U.S. DEPARTMENT OF ENERGY | Office of ENERGY EFFICIENCY & RENEWABLE ENERGY

Chapter 02 | Biomass Currently Used for Energy and Coproducts

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2 Biomass Currently Used for Energy and Coproducts

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

Summary

- 342 million tons of biomass were used for energy and bio-based chemicals in 2022. Corn grain for biofuels and forestry/wood and wood waste for heat and power remain top bioenergy sources. Biomass consumption highlights in 2022:[1]
  - 162 million dry tons of agricultural biomass.
  - 144 million dry tons of forest and woody biomass.
  - 37 million dry tons of biomass from waste resources.
- Trends in biomass energy production and consumption since BT16 Volume 1:[2]
  - Total biomass energy production in all 50 U.S. states decreased by approximately 0.5%. Total biomass energy consumption decreased by approximately 5.5% from the 365 million dry tons of total biomass consumption in BT16 Volume 1 but has been trending upward since 2020.
  - Biofuels increased biomass consumption by approximately 14% (from 127 to 146 million dry tons of feedstock).
  - Woody biomass energy consumption fell 25% (from 171 to 144 million dry tons of feedstock), and waste energy consumption fell 10% (from 41 to 37 million dry tons of feedstock).

[1] See Table 2.6 for more comprehensive biomass consumption data.
[2] Comparing biomass energy usage in 2014 (BT16 Volume 1 reporting year) to 2022 (BT23 reporting year).

2.1 Introduction

This chapter reviews primary domestic energy production and consumption; quantifies biomass as a feedstock for energy uses in all 50 U.S. states; provides details on biomass currently used to produce biomass-based transportation fuels, fuels for heat and power generation, and bio-based coproducts; and discusses emerging sources of bioenergy. It compares current consumption to the historical rates included in BTS, BT2, and BT16 Volume 1 (DOE 2005, 2011, 2016). The following chapters in this report discuss primary uses of biomass for sectors other than power production, heat generation, and transportation and offer estimates of the future potential of these uses.

2.2 Primary Energy Consumption

Primary energy consumption across all sectors is from the 2023 U.S. Energy Information Administration (EIA) Annual Energy Outlook (AEO) (EIA 2023a). All energy consumption comparisons in this chapter compare 2022 to the 2014 values that were reported in the 2016 Billion-Ton Report, based on the 2015 Annual Energy Outlooks, unless explicitly stated otherwise. Primary energy consumption is presented in units of quadrillion (10^{15}) British thermal units (Btu), or quads. Million Btu are expressed as MMBtu, and trillion Btu are expressed as TBtu. For perspective, 1 barrel (42 gallons) of crude oil produced in the United States contains about 5,691,000 Btu (5.69×10^6 Btu), and 1 quad equals about 176 million barrels of oil.

Primary energy consumption in the United States has decreased by 0.5% (from 95.3 quads to 94.8 quads) since 2014. At the time of publication of BT16 Volume 1, the total energy consumption was reported at 98.3 quads, but the EIA has since revised energy consumption estimates to match international formats more closely and update reporting methodology for current conditions (EIA 2023e, Appendix E). Consumption peaked at 97.4 quads in 2018, followed by a decline in total primary energy consumption in 2020 and 2021, primarily driven by reductions in fossil fuel use during the COVID-19 pandemic (Figure 2.1). From 2014 to 2022, coal consumption decreased approximately 45% (from 18.0 quads to 9.8 quads), and natural gas consumption grew about 21.9% (from 27.4 quads to 33.4 quads) as coal-fired power generation was phased out and replaced with renewables and natural gas.

Since 2014, total renewable energy consumption has risen by 19% (from 6.8 quads to 8.1 quads) (Figure 2.2), while fossil energy consumption decreased by about 2% (from 80.0 quads to 78.5 quads). In 2022, biofuels were the largest single category of renewable energy with 30% of total renewable energy consumption (2.4 quads), followed by wood energy at 24.5% (2.0 quads), wind at 18.3% (1.5 quads), hydropower at 11.1% (0.9 quads), solar at 9.4% (0.8 quads), waste at 5.1% (0.4 quads), and geothermal power at 1.5% (0.1 quads). Growth in renewable energy consumption was driven by increases in the consumption of wind (140%, 0.9 quads) and solar energy (373%, 0.6 quads). Biomass-based renewable energy constituted 60% (4.8 quads) of the total renewable energy consumption in 2022.

The following sections explain current bioenergy consumption, broken into biofuels and heat and power. Additional discussion of waste resource consumption is described in more detail in Chapter 3: Waste Resources and Byproducts.

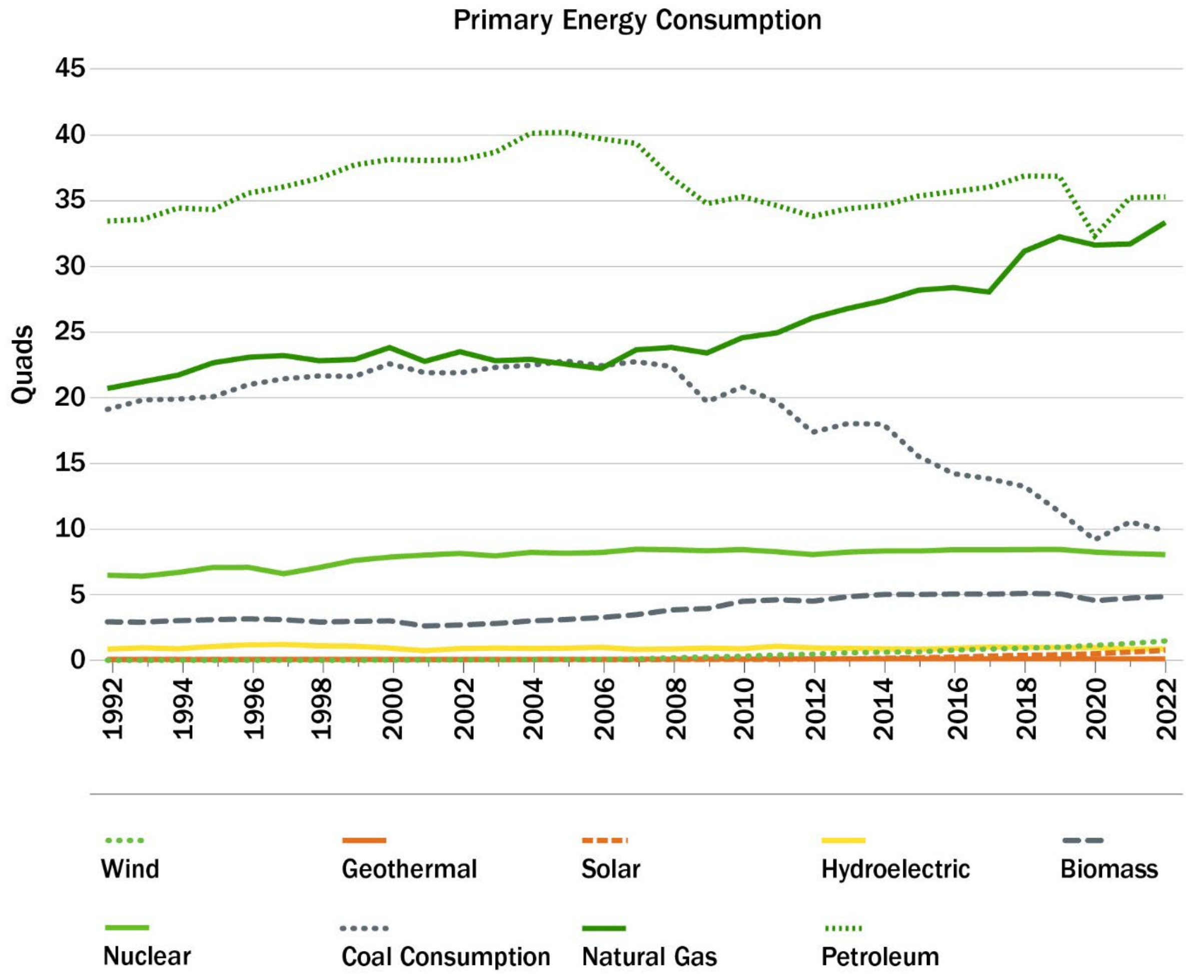


Figure 2.1. Primary energy consumption by source (1992–2022).

Source: (EIA 2023e, Table 1.3)

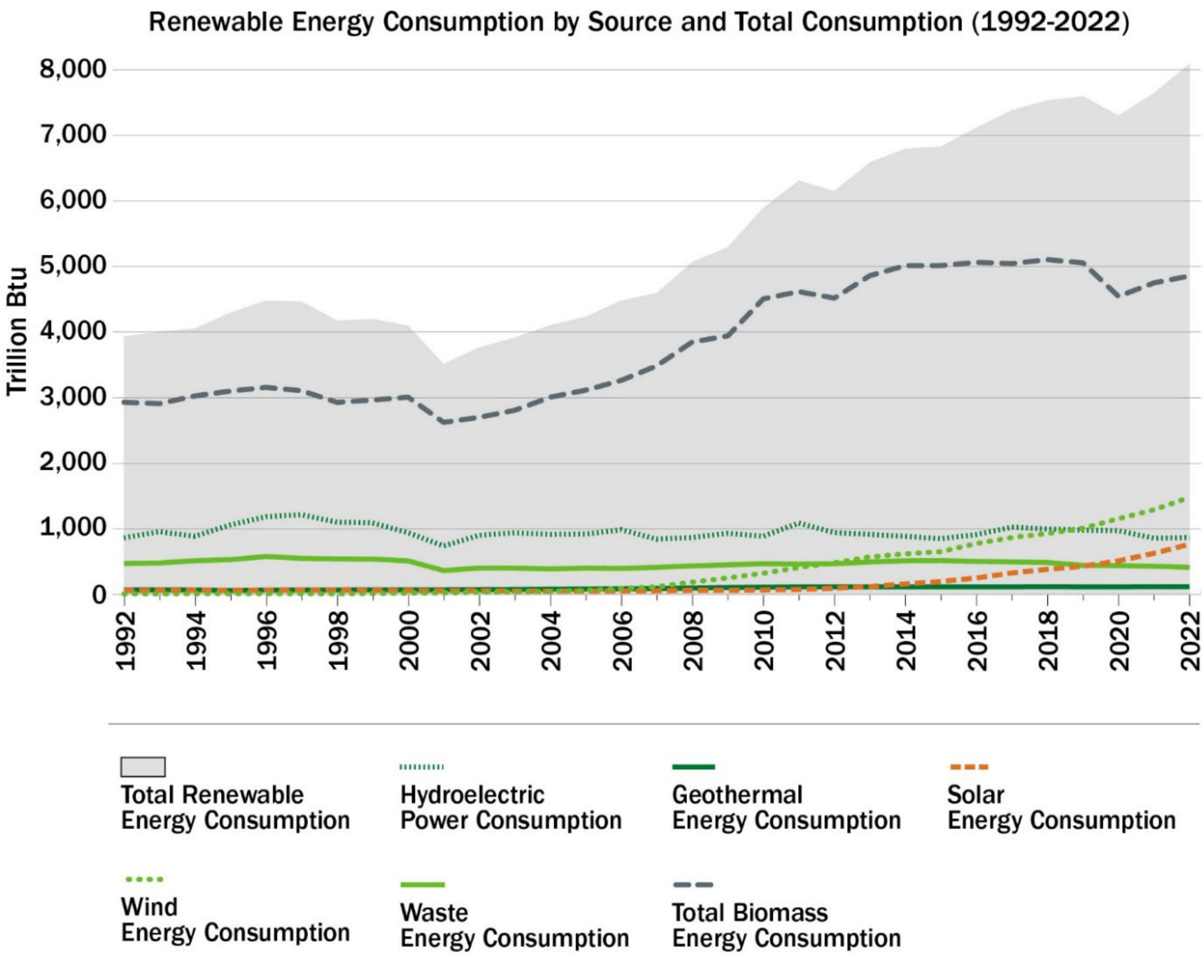


Figure 2.2. Primary renewable energy consumption by source and total consumption (1992–2022).

Source: *(EIA 2023e, Table 10.1)*

2.3 Transportation Fuels

The following sections discuss current biofuel production, describe the references and assumptions used to estimate the amount of biomass resources consumed in converting feedstocks to biofuels, and discuss trends in usage. The data on biofuel production for this report come from three sources: EIA (EIA 2023a), U.S. Environmental Protection Agency (EPA) renewable identification numbers (RINs) (EPA 2023c, 2024c), and the U.S. Department of Agriculture (USDA) (USDA 2023b).

EIA's reporting on biofuels includes fuel ethanol, biodiesel, renewable diesel, renewable heating oil, renewable jet fuel, renewable naphtha, renewable gasoline, biobutanol, and "other" biofuels and biointermediates. In 2022, the EIA reported that 18.7 billion gallons of biofuels were produced in the United States, and about 17.6 billion gallons were consumed (EIA 2022). In the same year, the EIA also reported that renewables accounted for 5.7% of the U.S. transportation sector's energy consumption (EIA 2023e, Table 2.5).

Corn Ethanol

Technological advancements have revolutionized the agricultural landscape, enabling farmers to reduce resource usage and costs and promote environmental stewardship. One such advancement is the significant reduction in fertilizer use, a crucial step toward cost efficiency, carbon reduction, and responsible ecological practices. Minimizing fertilizer application reduces costs and lessens the carbon intensity of crops. Innovative technologies enable precise and efficient fertilizer application, matching the exact needs of crops.

Ethanol production has played a pivotal role in enhancing the social and economic sustainability of rural communities. The establishment of ethanol biorefineries has created a steady and dependable market for grain. This has brought a new generation to farming and rejuvenated communities. Jobs and prospects offered by ethanol facilities strengthen agricultural economies, providing many positive influences on rural life.

Crops serve as a carbon sink, capturing CO_2 from the atmosphere. During CO_2 fermentation, some of this recycled CO_2 can be harnessed for various applications, such as carbon capture and storage, where it can be compressed or stored underground. The convergence of lower input costs, improvement of ethanol production, and CO_2 management showcases a sector poised to contribute to a sustainable and prosperous future.

Photo by Jan tenBensel, Nebraska Ethanol Board

The EPA reports public data for RINs generated as part of the RFS program for aggregated data on biofuel production and the feedstocks used for RIN generation (EPA 2023c). RINs (an energy-equivalent unit containing 77,000 Btu) are reported in terms of domestic or foreign/import production, and therefore may not match the EIA consumption numbers (Table 2.1). Some changes in the RIN reporting from 2014 used in BT16 Volume 1 include category name changes from biogas, compressed natural gas (CNG), and liquefied natural gas (LNG) to add the word "renewable" to the category: renewable CNG, renewable LNG, and renewable liquefied petroleum gas (LPG). This reporting converts RINs into RIN-gallons or gallons (the actual volume of biofuel). The total RIN-reported fuel volume domestically produced in 2022 was 18.2 billion gallons. The USDA also has primary data on many feedstocks used for biofuel production. For the EPA RINs and EIA data, domestic biofuel production in the United States grew 16.9%–18.5% from the 2014 reporting values, with significant increases in renewable diesel, renewable jet fuel/sustainable aviation fuel (SAF), and biogas.

Table 2.1 compares the 2014 and 2022 EIA and EPA RIN biofuel production volumes. Table 2.2 calculates the tons of feedstocks consumed during biofuel production for the RIN reporting year, following a similar methodology to that in Section 2.3 of BT16 Volume 1 (DOE 2016).

Table 2.1. Comparison of EPA RINs and EIA Bio-Based Fuel Production in 2014 and 2022 in the Current Bioeconomy (Million Gallons)

	Ethanol (Including Cellulosic)	Gasoline Blendstock/ Naphtha	Biodiesel	Renew. Diesel	Renew. Jet (SAF)	Biogas, Renew. Natural Gas (RNG)/Renew. LNG, Renew. LPG	Other	Total
2014 EIA totals	14,313	-	1,279	159	-	-	12	15,763
2022 EIA totals	15,361	-	1,622	1,499	-	-	203	18,685
% change EIA	7.4	0.0	26.8	833	0.0	0.0	1,591	18.5
2014 EPA totals	14,047	12.1	1,307	159	0.78	53	-	15,578
2022 EPA totals	14,433	63.4	1,620	1,452	7.9	636	-	18,211
% change EPA	2.7	424	23.9	813	912	1,100	0.0	16.9

Table 2.2. Bio-Based Fuel Production in the Current Bioeconomy (Million Gallons) for 2022 EPA RINs Data on Biofuels Produced Domestically

	Conv. Ethanol	Cellulosic Ethanol	Biodiesel	Renew. Diesel	Renew. Jet	Biogas, Renew. CNG, Renew. LNG, Renew. LPG	Naphtha, Gasoline Feedstock	Total
Cellulosic biomass – agricultural residues	-	1.40	-	-	-	-	-	1.4
Starch – corn	14,201	-	-	-	-	-	-	14,201
Sorghum – grain	76.7	-	-	-	-	-	-	76.7
Soybean oil	-	-	980	250	-	-	-	1,230
Canola oil	-	-	258	-	-	-	-	258
Biogenic waste fats, oils, and greases (FOG)	-	-	293	645	-	-	-	938
All other feedstock biodiesel/renewable diesel [a]	-	-	-	557	-	-	-	557
All other feedstock renewable jet	-	-	89.3	-	7.89	-	-	97.2
Non-cellulosic portions of separated food wastes	-	-	-	-	-	-	46.6	46.6
All other feedstocks naphtha	-	-	-	-	-	-	16.7	16.7
All other ethanol	152	-	-	-	-	-	-	152
Biogas from landfill [b]	-	-	-	-	-	481 [c]	-	481
Biogas from anaerobic digestion [b]	-	-	-	-	-	131	-	131
Biogas from municipal wastewater digesters [b]	-	-	-	-	-	19.4	-	19.4
Other for LPG [b]	-	-	-	-	-	4.4		4.4
Total	14,430	1.4	1,620	1,452	7.9	636	63.2	18,210

[a] Includes mixed feedstocks.
[b] Gases are reported in RIN-gallons (77,000 Btu/RIN-gallon).
[c] Estimated from total domestic RINs.

Table 2.3. Biomass Consumed for Fuel Production in the Current Bioeconomy (Million Bioenergy-Equivalent Dry Tons) Using a Combination of EPA and USDA Feedstock Data

Biomass Resource Category	Ethanol (Including Cellulosic)	Gasoline Blendstock/ Naphtha	Jet/ Aviation Fuels	Biodiesel/ Renew. Diesel	Biogas, Renew. CNG, Renew. LNG, Renew. LPG	Total
Agricultural residue	0.013	-	-	-	-	0.01
Corn grain	123.4	-	-	-	-	123.4
Vegetable oils	-	-	-	7.3	-	7.3
Other FOG	-	-	-	3.8	-	3.8
Feed for gasoline blendstock/naphtha	-	0.3	-	-	-	0.3
Feedstocks for renewable jet	-	-	0.01	-	-	0.01
Biogas from anaerobic digestion	-	-	-	-	0.8	0.8
Landfill gas	-	-	-	-	6.7 [a]	6.7
Algae	-	-	-	-	-	-
Total	123.4	0.3	0.01	11.1	7.5 [b]	142.3

[a] Estimated from total domestic RINs.
[b] Also includes biogas from municipal wastewater treatment facility digesters and others for LPG.

The following sections discuss the individual fuel pathways and feedstocks.

2.3.1 Fuel Ethanol

The EIA reported 15.4 billion gallons of fuel ethanol production (15.1 billion gallons when excluding denaturant) and 14.0 billion gallons of fuel ethanol consumption in the transportation sector, where most fuel ethanol is blended into finished motor gasoline (EIA 2023e, Table 10.3; USDA 2023b). The EPA generated RINs for 14.4 billion RIN-gallons of conventional ethanol and 1.5 billion RIN-gallons of cellulosic ethanol (EPA 2023c), and records show 1.3 billion gallons of ethanol were exported in 2022 (Renewable Fuels Association 2023). BT16 Volume 1 estimated that 14.1 billion gallons of ethanol were produced in 2014.

Feedstock for ethanol production is primarily corn grain (98% feedstock tonnage), with contributions from sorghum, soybean oil, and unlisted sources. Using the methodology described in multiple sources (Irwin 2023; Jayasinghe and Miller 2017), an average yield of 2.9 gallons of ethanol per bushel of corn was calculated from the ethanol production information provided by the EIA and bushels of corn provided for fuel ethanol production from the National Agricultural Statistics Service reports on corn grain and coproducts milling (EIA 2023f; National Agricultural Statistics Service 2023). Ethanol production consumed an estimated 123 million dry tons of corn grain, assuming 56 lbs. per bushel and 15.5% moisture content (EIA 2023d, Table 2a; USDA 2023a). BT16 Volume 1 estimated that corn grain was 100% of ethanol feedstock, and 119.6

million dry tons were consumed in 2014 (DOE 2016). Corn grain losses in the supply chain for biofuel production are estimated to total 14.5 million dry tons.

The EIA estimates that 1.7 million tons of sorghum grain were consumed for ethanol production in 2022 (EIA 2023d, Table 2a). Using the generated RIN-gallon estimates and a yield of 80 gallons per dry ton (Amosson et al. 2011), 0.96 million tons of sorghum were consumed for ethanol production.

Cellulosic ethanol grew from 0.0007 billion gallons in 2014 to 0.0014 billion gallons in 2022, per the EPA's RINs reporting (EPA 2024b). The 2022 RINs feedstock report indicates that this production used "Cellulosic Biomass – Agricultural Residues." The cellulosic ethanol volume is estimated to be derived from 0.013 million tons of agricultural residue using the 2022 EPA RINs feedstock volume data and an assumed yield of 109.2 gallons per dry ton (Wang et al. 2012).

2.3.2 Biodiesel and Renewable Diesel

Bioderived diesel fuels include biodiesel and renewable diesel. ASTM International standard D6751 defines biodiesel as a fatty acid methyl ester (ASTM International 2023). Renewable diesel is processed to be chemically equivalent to petroleum-derived diesel fuels and meets ASTM D975 specifications for petroleum in the United States (ASTM International 2022). Biodiesel is the second-largest type of biofuel behind fuel ethanol, and renewable diesel is a close third.

In 2022, the EIA reported that 1.62 billion gallons of biodiesel were domestically produced and 1.66 billion gallons of biodiesel consumed, which makes up 8.2% of biofuel consumption (EIA 2023e, Tables 10.4a and 10.2c). For the 2022 RINs reporting year, 1.62 billion gallons of biodiesel were produced (EPA 2023c). Biodiesel production consumed 3.6 million tons of soybean oil (EIA 2023d, Table 2c). Soybean oil generated more than 50% of all biodiesel RIN credits, followed by biogenic waste FOG at 16% and canola oil at 14%.[3]

The EIA reported that renewable diesel increased to represent 7.8% of biofuel consumption in 2022 (EIA 2023e, Tables 10.4b and 10.2c). In 2022, the EIA reported 1.5 billion gallons of renewable diesel were produced domestically, and 1.7 billion gallons were consumed (EIA 2023e, Table 10.4b). The EPA generated RINs for 1.5 billion RIN-gallons in the same year (EPA 2023c). In 2022, consumption outpaced production by about 0.02 billion gallons per month (14%) (EIA 2023e, Table 10.4b). The EIA reports 1.7 million tons of soybean oil was consumed in renewable diesel plants, accounting for 32% of the total soybean oil used for biodiesel and renewable diesel production combined (EIA 2023d, Table 2c). BT16 Volume 1 estimated that 0.16 billion gallons of renewable diesel were produced in 2014 (DOE 2016).

Bio-based heating oil also receives RIN credits but is reported as heat and power generation in this report—a change from BT16 Volume 1, which included this volume in transportation fuels.

[3] This includes imported feedstocks from the feedstock summary generation report.

2.3.3 Renewable Jet Fuel

In 2022, there were 15.8 million gallons of renewable jet fuel produced (7.89 million gallons of renewable jet fuel was reported for EPA RINs domestic production and 7.93 million gallons as foreign) (EPA 2023c), which is nearly 10 times more than the total production of about 0.8 million gallons in 2014 (Alternative Fuels Data Center 2023; U.S. Government Accountability Office 2023). While this volume is still moderately low compared to biodiesel and renewable diesel, it represents a sharp increase in production in a relatively short time frame. At the time of this report, there was only one North American producer of commercial renewable jet fuel, with a facility in California based on the HEFA (hydrotreated esters and fatty acids) process using agricultural fats and waste oils (Alternative Fuels Data Center 2023). Using the same waste oil yield as renewable diesel at 267 gallons per ton, an estimated 0.03 million tons of feedstock created the domestic supply of renewable jet fuel that accrued these RIN credits under the category “all other feedstocks.”

In 2022, DOE, the U.S. Department of Transportation, and the USDA launched a memorandum of understanding and road map to set goals for SAF production at 3 billion gallons annually by 2030 and 35 billion gallons annually by 2050 (Bioenergy Technologies Office 2023).

2.3.4 Renewable Gasoline Blendstocks and Naphthas

In 2022, the EPA reported that 63.2 million RIN-gallons of bioderived naphtha were produced, an increase from the 2014 EPA-reported volumes of 29,000 RIN-gallons of cellulosic renewable gasoline blendstock and 12 million gallons of naphtha (EPA 2023c). Most reported feedstock was listed as “Non-Cellulosic Portions of Separated Food Wastes,” which comprised 74% of the RINs generated, with the remainder listed as “other.”

2.3.5 Biogas

Renewable biogas includes renewable CNG (primarily methane), renewable LNG (methane), and renewable LPG. The AgSTAR database provides information on anaerobic digesters on livestock farms across the United States (EPA 2023a). The database indicated 93 dairy farms had digesters providing biogas for end use as CNG in early 2023, with additional operations producing pipeline gas. In 2022, the EPA reported the equivalent of 546 million RINs-equivalent gallons of RNG, about 74% of that derived from landfills and 23% from biogas from waste digesters. In addition, 84.1 million gallons of renewable LNG were produced, almost all of which were generated from landfills (EPA 2023c). About 4.4 million RINs-equivalent gallons of LPG were produced (EPA 2023c). Using a conversion of 1.036 MMBtu per thousand cubic feet, this would mean 71.5 billion cubic feet (BCF) of biogas from landfills, 19.5 BCF from anaerobic digesters, and 2.89 BCF from municipal wastewater treatment facilities was consumed (EPA 2023c). An additional 0.13 BCF of renewable LPG was consumed (EPA 2023c). AgSTAR reports 0.76 million tons of manure consumed for biofuel production through biogas pathways. This was not a reported resource in BT16 Volume 1 to account for an increase.

The bioenergy resources used to produce RNG and LNG for transportation from landfills are estimated using the same approach as in BT16 Volume 1: landfill gas is represented as tons of biomass by applying a conversion factor of about 0.267 lbs. per cubic foot (DOE 2016). This report converts all biogas generated to tons of biomass using the same conversion factor as landfill gas. A discussion of landfill gas for heat and power generation follows in Section 2.4.3.

2.4 Heat and Power Generation

Biomass is the United States's primary renewable source for heat and power generation, with industrial uses dominating the consumption of heat and power from biomass. Biomass contributes a small amount of overall renewable generation sources when compared to wind and solar, however its production of heat as a co-product allows for industrial uses that are distinct from other, non-combustible renewable sources. MSW, landfill gas, and woody biomass contribute to the electricity sector, and woody biomass contributes to residential and small-scale community heat and power operations. Animal manure can be collected and used as fuel in anaerobic digesters and heat to produce biogas, which can be collected and consumed for power and heat generation or flared off to remove the impact of methane from animal waste on the environment. In this chapter, we only consider facilities with operational anaerobic digesters.

EIA's *Electric Power Annual 2022* (EIA 2023b, Tables 5.5, 5.6, 5.7, and 5.8) record energy values by sector for the wood/wood waste, biogenic MSW, other waste biomass, and landfill gas consumed for electricity generation and useful thermal energy. The value for thermal energy consumed in the residential sector is obtained from the 2023 AEO (EIA 2023a, Table 17). The AgSTAR database provides information on anaerobic digesters on livestock farms across the United States. It reports that an additional 114 anaerobic digester operations have begun construction or entered operation since the reporting in BT16 Volume 1 (EPA 2023a).

Table 2.4 shows the inherent energy of biomass consumed for heat and power generation in the United States for 2022 across the electricity generation, industrial, commercial, and residential sectors. Table 2.5 calculates the tons of feedstocks consumed for heat and power generation across the sectors, following a similar methodology to that in Section 2.4 of BT16 Volume 1.

Heat and power generation saw a 19% net decrease in energy generated from biomass from BT16 Volume 1 (from 2,311 TBtu to 1,893 TBtu), driven by decreases in biomass resources used for both industrial and residential sectors. The industrial decrease was primarily driven by the closure of pulp and paper mills, reducing the biomass energy use in the industrial sector. Wood use in residential homes as the primary or secondary heating source also decreased.

Table 2.4. Inherent Energy of Biomass Resources Consumed for Heat and Power in 2022 (TBtu)

Biomass Category	Electricity		Industrial		Commercial		Residential		Farm Use	Total		
	E	T	E	T	E	T	E	T	Total	E	T	Total
Wood/wood waste	172	26.2	151	790	1.1	3.2	-	423	-	324	1,242	1,567
Animal manure	-	-	-	-	-	-	-	-	35.1	-	-	35.1
Biogenic MSW	56.5	3.0	0.0	0.0	52.0	9.3	-	-	-	109	12.2	121
Other waste biomass	10.4	9.1	4.9	33.4	4.5	2.6	-	-	-	19.9	45.2	65.1
Landfill gas	96.4	1.1	1.2	0.7	6.0	0.5	-	-	-	104	2.4	106
Total	335	39.4	157	824	63.7	15.6	0.0	423	35.1	556	1,302	1,893
% change from BT16	−24%	25%	−29%	−14%	74%	31%	0%	−27%	0%	−20%	−18%	−19%

Note: E = biomass consumed for electricity generation and T = biomass consumed for thermal energy output.

Table 2.5. Biomass Resources Consumed for Heat and Power in 2022 (Million Dry Tons)

Biomass Category	Electricity	Industrial	Commercial Residential	Farm Use	Total
Wood/wood waste	15.2	72.4	32.8	-	120
Animal manure	-	-	-	2.7	2.7
Biogenic MSW	6.6	-	6.8	-	13.4
Other waste biomass	2.4	4.8	0.9	-	8.1
Landfill gas	7.9	0.2	0.5	-	8.6
Total	32.1	77.3	41.1	2.7	153
% change from BT16	−5%	−17%	−17%	−74%	−18%

The following sections provide additional information on each feedstock type, noting when a conversion or efficiency factor is required to reach a resulting biomass tonnage.

2.4.1 Woody Biomass and Wood Waste

Using the EIA's *Electric Power Annual 2022*, it was reported that approximately 1.2% of U.S. annual energy consumption was from wood and wood waste (bark, sawdust, wood chips, wood scrap, and paper mill residues) (EIA 2023b, Tables 5.6d and 5.6e). The EIA's reporting estimates the tonnage and TBtu values of the incoming feedstock for heat and power generation, which was used to generate the values in this report section. When comparing the latest data, wood/wood waste electricity generation decreased from 0.4 quads in 2014 to 0.3 quads in 2022, and wood/wood waste thermal energy generation decreased from 1.5 quads in 2014 to 1.2 quads in 2022. Based on the midpoint in the range of energy contents included in EIA form EIA-923 detailing power plant fuel allowed energy ranges, an average energy content of 13 MMBtu per dry ton is assumed (EIA 2007), which results in an estimated 120.4 million dry tons of wood being consumed in 2022. Losses in the supply chain for wood/wood waste bioenergy are estimated to total 13.2 million dry tons using the same methodology as in Section 2.4.1 of BT16 Volume 1.

In BT16 Volume 1, wood pellets were reported separately, as most wood pellets were noted to be primarily for export. The latest data from the U.S. International Trade Commission noted that 9.9 million tons were exported (5%–10% moisture) (Pellet Fuels Institute 2017; Atasoy, Zhang, and Prestemon 2023), resulting in a total production of 11.6 million tons. This requires 10.5 million dry tons of timber and wood waste as feedstock for production, an increase of 38% from BT16 Volume 1. In this report, wood pellets are already included in the EIA generation report data for wood and wood waste and are not reported separately in this section. Losses in the supply chain for wood pellet energy are estimated to total 1.2 million dry tons using the same methodology as in Section 2.4.1 of BT16 Volume 1.

The decline in heat and power production from wood/wood waste energy is driven by the closure of pulp and paper mills, COVID-19 extended mill shutdowns, and extended maintenance cycles to buoy decreasing commodity prices (EIA 2023c). Table 2.4 details the breakdown of wood/wood waste by sector and energy type for heat and power.

2.4.2 Biogenic MSW

The biogenic portion of MSW not landfilled includes sludge waste, agricultural crop byproducts, and other biomass solids and liquids that can be separated and combusted for electricity and thermal energy generation. It excludes wood and wood-derived products (including black liquor) and biofuel feedstocks. The EIA estimated that 13.4 million dry tons of biogenic MSW were consumed to generate 108.5 TBtu of electricity and 12.2 TBtu of thermal energy in 2022 (EIA 2023b, Tables 5.7d and 5.7e). This is a reduction from the BT16 Volume 1 reporting of 135.8 TBtu of produced electricity and 15.2 TBtu of thermal energy. EIA's *Electric Power Annual 2022* assumes the estimates are in dry tons; using the methodology established in Section 2.4.2 of BT16 Volume 1 to estimate dry tons based on energy consumption yields a variance of less 0.1% from the reported tonnage estimates (EIA 2023b, Table 5.7c). Tables 2.4 and 2.5 summarize the biogenic MSW usage breakdown by sector and energy type for heat and power.

2.4.3 Landfill Gas

EIA's *Electric Power Annual 2022* reports the volume of landfill gas used as heat and power in the United States and reports the values in billion Btu and million cubic feet. EIA reported 216 BCF of landfill gas was consumed to produce 103.6 TBtu of electrical power and 2.4 TBtu of thermal energy in 2022 (EIA 2023b, Tables 5.6d and 5.6e). Consumption declined from the estimated 272 BCF of landfill gas used in the BT16 Volume 1 reporting, which generated 132.8 TBtu of electricity and 0.4 TBtu of thermal energy (DOE 2016). There has been a shift to producing transportation fuels from landfill gas, contributing to the decline in heat and power generation from this source (Mintz and Vos 2022). Table 2.4 details the breakdown of the usage of landfill gas for heat and power purposes by sector and energy type.

There are differences in the totals reported by the EIA and EPA for landfill gas usage, with EIA reporting that 216 BCF were consumed for heat and power, while EPA data report 334 BCF (EIA 2023b, Tables 5.6d and 5.6e; EPA 2023b). For consistency within the chapter, EIA estimates are included in this section; however, further details on the estimates from both sources are included in the appendix.[4]

In the United States, landfill gas is collected for both heat and power and used as biogas as a renewable transportation fuel, and those data are reported via RIN credits (EPA 2023c). Section 2.3.5 discusses anaerobic digester gas used for transportation fuels in the United States.

2.4.4 Anaerobic Digestion

EIA's *Electric Power Annual 2022* includes digester slurries and biogases as part of "other waste biomass" but does not segregate between the included materials, and therefore could contain overlap with this feedstock category. Approximately 55% of manure produced and collected in the United States is used for agricultural fertilizer, with an additional 4.6% going to anaerobic digestion (Milbrandt et al. 2018). The animal waste consumed in anaerobic digestion produces 40%–50% waste CO_2 and 50%–60% methane gas that can be burned to produce heat and power (EPA 2024a). Anaerobic digesters were estimated to use 1.9 million dry tons of manure in 2015 and had 264 active projects (Milbrandt et al. 2018; EPA 2023a). The 2023 reported data from the AgSTAR database show 250 active anaerobic digester projects in the United States producing heat and power energy by consuming 2.7 million dry tons of manure, an increase of 42% from BT16 Volume 1 (EPA 2023a, 2023c). Total anaerobic digester energy production (biofuel and heat and power production) increased 230% (from 1.9 to 3.5 million dry tons).

Anaerobic digestion biogas is also used to produce transportation fuels, as reported in Section 2.3.5, which is reported via calculations based on RIN credits and are not double counted here. Tables 2.4 and 2.5 summarize the breakdown of the usage of anaerobic digester gas for heat and power by sector and energy type.

2.4.5 Other Waste Biomass

In EIA's E*lectric Power Annual 2022*, "other waste biomass" for power and heat generation includes sludge waste, agricultural byproducts, other biomass solids, other biomass liquids, and other biomass gases (including digester gases, methane, and other biomass gases) (EIA 2023b, Tables 5.8d and 5.8e). It also reports the aggregate "other waste biomass" utilized for net generation in the electric utilities, independent power producers, commercial sector, and industrial sector, as was reported for landfill gas and MSW. Both the dry tons of biomass and TBtu values are estimated.

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

EIA reports a total of 8.1 million dry tons of "other waste biomass" were consumed to produce a total of 19.9 TBtu of electrical power and 45.2 TBtu of thermal energy in 2022 (EIA 2023b, Tables 5.8d and 5.8e). This is a reduction from the estimated 11.5 million dry tons consumed in the BT16 Volume 1 reporting that generated 29.4 TBtu of electricity and 62.5 TBtu of thermal energy.

Tables 2.4 and 2.5 summarize the breakdown of other waste biomass usage by sector and energy type for heat and power purposes. Chapter 3: Waste Resources and Byproducts reports several other waste resources for other uses (e.g., recycling, animal feed) that are not reported in this chapter.

2.5 Bio-Based Chemicals

The bio-based chemicals included in this section are generated as byproducts of bioenergy operations or directly compete for biomass resources with bioenergy operations. The most recent BioPreferred report (2021) reviewed the volume of biomass consumed in the bioproducts industry and estimated the same ratio between corn, soybean, and other oilseed crop processing for bioproducts as was reported in BT16 Volume 1 (Daystar et al. 2021). In 2021, 7.1 million dry tons of corn and 0.73 million dry tons of soybeans and other oilseed crops were consumed to generate starches and other bioproducts. This represents an increase from the BT16 Volume 1 reported numbers of 5.6 million dry tons for corn and 0.32 million dry tons for soybeans (Daystar et al. 2021).

2.6 Algae

Other emerging biomass-to-energy sources are noted in Chapter 7: Emerging Resources. At the time of this report in 2023, algae is not a measured energy source of significance in the U.S. bioeconomy.

2.7 Summary

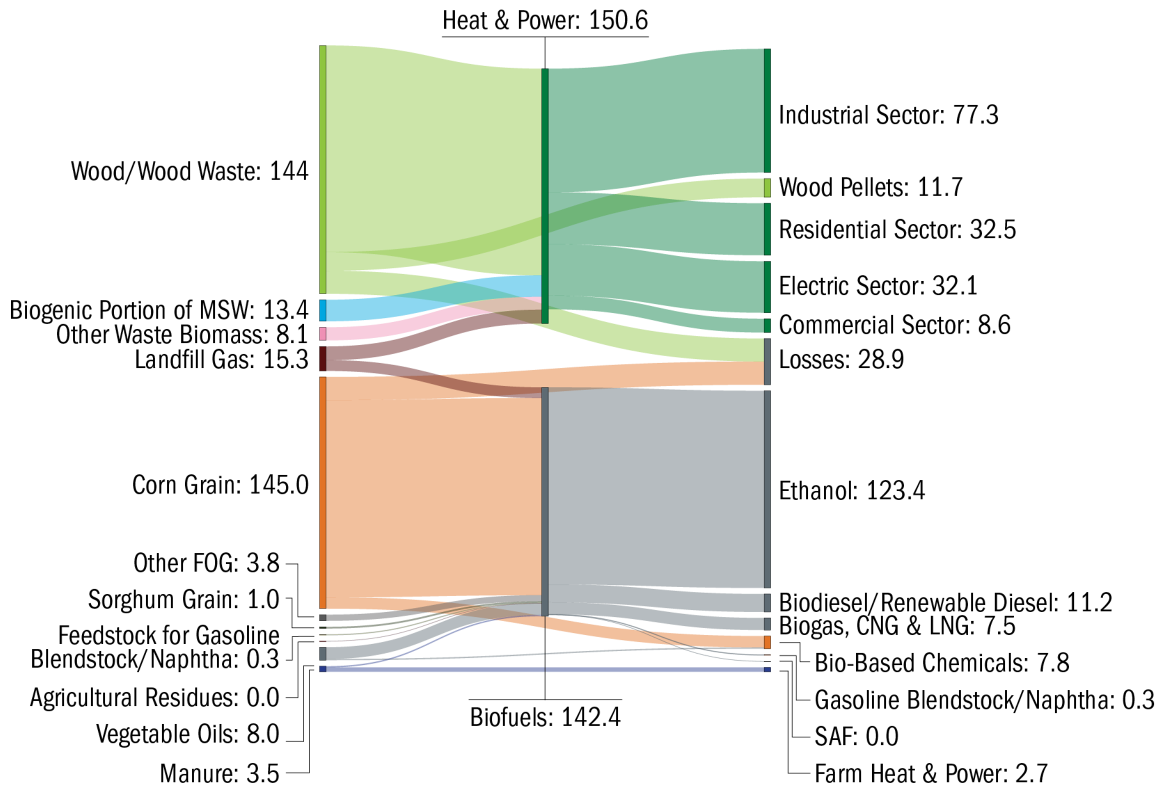
The total consumption of biomass resources for energy, including transportation, power, and heat, is reported in Table 2.6. Overall, the total biomass resources currently consumed to produce biomass-based transportation fuels and fuels for heat and power generation decreased from BT16 Volume 1 by about 18 million tons annually (6%). Biofuel production increased 19%, consuming about an additional 16 million tons of feedstock annually (11%), while the biomass used for heat and power generation fell 35 million tons per year (19%) and landfill gas usage increased 36% from BT16 Volume 1.

The flow of these resources from feedstock to end product is shown in the Sankey diagram in Figure 2.3. The primary biomass sources in the current bioeconomy remain corn grain for transportation fuel and forestry/wood and wood waste for heat and power.

Table 2.6. Total Current Consumption of Biomass for Energy Production and Bio-Based Chemicals, Including Losses (Million Bioenergy Dry Tons per Year)

Biomass Resource Category	Transportation Fuel	Heat and Power	Bio-Based Chemicals	Wood Pellets	Total Utilized Biomass
Agricultural	150	2.7	8.6	-	162
Corn grain	137	-	7.9	-	145
Sorghum grain	1.0	-	-	-	1.0
Vegetable oils	7.3	-	0.7	-	8.0
Other FOG	3.8	-	-	-	3.8
Feed for gasoline blendstock/naphtha	0.3	-	-	-	0.3
Agricultural residues	0.01	-	-	-	0.01
Manure	0.8	2.7	-	-	3.5
Forestry/wood	-	134	-	9.9 [a]	144
Wood/wood waste	-	132	-	-	132
Wood pellets	-	1.7	-	9.9 [a]	11.6
Energy crops	-	-	-	-	-
Herbaceous energy crops	-	-	-	-	-
Woody energy crops	-	-	-	-	-
MSW/other wastes	-	21.5	-	-	21.5
Biogenic portion of MSW	-	13.4	-	-	13.4
Other waste biomass	-	8.1	-	-	8.1
Landfill gas	6.7	8.6	-	-	15.2
Algae	-	-	-	-	-
Total biomass	157	167	8.6	8.9	342
% change from BT16	11%	−19%	31%	17%	−6%

[a] Wood pellets here are the exported-only mass.



NOTE: Units in million dry tons per year equivalent

Figure 2.3. Sankey diagram of feedstock, sector consumption, and final product distribution (million dry tons per year)

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