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2016 BILLION-TON REPORT

Advancing Domestic Resources for a Thriving Bioeconomy

A Study Sponsored by U.S. Department of Energy
Office of Energy Efficiency and Renewable Energy
Bioenergy Technologies Office

Volume 1:
Economic Availability of Feedstocks

July 2016

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for the
U.S. DEPARTMENT OF ENERGY

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Additional Information

The U.S. Department of Energy, Office of Energy Efficiency and Renewable Energy's Bioenergy Technologies Office and Oak Ridge National Laboratory provide access to information and publications on biomass availability and other topics. The following websites are available:

- energy.gov
- eere.energy.gov
- bioenergy.energy.gov
- web.ornl.gov/sci/transportation/research/bioenergy/

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DISCLAIMER

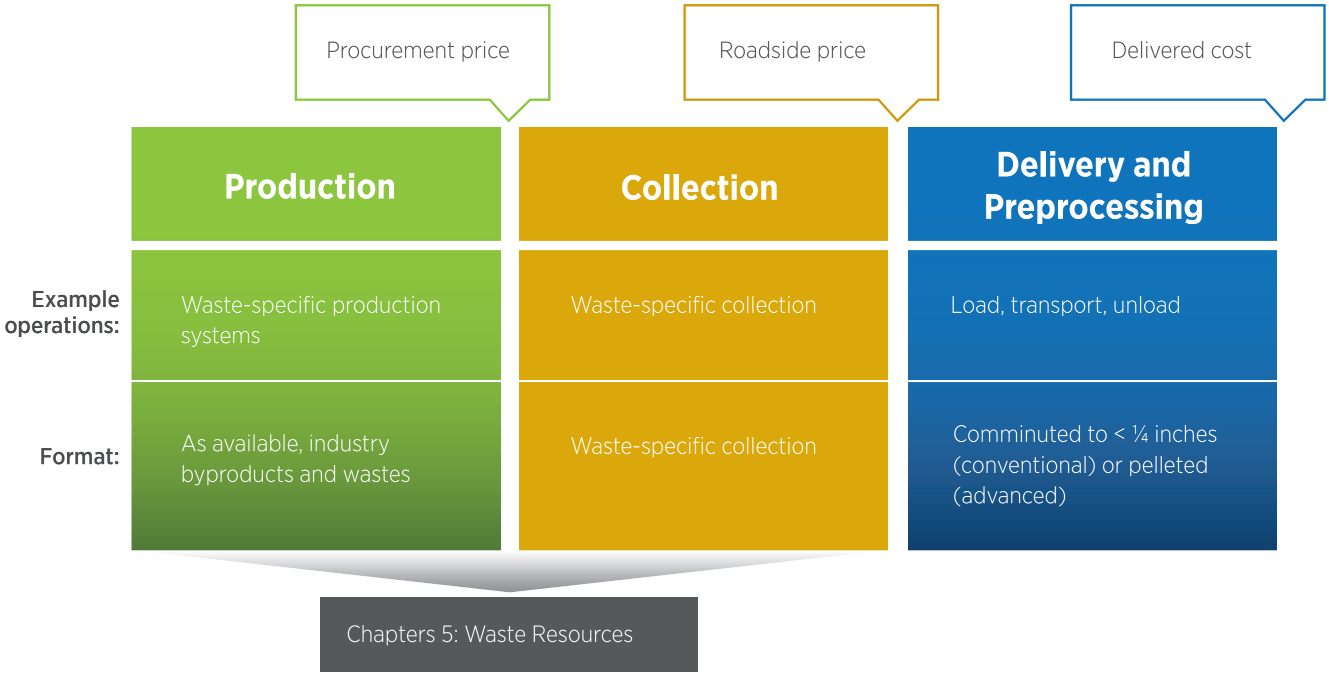
The authors have made every attempt to use the best information and data available, to provide transparency in the analysis, and to have experts provide input and review. However, the *2016 Billion-Ton Report* is a strategic assessment of potential biomass. It alone is not sufficiently designed, developed, and validated to be a tactical planning and decision tool, and it should not be the sole source of information for supporting business decisions. This analysis provides county by county estimates of the feedstocks at a selected cost, yet users should use associated information on the Bioenergy Knowledge Discovery Framework (bioenergykdf.net/billionton) to understand the assumptions and ramifications of using this analysis. The use of tradenames and brands are for reader convenience and are not, nor does their use imply, an endorsement by the U.S. Department of Energy or Oak Ridge National Laboratory.

The foundation of the agricultural sector analysis is the USDA Agricultural Projections to 2024. From the report, "projections cover agricultural commodities, agricultural trade, and aggregate indicators of the sector, such as farm income. The projections are based on specific assumptions about macroeconomic conditions, policy, weather, and international developments, with no domestic or external shocks to global agricultural markets." The *2016 Billion-Ton Report* agricultural simulations of energy crops and primary crop residues are introduced in alternative scenarios to the 2015 USDA Long Term Forecast. Only 2015-2024 Billion-Ton national level baseline scenario results of crop supply, price, and planted and harvested acres for the 8 major crops are considered to be consistent with the 2015 USDA Long Term Forecast. Additional years of 2025–2040 in the *2016 Billion-Ton Report* baseline scenario and downscaled reporting to the regional and county level were generated through application of separate data, analysis, and technical assumptions led by Oak Ridge National Laboratory and do not represent nor imply U.S. Department of Agriculture or U.S. Department of Energy quantitative forecasts or policy. The forest scenarios were adapted from U.S. Forest Service models and developed explicitly for this report and do not reflect, imply, or represent U.S. Forest Service policy or findings.

The biomass supply projections presented in this report are policy independent and estimate the potential economic availability of biomass feedstocks using specified market scenarios and guiding principles intended to be conservative and to reflect certain environmental and socio-economic considerations. For example, some principles aim to maintain food availability and environmental quality, including improved tillage and residue removal practices, exclusion of irrigation, and reserved land areas to protect biodiversity and soil quality. In this sense, this report (volume 1) and related analyses on environmental effects (forthcoming in volume 2) may differ from other efforts seeking to depict potential biomass demand and related market, environmental and land use interactions under business-as-usual or specific policy conditions.

The federal government prohibits discrimination in all its programs and activities on the basis of race, color, national origin, age, disability, and, where applicable, sex, marital status, familial status, parental status, religion, sexual orientation, genetic information, political beliefs, reprisal, or because all or part of an individual's income is derived from any public assistance program.

05 | Waste Resources



5.1 Introduction

The use of biomass from waste resources represents low-cost opportunities for bioenergy production without the need for additional agronomic inputs such as land and fertilizer. The economic accessibility of some waste resources has been demonstrated through their successful commercialization; for example, chapter 2 reports that mill residues, landfill gas, and waste grease are "currently used resources" (i.e., resources already being used for bioenergy or co-products). Other waste resources, while they offer a low or negative cost to potential users, may incur logistical and operational costs that challenge commercialization efforts. This chapter reviews a range of additional secondary and waste resources that may be mobilized as part of a bioeconomy strategy. The waste resources evaluated include agricultural secondary wastes, MSW, and forestry and wood wastes. Some resources, such as animal fats and sugarcane bagasse, are already accounted for in chapter 2. These resources are further described in this chapter, but they are not included in the resource totals it estimates. Estimates of the economic availability of these resources are updated from section 4.6 of the 2011 *BT2*, from which much of the descriptive material in this chapter is taken.

5.2 Agricultural Secondary Wastes

Secondary agricultural wastes are quantified in the 2011 *BT2*. The data used to make these estimates, where available, are updated in this report. Primary agricultural residue production is based on the production of corn, barley, oats, sorghum, and wheat, according to the production of the primary grains projected using POLYSYS. These resources are summarized by price in table 5.1.

5.2.1 Sugarcane Residues

Sugarcane is a tall, erect plant with a stalk (which has a high sugar content), leaves, and tops. After the sugar is extracted from the stalk, what remains of the stem is bagasse. The leaves, tops, and any parts of the stalk that remain in the field after harvest are referred to as trash. There are a number of technical coefficients in the literature that relate the amount of bagasse and trash produced per ton of sugarcane.[1] It is assumed that each ton of sugarcane produces 0.14 dry tons of bagasse and 0.075 dry tons of field trash and that one-half of the field trash can be collected.

Sugarcane residues are the product of the sugarcane yield, as reported on a wet basis by USDA (USDA-NASS 2015b), and a technical coefficient—0.14 for bagasse and 0.0375 for trash. Costs for sugarcane trash collection are based on the use of a rake and a large rectangular baler. Estimated supplies of sugarcane bagasse and residues, respectively, total 3.9 to 4.1 million dry tons and 1.1 million dry tons. Farmgate prices for sugarcane field trash are based on the use of a rake, a large rectangular baler, and a bale mover and a grower payment of $21 per dry ton for nutrient value. About 60% of sugar field trash is available at farmgate prices of $40 per dry ton and 100% at $50 per dry ton or less (table 5.2). The bagasse component is currently used for energy at sugarcane mills.

Projections of sugarcane production from the USDA-OCE/WAOB (2015) are used up to 2024. Starting from 2015, the projection shows a very modest increase over time, and it is assumed that after 2024, sugarcane production increases by 0.05 million tons per year. In 2012–2014, bagasse production and trash collected averages 4.36 and 1.13 million dry tons, respectively. In 2040, bagasse production and trash collected are 4.1 and 1.1 million dry tons, respectively (table 5.2). Projected supplies of sugarcane field trash are shown in table 5.1.

5.2.2 Soybean Hulls

Soybean hulls are produced when soybeans are processed to produce soybean meal and soybean oil. The hulls are used as a livestock feed, primarily for cattle. The quantity of soybean hulls produced from crushing soybeans has varied from 3.27 to 3.49 lb per bushel of soybeans over the period 2001 to 2010 and averaged 3.42 lb per bushel (USDA-ERS 2015). Production of soybean hulls over 2013 to 2015 averaged 2.84 million dry tons (assuming a hull moisture content of 9%).

The USDA long-term forecast projects the amount of soybeans crushed over the 2014 to 2024 period. The forecast increases from 1.815 billion bushels in 2014 to 1.975 billion bushels in 2024 (USDA-OCE/WAOB 2015). The extended USDA baseline used for POLYSYS is used for soybean crush for 2025 to 2040. The projected crush volume in 2040 is 1.996 billion bushels. Using 3.42 lb of soybean hulls per 60-lb bushel of soybeans crushed, and a moisture content of 9% for the hulls, current and 2040 soybean hull production are 2.84 and 3.10 million dry tons, respectively (table 5.3).

[1] Assumptions vary in the range of reported moisture, ash, and energy content of bagasse and sugar cane trash. For this report, results from Braunbeck et al. (2005) are adopted. For additional reference, see Deepchand (2005) and Ho (2006).

Table 5.1 | Summary of Agricultural Wastes Potentially Available at $40, $50, and $60 per Dry Ton for Selected Years

Waste type	Current supply[a]	2017			2022			2030			2040		
		$40	$50	$60	$40	$50	$60	$40	$50	$60	$40	$50	$60
	Million dry tons												
Animal manures	17.1	18.0	18.0	18.0	18.5	18.5	18.5	18.6	18.6	18.6	18.4	18.4	18.4
Cotton field residues	3.3	0.0	0.9	1.5	0.0	1.5	2.0	0.0	1.7	2.2	0.0	1.7	3.2
Cotton gin trash	1.7	1.7	1.7	1.7	1.9	1.9	1.9	2.0	2.0	2.0	2.1	2.1	2.1
Grain dust and chaff	5.1	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Orchard and vineyard prunings	5.5	5.5	5.5	5.5	5.6	5.6	5.6	5.8	5.8	5.8	6.0	6.0	6.0
Rice straw	4.3	0.0	4.9	4.9	0.0	5.2	5.2	0.0	5.4	5.4	0.0	5.6	5.6
Rice hulls	1.2	1.4	1.4	1.4	1.5	1.5	1.5	0.0	1.5	1.5	0.0	1.6	1.6
Soybean hulls	2.8	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0	0.0
Sugarcane field trash	1.1	0.6	1.0	1.0	0.6	1.1	1.1	0.6	1.1	1.1	0.6	1.1	1.1
Total	**34.2**	**27.1**	**33.4**	**34.0**	**28.0**	**35.3**	**35.7**	**27.0**	**36.1**	**36.6**	**27.1**	**36.5**	**37.9**

[a]Current supply without regard to price

Over the period of 2001 to 2010, prices for soybean hulls averaged $91.81 per ton (nominal price), and the price of corn averaged $3.26 per bushel or $116.41 per ton (USDA-ERS 2015). The ratio between the per-ton prices of soybean hulls and corn varied between 0.729 and 1.04 over this period, except in the marketing year 2009 (beginning September 1, 2009, and ending August 31, 2010), when the ratio was 0.479. Excluding this anomalous year (2009), the ratio averaged 0.847. The USDA baseline for 2014 to 2024 projects the average price of corn to be $3.56 per bushel over this period, or $150 per dry ton. Using this projected corn price, then, the price of soybean hulls at a 0.847 ratio would be $128 per dry ton over this period. Supplies are shown in table 5.1, but none are available at prices below $128 per dry ton.

Table 5.2 | Sugarcane and Bagasse Production and Sugarcane Trash Collected 2012 to 2040

Year	Sugarcane	Bagasse	Trash
	Million wet tons	Million dry tons	
2012	32.2	4.51	1.21
2013	30.8	4.31	1.15
2014	30.4	4.26	1.14
2015	31.3	4.38	1.04
2017	27.7	3.88	1.04
2022	28.4	3.98	1.07
2030	28.8	4.03	1.08
2040	29.3	4.10	1.10

Table 5.3 | Soybean Crush and Hull Production 2012 to 2040

Year	Soybean crush	Soybean hulls
	Million bushels	Million dry tons
2012	1,689	2.63
2013	1,734	2.70
2014	1,870	2.91
2015	1,870	2.91
2017	1,850	2.88
2022	1,940	3.02
2030	1,985	3.09
2040	1,996	3.10

5.2.3 Rice Hulls and Field Residues

When rice is milled, its hulls are removed. The hull represents 20% of the mass of rice and generally presents a disposal problem, although rice hulls currently can be used as a filter product or as chicken house bedding (Hirschey 2003). Rice hulls can potentially be used for energy.[2] Rice is produced in six states: Arkansas, California, Louisiana, Mississippi, Missouri, and Texas. Over the years 2013 to 2015, total rice production averaged 200 million hundredweight (cwt, 100 lb)—or 8.6 million dry tons, assuming 13.5% moisture content. Some rice—approximately 30% of total rice production on average—is exported as rough rice (not dehulled). Adjusting for rice that is exported as rough rice, and assuming that rice hulls represent 20% of the rice harvest, 1.2 million dry tons of rice hulls per year are currently produced. The USDA-OCE/WAOB (2015) projects

[2] A facility in Stuttgart, Arkansas, has plans to convert rice hulls into ethanol at a rate of 50 gallons of ethanol per ton and to produce silica sodium oxide at a rate of 440 lb per ton (Bennett 2008).

rice production to 2024. Rice production for 2025 to 2040, as projected in the extended baseline, is 259 million cwt. Rice hull production increases over time, reaching 1.6 million dry tons by 2040 (table 5.4). Prices for rice hulls are based on projected coal prices and supplies on a Btu basis, as shown in table 5.1. (Coal prices are used because as a solid fuel, rice hulls would compete with coal.)

Rice field residues (or straw) remaining on the field usually need to be disposed of. In the past, burning was common, but it is often not allowed now because of air quality concerns. Because the residue has such a high silica content, it is undesirable as a forage supplement. Sometimes it is incorporated into the soil, or it may be removed and used for energy, for example. The harvest index (HI) for rice straw (the ratio of grain to total biomass, or grain plus residue) has been reported in ranges of 0.5 to 0.3 (or straw-to-grain ratios of 1:1 to 2.3:1). Duke (1983) states that rice straw is usually estimated to be two times the grain yield, but for dwarf varieties, a straw-to-grain ratio of 1:1 prevails (HI of 0.5). Sumners et al. (2003) use a straw-to-grain ratio of 1:1. This study uses Sumner et al.'s more conservative HI of 0.5 (straw-to-grain ratio of 1:1) to estimate rice straw residues. Moisture content for grain is assumed to be 13.5%.

The USDA long-term forecast projects the amount of rice produced between 2014 and 2024 (USDA-OCE/WAOB 2015), and the extended USDA baseline used for POLYSYS is used to project rice production from 2025 to 2040. Total straw production is currently estimated at 8.6 million dry tons, increasing to 11.2 million dry tons by 2040. Rice straw is assumed to be harvested like corn stover and cotton residues with a shredding operation followed by raking and baling (a large rectangular baler is assumed for costing purposes). It is assumed that 50% of the rice straw is harvested, with the current resource (2013 to 2015 average) at 4.3 million dry tons and the 2040 resource at 5.6 million dry tons (table 5.4). The rice field straw

Table 5.4 | Rice Hull and Straw Collected 2012 to 2040

Year	Harvested	Yield	Rice production	Rice production	Hulls	Straw harvested
	Million acres	Lb/acre	Million cwt	Million dry tons		
2012	2.7	7,449	200	8.63	1.21	4.31
2013	2.5	7,694	190	8.21	1.15	4.11
2014	2.9	7,572	221	9.56	1.34	4.78
2015	2.9	7,307	188	8.12	1.14	4.06
2017	3.0	7,793	227	9.82	1.38	4.91
2022	3.0	7,981	241	10.41	1.46	5.21
2030	3.1	8,312	251	10.81	1.52	5.43
2040	3.1	8,537	259	11.20	1.57	5.59

price is based on harvesting with a shredder, a large rectangular baler, a bale mover, and a grower payment of $21 per dry ton. Rice straw is available at a farmgate price of $50 per dry ton or less (table 5.1).

5.2.4 Grain Dust and Chaff

Nelson (2010) estimates that wheat passing through an elevator produces approximately 1% of its weight as dust and chaff. Schnake (1981), in a report on the use of grain dust for animal feed, fuel, and fertilizer, considered the composition of wheat, corn, sorghum, and soybeans. We use Nelson's assumption that 1% of grain passing through an elevator (production plus imports) can be captured as dust and chaff. In 2013 to 2015, the average grain supply in the United States (corn, wheat, sorghum, barley, oats, and soybeans) was 507 million dry tons per year. One percent of that is 5.1 million dry tons. In his study, Schnake prices grain dust as an animal feed at 80% of the price of corn. The corn price has averaged $5.22 per bushel (or $221/dry ton) over the 36-month period from July 2012 to June 2015 (USDA-NASS 2014a, 2015a). The June 2015 price was $3.58 per bushel or $151/dry ton. Eighty percent of the 36-month and June 2015 price, respectively, was $176 and $121 per dry ton. The USDA baseline for 2014 to 2024 projects the average price of corn to be $3.56 over this period, or $150/dry ton. We assume the current supply of grain dust is half of the total produced, 1.67 million dry tons at $120 per dry ton.

Over time, the grain supply increases. Until 2024, projections from USDA-OCE/WAOB (2015) are used, and from 2025 to 2040, the extended baseline is used. In 2040, the total grain supply reaches 590 million dry tons, and the total grain dust and chaff that could be collected is 5.9 million dry tons (table 5.5).

Table 5.5 | Grain Supply (production plus imports) and Grain Dust and Chaff Collected 2012 to 2040

	Corn	Sorghum	Barley	Oats	Wheat	Soybeans	Grain produced	Dust collected
Moisture (%)	0.155	0.140	0.145	0.140	0.135	0.100		
Lb/bushel	56	56	48	32	60	60		
Year	Million bushels						Dry tons	
2012	10,915	258	242	154	2,375	3,078	416	4.16
2013	13,865	392	236	162	2,308	3,430	497	4.97
2014	14,246	433	201	177	2,176	4,002	519	5.19
2015	13,585	574	239	185	2,177	3,918	505	5.05
2017	14,130	403	228	158	2,236	3,635	507	5.07
2022	14,785	390	220	161	2,318	3,860	530	5.30
2030	15,735	392	223	163	2,437	3,997	560	5.60
2040	16,754	405	224	164	2,592	4,073	590	5.90

5.2.5 Orchard and Vineyard Prunings

Annual orchard and vineyard prunings are estimated for fruits, citrus fruits, and nuts. The fruits included in this analysis are apples, apricots, avocados, cherries, dates, figs, grapes, kiwi, nectarines, olives, peaches, pears, persimmons, pomegranates, and other non-citrus fruits. The citrus fruits are grapefruit, lemons, limes, oranges, tangerines, and other citrus fruit. The nuts are almonds, pecans, pistachios, walnuts, and other nuts. The estimated biomass available, according to Nelson (2010), totals 5.7 million dry tons. More than 80% of the orchard and vineyard prunings are from five crops: oranges, grapes, almonds, pecans, and apples. About half the resource is in California, 20% is in Florida, and the remainder is located primarily in Washington, Texas, Georgia, New York, Oklahoma, and Michigan. The USDA projections (USDA-OCE/WAOB 2015) forecast a slight increase in the production area of fruits and nuts. Production estimates from the USDA projections are used to index future orchard and vineyard prunings. Census of Agriculture data (USDA-NASS 2014b) from 2012 are indexed to future years using acreage estimates from the USDA projections (USDA-OCE/WAOB 2015), and from 2025 to 2040, acreage is projected to increase by 17,000 acres per year. Per-acre yield data for individual crops from Nelson (2010) are used. Currently available supplies of prunings are 5.5 million dry tons. Total supplies are shown in table 5.6. Half of the orchard and vineyard prunings are assumed to be available at $20 per dry ton, and all are expected to be available at $30 dry ton or less (table 5.6).

Table 5.6 | Orchard and Vineyard Prunings 2007 and 2013 to 2040

Year	Million dry tons
2013	5.47
2014	5.48
2015	5.50
2017	5.53
2022	5.63
2030	5.80
2040	6.02

5.2.6 Animal Fats and Yellow Grease

Animal fats suitable as a secondary agricultural feedstock for biodiesel production include edible and inedible tallow, lard, white grease, and poultry fat. Also included in this discussion is yellow grease. When animals are processed for meats, fats are a byproduct. For beef, these fats are separated into edible and inedible tallow. For hogs, these fats are lard, white grease, and choice white grease. Poultry produces poultry fat. Animal fats generally are a less costly feedstock than vegetable oils; however, animal fats contain high levels of saturated fatty acids, which result in a lesser flow quality than vegetable oil has. Animal fats tend to lose viscosity, causing the formation of crystals that plug fuel filters, especially in colder temperatures. Because biodiesel from animal fat feedstocks has the tendency to solidify in colder temperatures, vegetable oil will likely be the feedstock of choice for biodiesel in northern states during the winter. The supply of animal fats is limited and will not increase as demand for biodiesel increases.

Yellow grease differs from other animal fat feedstocks in that it is the recycled cooking oil from restaurants. It may contain the recycled oils of both vegetables and animals, but the vegetable oil is hydrogenated, so it acts more like animal fat when converted to biodiesel. Yellow grease is the cheapest available feedstock for biodiesel production.

Table 5.7 | Animal Fat Production 2012 to 2014 and Current Prices

Fat	2012	2013	2014	Average	2012	2013	2014	Average
	Million tons				$/ton			
Inedible tallow	1.60	1.59	1.50	1.56	874	805	727	802
Edible tallow	0.90	0.89	0.81	0.87	969	858	785	871
Yellow grease/ used cooking oil	0.97	0.99	1.03	1.00	715	660	555	643
White grease	0.65	0.65	0.64	0.65				
Choice white grease	0.58	0.58	0.57	0.58	840	767	645	751
Poultry fat	0.52	0.53	0.54	0.53	784	719	599	701
Lard	0.07	0.07	0.07	0.07	1,160	981	870	1,004
Total	**5.30**	**5.30**	**5.16**	**5.25**				

Source: Data from EIA (2015b).

Nelson (2010) provides estimates of edible and inedible tallow based on cattle processing at 72 locations in 21 states, and lard and choice white grease based on hog processing at 70 locations in 26 states. Edible and inedible tallow are produced at 95 and 90 lb per cow slaughtered, respectively. Lard and choice white grease are produced at 9 and 10.5 lb per hog slaughtered, respectively. Edible tallow, inedible tallow, lard, and choice white grease are estimated at 1.49, 1.41, 0.43, and 0.51 million tons, respectively, according to Nelson (2010). Nelson does not provide an estimate for poultry fat, but Pearl (2002) estimates poultry fat production at 1.11 million tons.

Swisher (2015) reports that from 2012 to 2014, inedible tallow, edible tallow, yellow grease/used cooking oil, white grease, choice white grease, poultry fat, and lard averaged 1.6, 0.9, 1.0, 0.6, 0.6, 0.5, and 0.1 million tons, respectively, and totaled 5.3 million tons (table 5.7).

Not all of these fats are necessarily available for energy use. Tallow, lard, and choice white grease are potential biodiesel feedstocks, but each also is used in markets such as edible food, soap, lubricants, resins, and plastics. Edible tallow is used for baking or frying fats and margarine, as well as for certain inedible products.

Inedible tallow is most often used as a supplement for animal feed—most of its market share—followed by use in fatty acids, soap, methyl esters (biodiesel), lubricants, and other uses. Poultry fats are used in soaps, pet foods, and a few other consumer products. The feedstock price greatly affects the end price of biodiesel, as feedstock price can account for up to 80% of the total biodiesel cost. Prices for fats (table 5.7) are much higher than prices for cellulosic resources, but fats have different characteristics and uses from cellulosic resources. In past years, prices for fats were lower—in the $400/ton to $600/ton range in 2009. It takes about 7.7 lb of fats to make a gallon of biodiesel, whereas cellulosic resources may yield 90 gallons per dry ton (or 22.2 lb per gallon) of ethanol. Assuming 128,000 Btu (higher heating value) per gallon of biodiesel and 84,500 Btu (higher heating value) per gallon of ethanol—considering fats on an equivalent feedstock basis with cellulosic resources—a ton of animal fat at $700 per ton is equivalent to a dry ton of a cellulosic resource at $160 per dry ton, ignoring conversion costs.

5.2.7 Cotton Gin Trash and Field Residues

Cotton gin trash is generated from the picking and cleaning processes of cotton harvesting and includes seeds, leaves, and other foreign material, which may include sand and soil. It may have high moisture and nutrient content, and disposal may be costly. Cotton residue refers to the stalks left on the field after the cotton lint has been harvested.

The two main types of cotton harvesters are spindle pickers and strippers (National Cotton Council of America 2009). The stripper is a single-pass system that harvests significantly more of the cotton plant and more foreign material (e.g., sand, soil) than do spindle pickers (0.15 to 0.50 tons per bale for a stripper versus 0.04 to 0.08 tons per bale for spindlers). Strippers are thus suitable for determinate cotton (i.e., produces bolls over a fixed period of time for a single harvest) (Holt et al. 2003; Kim, Park, and Daugherty 2004; Mayfield 2003; Weaver-Missick et al. 2000). Spindle pickers can be used more than once in a growing season to harvest cotton and thus are suitable for indeterminate varieties (i.e., produce bolls over an extended period of time with bolls maturing at different times in the growing season). About 25 to 33% of the U.S. cotton harvest is estimated to be stripper picked, leaving the remaining 67 to 75% to be harvested with spindle pickers (Glade and Johnson 1983–1985).

Cotton gin trash, generated in the cotton mill from cleaning the lint, has been estimated at various levels.[3] On average, cotton gin trash is produced at a rate of 0.16 tons of trash per bale of cotton (480 lb) after foreign material is counted.[4] Future production of cotton gin trash is estimated using state-level harvesting type percentages and applying cotton production forecasts of upland and pima cotton production (USDA-OCE/WAOB 2015). These results are shown in table 5.8. Cotton gin trash prices are based on projected coal prices; the supply is shown in table 5.1.

The USDA-OCE/WAOB (2015) projects upland cotton production up to 2024, forecasting 15.5 million bales from 10.4 million acres, yielding an average of 845 lb per acre of cotton lint in 2024. In 2040, planted upland cotton acreage and yield increase to 10.5 million acres and 893 lb per acre, respectively. Cotton gin trash production based on 2013 to 2015 cotton production is 1.7 million dry tons. This residue

[3] The range of cotton gin trash estimates includes 1.3 million tons (Buser 2001), 2.5 million tons (Comis 2002), and 3.2 million tons (Holt et al. 2003). Parnell, Columbus, and Mayfield (1994) state that in a typical year, gins that handle spindle-picked cotton generate 0.5 to 1.0 million tons of ginning trash, and those that handle stripped cotton generate 1.0 to 1.5 million tons of trash. Their total range of cotton ginning trash produced in a year is 1.5 to 2.5 million tons. Holt et al. (2003) state that in 2001 in the United States, 19.8 million bales of cotton (lint) and 3.2 million tons of cotton gin trash were produced, and in Texas, 4.2 million bales of cotton and 680,400 tons of cotton gin trash were produced.

[4] Holt et al. (2003) state that about 80% of cotton gin trash could be used for fuel pellets. Schacht and LePori (1978) report on six cotton gins in Texas where 11.1% of the cotton gin waste was cotton lint. According to Holt, Knabb, and Wedegaertner (2009), previous research shows that the quantity of recoverable fibers in cotton gin trash is between 10 and 25%. Based on the Texas average of cotton gin trash produced as reported by Holt et al. (2003), 0.1806 tons of trash per bale of cotton lint, applying the 11.1% figure of Schacht and LePori (1978), and assuming that cotton gin trash is 90% dry matter, 40 lb of lint are contained in the trash produced from one bale of cotton lint.

Table 5.8 | Cotton Gin Trash and Field Residues 2013 to 2040

Year	Production	Yield	Planted	Harvested	Cotton gin residue	Cotton field residue
	No. of 480-lb bales (1,000)	Harvest per acre (lb)	Millions of acres		Million dry tons	
2013	12.49	821	10.2	7.3	1.48	2.60
2014	16.94	838	10.8	9.7	2.00	3.53
2015	13.65	789	9.8	8.3	1.61	2.85
2017	14.00	810	9.8	8.3	1.74	3.75
2022	15.10	833	10.2	8.7	1.88	4.16
2030	15.94	863	10.4	8.9	1.98	4.53
2040	16.73	893	10.5	9.0	2.08	4.89

would be available at central sites (cotton gins) and not dispersed in agricultural fields.

Conversely, cotton stalks remain in the field after cotton harvest. The amount in a field will differ according to whether a stripper or spindle harvester is used. The assumptions for calculating cotton gin trash are that spindle and stripper harvesters take around 0.05 and 0.18 tons, respectively, of residue per bale of cotton with them. These amounts must be subtracted from the amount of residue available in the field. To estimate prices of cotton harvest residue, the following operations are assumed: shredding, raking, and bailing with a large rectangular baler. For cotton, shredding is a typical operation performed even if the residue is not harvested. Therefore, shredding operation costs are not included in the cost of harvesting residue. The amount of cotton residue available is estimated at 3.0 million dry tons currently (based on 2013 to 2015 production). Total production is shown in table 5.8. Costs are based on harvesting with a large rectangular baler and bale mover and a grower payment for nutrient content of $21 per dry ton. A shredder is also used, but it is presumed that a shredder would be used even without stalk collection. Cotton field residues supply various prices, as shown in table 5.1.

5.2.8 Animal Manure

Over the past several decades, livestock operations have experienced a trend toward fewer and more concentrated facilities. As a consequence, manure storage issues have arisen. Often, large, confined livestock operations do not have enough cropland or pasture to adequately distribute manure, resulting in excess manure that poses a risk to water quality and human health. Additionally, the land resources within close proximity to concentrated animal production facilities are constrained in their ability to absorb manure nutrients.

There are a number of estimates for the manure production potentially available for utilization. USDA

(2006) estimates 335 million dry tons from all animal feed operations and concentrated feed operations. The American Gas Association estimates usable manure production at between 216 and 721 million wet tons. Assuming 20% dry matter content, this range is 43 to 144 million dry tons (AGF 2011). The National Petroleum Council estimates total animal manure at 156 million dry tons and the practical resource at 24 million dry tons (NPC 2012).

USDA, EPA, and DOE estimate that livestock manure could produce 257 million ft^3 of biogas (USDA/EPA/DOE 2014). EPA (2011) estimates the biogas potential from swine and dairy operations assuming it is feasible to produce biogas from swine and dairy operations with more than 2,000 and 500 head, respectively. EPA (2011, 2015b) estimates that in November 2010 and March 2015, respectively, 160 and 247 manure anaerobic digester biogas systems were in operation. In its 2011 report, EPA estimates that 5,596 swine and 2,645 dairy farms have the potential to produce biogas, and that they produce 74.4 and 79.9 billion ft^3 of methane, respectively. Assuming 7.89 and 3.84 ft^3 of methane per pound of volatile solids for swine and dairy cattle, respectively (EPA 2011), and that volatile solids make up 70% of the manure, this would result in 22 million dry tons of manure.

To estimate manure production down to the county level, we utilized 2012 Census of Agriculture data for swine operations with 1,000 or more head and dairy operations with 500 or more head (USDA-NASS 2014b). Based on information from Penn State Extension (2016), dairy cattle (lactating cows, liquid) produce 13 gallons of manure per animal unit (AU)-day at 5% dry matter; and swine produce, farrow to wean 11 gallons per AU-day at 2.5% dry matter, nursery 14 gallons per AU-day at 1.5% dry matter, wean to finish 5.5 gallons per AU-day at 4% dry matter, and grow to finish 7 gallons per AU-day at 4% dry matter. Lactating cows produce 1 dry ton of manure per AU-year. Averaging over the four swine types results in approximately 0.375 dry tons of manure per AU-year. Each dairy cow is assumed to be 1.4 AU and each swine is 0.4 AU.

Table 5.9 | Manure Production

Year	Million dry tons
Current	17.1
2017	18.0
2022	18.5
2030	18.6
2040	18.4

Based on census data, a conservative estimate of current manure available is 17 million dry tons. Assuming that production changes with animal numbers, using an average of projected animal numbers (hogs, beef cattle, and chickens), production increases to 18 million dry tons in 2040 (table 5.9). Supplies are assumed to be available at a price of $40 per dry ton or less.

5.3 MSW, Garbage Fraction

MSW is a broad term potentially including a variety of industrial and residential waste streams. In this chapter, we limit MSW to garbage—mixed commercial and residential wastes generally destined for landfill or incineration disposal, as well as yard trimmings. Urban wood waste and construction and demolition (C&D) debris are discussed separately in section 5.4.6.

Organic MSW categories potentially available for biofuels include paper and paperboard, plastics, rubber and leather, textiles, food wastes, and yard trimmings. Although the estimates in this chapter represent gross supplies currently landfilled, not all of this supply is economically available because of preprocessing costs. Further, the highest use of MSW remains to be determined, after ongoing efforts toward source reduction and reuse, recycling, composting, and energy recovery.[5]

MSW consists of a variety of items, ranging from organic food scraps to discarded furniture, packaging materials, textiles, batteries, appliances, and other materials. In 2013, 254 million tons of MSW were generated (EPA 2014). About 35% of the total quantity generated (134 million tons) was discarded in municipal landfills. The remainder was either recycled, made into compost, or combusted for energy recovery. Containers and packaging are the single largest component of MSW generated, totaling some 75 million tons, or 30% of the total. Durable goods are the second largest portion, accounting for 20% of total MSW generated. Yard trimmings are the third largest portion and account for about 34 million tons, or 14%, of the total generated.

Estimates were generated by

1. Assuming an MSW landfilled generation rate—after current efforts toward reduction, reuse, recycling, and waste-to-energy—of 2.36 lb per person per day (with moisture), based on EPA (2015a, table 30)
2. Multiplying this rate by county-level 2012 U.S. population data from the U.S. Census Bureau
3. Multiplying these county-level results by MSW category fractions derived from EPA (2015a, table 3).

The resulting 134 million green tons/year landfilled is about half of the 269 million green tons/year estimated in BioCycle's 2010 report *The State of Garbage in America* (van Haaren, Themelis, and Goldstein 2010), and about 42% of Pacific Northwest National Laboratory's unpublished estimate of 305 million green tons/year (Drennan 2014). Shin (2014) estimates total MSW generation in 2011 at 389 million tons. Based on the EPA estimate, about 105 million green tons/year of this supply is organic or composed of organic compounds (including biomass, wood, yard, and food wastes; plastics; and rubber). The EPA data showed lower amounts than other estimates, and so using EPA numbers as a starting point is a more conservative estimate.

In recent years, EPA data show that, from 2005 to 2013, the amount of MSW generated has been relatively flat at around 250 million tons; and from 2009 to 2013, discards to landfills have been relatively flat at around 132 million tons. We assume that discards to landfills remain constant over the projection period, with any increased generation from population growth being offset by increased recycling and composting.

Yard trimmings are estimated to be 13.5% of the MSW generated and 8% of discarded MSW. In 2013 EPA estimated 34.2 million tons (wet basis) of yard trimmings were generated and 14.6 million tons (wet basis) were discarded, either landfilled or used for waste-to-energy. After adjusting for MSW used for waste-to-energy, on a wet weight basis, the amount of yard trimmings potentially available, above what is currently used for energy, is 10.8 million green tons, or 4.3 million dry tons based on 60% moisture. Another estimate, based on McKeever (2004), results in 3.3 million dry tons of wood in yard trimmings that are estimated to be recoverable and available for bioenergy applications after accounting for quantities that are likely to be composted, combusted, recycled, or contaminated and unavailable. The fractions composted, combusted, and contaminated are based on technical coefficients developed by McKeever (2004).

[5] D. Perla, 2014, EPA RICRA Program Office of Research, personal communication to John Jonston of EPA, Southeast U.S. Atlanta Office, and Hope Hillsburry of Office of Resource Conservation and Recovery, March 29, 2014. See http://www.epa.gov/wastes/nonhaz/municipal/hierarchy.htm for more information.

The 4.3 million dry ton estimate is used. To obtain county-level estimates of supply, this total is distributed among counties in proportion to the resident population per county.

The prices of garbage supplies available after sorting are unknown. Price estimates for sorted organic fractions are generated as follows:

- State-level average MSW tipping fees, ranging from $18 per green ton in Idaho to $105 per green ton in Massachusetts, are purchased from Klean Industries Inc.
- For counties with populations of less than 250,000, all material is assumed to be available at the state-level tipping fee (dollars per green ton) plus a $60 per green ton sorting cost.
- For counties with populations greater than or equal to 250,000, 50% of the material is assumed to be available at the state-level tipping fee (dollars per green ton) plus a $40 per green ton sorting cost; the remaining 50% of the material is assumed to be available at the state tipping fee (dollars per green ton) plus a $60 per green ton sorting cost.

Resources with resulting prices of less than $20 per green ton are assumed to be available at $20 per green ton. All supplies and prices are converted to dry tons and to a dollar per dry ton basis assuming the following moisture contents: food wastes 70%, yard trimmings 60%, paper and paperboard 15%, textiles 15%, rubber and leather 10%, and plastics 10%.

It is estimated that 51 to 55 million dry tons per year may be available at prices ranging from $40 to $60 per dry ton (table 5.10) As in the case for terrestrial feedstocks, it is not implied that all of the MSW material is available for biofuels; rather, this is an estimate of supplies and prices that might be available beyond what is currently used for an emerging market or markets. These estimates indicate gross potential and do not capture trends and variability in MSW availability associated with future population growth; innovations in MSW logistics and handling; efforts to reduce, reuse, and recycle; and limitations and opportunities that might be associated with local waste handling contracts. Economic theory suggests that without market intervention, MSW resources would be allocated to the highest-value use, which may or may not be biofuels. MSW garbage supply and price estimates presented here are subject to modification with better information.

In table 5.10, paper and paperboard is estimated at 16–17 million dry tons. This quantity of paper and paperboard is currently disposed of in landfills. Note that in section 932 of the Energy Policy Act of 2005[6] and sections 1201 and 1203 of EISA,[7] paper that is commonly recycled is excluded from the definition of biomass. However, the part of paper and paperboard that is currently landfilled is included as a potential energy resource.

One of the challenges with energy recovery from halogenated plastics is the production of HCl and dioxins/furans. (A halogenated compound contains chlorine, fluorine, bromine, or iodine.) Examples of halogenated plastics include polyvinyl chloride (PVC), chlorinated polyethylene, chloroprene, chlorinated PVC, chlorosulfonated polyethylene, polychloroprene (marketed under the trade name Neoprene) and fluorinated ethylene propylene (NIH 2016).

Estimates of halogenated plastics can be found for PVC. In 2014, the American Chemistry Council (2016) estimated PVC production in the United States at 7.5 million tons and domestic demand at 5.2

[6] Energy Policy Act of 2005, Pub. L. 109-58 Stat. 594, https://www.gpo.gov/fdsys/pkg/PLAW-109publ58.

[7] Energy Independence and Security Act of 2007, Pub. L. 110-140, 121 Stat. 1492, http://www.gpo.gov/fdsys/pkg/BILLS-110hr6enr.

Table 5.10 | Supplies Available from MSW Sources, Excluding Wood and Construction and Demolition Wastes, 2017 to 2040

MSW Sources	$40 per dry ton	$50 per dry ton	$60 per dry ton
	Million Dry Tons		
Paper and paperboard	15.7	17.0	17.1
Plastics	20.0	20.1	20.1
Rubber and leather	4.4	4.4	4.4
Textiles	8.0	8.2	8.2
Other	2.5	2.6	2.7
Food waste	0	0	0
Yard trimmings	0	3.1	3.3
Total	**50.6**	**54.7**	**54.8**

million tons. EPA (2015a) reported that in 2013, total PVC in MSW was 900,000 tons (about 3% of plastics in MSW discards) and that a negligible amount was recovered. In durable goods (which include computer equipment), nondurable goods, and containers and packaging, the amount of PVC in MSW in 2013 was 240,000, 230,000, and 430,000 tons, respectively. If one assumes that the other halogenated plastics are relatively small in quantity, then about 1.0 million tons of halogenated plastics were landfilled.

After extraction of higher-quality fractions for recycling, there remains a mix of plastics contaminated with other compounds (Alston and Arnold 2011). Possible disposal methods for the remaining material include pyrolysis, supercritical fluids, and gasification (Wang and Xu 2014), incineration, and landfilling. Pyrolysis is proposed as a recycling mechanism for plastics from waste electrical and electronic equipment, but steps must be taken so the pyrolysis oil is not contaminated with halogenated compounds (Yang et al. 2013). Hall and Williams (2006) examined fast pyrolysis of halogenated plastics from waste computers. They found conversion of most of the plastics to pyrolysis oil, but the PVC computer cases also produced large quantities of HCl. Incineration and energy recovery of plastic is less prevalent than landfilling primarily because of the perceived risk of hazardous substance release into the atmosphere (e.g., dioxins, other polychlorinated biphenyls, and furans) (Hopewell, Dvorak, and Kosoir 2009). They note that some nations (including Japan, Sweden, and Denmark) use extensive incinerator infrastructure to deal with MSW, including plastics. Although care must be taken to ensure that the energy products are not contaminated with undesirable compounds nor hazardous materials released into the environment, there are options for recovering energy from halogenated plastics. Therefore, we include halogenated plastics in the MSW resources that are potentially available.

5.4 Forestry and Wood Wastes

Forestry and wood wastes are one of the most accessible and, in turn, one of the currently most used biomass resources. Current uses of wood waste total 123 million tons. Some quantity of these currently used wood wastes could shift to bioenergy applications at the right price. However, estimating what amount of these resources could move into bioenergy production is difficult and speculative, as many of these wood wastes not only are used but are also confined or dedicated to a specific process. The following are definitions of the major wood categories that can supply potential biomass resources:

- **Other removal residues:** Unused wood that is cut during the conversion of timberland to non-forest uses and in silvicultural operations such as precommercial thinning (Smith et al. 2009).
- **Thinnings from other forestland:** Wood from removals reducing the number of plants in an area or the quantity of vegetative or reproductive structures on individual plants. Thinning cuts are conducted on other forestland (non-timberland) to improve forest health by removing excess biomass on low-productivity land.
- **Unused primary and secondary mill processing residues:** Bark, mill residues (coarse and fine wood), and pulping liquors generated from the processing of sawlogs, pulpwood, and veneer logs into conventional forest products.
- **Urban wood wastes:** The urban wood waste resource includes a wide variety of woody materials, including discarded furniture; landscaping wood waste; and wood used in the construction, remodeling, and demolition of buildings.

Additional information for each is found in the glossary of this report (see other removals and residues, thinnings, mill processing residues, and urban wood wastes). The following sections discuss the potential additional biomass resources that may be available for each.

5.4.1 Other Removal Residues

The conversion of timberland to non-forest land uses (e.g., cropland, pasture, roads, urban settlements) and precommercial thinning operations generate a relatively significant amount of forest residue biomass. These other removals, especially from land-clearing operations, usually produce various forms of residues that are generally not feasible or economical to recover. It is expected that only half of the residues from other removals can be recovered.

Amounts of other forest removals, by county, are obtained from the TPO database for 2012 (USDA Forest Service 2012). The 2005 *BTS* and the 2011 *BT2* assume that 50% of the TPO residue estimate is recoverable and available. The original estimate is based on discussion with experts concerning the level of difficulty of recovering this feedstock. Specific characteristics of this feedstock—such as small land areas, trees pushed up and piled, and trees cut into small pieces—make it difficult to recover it fully. The assumption that 50% is recoverable is used in this update as well. Few price data are available for these types of feedstocks. Assumptions are made based on the expertise of the contributing authors concerning recovery and transport costs and market prices to derive the stumpage values. Specifically, one-third (4.1 million dry tons) is assumed to be available at $20 per dry ton at roadside and the remainder (~12.2 million dry tons) at $30 or more per dry ton at roadside. Future estimates of other removal residue are based on RPA projections of forest area (Wear 2011). Through 2040, total forest area is projected to decline by 8 to14 million acres, depending on the RPA scenario, which could mean that there could be more "other removals" residues over time through 2040. Table 5.11 shows a slight increase in potential recovery of this biomass over time.

Table 5.11 | Summary of Baseline Potential Forest Biomass and Wood Wastes at Selected Roadside Prices

Feedstock ($ per dry ton)	2017			2022			2030			2040		
	$40	$50	$60	$40	$50	$60	$40	$50	$60	$40	$50	$60
	Million Dry Tons											
Other removal residues	12	12	12	13	13	13	13	13	13	13	13	13
Treatment thinnings, other forestland	0.0	0.0	2.6	0.0	0.0	2.6	0.0	0.0	2.6	0.0	0.0	2.6
Mill residue, unused secondary	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2	4.2
Mill residue, unused primary	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Urban wood waste—construction and demolition (method one[a])	15	23	23	15	23	23	16	25	25	16	25	25
Urban wood waste—MSW (method one[a])	5.1	5.3	6.3	5.1	5.3	6.3	5.1	5.3	6.3	5.1	5.3	6.3
Total	**36**	**45**	**49**	**38**	**47**	**51**	**39**	**49**	**53**	**39**	**49**	**53**

[a]Based on a methodology utilizing McKeever (2004).

5.4.2 Forest Residue Thinnings on Other Forestland

Other forestlands, also known as woodlands, are defined as being incapable of producing at least 20 cubic feet per acre per year of industrial wood under natural conditions because of a variety of adverse site conditions, including poor soils, lack of rainfall, and high elevation. Many of these woodlands (low-stature or sparse forests) are in the western states and are overstocked, especially with stands of pinyon pine and juniper. As with the fuel reduction thinnings on timberland, removal of the excess biomass could greatly reduce catastrophic fire hazards. FIA data (USDA Forest Service 2010) are used to identify overstocked western woodlands. Assumptions similar to those used in the 2005 *BTS* and the 2011 *BT2* are used for this update. The amounts of live biomass on woodland are given in the FIA EVALIDator web application and database (Miles 2015). We assume road access limits the availability to 60% of biomass, which corresponds approximately to the amount of biomass from woodland that is within 1 mile of a road. The biomass would be removed in equal annual amounts over 30 years. In table 5.11, the total residue biomass from thinning other forestlands is estimated at 2.6 million dry tons at a price of $60 per dry ton (none is expected to be available below this price because of the high cost of thinning other forestlands). Above $80 per dry ton, 5.3 million dry tons annually becomes available for all lands. When federal forestlands are removed, 3.1 million dry tons are available above $80 per dry ton, about 40% less. By definition, these lands do not produce commercial-size pulpwood or sawlogs, so the cost of removing the thinnings is borne fully by the biomass harvesting operation. An assumption used in the analysis is that about 50% of the biomass could be removed at a price of $60 per dry ton and the remainder at a price of $70 per dry ton. Again, these assumptions are the best estimates by the contributing authors with knowledge of these types of harvesting systems. The estimates are considered conservative because they represent the high end of thinning costs, as no higher-valued wood is removed with the biomass.

5.4.3 Primary and Secondary Mill Residue

The processing of sawlogs, pulpwood, and veneer logs into conventional forest products generates significant quantities of bark, mill residues (coarse and fine wood), and pulping liquors. Primary mills convert roundwood (tree trunks and logs) into other wood products and include sawmills, pulp mills, and veneer mills. Secondary mills use products from primary mills to produce other products such as furniture and cabinets. With the exception of small quantities of mill residues, these secondary forest product industry residues are currently used in the manufacture of forest products or for heat and power production, and valuable chemicals are recovered from pulping liquors.

Amounts of wood and bark residue from primary product milling operations (by county) are obtained from the TPO database for 2012 (USDA Forest Service 2012). For the baseline case, it is assumed that only unused mill residues are available. Neither the U.S. Forest Service nor any other federal agency systematically collects data on secondary mill residue. One of the few estimates of the amount of secondary mill residue available is provided by Rooney (1998) and subsequently revised by Fehrs and Williston (1999). Fehrs estimates that about 12.5 million dry tons are generated annually, about 40% of which is potentially available and recoverable. The remaining fraction is used to make higher-value products, used onsite to meet some energy needs (such as heat for drying operations), or is not available for other reasons. An estimate of 15.6 million green tons is incorrectly cited from Fehrs as a dry ton amount in the 2011 *BT2*. Milbrandt (2015b) uses Rooney's method and data on number and employee size of secondary wood products establishments for 2012 to estimate residue generation of 8.7 million dry tons for 2012. We estimate 40% of 8.7 million tons, or 3.5 million dry tons, is available.

In 2011, of primary product mill residues, about 26 million tons were used for energy, 33 million tons were used for fiber products and other uses, and 0.5 million tons were unused. Baseline projections estimate primary mill residue consumption in 2040 to be 46 million dry tons (Nepal et al. 2016). Baseline projections of secondary mill residue consumption for energy are very rough and assume that 48% of the current generated amount is used for energy (Rooney 1998). The rate of increase in consumption of secondary mill residues for energy is assumed to be the same as for consumption of primary mill residues. Secondary mill residue consumption for energy is projected to increase from 4 to 6 million dry tons by 2030. It is assumed that the unused mill residues can be purchased at the mill for $20 per dry ton or less, which is comparable to the disposal cost if there are no markets available. Delivered prices could be much higher, especially for secondary mill residues where facilities are small, dispersed, and operate seasonally. There are 0.5 million dry tons of primary mill residues and 3.5 million dry tons of secondary mill residues available annually at $20 per dry ton (table 5.11). It is assumed that any residue associated with increased future demand for primary and secondary wood products is offset by greater mill efficiencies and a continued increase in the use of this material for byproducts.

5.4.4 Fuelwood

All currently used fuelwood (residential and commercial) is estimated to be 34 million dry tons per year. The quantity of fuelwood used for residential and commercial space heating applications, as well as feedstock for dedicated wood-fired facilities and co-firing applications, is projected to decline to 27 million dry tons per year by 2040 (EIA 2015a). This is not an additional supply, as it is already accounted for as currently used supplies in chapter 2.

5.4.5 Pulping Liquors

As is explained in chapter 2, combustible chemical byproducts, such as black liquor from pulping facilities, are currently used for energy production and are not counted as an additional feedstock resource. The available amount is 44 million dry tons, with projections of 37 million dry tons in 2030 (EIA 2015a).

5.4.6 Urban Wood Wastes

The two major sources of urban wood residues are the woody components of MSW and C&D waste wood. The MSW wood component of containers and packaging and durable goods (e.g., lumber scraps and discarded furniture) is 15.8 million tons (EPA 2014). About 15% of this is recycled (EPA 2014). Falk and McKeever (2004) estimate 22% is combusted for energy recovery, leaving 10.0 million tons to be discarded and landfilled. About one-third of this discarded material is unacceptable for recovery because of contamination; commingling with other wastes; or other reasons such as size and distribution of the material (McKeever 2004). The remainder that is potentially available for bioenergy (based on what is refered to here as "method one") totals about 6.6 million dry tons annually. To obtain county-level estimates of supply, this total is distributed among counties in proportion to the resident population per county.

A second method (method two) is used to calculate woody waste from MSW based on coefficients developed by Wiltsee (1998b). For MSW wood, Wiltsee estimates per capita wood generated in MSW as 0.054 tons per person-year either landfilled or incinerated, and 0.03 tons per person-year disposed of by rural dumping. Based on these two categories, 0.057 tons per person-year and assuming 50% moisture content, a total of 9.0 million dry tons of wood was available for use in 2013.

A minimum price of $20 per green ton is assumed. The price is determined by county by subtracting the county tipping fee (based on state tipping fees) from $60 per green ton if the county has a population of less than 250,000. The same calculation is used for half the MSW generated in a county with more than 250,000 people. For the other half of the MSW in a county with a population above 250,000, the tipping fee is subtracted from $40 per green ton, with a minimum MSW price of $20 per green ton.

The other principal source of urban wood residue is C&D debris. C&D wood waste is generated during the construction of new buildings and structures, the repair and remodeling of existing buildings and structures, and the demolition of existing buildings and structures (McKeever 2004). These materials are considered separately from MSW because they come from many different sources. These debris materials are correlated with economic activity (e.g., housing starts), population, demolition activity, and the extent of recycling and reuse programs. The updated estimates of C&D debris wastes total about 23.3 million dry tons. About 10.8 million dry tons are construction debris and 12.5 million dry tons are demolition debris. These estimates are based on technical coefficients developed by McKeever (2004) (method one). To obtain county-level estimates of supply, this total is distributed among counties in proportion to the resident population per county.

A second method (method two) is used to determine the amount of C&D debris available for energy based on Wiltsee (1998b). For C&D debris, Wiltsee estimates that 0.052 tons per person-year are either landfilled or incinerated and 0.002 tons per person-year are disposed of by rural dumping. Based on these two categories (0.054 tons per person-year and assuming 15% moisture), 14.5 million dry tons was generated in 2013. This increases to 14.7 million dry tons in 2015, 14.9 million dry tons in 2017, 15.5 million dry tons in 2022, 16.4 million dry tons in 2030, and 17.4 million dry tons in 2040, with the increase based on projected population growth. The price is determined using the same methodology as described earlier for MSW wood.

Using method one, MSW wood waste, together with C&D debris, sums to 33 million dry tons per year as potential energy feedstocks. As noted by McKeever (1998), many factors affect the availability of urban wood residues, such as size and condition of the material; extent of commingling with other materials; contamination; location and concentration; and costs associated with acquisition, transport, and processing.

Chapter 2 estimates the currently used MSW wood at 15 million dry tons annually and projects that it increases to 16 million dry tons per year by 2040 (EIA 2015a). In this chapter, the unused MSW wood and yard trimming wastes total 10 million dry tons, and the unused C&D debris wood could provide an additional 23.3 million dry tons. Future quantities of unused urban wood wastes (from MSW and C&D sources) will no doubt rise as population increases; however, the increase will likely be less because of ongoing waste recovery efforts and higher landfill disposal costs. For construction waste, it is likely that higher fractions will be recycled and reused; and there will be greater use of engineered lumber, which will reduce dimensional lumber use and also make less waste available.

For C&D wastes, prices were estimated in the same way as MSW wood wastes. After the analysis was completed, data were received on prices for C&D wastes from Ecostrat (2016). The Ecostrat data had prices for 37 states. Prices for C&D wastes from the Ecostrat data ranged from $6.25 to $80 per dry ton. The prices used in the *BT16* analysis range from $24 to $49 per dry ton.

5.5 Other Supplies

5.5.1 Biosolids

Biosolids come from sewage treatment facilities, and about 7 to 8 million dry tons are estimated to be available (Bastian 2013; Beecher et al. 2007). Approximately 55% of biosolids are land-applied for agricultural, forestry, or land restoration purposes (Beecher et al. 2007). We assume that the remaining 45% is potentially available for energy purposes. Beecher et al. (2007) estimate total biosolids production at 7.2 million dry tons in 2004. We assume this increases with population, so in 2015 and 2040, respectively, biosolids production would be 7.9 and 9.3 million dry tons, 45% of which is 3.6 and 4.2 million dry tons. We assume this is available at $40 per dry ton (table 5.12).

5.5.2 Used Cooking Oils

Used cooking oils are generally collected and used for livestock feed, biodiesel, or other products. Subcategories of used cooking oil are yellow grease—which has a free fatty acid content of less than 15%—and brown grease, which is used cooking oil with a free fatty acid content of greater than 15% (Van Gerpen 2015). Yellow grease is accounted for in EIA data on current uses, as is brown grease, which is included under other recycled feedstocks (EIA 2015b).

5.5.3 Brown and Trap Greases

Brown grease can encompass many feedstocks, including used cooking oil with greater than 15% free

Table 5.12 | Biosolids; Trap Grease; Food Processing Wastes from Industrial, Institutional, and Commercial Sources; Utility Tree Trimmings; and Additional Supplies of Landfill Gas

Feedstock ($ per dry ton)	Current	2017			2022			2030			2040		
		$40	$50	$60	$40	$50	$60	$40	$50	$60	$40	$50	$60
Million dry tons													
Biosolids	3.6	3.6	3.6	3.6	3.8	3.8	3.8	4.0	4.0	4.0	4.2	4.2	4.2
Trap grease	1.0	1.1	1.1	1.1	1.1	1.1	1.1	1.2	1.2	1.2	1.2	1.2	1.2
Food processing wastes—industrial, institutional, commercial	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0	4.0
Total biosolids, trap grease, and food processing wastes	8.6	8.7	8.7	8.7	8.9	8.9	8.9	9.2	9.2	9.2	9.4	9.4	9.4
Utility tree trimmings	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5	0.5
Billion ft^3 (no price estimated)													
Landfill gas—additional supplies		45			229			229			229		

fatty acids, trap grease (i.e., kitchen waste), sewage grease, and black grease (Tyson 2002). Trap grease is generally disposed of at wastewater treatment facilities and landfills. Wiltsee (1998a) estimates that 13 pounds of trap grease were generated per person per year in the United States, or about 2.1 million tons total (table 5.12).

5.5.4 Industrial, Institutional, and Commercial Food Processing Wastes

Food wastes, such as those from industrial sources, are not included in EPA MSW data. It is not clear whether food wastes from institutional and commercial sources are included in the EPA MSW data. Matteson and Jenkins (2007) estimate that in California, food processing wastes total 229,000 dry tons. The California Biomass Collaborative estimates that 3.8 million dry tons of food processing wastes are generated in California.[8] The National Renewable Energy Laboratory (NREL) has estimated that 20.6 million wet tons of food waste were generated in 2012 (Milbrandt 2015a). We assume that 65% of this wet weight (Matteson and Jenkins 2007), with a moisture content of 70%, or 4.0 million dry tons, is available at a price of $40/dry ton.

5.5.5 Landfill Gas

EPA (2016) estimates that as of February 2016 there were

- 119 landfills with energy projects that flare landfill gas at 45.3 billion ft^3 per year
- 26 landfills with energy projects either under construction or in the planning phase flaring 22.3 billion ft^3 per year
- 400 candidate landfills that could produce 161 billion ft^3 per year of landfill gas.

In total there is a potential for 229 billion ft^3 per year of additional landfill gas in addition to what is currently being captured and utilized. Currently utilized landfill gas is discussed in chapter 2. EPA defines a candidate landfill as a landfill that is currently accepting wastes or has been closed less than 5 years; that has at least one million tons of waste; that has no operational, under construction, or planned project; or that can be designated as a candidate landfill based on actual interest by the site. For 2017 the estimate of additional supplies is the flared gas at landfills with existing energy projects. For later years it is 229 billion ft^3 per year of additional landfill gas.

5.5.6 Utility Tree Trimmings

NREL estimates that, in 2012, utility tree trimmings were 913,000 dry tons (Milbrandt 2016; NREL 2016). We assume that 50% of these are available (479,000 dry tons) at a price of less than $40 per dry ton, and that supplies are roughly 500,000 tons per year out to 2040 (table 5.12).

5.6 Summary

Biomass from waste resources represents low-cost opportunities for bioenergy without the need for significant additional inputs. A diverse set of agricultural, woody, and MSW resources are covered in this chapter. Some resources are currently used, such as mill residues, sugar cane bagasse, and animal fats, and are included in quantities reported in chapter 2. From 2017 to 2040, at prices ranging from $40 to $60 per dry ton, additional agricultural wastes; MSW wastes, excluding wood and C&D waste; forestry residues; and other waste resources are available in amounts ranging from 27–38 million dry tons (table 5.1), 51–55 million dry tons (table 5.10), 36–53 million dry tons (table 5.11), and 9 million dry tons, respectively (table 5.12). Total biomass waste supplies from sources currently not used total 123 to 155 million dry tons (table 5.13).

[8] N. Parker, 2015, personal communication to A. Turhollow, December 9, 2015.

Table 5.13 | Summary of Baseline Potential of All Biomass and Wood Wastes at Selected Roadside Prices

Feedstock ($ per dry ton)	2017			2022			2030			2040		
	$40	$50	$60	$40	$50	$60	$40	$50	$60	$40	$50	$60
Agricultural	27	33	34	28	35	36	27	36	37	27	36	38
MSW[a]	51	55	55	51	55	55	51	55	55	51	55	55
Forestry	36	45	49	38	47	51	39	49	53	39	49	53
Other	8.7	8.7	8.7	8.9	8.9	8.9	9.2	9.2	9.2	9.4	9.4	9.4
Total	**123**	**142**	**147**	**126**	**146**	**151**	**126**	**149**	**154**	**126**	**149**	**155**

[a]Excluding wood and C&D wastes and about 230 billion ft^3 per year of potential biogas from landfills as shown in table 5.12.

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