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# Biomass Crop and Ethanol Supply From Agricultural Lands in the United States with Methodology, Estimation Results, and State-by-State Simulations

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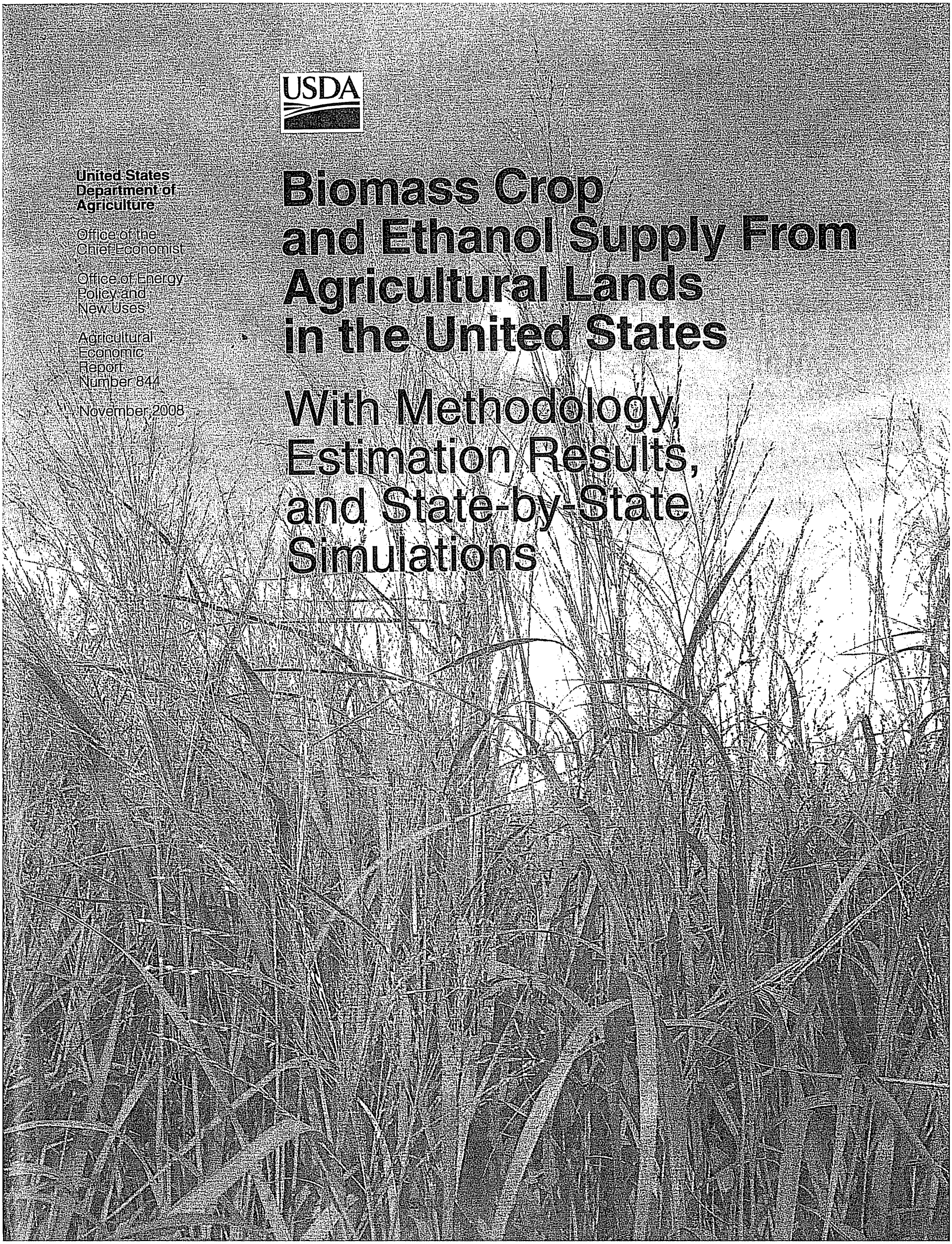

**United States Department of Agriculture**

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# Biomass Crop and Ethanol Supply From Agricultural Lands in the United States

## With Methodology, Estimation Results, and State-by-State Simulations

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# Biomass Crop and Ethanol Supply From Agricultural Lands in the United States with Methodology, Estimation Results, and State-by-State Simulations

*Paul W. Gallagher and Hosein Shapouri

## Abstract

We estimated the biomass crop supply from U.S. farmland, accounting for the contribution of marginal lands, gauging effects of removing income support programs, and returning some Conservation Reserve Program (CRP) land where biomass production can be sustained. We excluded biomass yield growth because we believe the infrastructure to sustain this growth is not in place. We estimate that 484 million tons of biomass could be brought into production, with 176 million tons on cropland and the remainder coming from marginal farmland. However, it could take a decade with sustained high biomass prices to induce the necessary reallocation of farmland resources. Presently, the land-value effects of existing programs may deter the adoption of biomass processing technologies. Cropland policies more conducive to biomass expansion are reviewed.

The ethanol market analysis sketches some plausible market developments that could influence the adoption of biomass ethanol (BE). That is, a corn-ethanol (CE) industry expansion has pushed CE costs up to the point where BE could be competitive. Still, the new entrant, BE, would likely compete with narrow profit margins in the commodity fuel market. But the equilibrium with impending technology suggests ethanol output of 45 billion gallons, or about one-third of U.S. gasoline consumption. However, removing the ethanol subsidy would reduce profitability to near the competitive margin, even if anticipated processing yields for BE occur in the intermediate term. Justifications for retaining the ethanol subsidy are reviewed.

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# Biomass Crop and Ethanol Supply From Agricultural Lands in the United States with Methodology, Estimation Results, and State-by-State Simulations

An adequate resource base and a viable processing sector are the main issues regarding a public investment for a biomass-fuel industry in agriculture. Further scrutiny of both issues may point to an improving outlook for this industry in the intermediate term. First, the farmland resource base likely extends beyond cropland. Second, the technology situation is changing rapidly; technical feasibility of processing was questionable a few years ago, but now construction of commercial processing facilities is beginning because some important technical barriers, such as the need for pre-treatment enzymes and continuous process operation, have diminished. Competitiveness is emerging as the dominant processing issue for the intermediate term. Both the resource and processing dimension are considered in this report.

Previous research has established biomass as an economically accessible resource that could support a limited energy industry. For instance, crop residues are a potentially low-cost source of biomass (Gallagher et al. 2003). Adding an energy crop to substitute for conventional crops on commercial cropland could also contribute, especially if the cropland in the sustainable component of the Conservation Reserve Program (CRP), a U.S. Department of Agriculture (USDA) program that pays farmers to remove cropland from production, is used for energy crop production (Walsh et al. 2003). Both supply sources could account for about 15 percent of current gasoline consumption in the U.S., which is a moderate contribution.

But the biomass crop supply potential could still be larger, because some important supply sources have not been analyzed. First, the farmland resource base could extend beyond cropland and crop residues. According to a State-level analysis, biomass crops such as switchgrass, poplar, willow, and cottonwood are sustainable on land that is not suitable for annual crops (Downing and Graham); there are about 85 million acres of farmland used for pasture in the eastern half of the U.S. that could support a biomass perennial or tree crop. Second, crops that rely on income-supporting Government payments or land-idling conservation payments to supplement market-derived revenues could profitably switch to energy crop production, given today's high fuel prices and a suitable processing industry. So biomass crop supplies could replace some other, less competitive, crops.

The supply estimates presented in this paper account for a large-scale presence of biomass crops in U.S. agriculture, including elimination of Government programs that divert land from production or to marginal crops. We analyze an industry that does not yet exist, using a combination of econometrics, cost calculations, and programming methods, which are presented in three subsequent sections of this paper. First, we explain a model of land use and rent determination measures, and the effects of reallocating land from food crops and livestock pasture to biomass crops. Second, crop cost-estimation methods for perennials and trees are modified to incorporate the land value analysis, the implications of large-scale land use for biomass on land rent values, and energy crop cost. Third, the least-cost allocation of cropland and pastureland to biomass crops for a given level of output is determined through simulation. The model components determine a biomass supply curve, taken as a set of cost-output pairs from simulations of the least-cost output model. We show that biomass supply may approach 500 million tons on cropland and marginal land, given high biomass prices, a 10- to 15-year adjustment, and the elimination of Government programs.

Next, we review the implications of the biomass supply analysis for the emergence of a biomass-crop-ethanol industry. The biomass-ethanol (BE) supply curve is a simple reflection of the biomass supply curve through an available processing cost analysis. Then BE supply prices are compared with corn-ethanol (CE) supply prices, which are based on an agricultural market impact study. Finally, implications of a recent ethanol demand study are reviewed. We show that cost and demand conditions for adoption of a BE industry are favorable in the current environment of high energy prices.

## Land Rental Market

Large-scale energy crop production means that the new crop must bid land away from existing uses, and possibly attract unused land to biomass production. Thus, a model of land use was created. The model, derived from land supplies and demands for specific uses, defines the equilibrium price (rental rate) for using a unit of land. An excess supply curve for land bid into biomass crops features a positive relation between land used for biomass crops and the price (rental rate) for using a unit of land. Two distinct land markets, a cropland market for high quality land and a grazing (pasture) land market for lower quality land, are specified.

1. Theory: Consider the cropland market, as depicted in figure 1a. There is a fixed supply of cropland ($L_c$) in panel b. Also, the total demand is the sum of land demand for crop production (panel c) and demand for land in the CRP program (panel d). When there are no biomass crops, the equilibrium cash rental rate for cropland ($R_c^0$) is determined by the intersection of supply and total demand. Finally, the Excess Supply of cropland for Biomass Production ($C_e$) in panel a is defined as the difference between cropland supply and demand at a given value of the cash rental rate. Hence, increasing cropland used for biomass crops means that the land (rental) values must increase in order to bid the land away from food crop production and Government programs that remove land from production.

In the pasture land market in figure 1b, livestock-based grazing ($G_d$) is the main source of demand (panel b). Also, the supply of grazing land ($G_s$) is upward sloping (panel c), reflecting the possibility of bringing unused farmland (other than cropland) into use. Also, some cropland is used for pasture ($C_g$) in certain areas of the U.S. when pasture rents are high and cropland rents are low (panel d). Again, the equilibrium cash rental rate for pasture land ($R_g^0$) is determined by the intersection of supply and demand when no biomass crops are produced on marginal land. The excess supply of grazing land for biomass production ($G_e$) in panel a is the difference between supply ($G_s + C_g$) and demand ($G_d$) at a given rental rate for grazing land. Hence, increasing grazing land used for biomass crops can increase rental values.

2. Land Market Component of Simulation Model: An algebraic version of the land use model is useful for simulations of the rental market implications of using land for biomass crops. In a linear econometric version of this model (below), component supply and demand equations are given in equations 1, 2, 4, and 5. Market equilibrium conditions for pastureland (equation 3) and cropland (equation 6) are also given. And the transfer of cropland to grazing use is specified as a function of the ratio of cash rents for grazing and crops. The categories of land use (demand) correspond to the U.S. Census of Agriculture. Thus, specification of land supply and demand equations is possible. Finally, notice that the values for biomass crop production on cropland

($C_e$) and grazing land ($G_e$) are specified as exogenous variables; then the implications of a given level of land in biomass crops for land rents and utilization for other purposes can be calculated.

Notice that the farmland base is exogenous to the land rent model. First, the amount of cropland ($L_g^*$) is perfectly inelastic in figure 1a and exogenous in the econometric model. Second, the amount of grazing land is potentially limited, even though the pasture supply curve in figure 1b is upward sloping—the amount of potential grazing land ($L_g^*$), defined as total farmland less cropland, is included as an exogenous shift variable in the pasture supply function.

**Pastureland:** 1. $G_d = \alpha_1 - \beta_1 R_g + \gamma_1 \overline{N}^*$ *(Demand)*
2. $G_s = \alpha_2 + \beta_2 R_g + \gamma_2 L_g^*$ *(Supply)*
3. $G_s + C_g = G_d + G_e^*$ *(Equilibrium)*
**Cropland:** 4. $C_d = \alpha_4 - \beta_4 R_c + \gamma_4 X^*$ *(Demand)*
5. $C_z = \alpha_5 - \beta_5 R_c + \gamma_5 \overline{R}_z^*$ *(CRP)*
6. $\overline{L}_c^* = C_d + C_z + C_g + C_e^*$ *(Equilibrium)*
**Arbitrage:** 7. $C_g / \overline{L}_c^* = \alpha_7 + \beta_7 \left(R_g / R_c\right)$
**Endogenous:** $G_s$, $G_d$, $C_g$, $C_d$, $C_z$, $R_g$, $R_c$
$G_s$ : Grazing Land Supply, in million acres
$G_d$ : Grazing Land Demand (livestock), in million acres
$C_g$ : Cropland Used for Grazing, in million acres
$C_d$ : Cropland Demand for Crops, in million acres
$C_z$ : Cropland Demand for Conservation, in million acres
$R_g$ : Rental Rate for Grazing Land, in \$/acre
$R_c$ : Rental Rate for Crop land, in \$/acre
**Exogenous:** $N^*$, $L_g^*$, $G_e^*$, $P_c^*$, $R_z^*$, $L_c^*$, $C_e^*$
$N^*$ : Cattle population, in million head
$L_g^*$ : Grazing Land (farmland, other cropland), in million acres
$G_e^*$ : Grazing Land Used for Biomass Production, in million acres
$X^*$ : Food-Crop Returns, in \$/acre
$R_z^*$ : Government Payment Rate to Idle Land (CRP), in \$/acre
$L_c^*$ : Cropland, in million acres
$C_e^*$ : Cropland Used for Biomass Production, in million acres
$P^*$ : Consumer Price Index

3. Estimates: Supply and demand relationships of the land use model were estimated using cross section time-series data. The cross section element consists of State-level data for 27 major agricultural States of the U.S. Also, time series uses data from the 1997 and the 2002 censuses of agriculture for quantity data that are available. The cash rental rates are published annually by the USDA, but were not available for previous census years.

Other characteristics of specifications are also important. First, the estimated supply and demand functions adjust for States of different sizes. In particular, utilization rates, such as the fraction (0/1) of cropland used for crop production, are used as the dependent variable in regressions. Second, log-linear regressions are employed, ensuring equal percentage responses in States of different sizes. Third, the shift variable in the food demand equation, food crop revenues per acre ($X_i$)—the composite of (price plus Government payments) times yield—is a convenient way to account for technology improvements over time, land quality variation across space, and the presence of different Government commodity support programs across States[1]. Estimates of the component supply and demand schedules are given in table 1.

## Estimation of Biomass Cost

The cost analysis brings together the results of our land value analysis, experiments on biomass yield growth at various locations around the U.S., and biomass cost estimation methods that have been studied elsewhere. First, cost estimation procedures for perennial crops and tree crops with explicit land rent variables are given. Second, experiments on biomass crop yield and cost at specific locations within the agricultural area of the U.S. are reviewed. Third, procedures for approximating representative yields and costs in various regions of the U.S. are discussed.

1. Perennial Biomass Crops: A general cost function for a perennial crop splits expenditures into (1) establishment costs that are incurred once when the land is prepared for production, and (2) the annual costs of fertilization and harvest that are incurred for each year's crop (Hallam). As a first approximation, the establishment and annual costs are defined by fixed proportions production technology, and remain roughly constant for a given acreage across locations. However, the land rental component of annual costs and yields varies as the location and land quality vary. Hence, the cost function can be expressed as

$$C = (k\,E + A + R)\,/\,Y, \text{ and } k = r/\left(1 - 1/(1+r)^n\right),$$

where C: cost of production, in \$/ton
E: establishment costs—land preparation, seedlings, chemicals, in \$/acre
A: annual expenses for fertilizer and harvest, in \$/acre
R: annual expenses for land rental, in \$/acre
Y: annual crop yield, in tons per acre (t/acre)
k: amortization factor for establishment expenses
n: length of productive life of the perennial crop
r: interest rate

The amortized establishment expense, kE, can be thought of as the annual payment on a mortgage with a length that equals the useful life of the perennial crop. This cost function can be derived from a present value investment analysis that specifies a present value equal to zero.

2. Tree Crops: Production cost equals the average compounded value of annual costs in the numerator divided by the average annual yield of the plantation, as shown below: [2]

$$C = [E^* + m\,R]\,/Y^*, \text{ where}$$

$$E^* = [C_0\,(1+r)^9 + C_1\,(1+r)^8 + C_2\,(1+r)^7 + \ldots + C_8\,(1+r) + C_9]\,/\,9,$$

$$m = [(1+r)^8 + (1+r)^7 + \ldots + (1+r) + 1]\,/\,9, \text{ and}$$

$Y^* = Y / 9$

$C_i$: costs incurred in period i, for planting, maintenance, or harvest

In the numerator, we have separated establishment, maintenance, and harvest costs (E*) from average compounded rental costs (mR) because R varies across locations, while E* does not. Also, the stand yield is divided by the rotation period, which is the annual average yield when 1/9 of the stand is harvested each year with yield Y.

For demonstration, consider the investment analysis for a tree crop on one unit of land. Tree seedlings are planted at the end of an initial period 0, and then the stand is harvested at the end of year n. Expenditures are incurred in each period: for establishment in the initial periods, for maintenance in intermediate years, and for harvest in period n. Denote the costs for period i by $C_i$, where costs are measured in \$/acre. Separately, annual land rental, R, is paid at the beginning of every period. Finally, the logs are harvested at the end of period n with yield Y and sold at price C. The present value at the end of period 0 for a tree-crop investment with a 9-year rotation is:

$$V = -[\ (C_0 + R) + \ (C_1 + R)/(1+r) \ + \ (C_2 + R)/(1+r)^2 \ + \ldots\ldots + \ C_9/(1+r)^9\ ] \ + \ CPY/(1+r)^9 .$$

To find the break-even price where discounted returns exactly balance discounted costs, set V=0 and solve for P to obtain:

$$C = [\ (C_0 + R)\ (1+r)^9 + (C_1 + R)(1+r)^8 + (C_2 + R)(1+r)^7 + \ldots + (C_8 + R)\ (1+r) + \ C_9\ ]\ /\ Y.$$

Separating rental expenses and dividing by the rotation period gives the tree crop cost function. Cost functions for tree crops are discussed more generally, but without explicit land rental, by Hassan and Rose.

3. Yield Estimates, Cost Parameters, and Regions: Table 2 summarizes the critical results from several studies that were used for our cost estimates. Indeed, we found that field trial results for the main biomass crops are available for most of the main production regions around the U.S. Perusal of table 2 indicates that some of these studies focus exclusively on yield results; but some yield estimates in table 2 are the representative yield for an experiment. The parameters of the cost functions are also included when given.

Three principles were used to develop representative yield estimates from the reported yield estimates of an individual study in a particular State. First, yields that are reported for a single location experiment are given a 15-percent land quality discount to convert to the yield that would be obtained by a farmer with a typical quality of cropland. Second, a 20-percent discount on the yield from a "typical quality cropland" is applied when pastureland is used, because Downing and Graham report discounts of this magnitude for pastureland in Kentucky. Third, from experiments reporting yields for several varieties, average yields across varieties are used; but sometimes a variety or two are excluded from the average if their yields were exceptionally low.

The States included in the analysis focus on the eastern half of the United States, the section of the country that is naturally forested. For tree crops, States with an eastern border on the Mississippi River are included (figure 2a). For switchgrass, the eastern section of the next column of States (ND, SD, NE, KS, OK, and TX) was also included because crop agriculture still resembles the Midwest section of the U.S. (figure 2b). However, the rangeland of the Western U.S. was excluded, because experiments in the semi-arid regions of the U.S. are not readily available to determine yield potential, cost, and sustainability.

After land quality adjustments, a reported experimental yield is used for the State average yield in the State of the experiment. The same state average yield is also used for some nearby States in a similar agronomic region. For instance, the Iowa experiment for switchgrass is 4.3 tons per acre. So switchgrass yields of 4.3 tons per acre on cropland were used for the Cornbelt States: Iowa, Illinois, Indiana, Ohio, and Nebraska. The yield, cost estimates, and potential tree crops from various studies are shown in table 2. The yield estimates used for State averages are also shown in figure 2.

The inflation multiplier at the right of table 2 adjusts a particular study's cost estimates to the equivalent cost in 2005. The cost multipliers were constructed using the prices paid index for crops reported by the USDA/NASS. In turn, the 2005 cost estimates reflect \$55/bbl petroleum prices to define farmers' machinery operating costs and fertilizer expenses. Hence, 2005 equivalent costs were used in subsequent simulations because they approximate current conditions.

## Biomass Supply

A combined Land Market, Biomass Cost and Supply (LMBCAS) model was formed for each of the 27 States in the eastern part of the U.S. Each of these models was formed by adding equations to the State's land rent model. First, a set of equilibrium estimates of land rents, land allocations, energy crop costs, and quantities is given for any exogenously specified quantity cropland and grazing land to biomass crop production ($C_e$ and $G_e$). A typical State model considered the cost and yield of switchgrass and one tree crop on both cropland and grazing land. Second, the low-cost energy crop is chosen for each land type, and output is determined as the product of energy crop area and yield. The cost estimate approximates the minimum entry price at the farm level. Finally, the energy cropland allocations associated with a given farm price are determined, so that biomass production associated with a given farm-level price is also identified.

The following four equations determine levels for four additional endogenous variables, the cost on cropland and grazing land ($C_c$ and $C_g$), and biomass output from cropland and grazing land ($Q_c$ and $Q_g$):

$$8. \quad C_c = \begin{cases} C_c^s = \alpha_8 + \beta_8 R_c \; ; & if \; C_c^s < C_c^p \\ C_c^p = \alpha_8^t + \beta_8^t R_c \; ; & if \; C_c^s > C_c^p \end{cases}$$

$$9. \quad C_g = \begin{cases} C_g^s = \alpha_9 + \beta_9 R_c \; ; & if \; C_g^s < C_g^p \\ C_g^p = \alpha_9^t + \beta_9^t R_c \; ; & if \; C_g^s > C_g^p \end{cases}$$

$$10. \quad Q_c = Y_c \, C_e \, , \; where \;\; Y_c = \begin{cases} Y^s \; ; & if \; C_c^s < C_c^p \\ Y^p \; ; & if \; C_c^s > C_c^p \end{cases}$$

$$11. \quad Q_g = Y_g \, G_e \, , \; where \;\; Y_g = \begin{cases} 0.8 \, Y^s \; ; & if \; C_g^s < C_g^p \\ 0.8 \, Y^p \; ; & if \; C_g^s > C_g^p \end{cases}$$

Several component cost functions, $C_i^j$ are defined with i=c for cropland, i=g for pasture, j=s for switchgrass, j=p for poplar, j=w for willow, and j=c for cottonwood. The individual crop yield functions $Y^j$ are defined with a similar notation, using a 20-percent yield discount to distinguish between yields on cropland and grazing land. The cost functions are reduced to a linear function of land rents, using the component cost estimates and yields given in the previous section.

$C_e$ and $G_e$, the land allocations to biomass crops, are still exogenous. However, there would be an arbitrage process operating in the biomass market to determine these land allocations. To illustrate, suppose initially that $C_c>C_g$. Then processors would quit purchasing from cropland producers and begin buying from pastureland producers. Then the cropland allocation to biomass crops would decrease, $\Delta C_e<0$, and the grazing land allocation to biomass crops would increase, $\Delta G_e>0$. In turn, adjustments in the respective land rental markets would tend to reduce $C_c$ and $R_C$, and increase $C_g$ and $R_g$, eventually forcing the equality $C_c=C_g$. Similarly, if biomass consumers define an exogenous biomass price, P, then arbitrage will cause land reallocation to enforce two arbitrage conditions:

12. $P=C_C$
13. $P=C_g$

For simulation, a few programming statements were added to the LMBCAS model to enforce arbitrage and determine land allocations to biomass crops ($C_e$ and $G_e$) in the presence of discontinuities. First, a given biomass farm price, such as P=\$40/ton, is specified. Then the LMBCAS model is solved with arbitrary values of $C_e$ and $G_e$. After the $C_c$ and $C_g$ values are compared to each other and to P, $C_e$ and $G_e$ are adjusted incrementally to move towards the arbitrage equilibrium, equations (12) and (13). The biomass supply curve is empirically defined by choosing various values of P and finding the solution that had equal costs for both land sources.

We also determined biomass market entry conditions. The lowest entry price for a State is defined by the condition that there are no biomass crops, because any solution with $C_e>0$ or $G_e>0$ would have higher land rents and crop costs. Thus, biomass supply entry point is the lowest cost energy crop, with costs calculated using the "no-biomass-crop rental rate." In turn, the no-biomass-crop rental rates ($R_c^0$ and $R_g^0$) are the vertical intercepts for the $ES_c$ and $ES_g$ curves in figure 1. For instance, if $C_g^0$ and $C_c0$ are the farm cost for pasture and cropland using rental rates $R_c^0$ and $R_g^0$, and $C_g^0<C_c^0$, then $C_g^0$ defines the minimum farm level entry price for the State. Further, pastureland is initially the more efficient land source.

When $C_g^0< C_c^0$, there is a range of expansion where $C_e=0$ and $G_e>0$. This will occur as $G_e$ increases in this range, and Rg and Cg both increase. In this range, no cropland is used for biomass crops and there is no arbitrage. However, when $C_g$ increases to $C_g=C_c^0$, further expansions will include $C_e>0$ and arbitrage across land qualities will begin.

The entry point prices for the baseline can also be calculated using observed rental rates for 2002. The land market model was calibrated using constant level adjustments, so that observed rental rates for 2002 are estimated by the model when the actual energy crop allocations of $C_e=0$ and $G_e=0$, and 2002 values of exogenous variables are used to calculate model solutions. When any exogenous variable is altered, due to a modified Government policy or analysis for another year, entry point prices are calculated as solutions to the equations (1)–8

(11), also imposing $C_e$=0 and $G_e$=0. Each State is considered as a distinct market because agronomic conditions are relatively uniform within most States. In some equations of the land use model, such as pasture demand, changing States merely requires a different value for the exogenous livestock population variable. In other equations, such as cropland demand, different States have different parameters or specifications, due to regional differences in agronomic conditions. Agronomic conditions also define the production alternatives and cost conditions for biomass crops; specifically, switchgrass and one tree crop were defined as the production alternatives in most States. However, we assumed that only switchgrass would be produced in the States with land on the edge of rangeland in the Great Plains. Production alternatives and regional biomass yields are given in figure 2.

## Changing Government Programs

The biomass supply curve for each State was calculated for two situations. First, the baseline is the situation that existed recently in the 2002 Census Year. That is, all market conditions and Government programs are as they existed. Second, a "reduced Government programs scenario" was constructed to approximate the joint adoption of two policy changes. One policy change removes Government payments to produce food and feed crops.[2] The second policy change would allow the component of CRP land that is not environmentally sensitive to return to production. The means of estimating these policy changes are described below.

To simulate the removal of deficiency payments, the Government payments component was removed from the X variable in the cropland demand equation (4e).[3] The effect is to reduce the demand for land for food crop production and create pressure for reduced value for food crops. For a preliminary indication of the magnitude of this estimated effect, we calculated the demand shift from equation (4e) without regard for the simultaneous effect on the cash rent market. Nationwide, 12.6 million acres would be released from crop production and available for biomass crops, consisting of 4.4 million acres in the Great Lakes area, 7.5 million acres in the Great Plains, and widely dispersed acreage in the South and Delta.

Regarding the CRP program, the baseline simulation included an endogenous CRP demand equation (5e), which allowed CRP demand to adjust downward some as cropland rental rates increased. In the reduced programs scenario, the CRP allocation of cropland was taken as fixed and exogenous; equation (5e) was removed from the simulation model. We assumed that the environmentally sensitive component remained in CRP land. However, other CRP land is allowed to return to production. The idea is that acceptable conservation practices could be followed while making biomass crops. Table 3 gives CRP land in 2002. Table 4 summarizes CRP land in environmentally sensitive classifications, which remains out of production under our hypothetical program. Nationally there were 23.6 million acres in CRP in the baseline year. Under the reduced programs scenario, only 6.3 million aces would remain in the CRP.[4]

## Biomass Supply Estimates

Simulations shed light on biomass supply potential at the national and State level. First, consider estimates of the initial entry prices for biomass production in table 5. Regarding calculation, actual baseline (2002) data values for land rents are used to calculate cost for existing programs during the baseline year. In the second numerical column, the model solution uses estimates of land rental values for cropland and grazing land; the rent estimates use baseline (2002) values for most exogenous variables, but assume the release of CRP land, the removal of Government payments, and again, no production of biomass crops. The crop costs are significantly lower in the second numerical column, because Government programs are no longer supporting land values.

The farm-level entry prices from table 5 suggest locations for low-cost biomass. The lowest biomass crop cost will be found in the South and Delta regions initially, regardless of whether Government programs are present. Typical entry prices are around $25/ton with the Government programs. Without these programs, entry prices fall to $17.4/ton in the South to $25/ton in the Delta. Without Government programs, entry prices for some of the Great Lake States (MN, WI, and MI) are also low, about $25/ton. The entry prices of other States, mainly Midwest and borderline Plains States, are $10/ton to $15/ton higher.

The competitive advantage of Southern and Delta States stems from relatively low land values and high biomass yields. In contrast, biomass yields are lower and land values higher in Great Lakes and Plains States. Finally, higher land values in Lake and Plains States reflects relatively high yields of mainstream agricultural commodities, like corn, soybeans, and wheat.

Biomass supply potential is evaluated using moderate to relatively high biomass prices. The higher biomass price ($60/ton) in table 4 relates to the 2006 fuel market, today's biomass ethanol technology, and small plants. The lower biomass price ($35/ton) is derived from the 10-year trend value of gasoline prices and a moderate improvement in biomass-ethanol technology.

We calculated the derived demand prices for biomass given the existing state of biomass processing technology. A biomass demand price of $60/ton is consistent with wholesale gasoline prices from 2006 market conditions, biomass-ethanol processing yields that are achievable today (ethanol yield of 80 gallons per ton), and relatively small plants (capacity of 25 million gallons per year [Mgal/yr]) that can manage the input logistics. In contrast, a biomass demand price of $35/ton is consistent with the 10-year trend value of premium gasoline, a moderate improvement in processing yields (yield of 90 gal/ton), and an increase in the plant scale to the size of corn-ethanol plants (capacity of 75 Mgal/yr). These estimates build on a recent engineering cost study for biomass ethanol (McAloon et al.).

The details of the $60/ton calculations are:

| | | | |
|---|---|---|---|
| Premium gasoline price | $ | 2.05 | /gal |
| Less ethanol processing cost | $ | 1.326946 | /gal |
| Equals | $ | 0.723054 | /gal |
| Times yield | | 79.2 | /gal/ton |
| Equals | $ | 57.2659 | /ton |

Biomass Supply Estimates are summarized in table 6. The first two numerical columns again use baseline (2002) values for exogenous variables. The third column uses a recent USDA forecast of crop revenues for 2007 to evaluate the effects if recent high corn and soybean prices are sustained. State-level crop revenues were estimated using a national market revenue forecast for conventional food and feed crops and recent State shares of national revenues.

But Government payments were excluded to evaluate the full potential of biomass crops.

At $35/ton, U.S. biomass production is about 180 million tons, and most of the production is concentrated in the States with the low entry prices (South and Delta). Outside the South, Minnesota and Virginia also contribute. At a biomass price of $60/ton, supplies from the South and Delta increase about 60 percent. Also, Great Lakes and Great Plains States enter and produce amounts that are comparable to the South and Delta. The U.S. total production without Government programs is 484 million tons.

At $60/ton in 2007's high food price environment, the total biomass supply is 466.6 million tons. Compared to production at lower food and feed crop prices, there is 17.8 million tons (3.7 percent) less biomass production. Further, most of the biomass reduction is concentrated in the Great Lakes area, where biomass production declined by 12.9 million tons, and in the Great Plains, where biomass production declined by 5.1 million tons. In contrast, biomass production in the South, Delta, and East is essentially unchanged. Partly, the Midwest biomass reduction is large because the land demand for crops response is larger. Also, the revenue increase for corn and soybeans was concentrated in the Midwest, whereas southern commodities, such as cotton, rice, and sugar, did not experience large increases in 2007.

The biomass supply schedule for the United States and the composition of cropland and grazing land is shown in figure 3. This aggregation of State-level cost curves assumes that the Government features reduced CRP area and removed deficiency payment programs. At $60/ton, the total biomass supply of about 485.0 million tons includes 176.0 million tons coming from cropland.[5]

For comparison, Walsh et al. report a biomass supply from cropland of 188 million tons at an inflation-adjusted cost of $50/ton (p. 332). Our cropland estimate is about 122 million tons at $50/ton. Possibly, our estimate is lower because a biomass price increase boosts the demand for grazing land in biomass and reduces cropland supplies that are available for grazing or biomass. However, our overall estimate of biomass supply at $50/ton is 391 million tons, more than twice the Walsh et al. estimate, because we included grazing land conversion as a biomass crop supply.

## Land Market Reallocation

The increase in biomass production, accomplished with a $60/ton price, requires a considerable reallocation of farmland resources. For instance, about 40 million acres of cropland is reallocated to energy crops (Tables 7 and 8). Nationally, land released from CRP contributes 17 million acres, removing deficiency payments accounts for 12.6 million acres, and energy crop competition with food crops accounts for about 10.0 million acres. Besides cropland, about 85 million acres of other land is drawn to biomass crops; 46 million acres is diverted from livestock pasture use, and 38 million acres of heretofore unused farmland is planted to energy crops. But, one-third of the Nation's non-cropland farmland would be used for biomass crops.

Adjustments vary from State to State, depending on a particular land resource. Most States would use a mix of cropland and other land for biomass crops. But the top five States using cropland for energy crops in the simulations are Texas, Minnesota, North Dakota, Wisconsin, and Kansas. These five States account for 43 percent of the U.S. cropland used for biomass. The top five States using pasture for energy crops are Texas, Missouri, Oklahoma, Virginia, Kentucky, and Tennessee—these States account for 35 percent of the land used.

In turn, a considerable cash rent increase for land would be necessary to induce this extensive land reallocation. Across the country, cropland rental rates increase by at least 40 percent and often 100 percent above the baseline to accommodate $60/ton biomass (Table 9). Further, pastureland rental rates generally increase more than cropland in percentage terms. Hence, the difference between cropland and pastureland use values narrows. In fact, $60/ton biomass nearly elevates pasture rentals to cropland rentals in some States.

The advantage of tree crops over switchgrass depends on the level of land values. In the regions where a tree crop could be chosen, Lake States, Delta, and South, a tree crop was chosen at relatively low biomass supply levels and land values. Specifically, the estimated cost advantage for poplar over switchgrass is initially about $3/ton in Minnesota when biomass cost is $35/ton. Then the cost for both crops is about the same at $45/ton. And poplar has a $6/ton disadvantage by the time that the biomass price reaches $60/ton. The reason that the tree-crop advantage erodes is the 10-year delay before harvest and rising land values—switchgrass (or willow) harvesting can occur without much delay. In specific cases, the terrain or water availability of a specific location may at times dictate a departure from our least-cost calculation for crop choice. Then, adjustments to the supply price for biomass would be required.

Generally, removing Government production payments and conservation programs from cropland can improve land values and increase biomass supply at the same time in the presence of relatively strong biomass prices. To see this, consider the land supply estimates for Minnesota when CRP and payment programs are eliminated (figure 4). The pastureland supply is stable when programs are removed. But the cropland Excess Supply (ES) shifts rightward by about 1.5 million acres when the programs are removed. The vertical intercept of the initial cropland ES curve gives the baseline cropland rental rate without biomass crops at $85/acre. Cropland values would increase to $150/acre, and about 4.0 million acres of additional cropland supply would be available for biomass production when the biomass price is $60/ton. However, if the demand price for cropland corresponds to $35/ton biomass, about 1 million acres of cropland would be used for biomass and the cropland value would fall to $50/acre without Government programs.

## Implications for Biomass Ethanol Processing

Biomass ethanol (BE) may be entering the earliest phase of commercial production. A U.S. Government-supported project for the construction of six commercial-scale BE plants is underway (U.S. Department Energy [DOE] staff). Some firms with large pilot plants anticipate yields of 80 gal/ton. Others informally report the capability of continuous operation with similar yields in large pilot plants now. However, more pessimistic observers, such as bankers, base analysis on yields of 65 gal/ton (Russo).

Still, assessment of competitiveness and adoption prospects for BE processing may be relevant for the intermediate term. The components for our analysis are a BE supply curve that reflects the biomass supply curve; an estimate of CE supply that accounts for production cost and corn market impacts; and ethanol demand.

1. Biomass Ethanol Supply. For the biomass component of ethanol supply, the biomass supply curve (figure 5) is combined with the cost analysis of a hypothetical 25 Mgal/yr plant that obtains 80 gal/ton yield (McAloon, et al. p. 36). Our extension of this cost analysis is shown in Table 10. We also include labor requirements and estimate annual capital cost, including a risk premium. Initially the biomass input cost is \$60/ton in Table 10. Generally, the biomass cost estimate defines an ethanol supply curve when ethanol cost is calculated using various biomass prices, and the corresponding biomass supplies are multiplied by processing yield to arrive at ethanol output.

Further, a transportation and storage cost is added to the farm-level biomass price, so that BE supply prices are expressed on a Cost, Insurance, Freight (CIF) plant basis and ethanol cost is calculated on the basis of delivered biomass prices. The transport cost estimate, \$5.06/ton, is calculated with a current market truck transport rate, a truck capacity of 33,000 lbs, and a typical size of market areas. The storage cost estimate, \$5.5/ton, derives from a market rate of machine storage (\$0.432/ft$^2$), a storage density for biomass (11.25 ft$^2$/ton), and a storage loss of 2 percent annually. The combined handling cost for storage and transportation is \$10.57/ton. The transport cost estimate and the storage rental rate come from recent surveys (Iowa State University Extension).

Hence, the BE entry price (\$1.70/gal in figure 5a), reflects a delivered biomass price consisting of the lowest Alabama farm price plus handling costs of \$29/ton. The BE entry price (\$1.80) is somewhat higher in figure 3b, because processing yields are lower.

2. Corn-Ethanol Supply. An initial point and slope define an approximation for the CE supply curve ($S_{ce}$ [supply of corn ethanol] in figure 5). For the slope, we use a multiplier that gives the effect of a corn-processing demand shift in the corn and feed market on net corn cost (Gallagher and Schamel). The main adjustments included in this multiplier are reductions in corn feed demand, increases in corn area and production, and increases in byproduct feeding as corn prices rise and distillers dried grain (DDG) prices fall. The increase in corn use is converted from bushels of corn to gallons of ethanol by dividing by the ethanol processing yield (2.7 gallons e / bushel c)—the implied CE supply elasticity is 2.2, and the slope indicates that an ethanol price increase of \$1.00 increases output by 6.9 billion gallons.

For a reference point on the CE supply curve, use a price-output pair defined by a recent cost of production survey (Shapouri and Gallagher) to approximate price and actual conditions at the end of the 2006/07 crop year. The CE output is 5.43 billion gallons. Adjusting the survey result for changes in corn, byproduct, energy inputs, and the annual component of capital outlays gives CE production cost at \$1.67/gallon during the end of July.

The recent output growth rate of 1.25 billion gallons per year (Bgal/yr) in ethanol production for the 06/07 crop year may be a reasonable approximation for the growth rate in the intermediate future. First, it is the demonstrated capacity of input suppliers. Second, specialized capital goods producers tend not to over expand because they realize that their market may shrink to replacement demand after the investment boom recedes. For instance, distillation tanks and other equipment that last 15 years in a 15 Bgal/yr ethanol industry would require about 1 Bgal/yr of replacement equipment in a steady state. When the historical growth rate of production is applied for 6 years, we arrive at a capacity increase of 7.5 billion gallons, or an output level of 13.0 billion gallons (shown as $K_{ce}$ [capacity of corn ethanol] in figure 5), for the 2012 crop year.

CE production costs may increase with the capacity expansion if corn production growth is less than ethanol-based corn demand growth over the 6-year period. In turn, there has been an acreage component and a yield component to production growth. Specifically, there was a large acreage expansion in 2007, and likely a steady yield expansion, in excess of growth rates for feed and export demand. We determined an (exogenous) annual growth increment for corn production of about 4.46 billion gallons for 2007, due mainly to the large area increase. In subsequent years, the growth increment of about 0.6 billion gallons will be due mainly to corn yield increases on the recent trend line that would exceed trend growth rates for corn feed and export demand. Interestingly, the net supply growth for corn over the next 6 years is 7.45 billion gallons when converted to the ethanol equivalent supply shift. The ethanol supply growth based on corn production and demand trend shifts identifies the shift in ethanol supply and, therefore, the demand expansion that could occur without bidding up the corn price; it almost exactly matches the capacity growth estimate. Hence, ethanol production costs for corn could be about the same in the 2012 and 2006 crop years.

The combined ethanol supply curve ($S_t$ [total supply]in figure 5) indicates the cost of further output expansions and the potential allocations between CE and BE. Initially, expansions beyond the anticipated capacity for 2012 of 13.0 billion gallons go to lower cost CE. When the marginal cost reaches $1.67/gallon, however, the expansions would favor BE.

3. Ethanol Demand. There are two distinct markets for ethanol. First, ethanol can generally be sold at a high price (figure 5a) in the low-volume additives market, due to quality demands for clean and high octane fuel. However, there is a vertical segment of the demand curve at a volume where the quality demand is filled and the price drops. Second, ethanol competes directly with gasoline in this lower priced commodity fuel market. For instance, E85 would sell at a discount to gasoline in a market with informed consumers, because a dual fuel automobile does not go as far with E85 as it does with gasoline. Hence, the derived demand price in the ethanol market is lower than the additives market price.

The additive premium for ethanol over gasoline is limited to relatively low-volume ethanol markets. But a measure of the premium's extent in recent markets is useful, because the extent of potential price declines in large volume markets is also identified. In the recent past, State bans and Federal denial of liability waivers for methyl tertiary butyl ether (MTBE) have been removing an additive with quality attributes similar to ethanol's from the market. Indeed, there is evidence of a quality premium for ethanol during this removal period. Consider the difference between the wholesale ethanol price and the wholesale gasoline price ($d_t$) as the dependent variable in the regression. The independent variable, $Qm_t$, is the quantity of MTBE produced during the time period. For estimation, monthly data were used from the beginning of the first California MTBE ban in 2003 until the present. Also, the ethanol price at Bettendorf, Iowa, and the average wholesale price for regular gasoline was used to construct $d_t$. The regression using the most recent weekly data is

$$d_t = \underset{(3.88)}{0.854} - \underset{(2.5)}{0.00013}\, Me_t,$$

Std. dev of residuals = 0.304 $/gal, sample size=44

Where $d_t = Pe_t - Pg_t$, $Pe_t$ = Bettendorf ethanol price in week k, in $/gallon
$Pg_t$ =Iowa wholesale gasoline price in week k, in $/gallon
$Qm_t$ = MTBE production in 1,000 bbl/month
And t-values are given in parentheses.

This estimate suggests that declines in MTBE production increase $d_t$. Also, the dependent variable value $d_t = 0.854$ should occur when the MTBE phase-out is complete.

Another possible hypothesis is $H_0$: $d_t = 0.5$, the value of the consumption subsidy. The implied test statistic under this null hypothesis is F(2,43)=11.1, whereas the critical value is F*=3.2 at the 5-percent significance level. The null hypothesis is rejected.

Additives are also a major source of demand growth. We estimate the increase in ethanol's additive market for an outlook with high gasoline prices ($1.75/gal from a recent DOE baseline) by calculating the market expansions that would have gone to petro-additives with low oil prices. Specifically, we used the consumption of ethanol, MTBE, benzene, and alklylates from the baseline and the MTBE ban in 2012 from Gallagher et al. (p. 600). Then we calculated the increase in total additive consumption and added it to the 2005 baseline ethanol output. Accordingly, the estimate of ethanol's additive demand for 2012 is Qa=14.0 Bgal/yr. If gasoline prices do return to lower levels, though, petro-additive capacity that reduces ethanol's demand could be added. *Note:* $D^1_e$ and $D^0_e$ are ethanol demand with/without subsidy. $Q^0_c$, $Q^0_T$ and $Q^1_c$ are ethanol ouput. $S_{be}$ is supply of biomass ethanol.

In a commodity fuel market where consumers choose between gasoline and a blended fuel with ethanol concentration $\alpha$, retail market arbitrage accounts for the fuel substitution rate ($f_\alpha$) and forces price equality between fuels. Suppose retailers receive an ethanol blending subsidy (S) but otherwise apply the same competitive margin (M) to wholesale prices for gasoline ($P_g$) gasoline and blended fuel. Then the derived demand price for ethanol is (Gallagher 2007):

$$P_e = P_g + S - (P_g + M)\,(l/\alpha), \text{ where } l = 1 - 1/f_\alpha.$$

Interpolations between four observations on the fuel substitution-concentration function are defined by:

$$f_\alpha = 1.006641 - .05913\,\alpha + 0.97285\,\alpha^2 - 0.53679\,\alpha^3.$$

Then ethanol demand ($Q_e^d$) is the blending rate times gasoline demand ($Q_g^d$):

$$Q_e^d = \alpha\, Q_g^d$$

One ethanol demand function results from substitution to eliminate $f_\alpha$ and $\alpha$ from the ethanol price equation. The ethanol commodity demand estimate is defined for uniform blending rates greater than 10 percent.

The 2012 estimate uses anticipated price (Pg=\$2.06/gal) and consumption estimates ($Q_g^d$=150 billion gal) for the gasoline market (DOE). To complete the ethanol demand model, we also assume that recent gasoline retailing margins (M=\$0.47/gal) and recent ethanol subsidy policy (S=0.5 \$/gal) are maintained for the intermediate term. In figure 5a, notice that the price declines by about 25 percent as ethanol concentration increases from 10 percent (quantity is 15 Bgal/yr) to 66 percent (100 Bgal/yr), due to the reduced fuel economy associated with ethanol.

4. Market Equilibrium. A short-run and long-run equilibrium for 2012 are both given in figure 5a. For the short-run, the 13.0 Bgal/yr output and capacity is slightly less than the estimate of the additives market, so relatively high ethanol prices (e.g., \$2.9/gal) might occur briefly. At the long-run equilibrium, the market may clear at the lower commodity fuel price of $P_e^0$ = \$2.08/gal due to the entry of BE in addition to CE. Corn-ethanol production would still expand some, to about $Q_c^0$ = 15.9 Bgal/yr, and total output would expand to about $Q_t^0$ = 45.0 Bgal/yr. The difference, 31.3 Bgal/yr, is BE output.

However, BE would approach the competitive margin and contract considerably if the ethanol subsidy is removed (S=0.0). When ethanol demand shifts downward to $D_c^1$ in figure 5a, the ethanol price declines to $P_e^1$ = \$1.80/gallon and total output declines to $Q_t^1$ = 20 Bgal/yr. CE adjusts downward slightly to $Q_c^1$ = 14 Bgal/yr, and BE adjusts downward substantially to 6 Bgal/yr. The ethanol price is very close to the entry price of \$1.7/gal, which defines the competitive margin for the lowest cost biomass crops.

A similar analysis, based on lower processing yields (Y=65 gal/t), has a steeper total supply schedule figure 5b. Initially, the equilibrium price is somewhat higher, the total ethanol output lower, and the BE output is more than proportionately lower, at 16 Bgal/yr. Further, removing the subsidy shifts ethanol demand below the competitive margin, and BE output is zero.

The market equilibrium analysis considers intermediate (1 to 2 years) to long-run (10-15 year) adjustments. The CE supply adjustments include adjusting feed demand within a marketing year, corn acreage allocation between crop years, and historical corn-yield growth. Similarly, the cropland component of BE supply includes interyear reallocation of cropland to other biomass crops in other regions of the United States. But longer run land conversions of pastureland are also included in the BE supply curve. Similarly, the demand analysis assumes uniform blending above the 10-percent level in conventional automobiles and the adoption of E85 technology across the fuel market. Hence, it would take several years to attain the equilibrium, even after CE expansion and cost increases put it on equal footing with BE.

5. Incremental Welfare Analysis. It turns out that there is a net social cost of extending the subsidy to BE in the intermediate term. However, the net cost is considerably smaller than the U.S. Treasury outlays. For demonstration, consider figure 6. Initially, CE output satisfies

ethanol demand at price $P_e^0$ = \$2.30/gal and $Q_c^0$ = 17.6 Bgal/yr. Eventually, extending the subsidy to BE yields market-clearing quantity, $Q_t^1$ = 45.0 Bgal/yr, and price, $P_e^1$= \$2.07/gal.

The welfare change areas in figure 6, and associated estimates, are:

| | | |
|---|---|---|
| Consumer Surplus: | + (A+C) | + \$7.19 billion |
| BE Producer Surplus: | + (Z+B) | + \$4.71 billion |
| CE Producer Surplus: | - C | - \$3.84 billion |
| BE Subsidy Expenditures: | - (B+D) | - \$14.57 billion |
| CE Subsidy Expenditures: | | + \$0.85 billion |
| Net | | - \$ 5.68 billion |

Definitions:
A and C: Consumer surplus
Z and B: Producer surplus
- C : Producer surplus
- (B + D) BE Subsidy expenditures

$S_t$: Total supply
$S_{ce}$ Corn ethanol supply
$S_{be}$ Biomass ethanol supply

The change in CE subsidies, not shown graphically, is the change in CE production (17.6 - 15.86 Bgal/yr) times the subsidy rate of \$0.51/gal.

The net welfare loss is smaller than the subsidy because the consumer and BE gains offset the welfare cost. Equivalently, the net loss can be expressed on a per unit basis by dividing the welfare loss by the BE output in equilibrium. Thus, the net welfare cost is \$0.21/gallon of BE in the intermediate term.

## Conclusions

In this study, we have estimated the biomass crop supply from U.S. farmland. We accounted for the contribution of marginal lands. We also gauged the implications of removing income support programs that are tied to food and feed crop production and returning some CRP land where biomass production can be sustained.

To conduct these estimations, we used the periodic census of agriculture instead of relying exclusively on the annual data from the usual commodity markets that have dominated farm income determination in the past. Cross section/time-series estimates from two recent censuses suggest statistically significant livestock pasture and cropland use response to rental rates in the eastern half of the United States. Also, the land use effects of shifts in cattle population and crop returns (commodity prices, Government payments, and yields) were significantly measured, at least for a first approximation, using a combination of spatial and time-series variation. Still, continual updating of such important economic relationships is important for ongoing research activity. For simulation, we relied on a 2002 baseline year from the most recent census—this gives one consistent reference point from the end of a long period of relatively steady market situation and policies. Our simulations calculate the changes associated with the introduction of a set of biomass crops, the associated ethanol industry, and the biomass supply estimates associated with price increases for conventional commodities.[6]

For an upper limit estimate of biomass crop supply, we considered a relatively strong biomass price. We also excluded biomass yield growth because the infrastructure to sustain this growth is not in place. We estimate that 484 million tons of biomass could be brought into production, with 176 million tons on cropland and the remainder coming from marginal farmland. At best, with sustained high prices and today's ethanol yields, an industry based on biomass and corn crops could provide enough to meet about 30 percent of current U.S. gasoline consumption.

It will take a while to establish a large biomass ethanol industry. The cropland component could enter production within a few years by switching crops on cropland. But a sustained biomass price increase would be necessary to induce conversion of marginal lands. Indeed, lags of a decade could occur with tree crops before land conversion and tree rotation periods are completed. An extensive reallocation of the farmland resource would be required.

Biomass crops could sustain current cropland values without the existing Government programs. In fact, the rent increases for some simulations with $60/ton biomass and no Government programs were substantial in many States. Presently the land-value effects of existing programs may deter the processing adoption that could sustain farm prices of $60/ton for biomass. One possibility is to allow a biomass production subsidy to replace Government payments for conventional crops and CRP diversion. Alternatively, a biomass production subsidy could be focused on marginal land, without major effects on cropland values and conventional crop markets.

The ethanol market analysis sketched some plausible market developments that could influence the adoption of BE. That is, a CE industry expansion has pushed CE costs up to the point where BE could be competitive. But the favorable additive-based ethanol prices may erode with significant ethanol expansions. Then the new entrant, BE, would likely compete with narrow profit margins in the commodity fuel market. Yet the equilibrium with impending technology suggests ethanol output of 45 billion gallons, or about one-third of U.S. gasoline consumption.

However, removing the ethanol subsidy would reduce profitability to near the competitive margin, even if anticipated processing yields (80 gal/ton) for BE occur in the intermediate term. And lower processing yields (65 gal/ton) would push BE crop processing below the competitive margin *sans* subsidy. Hence, BE processing from crops will likely be a subsidy-dependent sector in the intermediate term.

In short, our analysis took a market-and-subsidy approach instead of explicitly modeling the mandates of the Energy Independence and Security Act (EISA) of 2007. But our equilibrium estimates of 15 million gallons of CE and 45.0 million gallons of total ethanol output, with present policies and anticipated processing technology, conform to the mandates of the EISA. The event-based uncertainty associated with this result stems from the amount of time it will take to (a) develop the assumed biomass processing industry, and (b) realize the estimated biomass crop supplies. Technically speaking, there is also a risk of compound estimation error due to the unavoidable use of stacked and overlapping simulation models.

Strict competitiveness in today's market environment is a harsh performance standard for public investment in this emerging industry. First, induced innovation theory suggests that recent high energy prices create an incentive to develop technology for higher processing yields, higher crop yields, and improved ethanol fuel economy. It may take a decade or so for the induced innovation cycle to run its course, based on our experience with the CE industry. Indeed, the CE industry experienced a 25 percent growth in processing yields and a doubling of crop yields, but the improvements took 30 years. Intermediate-term market performance and welfare evaluation should acknowledge the possibility for considerable improvement.

Second, externalities that were not considered in this report may justify the consumption subsidy for BE in the intermediate term. These external effects include local economy benefits, trade and macroeconomic disruption costs avoided, and $CO_2$ reductions. In converting pastureland, the U.S. agriculture sector might take an initial step backwards on the $CO_2$ front before beginning to make annual contributions to global warming improvements through biomass production. But the large supply estimates of this report suggest the possibility of stabilizing the U.S. economy. And our market-based estimate of the social cost (dead weight loss) from developing this new industry ($0.21/gal) is moderate in comparison to recent gasoline price increases. Finally, the market impacts of pasture conversion may include other factors, such as cattle population reductions, that point to an immediate and offsetting improvement in the $CO_2$ balance.

## Table 1. Estimates of Land Market Supply and Demand (t-values in parentheses).

### (1e) Pasture Demand

**Corn Belt, South, Delta, East:**

$$\ln(G_{d_i}) = \underset{(16.23)}{3.03172} - \underset{(12.82)}{0.79787}\ \ln(R_{g_i}/P_t) + \underset{(21.09)}{0.88503}\ \ln(N_i)$$

$i = mi, mn, wi, il, in, ia, mo, oh, ky, tn, al, fl, ga, ar, la, ms, ny, pa, va, nc, sc$

**Southern Plains:**

$$\ln(G_{d_i}) = \underset{(5.35)}{4.266752} - \underset{(1.65)}{0.5472}\ \ln(R_{g_i}/P_t) + \underset{(7.22)}{0.074466}\ \ln(N_i)$$

$i = sd, ne, ks; ok, tx$

$P_t$ is a consumer price index. $P_t = 1.0$ in 2002.

### (2e) Pasture Supply

$$\ln\left(G_{s_i}/L_{g_i}\right) = -\underset{(2.82)}{1.2049}\ D_{cb_i} - \underset{(1.71)}{0.6124}\ D_{se_i} - \underset{(1.05)}{0.3362}\ D_{dl_i} - \underset{(2.62)}{0.9773}\ D_{ee_i} - \underset{(1.79)}{0.6115}\ D_{gp_i} + \underset{(2.20)}{0.2579}\ \ln\left(R_{g_i}/P_t\right)$$

$$D_{cb_i} = \begin{cases} 0, & otherwise \\ 1, & for\ mi, mn, wi, il, in, ia, mo, oh, ne, sd, nd \end{cases} \qquad D_{dl_i} = \begin{cases} 0, & otherwise \\ 1, & for\ ky, tn, ar, la, ms \end{cases}$$

$$D_{se_i} = \begin{cases} 0, & otherwise \\ 1, & for\ al, fl, ga, nc, sc \end{cases} \qquad D_{ee_i} = \begin{cases} 0, & otherwise \\ 1, & for, ny, pa, va \end{cases}$$

$$D_{gp_i} = \begin{cases} 0, & otherwise \\ 1, & for\ ks, ok, tx \end{cases}$$

### (4e) Cropland Demand

**Corn Belt:**

$$\ln\left(C_{d_i}/L_{c_i}\right) = -\underset{(11.41)}{1.36777} + \underset{(9.78)}{0.235345}\ \ln\left[(X_i - R_i)/P_t\right] - \underset{(2.35)}{0.04322}\ \ln\left[N_i/L_{c_i}\right]; \quad i = nd, ia, il, in, mn, oh, ne, sd, wi$$

**South:**

$$\ln\left(C_{d_i}/L_{c_i}\right) = -1.09243 + \underset{(2.55)}{0.09896}\left[(X_i - R_i)/P_t\right] - \underset{(2.38)}{0.23309}\ \ln\left[N_i/L_{c_i}\right]; \qquad i = al, ga, va, fl, nc, sc$$

**Mississippi Delta:**

$$\ln\left(C_{d_i}/L_{c_i}\right) = -\underset{(4.77)}{0.56237} + \underset{(1.50)}{0.100336}\left(X_i/R_i\right); \qquad i = ar, ky, la, mo, ms, tn$$

**Great Plains:**

$$\ln\left(C_{d_i}/L_{c_i}\right) = -\underset{(1.81)}{1.77275} + \underset{(1.47)}{0.3603}\ \ln\left[(X_i - R_i)/P_t\right] - \underset{(2.32)}{0.66511}\ \ln\left[N_i/L_{c_i}\right]; \qquad i = ks, ok, tx$$

No land-use response in NE region: mi, ny, pa

### (5e) CRP Demand

$$\ln\left(C_{z_i}/L_{c_i}\right) = -\underset{(3.49)}{0.7645} + \underset{(3.13)}{0.0976}\ D_{z_i} - \underset{(3.13)}{0.5301}\ \ln\left(R_{z_i}/Rc_{i_t}\right)$$

$$D_{z_i} = \begin{cases} 0; & otherwise \\ 1; & when\ R_{z_i} \geq R_{c_i}\ \ In\ 2002,\ D_z = 1.0\ for\ al, ga, fl, ky, mo, oh, ka, ok, tx, mi, ny, pa, wi \end{cases}$$

## (7e) Cropland Supply for Pasture

$$\ln\left(C_{g_i}/L_{c_i}\right) = \underset{(21.2)}{-2.6990}\,D_{gl_i} \underset{(18.5)}{-2.5239}\,D_{cb_i} \underset{(9.7)}{-2.2516}\,D_{np_i} \underset{(3.97)}{-0.8099}\,D_{ap_i} \underset{(13.4)}{-1.3868}\,D_{se_i} \underset{(8.9)}{-1.4787}\,D_{dl_i}$$
$$\underset{(4.8)}{-1.2926}\,D_{sp_i} \underset{(1.5)}{+0.1901}\,\ln\left(R_{g_i}/R_{c_i}\right)$$

$$D_{gl_i} = \begin{cases} 0; & otherwise \\ 1; & for\ mi,\ mn,\ wi \end{cases} \quad D_{cb_i} = \begin{cases} 0; & otherwise \\ 1; & for\ il,\ in,\ ia,\ mo,\ oh \end{cases} \quad D_{np_i} = \begin{cases} 0; & otherwise \\ 1; & for\ ne,\ nd,\ sd \end{cases}$$

$$D_{ap_i} = \begin{cases} 0; & otherwise \\ 1; & for\ ky,\ tn \end{cases} \quad D_{se} = \begin{cases} 0; & otherwise \\ 1; & for\ al,\ fl,\ ga, nc, sc \end{cases} \quad D_{dl} = \begin{cases} 0; & otherwise \\ 1; & for\ ar,\ la,\ ms \end{cases}$$

$$D_{sp} = \begin{cases} 0; & otherwise \\ 1; & for\ ks, ok, tx \end{cases}$$

ny, pa, va excluded

Table 2. Summary of Yield Experiments at Various Locations in Main Production Areas of U.S.

| | Author | Location | Crop | Establish Expense | | Annual Expense | Rental Multiplier | Annual Yield | | | Rotation | Year | Cost Baseline Year | Inflation Multiplier for 2005 |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | | | E ($/acre) | E* | An ($/acre) | m | | Y (tons/acre/yr) | Y* | n | | | |
| (1) | Hallam | Central Iowa | Switchgrass | 87.66 | | 61.46 | | | 4.3 | | 10 | 2001 | 1993 | 1.394 |
| (2) | Hallam | Southern Iowa | Switchgrass | 92.61 | | 61.90 | | | 3.3 | | 10 | 2001 | 1993 | 1.394 |
| (3) | Fox et al. | Eastern Ontario | Switchgrass | 88.96 | | 64.99 | | | 4.1 | | 10 | 1999 | 1994 | 1.343 |
| (4) | Epplin | Oklahoma | Switchgrass | 90.49 | | 57.88 | | | 3.6 | | 10 | 1996 | 1995 | 1.283 |
| (5) | Downing & Graham | Tennessee | Switchgrass | | | | | Cropland | 5.6 | | | 1996 | | |
| | | | | | | | | Pasture | 4.5 | | | | | |
| | | | Hardwoods | | | | | Cropland | 3.2 | | | | | |
| | | | | | | | | Pasture | 2.5 | | | | | |
| (6) | Nienow et al./ Kopp et al. | Northern Indiana (Tully, NY) | Willow | 708.76 | | 17.50 | | | 3.9 | | 20 | 2000, 2001 | 1996 | 1.239 |
| (7) | Volk et al. | | Willow | | | | | | 4.9 | | | | | |
| (8) | Husain et al./ Netzer et al. | Western Minnesota | Poplar | | 73.02 | | 1.286 | Cropland | | 3.9 | 9 | | 1993 | 1.394 |
| | | | | | | | | Pasture | | 3.2 | | | | |
| (9) | Reimenschneider et al. | Midwest U.S. | Poplar | | | | | | | 6.0 | | | | |
| (10) | Coletti | Central Iowa | Silver Maple | | 79.28 | | 1.36 | | | 4.4 | 5 | 1994 | 1993 | 1.394 |
| (11) | Sanderson et al. | Southern Summary | Switchgrass | | | | | E. Texas | 4.8 | | | 1996 | | |
| | | | | | | | | Tennessee | 5.0 | | | | | |
| | | | | | | | | Alabama | 6.2 | | | | | |
| (12) | Stricker et al. | Florida (NO) | Cottonwood | | | | | | | 8.9 | | 2000 | | |
| (13) | Fuentes & Taliaferro | Oklahoma (Chicksa) | Switchgrass (upland) | | | | | | 4.2 | | | 2002 | | |

[1]See page 5-6 for variable definitions.

**Table 3. Area in CRP Program in 2002, by State**

| | | | in million acres | |
|---|---|---|---|---|
| Region | | State | Existing Program | New[1] Program |
| Great Lakes | | MN | 1.628 | 1.029 |
| | | WI | 0.614 | 0.088 |
| | | IL | 0.923 | 0.461 |
| | | IN | 0.291 | 0.098 |
| | | IA | 1.694 | 0.849 |
| | | OH | 0.365 | 0.125 |
| | Subtotal | | 5.515 | 2.650 |
| South | | AL | 0.472 | 0.046 |
| | | FL | 0.097 | 0.004 |
| | | GA | 0.458 | 0.011 |
| | | NC[2] | 0.183 | 0.050 |
| | | SC[2] | 0.228 | 0.049 |
| | Subtotal | | 1.438 | 0.160 |
| Delta | | MO | 1.418 | 0.167 |
| | | KY | 0.403 | 0.067 |
| | | TN | 0.227 | 0.029 |
| | | AR | 0.147 | 0.079 |
| | | LA[2] | 0.273 | 0.071 |
| | | MS | 0.807 | 0.179 |
| | Subtotal | | 3.275 | 0.592 |
| East | | MI | 0.296 | 0.095 |
| | | NY[2] | 0.211 | 0.014 |
| | | PA[2] | 0.190 | 0.024 |
| | | VA[2] | 0.107 | 0.025 |
| | Subtotal | | 0.804 | 0.158 |
| Great Plains | | ND | 3.043 | 1.371 |
| | | SD | 1.342 | 0.553 |
| | | NE | 1.165 | 0.211 |
| | | KS | 2.566 | 0.487 |
| | | OK | 1.103 | 0.028 |
| | | TX | 3.302 | 0.089 |
| | Subtotal | | 12.521 | 2.739 |
| TOTAL | | | 23.553 | 6.299 |

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1. Land in environmentally sensitive classifications. See Appendix Table A2.
2. Area change not included in simulation analysis.

**Table 4. Conservation Reserve Program Land and Classifications Not Suitable for Biomass Production**

| Number | Description | Area (acres) |
|---|---|---|
| CP4 | Wildlife habitat | 38.9 |
| CP4A | Wildlife habitat corridor | 83.9 |
| CP4B | Wildlife habitat corridor | 10,707.4 |
| CP4D | Wildlife habitat | 2,480,904.7 |
| CP9 | Wildlife water | 51,563.6 |
| CP12 | Wildlife food plots | 81,678.4 |
| CP23 | Wetland restoration | 1,741,736.9 |
| CP23A | Wetland restoration, non-flood plain | 17,779.8 |
| CP25 | Rare and declining habitat | 1,005,789.3 |
| CP27 | Farmable wetland, pilot wetland | 43,565.7 |
| CP28 | Farmable wetland, pilot buffer | 105,040.6 |
| CP29 | Marginal pastureland, wildlife habitat | 23,877.6 |
| CP30 | Marginal pastureland, wetland buffer | 15,870.3 |
| CP33 | Upland bird habitat, buffers | 99,323.7 |
|  | Total | 5,677,960.8 |

## Table 5. Minimum Entry Price, by State

| Region | State | Existing Program (in $/ton) | New Program (in $/ton) |
|---|---|---|---|
| Great Lakes | MN | 33.09 | 23.98 |
| | WI | 39.80 | 25.25 |
| | MI | 43.65 | 27.52 |
| | IL | 35.99 | 38.73 |
| | IN | 43.86 | 39.79 |
| | IA | 37.42 | 37.05 |
| | OH | 43.50 | 34.45 |
| Average[1] | | 39.62 | 32.39 |
| South | AL | 22.60 | 17.37 |
| | FL | 25.25 | 17.65 |
| | GA | 23.09 | 22.90 |
| | VA | 30.00 | ----- |
| | NC | 32.00 | ----- |
| | SC | 22.53 | ----- |
| Average | | 25.09 (23.64) | 19.37 |
| Delta | MO | 34.94 | 29.13 |
| | KY | 28.62 | 28.57 |
| | TN | 30.16 | 30.10 |
| | AR | 23.90 | 19.96 |
| | LA | 24.22 | ----- |
| | MS | 24.62 | 19.96 |
| Average | | 27.74(28.45) | 25.54(21.29) |
| East | NY | 38.05 | ----- |
| | PA | 38.73 | ----- |
| | VA | 30.00 | ----- |
| Average | | 35.60 | ----- |
| Great Plains | ND | 45.40 | 43.58 |
| | SD | 46.44 | 35.45 |
| | NE | 46.31 | 36.31 |
| | KS | 45.00 | 35.00 |
| | OK | 45.40 | 44.67 |
| | TX | 40.37 | 34.58 |
| Average | | 44.82 | 38.27 |

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[1] The regional average, in parentheses, includes only states in the CRP area change analysis.

**Table 6. Biomass Production (million tons), with Reduced Government Programs**

| | | @$35/Ton | @$60/Ton | |
|---|---|---|---|---|
| **Region** | **State** | **Baseline** | **Baseline** | **High Price** |
| Great Lakes | MN | 8.46 | 30.40 | 30.32 |
| | WI | 2.21 | 21.55 | 19.35 |
| | MI | 0.91 | 5.58 | 5.43 |
| | IL | 0.00 | 14.59 | 12.87 |
| | IN | 0.00 | 14.32 | 11.52 |
| | IA | 0.00 | 24.01 | 22.24 |
| | OH | 0.19 | 15.35 | 11.77 |
| Subtotal | | 11.77 | 125.80 | 113.50 |
| South | AL | 19.97 | 22.20 | 21.80 |
| | FL | 15.75 | 16.89 | 16.93 |
| | GA | 16.33 | 17.63 | 17.59 |
| | NC | 3.86 | 10.35 | 10.20 |
| | SC | 6.45 | 7.50 | 7.69 |
| Subtotal | | 62.36 | 74.57 | 74.20 |
| Delta | MO | 3.74 | 36.20 | 35.89 |
| | KY | 20.33 | 24.25 | 24.25 |
| | TN | 13.89 | 22.30 | 22.30 |
| | AR | 25.36 | 30.75 | 30.81 |
| | LA | 11.64 | 15.50 | 15.56 |
| | MS | 20.40 | 23.18 | 23.25 |
| Subtotal | | 95.36 | 152.18 | 152.07 |
| East | NY | 0.00 | 9.53 | 9.52 |
| | PA | 0.00 | 9.02 | 9.20 |
| | VA | 9.16 | 19.40 | 19.40 |
| Subtotal | | 9.16 | 37.95 | 38.08 |
| Great Plains | ND | 0.00 | 14.64 | 13.93 |
| | SD | 0.00 | 9.33 | 8.62 |
| | NE | 0.00 | 7.42 | 7.17 |
| | KS | 0.00 | 14.19 | 10.32 |
| | OK | 0.00 | 17.36 | 17.83 |
| | TX | 2.08 | 31.00 | 30.91 |
| Subtotal | | 2.08 | 93.94 | 88.76 |
| TOTAL | | 180.73 | 484.38 | 466.60 |

Table 7. 2002 Baseline: Farmland Resource and Its Utilization, in million acres

| | Farmland Resource | | | Pastureland Supply and Utilization | | | Cropland Utilization | | |
|---|---|---|---|---|---|---|---|---|---|
| State | Total Farm Land | Crop Land Lc | Other Land Lg | Cropland Used as Pasture Cg | Supply of Pasture-land[1] Gs | Land Used for Pasture Gd | Food Crops Cd | for CRP Program Cz | Grazing Cg |
| Great Lakes | | | | | | | | | |
| MN | 27.512 | 22.729 | 4.783 | 0.729 | 1.829 | 2.557 | 19.398 | 1.628 | 0.729 |
| WI | 15.741 | 10.728 | 5.013 | 0.764 | 1.460 | 2.224 | 8.928 | 0.614 | 0.764 |
| IL | 27.310 | 24.171 | 3.139 | 0.528 | 1.145 | 1.674 | 22.562 | 0.925 | 0.528 |
| IN | 15.058 | 12.909 | 2.149 | 0.449 | 0.650 | 1.098 | 11.937 | 0.291 | 0.449 |
| IA | 31.729 | 27.153 | 4.576 | 1.355 | 2.284 | 3.639 | 23.994 | 1.694 | 1.355 |
| OH | 14.583 | 11.424 | 3.159 | 0.698 | 1.134 | 1.832 | 10.041 | 0.365 | 0.698 |
| South | | | | | | | | | |
| AL | 8.904 | 3.732 | 5.172 | 1.180 | 2.344 | 3.524 | 1.995 | 1.514 | 1.180 |
| FL | 10.714 | 3.715 | 6.999 | 1.104 | 4.959 | 6.063 | 2.313 | 0.097 | 1.104 |
| GA | 10.744 | 4.677 | 6.067 | 0.866 | 2.058 | 2.924 | 3.256 | 0.458 | 0.866 |
| NC | 9.079 | 5.472 | 3.607 | 0.668 | 1.077 | 1.745 | 4.308 | 0.183 | 0.668 |
| SC | 10.740 | 7.270 | 3.470 | 0.395 | 0.824 | 1.219 | 1.374 | 0.228 | 0.395 |
| Delta | | | | | | | | | |
| MO | 29.946 | 18.884 | 11.062 | 4.179 | 7.135 | 11.313 | 13.137 | 1.418 | 4.179 |
| KY | 13.843 | 8.412 | 5.431 | 2.580 | 2.516 | 5.096 | 4.978 | 0.403 | 2.580 |
| TN | 11.681 | 6.992 | 4.689 | 2.066 | 2.798 | 4.864 | 4.365 | 0.227 | 2.066 |
| AR | 14.502 | 9.576 | 4.926 | 1.705 | 2.886 | 4.591 | 7.457 | 0.147 | 1.705 |
| IA | 7.830 | 5.071 | 2.759 | 0.841 | 1.493 | 2.334 | 3.332 | 0.273 | 0.841 |
| MS | 11.097 | 5.823 | 5.274 | 0.896 | 2.210 | 3.106 | 4.139 | 0.807 | 0.896 |
| East | | | | | | | | | |
| MI | 10.142 | 7.983 | 2.159 | 0.409 | 0.416 | 0.825 | 6.827 | 0.296 | 0.409 |
| NY | 7.660 | 4.841 | 2.819 | 0.511 | 0.786 | 1.297 | 3.846 | 0.211 | 0.511 |
| PA | 7.745 | 5.120 | 2.625 | 0.591 | 0.746 | 1.337 | 4.079 | 0.190 | 0.591 |
| VA | 8.622 | 4.192 | 4.430 | 1.267 | 2.049 | 3.316 | 2.623 | 0.107 | 1.267 |
| Great Plains[1] | | | | | | | | | |
| ND | 28.310 | 26.506 | 1.804 | 1.285 | 0.125 | 1.410 | 19.908 | 3.043 | 1.285 |
| SD | 21.760 | 20.318 | 1.442 | 2.351 | 0.165 | 2.516 | 13.492 | 1.342 | 2.351 |
| NE | 23.963 | 22.520 | 1.443 | 1.882 | 0.233 | 2.115 | 17.336 | 1.165 | 1.882 |
| KS | 31.723 | 29.542 | 2.181 | 2.401 | 0.356 | 2.758 | 18.967 | 2.566 | 2.401 |
| OK | 17.929 | 14.843 | 3.086 | 5.050 | 1.638 | 6.689 | 7.705 | 1.103 | 5.050 |
| TX | 46.475 | 38.657 | 7.818 | 12.973 | 4.202 | 17.175 | 17.750 | 3.302 | 12.973 |
| Total | 475.342 | 363.260 | 112.082 | 49.722 | 49.518 | 99.240 | 260.047 | 24.595 | 49.722 |

[1] In Great Plains States, the land use category "other pastureland" is subtracted from "total farmland" before calculating "other land" so that Great Plains rangeland is excluded from the land resource base. Similarly, "other pastureland" was excluded when calculating pasture supply, so as to exclude the rangeland in the western section of these States from pasture land.

Table 8. $60/ton Biomass: Farmland Resource and Its Utilization, in Million Acres

| | Farmland Resource | | | Pastureland Supply and Utilization | | | | Cropland Utilization for | | |
|---|---|---|---|---|---|---|---|---|---|---|
| State | Total Farm Land | Crop Land Lc | Other Land Lg | Cropland Used as Pasture Cg | Supply of Pasture-land[1] Gs | Land Used for Pasture Gd | Energy Crops Ge | Food Crops Cd | CRP Program Cz | Energy Crops Ce |
| Great Lakes | | | | | | | | | | |
| MN | 27.512 | 22.729 | 4.783 | 0.858 | 2.937 | 0.046 | 3.750 | 16.830 | 1.029 | 4.080 |
| WI | 15.741 | 10.728 | 5.013 | 0.780 | 2.580 | 0.410 | 2.950 | 6.780 | 0.088 | 2.660 |
| IL | 27.310 | 24.171 | 3.139 | 0.790 | 1.990 | 0.550 | 2.230 | 21.150 | 0.461 | 1.620 |
| IN | 15.058 | 12.909 | 2.149 | 0.520 | 1.190 | 0.570 | 1.140 | 10.050 | 0.098 | 2.020 |
| IA | 31.729 | 27.153 | 4.576 | 1.700 | 3.520 | 0.970 | 4.240 | 22.310 | 0.849 | 2.200 |
| OH | 14.583 | 11.424 | 3.159 | 0.708 | 1.780 | 1.250 | 1.240 | 8.130 | 0.125 | 2.150 |
| South | | | | | | | | | | |
| AL | 8.904 | 3.732 | 5.172 | 1.047 | 4.229 | 1.885 | 3.390 | 1.684 | 0.046 | 0.880 |
| FL | 10.714 | 3.715 | 6.999 | 0.935 | 6.847 | 4.783 | 3.000 | 2.293 | 0.000 | 0.340 |
| GA | 10.744 | 4.677 | 6.067 | 0.666 | 3.802 | 1.913 | 2.554 | 2.987 | 0.238 | 1.030 |
| NC | 9.079 | 5.472 | 3.607 | 0.752 | 2.690 | 1.000 | 1.600 | 2.836 | 0.118 | 0.800 |
| SC | 10.740 | 7.270 | 3.470 | 0.270 | 1.531 | 0.700 | 1.100 | 1.264 | 0.093 | 0.340 |
| Delta | | | | | | | | | | |
| MO | 29.946 | 18.884 | 11.062 | 4.335 | 10.640 | 6.971 | 8.000 | 12.213 | 0.167 | 2.020 |
| KY | 13.843 | 8.412 | 5.431 | 2.450 | 4.150 | 1.803 | 4.800 | 4.431 | 0.067 | 1.020 |
| TN | 11.681 | 6.992 | 4.689 | 2.000 | 4.920 | 2.320 | 4.600 | 3.850 | 0.029 | 0.790 |
| AR | 14.502 | 9.576 | 4.926 | 1.528 | 5.073 | 2.201 | 4.400 | 6.508 | 0.000 | 1.450 |
| LA | 7.830 | 5.071 | 2.759 | 0.752 | 2.690 | 1.242 | 2.200 | 2.836 | 0.118 | 0.750 |
| MS | 11.097 | 5.823 | 5.274 | 0.758 | 4.240 | 2.000 | 3.000 | 3.560 | 0.179 | 1.350 |
| East | | | | | | | | | | |
| MI | 10.142 | 7.983 | 2.159 | 0.394 | 0.742 | 0.416 | 0.730 | 6.220 | 0.095 | 0.820 |
| NY | 7.660 | 4.841 | 2.819 | 0.511 | 1.556 | 0.000 | 2.440 | | | |
| PA | 7.745 | 5.120 | 2.625 | 0.591 | 1.550 | 0.000 | 2.310 | | | |
| VA | 8.622 | 4.192 | 4.430 | 1.267 | 4.050 | 0.470 | 4.860 | | | |
| Great Plains[1] | | | | | | | | | | |
| ND | 28.310 | 26.506 | 1.804 | 1.528 | 0.595 | 0.933 | 1.190 | 17.570 | 1.371 | 3.780 |
| SD | 21.760 | 20.318 | 1.442 | 2.541 | 0.515 | 1.150 | 1.920 | 12.610 | 0.553 | 1.480 |
| NE | 23.963 | 22.520 | 1.443 | 2.214 | 0.589 | 1.160 | 1.640 | 16.880 | 0.211 | 1.090 |
| KS | 31.723 | 29.542 | 2.181 | 2.960 | 1.210 | 1.580 | 2.590 | 18.020 | 0.487 | 2.510 |
| OK | 17.929 | 14.843 | 3.086 | 5.410 | 3.190 | 3.550 | 5.060 | 6.940 | 0.028 | 1.560 |
| TX | 46.475 | 38.657 | 7.818 | 12.150 | 8.076 | 13.227 | 7.000 | 17.650 | 0.089 | 4.630 |
| Total | 475.342 | 363.260 | 112.082 | 50.415 | 86.882 | 53.100 | 83.934 | 225.602 | 6.539 | 41.370 |

[1] See Table 7.

Table 9. Cash Rental Rates, in $/acre[1]

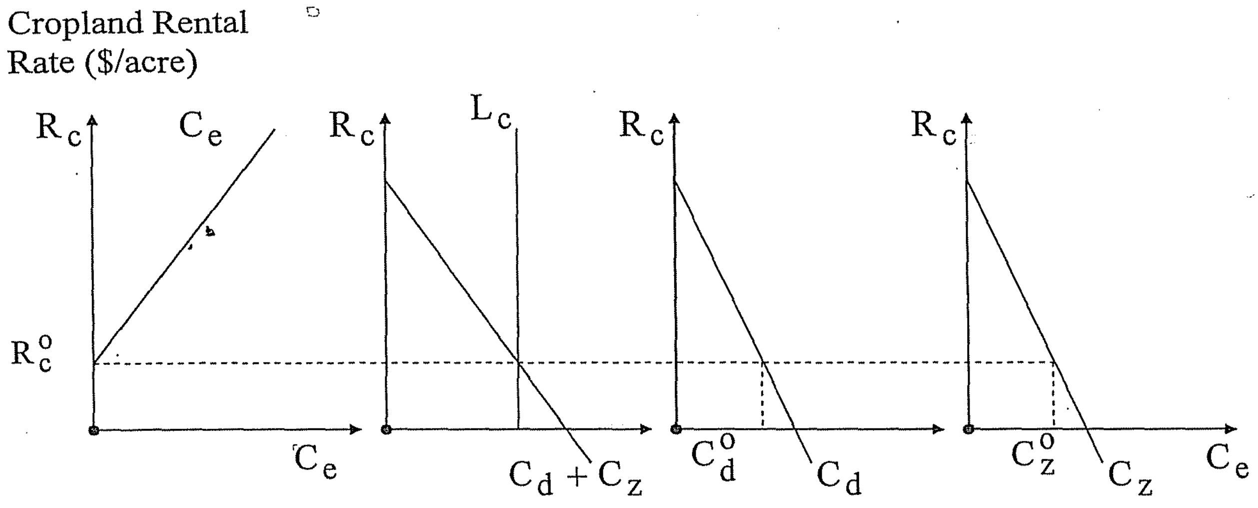
| State | Pasture Land (Rg) | | Cropland (Rc) | |
|---|---|---|---|---|
| | 2002 baselne | with $60/ton biomass | 2002 baseline | with $60/ton biomass |
| Great Lakes | | | | |
| MN | 19.00 | 102.48 | 81.00 | 153.69 |
| WI | 38.00 | 102.55 | 67.00 | 153.98 |
| IL | 30.00 | 102.49 | 122.00 | 153.48 |
| IN | 42.54 | 124.84 | 101.00 | 182.64 |
| IA | 29.70 | 102.30 | 120.00 | 153.62 |
| OH | 46.72 | 111.80 | 77.00 | 170.37 |
| South | | | | |
| AL | 18.00 | 52.67 | 36.00 | 237.00 |
| FL | 15.00 | 50.00 | 32.00 | 275.90 |
| GA | 23.00 | 52.00 | 39.00 | 268.00 |
| NC | 24.00 | 43.87 | 55.00 | 269.21 |
| SC | 13.58 | 26.81 | 29.00 | 268.66 |
| Delta | | | | |
| MO | 23.60 | 104.36 | 66.00 | 156.57 |
| KY | 10.36 | 23.15 | 68.00 | 197.00 |
| TN | 16.50 | 46.65 | 60.50 | 198.23 |
| AR | 14.40 | 41.32 | 53.00 | 270.60 |
| LA | 16.00 | 43.87 | 57.00 | 269.21 |
| MS | 18.00 | 43.48 | 54.00 | 268.07 |
| East | | | | |
| MI | 45.24 | 88.35 | 60.00 | 136.95 |
| NY | 25.33 | | 35.00 | |
| PA | 28.00 | 112.00 | 40.00 | |
| VA | 16.00 | 136.00 | 36.00 | |
| Great Plains | | | | |
| ND | 9.70 | 44.86 | 36.50 | 81.99 |
| SD | 10.80 | 44.23 | 42.00 | 82.06 |
| NE | 10.70 | 44.23 | 66.00 | 81.90 |
| KS | 12.60 | 43.62 | 36.00 | 81.86 |
| OK | 8.50 | 44.82 | 27.00 | 82.23 |
| TX | 7.20 | 16.60 | 21.00 | 81.90 |

1 States with missing simulation values were not included in the "no-CRP" simulation.

Table 10. Biomass Ethanol, Cost of Production.

| Input | Units per Gallon | 2002 Price | (Units) | Expense ($/gallon) | |
|---|---|---|---|---|---|
| | | | | | |
| **Cost Components:** | | | | | |
| Biomass, st | 0.012626 | 60 | $/ton | 0.758 | |
| Other operating costs | | | | 0.670 | |
| | | | | | |
| Labor, man years | 41 | 44172.5 | $/yr | 0.072 | |
| Foremen, man yrs | 9 | 50398.2 | $/yr | 0.018 | |
| Supervisors, man yrs | 1 | 57672 | $/yr | 0.002 | |
| Sub-total labor | | | | 0.0929 | |
| | | | | | |
| **Cost Summary:** | | | | | |
| Total processing cost | | | | 1.327 | |
| Capital allowance | | | | 0.564 | |
| Total production cost | | | | 2.083 | |
| | | | | | |
| **Plant Characteristics:** | | | | | |
| Ethanol yield | | 79.2 | gal/ton | | |
| Ethanol output | | 25 | mil gal | | |
| Input requirement | | 0.316 | mil ton | | |
| Capital cost/output ratio | | 4.828 | $/gal | | |
| Plant cost | | 120.700 | mil $ | | |
| | | | | | |
| **Finance:** | | | | | |
| Outstanding mortgage balance (D) | | | | 4.828 | $/gal |
| Annual interest rate (R) | | | | 0.08 | percent |
| Loan length (n) | | | | 15 | years |
| Annual payment at end of year i | | | | 0.564 | $/gal |

**Figure 1a. Excess Supply of Cropland for Energy Crop Production**



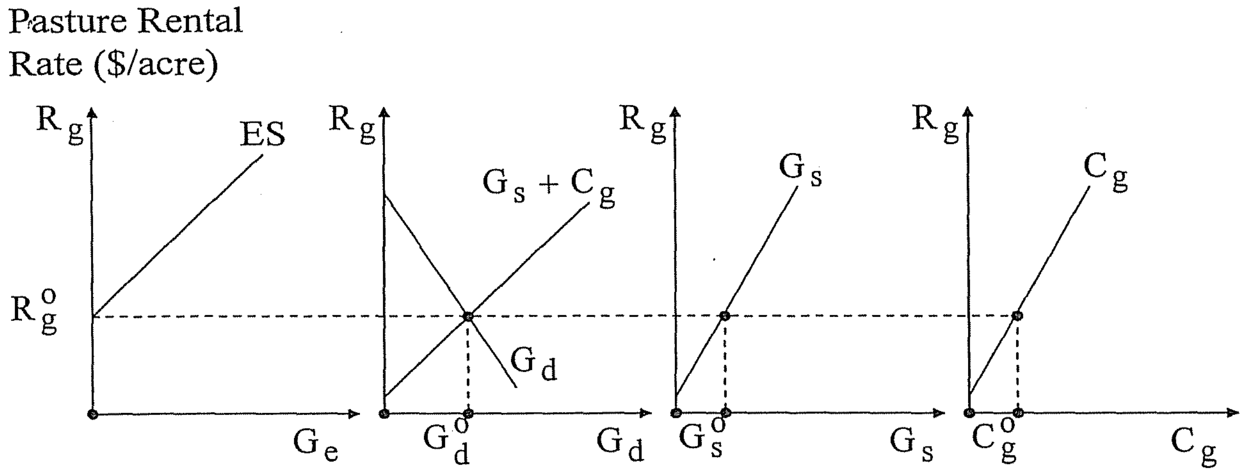
**(a) Excess Supply: Biomass From Cropland**

**(b) Cropland Used Supply and Demand**

**(c) Cropland Demand for Crop Production**

**(d) Cropland Demand for Conservation**

**Figure 1b. Excess Supply of Grazing (Pasture) Land for Energy Crop Use**



**(a) Excess Supply: Biomass From Grazing Land**

**(b) Pasture Land Supply & Demand (Livestock)**

**(c) Pasture Land Supply for Pasture**

**(d) Cropland Supply for Pasture**

Variable definitions appear on pages 3 and 4.

Figure 2a. Switchgrass Yield (tons/acre)

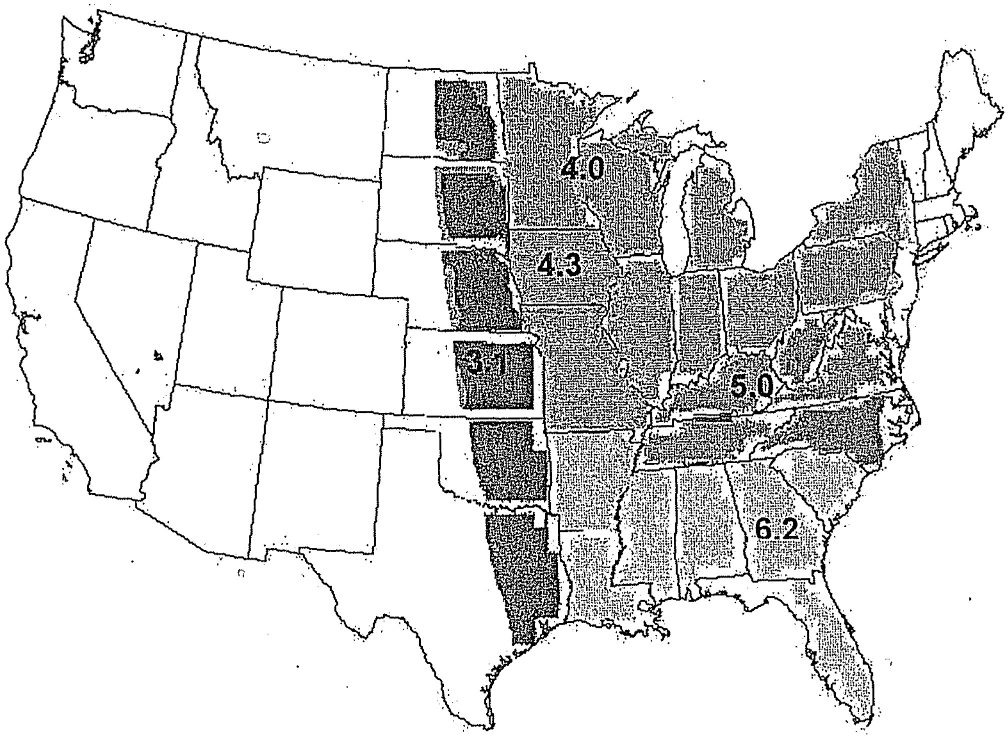
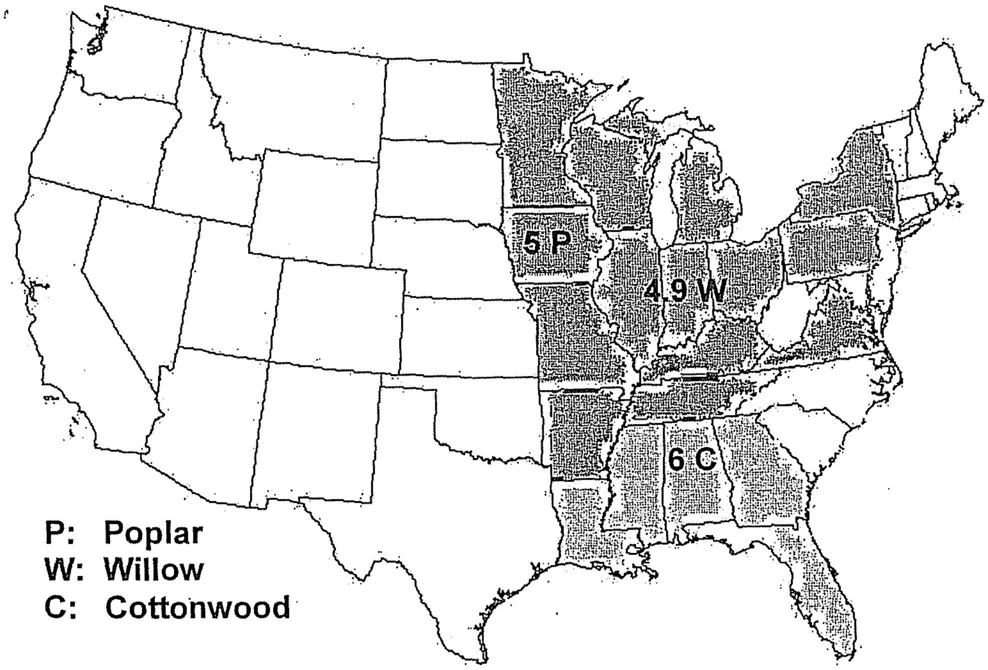
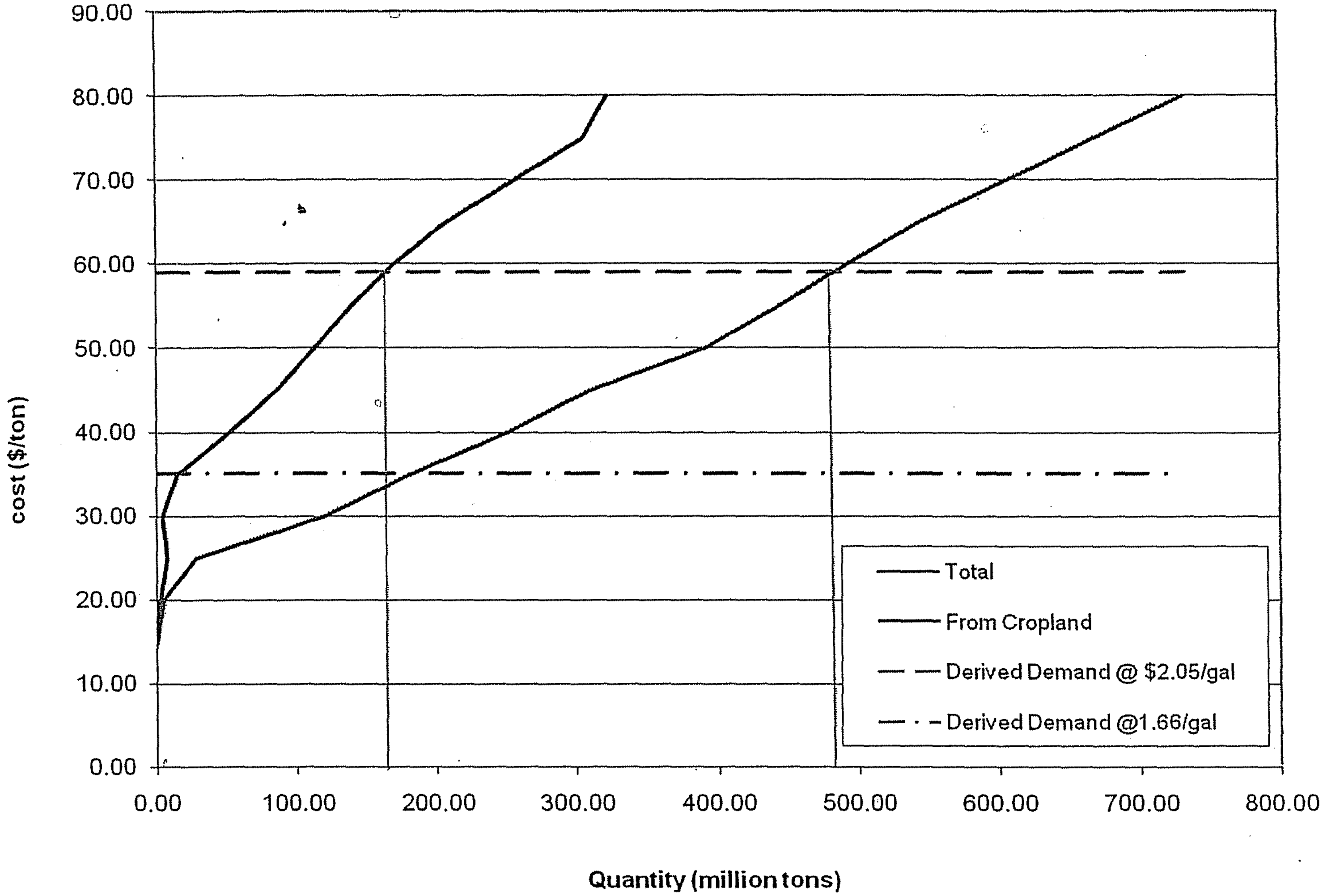


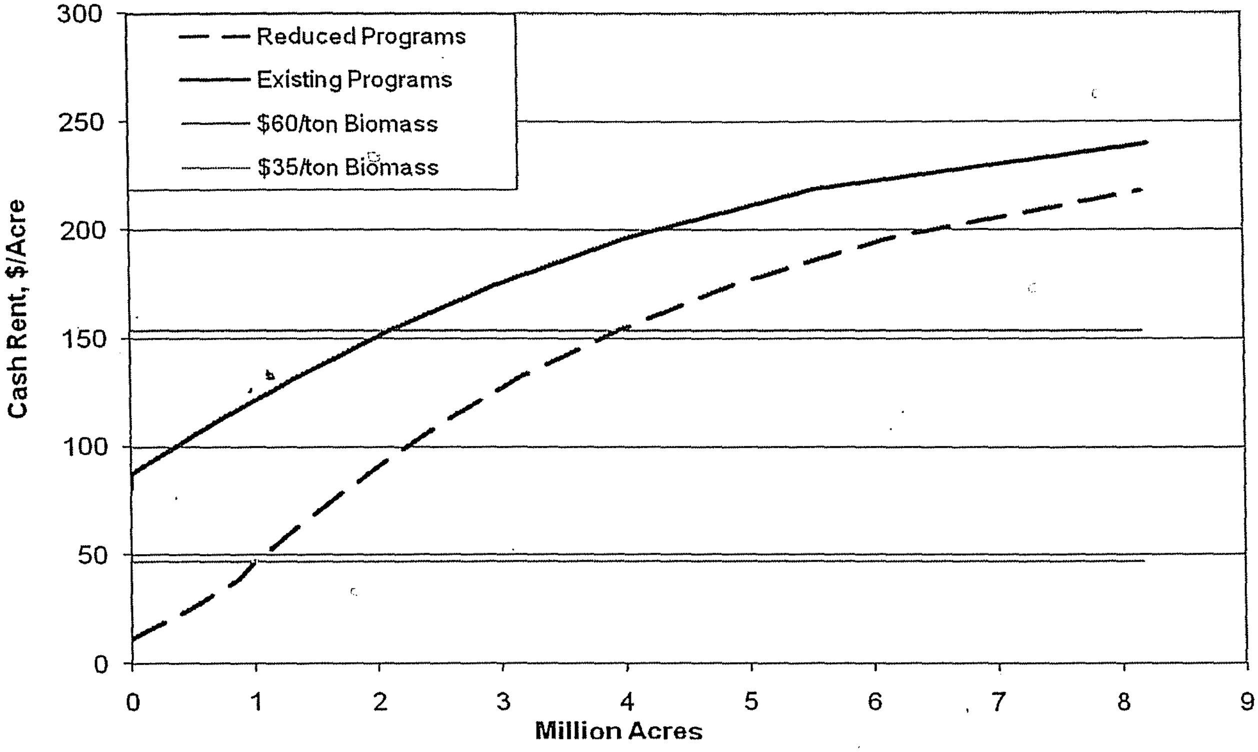
Figure 2b. Wood Yield (tons/acre/year)



## Figure 3. U.S. Biomass Supply



### Figure 4a. Minnesota, Cropland Excess Supply for Biomass



### Figure 4b. Minnesota, Pastureland Excess Supply for Biomass

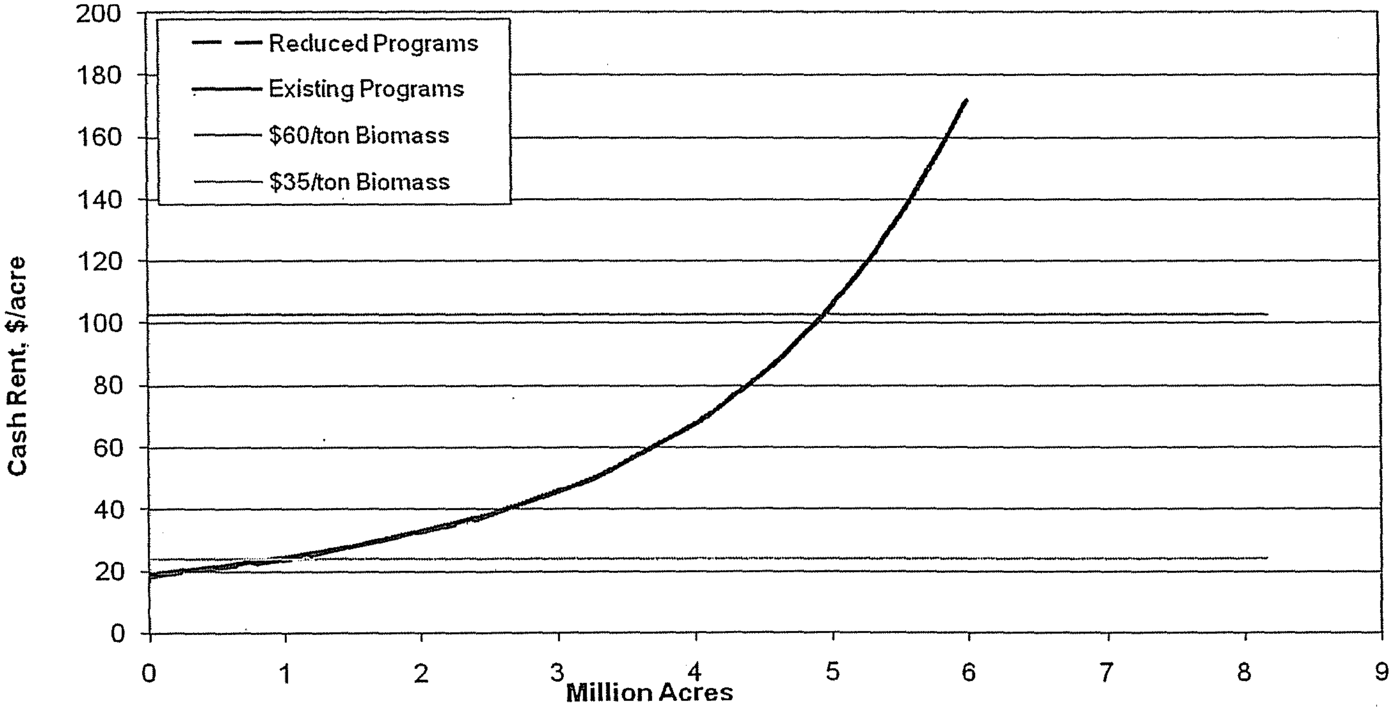


Figure 5a. Ethanol Market, 2012,
Pg=$2.08/gal,Y=80gal/ton

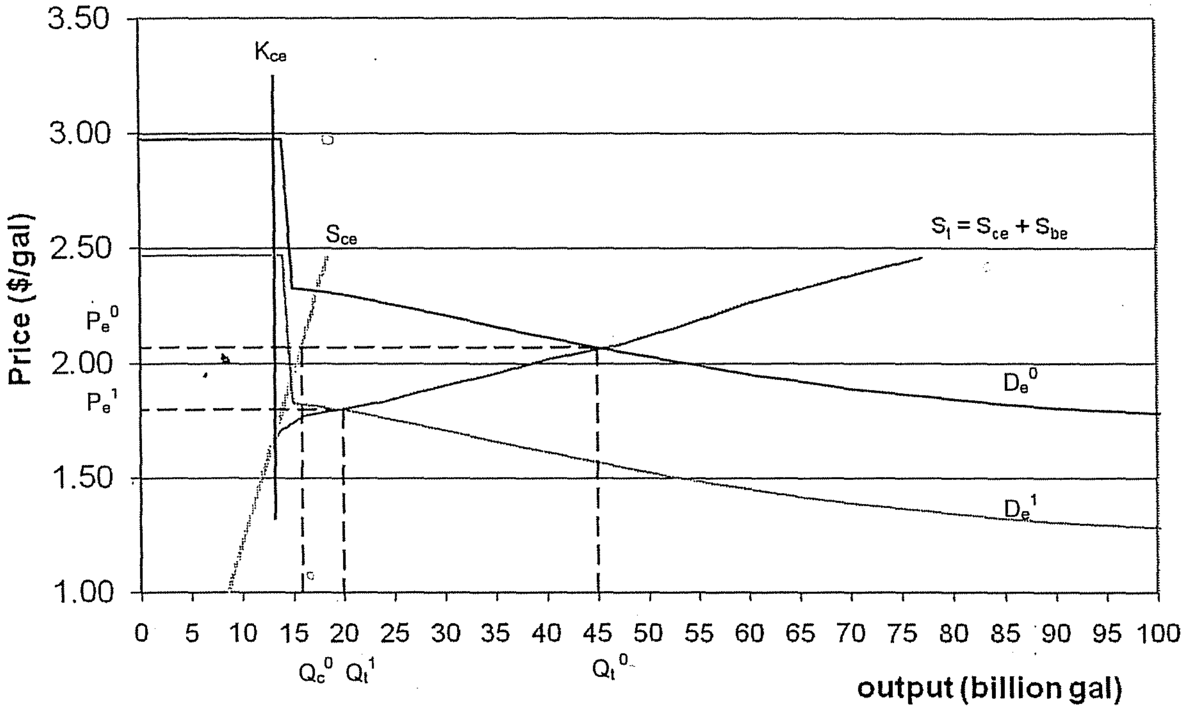
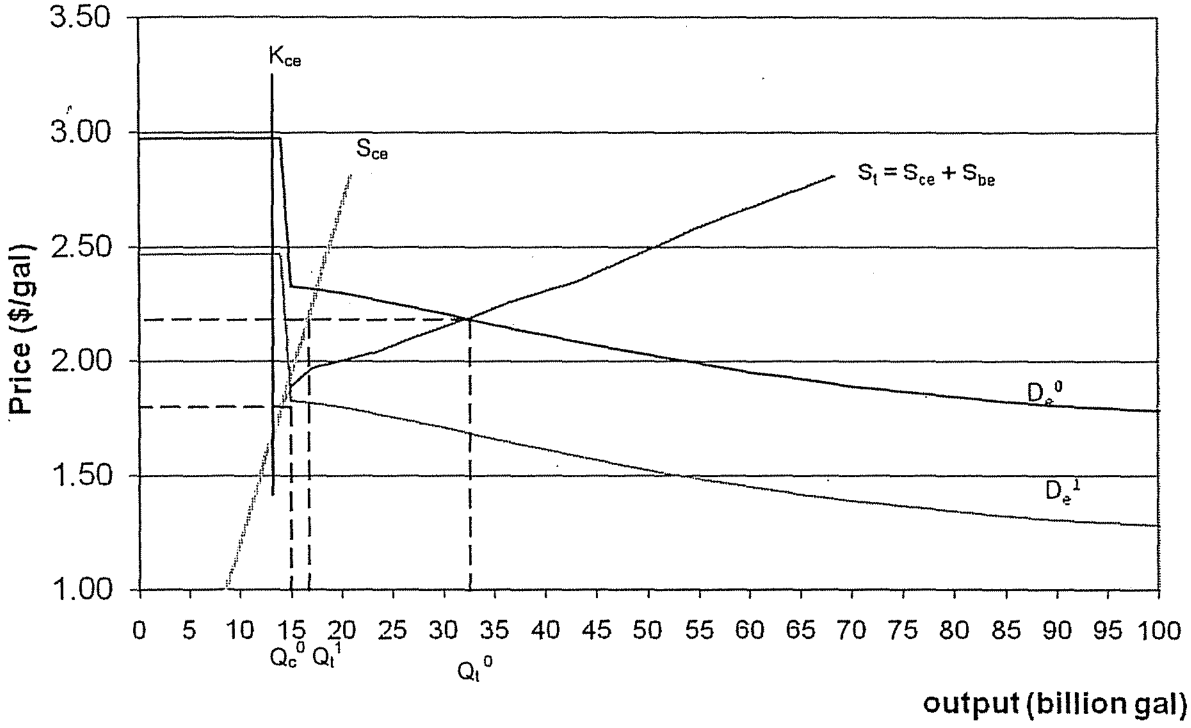


Figure 5b. Ethanol Market, 2012,
Pg=$2.08/gal,Y=65gal/ton



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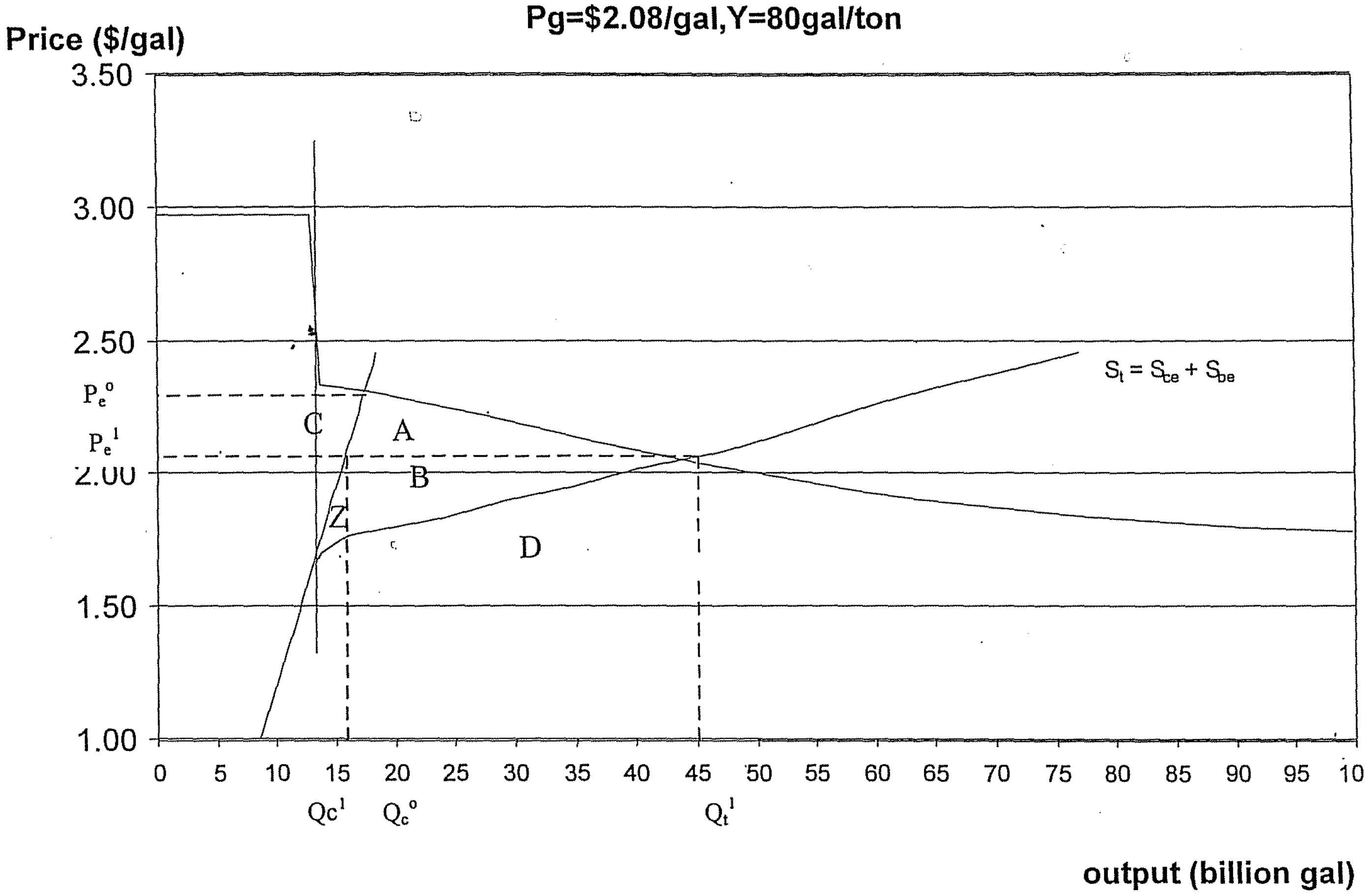
[1] See p. 13-16 for variable definitions.

Figure 6. Welfare Analysis, 2012, Pg=$2.08/gal,Y=80gal/ton



See p. 17 for variable definitions.

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## Endnotes

1. Analysis of land allocation of individual crops based on net revenues per unit of land is a well-established statistical procedure (Westcott; Chen and Ito). Judging from the results, the composite net returns variables also works; it is an alternative to a very large simulation model of several agricultural commodity markets.

2. Payments for conservation programs (CRP) are not included with other Government payments. The main components of the other Government expenditures are counter-cyclical payments, loan deficiency payments, and fixed direct payments, which provide incentives to produce the main program commodities. In 2002, the fixed direct payment program replaced the production flexibility contracts of the 1996 Farm Law. Some considered the 1996 program non-distorting. However the 2002 fixed direct payments are defined per unit of production for the major program commodities (See ERS staff).

3. Also, to the extent that removing Government payments causes a sustained farm price decrease for food and feed crops, underestimates of the biomass increase effect may occur. Further, simulations with high agricultural prices (table 4) suggest that the effect on biomass supply would be moderate in any event.

4. The change in biomass supply associated with these CRP program changes in six Southern and Eastern States (NC, SC, LA, NY, PA, and VA) was not evaluated because the potential CRP land area to return to production was small, relative to national supplies. The CRP land that is potentially returnable for each of these States is 0.2 million acres or less, and totals 0.9 million acres. The baseline supply curve was used before and after the policy changes. In effect, we assumed that none of the CRP land in these States was returned to crop production.

5. Some other simulations (not shown) compared the national supply curve with and without Government programs. The main finding is that at a given relatively high price, a 20 percent increase in biomass volume can be secured by modifying Government programs. But at lower prices, not much output effect is realized.

6. It was not clear at the time of publication that the most recent market data would provide an improved baseline. Unusual events that have dominated agricultural markets in 2007 and 2008 include: an unusual worldwide shortage in major grain markets, the resurgence of protection in other major exporting countries, excessive speculation and hoarding in the corn market, Iraq-war-based speculation on inventory needs in the petroleum market, an unusually low value for the U.S. dollar, and an initial over-expansion in the ethanol industry.

# APPENDIX A.

Composition of Biomass Output From Cropland and Grazing Land with $60/ton Biomass, Reduced Government Programs

| | Cropland | | | | Grazing Land | | | | | share of production (0/1) | |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | area Ce million acres | production $Q_c$ million tons | yield Yc ton/acre | crop choice[1] | area Ge million acres | production $Q_g$ million tons | yield Yg ton/acre | crop choice | | cropland | grazing land |
| MN | 4.08 | 17.50 | 4.30 | s | 3.75 | 12.90 | 3.44 | s | | 0.58 | 0.42 |
| WI | 2.66 | 11.40 | 4.30 | s | 2.95 | 10.15 | 3.44 | s | | 0.53 | 0.47 |
| IL | 1.62 | 6.92 | 4.30 | s | 2.23 | 7.67 | 3.44 | s | | 0.47 | 0.53 |
| IN | 2.02 | 9.85 | 4.90 | w | 1.14 | 4.47 | 3.92 | w | | 0.69 | 0.31 |
| IA | 2.20 | 9.42 | 4.30 | s | 4.24 | 14.59 | 3.44 | s | | 0.39 | 0.61 |
| OH | 2.15 | 10.47 | 4.90 | w | 1.24 | 4.86 | 3.92 | w | | 0.68 | 0.32 |
| Great Lakes | 14.73 | 65.55 | | | 15.55 | 54.64 | | | region | 0.55 | 0.45 |
| AL | 0.88 | 5.39 | 6.20 | s | 3.39 | 16.81 | 4.96 | s | | 0.24 | 0.76 |
| FL | 0.34 | 2.01 | 6.20 | s | 3.00 | 14.88 | 4.96 | s | | 0.12 | 0.88 |
| GA | 1.03 | 6.38 | 6.20 | s | 2.55 | 12.67 | 4.96 | s | | 0.33 | 0.67 |
| NC | 0.80 | 3.95 | 5.00 | c | 1.60 | 6.40 | 4 | c | | 0.38 | 0.62 |
| SC | 0.34 | 2.05 | 6.20 | s | 1.10 | 5.46 | 4.96 | s | | 0.27 | 0.73 |
| South | 3.39 | 19.78 | | | 11.64 | 56.22 | | | region | 0.26 | 0.74 |
| MO | 2.02 | 8.68 | 4.30 | s | 8.00 | 27.52 | 3.44 | s | | 0.24 | 0.76 |
| KY | 1.02 | 5.05 | 5.00 | s | 4.80 | 19.20 | 4 | s | | 0.21 | 0.79 |
| TN | 0.79 | 3.90 | 5.00 | s | 4.60 | 18.40 | 4 | s | | 0.17 | 0.83 |
| AR | 1.45 | 8.93 | 6.20 | s | 4.40 | 21.82 | 4.96 | s | | 0.29 | 0.71 |
| IA | 0.75 | 4.59 | 6.20 | s | 2.20 | 10.90 | 4.96 | s | | 0.30 | 0.70 |
| MS | 1.35 | 8.30 | 6.20 | s | 3.00 | 14.88 | 4.96 | s | | 0.36 | 0.64 |
| Delta | 7.38 | 39.45 | | | 27.00 | 112.72 | | | region | 0.26 | 0.74 |
| MI | 0.82 | 3.28 | 4.00 | s | 0.73 | 2.30 | 3.2 | s | | 0.59 | 0.41 |
| NY | 0.00 | 0.00 | 4.90 | w | 2.44 | 9.53 | 3.92 | w | | 0.00 | 1.00 |
| PA | 0.00 | 0.00 | 4.90 | w | 2.31 | 9.01 | 9.01 | w | | 0.00 | 1.00 |
| VA | 0.00 | 0.00 | 5.00 | p | 4.86 | 19.40 | 4 | p | | 0.00 | 1.00 |
| East | 0.82 | 3.28 | | | 10.34 | 40.24 | | | region | 0.08 | 0.92 |
| ND | 3.78 | 11.69 | 3.10 | s | 1.19 | 2.95 | 2.48 | s | | 0.80 | 0.20 |
| SD | 1.48 | 4.59 | 3.10 | s | 1.92 | 4.73 | 2.48 | s | | 0.49 | 0.51 |
| NE | 1.09 | 3.35 | 3.10 | s | 1.64 | 4.07 | 2.48 | s | | 0.45 | 0.55 |
| KS | 2.51 | 7.77 | 3.10 | s | 2.59 | 6.42 | 2.48 | s | | 0.55 | 0.45 |
| OK | 1.56 | 4.84 | 3.10 | s | 5.06 | 12.52 | 2.48 | s | | 0.28 | 0.72 |
| TX | 4.63 | 14.32 | 3.10 | s | 7.00 | 17.36 | 2.48 | s | | 0.45 | 0.55 |
| Great Plains | 15.05 | 46.55 | | | 19.40 | 48.05 | | | region | 0.49 | 0.51 |

[1] s=switchgrass, c=cottonwood, w=willow, p=poplar

Variable definitions:

$C_e$: Biomass area cropland  
$Q_c$: Biomass products  
$Y_c$: Cropland Biomass yield  
$G_e$ Grazing land used for biomass  
$G_g$: Grazing land biomass products  
$Y_g$: Grazing land Biomass yield

# APPENDIX B.

Appendix Table B. Exogenous Data for 2002.

| State | Gp | Xc | N | Lg | Lc | Dz | Ys | Yp | Yw | Es | As | Ep | Aw | Ew |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| MN | 13.72 | 235.28 | 2.265 | 4.783 | 22.729 | 0.0000 | 4.30 | 5.00 |  | 122.19 | 85.93 | 101.78 |  |  |
| WI | 23.39 | 189.29 | 3.338 | 5.013 | 10.728 | 1.0000 | 4.30 | 5.00 |  | 122.19 | 85.93 | 101.78 |  |  |
| IL | 14.91 | 260.22 | 1.360 | 3.139 | 24.171 | 0.0000 | 4.30 |  | 4.90 | 122.19 | 85.93 |  | 896.44 | 32.50 |
| IN | 16.99 | 250.65 | 0.862 | 2.149 | 12.909 | 0.0000 | 4.30 |  | 4.90 | 122.19 | 85.93 |  | 896.44 | 32.50 |
| IA | 16.19 | 253.02 | 3.550 | 4.576 | 27.153 | 0.0000 | 4.30 | 5.00 |  | 122.19 | 85.93 | 101.78 |  |  |
| OH | 17.31 | 229.46 | 1.240 | 3.159 | 11.424 | 1.0000 | 4.30 |  | 4.90 | 122.19 | 85.93 |  | 896.44 | 32.50 |
| AL | 28.91 | 295.84 | 1.437 | 5.172 | 3.732 | 1.0000 | 6.20 | 6.00 |  | 122.19 | 85.93 | 101.78 |  |  |
| FL | 7.80 | 2179.42 | 1.738 | 6.999 | 3.715 | 1.0000 | 6.20 | 6.00 |  | 122.19 | 85.93 | 101.78 |  |  |
| GA | 31.48 | 484.95 | 1.272 | 6.067 | 4.677 | 1.0000 | 6.20 | 6.00 |  | 122.19 | 85.93 | 101.78 |  |  |
| NC | 20.95 | 466.11 | 0.920 | 3.607 | 5.472 | 1.0000 | 6.20 | 6.00 |  | 122.19 | 85.93 | 101.78 |  |  |
| SC | 22.67 | 431.59 | 0.435 | 3.470 | 2.270 | 1.0000 | 6.20 | 6.00 |  | 122.19 | 85.93 | 101.78 |  |  |
| MO | 13.51 | 151.71 | 4.460 | 11.062 | 18.884 | 1.0000 | 4.30 | 5.00 |  | 122.19 | 85.93 | 101.78 |  |  |
| KY | 13.91 | 222.98 | 2.395 | 5.431 | 8.412 | 1.0000 | 5.00 | 5.00 |  | 122.19 | 85.93 | 101.78 |  |  |
| TN | 10.89 | 245.59 | 2.233 | 4.689 | 6.992 | 0.0000 | 5.00 | 5.00 |  | 122.19 | 85.93 | 101.78 |  |  |
| AR | 31.18 | 217.25 | 1.842 | 4.926 | 9.576 | 0.0000 | 6.20 | 6.00 |  | 122.19 | 85.93 | 101.78 |  |  |
| LA | 34.15 | 319.63 | 0.855 | 2.759 | 5.071 | 0.0000 | 6.20 | 6.00 |  | 122.19 | 85.93 | 101.78 |  |  |
| MS | 28.12 | 247.64 | 1.072 | 5.274 | 5.823 | 0.0000 | 6.20 | 6.00 |  | 122.19 | 85.93 | 101.78 |  |  |
| MI | 18.37 | 345.98 | 0.998 | 2.159 | 7.983 | 1.0000 | 4.00 | 5.00 |  | 122.19 | 85.93 | 101.78 |  |  |
| NY | 26.70 | 295.11 | 1.453 | 2.819 | 4.841 | 1.0000 | 4.00 |  | 4.90 | 122.19 | 85.93 | 101.78 | 896.44 | 32.50 |
| PA | 18.91 | 323.61 | 1.632 | 2.625 | 5.120 | 1.0000 | 4.00 |  | 4.90 | 122.19 | 85.93 |  | 896.44 | 32.50 |
| VA | 19.02 | 273.73 | 1.622 | 4.430 | 4.192 |  | 5.00 | 5.00 |  | 122.19 | 85.93 | 101.78 |  |  |
| ND | 10.09 | 123.62 | 1.873 | 1.804 | 26.506 | 0.0000 | 3.10 |  |  | 122.19 | 85.93 | 101.78 |  |  |
| SD | 12.17 | 116.74 | 3.695 | 1.442 | 20.318 | 0.0000 | 3.10 |  |  | 122.19 | 85.93 | 101.78 |  |  |
| NE | 16.60 | 195.50 | 6.202 | 1.443 | 22.520 | 0.0000 | 3.10 |  |  | 122.19 | 85.93 | 101.78 |  |  |
| KS | 12.33 | 127.49 | 6.321 | 2.181 | 29.542 | 1.0000 | 3.10 |  |  | 122.19 | 85.93 | 101.78 |  |  |
| OK | 15.34 | 106.30 | 5.342 | 3.086 | 14.843 | 1.0000 | 3.10 |  |  | 122.19 | 85.93 | 101.78 |  |  |
| TX | 23.94 | 210.20 | 13.978 | 7.818 | 38.657 | 1.0000 | 3.10 |  |  | 122.19 | 85.93 | 101.78 |  |  |

See page 44 for variable definitions.

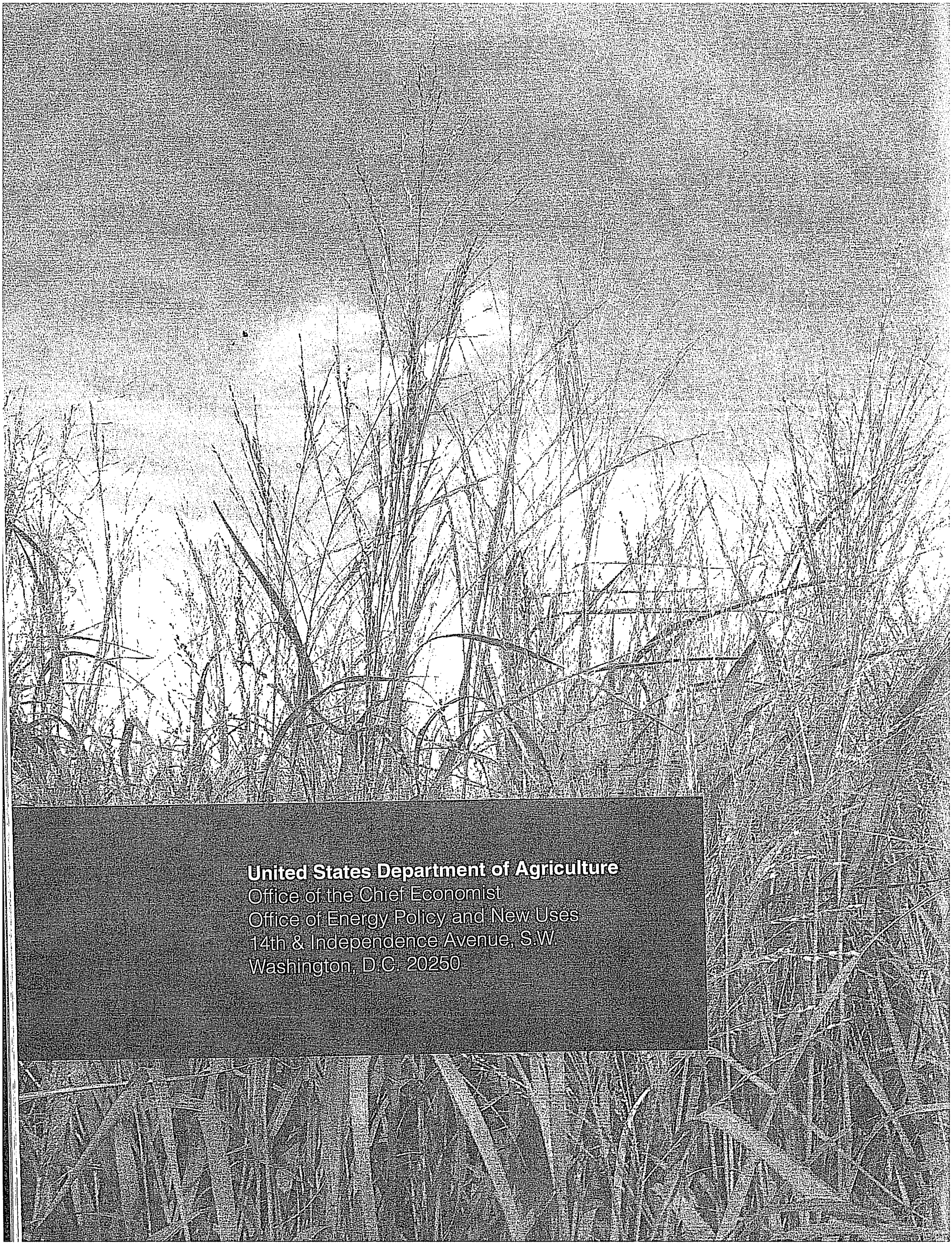
Appendix Table B. Exogenous Data for 2002, continued.

| State | Rg | Rc | Rz |
|---|---|---|---|
| MN | 19.00 | 81.00 | 58.89 |
| WI | 38.00 | 67.00 | 69.09 |
| IL | 30.00 | 122.00 | 102.10 |
| IN | 42.54 | 101.00 | 89.86 |
| IA | 29.70 | 120.00 | 102.24 |
| OH | 46.72 | 77.00 | 85.20 |
| AL | 18.00 | 36.00 | 45.05 |
| FL | 15.00 | 32.00 | 37.62 |
| GA | 23.00 | 39.00 | 39.70 |
| NC | 24.00 | 55.00 | 73.70 |
| SC | 13.58 | 29.00 | 41.90 |
| MO | 23.60 | 66.00 | 66.21 |
| KY | 10.36 | 68.00 | 74.29 |
| TN | 16.50 | 60.50 | 58.36 |
| AR | 14.40 | 53.00 | 49.67 |
| IA | 16.00 | 57.00 | 46.69 |
| MS | 18.00 | 54.00 | 41.74 |
| MI | 45.24 | 60.00 | 72.21 |
| NY | 25.33 | 35.00 | 49.31 |
| PA | 28.00 | 40.00 | 83.60 |
| VA | 16.00 | 36.00 | 287.00 |
| ND | 9.70 | 36.50 | 33.11 |
| SD | 10.80 | 42.00 | 41.15 |
| NE | 10.70 | 66.00 | 54.89 |
| KS | 12.60 | 36.00 | 38.80 |
| OK | 8.50 | 27.00 | 32.28 |
| TX | 7.20 | 21.00 | 35.20 |

See page 44 for definitions.

Appendix Table B (continued): Variable definitions for exogenous data

| | | | | | |
|---|---|---|---|---|---|
| Gp | Government Payments | $/acre | | | |
| Xc | Crop Revenue | $/acre | Ys | yield, switchgrass | ton/acre |
| N | Cattle & calves | millions | Yp | yield, poplar | ton/acre |
| Lg | Other (Non-cropland) Farmland | million acres | Yw | yield, willow | ton/acre |
| Lc | Cropland | million acres | Es | Establishment expense, switchgrass | $/acre |
| Dz | Dummy Variable, lo CRP pay | 0/1 | As | annual expense, switchgrass | $/ acre |
| Rz | CRP Rental Rate | $/acre | Ep | Establishment expense, poplar | $/acre |
| Rc | Cropland Rental Rate | $/acre | Aw | annual expense, switchgrass | $/acre |
| Rg | Grazing Land Rental Rate | $/acre | Ew | Establishment Expense, willow | $/acre |



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