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Appendix C. Appendix to Chapter 5: Biomass from Agriculture

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Disclaimer

Availability

This report and supporting documentation, data, and analysis tools are available online:

Report landing page: https://www.energy.gov/eere/bioenergy/2023-billion-ton-report-assessment-us-renewable-carbon-resources

Data portal: https://bioenergykdf.ornl.gov/bt23-data-portal

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Appendix C. Appendix to Chapter 5: Biomass from Agriculture

POLYSYS Model

To evaluate potential farmgate supplies of agricultural resources, this study employs the Policy Analysis System Model (POLYSYS), a policy simulation model of the U.S. agricultural sector (De La Torre Ugarte and Ray 2000). POLYSYS is a socioeconomic model with market clearing conditions and was previously developed to simulate changes in economic policy, agricultural management, and natural resource conditions, and to estimate the impacts to the U.S. agricultural sector from these changes. An important component of POLYSYS is its ability to simulate how commodity markets balance supply and demand via price adjustments based on known economic relationships. POLYSYS is used to estimate how agricultural producers may respond to new agricultural market opportunities, such as new demand for biomass, while simultaneously considering the impact on the land use and price of other non-energy crops. POLYSYS was used to quantify potential biomass resources in previous billion-ton reports and has been used in other agricultural and biofuels analyses (Ray, Richardson, et al. 1998; Langholtz et al. 2014; Ray, De la Torre Ugarte, et al. 1998; Lin et al. 2000; De la Torre Ugarte et al. 2006; Larson et al. 2010; De La Torre Ugarte et al. 2003).

At its core, POLYSYS is structured as a system of interdependent modules simulating (1) county-level crop supply for the continental United States; (2) national crop demands, export demands, and prices; (3) national livestock supply and demand; and (4) agricultural income. Variables that drive the modules include planted and harvested area, production inputs, yields, exports, costs of production, demand by use, commodity price, government program outlays, and net realized income. Exports are estimated endogenously through a set of short- and long-term export demand response to U.S. price changes (elasticities), as the United States is a price leader in key crops like corn, soybeans, and wheat. Crop transitions among agricultural lands are based on cropland allocation decisions made by individual farmers, and are primarily driven by the expected productivity of land, the cost of crop production, the expected economic return on the crop, and market conditions. POLYSYS is used to model the introduction of a biomass market under specified agronomic assumptions and market scenarios. These assumptions are summarized in the following sections and described in more detail in BT16 Appendix C.1 and BT2 Section 5.2.

POLYSYS anchors its analyses to the published baseline of yield, acreage, and price projections for the agriculture sector from the U.S. Department of Agriculture (USDA) (USDA 2023), which are extended from the USDA 10-year baseline projection period through 2041 for this analysis. Conventional crops currently considered in this analysis include corn, grain sorghum, oats, barley, wheat, soybeans, cotton, rice, and hay, which together comprise approximately 80% of the U.S. agricultural land acreage. Conventional crops simulated for residues include corn, grain sorghum, oats, barley, and wheat (winter plus spring). Production costs associated with residue removal from these crops include replacement of embodied nutrients and per-acre harvest costs associated with shredding, raking, and baling (with a large square baler; see BT16 Appendix C.3) and transportation to the field edge. Production costs associated with purpose-grown energy crops include establishment, maintenance, and per-acre harvest costs (see BT16 Tables C.3 and C.4).

Land Base

POLYSYS is calibrated to current estimates of land use. We use satellite data from the 2022 Cropland Data Layer to determine county-level acreage for the major crops, and 2017 Census of Agriculture data to determine cropland in pasture and permanent pasture. We eliminate county crop acreage if satellite data indicate less than 100 acres to avoid misidentification errors. We cross-checked with the National Agricultural Statistics database to ensure quantities were in harmony. County-level yields of the major crops are taken from this database.

Crop Budgets

We developed detailed operational budgets for all crops in nine regions corresponding to the Farm Resource Regions defined by the USDA. Operations and input quantities were compiled from published state extension budgets. Operational assumptions were derived from EcoWillow 2.0 in coordination with Volk and Eisenbies (personal communication, June 2023).[1] Input costs were updated in 2023 and estimated at the regional level. With these nine regions, we used the spatial interpolation method of inverse distance weighting to increase the resolution of crop production costs to the 305 Agricultural Statistic Regions. A detailed explanation of the spatial interpolation methods used can be found in “Spatial Interpolation of Crop Budgets: Documentation of POLYSYS regional budget estimation.”[2]

Baseline Extension

For the mature market scenario, we simulated markets 20 years into the future. The USDA baseline only projects for 10 years. We extend the USDA baseline an additional 10 years by expanding one exogenous variable in the supply module (yield); expanding one exogenous variables in the demand module (population); and by “shocking” one endogenous variable in the demand module (exports). Yields are expanded at half the rate of increase as the average of the last 4 years of USDA baseline. Population is expanded at the same rate as the average of the last 4 years of USDA baseline, and exports are shocked at half the rate of increase as the average of the last 4 years of USDA baseline.[3]

Pastureland Transition, Management-Intensive Grazing

For the number of local livestock to not be impacted by pastureland conversion to energy crops, the cost of pastureland intensification to sustain livestock numbers must be paid by the new

[1] https://www.esf.edu/willow/download.php

[2] https://arec.tennessee.edu/wp-content/uploads/sites/17/2021/03/POLYSYS_documentation_3_budgeting_database.pdf

[3] https://arec.tennessee.edu/wp-content/uploads/sites/17/2021/03/POLYSYS_documentation_11_baseline-Extension-beyond-USDAbaseline.pdf

purpose-grown energy crops. We assume that 1.5 acres of pasture need to be intensified for every one acre of purpose-grown energy crop in non-arid regions, which is equivalent to a 67% increase in stocking rates under management-intensive grazing. In arid Western regions we assume 2.5 acres of pasture need to be intensified per acre pasture converted to purpose-grown energy crops, which is equivalent to a 40% increase in stocking rate. The cost of intensification is a first-year cost of $50 per acre for pasture (fencing, water for animal drinking, management) and $15 per acre for future years (management).

Agriculture Residue Removal

Agricultural residue modeling mostly follows the same methodology as the BT16 and can be found in BT16 Appendix C2. Budgets were updated from BT16 with 2023 input costs and nitrogen was eliminated as needed for nutrient replacement (assume enough put on as part of crop operations).

Another modeling change from the BT16 is that a limit was put on residue removal of 60%. We assume, based on surveys, that 40% of farmers will want to keep residues in field and not harvest residues (Schmer et al. 2017). Residues estimated include residues from corn, wheat, sorghum, barley, and oats.

Since the BT16, short-stature corn has started trials as an approach to increase yield, decrease inputs, and reduce risk of wind damage (Stoksad 2023). The 1:1 stover-to-grain ratios assumed here could decrease because of shorter stalks, but this reduction may be mitigated by thicker stalks. Reduced risk of wind damage could be beneficial for both grain and stover availability. At this writing, it is unclear if and how modeling assumptions should be changed should short-stature corn become prevalent. The potential for adoption of short-stature corn is a source of uncertainty in this analysis.

Oilseed Assumptions

We assume brassicas varieties that can be planted in fall to grow over the winter months and harvested in the spring before soybean planting. Due to the probability of a delayed soybean planting, we dock soybean yields in the rotation by 6.5%.

Yields and costs of production for brassica oilseeds are sourced from Markel et al. (2016) and Trejo-Pech et al. (2019) (pennycress), Robertson (2020) (Carinata), and Rahman (2018) (Camelina). These analyses used the EPIC model to estimate seed yield regionally.

Carbon Accounting Methods

POLYSYS assumes a national rate of change in soil carbon unique to each purpose-grown energy crop. We then adjust this national rate of change based on a weighted county-level base estimate of soil organic carbon (SOC). The method we employ is discussed in detail in Hellwinckel (2008) and West et al. (2008). The national rate of change we assume for switchgrass is 5% increase in SOC per year. On average this equates to 0.52 Mt C acre^{-1} yr^{-1} (1.28 Mg ha^{-1} yr^{-1}), which is what Qin et al. (2016b) determined from analysis of widespread field data in the full top meter soil profile. The same study determined miscanthus SOC rates are on average 24% lower than switchgrass, therefore we use are rate of 3.8% for miscanthus, which equates to a national average of 0.4 Mt C acre^{-1} yr^{-1} (0.97 Mg ha^{-1} yr^{-1}). For short-rotation woody purpose-grown energy crops we assume a minimal SOC increase of 0.17% per year, taken from tree crop estimates in Zang et al. (2018) and Agostini et al. (2015). We assume SOC increases only on cropland converting to purpose-grown energy crops and assume zero SOC change on pasturelands converting to purpose-grown energy crops. We assume SOC can only increase until pre-plow levels of SOC are reached or a 100% increase in soil carbon over current levels (Nelson et al. 2009; Hellwinckel 2019).

Additional Residues (Rice Straw, Cotton Field Residues) and Agricultural Processing Wastes (Rice Hulls, Cotton Gin Trash, and Orchard Prunings)

Calculations for rice hulls, rice straw, cotton gin trash, cotton field residues, and orchard prunings are based on assumptions from DOE (2016) Chapter 5, under revised USDA data, as follows:

1. Rice hulls
    a. Rice assumed 20% hulls; 20% rice moisture content; i.e., 1 hundredweight of rice at 20% moisture content = 0.04 tons of rice = 0.008 tons of rice hulls.
    b. Rice hulls are assumed to be 100% available.
    c. Rice hulls were assumed $40 per dry ton in 2014 dollars, inflation multiplier 1.2 based on CPI = assumed $48 per dry ton rice hulls in 2022 dollars.
    d. County-level rice production derived from POLYSYS USDA baseline, 2023, assumed flat in all scenarios and years.
2. Rice straw, based on DOE (2016), Chapter 5
    a. 1:1 straw-to-grain ratio, 20% rice moisture content; i.e., 1 hundredweight of rice at 20% moisture content = 0.04 tons of rice = 0.04 tons of rice straw.
    b. Rice straw is assumed to be 50% available.
    c. Rice straw was assumed $50 per dry ton in 2014 dollars, assumed $60 per dry ton rice straw in 2022 dollars, assumed flat in all scenarios and years.
    d. County-level rice production derived from POLYSYS USDA baseline, 2023, assumed flat, assumed flat in all scenarios and years.
3. Cotton field residues
    a. For every unit of cotton harvested, units of standing stalk available: 0.509.
    b. i.e., 100 tons of cotton harvested = 50.9 tons of cotton field residues available.
    c. 1st half, 2022 $ $60.00 per dry ton
    d. 2nd half, 2022 $ $72.00 per dry ton

e. County-level cotton production derived from POLYSYS USDA baseline, 2023, assumed flat, assumed flat in all scenarios and years.

4. Cotton gin trash

   a. Cotton gin trash converted to production basis: 0.16 tons of cotton gin trash per bale of cotton. A bale of cotton is 480 lbs. Price for cotton gin trash assumed $48 per ton in 2022$ based on DOE (2016) Chapter 5.

5. Orchard pruning residues

   a. Categories:

      i. Pruning residues, citrus

      ii. Pruning residues, non-citrus

      iii. Pruning residues, tree nuts.

   b. Based on USDA 2017 census data (USDA 2017), assumed flat. Dry tons of prunings available are based on USDA 2017 county census acreage data for the selected commodities. These areas are multiplied by conversion factors used in BT16 (DOE 2016) to estimate dry tons of prunings. The conversion factors for per-acre yield data for individual crops from (Nelson 2010) are provided in Table C-1.

Table C-1. Conversion Factors of Acres to Dry Tons by Commodity Type

USDA Commodity	BT23 Resource	Dry Tons Trimmings per Acre
Almonds	Pruning residues, tree nuts	0.85
Apples	Pruning residues, non-citrus	1.43
Apricots	Pruning residues, non-citrus	1.30
Avocados	Pruning residues, non-citrus	0.98
Cherries	Pruning residues, non-citrus	0.26
Chestnuts	Pruning residues, tree nuts	0.65
Citrus, other	Pruning residues, citrus	0.65
Dates	Pruning residues, non-citrus	0.39
Figs	Pruning residues, non-citrus	1.43
Grapefruit	Pruning residues, citrus	0.65
Grapes	Pruning residues, non-citrus	1.30
Hazelnuts	Pruning residues, tree nuts	0.65
Kiwifruit	Pruning residues, non-citrus	1.30
Lemons	Pruning residues, citrus	1.30

USDA Commodity	BT23 Resource	Dry Tons Trimmings per Acre
Limes	Pruning residues, citrus	1.30
Nectarines	Pruning residues, non-citrus	1.04
Non-citrus fruit, other	Pruning residues, non-citrus	1.04
Olives	Pruning residues, non-citrus	0.98
Oranges	Pruning residues, citrus	1.95
Peaches	Pruning residues, non-citrus	1.30
Pears	Pruning residues, non-citrus	1.50
Pecans	Pruning residues, tree nuts	1.04
Persimmons	Pruning residues, non-citrus	1.04
Pistachios	Pruning residues, tree nuts	0.65
Plums and prunes	Pruning residues, non-citrus	0.98
Pomegranates	Pruning residues, non-citrus	1.04
Tangerines	Pruning residues, citrus	0.65
Tree nuts, other	Pruning residues, tree nuts	0.65
Walnuts, English	Pruning residues, tree nuts	0.65

c. Half of the orchard and vineyard prunings were assumed to be available at $20 per dry ton in BT16 (estimated as $25 in 2022 dollars), all are expected to be available at $30 dry ton in BT16 (estimated as $40 in 2022 dollars)

d. National totals as summarized by subclass from the USDA National Agricultural Statistics Service (USDA 2017) are provided in Table C-2.

Table C-2. National Summary of Orchard Prunings by Resource Based on County-Level Data from USDA National Agricultural Statistics Service (USDA 2017)

Resources	Dry Tons
Pruning residues, citrus	**1,982,012**
Citrus, other	6,632
Grapefruit	64,162
Lemons	123,533
Limes	1,084
Oranges	1,712,688
Tangerines	73,914

Resources	Dry Tons
Pruning residues, non-citrus	**4,208,184**
Apples	787,451
Apricots	26,299
Avocados	90,842
Cherries	58,045
Dates	9,431
Figs	14,798
Grapes	2,188,360
Kiwifruit	7,886
Nectarines	30,471
Non-citrus fruit, other	425,079
Olives	62,408
Peaches	162,949
Pears	116,273
Persimmons	5,773
Plums and prunes	189,443
Pomegranates	32,678
Pruning residues, tree nuts	**2,876,891**
Almonds	1,596,477
Chestnuts	1,184
Hazelnuts	67,425
Pecans	491,624
Pistachios	321,643
Tree nuts, other	772
Walnuts, English	397,767
Grand total	**9,067,087**

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