Cellulosic-Based Ethanol and the Contribution from Agriculture and Forestry

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

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

Scenarios

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

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

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

Cropland Cellulosic Modeling Methods

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

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

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

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

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

Consequences for Crop Markets and Land-Use Change

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

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

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

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

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

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

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

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

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

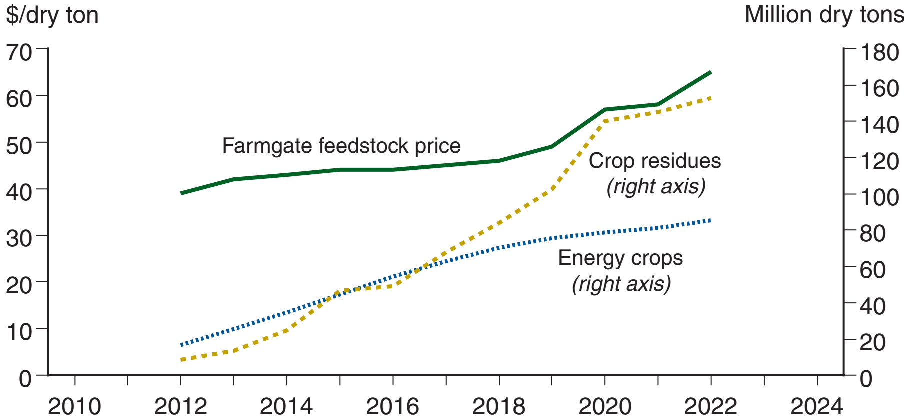
These scenarios requiring 12 to 20 BGY of biofuel from cropland feedstock were evaluated under a case where yield growth for corn is doubled and yield growth for energy crops is increased by 1.5 percent annually. A doubling of the baseline-projected increase in corn yield is higher than that assumed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

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

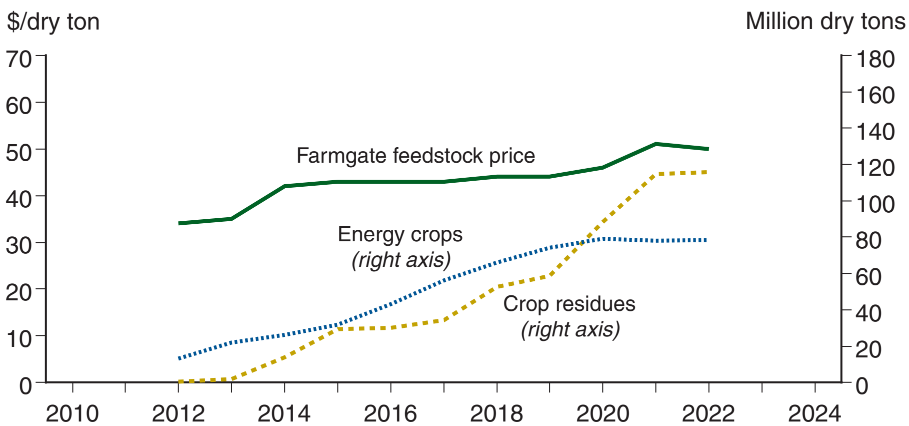
Figure 6.1

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

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



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



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

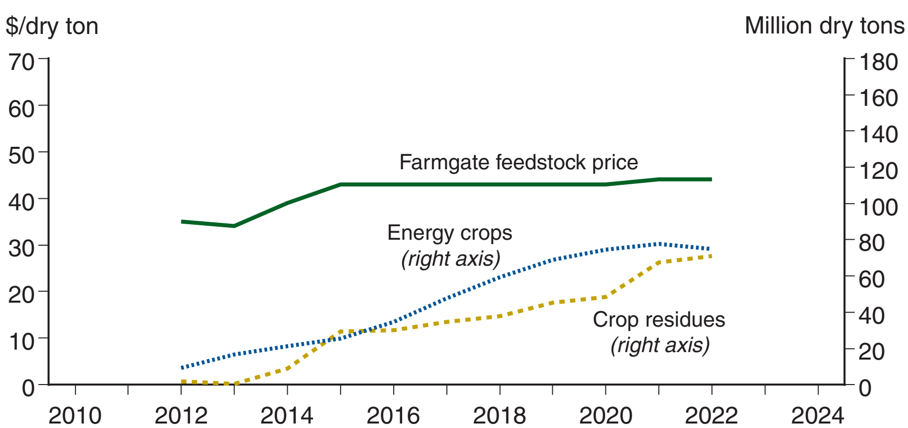


Table 6.1

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

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

--continued

Table 6.1

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

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

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

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

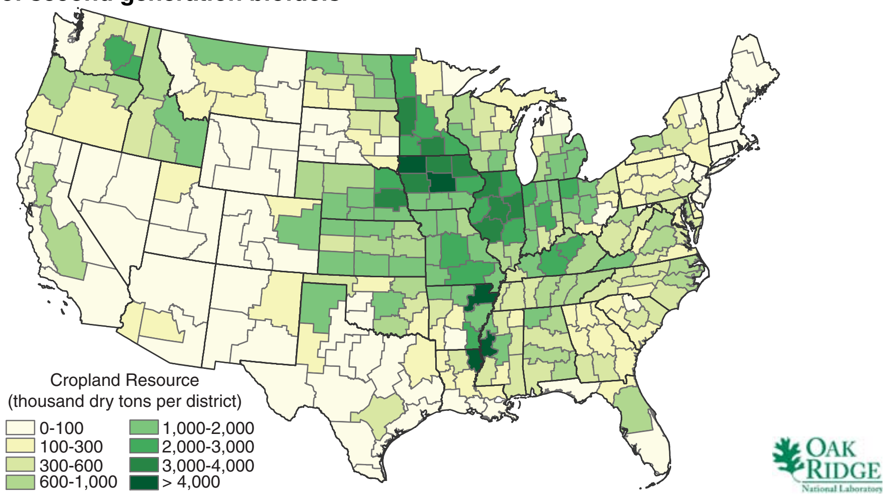
The regional breakdown of the feedstock requirements needed to produce 20 BGY of advanced biofuels from cropland (table 6.1) shows, as expected, the Corn Belt and Lake States dominant in the production of corn stover; the Northern Plains, Mountain States, and Pacific region tops in the production of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

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

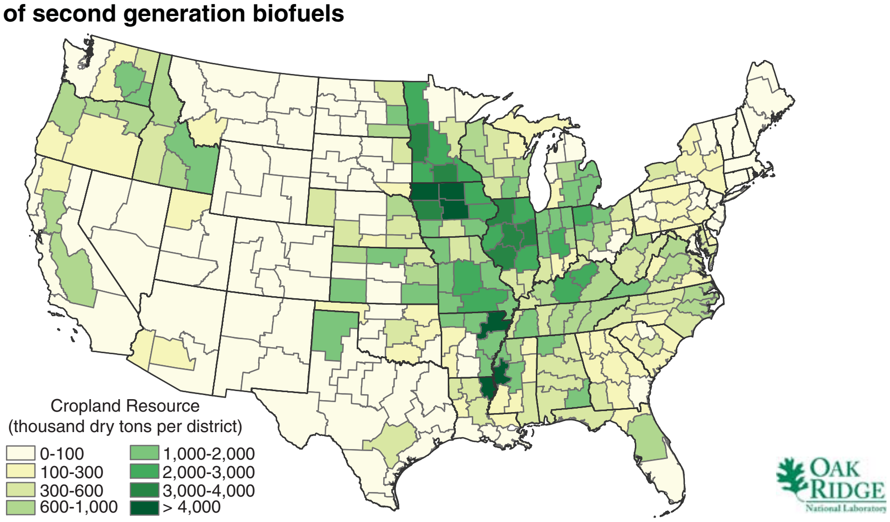
Figure 6.2

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

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



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



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

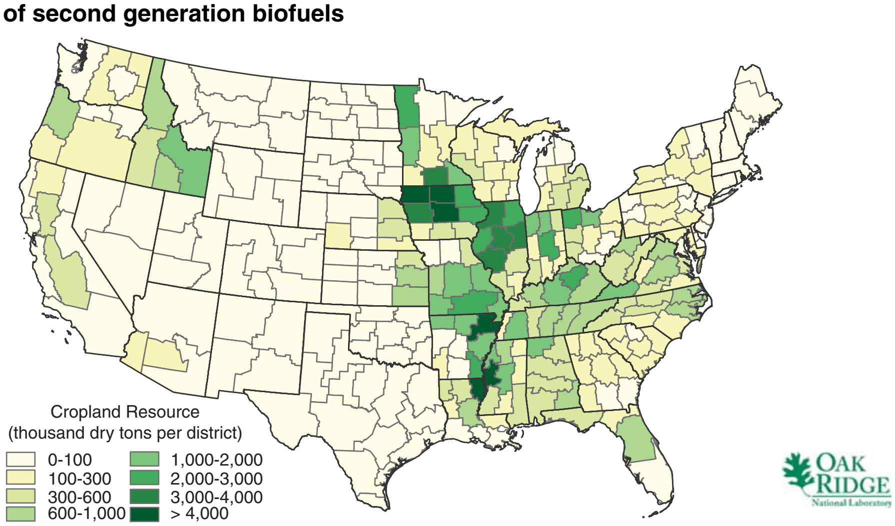


Figure 6.3a
Distribution of acres among major categories of land use in 2022

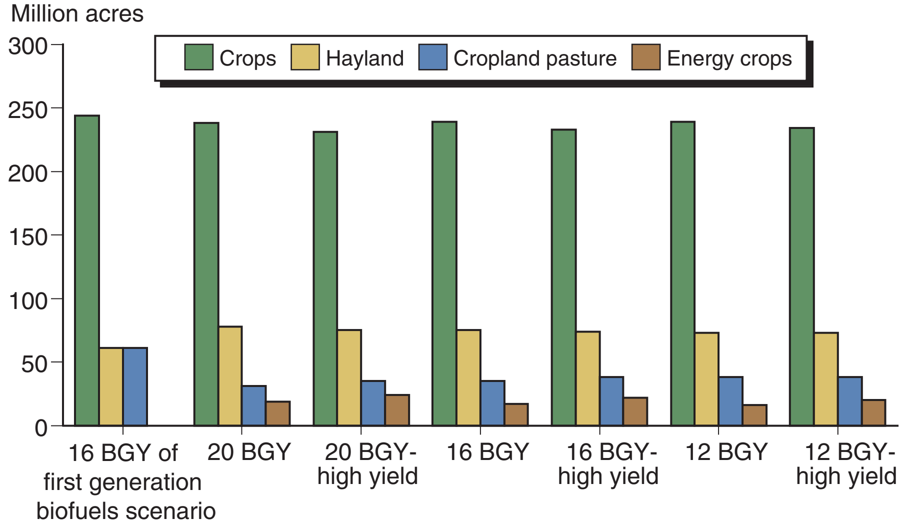
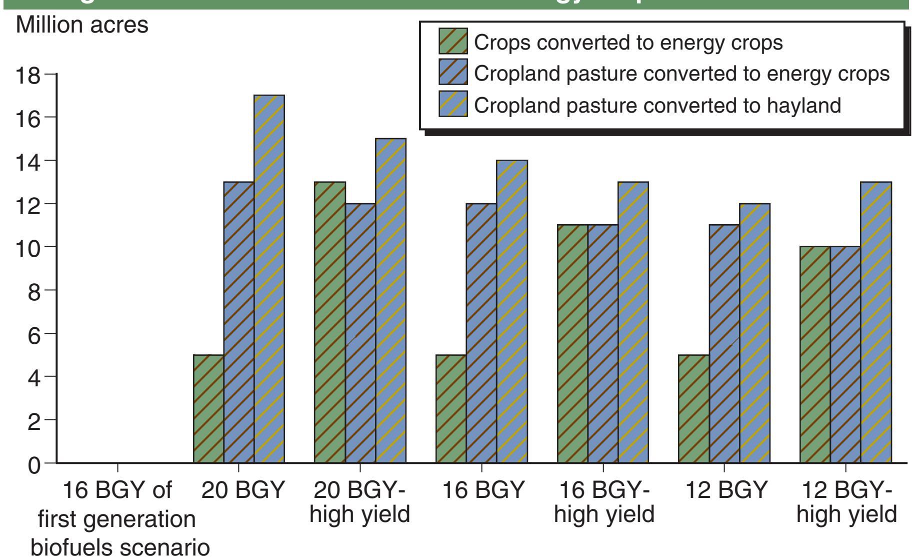


Figure 6.3b
Changes in land use to accommodate energy crops in 2022



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

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

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

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

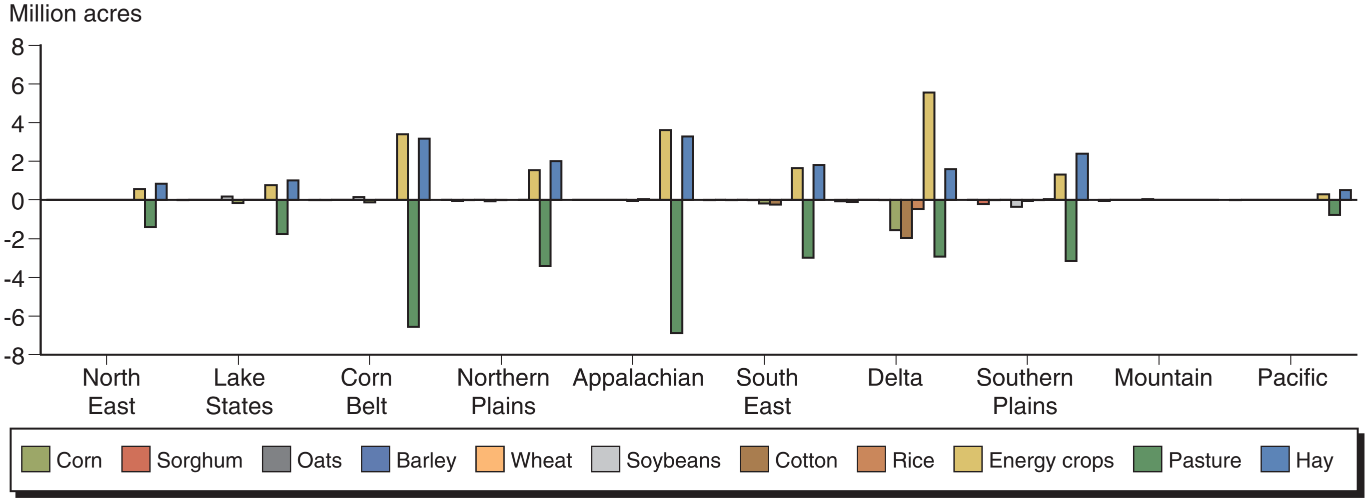
Land allocated to energy crops increases under the high-yield scenarios owing to the higher net returns from energy crops relative to corn and wheat with residue removal. Under higher assumed yields for energy crops, there is more displacement of cropland used for crops with energy crops and less conversion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

Contributions From Forestlands

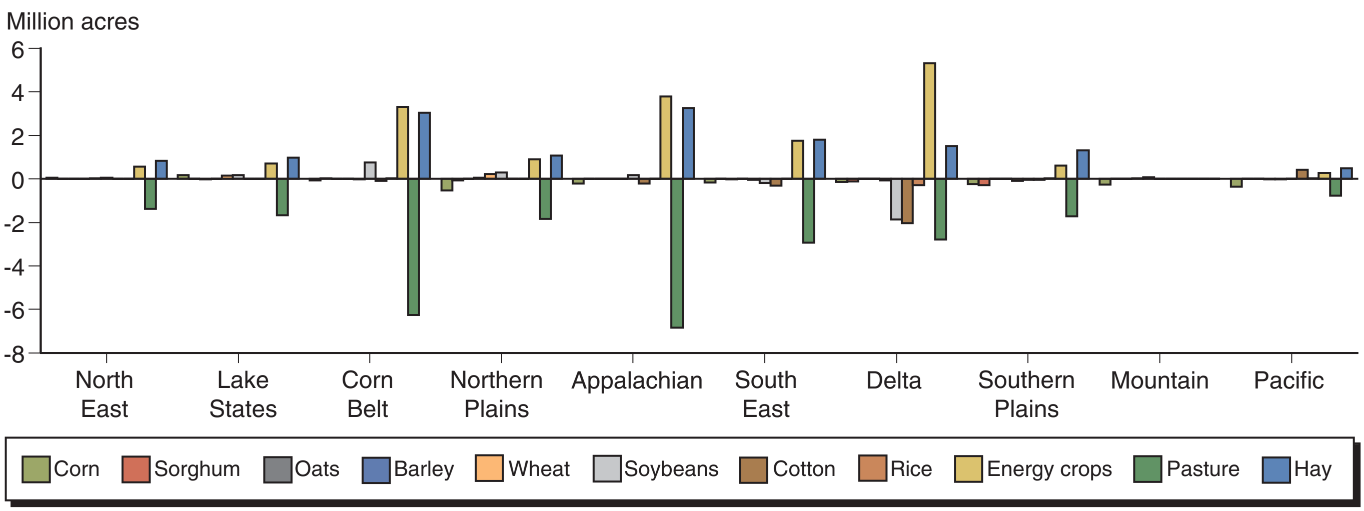
Contributions from forestland are assumed to provide sufficient feedstock to produce 4 BGY of second-generation and other renewable fuels. This biomass feedstock contribution is based on an examination of aggregated supply curves for forest residues and what could be available at forest road-side prices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

Figure 6.4
Summary of estimated land use change required to produce 36 BGY of renewable fuels in 2022

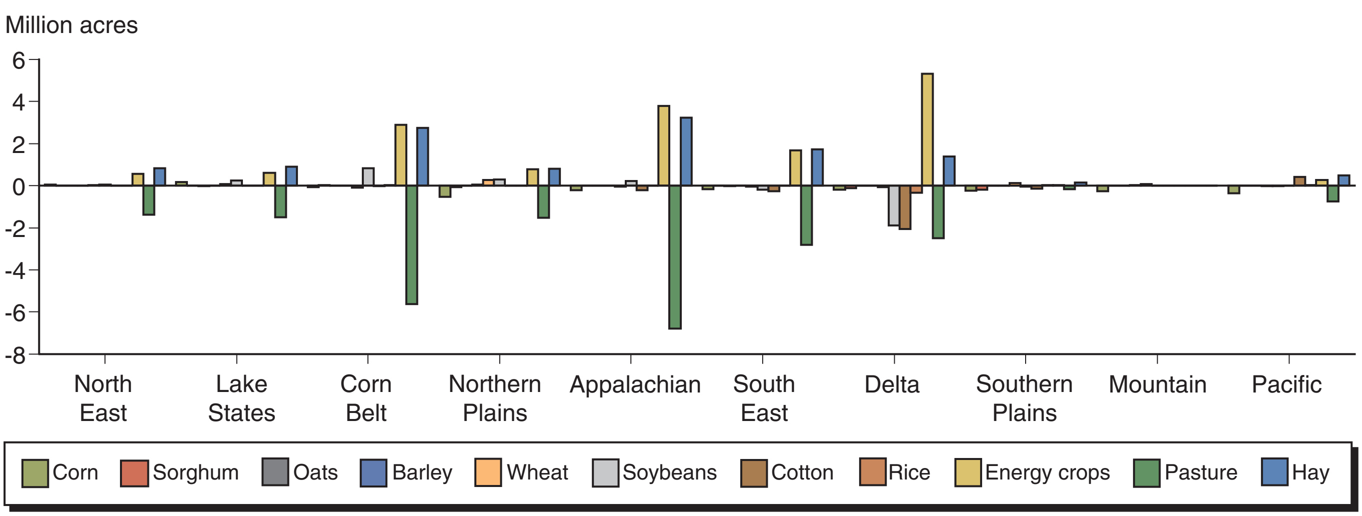
Cellulosic scenario - 20 BGY from cropland, 0 BGY from forestland, 0 BGY from imports



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



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



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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

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

Table 6.2

Annual forestland biomass availability

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

Notes:

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

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

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

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

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

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

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

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

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

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

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

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

Figure 6.5

Production and costs for forestland wood

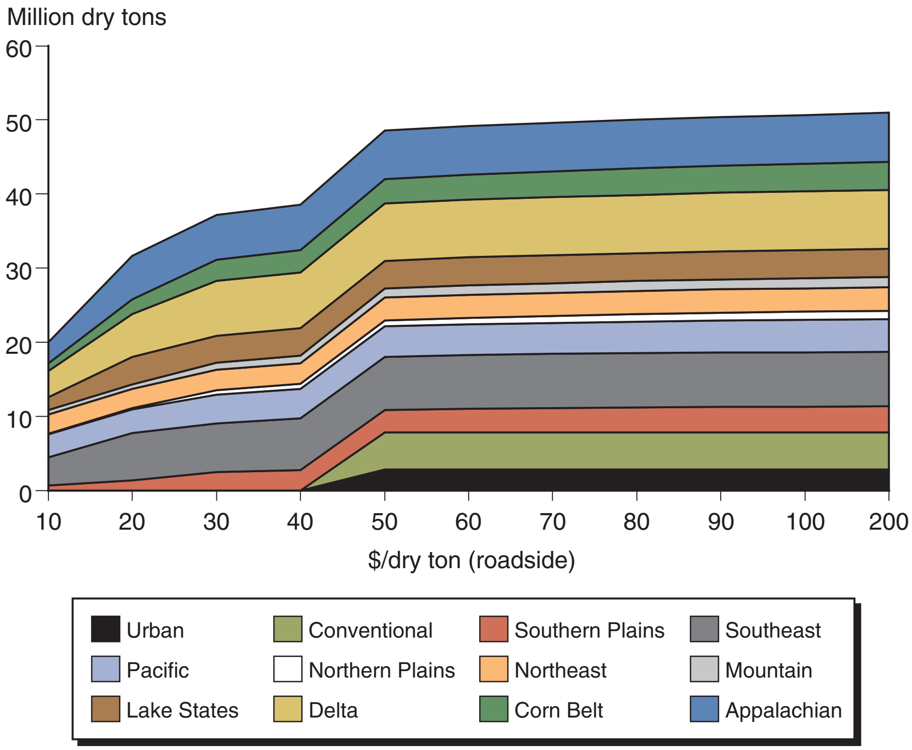


Figure 6.6

Forestland biomass resources

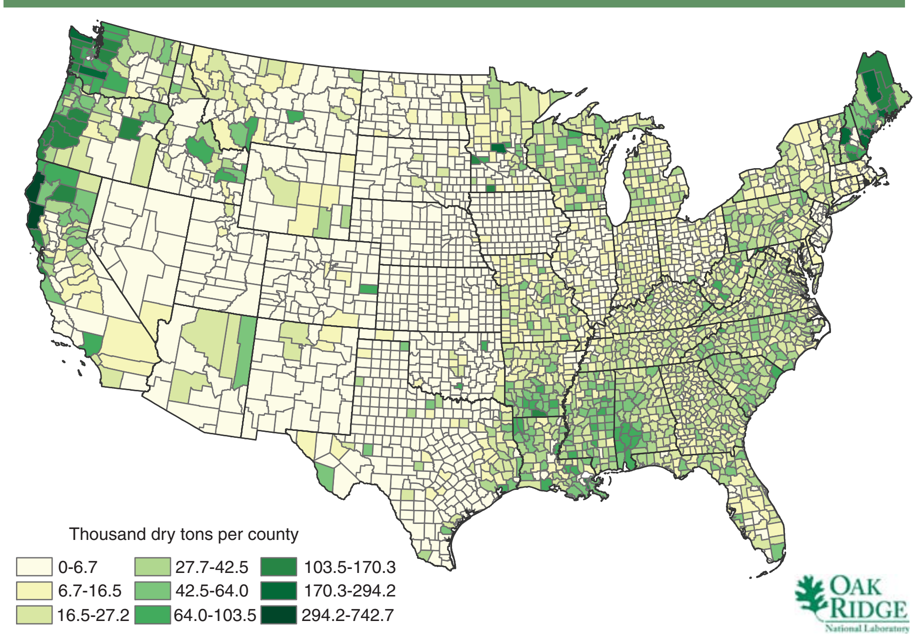
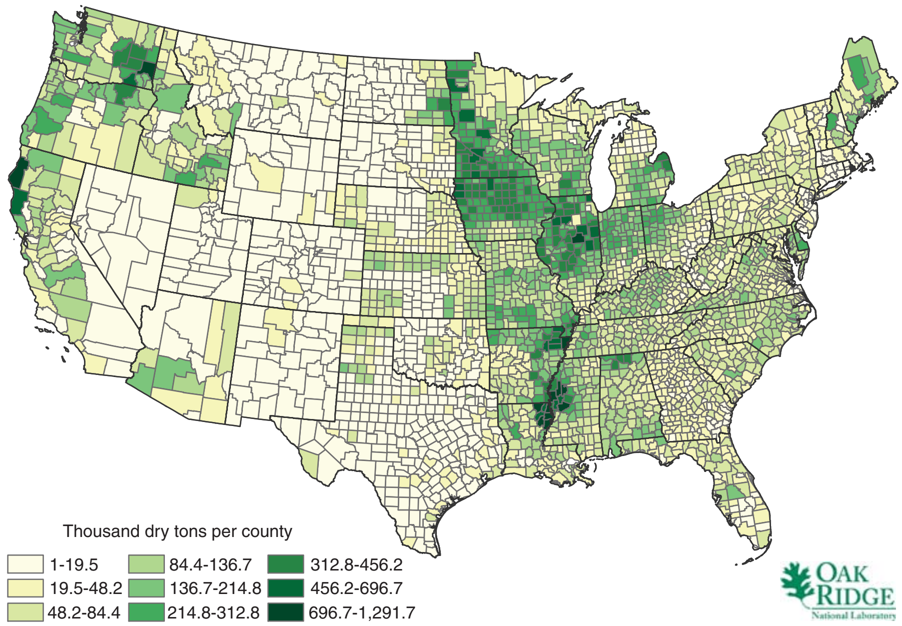


Figure 6.7
Cropland and forestland biomass resources



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

Contributions From Imports

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

Implications for Future Research

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

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

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

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

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

Skog, K. 2009. Cellulosic-based ethanol and the contributions from agriculture and forestry In: Increasing feedstock production for biofuels. Economic drivers, environmental implications, and the role of research. Biomass Research, a development initiative: 63-80; 2009