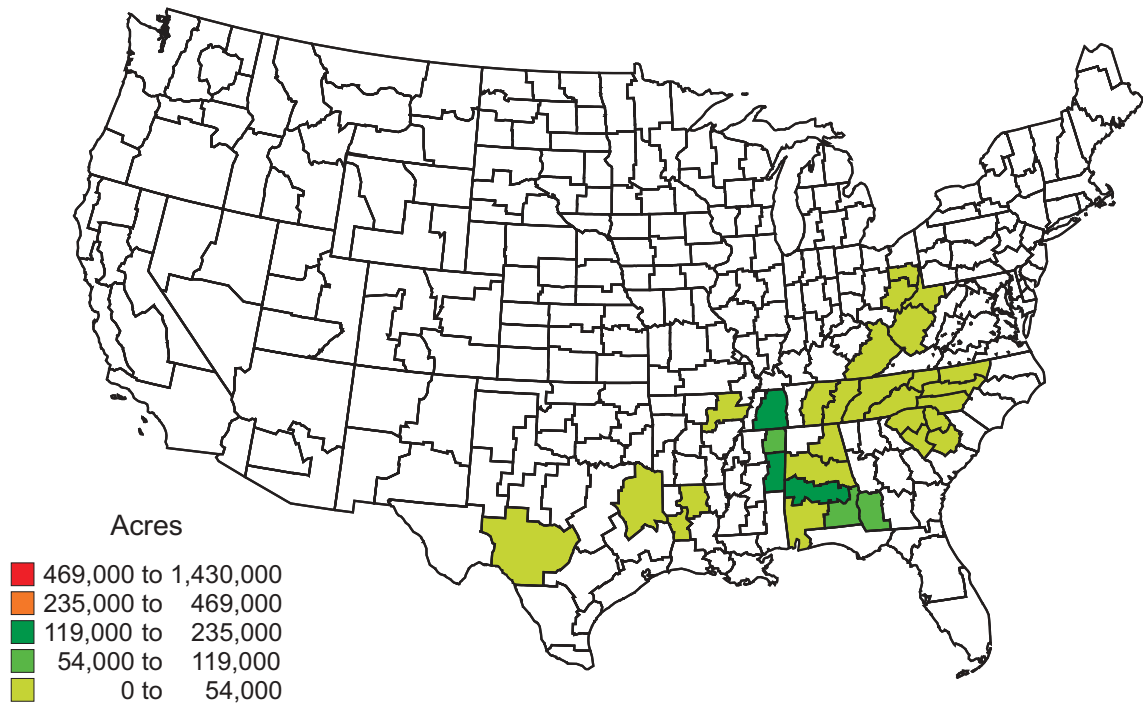
Figure 7. Switchgrass plantings on cropland enrolled in CRP, 2008

WILDLIFE MANAGEMENT SCENARIO

Acres

- ■ 469,000 to 1,430,000
- ■ 235,000 to   469,000
- ■ 119,000 to   235,000
- ■ 54,000 to   119,000
- ■   0 to   54,000
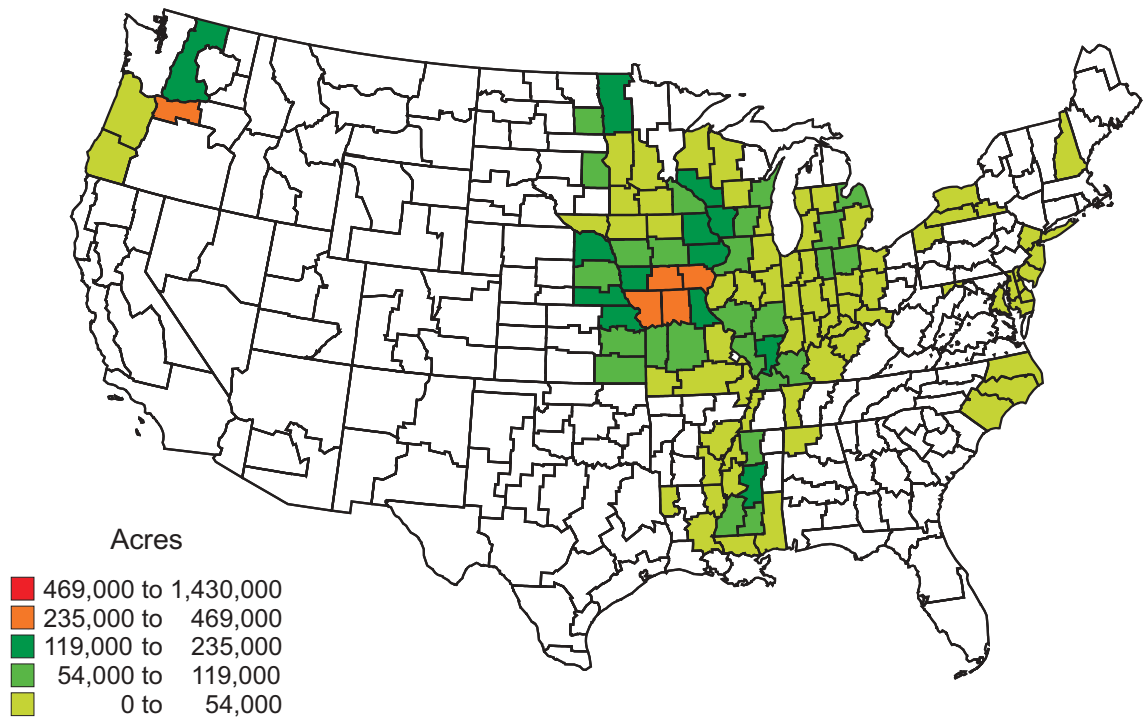
Figure 8. Poplar plantings on cropland enrolled in CRP, 2008

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PRODUCTION MANAGEMENT SCENARIO

Acres

- 469,000 to 1,430,000
- 235,000 to 469,000
- 119,000 to 235,000
- 54,000 to 119,000
- 0 to 54,000
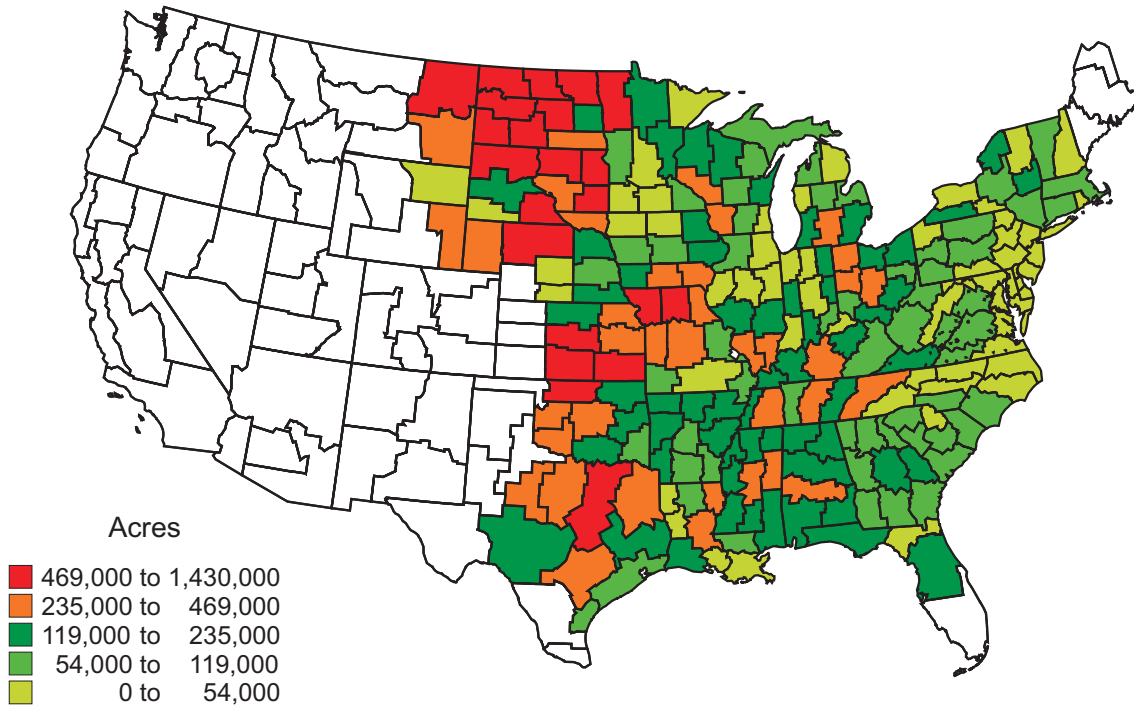
Figure 9. Switchgrass plantings on all cropland, 2008

PRODUCTION MANAGEMENT SCENARIO

Acres

- 469,000 to 1,430,000
- 235,000 to 469,000
- 119,000 to 235,000
- 54,000 to 119,000
- 0 to 54,000
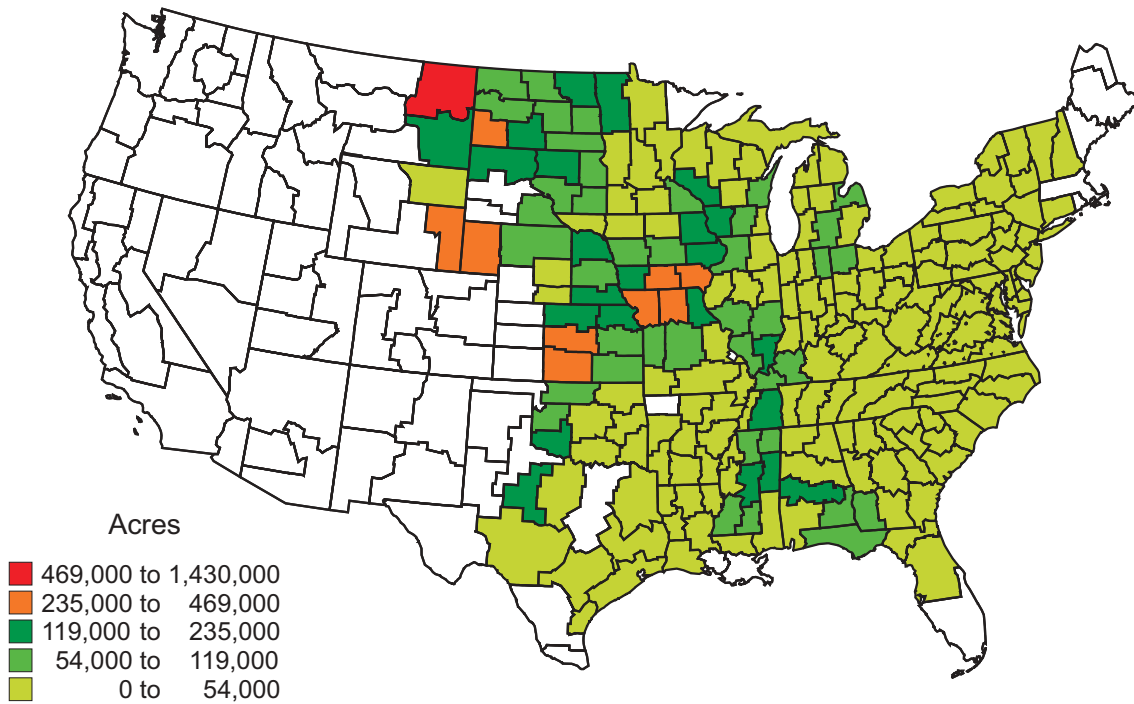
Figure 10. Switchgrass plantings on cropland enrolled in CRP

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WILDLIFE MANAGEMENT SCENARIO

Dry Tons

■ 1,300,000 to 3,420,000
■ 730,000 to 1,300,000
■ 450,000 to 730,000
■ 220,000 to 450,000
■ 0 to 220,000
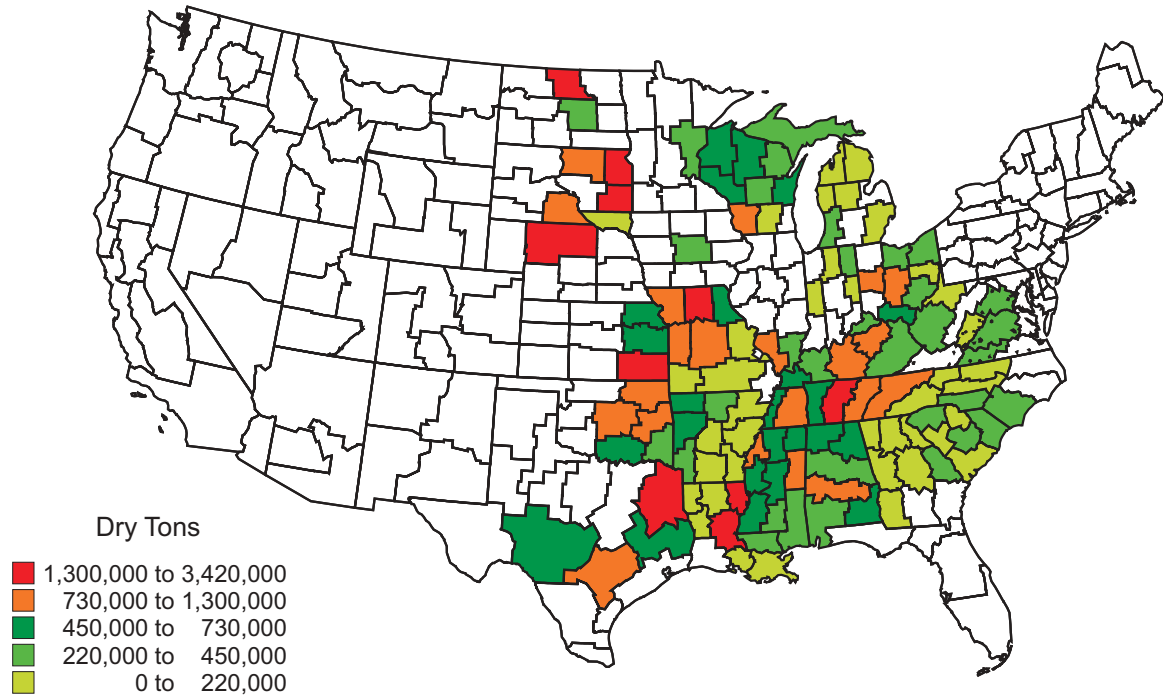
Figure 11. Production of biomass by ASD, 2008

PRODUCTION MANAGEMENT SCENARIO

Dry Tons

■ 1,300,000 to 3,420,000
■ 730,000 to 1,300,000
■ 450,000 to 730,000
■ 220,000 to 450,000
■ 0 to 220,000
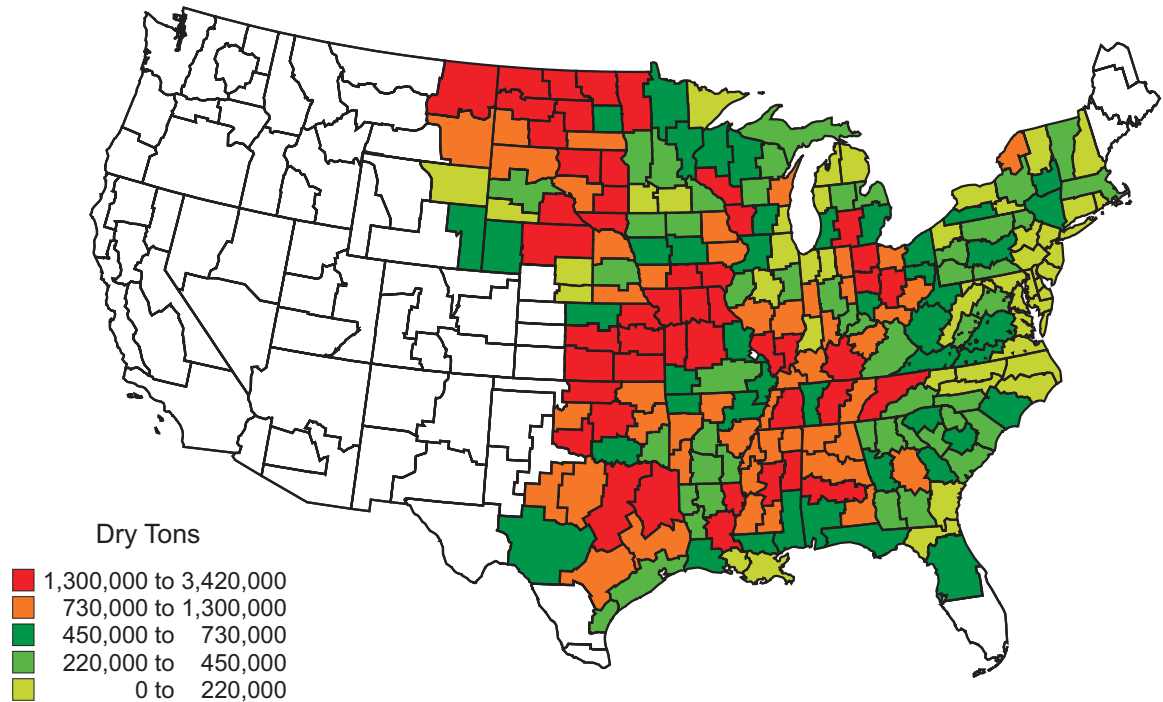
Figure 12. Production of biomass by ASD, 2008

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	Wildlife Management Scenario	Production Management Scenario
State	Production in million dry tons	
Alabama	3.1	6.6
Arkansas	2.2	5.5
Connecticut	0.0	0.2
Delaware	0.0	0.0*
Florida	0.0	1.3
Georgia	1.3	4.0
Illinois	0.8	7.7
Indiana	0.0	5.0
Iowa	0.0	8.3
Kansas	2.9	11.4
Kentucky	3.0	5.1
Louisiana	3.7	5.8
Maryland	0.0	0.3
Massachusetts	0.0	0.2
Michigan	1.2	4.2
Minnesota	0.4	5.8
Mississippi	4.3	9.3
Missouri	2.5	12.8
Montana	0.0	2.8
Nebraska	1.9	5.2
New Hampshire	0.0	0.2
New Jersey	0.0	0.1
New York	0.0	3.4
North Carolina	0.6	1.6
North Dakota	1.9	16.8
Ohio	3.8	9.7
Oklahoma	3.6	8.1
Pennsylvania	0.0	2.3
Rhode Island	0.0	0.0*
South Carolina	1.3	2.4
South Dakota	5.6	12.8
Tennessee	6.5	9.4
Texas	4.5	9.1
Vermont	0.0	0.3
Virginia	1.3	2.6
West Virginia	0.3	1.2
Wisconsin	3.6	6.1
Wyoming	0.0	0.5
Total	60.5	188.1

Note: The production of bioenergy crops is not assumed in Arizona, California, Idaho, Nevada, New Mexico, and Utah. Although production occurs in Oregon and Washington, harvest has not yet occurred by 2008. Addition of annualized production of poplar under Scenario 1 adds an additional 35.5 million dry tons with production occurring in Oregon and Washington.
* Delaware 0.03; Rhode Island 0.005

Table 11. Production of switchgrass by State, 2008
Comparison between the wildlife management scenario and
the production management scenario

Figure 13. Biomass production at selected prices by cropland type and assuming the production management scenario on CRP acres (million dt)
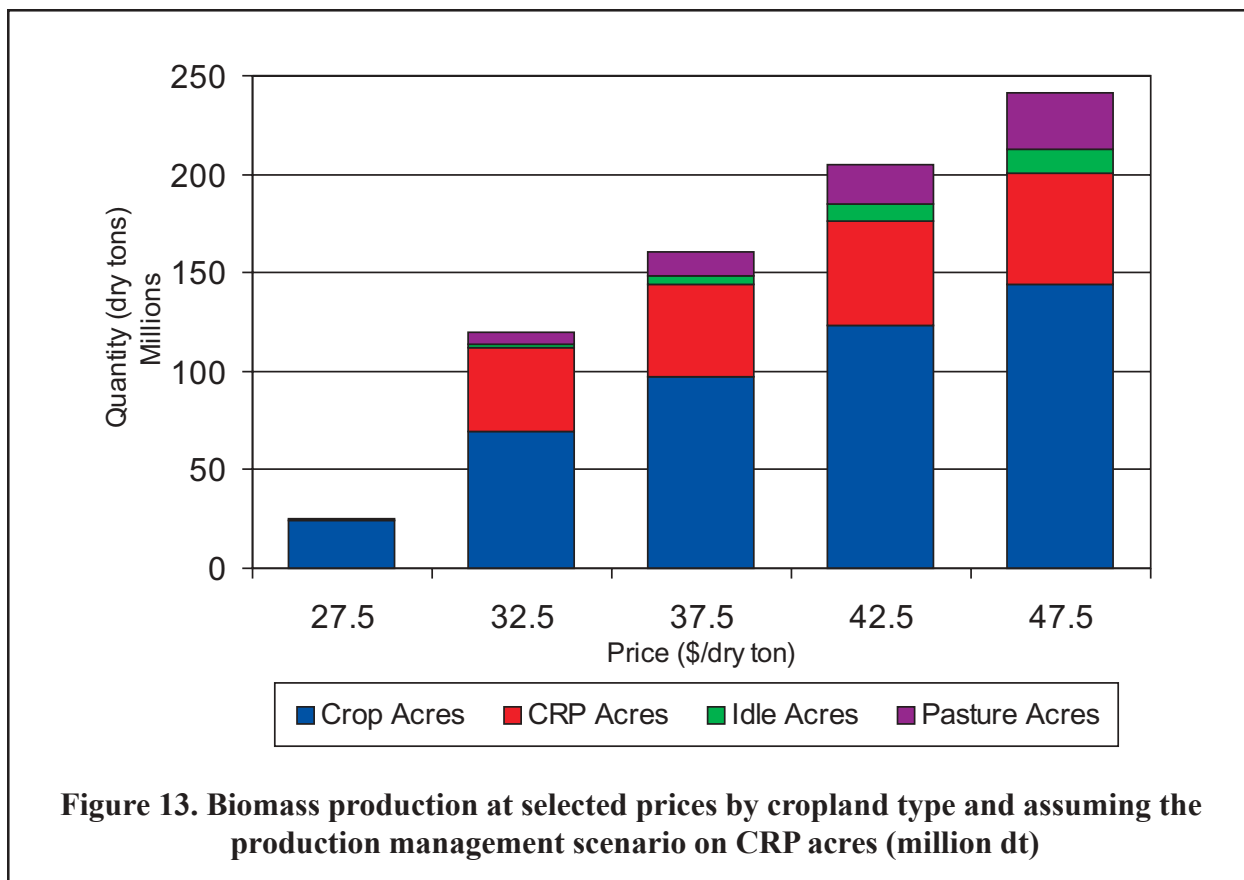
national production in the year 2008 under the wildlife management scenario is an estimated 60.5 million dry tons annually. While most of the poplar is not harvested until after 2008, its contribution can be annualized to provide an equivalent annual amount of 35.5 million dry tons, for a total of 96 million tons of feedstock. Under the production management scenario, an estimated 188 million dry tons could be produced annually, exclusively from switchgrass.

For convenience, we present detailed results of the analysis for two price scenarios only. It is useful, however, to elucidate the potential national supply by cropland type (cropland in traditional crops, idle, pasture and CRP) for different price scenarios. Figure 13 presents these estimates for selected bioenergy crop prices assuming the production management scenario for bioenergy crops on CRP acres.

Price Impacts

The shift of cropland from traditional crops to bioenergy crops results in higher prices for traditional crops. The impact on traditional crop prices is a function of the acreage shifted to bioenergy crops, as well as the elasticity of supply and demand parameters for each crop. Price

impacts for the two scenarios are presented in Table 12. Traditional crop prices increase by an estimated 4 percent to 9 percent under the wildlife management scenario, depending on crop, and by an estimated 9 percent to 14 percent under the production management scenario. Cotton and rice experience the largest price increases under the wildlife management scenario, while cotton and sorghum show the largest increases under the production management scenario. It should be noted that the higher estimated prices for the major crops, except wheat, are within the range of historical market prices experienced by these crops over the last 5 years. For example, corn prices have ranged between $1.95/bu and $3.24/bu. Because POLY-SYS calculates the price as changes from the baseline price, the level of the final prices is highly influenced by the price level assumed in the baseline. It should also be noted that POLYSYS is not able to estimate price changes for alfalfa and other hay crops that are generally determined locally rather than at the national level.

Net Farm Income Impacts

The overall impact of bioenergy crop production on agriculture is summarized by changes in net farm income. To account for the contribution of bioenergy crops to net

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Crop	Baseline Price	Bioenergy Crop Management Scenario						
		Value		Difference				
		Wildlife	Production	Wildlife		Production		
Corn/bu.	$2.55	2.65	2.79	$0.10	4%	$0.24	9%
Sorghum/bu.	2.44	2.57	2.77	0.13	5%	0.33	14%
Oats/bu.	**1.50**	**1.58**	**1.67**	**0.08**	**5%**	**0.17**	**11%**
Barley/bu.	**2.35**	**2.43**	**2.55**	**0.08**	**3%**	**0.20**	**9%**
Wheat/bu.	4.25	4.40	4.74	0.15	4%	0.49	12%
Soybeans/bu.	6.10	6.42	6.71	0.32	5%	0.61	10%
Cotton/cwt.	**0.68**	**0.74**	**0.77**	**0.06**	**9%**	**0.09**	**13%**
Rice/cwt.	**10.37**	**11.23**	**11.37**	**0.86**	**8%**	**1.00**	**10%**

Table 12. Price changes for major crops in 2008

	Billion $		
	USDA Baseline (Feb. 1999)	**Wildlife management scenario**	**Production management scenario**
Crops & Livestock	50.5	52.6	54.2
Bioenergy Crops	0	0.7	2.3
Total Net Farm Income	50.5	53.3	56.5

Table 13. Changes in net farm income, 2008

farm income, the net present value resulting from the production of biomass is expressed in terms of an annuity and added to the farm income measures used for the major crops and livestock sector. Again, POLYSYS is not able to estimate changes in alfalfa and other hay prices, which are generally determined locally rather than nationally. Alfalfa and other hay prices are likely to increase, generating extra income for producers and, consequently, to cause losses for livestock producers who feed hay and alfalfa to their cattle. The net effects, which could be negative, neutral, or positive, have not been accounted for in the income estimates.

The changes in the annual net farm income generated in the year 2008 under the two scenarios are shown in Table 13. Under the wildlife management scenario, a gain of $2.8 billion is projected, with bioenergy crops accounting for $700 million of that total and the rest resulting from higher traditional crop prices. Under the production management scenario, a gain of $6.0 billion is pro-

jected, with bioenergy crops accounting for $2.3 billion of that total and the rest resulting from higher traditional crop prices.

Table 14 presents the change in estimated net farm income resulting directly from the introduction of bioenergy crop production by State for the two scenarios. Under the wildlife management scenario, the gains in income generated by the production of bioenergy crops are highest in the Midwest, Northern Plains, Southeast, and Delta regions, although gains are also experienced in the Southern Plains and New England. Under the higher price scenario, North and South Dakota experience significant income gains from bioenergy crop production. Bioenergy crops could potentially provide an effective alternative for these wheat-dependent States. States with a relatively larger agricultural base also benefit the most from the price increase experienced by the major crops.

State	Wildlife management scenario	Production management scenario
	Million dollars	
Alabama	22	89
Arkansas	10	63
Connecticut	0	1
Delaware	0	0
Florida	0	11
Georgia	3	40
Illinois	53	128
Indiana	19	76
Iowa	112	184
Kansas	26	127
Kentucky	27	75
Louisiana	20	76
Maryland	1	3
Massachusetts	0	2
Michigan	17	55
Minnesota	16	58
Mississippi	36	131
Missouri	88	214
Montana	0	19
Nebraska	32	83
New Hampshire	0	1
New Jersey	0	1
New York	1	25
North Carolina	4	21
North Dakota	1	137
Ohio	32	128
Oklahoma	7	55
Oregon	9	0
Pennsylvania	0	22
Rhode Island	0	0
South Carolina	7	32
South Dakota	20	137
Tennessee	37	129
Texas	16	75
Vermont	0	2
Virginia	2	27
Washington	6	0
West Virginia	1	12
Wisconsin	41	87
Wyoming	0	5
Total	666	2,331

Note: The production of bioenergy crops is not assumed in Arizona, California, Idaho, Nevada, New Mexico, and Utah.

Table 14. Changes in net farm income by State, 2008
Comparison between the wildlife management scenario and
the production management scenario

	Wildlife management scenario		Production management scenario	
	Switchgrass	**SRWC***	**Switchgrass**	**SRWC***
Million Acres	12.3	7.1	41.9	0
Million Dry tons	60.5	35.5	188.1	0
Quads	0.94	0.60	2.92	0
Billion Gallons of ethanol	5.36	3.15	16.67	0
Million Barrels of oil displaced	81.2	47.7	252.4	0
MW electricity capacity	14,119	9.086	43,897	0
Percent of electricity capacity	1.51	0.97	4.67	0
Billion kWh electricity (gasifier combined cycle)	98.9	63.7	307.6	0
Percent of electricity supplied	2.3	1.5	7.3	0

* SWRC - Short Rotation Woody Crop (poplar and willow)

Notes: Energy content of energy crops assumes 15.5 MBtu/dt for switchgrass and 17 MBtu/dt for hybrid poplar.
Ethanol conversion rate is assumed to be 88.8 gallons/dt.
Oil displaced does not subtract fuel used in crop production and conversion.
Electricity estimates assume gasifier combined cycle with 36% conversion efficiency and 80% operating rate.
Electricity capacity and supply taken from DOE energy Information Administration, *Annual Energy Outlook '99*
reference case for the year 2008.

Table 15. Annual energy production equivalents for bioenergy crops, 2008

Energy Supply Implications

Bioenergy crops are being developed as feedstocks for energy or biobased products. Table 15 presents the energy equivalents that could be obtained from bioenergy crop production under the two scenarios. Under the wildlife management scenario, the 96 million dry tons of biomass (60.5 million tons of switchgrass and an additional 35.5 millions tons from the annualized production of poplar that are harvested starting in 2009) produced is equivalent to 1.54 Quads (10^{15}Btu) of primary energy. Given current conversion efficiencies, this quantity could be used to produce 8.5 billion gallons of ethanol and displace 129 million barrels of oil annually if used as a transportation fuel in place of gasoline. Current annual fuel ethanol pro-

duction from corn is about 1.4 billion gallons. Alternatively, this quantity of biomass could be used to produce 163 billion kilowatthours of electricity (assuming a gasifier combined cycle technology), which is equivalent to about 3.8 percent of the electricity currently produced in the United States.

Under the production management scenario, annual bioenergy crop production of 188.1 million tons is equivalent to 2.92 Quads of primary energy. Given current conversion efficiencies, it could be used to produce 16.7 billion gallons of ethanol and displace 252 million barrels of oil each year. Alternatively, that quantity of biomass could be used to produce 308 billion kilowatthours of electricity which is equivalent to about 7.3 percent of the electricity currently produced in the United States.

SUMMARY AND CONCLUSIONS

The widespread introduction of bioenergy crops to agriculture could have significant impacts for the agricultural sector. Substantial cropland acres (up to 42 million acres at a switchgrass price of $40/dt) could be profitably shifted to the production of bioenergy crops under the price and management scenarios analyzed in this study. This level of production would make bioenergy crops the fourth largest crop produced in the United States, in terms of total acres, behind corn, wheat, and soybeans.

Net farm income is estimated to increase in the year 2008 by $2.8 wildlife management scenario and $6.0 billion under the production management scenario. In recent years, prices for traditional crops have been low. To maintain farm income, the Federal Government has made direct payments to farmers. These direct payments equaled $12.3 billion in 1998, $21.5 billion in 1999, and $22.9 billion in 2000. Bioenergy crops offer a potential new production activity that could have a positive impact on farm income.

Increased farm income is a result of the value of the bioenergy crop production itself, as well as an increase over projected baseline prices for traditional crops. Prices for traditional crops are estimated to increase from 3 percent to 14 percent depending on the traditional crop and the bioenergy crop scenario analyzed. Estimated prices are well within the range of the historic variability of traditional crop prices. For example, under the production management scenario ($40/dt for switchgrass), the corn price is projected to increase from a baseline price of $2.55/bu to $2.79/bu, a 9 percent increase. Over the past 5 years, market prices for corn have ranged from $1.95/bu to $3.24/bu (USDA, April 1999). During this same time, food prices have remained stable, generally averaging less than a 3 percent increase per year (Elitzak).

The analysis also indicates that CRP acres could become a significant source of biomass crops. Clearly, criteria to determine suitable CRP acres and appropriate bioenergy crop management practices must be developed before CRP acres can be used for bioenergy crop production. However, the analysis of the two management practices examined suggests substantial economic potential to use CRP program acreage for bioenergy crop production. The environmental ramifications of various management practices must be examined to ensure that there is not a substantial loss of environmental benefits resulting from the production of bioenergy crops on CRP acres. Research is ongoing to determine the implications of bioenergy crop production on environmental parameters such as biodiversity and soil and water quality (see, for example, the 1998 edition of Biomass and Bioen-

ergy, volume 14, number 4, for several articles. Also see Tolbert and Wright, 1998; Christian et al, 1997; Christian, 1997; Hanowski et al, 1997; Schiller et al, 2000; Ma et al, 2000, Tolbert et al, 1999; and Perry et al, 2000 among other studies).

Currently, about 2.6 Quads of the primary energy used in the industrial sector in the United States comes from biomass resources (USDOE, 1999). President Clinton, in an Executive Order signed August 12, 1999, called for a threefold increase in the use of bioenergy and bio-based products. Bioenergy crops could play a significant role in achieving that goal. Under the production management scenario, an estimated 188 million dry tons of biomass could be produced. This quantity is equivalent to 2.92 Quads of primary energy. If used to produce ethanol, production would increase nearly 1,100 percent over the current ethanol production level. Alternatively, 188 million dry tons of biomass could be used to produce nearly 7.3 percent of the electricity currently produced in the United States.

Interpretation of the results should consider the limitations to the analysis. For example, in the analysis, acres are allocated based on relative average profitability for an entire ASD. Variations within an ASD are not considered. Thus, while the average profitability of switchgrass may be greater than the average profitability of hybrid poplar and willow in most ASDs, there may be some acres within any given ASD for which hybrid poplar or willow are relatively more profitable than switchgrass. These situations are not captured by the analysis. As a result, nearly all of the acres allocated to bioenergy crop production are allocated to switchgrass. Additionally, the analysis considers only the timeframe of 1999-2008. Improvements in yields and production technologies are occurring for both bioenergy crops and traditional crops.

The analysis is also limited by the inability of the model to estimate price changes for alfalfa and hay. Thus, there may be some income losses in the livestock sector not accounted for in the analysis as well as corresponding gains in the production of hay and alfalfa.

Additionally, the analysis is a supply-side analysis only. It is beyond the scope of this project to analyze the infrastructure and prices needed to make bioenergy a reality. Farmgate prices of $40/dt are higher than mid-1999 market prices for fossil fuels. In addition, it should be noted that fossil fuel market prices do not fully reflect many of the environmental and social externalities associated with their use. This point is particularly significant in light of growing concerns over global climate change.

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GLOSSARY

Alternative crops – Crops other than the eight major U.S. crops (corn, wheat, soybeans, cotton, rice, grain sorghum, barley, and oats), alfalfa and other hay.

Bioenergy crops – Crops grown for industrial use (i.e., bioethanol, biodiesel, electricity, other bioproducts such as chemicals, plastics) rather than food and feed uses.

Biomass – Any product of a biological process that can be used to produce energy or bioproducts. This includes bioenergy crops as well as food processing wastes, agricultural residues such as corn stover and grain straw, other agricultural processing wastes such as cotton gin, forest and mill residues, animal wastes, and urban wood wastes.

Conservation Reserve Program – A land retirement program authorized by U.S. law to take environmentally sensitive agricultural land out of production in exchange for direct rental payments and cost-sharing.

Crop acreage shifts – A change in acreage dedicated to a given crop in response to changes in economic and/or production considerations.

Cropland - Agricultural land used for crops, pasture, or grazing. This category includes land from which crops were harvested or hay was cut, land in orchards, citrus groves, vineyards, nurseries, and greenhouses; cropland used only for pasture or grazing; land in covered crops, legumes, and soil-improvement grasses; land on which all crops failed; land in cultivated summer fallow; and idle cropland.

Crop budgeting – A detailed listing of prices, yields, practices, input and machinery use, and costs, associated with a specific crop or crop rotation.

Filter strips – Narrow bands of crop acreage, generally planted to grass, used to filter runoff from cultivated fields before the water enters a lake or a stream.

Fossil fuel – Fuel derived from plants that grew in past geologic ages (e.g. coal, natural gas, crude oil)

Hybrid poplars – Any one of a variety of poplars (genus *Populus*) bred for high productivity and short production cycles and used for fiber, energy or bioproducts.

Hybrid willow – Any one of a variety of willows (genus *Salix*) bred for high productivity and short production cycles and used for fiber, energy or bioproducts.

POLYSYS – A computerized economic simulation model of the U.S. agricultural sector in which planting decisions are made at the regional level (305 Agricultural Statistics District), while crop and livestock demands and market prices are solved at the national level.

Riparian buffers – Usually grass strips and/or trees and shrubs that are grown along the banks of water courses to protect the waterway from pollution caused by surrounding crop or pasture land. (See filter strips.)

Switchgrass- A warm season, native perennial grass (*Panicum virgatum)* that can be grown as a dedicated bioenergy crop.

Wetlands – an ecosystem that depends on constant or recurrent, shallow inundation or saturation at or near the surface of the substrate and displays the physical, chemical, and biological features reflective of a recurrent or sustained inundation. Common diagnostic features of wetlands are hydric soils, and hydrophytic vegetation.

Windbreaks – plantings of trees or brush for the purpose of sheltering an area from the direct impact of wind or to control snow drifting.

APPENDICES

Table of Contents

Appendix 1. List of Participants in POLYSYS Data Review Workshop
Knoxville, TN
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Appendix 2. Sources used in developing biomass budgets

Primary Data Source

State	Level of Resolution of Information	Source
Alabama	Substate	USDA (Benson), The University of Tennessee (De La Torre Ugarte)
Arizona	Substate	Experiment Station
Arkansas	Substate	Extension Service
California	**Substate**	**USDA (Benson), Extension Service**
Colorado	**Substate**	**Extension Service**
Connecticut	**State**	**Neighboring State (NY)**
Delaware	State	Extension Service
Florida	State	Extension Service, The University of Tennessee (De La Torre Ugarte)
Georgia	State	USDA (Benson), The University of Tennessee (De La Torre Ugarte)
Idaho	**Substate**	**Extension Service**
Illinois	**State**	**USDA (Benson)**
Indiana	**Substate**	**Neighboring State (IL and OH)**
Iowa	State	USDA (Benson)
Kansas	State	USDA (Benson), Experiment Station (Kansas State University)
Kentucky	State	Neighboring State (TN), Extension Service
Louisiana	**Substate**	**Extension Service**
Maine	**State**	**Extension Service**
Maryland	**State**	**Extension Service**
Massachusetts	State	Neighboring State (NY)
Michigan	State	USDA (Benson), Neighboring State (MN and IL)
Minnesota	Substate	The University of Tennessee (English)
Mississippi	**Substate**	**Extension Service, The University of Tennessee (De La Torre Ugarte)**
Missouri	**Substate**	**USDA, NC214 Regional Project**
Montana	**Substate**	**Extension Service and Personal Communication (Zidack)**
Nebraska	Substate	Extension Service, NC214 (Baker), Personal Communication (Bernhardt)
Nevada	State	Neighboring State (UT)
New Hampshire	State	Neighboring State (NY)
New Jersey	**State**	**Neighboring State (PA)**
New Mexico	**State**	**USDA (Benson), Extension Service**
New York	**State**	**Extension Service**
North Carolina	State	USDA, The University of Tennessee (De La Torre Ugarte)
North Dakota	Substate	Neighboring States (MT, SD, and MN)
Ohio	Substate	Personal Communication (Batte)
Oklahoma	**State**	**USDA (Benson)**
Oregon	**Substate**	**Extension Service**
Pennsylvania	**State**	**Extension Service**
Rhode Island	State	Neighboring State (NY)
South Carolina	State	USDA, The University of Tennessee (De La Torre Ugarte)
South Dakota	Substate	Extension Service and NC214 (Janssen)
Tennessee	**State**	**Extension Service, The University of Tennessee (De La Torre Ugarte)**
Texas	**Substate**	**USDA (Benson)**
Utah	State	USDA (Benson)
Vermont	State	Neighboring State (Maine)
Virginia	State	USDA
Washington	**Substate**	**Extension Service and Personal Communication**
West Virginia	**State**	**Neighboring State (VA)**
Wisconsin	**Substate**	**Neighboring States (MN and IL)**
Wyoming	State	Extension Service

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Appendix 3: Bioenergy Crops Management Practices

Appendix Table 3.1: Management Practices for Bioenergy Crops on Cropland Acres Currently Planted to Traditional Crops

(SE = Southeast; App = Appalachia; CB = Corn Belt; LS = Lake States; NP = Northern Plains; SP = Southern Plains; PNW = Pacific Northwest; NE = Northeast)

I. Switchgrass
   A. Establishment Year
      1. 1x disk, 1.15x grain drill
      2. 5.75 lb seed/acre (Alamo in SE, APP, SP; Cave-in-Rock in NP; Pathfinder in CB, LS)
      3. 1x lime (1 ton/ac in LS, CB; 2 ton/ac in SE, APP; 0 elsewhere).
      4. 1x P (15 lb/ac P in all regions) and N (20 lb/dry ton yield in SE; 25 lb/dt yield in SP; 0 elsewhere).
      5. 1x 2,4-D (1 lb a.i./acre in all regions)
      6. 1x Plateau (2 lb a.i./acre in all regions)
      7. 1x harvest (mow, rake, 4x6 round bale, move to side of field and stack)
      8. Yield is 30 percent of expected average annual yield
   B. Maintenance Years (Years 2-10)
      1. 1x K (25 lb/ac in years 3, 6, and 9 east of the Mississippi River; no K west of the Mississippi River) and N (25 lb/dry yield ton annually in SP; 20 lb/dry ton yield annually elsewhere)
      2. 1x harvest annually (mow, rake, 4x6 round bale, move to side of field and stack)
      3. Yield is 67 percent of expected yield in year 2 and 100 percent in yrs. 3-10
      4. In year 10 following harvest, 1x application glyphosate (2 lb a.i./acre)

II. Hybrid Poplar
   A. Establishment Year
      1. 2x disk
      2. Manual planting of cuttings (8' x 10' spacing; 545 trees/acre; $0.24/cutting-planting)
      3. 1x Fusilade (quart/acre) or Transline (pint/acre) in all regions
      4. 1x Linuron (1.5 lb a.i./acre in LS) or 1x Oust (0.15 lb a.i./acre elsewhere)
      5. 3x cultivations
   B. Maintenance Years
      1. 1x N (75 lb/ac in yr 3 in PNW; 75 lb/ac in yr 4 elsewhere)
      2. 1x lime in yr 3 (1 ton/ac in SE, APP; 1.5 ton/acre in NP, SP; none elsewhere)
      3. 1x K in yr 3 (35 lb/ac in LS; 50 lb/ac in CB, APP; 40 lb/ac in SE; 15 lb/ac in NP, PNW; and 25 lb/ac SP) and 1x P in yr 3 (20 lb/ac in LS, SE, PNW; 15 lb/ac in NP, SP; 25 lb/ac in APP; 50 lb/ac in CB)
      4. 2x cultivation in yr 2 (all regions but PNW where it is 1x)
      5. 1x cultivation in yr 3 (all regions but PNW where it is 0x)
      6. 1x Seven in yr 2 (all regions but PNW where it is 0x)
      7. 1x harvest (feller buncher, skid, chip, blow into truck) (yr 10 in LS, CB, NP, NE; yr 8 in SE, SP; yr 6 in PNW)
      8. Following harvest, 1x glyphosate (2 lb a.i./ac) - forestry disk

III. Willow
   A. Establishment Year
      1. 2x disk
      2. Mechanical planting (6200 trees/acre; $0.10/cutting; $0.02/cutting to plant)
      3. 1x glyphosate (2 lb a.i./acre)
      4. 1x Goal (1 lb a.i./acre)
   B. Maintenance Years (Years 2-22)
      1. 1x N (100 lb/ac in yrs 2, 5, 8, 11, 14, 17, 20)
      2. 1x harvest in yrs 4, 7, 10, 13, 16, 19, 22 (Claas-Jaguar; blow into trailer; load into chip van)
      3. After final harvest, 1x glyphosate (2 lb a.i./ac), 2x heavy forestry disk, 1x harrow rake
      4. Yield is 60 percent expected yield in yr 4 and 100 percent expected yield thereafter

Appendix Table 3.2: Management Practices for Bioenergy Crops on Cropland Acres Currently Idled or Planted to Pasture

(SE = Southeast; App = Appalachia; CB = Corn Belt; LS = Lake States; NP = North Plains; SP = South Plains; PNW = Pacific Northwest; NE = Northeast)

I. Switchgrass
    A. Establishment Year
        1. 1x glyphosate (2 lb a.i./ac)
        2. 2x disk
        3. 1.15 grain drill
        4. 5.75 lb seed/acre (Alamo in SE, APP, SP; Cave-in-Rock in NP; Pathfinder in CB, LS)
        5. 1x lime (1 ton/ac in LS, CB; 2 ton/ac in SE, APP; 0 elsewhere).
        6. 1x P (15 lb/ac P in all regions) and N (20 lb/dry ton yield in SE; 25 lb/dt yield in SP; 0 elsewhere)
        7. 1x Plateau (2 lb a.i./acre in all regions)
        8. 1x harvest (mow, rake, 4x6 round bale, move to side of field and stack)
        9. Yield is 30 percent of expected average annual yield
    B. Maintenance Years (Years 2-10)
        1. 1x K (25 lb/ac in years 3, 6, and 9 east of the Mississippi River; no K west of the Mississippi River) and N (25 lb/dry yield ton annually in SP; 20 lb/dry ton yield annually elsewhere)
        2. 1x harvest annually (mow, rake, 4x6 round bale, move to side of field and stack)
        3. Yield is 67 percent of expected yield in year 2 and 100 percent in yrs. 3-10
        4. In year 10 following harvest, 1x application glyphosate (2 lb a.i./acre)
II. Hybrid Poplar
    A. Establishment Year
        1. 1x glyphosate (2 lb a.i./ac)
        2. Moldboard plow, 2x disk
        3. Manual planting of cuttings (8' x 10' spacing; 545 trees/acre; $0.24/cutting)
        4. 1x Fusilade (quart/acre) or Transline (pint/acre) in all regions
        5. 3x cultivations
    B. Maintenance Years
        1. 1x N (75 lb/ac in yr 3 in PNW; 75 lb/ac in yr 4 elsewhere)
        2. 1x lime in yr 3 (1 ton/ac in SE, APP; 1.5 ton/acre in NP, SP; none elsewhere)
        3. 1x K in yr 3 (35 lb/ac in LS; 50 lb/ac in CB, APP; 40 lb/ac in SE; 15 lb/ac in NP, PNW; and 25 lb/ac SP) and 1x P in yr 3 (20 lb/ac in LS, SE, PNW; 15 lb/ac in NP, SP; 25 lb/ac in APP; 50 lb/ac in CB)
        4. 2x cultivation in yr 2 (all regions but PNW where it is 1x)
        5. 1x cultivation in yr 3 (all regions but PNW where it is 0x)
        6. 1x Seven in yr 2 (all regions but PNW where it is 0x)
        7. 1x harvest (feller buncher, skid, chip, blow into truck) (yr 10 in LS, CB, NP, NE; yr 8 in SE, SP; yr 6 in PNW)
        8. Following harvest, 1x glyphosate (2 lb a.i./ac)
III. Willow
    A. Establishment Year
        1. 2x disk
        2. Mechanical planting (6200 trees/acre; $0.02/cutting)(0.10/cutting; 0.02/cutting to plant)
        3. 1x glyphosate (2 lb a.i./acre)
        4. 1x Goal (1 lb a.i./acre)
    B. Maintenance Years (Years 2-22)
        1. 1x N (100 lb/ac in yrs 2, 5, 8, 11, 14, 17, 20)
        2. 1x harvest in yrs 4, 7, 10, 13, 16, 19, 22 (Claas-Jaguar; blow into trailer; load into chip van)
        3. After final harvest, 1x glyphosate (2 lb a.i./ac), 2x heavy forestry disk, 1x harrow rake
        4. Yield is 60 percent expected yield in yr 4 and 100 percent expected yield thereafter

Appendix Table 3.3: Management Practices of Bioenergy Crops on Conservation Reserve Program Acres

I. CRP Acres under the Production Management Scenario
A. This scenario assumes that upon expiration of current CRP contracts:
1. The same acres are reenrolled in a CRP program at 75 percent of the rental rate that they currently receive
2. The acres will be allowed to be replanted into switchgrass, poplar, or willow
3. Government sharing of establishment costs is not assumed
4. Annual harvest is allowed
5. Management practices to encourage high biomass yields are used
6. Early-out options with no penalty are allowed
B. CRP acres allowed to be harvested include all acres currently enrolled in CRP program in designated geographic areas for biomass energy crop production except:
1. Acres in special-uses categories (riparian buffers, filter strips, windbreaks, wetlands, etc.)
2. Acres designated as essential to maintaining water quality in watersheds
3. Acres designated as essential to maintaining critical wildlife habitat in high-priority wildlife regions (i.e., Prairie Pothole region, etc.)
C. Management practices:
1. Acres replanted to high-yielding switchgrass or poplar or willow varieties suitable to region
2. Herbicide applications the same as for non-CRP biomass acres
3. Fertilizer applications applied in same years as for non-CRP biomass acres at the same rate for poplar and willow. For switchgrass, P, K, and lime applied as for non-CRP acres and nitrogen applied at a rate of 10 lb/ton expected yield for switchgrass everywhere but in the South Plains where the rate is 15 lb/ton expected yield
D. Harvest practices:
1. For switchgrass, annual harvest of entire field is allowed, 4-6" height
2. For poplar and willow, harvest of entire field in same years as for non-CRP acres
E. Biomass yields on CRP acres are adjusted relative to yields on non-CRP acres using a crop efficiency index provided by FSA

II. CRP Acres under the Wildlife Management Scenario
A. This scenario assumes that upon expiration of current CRP contracts:
1. The same acres are reenrolled in the CRP program at 75 percent of the rental rate that they currently receive
2. The acres will be allowed to be replanted into switchgrass, poplar, or willow
3. No government sharing of establishment costs is assumed
4. Management practices to ensure high wildlife diversity are used
5. Early-out options with no penalties are allowed
B. CRP acres allowed to be harvested include all acres currently enrolled in CRP program in designated geographic areas for biomass energy crop production except:
1. Acres in special-uses categories (riparian buffers, filter strips, windbreaks, wetlands, etc.)
2. Acres designated as essential to maintaining water quality in watersheds
3. Acres designated as essential to maintaining critical habitat in high-priority wildlife regions (i.e., Prairie Pothole region, etc.)
C. Management practices:
1. Acres replanted to high-yielding switchgrass or poplar or willow varieties suitable to region. Planting will use no-till operations. Poplar and willow will be planted with a cover crop
2. Glyphosate herbicide application of 2 lb a.i. in establishment year
3. Nitrogen fertilizer applied every 3 years beginning in year 2 to switchgrass at a rate of 10 lb/expected ton in all regions but the South Plains where the rate is 15 lb/expected ton. Nitrogen applied to poplar and willow as on non-CRP acres. Potassium and phosphorus added as on non-CRP acres for all biomass crops. No lime added for any biomass crop
4. Cover crop of annual ryegrass planted with switchgrass and poplar and willow at a rate of 3 lb/ac and 5 lb/ac respectively

D. Harvest Practices:
    1. Harvest will be every 3 years for willow and after 10 years for poplar
    2. For switchgrass, half of the field will be harvested in years 3, 5, 7, and 9 and the other half will be harvested in years 4, 6, 8, and 10 at a height of 6-8"
E. Biomass yields are adjusted by an index of crops on CRP acres compared to non-CRP acres

Appendix 4.   Regional Net Present Value production costs and returns for bioenergy crops (per acre)(price=$2.58/MBtu)

	Northeast			Appalachia		
	Switchgrass	Poplars	Willows	Switchgrass	Poplars	Willows
Mature Yield	4.87	39.87	16.23	5.84	35.77	15.00
Revenue	$1,246.16	$976.69	$2,176.78	$1,494.37	$984.55	$2,011.82
Seed Cost	$27.93	$123.40	$701.89	$27.93	$123.40	$701.89
Fertilizer N	$240.39	$23.99	$158.20	$260.95	$21.73	$144.93
Fertilizer P	$4.26	$6.33	$0.00	$4.02	$5.98	$0.00
Fertilizer K	$6.82	$5.36	$0.00	$7.30	$5.73	$0.00
Fertilizer Lime	$47.15	$20.98	$0.00	$45.33	$20.18	$0.00
PH* Chemical	$13.09	$34.76	$88.11	$13.09	$34.76	$88.11
PH Labor	$15.50	$15.92	$7.66	$13.01	$13.20	$6.45
PH Mach Var	$24.16	$21.23	$7.98	$19.28	$18.94	$8.25
PH Mach Fixed	$33.79	$27.72	$11.55	$27.31	$25.30	$11.88
Interest OPI	$15.95	$166.15	$238.66	$16.54	$143.92	$235.80
Harvest Cost	$523.02	$403.74	$956.27	$504.81	$481.57	$934.22
CU* Chemical	$25.44	$25.44	$12.64	$25.44	$28.58	$12.64
CU Labor	$0.94	$3.94	$2.24	$0.79	$3.67	$1.89
CU Mach Var	$1.93	$14.91	$7.53	$1.43	$15.37	$6.79
CU Mach Fixed	$2.78	$26.52	$13.59	$2.25	$25.24	$10.88
Total Cost	$983.14	$920.38	$2,206.33	$969.50	$967.56	$2,163.76
Returns	$263.02	$56.31	($29.55)	$524.86	$16.99	($151.94)

	Corn Belt			Lake States		
	Switchgrass	Poplars	Willows	Switchgrass	Poplars	Willows
Mature Yield	5.98	46.26	15.80	4.80	44.06	15.34
Revenue	$1,530.19	$1,133.22	$2,119.11	$1,228.25	$1,079.33	$2,057.42
Seed Cost	$10.85	$123.40	$701.89	$10.85	$123.40	$701.89
Fertilizer N	$243.60	$19.79	$130.51	$195.66	$19.79	$130.51
Fertilizer P	$3.92	$11.63	$0.00	$3.92	$4.65	$0.00
Fertilizer K	$4.05	$5.31	$0.00	$4.50	$3.72	$0.00
Fertilizer Lime	$12.04	$0.00	$0.00	$12.04	$0.00	$0.00
PH* Chemical	$13.09	$34.76	$88.11	$13.09	$32.89	$88.11
PH Labor	$14.82	$15.07	$7.22	$16.14	$16.43	$7.79
PH Mach Var	$24.03	$20.56	$8.23	$24.80	$20.55	$7.96
PH Mach Fixed	$35.48	$27.92	$12.16	$36.12	$27.02	$11.82
Interest OPI	$13.69	$155.13	$233.04	$11.74	$147.80	$233.12
Harvest Cost	$569.02	$435.20	$945.32	$502.85	$425.70	$937.70
CU* Chemical	$25.44	$25.44	$12.64	$25.44	$25.44	$12.64
CU Labor	$0.90	$3.73	$2.11	$0.98	$4.07	$2.28
CU Mach Var	$1.90	$14.36	$7.29	$1.97	$14.96	$7.42
CU Mach Fixed	$2.89	$24.98	$12.77	$2.95	$26.39	$13.07
Total Cost	$975.75	$917.26	$2,161.30	$863.10	$892.82	$2,154.30
Returns	$554.44	$215.96	($42.19)	$365.14	$186.51	($96.88)

*PH - Pre Harvest
*CU - Post Harvest

	Southeast		Southern Plains		Northern Plains		Pacific Northwest
	Switchgrass	Poplars	Switchgrass	Poplars	Switchgrass	Poplars	Poplars
Mature Yield	5.49	36.00	4.30	30.01	3.47	38.31	34.37
Revenue	$1,404.81	$990.88	$1,100.30	$826.01	$887.92	$960.22	$1,062.95
Seed Cost	$27.93	$123.40	$27.93	$123.40	$10.85	$123.40	$123.40
Fertilizer N	$248.11	$21.02	$249.77	$19.61	$149.75	$18.67	$23.38
Fertilizer P	$3.98	$4.72	$3.90	$3.47	$3.98	$3.54	$5.28
Fertilizer K	$7.20	$4.52	$0.00	$2.61	$0.00	$1.65	$1.95
Fertilizer Lime	$44.21	$19.68	$0.00	$29.87	$0.00	$22.04	$0.00
PH* Chemical	$13.09	$34.76	$13.09	$34.76	$13.09	$34.76	$33.14
PH Labor	$13.03	$13.24	$12.45	$12.73	$15.49	$15.73	$10.51
PH Mach Var	$20.20	$19.44	$20.61	$19.49	$24.87	$20.88	$16.30
PH Mach Fixed	$29.38	$26.33	$28.95	$27.01	$37.40	$28.93	$22.23
Interest OPI	$15.96	$143.38	$14.11	$145.43	$9.69	$157.96	$93.09
Harvest Cost	$476.44	$481.53	$445.97	$433.49	$405.86	$400.78	$624.69
CU* Chemical	$25.44	$28.58	$25.44	$28.58	$25.44	$26.03	$32.12
CU Labor	$0.79	$3.68	$0.76	$3.54	$0.94	$4.00	$4.85
CU Mach Var	$1.50	$15.93	$1.75	$16.23	$1.97	$15.25	$20.84
CU Mach Fixed	$2.43	$27.35	$2.65	$28.55	$3.09	$27.13	$39.30
Total Cost	$929.73	$967.57	$847.37	$928.78	$714.25	$900.74	$1,051.08
Returns	$475.08	$23.32	$252.93	($102.76)	$173.67	$59.48	$11.87

*PH - Pre Harvest
*CU - Post Harvest