Chapter 05

Biomass from Agriculture

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5 Biomass from Agriculture

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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

Summary

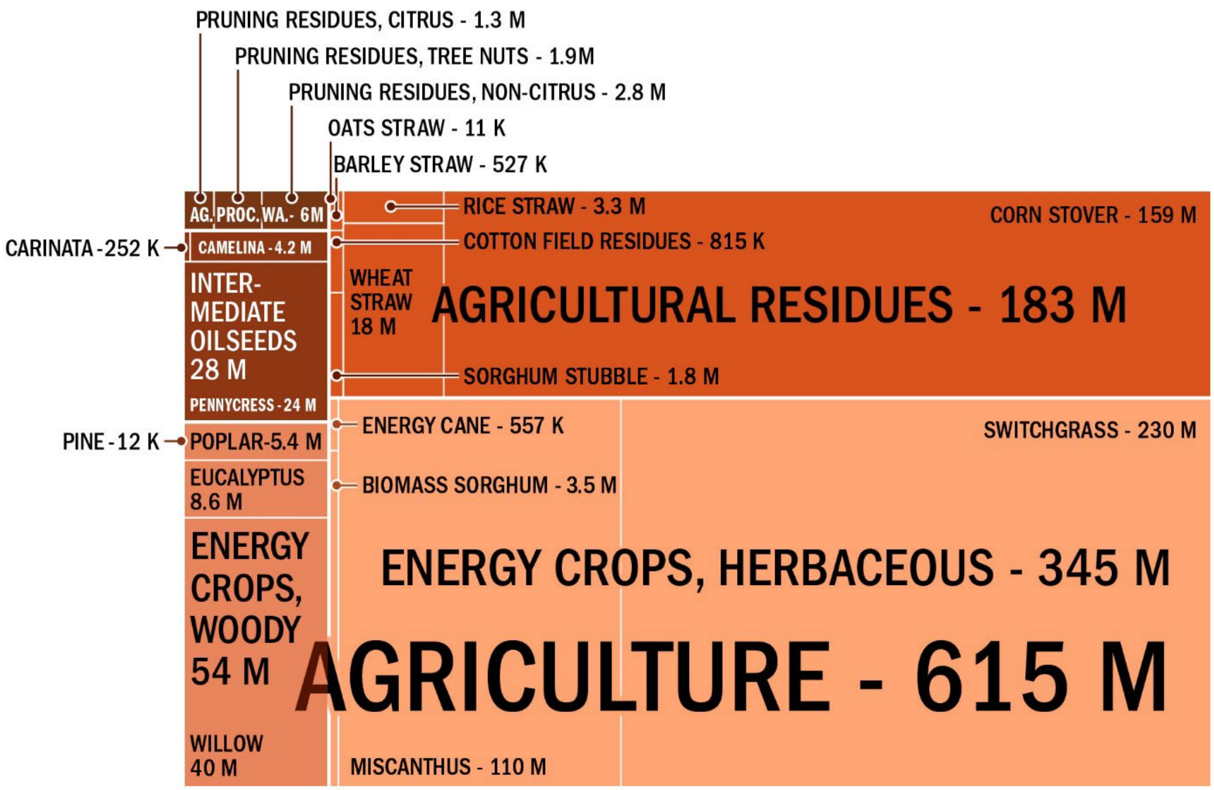

Figure 5.1. National biomass resources from agricultural lands, mature-market medium scenario, $70 per dry ton for cellulosic resources, $400 per dry ton of seed for intermediate oilseed resources. Units in dry tons of biomass except for carinata, camelina, and pennycress, which are in units of tons of oilseed.

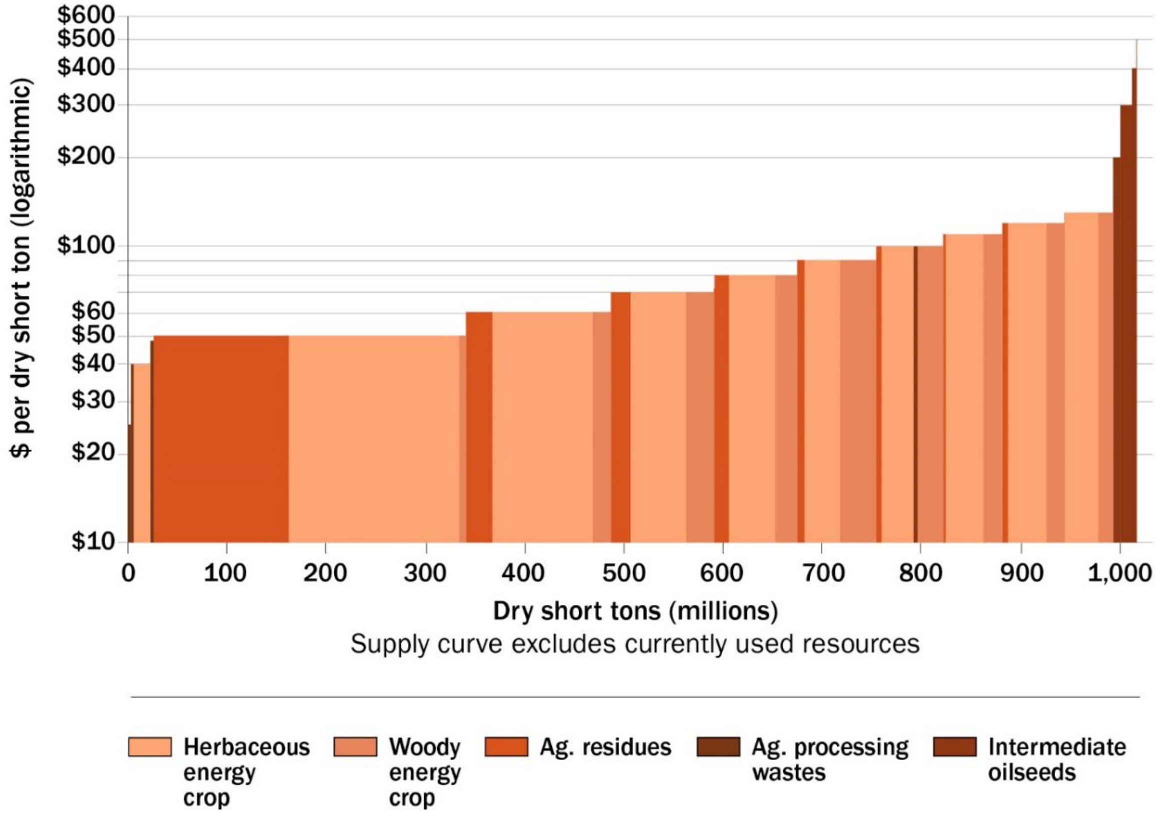

Figure 5.2. Stepwise supply curve of agricultural resources, mature-market medium scenario

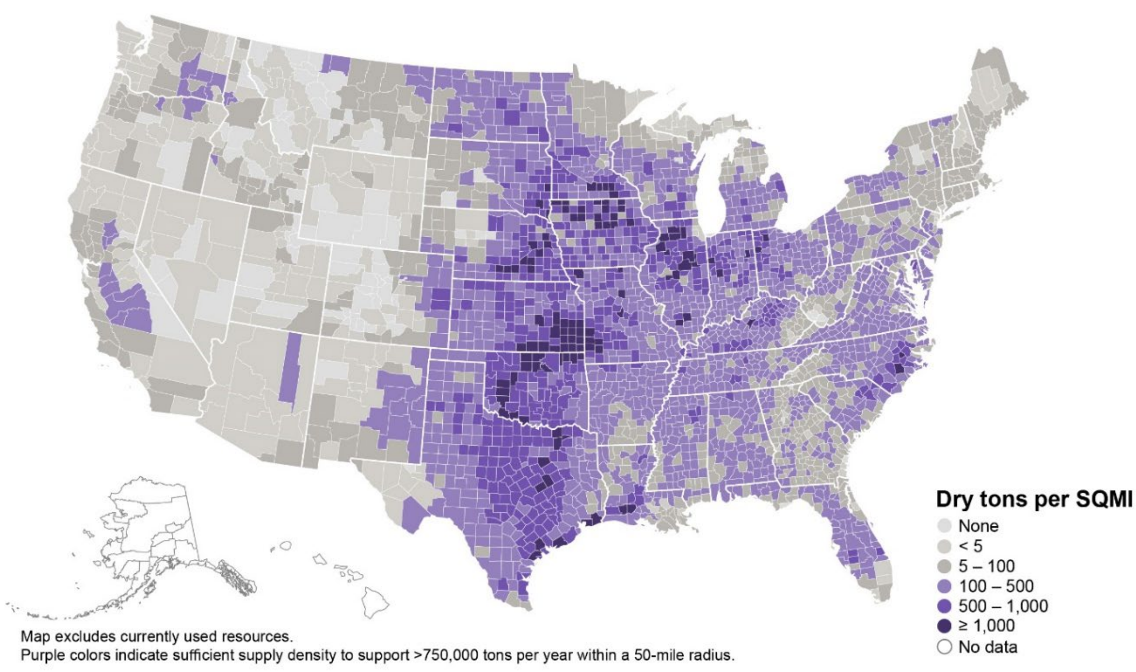

Figure 5.3. Spatial distribution of agricultural resources, mature-market medium scenario, cellulosic resources at $70 per dry ton, intermediate oilseed crops at $400 per ton of seed

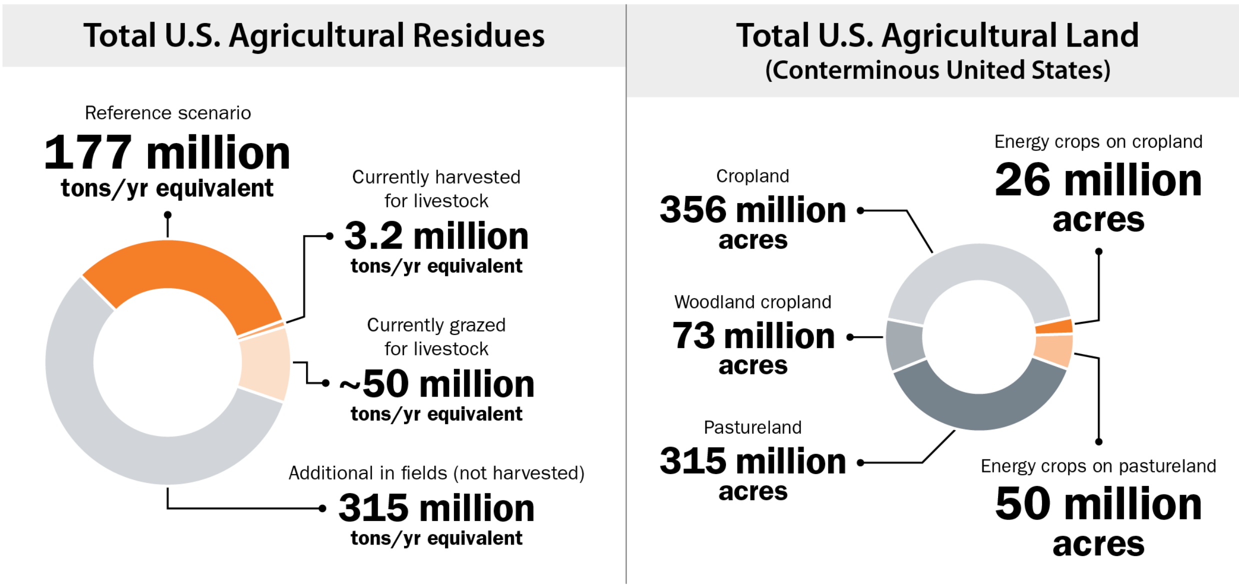

Figure 5.4. Agricultural residues (corn stover and wheat straw) reported as available in mature-market medium scenario at $70 per dry ton in proportion to total in-field production; agricultural land allocated to purposed-grown energy crops in the mature-market medium scenario at $70 per dry ton in proportion to total U.S. agricultural lands

- Sustainability constraints of this analysis are summarized in Table 1.4, and risks of deviating from these constraints are discussed in Chapter 6.
- Biomass resources from agricultural lands explored in this chapter provide the major share of biomass in future market scenarios. At a reference price of $70/dry ton (2022 $), this includes about 140–180 million tons per year of agricultural residues, and roughly 300–500 million tons of purpose-grown energy crops on about 9% of total U.S. agricultural lands, depending on scenario assumptions. Agricultural residue removal is constrained for soil conservation and adoption rates as described below, resulting in less than one-third of residues being removed nationally in the mature-market medium scenario.
- Purpose-grown energy crops are shown to have comparative advantages in regions of less intensive conventional crop production (e.g., the southern Plains, as compared to the Corn Belt). Other studies have sometimes restricted purpose-grown energy crop siting *a priori* to tracts of land with lower yields, higher vulnerability to degradation, or other biophysical characteristics that make sustained production of conventional crops challenging (Khanna et al. 2021). However, farmers make crop production and land allocation decisions based on a variety of factors, and we believe that allocating purpose-grown energy crop production to tracts of low-yielding lands in isolation of economic interactions would fail to reflect realistic futures and inevitable economic interactions among crop markets (Skevas et al. 2016; Swinton et al. 2017). As with previous reports, we instead evaluate purpose-grown energy crop production potential within an economic context of other crop options.

- About 587 million dry tons per year of cellulosic biomass resources can be produced in the United States under a mature-market medium scenario price of $70/dry ton. Of this, 183 million tons is sourced from crop residues and 398 million tons is from purpose-grown energy crops grown on cropland and pastureland, with the remainder from agricultural processing wastes. In this scenario, major grains and soybean commodity prices are estimated to increase by 5% to 20% over business as usual as biomass markets reach maturity, which is well within recent historic annual variability. This translates to up to a 0.7% weighted average finished food price increase. The combined impact is modeled to increase in total farm market net revenues of 31% over business as usual.
- A mature cellulosic market would result in the uptake of 32 million metric tons of CO_2 in soils growing perennial purpose-grown energy crops. Assuming one vehicle emits 4.6 metric tons of CO_2 per year, this is the equivalent of displacing emissions from nearly 7 million cars.
- Intermediate oilseed crops grown in winter as part of a rotation with summer-grown crops can provide 21 billion lbs. (10.5 million tons) of lipid oil per year. Commodity price impacts due to intermediate crops are minimal due to no land use competition for off-season crops.

5.1 Background

5.1.1 Introduction

We present an updated estimate of potential biomass supplies from agricultural lands. The potential for farmers to respond to new markets for biomass has been assessed with the Policy Analysis System Model (POLYSYS) in previous versions of the billion-ton report (DOE 2017, 2016, 2011) and other studies (Oyedeji et al. 2021; Davis et al. 2020; Langholtz et al. 2019; Woodbury et al. 2018; Eaton, Langholtz, and Davis 2018; Langholtz et al. 2014; Langholtz et al. 2012; Jensen et al. 2007; De la Torre Ugarte and Ray 2000; Hellwinckel et al. 2015). Building on previous analyses, POLYSYS was used to update estimates of biomass supplies and prices from agricultural lands given environmental, land use, and technical constraints. The POLYSYS model, methods, and constraints are summarized below and detailed in the appendix.[1] Model dynamics are illustrated in Figure 5.5.

Changes from previous billion-ton reports include the use of the new 2023 USDA baseline, reporting of mature-market biomass supplies (see Section 5.2: Methods Summary), oilseed supply estimates, and reporting of changes to carbon emissions and soil sequestration.

5.1.2 Agricultural Land Potential

U.S. agricultural lands consist of 382 million acres of cropland and 415 million acres of pastureland; 80% of cropland is planted to only eight annual crops. Corn is the largest crop in the United States with 95 million acres in 2023 (USDA-NASS 2023b); 37% of corn production goes

[1] Access BT23 appendices at www.energy.gov/eere/2023-billion-ton-report.html.

directly to feeding livestock and 35% is processed for ethanol production while coproducing high-protein feed ingredient (dried distillers grains with solubles). Soybeans are the second-largest crop in the United States with 87 million acres, where 51% of production is crushed to coproduce meal and oil. Almost 100% of the meal is fed to livestock, and 39% of the oil is used to produce biofuels. The majority of pastureland is devoted to low-intensity grazing of livestock. The introduction of perennial purpose-grown energy crops can be a net energy resource for the nation while also playing a role in crop diversification, soil conservation, and improving farm income. Sustainably harvesting agricultural residues and winter intermediate oilseeds from annual cropland can also be a major source of bioenergy feedstock while simultaneously ensuring soil health.

5.2 Methods Summary

- Quantifying biomass resources from agricultural lands must account for sustainability constraints, alternative land use options, operational costs, spatially explicit crop productivity potential, and competing demands for conventional agricultural products. These are quantified with POLYSYS, a partial equilibrium socioeconomic model. As a starting point, POLYSYS determines land use at the county level based on USDA-projected national acreage yield and prices and demands for food, feed, fiber, and exports for conventional crops.[2] Then it models land allocation, introducing purpose-grown energy crop demands, and reports changes in supply, demand, and price effects of traditional and energy purpose-grown crops.
- The USDA baseline and its extension to 2041 does not make any explicit assumptions on impacts of climate change in U.S. or international crop yields. Neither makes any explicit reference to wide interventions toward reducing the economy's carbon footprint—e.g., changes in corn ethanol demand driven by electrification of the light-duty vehicle fleet. Regarding biofuels, corn ethanol demand is projected at 15 billion gallons per year and biodiesel from soybeans at 1.5 billion gallons per year throughout the period of 2023–2041.
- Crop residue removals cannot exceed the tolerable soil loss limit as recommended by the USDA's Natural Resources Conservation Service.
- Crop residue removal cannot result in long-term loss of soil organic matter as estimated by the Revised Universal Soil Loss Equation and the Wind Erosion Prediction System.
- A 60% limit was put on residue removal. Based on current surveys, 40% of farmers will want to keep residues in field and not harvest them (Schmer et al. 2017).

[2] USDA baseline contains national projections for the agricultural sector through the 2032/2033 crop year, then POLYSYS uses its own parameters and exogenous projections for population and yields to extend the USDA baseline to the year 2040.

- For the number of local livestock to not be impacted by pastureland conversion to purpose-grown energy crops, pastureland needs to be managed more intensively through timed rotations using paddocks that increase sustainable stocking density. We assume that 1.5 acres of pasture need intensified management for every acre of purpose-grown energy crop in non-arid regions, and in arid regions we assume 2.5 acres of pasture need intensified management per acre of pasture converted to purpose-grown energy crops. The cost of intensified management is a first-year cost of $50 per acre for pasture (fencing, water, and management) and $15 per acre for future years (management). The cost of pastureland intensification, as defined above, to sustain livestock numbers must be paid by the new purpose-grown energy crops.

Annual production quantities for each traditional crop (corn, sorghum, oats, barley, wheat, soybeans, cotton, and rice) are summed to the national level, where crop supply and demand interact to determine crop prices simultaneously. POLYSYS solves every year for 20 years, starting in 2023, where crop prices of the previous year determine land use decisions for the next year. POLYSYS models the eight major commodity crops and also the purpose-grown energy crops—switchgrass, miscanthus, poplars, willows, energy sorghum, and energy cane, as well as crop residue collection. The same model is used to illustrate the contribution of the intermediate oilseed winter crops. A conceptual illustration of the POLYSYS model is shown in Figure 5.5 and detailed in the appendix.

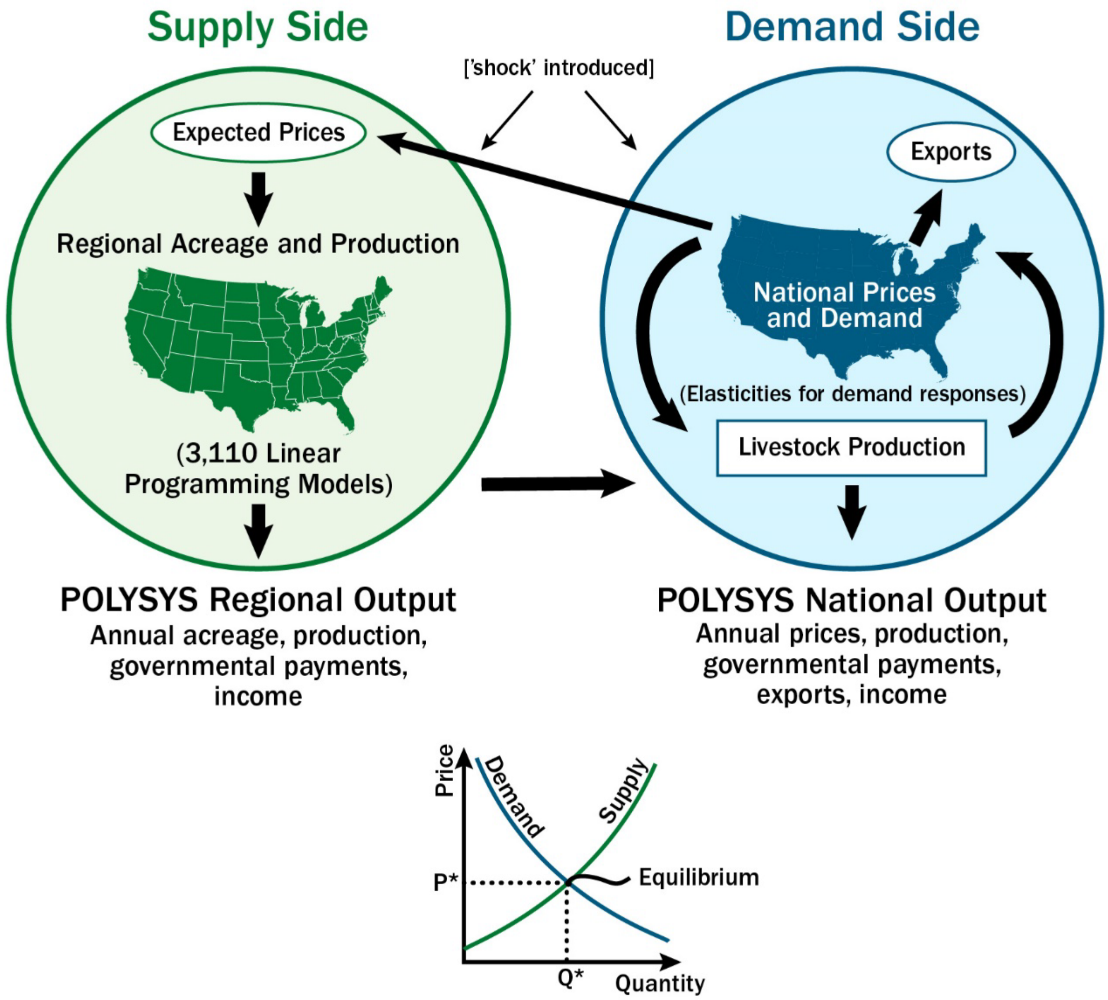

Figure 5.5. POLYSYS model iterative flow; county-level supplies are estimated and summed to the national level, where demands and prices are solved simultaneously to clear available supplies. The new prices are used in the next year to estimate supplies.

5.2.1 Biomass Scenarios

There is uncertainty in how future crop yields will improve and how quickly harvesting technology will advance. We estimate biomass potential under three different market conditions that reflect differing crop yields, designated as low, medium, or high (Table 5.1). All scenarios reflect mature-market conditions, where we assume there will be an active national biomass market for 20 years. The medium scenario assumes conventional crop yields improve following the USDA baseline, energy crop yields increase at the rate of 1% per year, and residues machinery harvest technologies improve from 50% to 90% efficiency. The low scenario assumes progress lags, and the high scenario assumes improvements in yields and technologies exceed expectations. We constrain residue harvest estimates based on current surveys that 40% of farmers will want to keep residues in the field and not harvest them (Schmer et al. 2017). We run all scenarios under a range of biomass prices to determine implications on biomass supply.

Table 5.1. Descriptions of Biomass Supply Scenarios Simulated in POLYSYS, at Prices from $40 to $130 per Dry Ton in $10 Increments (2022 $)

Scenario	Assumptions
Near term	Near term (simulated as 7 years after 2023) Only crop residues (corn, wheat, sorghum, barley, and oat) No harvest technology improvements
Low	Mature market (simulated as 18 years after 2023) No energy crop yield improvements Conventional crop yield improvements assume USDA baseline No harvest technology improvements
Medium	Mature market (simulated as 18 years after 2023) 1% per year energy crop yield improvements Conventional crop yield improvements assume USDA baseline Harvest technology improves from 50% to 90% efficiency
High	Mature market (simulated as 18 years after 2023) 3% per year energy crop yield improvements Conventional crop yields improve 1.5 times the USDA trend Harvest technology improves from 50% to 90% efficiency

5.2.2 Intermediate Non-Food Oilseed Crop Scenarios

The White House's SAF Grand Challenge has set a goal of using 3 billion gallons of SAF by 2030 and 35 billion gallons by 2050. The contribution to soybean oil as feedstock for biodiesel is around 70%, while canola and corn oil contribute 10% and 19%, respectively. All three are also well-established food crops for vegetable oil. In this analysis we focus on the introduction of non-food oilseeds or intermediate oilseeds as an independent scenario. We exclude canola from the analysis because it typically has higher costs and lower yields than the other brassica oilseeds. Consequently, we estimate future oilseed supply potential of three intermediate winter-grown oilseed crops—pennycress, camelina, and carinata—in rotation with conventional summer crops and along with the use of conventional soybeans. The intermediate oilseed crops grow in the winter between corn (or cotton) and soybeans when fields are typically fallow, but alternating production only every other winter to allow earlier corn planting and to minimize crop pest pressure by leaving fields fallow after soybeans. Oilseed crop supply scenario assumptions are shown in Table 5.2. Herbaceous intermediate crops (e.g., winter rye, alfalfa) are widely adopted for soil conservation. In one estimate they have the potential to increase biomass supply by approximately 20 million tons per year while providing environmental services (Malone et al. 2023). At this time we are excluding herbaceous intermediate crops from the analysis and focusing on lipid oil production. They will be included in ongoing follow-up analyses to this report.

Table 5.2. Descriptions of Oilseed Supply Scenarios as Simulated in POLYSYS

Scenarios	Assumptions
Intermediate oilseeds	Mature market (simulated as 18 years after 2023) Intermediate oilseed crops (pennycress, carinata, and camelina) In 2-year rotation corn (or cotton) and soybean Run farm gate prices at \$0.05–\$0.25/lb. oilseed
Soybean oilseed	Mature market (simulated as 18 years after 2023) Soybeans as oilseed crops Run at increasing oilseed demand levels

5.2.3 Other Agricultural Residues and Processing Wastes

Additional crop residues (rice straw and cotton field residues) and agricultural processing wastes (orchard prunings) are estimated as fractions of county-level production, totaling 10.1 million tons per year. Additional supplies for rice hulls and cotton gin trash, totaling about 10 million tons per year, are not reported here but data are provided at https://bioenergykdf.ornl.gov/bt23-data-portal. Assumptions for estimating these additional resources, totaling 21 million tons per year, are provided in the appendix.

5.3 Results

5.3.1 Biomass Supply

The general results of the simulations are summarized in Table 5.3, showing results of mature-market low, medium, and high scenarios simulated at \$70 per dry ton. The table displays production of energy crops and agricultural residues, percent reduction from baseline in the total production of the three major traditional crops (corn, wheat, and soybeans), corresponding change in their weighted average price, change in food prices, and finally percentage change in total market returns from traditional crop production and residue collection. These indicators show that the production in biomass feedstock from cropland implied a small reduction in production, a small increase in crop and food prices, but a significant increase in total market returns from the baseline that ranges from 26% in the low scenario and more than 30% in the medium and high scenarios. The key message is that the shift of a small portion of acres to the production of energy crops and the added income contribution of collecting residues for energy have large returns for corn, wheat, and soybeans producers. A detailed analysis of these impacts follows.

Regenerative Grasses Benefit Farmers, Consumers, and the Environment

Regenerative grasses, with their deep root systems, have the power to improve soil health, sequester carbon, and prevent soil erosion. Cultivated annually, they can minimize environmental impact and help restore degraded land. Also, fibers from regenerative grasses such as switchgrass and giant miscanthus can benefit rural agricultural communities while offering sustainable alternatives to single-use plastics. Agricultural fiber manufacturers can help farmers produce high-yielding, carbon-negative regenerative grasses on underutilized farmland not suitable for most crops.

One company, Genera, is doing just that. Locally sourced agricultural feedstocks supply Genera's East Tennessee non-wood fiber and converting facility, where it transforms fibers into a variety of packaging products, from corrugated cardboard to biodegradable trays and containers. These materials are not only renewable but also compostable, making them an environmentally responsible choice for consumer packaging for food service and retail uses. The process uses a fraction of the energy, water, and harsh chemicals required for other types of recycled fibers.

Such products are cost-competitive and domestically sourced alternatives to single-use plastics, foam, and imported fiber products. The industry can respond to this high demand with new fiber-based products, including SAF, that benefits farmers, consumers, and the environment. Farmers get an additional source of income through the cultivation of these grasses, the packaging industry gains access to a sustainable supply of raw materials, and the environment benefits from soil conservation and carbon capture. Thus, the use of these grasses in consumer packaging demonstrates that a more sustainable future is rooted in agricultural regenerative practices with promise for a greener world for generations.

Photos from Sam Jackson, Genera Inc.

Table 5.3. Modeled Impacts of Energy Crop Scenarios on U.S. Commodity Crop Production, Commodity Crop Prices, Food Prices, and Farm Revenues. Future Yield Improvements Simulated in the Mature-Market High Scenario Mitigate Impacts on Conventional Production and Increase Biomass Production.

Scenario [a]	Energy Crops Produced (Million Dry Tons) [a,b]	Agricultural Residues Harvested (Million Dry Tons) [a,c]	Production of Corn, Soy, and Wheat	Change in Commodity Price [d]	Change in Finished Food Price [d,e]	Total Farm Market Net Revenues [f]
			(% Change from Baseline, Mature Market)			
Mature-market low	318	152	−3%	+5%	+0.6%	+26%
Mature-market medium	398	177	−3%	+6%	+0.7%	+31%
Mature-market high	638	200	−1%	+1%	+0.1%	+31%

[a] Simulated biomass price of $70 per dry ton, selected as modeling year 2041 as described in this chapter and summarized in Figure ES.1.
[b] Sum of modeled cellulosic terrestrial (i.e., intermediate oilseeds and excluding algae) purpose-grown energy crops within modeling constraints as summarized in Figure ES.1.
[c] Sum of corn stover and wheat straw within modeling constraints as summarized in Figure ES.1.
[d] Weighted average of corn, soy, and wheat.
[e] Assumes raw food commodities comprise 16.6% of the price of finished food prices based on average from 1993–2022 .
[f] Total market revenues minus total variable costs on cropland, as compared to the USDA baseline simulation without energy crop production, 2041. Excludes government payments.

Detailed simulation results indicate that biomass supplies from agricultural lands (i.e., crop residues [excluding rice and cotton] and purpose-grown energy crops) come into production at prices over $50 per dry ton and increase as the offered biomass price increases. At the reference price of $70 per dry ton, 471, 577, and 839 million dry tons are estimated to be produced under the low-, medium-, and high-yield assumptions, respectively (Table 5.4 and Figure 5.6). At the high price of $130 per dry ton, quantities increase to 788, 973, and 1,365 million dry tons under low-, medium-, and high-yield assumptions, respectively (Figure 5.7). An additional 10.2 million tons per year of rice straw, cotton field residues, and orchard prunings is accounted for separately, as described in the appendix.

Table 5.4. Biomass Supply Potential per Year from Agricultural Lands for Residues and Purpose-Grown Energy Crops at Increasing Biomass Prices under Low, Medium, and High Mature-Market Scenario Assumptions

	Low				Medium				High			
Price	Crop Residues	Herbaceous Energy Crops	Woody Energy Crops	Total (Residues + All Energy Crops)	Crop Residues	Herbaceous Energy Crops	Dedicated Woody	Total (Residues + All Energy Crops)	Crop Residues	Herbaceous Energy Crops	Woody Energy Crops	Total (Residues + All Energy Crops)
($/dt)	(million dry tons)				(million dry tons)				(million dry tons)			
$-	0	0	0	0	0	0	0	0	0	0	0	0
$30	0	0	0	0	0	0	0	0	0	0	0	0
$40	0	7	0	7	0	17	0	17	0	97	3	99
$50	121	123	3	247	136	188	7	331	169	337	30	536
$60	136	226	16	379	158	289	26	473	187	454	63	704
$70	**153**	**284**	**34**	**471**	**179**	**345**	**54**	**577**	**201**	**535**	**103**	**839**
$80	163	317	57	538	192	391	76	658	208	606	148	962
$90	172	353	79	603	199	427	113	738	214	664	185	1,064
$100	176	376	109	661	205	459	138	801	218	731	211	1,160
$110	181	396	129	707	208	496	157	861	221	788	235	1,244
$120	183	420	146	749	213	535	176	924	221	832	253	1,306
$130	186	443	159	788	214	569	191	973	219	871	275	1,365

Estimated residue harvest quantities are considerably below total residues available in the field (harvest approximately one-third of total residues) due to model limits that (1) ensure adequate quantities remain in the field to prevent erosion; (2) account for harvesting equipment efficiency limits, which currently can only capture 50% of total residues; and (3) ensure quantities remain for livestock uses (see the appendix for details). Corn and wheat residues comprise 89% and 10% of total harvestable residues, respectively, with sorghum, oat, and barley residues making up less than 1% of total residues.

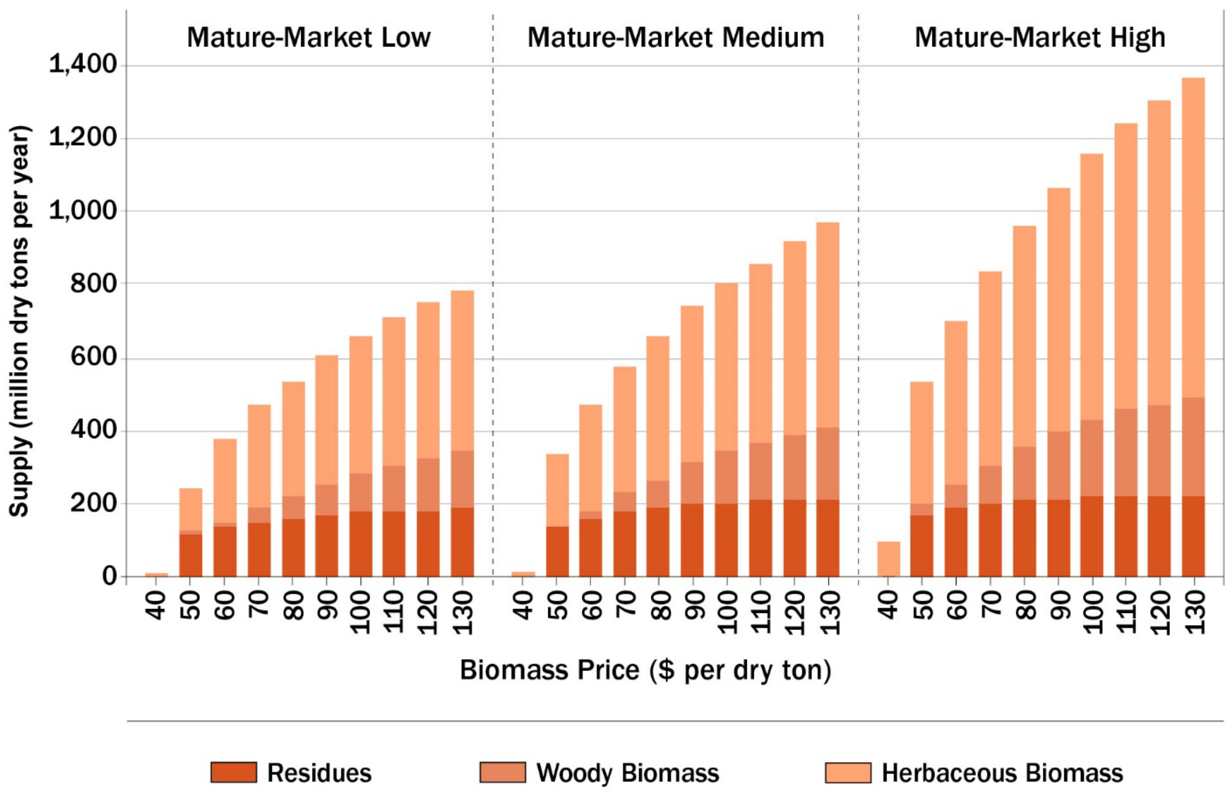

Figure 5.6. Modeled biomass production by scenario, price, and subclass

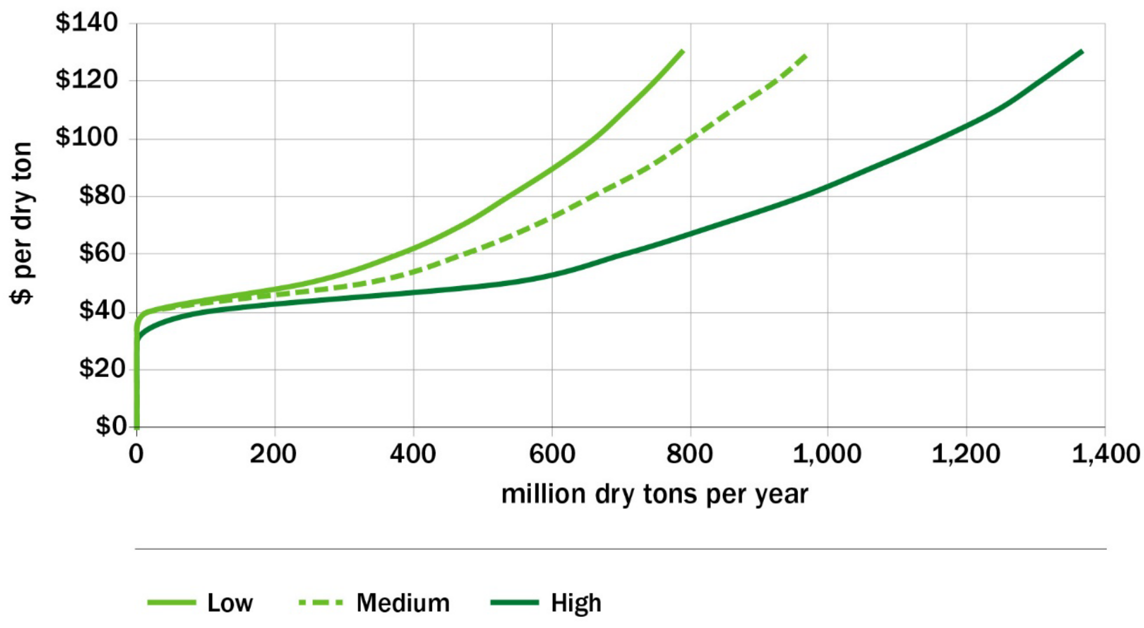

Figure 5.7. Biomass supply potential per year from agricultural lands (i.e., crop residues and purpose-grown energy crops combined) at increasing biomass prices under low, medium, and high mature-market scenario assumptions

5.3.2 Agricultural Land Competition for Purpose-Grown Energy Crops

Key points of agricultural land use competition:

- In this analysis, we do not presuppose that farmers are constrained to purpose-grown energy crop production on marginal lands, because future practices could be expected to deviate from this assumption (Skevas et al. 2016; Swinton et al. 2017). Rather, we model for an economic solution to simulate expected farmer production decisions in a free market. Modeled results suggest that conventional crops (e.g., corn and soy) maintain their position of economic competitive advantage on prime cropland (e.g., the Corn Belt), and purpose-grown energy crops are allocated to regions of less intensive conventional crop production outside the Corn Belt, and to pasturelands largely in the southern Plains (Figure 5.8).
- Under simulated mature-market conditions at a reference price of $70 per dry ton, approximately 398 million tons of purpose-grown energy crops are produced on 76 million acres planted to purpose-grown energy crops, including 26 million acres of cropland and 50 million acres of pastureland (Figure 5.9). The total land planted to purpose-gown energy crops represents about 9% of agricultural lands (Figure 5.10), while meeting demands for food, feed, fiber, and exports.

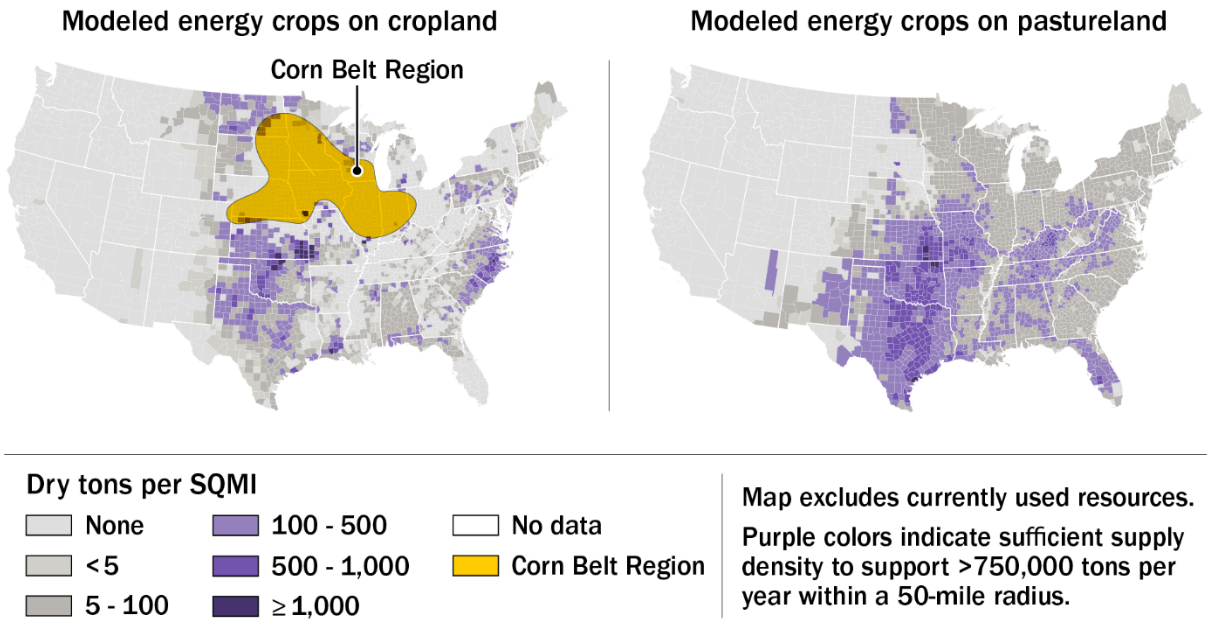

Figure 5.8. Energy crop production density on cropland and pastureland in the simulated mature-market medium scenario under a biomass price of $70 per dry ton. Orange region indicates corn/soy production region as indicated by the USDA National Agricultural Statistics Service (2023a). Little purpose-grown energy crop production is modeled on cropland in the Corn Belt, but rather is concentrated in the southern Plains.

Estimated agricultural land allocation to purpose-grown energy crop production as a function of biomass price is shown in Figure 5.9. As biomass prices rise, pasture converts rapidly in the East but slows in the West, where purpose-grown energy crop yields decline and pasture intensification costs increase. Cropland conversion steadily increases as biomass prices increase. For the mature-market medium scenario at the reference price of $70 per dry ton, 76 million acres are planted to purpose-grown energy crops, including 26 million acres of cropland and 50 million acres of pastureland. An additional 70 million acres are harvested for crop residues. Prime farmland in the Midwest does not convert to purpose-grown energy crops because of economic comparative advantages of commodity crops in that region (i.e., the Prairie Gateway Farm Resource Region [USDA-ERS 2000]). Land tends to convert to purpose-grown crops in regions of less intensive production, where cultivated cropland area grows or shrinks depending on commodity prices (Swinton et al. 2011; Lark, Salmon, and Gibbs 2015). Inclusion of other parameters such as soil conservation, water quality, or regional cooling could result in a different spatial distribution of purpose-grown energy crop potential (e.g., Uludere Aragon et al. 2023). Similarly, subcounty and subfield optimization could increase biomass production, reduce biomass price, and enhance ecosystem services (Abodeely et al. 2013; Brandes et al. 2016, 2018; Griffel et al. 2022). This could lead to more optimistic results than those presented here and provide opportunities for subcounty optimization of county-level outputs provided here.

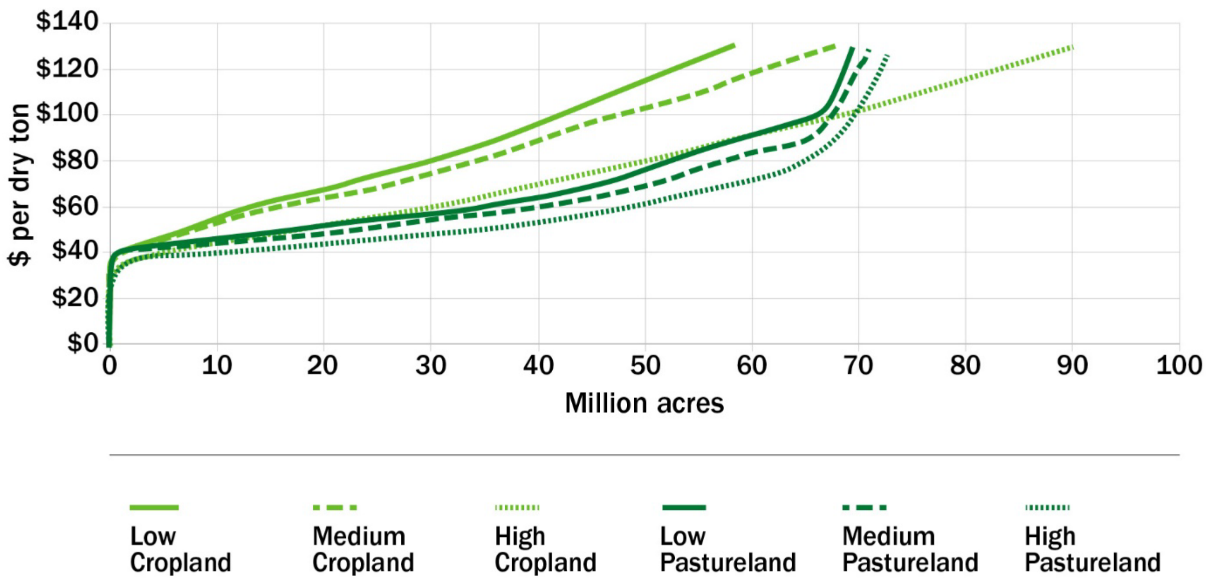

Figure 5.9. Land transitions to purpose-grown energy crops at increasing biomass prices for cropland and pastureland

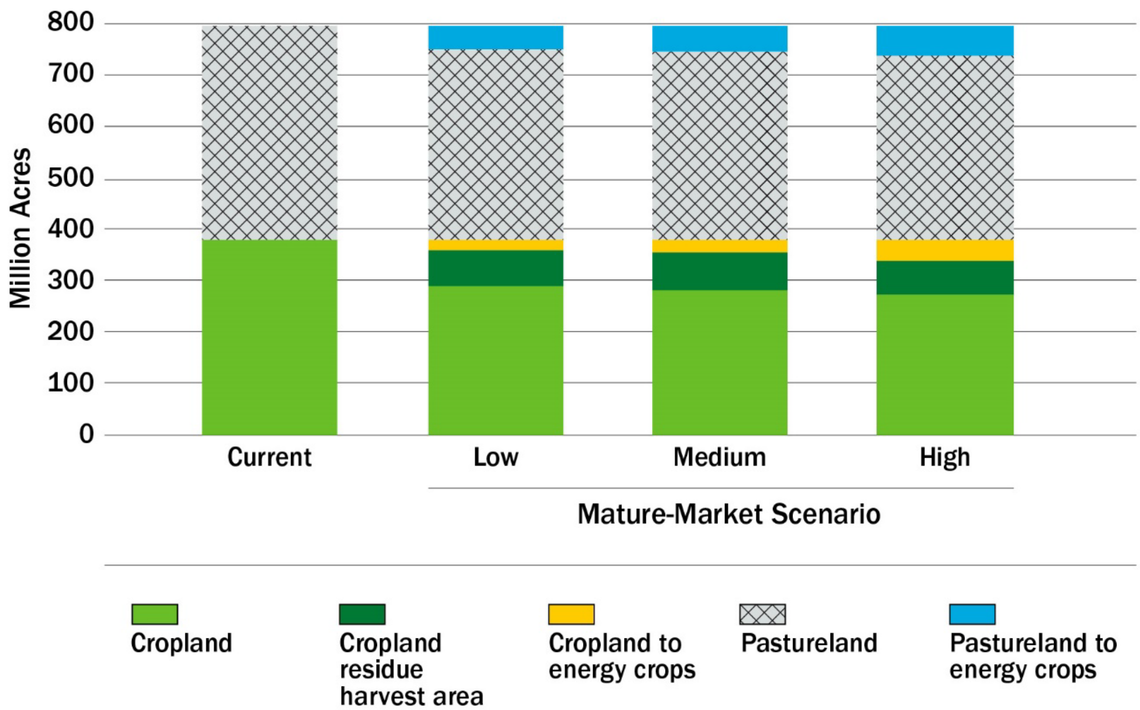

Figure 5.10. Current agricultural land area (CONUS) and land area of modeled low, medium, and high mature-market scenarios at the reference price of $70 per dry ton

5.3.3 Commodity Crop Price Impacts

Purpose-grown energy crops face scrutiny over concerns of food security. The mature-market scenarios were analyzed at biomass prices ranging from $30 to $130 per ton. As biomass prices increase and purpose-grown energy crops outbid conventional commodity crops for land use, commodity prices are estimated to increase. For example, the mature-market medium scenario with a reference price of $70 per dry ton incentivizes the production of 398 million dry tons of purpose-grown energy crops, corn prices increase 5%, wheat increases 19%, and soy increases 9% (Figure 5.11).

In relation to recent market price spikes, these increases are relatively low. For example, during the three most recent price spikes, wheat prices rose from the year before by 127%, 48%, and 64%; corn by 120%, 124%, and 128%; and soybeans by 89%, 50%, and 84% for 2008, 2012, and 2022, respectively. Given that raw food commodities comprised an average of 16.6% of the price of finished food prices from 1993–2022 , commodity price increases in the range of 5%–20% would correspond to finished food price increases of 0.8% to 3.3%. In Chapter 6 we discuss how the demand for purpose-grown energy crops can play a role in chronic oversupply issues in agriculture.

As purpose-grown energy crops expand and market prices increase, U.S. exports of commodities decrease. In our modeling analysis, prices and demand levels, including exports, are determined simultaneously using demand and income elasticities. In the medium scenario at $70 per dry ton, exports of corn, wheat, and soybeans decrease by 8%, 12%, and 11%, respectively. However, due to the higher commodity prices, the value of exports for corn decline by 3.7%, for wheat increase by 2.2%, and for soybeans decline by 2.8%. The impact of the reduction in export volume must be put in the context that according to the USDA 2023 baseline, the average U.S. share of global markets is 31%, 11%, and 28% for corn, wheat, and soybeans, respectively. Consequently, the reductions in the U.S. export volumes represent only 2.5%, 1.3%, and 3% of the global market (global trade) in the case of corn, wheat, and soybeans.

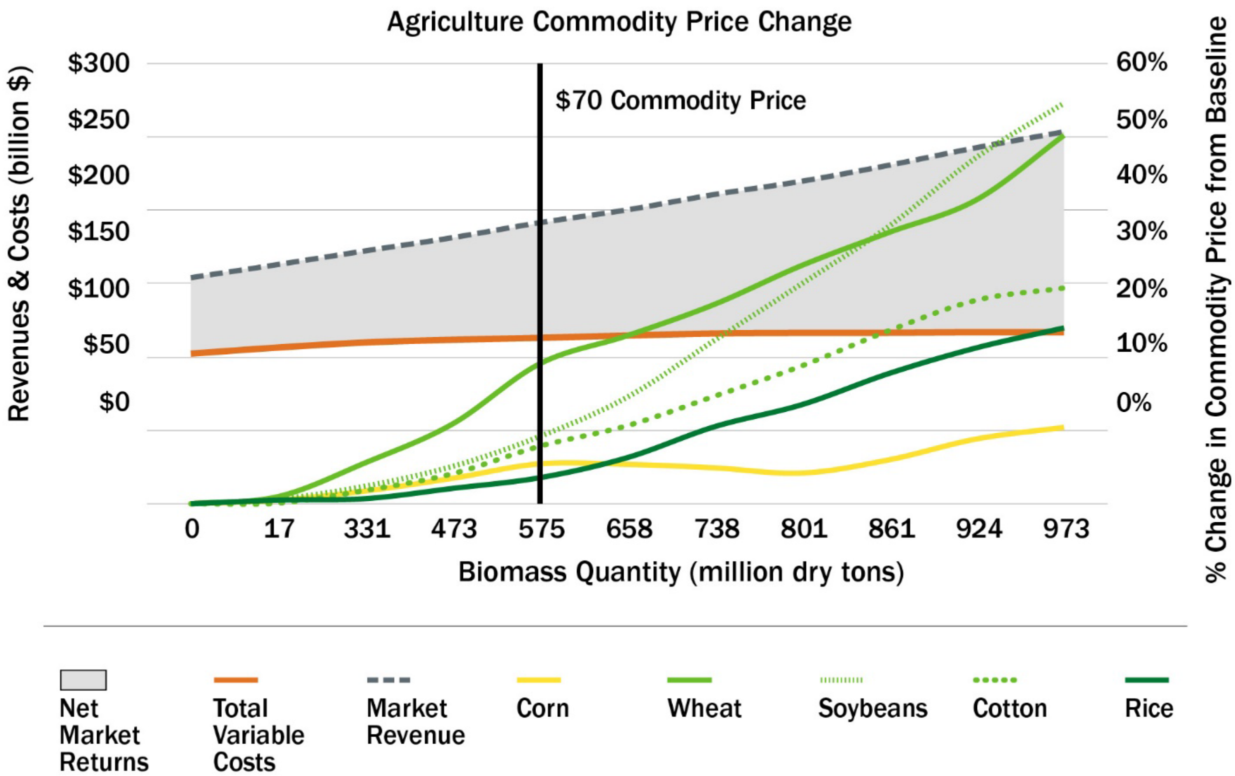

Figure 5.11. Increase in net market returns and percentage increase in commodity prices at increasing quantities of biomass produced from U.S. agriculture under medium scenario assumptions. At $70 per dry ton, approximately 577 million dry tons of biomass can be produced. Commodity prices increase by less than 20%. Increasing commodity prices increases U.S. farmer net market returns by $23 billion per year from baseline.

Nationally, total net market returns to crop agriculture increase by 43%, or $23 billion per year, over baseline in the mature-market medium scenario at $70 per dry ton. Of the total net increase in returns, conventional grains and oilseeds comprise 26% of the increase ($13.5 billion), energy crop returns 18% ($9 billion), and residue returns an additional 8% ($4 billion). Livestock returns are not estimated, but will likely decline due to increased feed prices. Figure 5.12 indicates the regional increases in market net returns to crop agriculture. Commodity price increases and residue returns lead to the greatest increases in returns in the prime agriculture regions in the Midwest, but energy crops grown in the Southeast and Western Plains act to increase regional net returns as well.

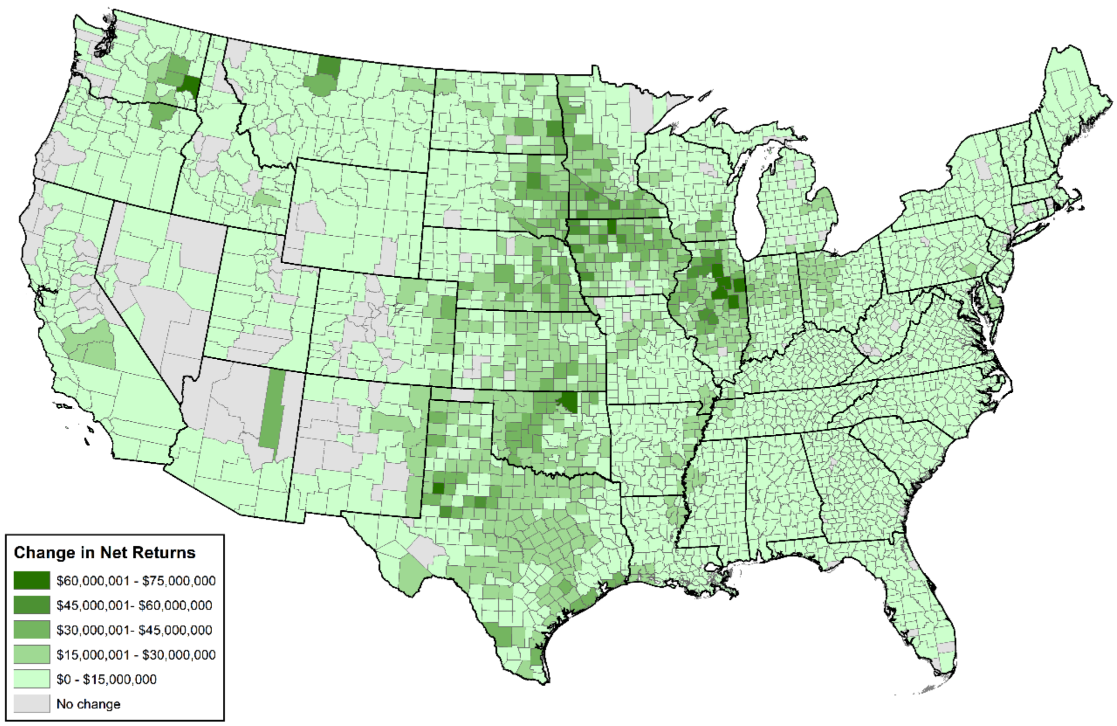

Figure 5.12. Farm net income changes of the mature-market medium reference case scenario over baseline

The higher market returns reduce government payments nationally and act to reduce the percent of U.S. agricultural commodities dumped at below the cost of production, hence improving global prices received by farmers throughout the world (Murphy and Hansen-Kuhn 2020). There has been a century-long problem of overproduction in agriculture, forcing commodity prices below the cost to produce them, and therefore costing about $2 billion in federal expenditures annually to keep farmers out of bankruptcy (USDA-FSA 2023). Purpose-grown energy crops can play a role in helping the chronic oversupply problem in agriculture (De La Torre Ugarte and Hellwinckel 2010). Since the mid-20th century, when technology, education, and new seeds quickly increased yields, U.S. agriculture has faced recurrent oversupply problems where the prices of commodities are most often below the cost of production. For example, Murphy and Hansen-Kuhn (2020) show dumping rates from 1990–2017. Low prices have set off cycles of farmer bankruptcies and have institutionalized large government support payments to keep remaining farmers economically viable. Farmers in developing countries have been harmed by oversupply problems as well by having to compete with cheap imports from the United States. This has driven rural flight to urban areas, underinvestment in agricultural sectors of developing nations, and associated environmental and social problems (Murphy and Hansen-Kuhn 2020). Production of purpose-grown energy crops can be part of a strategy to keep prices within an acceptable range, where they are equal to or above the cost of production for farmers, but low enough to avoid hardship for consumers (De La Torre Ugarte and Hellwinckel 2010; Ray and Schaffer 2018; De La Torre Ugarte et al. 2012).

5.3.4 Carbon Sequestration

Purpose-grown perennial energy crops pull carbon out of the atmosphere and sequester carbon in the soil as they grow, but growing purpose-grown energy crops also requires some GHG emissions of carbon during production (e.g., establishment, maintenance, harvest) and upstream emissions associated with fertilizer production. The balance of sequestration and emissions equals the net GHG flux from agriculture to the atmosphere. Here we give a simplified estimate of the soil sequestration impacts of purpose-grown perennial energy crops, but we do not quantify the direct or upstream life cycle GHG emissions. We assume purpose-grown perennial energy crops increase soil carbon levels annually by approximately 5%, 3.8%, and 0.17% for switchgrass, miscanthus, and short-rotation woody crops, respectively, on land previously growing annual crops (Agostini, Gregory, and Richter 2015; Qin et al. 2016b) (see the appendix for more detail). We assume no soil carbon change on pastureland converting to purpose-grown energy crops (Chamberlain, Miller, and Frederick 2011; Qin et al. 2016b, 2016a). In the baseline case we assume soils have reached a steady state and no carbon is being sequestered or removed per year in U.S. crop agriculture.[3] There is great uncertainty around carbon sequestration estimation; future studies should estimate impacts in more detail using dedicated soils models.

In the medium scenario and at a reference price of $70 per dry ton, we estimate that soils under perennial purpose-grown energy crops can sequester 32 million metric tons of CO_2 per year. At higher prices, the additional sequestration from purpose-grown energy crops would lead to greater reductions in carbon from agriculture to the atmosphere, reaching a maximum reduction of 75 million metric tons of CO_2. Assuming a typical passenger vehicle emits 4.6 metric tons of CO_2 per year, this is the equivalent of removing more than 16 million vehicles. In comparison, it has been estimated that universal adoption of cover crops across the major cropping regions of the United States would sequester approximately 100 million metric tons of CO_2 per year (Fargione et al. 2018), and adoption of all practically achievable agricultural soil carbon measures could sequester 250 million metric tons of CO_2 per year (National Academies of Sciences, Engineering, and Medicine 2019). We are not estimating changes in emissions of carbon during production, which would likely increase moderately with the production of purpose-grown energy crops and harvesting of residues, and consequently decrease the net atmospheric carbon impact of the soil carbon changes.

5.3.5 Intermediate Non-Food Oilseed Crops

Brassica oilseed intermediate crops, including pennycress, camelina, and carinata, can be grown in the winter fallow season between a typical corn (or cotton) and soybean rotation. The oilseed can be grown in between summer crops every other winter, hence becoming an "intermediate" crop with no need for additional land and therefore little impact on production capacity of agricultural lands (see the appendix for modeling assumptions). Oilseed intermediate crops can also provide ecosystem benefits while producing a secondary product (Karami 2021;

[3] Recent studies have placed uncertainty upon whether no-tillage increases soil carbon; therefore, we assume no net soil carbon accumulation under no-till.

McClelland, Paustian, and Schipanski 2021). Figure 5.13 shows intermediate crop oilseed production potential as a function of offered price. Intermediate oilseeds can produce up to 21 billion lbs. of lipid oil from oilseeds per year from 47 million acres, which, once converted, can produce 1.4 billion gallons of SAF.[4] From the pressing of oilseeds to produce 21 billion lbs. of lipid oil, 16 million tons of meal are coproduced, which can be used to feed livestock. This amounts to 20% of current soybean meal demand. We assume the meal coproduct of intermediate oilseeds can be used for animal feed through pre-crush processing, hence impacting the soy meal market (Alhotan et al. 2017). At $0.15/lb, the additional meal entering the market from oilseeds meal coproduct lowers meal prices by 17%, reducing soybean feed demand and lowering soybean prices by 4% below baseline. Based on current assumptions on yields and costs of production, pennycress is the largest potential intermediate oilseed producer with 87% of the total, followed by camelina with 13% and carinata with less than 1%. Figure 5.14 shows that the geographic range of potential intermediate oilseed crops extends north and south. Camelina and carinata dominate in southern warmer regions, but their yields decline as the probability of freezing increases at more northern latitudes where pennycress, a cold-tolerant species, dominates projections.

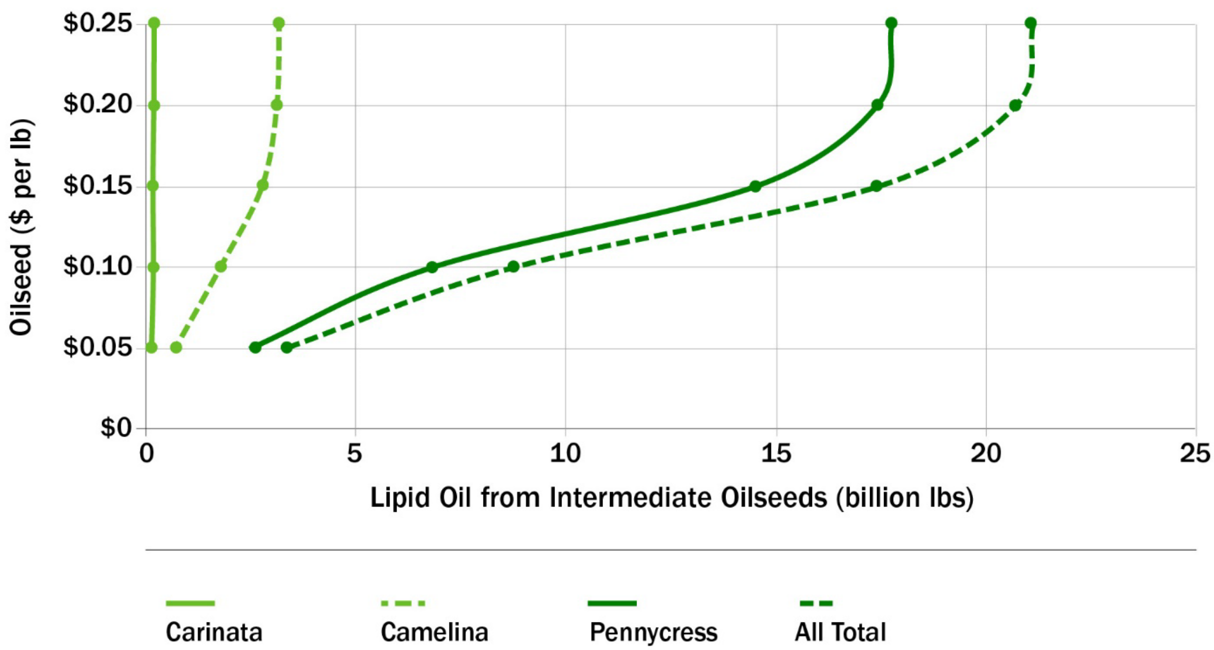

Figure 5.13. Intermediate oilseed supplies per year at increasing oilseed prices at mature market

[4] We assume pennycress, camelina, and carinata are 38%, 37%, and 47% lipid oil, respectively. We assume a conversion rate of 0.0722 gallons of SAF per pound of lipid oil.

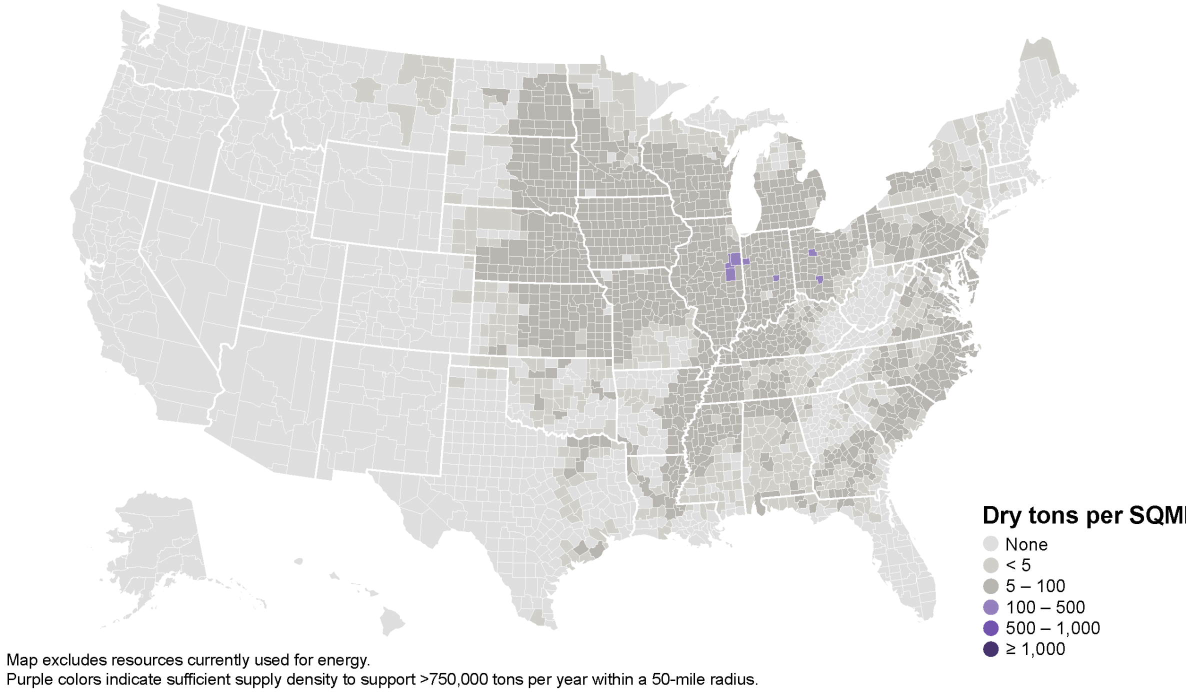

Figure 5.14. Geographic distribution of mature-market intermediate oilseed crop production

To show the market differences between meeting future oilseed demand from intermediate crops compared to soybeans, we develop a supply curve for soybeans meeting equivalent SAF demands as intermediate crops. If additional soybeans were used for aviation fuels, it would be another demand for soybeans that would compete with other uses. Currently, 6.3 billion lbs. of soybean lipid oil are used for bioenergy at a market price of $0.17/lb. for soybeans. We simulated increasing demand levels for soybeans for energy oilseed in POLYSYS, with resulting price impacts associated with increased production shown in Figure 5.15. As demand increases, competition for soybeans increases. As prices increase, soybeans gain acreage and land use competition increases the price of other crops simultaneously. For soybeans to provide 21 billion lbs. of lipid oil, 2 billion bushels of soybeans would be needed. This additional demand for soybeans would increase prices of soybean, corn, and wheat by 16%, 13%, and 23%, respectively. Soybean exports also decline as oilseed demand increases. An average acre of soybeans can produce about 73 gallons of biodiesel (or 39 gallons of SAF).[5] In comparison, an acre of corn can produce about 470 gallons of ethanol. This illustrates the differences in meeting future energy demand from conventional soybeans versus intermediate crops.

[5] We assume conversion rates of 0.7579 gallons of SAF per bushel of soybeans, 1.4 gallons of biodiesel per bushel of soybeans, and 3 gallons of ethanol per bushel of corn.

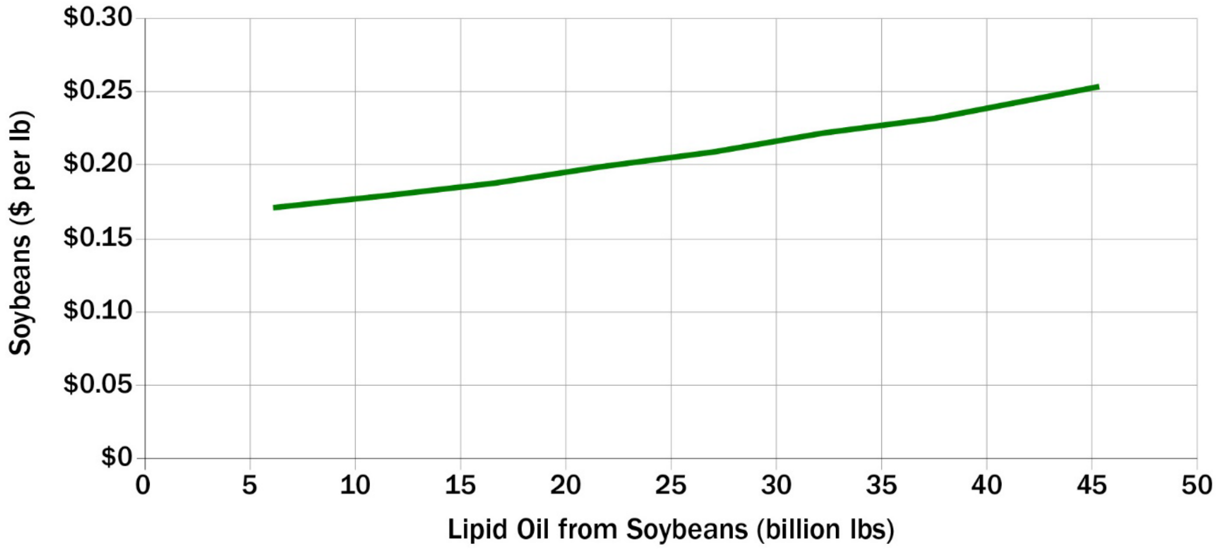

Figure 5.15. Supply of soybeans for energy oilseed per year at increasing prices. In 2022, the United States used 6.3 billion lbs. of oil from soybeans for energy uses.

Conclusions

- Agricultural lands are the greatest single source of biomass production potential explored in this report. By harvesting about one-third of agricultural residues and integrating about 9% of agricultural land into purpose-grown energy crop production, agricultural lands can provide about 179 (major residues), 398 (purpose-grown energy crops), and 10 (msc. residues and processing wastes) million tons of cellulosic biomass per year, for a total of 587 million tons per year, in a mature-market reference scenario and price, within specified economic and environmental constraints.
- Modeling commodity prices rise by 6%–18% in a mature-market reference scenario for a mid-range of bioenergy production. Modeled exports decline by approximately 10% as prices rise, but the value of exports decline by about half, or less than the volume decline. These price rises contribute to a 1%–3% increase in U.S. food costs. This modeling does not account for the potential increase in yield due to the higher prices, which would mitigate the impact on consumer prices.
- Estimates of oilseed supplies are new in this report. Intermediate oilseeds can produce more than 21 billion lbs. (10.5 million tons) of lipid oil per year.

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