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Indicators of the U.S. Biobased Economy, 2018

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Executive Summary

The biobased economy is defined as activities related to any good produced from biological feedstocks. This definition includes a wide variety of products such as biofuels from agriculture and forestry, biochemicals from enzymes, microorganisms or renewable sources, end-use consumer products from agriculture or renewable sources, and biopower from biomass, agriculture, or forestry.

This report is the third in a series published by the Office of the Chief Economist at the U.S. Department of Agriculture, beginning in 2017. The purpose of the report is to provide policy makers and the general public an annual update on the positive impacts that the biobased economy is having for the American economy and the environment. In generating each annual report, the research team reviews an extensive set of government agency and private sector databases as well as published reports, peer reviewed academic journals, and general interest publications. This report was supported through a cooperative agreement (58-0111-19-017) issued by the Office of the Chief Economist of the U.S. Department of Agriculture.

As presented, the 2018 report is divided into three primary sections which include: (1). Field crops used as feedstocks for the biobased economy; (2). Bioenergy indicators including transportation fuels such as ethanol, biodiesel and renewable aviation fuels as well as renewable energy sources spanning biogas to wood pellets. And finally, (3). we examine biobased products including chemicals, consumer products, forestry as well as textiles and apparels.

Field Crops

The crops used in the bioeconomy supplement the highly productive American farmer who not only meets the dietary needs of the Nation but through a highly productive workforce made the United States the largest agriculture exporter in the world in 2018, according to the World Bank. Consolidation was partially due to the number of farms and acreage decreasing between 2008 and 2018. Despite this trend, the average size of farms increased by 5 percent, from 421 acres to 443 acres over the same period of time.

Corn remains the dominant crop in the United States with concentrated production in the Midwest. Corn production in the United States surpassed 366 million metric tons in 2018. About 38 percent of corn grown in the United States was used for ethanol production, and 36 percent of corn oil was used for biodiesel production.

Soy, the second largest crop in the United States, is used as a primary feedstock for biodiesel production. In 2018, 54 percent of biodiesel was produced from soybean oil. Soy production increased 53 percent from 2008 to 2018, amounting to 123 million metric tons in 2018. Consumption also increased 26 percent from 2008 to 2018, for a total of 60 million metric tons of soy being consumed in the United States in 2018.

Canola is used as feedstock for biodiesel production, with 20 percent of all canola oil being used for this purpose. Canola is a relatively minor oilseed in the United States; domestic production is concentrated in North Dakota. In 2018, consumption of canola in the United States was 37 percent higher than production, rendering the United States a net importer.

Production of sorghum in the United States is small compared to other crops, amounting to 9 million metric tons in 2018. It is also highly concentrated, with 55.2 percent of total production located in Kansas and 26 percent in Texas. In 2018, 65 percent of total sorghum production (4 million metric tons) was exported, 67 percent of which went to China.

Bioenergy

Bioenergy is a form of renewable energy that uses biomass from agriculture including corn (most common for fuels), soy, forestry and other and their agricultural wastes. It also takes advantage of organic wastewater, municipal wastes and the waste gases generated in landfills. Bioenergy also plays an important role as governments and companies commit to reduce greenhouse gas emissions.

Bioenergy accounts for one-tenth of the world's total primary energy supply and globally bioenergy was the source of half of all renewable energy used in 2017. Bioenergy is expected to be the largest source of growth in renewable energy consumption between 2018 to 2023. The International Energy Agency forecasts that bioenergy, including solid, liquid, and gaseous fuels, will account for 30percent of the growth in renewable consumption. The forecasted growth is primarily from bioenergy used for heat and transport which account for 80percent of total final energy consumption.

In the United States, consumption of ethanol increased 12 percent between 2010 to 2018, with 14.4 billion gallons of ethanol being consumed in 2018.The number of ethanol plants in the United States slightly increased from 204 plants in 2010 to 210 plants in 2018. Ethanol production in the United States increased 21 percent from 2010 to 2018, achieving 16 billion gallons of ethanol produced in 2018. In 2018, the United States was the world's leading ethanol producer, exporting 1.7 billion gallons of ethanol, primarily to Brazil and Canada. Approximately, 54 million gallons of ethanol were imported in 2018, 98 percent of which came from Brazil.

Biodiesel also plays an important role in our national renewable fuel strategy. Biodiesel production increased 440 percent from 2010 to 2018, amounting to 1.9 billion gallons in 2018. Consumption of biodiesel increased an amazing 636 percent in the same period. The number of biodiesel plants in the United States slightly decreased from 103 plants in 2011 to 100 plants in 2018. In 2018, consumption of biodiesel in the United States was 3 percent higher than production, indicating that the United States is a net importer of biodiesel. Imports of biodiesel reached 167 billion gallons in 2018, an increase of 604 percent from 2010.

The United States can produce an estimated 2 billion gallons of biobutanol, which is equivalent to roughly 12% of total domestic gasoline consumption, even though production ceased in 2017.

While there has been significant market penetration and growth of renewable biofuels for ground transportation, there has not been similar results within the aviation and sea transportation sectors. Since 2008, approximately 215,000 flights have used renewable jet fuel globally. The global production of renewable jet fuel in 2018 was 4 million gallons, accounting for less than 0.1percent of the total jet fuel consumption and only five airports in the world have regular renewable jet fuel supply; one located in Los Angeles, CA. Ocean shipping has been even slower to adopt renewable fuels.

However, in 2018, the International Maritime Organization, the United Nations marine regulator, established deadlines for the transformation of the global shipping industry to convert to renewable fuels with plans by 2023, cutting GHG emissions in half by 2050 compared to 2008 levels. Some carriers have already announced plans to become carbon-neutral by 2050. The industry is exploring biofuels as well as biomethanol, ammonia and green hydrogen.

American forests, especially those located in the southeast, continue to provide the world sources for primary energy. The United States is the world's leading wood pellets producer, achieving 7.5 million metric tons of wood pellets in 2018, a 115-percent increase from 2012. Only 23 percent of the total production is consumed domestically, and it is used primarily for heating. The number of wood pellet plants in the United States increased from 123 plants in 2013 to 140 production plants in 2018. Wood pellet production plants are primarily located in the southeastern United States. This accounts for 25,000 direct jobs. Exports of wood pellets reached 6.0 million metric tons in 2018, a 207-percent increase from 2012. The European Union is the main destination for American wood pellets, and they are used in coal-fired power plants for electricity generation to reduce greenhouse gas emissions.

The beneficial use of wastes and waste by-products is an important source of renewable bioenergy. Total of 151 trillion BTUs of energy were generated from waste in the United States in 2018. Almost all, 89 percent, of energy generated from waste was used in electricity generation. The number of waste-to-energy plants in the United States decreased from 86 plants in 2010 to 75 plants in 2018.

Biogas production surpassed 282 billion cubic feet in 2018, an increase of 25 percent from 2010. In 2018, there were 2,000 sites producing biogas in the United States: 245 anaerobic digesters on farms; 514 landfills biogas plants; and 1,268 wastewater treatment facilities. The collection and use of biogas have direct benefits for the environment. Biogas capture systems in farms and landfills reduced greenhouse gas emission by 119 million metric tons of CO_2 equivalent in 2018.

Biobased Products

Biobased products are available for both industrial and consumer applications, and the sector spans many product categories ranging from personal care to industrial solvents and paints, to construction materials as well as apparel and textiles.

In the United States, the U.S. Department of Agriculture maintains a voluntary labeling program through a structured certification process known as the USDA BioPreferred[1] Program. More than 2,200 companies participate in the BioPreferred Program; California has the largest number of participating companies. The number of categories that qualify for mandatory Federal purchasing increased from 32 in 2008 to 109 in 2018. In addition, the number of categories certified through the voluntary labeling initiative increased from 50 in 2011 to 100 in 2016. The BioPreferred Program estimates that the number of biobased products in the United States was greater than 40,000 in 2014 compared to 17,000 in 2008. Researchers at Eastern Carolina University, North Carolina State University, and Duke University estimate that the bioproducts industry directly added $150 billion to the U.S. economy in 2017, an increase of 18 percent with respect to 2014.

Due to a number of global environmental initiatives including wastes in oceans, there is an increased focus on the reduction of our dependence on non-renewable plastics and non-biodegradable plastics. The production of bioplastics at global scale increased 3,500 percent from 2008 to 2018, for a total production of 6.7 million metric tons in 2018. In 2018, 81 percent of global bioplastics were used for packaging. The biobased chemical industry directly created 4,700 jobs between 2014 and 2017. In the most recent year of published data, 2017, the biobased chemical industry contributed $6.2 billion in value-added to the United States economy.

[1] https://www.biopreferred.gov/BioPreferred/

Enzymes also play an important role in the biobased products sector. Enzymes are used in detergents as well as aiding in the conversion of feedstocks into biogas and optimizing viscosity in anaerobic digestors. The global market of enzymes reached $5.5 billion in 2018, an increase of 88 percent from 2008. Between 2014 and 2017, the enzymes industry directly created 68,550 jobs in the United States and the direct valueadded to the United States economy from the enzyme industry in 2017 was $21.7 billion.

How To Cite This Report

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Golden's research covers the dynamics of the global sustainability transition which include risks, opportunities and policy implications. He focuses on production consumption systems exploring critical earth resources, biobased resources, energy transitions, supply chains, ESG investments and national security. Golden received his Ph.D. in engineering from the University of Cambridge and his master's degree in Environmental Engineering and Sustainable Development from a joint program of the Massachusetts Institute of Technology and the University of Cambridge. He also holds a Professional Mastery of Project Management Certificate from Stanford University, an MLE in Higher Education from Harvard, and has a B.A. degree in Management. He can be reached at JGolde04@Syr.edu

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Glossary of Terms

Anaerobic digestion:	Collection of processes in which organic material is broken down by bacteria in the absence of oxygen.
Biobased chemical:	Chemical totally or partially produced from plants or renewable sources.
Biodegradable:	Can be degraded by naturally occurring microorganisms in a defined environmental and timescale.
Biodiesel:	Diesel fuel derived from vegetable oils, animal fats, or recycled grease. Chemically distinct from petroleum diesel.
Bioenergy:	Form of renewable energy derived from biomass.
Biofuel:	Fuel produced from biological or renewable materials. Examples include biodiesel and ethanol.
Biogas:	Mixture of gases, primarily methane and carbon dioxide, produced by anaerobic digestion from different waste sources.
Biogenic material:	Material made by or from living organisms (i.e., plants and animals).
Bioplastic:	Type of plastic that is partially or fully biobased and/or biodegradable.
BioPreferred Program:	A program administered by the U.S. Department of Agriculture with the goal of increasing the Federal purchase and use of biobased products. The program's purpose is to spur rural economic development, create new jobs, and provide new markets for farm commodities.
Bioproduct:	Products derived in whole, or in significant part, from biological or renewable materials.
British Thermal Units:	Amount of heat needed to raise 1 pound of water at maximum density through 1 degree Fahrenheit.
Cellulosic material:	The world's most abundant biological material. Corn stover, switchgrass, or wood chips are some examples of cellulosic materials. Cellulose is a group of organic compounds with the formula $(C_6H_{10}O_5)_n$.
Cubic feet:	Volume of a cube with sides of 1 foot.
Enzyme:	Substance produced by living organisms that act as a catalyst on a specific biochemical reaction.
Fuel ethanol:	Motor gasoline blending component produced from fermenting biomass that is rich in starches and sugars. It is typically derived from corn and sugar cane.

Global warming potential:	Amount of heat a greenhouse gas traps in the atmosphere. Expressed in relation to carbon dioxide.
Gross domestic product:	Monetary value of all the finished goods and services produced within a country's borders in a specific period of time, usually a year.
Irrigation water:	Water applied to plants in controlled amounts at needed intervals.
Methane potential:	Amount of methane in the biogas produced during anaerobic digestion, expressed under Normal conditions of Temperature and Pressure.
Non-biogenic material:	Material of nonbiological origin such as plastics and synthetic materials made from petroleum.
Noncombustible material:	Material that does not support combustion such as glass and metals.
Organic material:	Material made from living organisms (i.e., plants and animals).
Waste-to-energy:	Production of energy or heat from waste.
Waste-to-energy plant:	Facility that incinerates waste for energy recovery. In these plants, the waste is burned to capture the heat from the burning process and produce steam, which is used to generate electricity or heat.

1. MAJOR FIELD CROPS FOR BIOENERGY AND BIOBASED PRODUCTS

1.1. Summary

Land in farms in the U.S. ↓ 0.1% [Annual Change]

TOP 5 FIELD CROPS

2017	2018
252 M acres	**254 M acres**
Corn [90]	Corn [89]
Soy [90]	Soy [89]
Wheat [46]	Wheat [48]
Cotton [13]	Cotton [14]
Sorghum [6]	Sorghum [6]

TOP 5 STATES

2017	2018
900 M acres	**900 M acres**
Texas [127]	Texas [127]
Montana [58]	Montana [58]
Kansas [46]	Kansas [46]
Nebraska [45]	Nebraska [45]
South Dakota [43]	South Dakota [43]

Value of field crops in the U.S. ↑ 1.6 % [Annual Change]

TOP 5 FIELD CROPS

2017	2018
111 B Dollars	**109 B Dollars**
Corn [50]	Corn [52]
Soy [41]	Soy [37]
Wheat [8]	Wheat [10]
Cotton [7]	Cotton [6]
Peanuts [2]	Peanuts [1]

TOP 5 STATES

2017	2018
111 B Dollars	**109 B Dollars**
Iowa [14]	Illinois [14]
Illinois [14]	Iowa [14]
Minnesota [9]	Nebraska [9]
Nebraska [9]	Minnesota [8]
Indiana [7]	Indiana [7]

Value of field crops exported from the U.S. ↑ 5.2% [Annual Change]

TOP 5 FIELD CROPS

2017	2018
38 B Dollars	**36 B Dollars**
Soy [21]	Soy [17]
Corn [9]	Corn [12]
Wheat [6]	Wheat [5]
Sorghum [1]	Sorghum [1]
Peanuts [1]	Peanuts [1]

TOP 5 DESTINATIONS

2017	2018
38 B Dollars	**36 B Dollars**
China [14]	Mexico [6]
Mexico [5]	Japan [5]
Japan [4]	China [4]
South Korea [1]	South Korea [2]
Taiwan [1]	Taiwan [2]

Value of field crops imported into the U.S. ↓ **5.0%** [Annual Change]

TOP 5 FIELD CROPS

2017	2018
1,529 M Dollars	**1,453 M Dollars**
Wheat [690]	Wheat [787]
Soy [368]	Soy [282]
Corn [274]	Corn [198]
Peanuts [83]	Peanuts [91]
Barley [51]	Sunflowers [58]

TOP 5 SOURCES

2017	2018
1,529 M Dollars	**1,453 M Dollars**
Canada [929]	Canada [988]
Turkey [164]	Argentina [99]
Argentina [141]	India[79]
India [100]	Mexico [60]
Mexico [54]	Ukraine [28]

Corn produced used for ethanol production ↑

2017 37% VS **2018** 38%

Corn oil produced used for biodiesel production ↑

2017 26% VS **2018** 36%

Soy oil produced used for biodiesel production ↑

2017 28% VS **2018** 30%

Canola oil produced used for biodiesel production ↓

2017 23% VS **2018** 20%

In the last decade, the number of farms in the United States has decreased slightly from 2.2 million farms in 2008 to 2.0 million farms in 2018 (Figure 1.1.1). Despite this reduction, the total land in farms has remained rather constant over the years, with a reduction of just 2 percent over 10 years.

The average size of farms steadily increased from 421 acres to 443 acres between 2008 and 2018. In the United States, most of the farmland is used as permanent pasture and cropland (Figure 1.1.2).

Figure 1.1.1. Total number of farms in the United States from 2008 to 2018 (1).

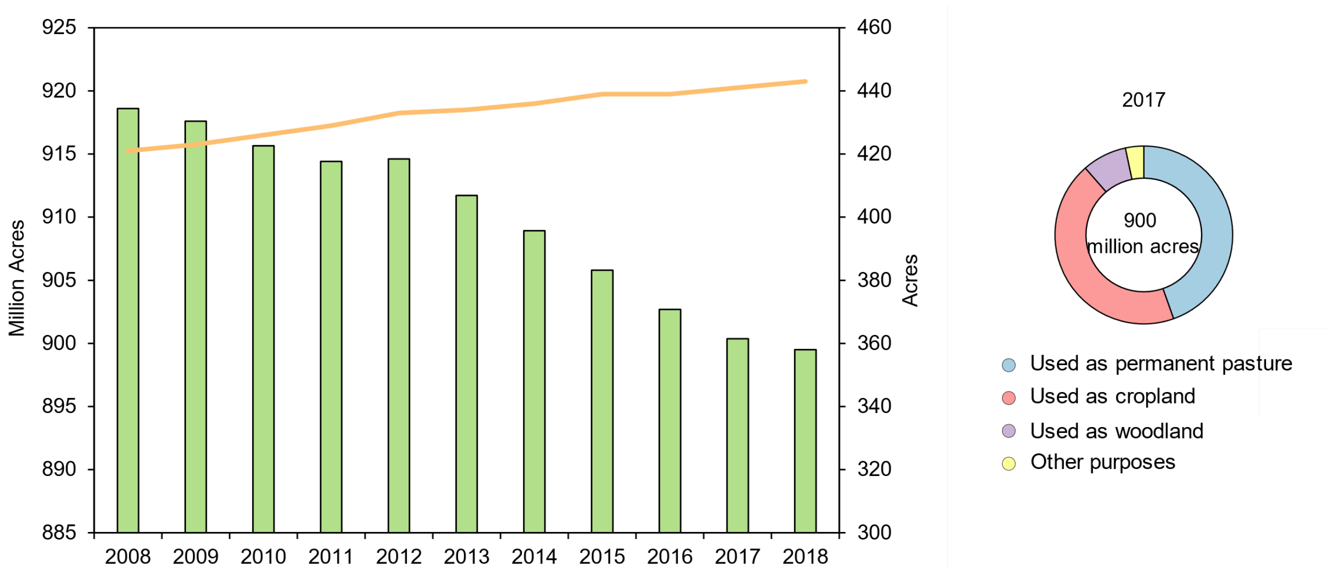

Figure 1.1.2. The bars represent the total land in farms in the United States from 2008 to 2018 (in million acres; left axis), and the line the average farm size in the United States from 2008 to 2018 (in acres; right axis) (1-3)**.**

Most farms and most of the land in farming is found in the Midwestern United States (Figures 1.1.3 and 1.1.4). The top 5 States with highest land in farms are Texas, Montana, Kansas, Nebraska, and South Dakota (see Table 1.1.1 for more detail). The five States with the greatest number of farms are Texas, Missouri, Iowa, Ohio, and Oklahoma (see Table 1.1.2 for more detail).

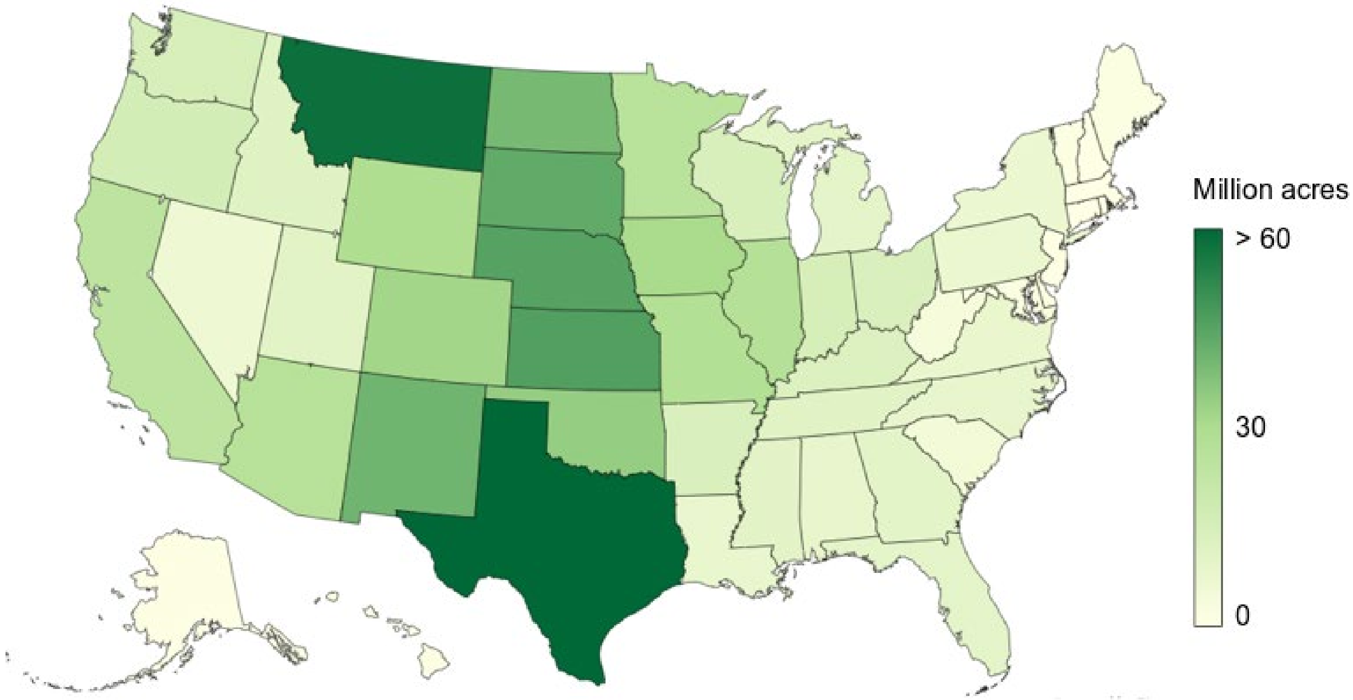

Figure 1.1.3. Total land in farms in the United States by State in 2018 (in million acres) (1).

State	Million Acres	Percentage
Texas	127	14.1
Montana	58	6.5
Kansas	46	5.1
Nebraska	45	5.0
South Dakota	43	4.8

Table 1.1.1. Five States with greatest land in farms in the United States in 2018 (in million acres) (1).

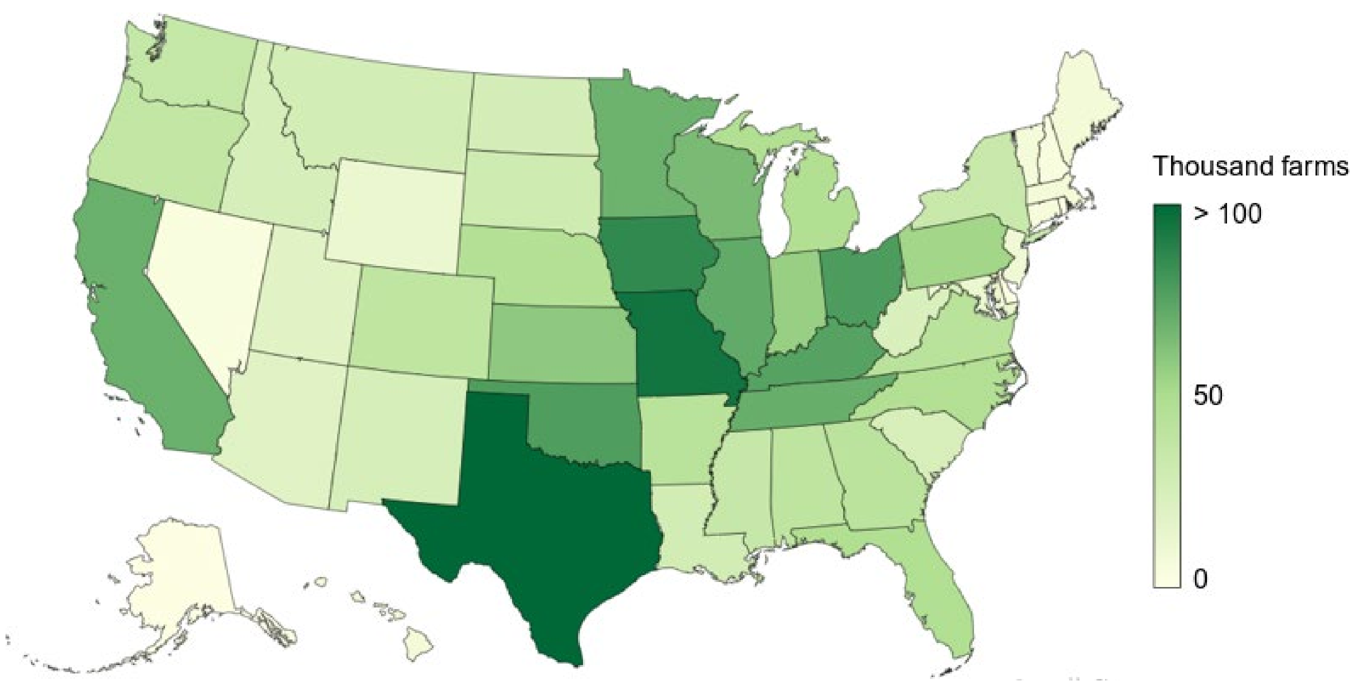

Figure 1.1.4. Total number of farms in the United States by State in 2018 (1).

State	Acreage	Percentage
Texas	247	12.2
Missouri	95	4.7
Iowa	86	4.2
Ohio	79	3.8
Oklahoma	77	3.8

Table 1.1.2. Five States with largest number of farms in the United States in 2018 (in thousand farms) (1).

Production

The economic value of U.S. agricultural production increased from 2008 to 2012, peaking at $224 billion. After that, the value of agriculture production decreased slightly through 2015 before expanding to $188 billion in 2017 (Figure 1.1.5).

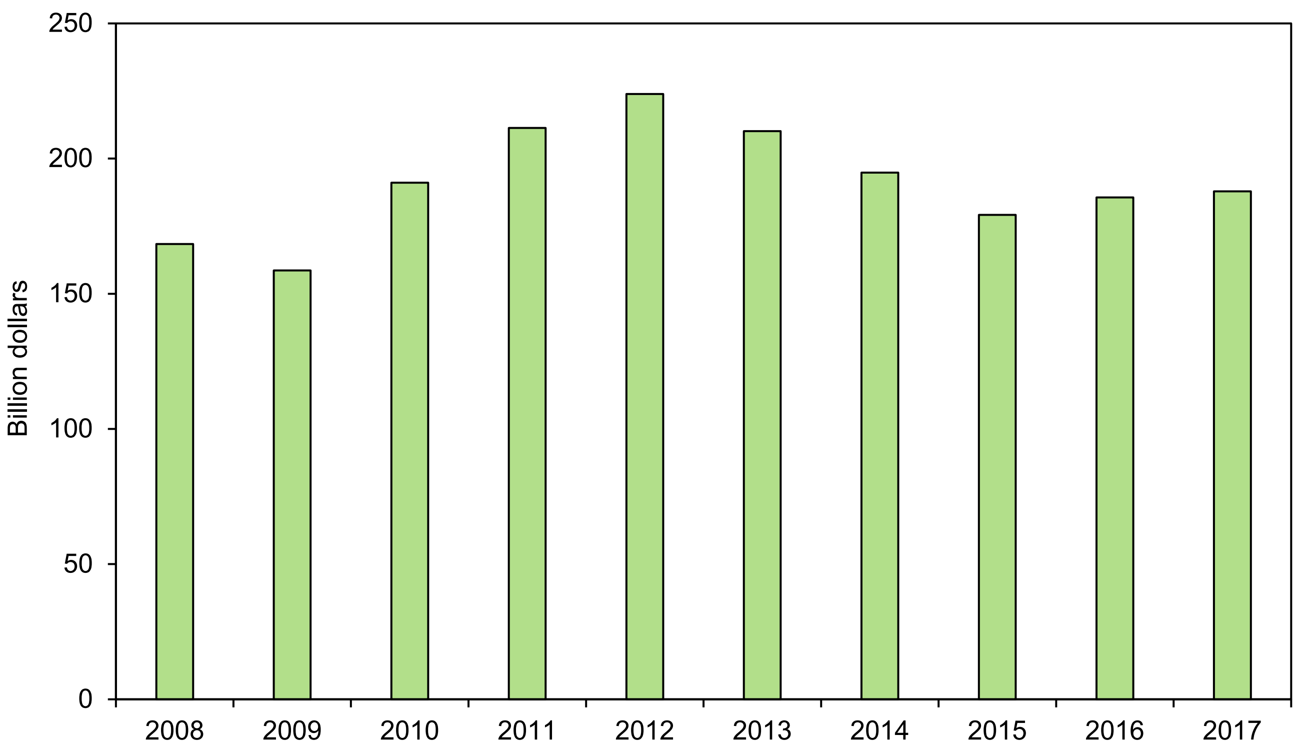

Figure 1.1.5. Value of agriculture production in the United States from 2008 to 2017 (in billion dollars) (4).

The value of agriculture exports increased by 22 percent from $115 billion in 2008 to $140 billion in 2018. Canada is the largest market destination for the U.S. agriculture goods, followed closely by Mexico and China (Figure 1.1.6).

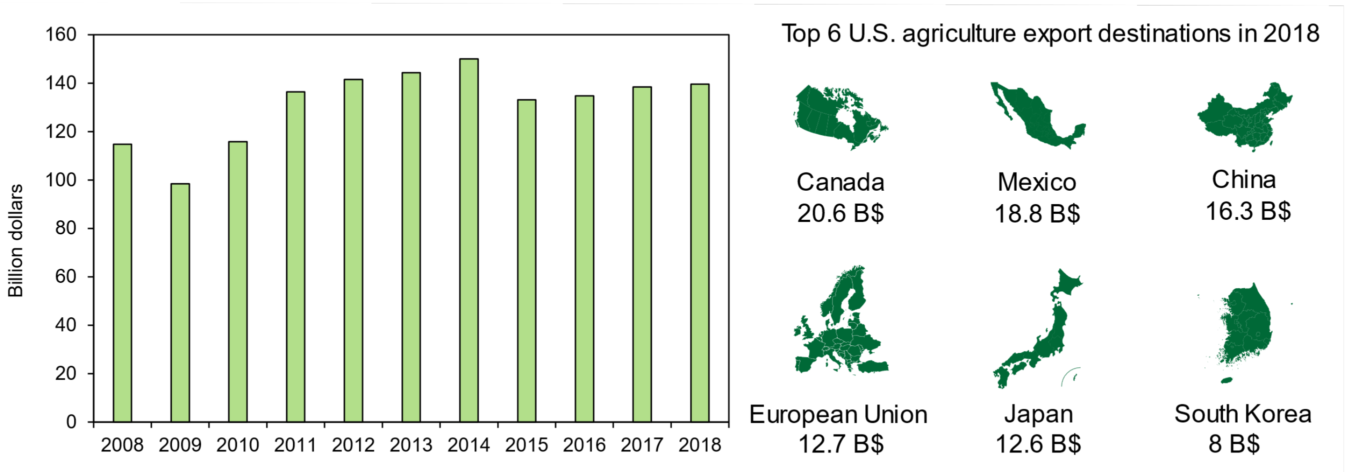

Figure 1.1.6. Exports of agriculture in the United States from 2008 to 2018 (in billion dollars) (5) and top 6 United States export destinations in 2018 (in billion dollars) (6).

The value of agricultural imports steadily increased from $80 billion to $129 billion in the last 10 years. In 2018, Mexico, Canada and the European Union were the largest sources of agriculture products, well ahead of China, which is the fourth largest exporter to the United States (Figure 1.1.7).

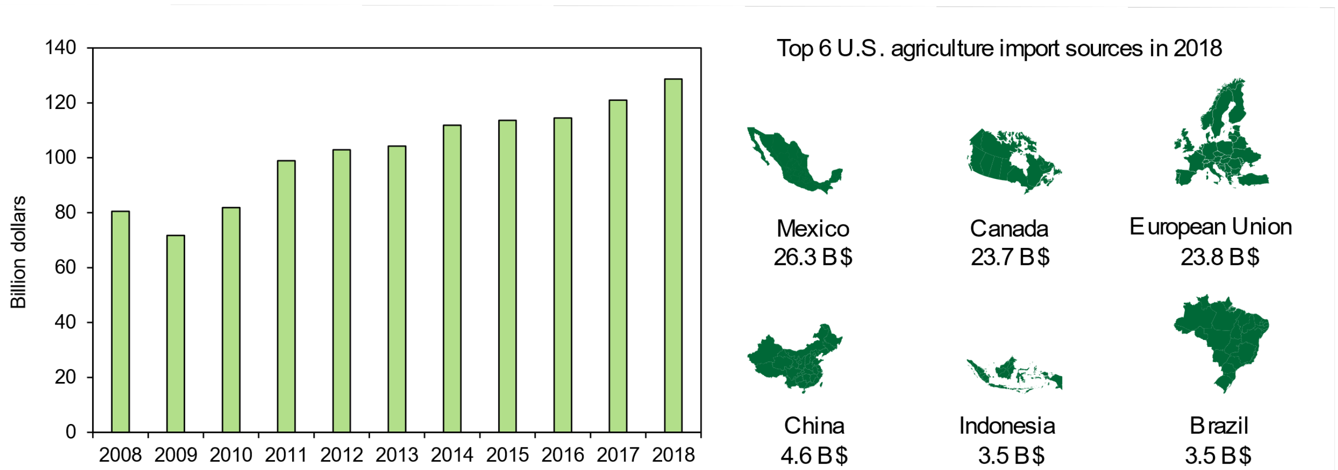

Figure 1.1.7. Imports of agricultural products in the United States from 2008 to 2018 (in billion dollars) (5) and top 6 U.S. import sources in 2018 (in billion dollars) (6).

Economics

Net farm income in the United States decreased until 2016 when it reached $62 billion. In 2017 net farm income grew with exports reaching $84 billion by 2018 (Figure 1.1.8).

Net farm income is significantly higher in California and in the Midwest United States (see Figure 1.1.9 and Table 1.1.3 for more detail).

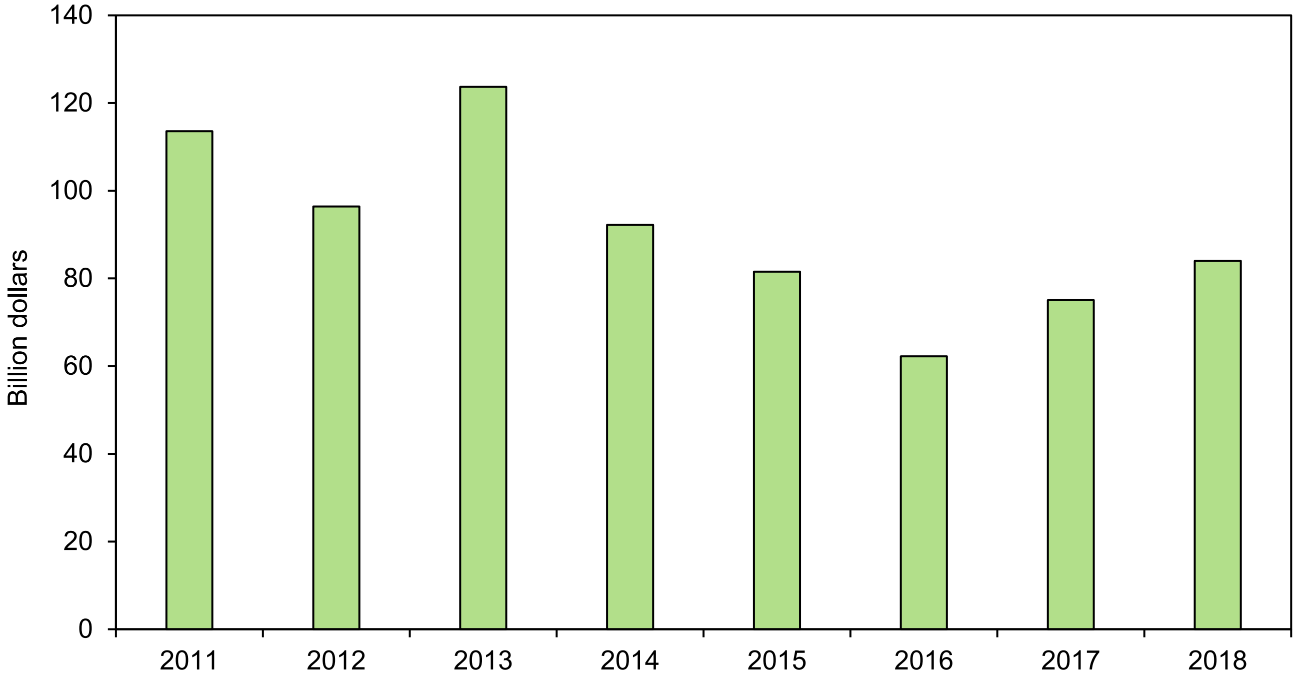

Figure 1.1.8. Net farm income in the United States from 2011 to 2018 (in billion dollars) (7).

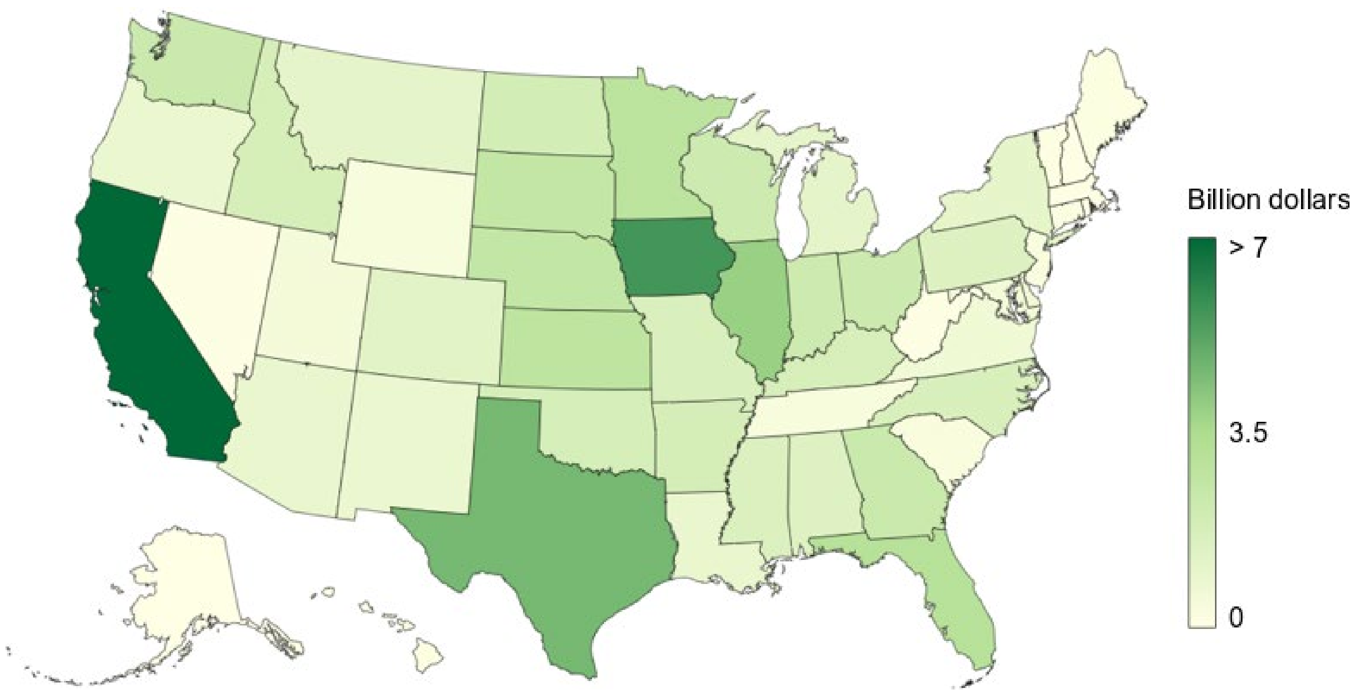

Figure 1.1.9. Net farm income in the United States by State in 2018 (in billion dollars) (7).

State	Net cash income	Percentage
California	15.6	18.6
Iowa	5.6	6.7
Texas	4.6	5.5
Illinois	3.9	4.7
Florida	3.1	3.7

Table 1.1.3. 5 States with highest net farm income in the United States in 2018 (in billion dollars) (7).

Over the last decade, farm assets, farm equity and farm debt in the United States all steadily increased by an average of 33 percent (Figure 1.1.10).

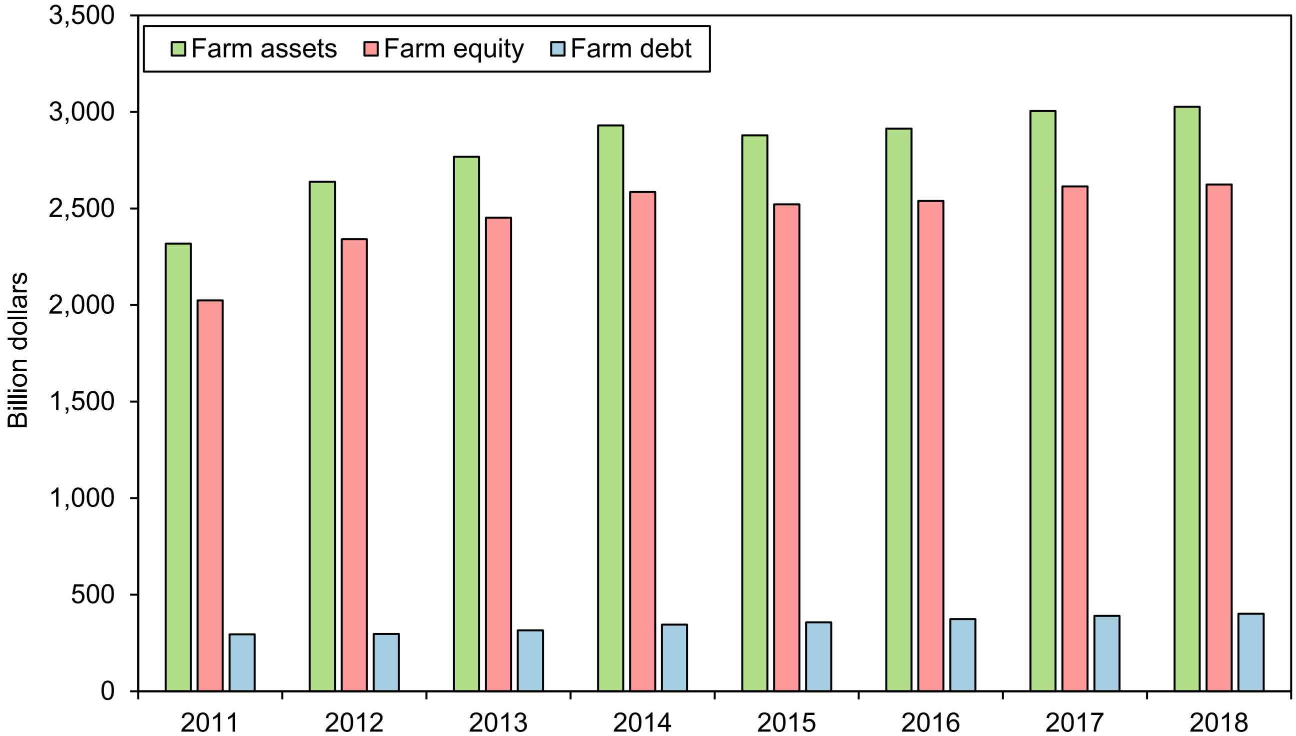

Figure 1.1.10. Total farm assets, debt and equity in the United States from 2011 to 2018 (in billion dollars) (7).

Environmental indicators

Agricultural production in the United States has a direct impact on the environment since it relies heavily on land, water, and natural resources (8). The following sections analyze the impact of agricultural activities in water, fertilizer, and pesticide use.

Fertilizer Use

Nitrogen (N), phosphate (P_2O_5), and potash (K_2O) are essential in the production of the crops used for food, feed, fiber, fuel, and bioproducts (12). The use of these fertilizers fluctuated but did not follow any particular trend between 2008 and 2015. There was a decline in fertilizer consumption in 2009, driven by record-high fertilizer prices in 2008 and 2009 (see Figure 1.1.12) and the impacts from the 2008--2009 economic crisis, which also reduced the global demand for U.S. agricultural products (14, 15).

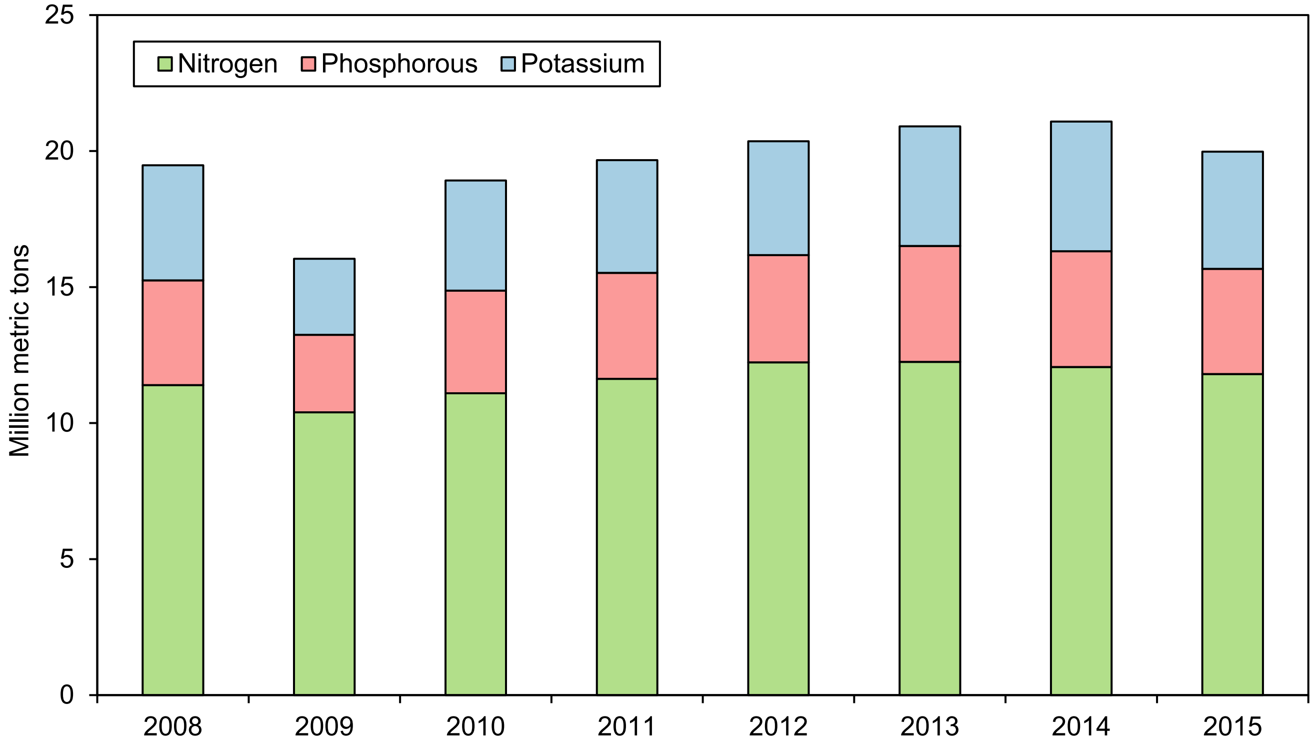

Figure 1.1.11. Total chemical fertilizers applied to farms in the United States from 2008 to 2015 (in million metric tons) (14).

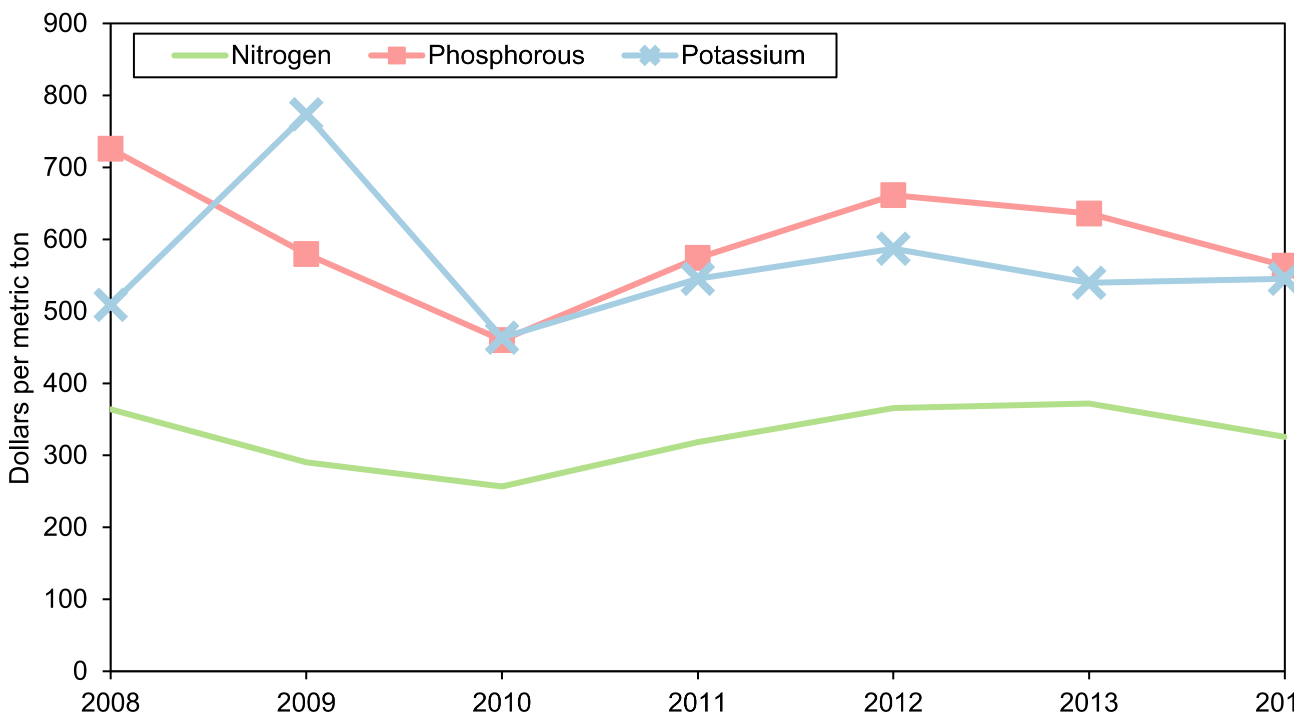

Figure 1.1.12. Average price for chemical fertilizers in the United States from 2008 to 2014 (in million metric tons) (14).

Fertilized applied to three selected crops (i.e., corn, soybeans, and wheat) is presented in Table 1.1.4.

Nitrogen and phosphate were most widely applied to corn and wheat, and potash was applied most widely to corn crops (13).

	Nitrogen		Phosphate		Potash	
	Planted acres (%)	**Average rate for year (lbs./acre)**	**Planted acres (%)**	**Average rate for year (lbs./acre)**	**Planted acres (%)**	**Average rate for year (lbs./acre)**
Corn	98	149	79	69	63	87
Soybeans	29	17	42	55	43	87
Wheat	92	86	79	34	26	25

Table 1.1.4. Fertilizer applied to planted acres for three selected crops: corn, soybeans, and wheat. Data presented is from the 2017 and 2018 Agricultural Chemical Use Surveys. Data for wheat is averaged for the year, given that application rates vary among winter wheat, spring (excl. durum) wheat, and durum wheat (13).

Pesticide Use

This section considers the application of chemical pesticides to corn, soybeans, and wheat, using data from the USDA, National Agricultural Statistics Services (NASS). The NASS has surveyed farmers since 1990 to collect information on the chemicals that farmers apply to agricultural commodities.

The Federal Insecticide, Fungicide, and Rodenticide Act (FIFRA) includes four classes of pesticides that are included within the report: herbicides targeting weeds; insecticides targeting insects; fungicides targeting fungal disease; and other chemicals targeting all other pests and other materials, including extraneous crop foliage.

Data presented are from both the 2017 and 2018 Agricultural Chemical Use Surveys. More specifically, the values for wheat are from the 2017 Agricultural Chemical Use Survey, while all other values displayed are from the 2018 survey. The value of herbicide applied to each crop outweighs the respective totals of insecticide, fungicide, and other pesticides (Figure 1.1.13).

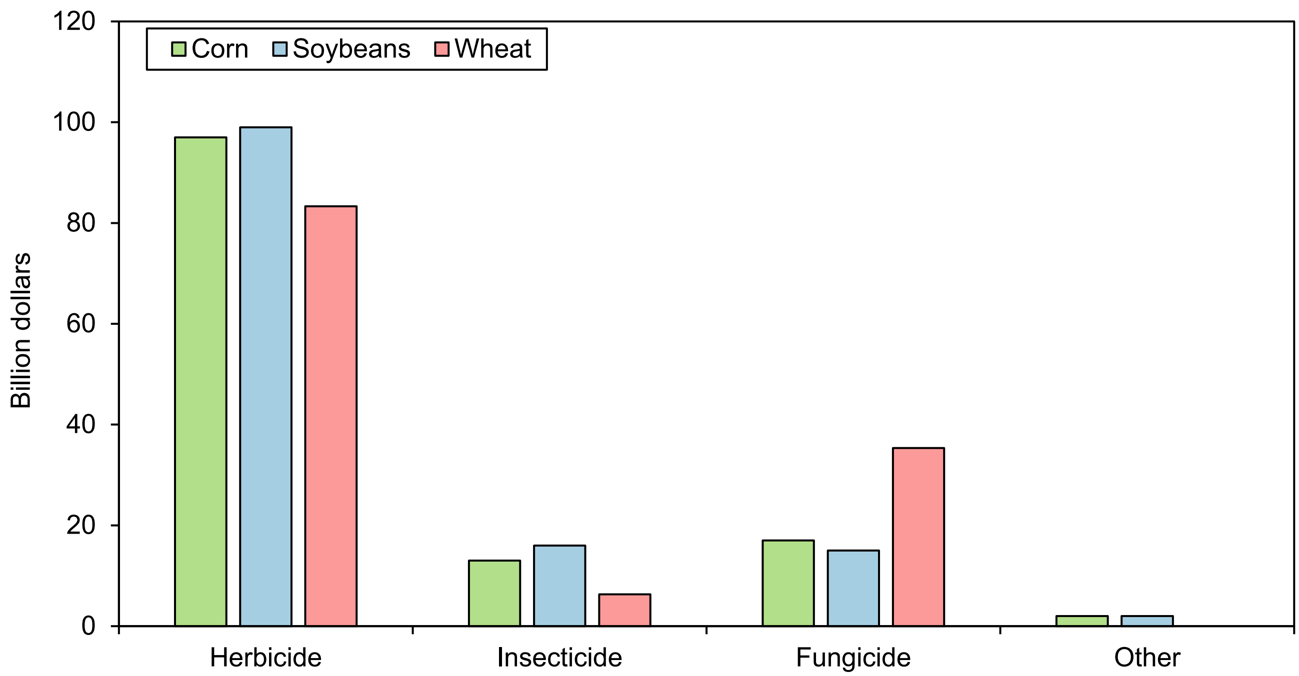

Figure 1.1.13. Pesticides applied to planted acres for three representative crops, 2017-2018 crop years. The values for wheat represent an annual average, given that pesticide use varies among winter wheat, spring (excl. durum) wheat, and durum wheat (13).

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1.2. Corn

Corn is the most abundant crop grown in the United States and the most important cereal grain in terms of production around the world, surpassing rice and wheat. The domestic production of corn is concentrated in the Midwest.

Nearly all the corn grown in the United States is USDA #2 yellow dent corn, also known as field corn. This type of corn is widely used for biofuel production. In 2018, 44 percent of total corn consumption in the United States was used to produce ethanol and 36 percent of corn oil for biodiesel production. This makes corn the most important crop in the production of biofuels. One ton of corn yields between 380 and 540 liters of ethanol, depending on the process used in its production. The production of ethanol also yields dried distiller grains or DDGs, which is a protein-rich coproduct of ethanol refining that is primarily used in animal feed. DDGs can be dried and pelletized for easier transport, which allows international shipping of DDGs. With a production of 38.5 million metric tons in 2018 and a total export volume of 12 million tons in the same year, DDGs are the most significant coproduct of ethanol production, both in volume and in value.

The United States produces more corn than it consumes, making the Nation a net exporter of corn. Mexico is the largest market destination, with a total of 17 million metric tons exported to Mexico in 2018.

In the United States, corn occupied the largest acreage of all starch crops in the last decade.

The number of acres planted of corn has not significantly increased over the years. Increased corn output is instead accomplished by raising the productivity of the average acre. In 2018, 89 million acres of corn were planted, in comparison with 86 million acres in 2008 (Figure 1.2.1). Most of the total corn acreage, 82 percent, is planted in the Midwest. Iowa, Illinois, Nebraska, Minnesota, and Kansas are the top 5 States for corn planting (see Figure 1.2.2 and Table 1.2.1 for more details).

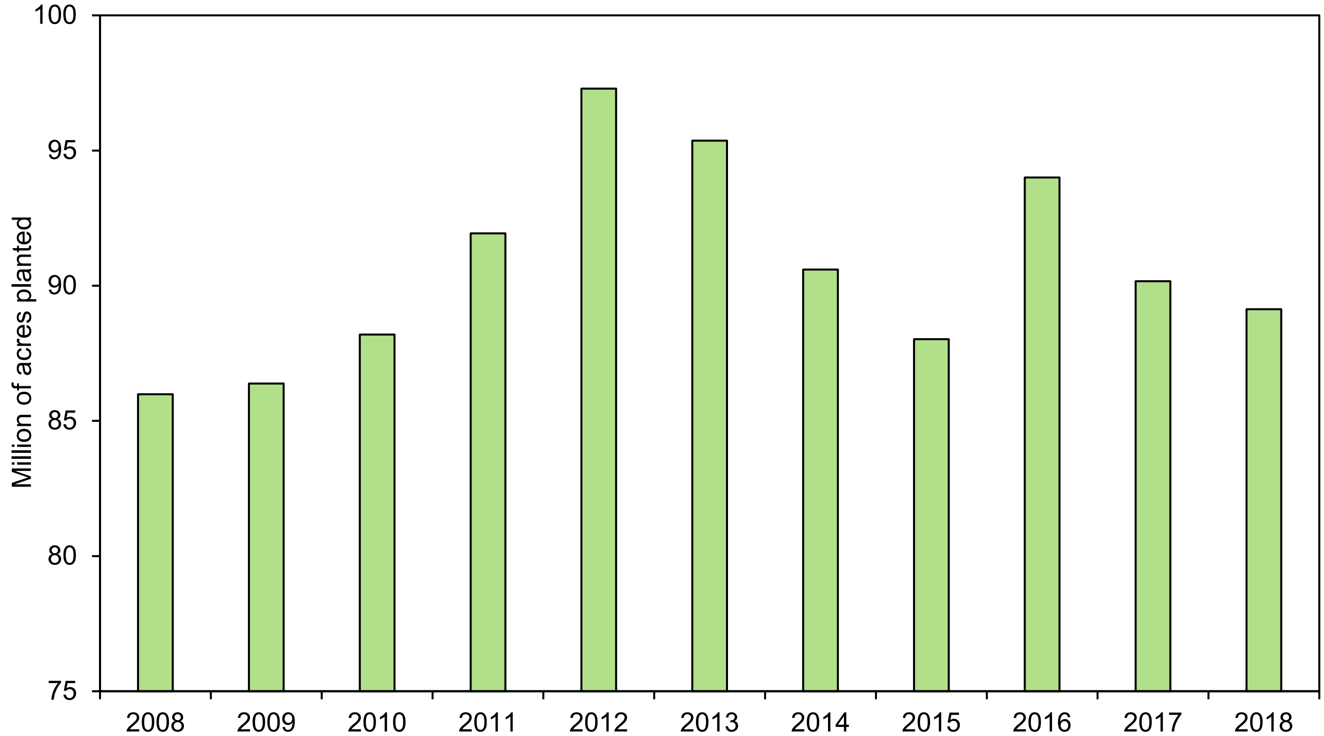

Figure 1.2.1. Total acreage of corn planted in the United States from 2008 to 2018 (in million acres) (1).

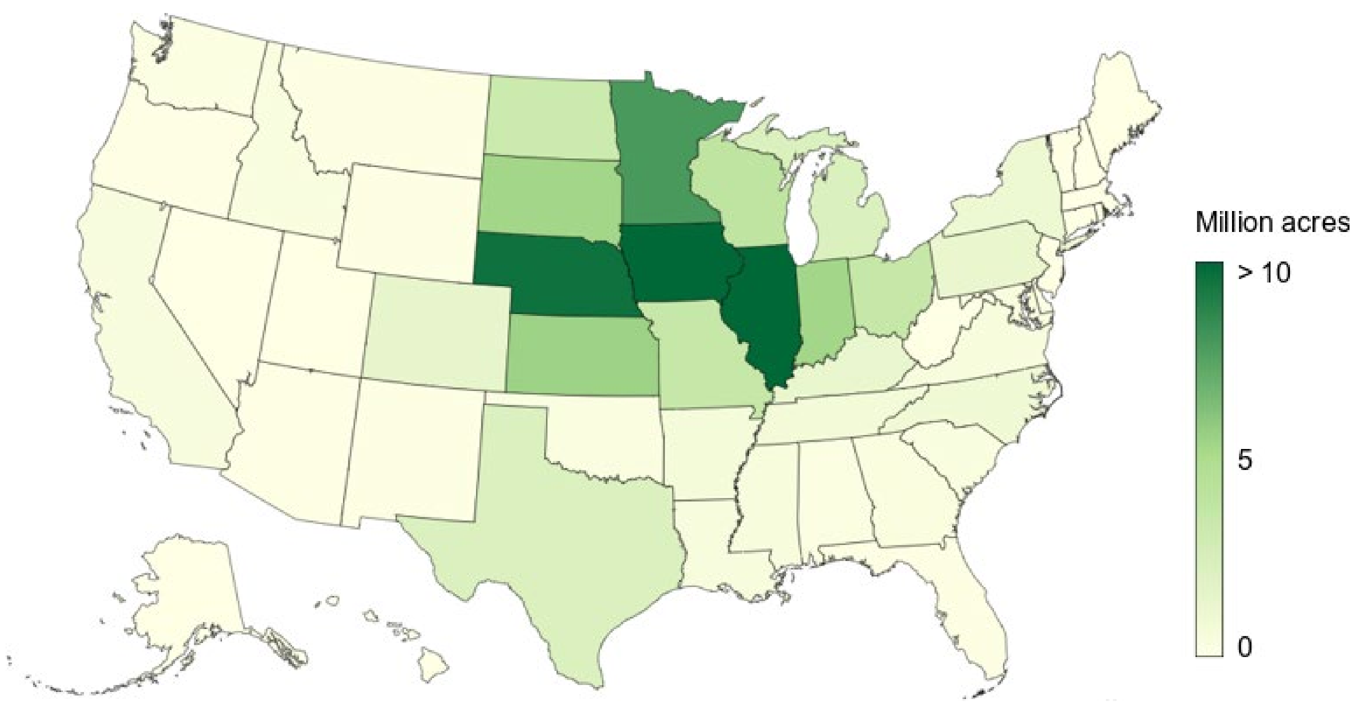

Figure 1.2.2. Total acreage of corn in the United States by State in 2018 (in million acres) (2).

State	Million Acres	Percentage
Iowa	13.2	14.6
Illinois	11.0	12.2
Nebraska	9.6	10.6
Minnesota	7.9	8.8
Kansas	5.5	6.0

Table 1.2.1. 5 States with largest acreage of yellow dent corn in the United States in 2018 (in million acres) (2).

Production

The United States grows more corn than it consumes. Fourteen percent of corn produced in the United States was exported in 2018. Domestic corn is mainly used for animal feed and fuel alcohol. Thirty-eight percent of corn is used for ethanol production and 36 percent for animal feed in 2018 (Figure 1.2.3).

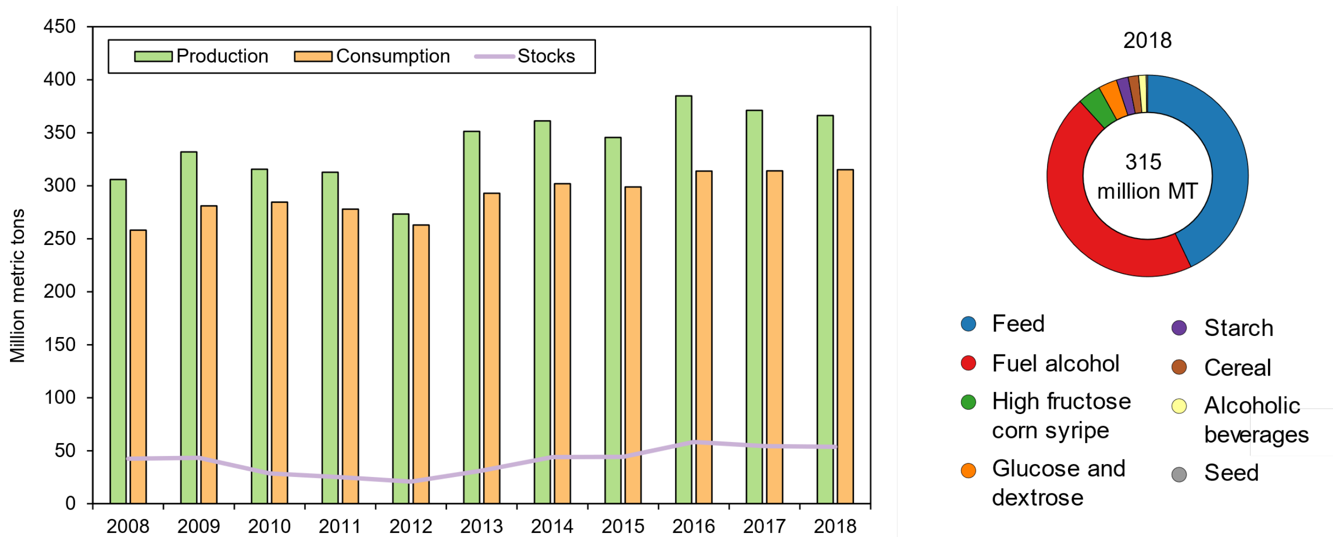

Figure 1.2.3. Total corn production versus total corn consumption and ending stocks of corn in the United States from 2008 to 2018 (in million metric tons) and yellow dent corn uses in the United States in 2018 (3, 4).

In 2012, there was a major drought that significantly reduced production of corn (see the minimum value in the figure 1.2.3), and with strong demand, prices increased (Figure 1.2.10). Despite that, 2011-2012 were the highest years for corn earning (Figure 1.2.4). The inelastic demand of corn during this time period provides further evidence for this trend.

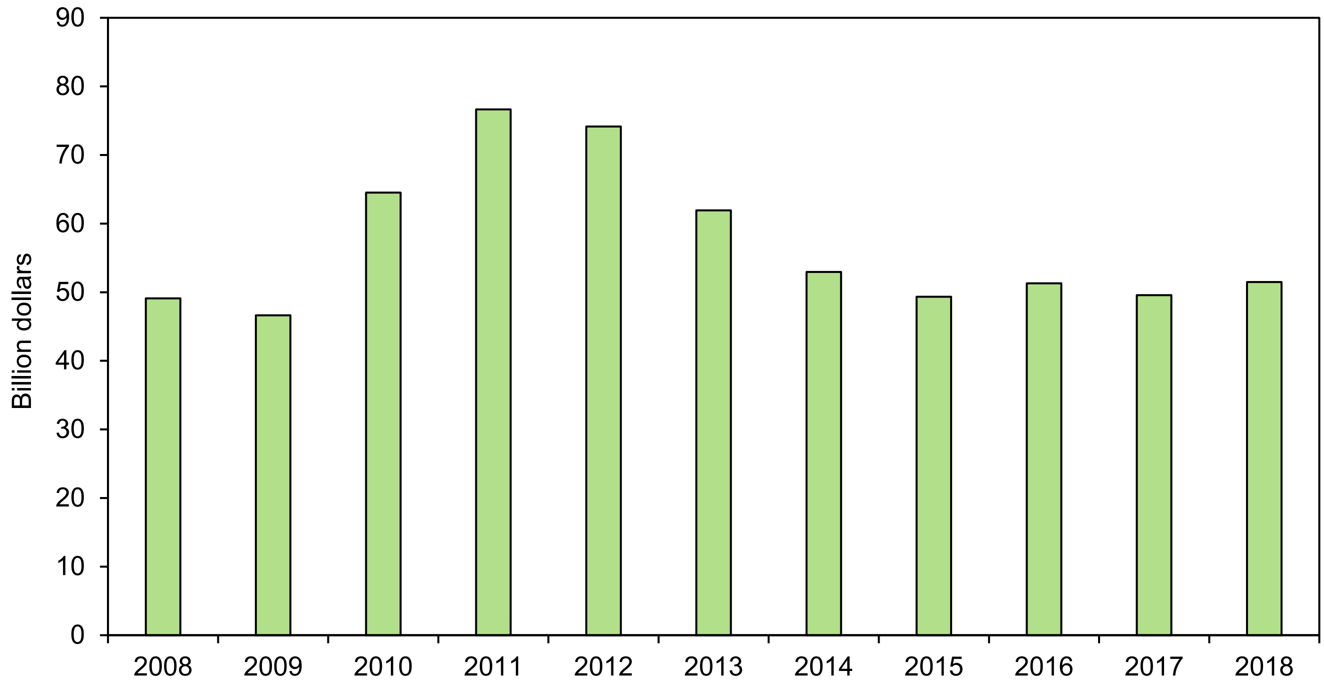

Figure 1.2.4. Production of corn in the United States from 2008 to 2017 (in billion dollars) (5).

Eighty-seven percent of total corn produced in the United States is produced in the Midwest. Iowa, Illinois, Nebraska, Minnesota, and Indiana are the top 5 States for corn production (Figure 1.2.5 and Table 1.2.1). This is consistent with the geographical information about yellow dent corn acreage.

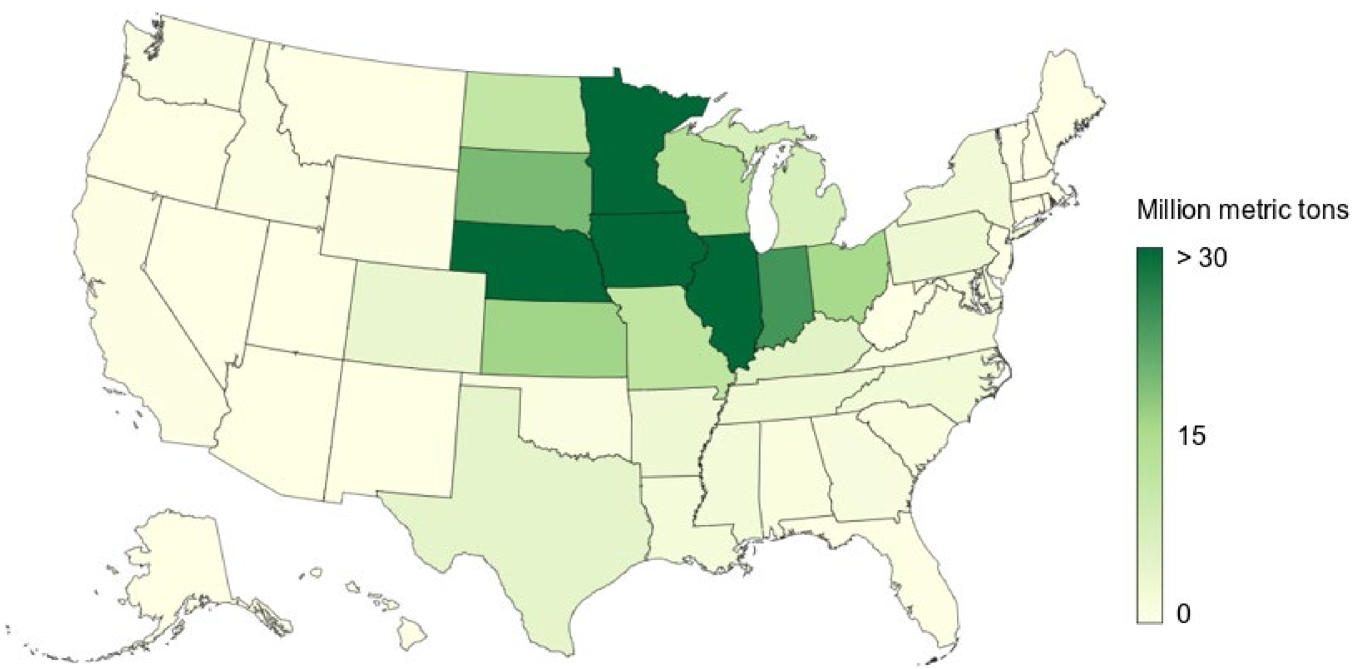

Figure 1.2.5. Total production of corn in the United States by State in 2018 (in million metric tons) (6).

State	Million metric tons	Percentage
Iowa	62	17.2
Illinois	57	15.6
Nebraska	45	12.3
Minnesota	34	9.4
Indiana	24	6.7

Table 1.2.2. 5 States with highest production of yellow dent corn in the United States in 2018 (in million metric tons) (6).

Corn starch is used for ethanol production and distillers corn oil (DCO) is used to produce biodiesel, which makes corn the most versatile crop regarding biofuel production. DCO is one of the six feedstocks approved by the EPA to produce biodiesel. The use of corn for production of fuel ethanol, DCO, and other coproducts increased from 76 million metric tons in 2008 to 140 million metric tons in 2018 (Figure 1.2.6). This is equivalent to 24 percent of total corn used in 2008 and 38 percent in 2018, which is consistent with the increase in ethanol production (see Figure 2.1.3).

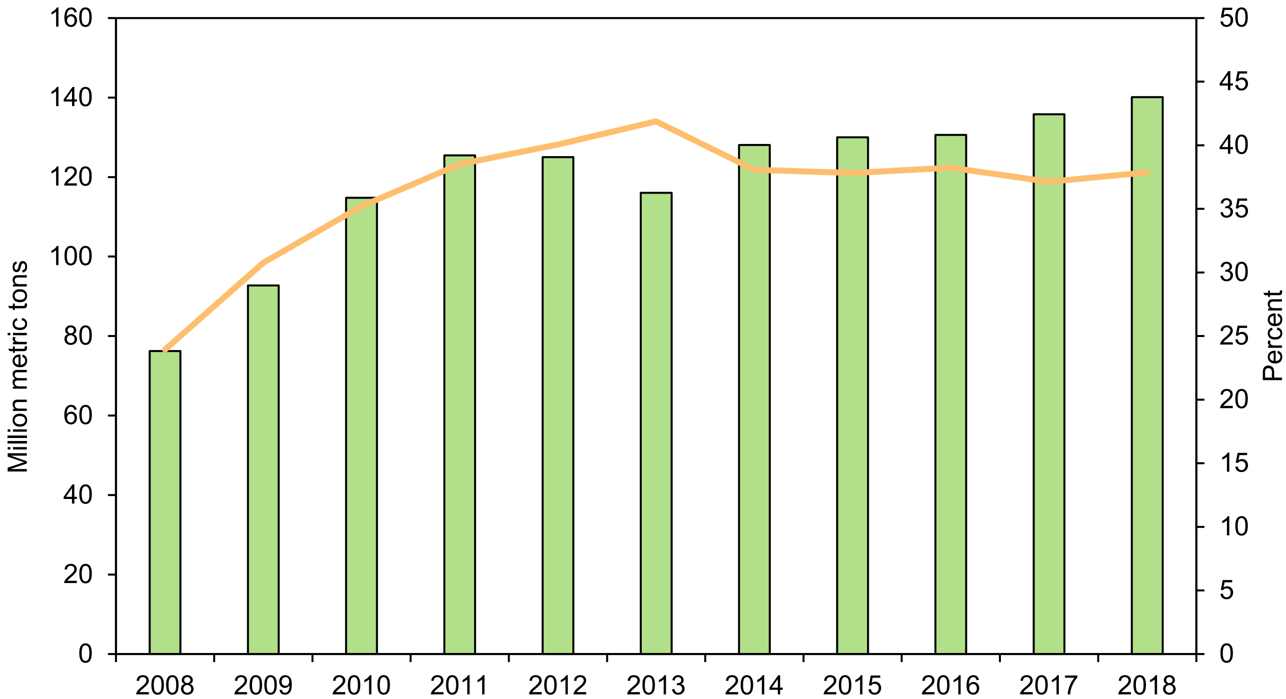

Figure 1.2.6. The bars represent the amount of corn processed into ethanol in the United States from 2008 to 2018 (in million metric tons) (left axis) and the line the percentage of total yellow dent corn consumption being devoted to ethanol from 2008 to 2018 (in percentage) (right axis) (4, 7).

The quantity of corn oil used as feedstock for biodiesel production grew exponentially in the last decade; corn oil's share of biodiesel production grew from 3 percent in 2008 to 36 percent in 2017 (Figure 1.2.7 and Figure 2.2.3).

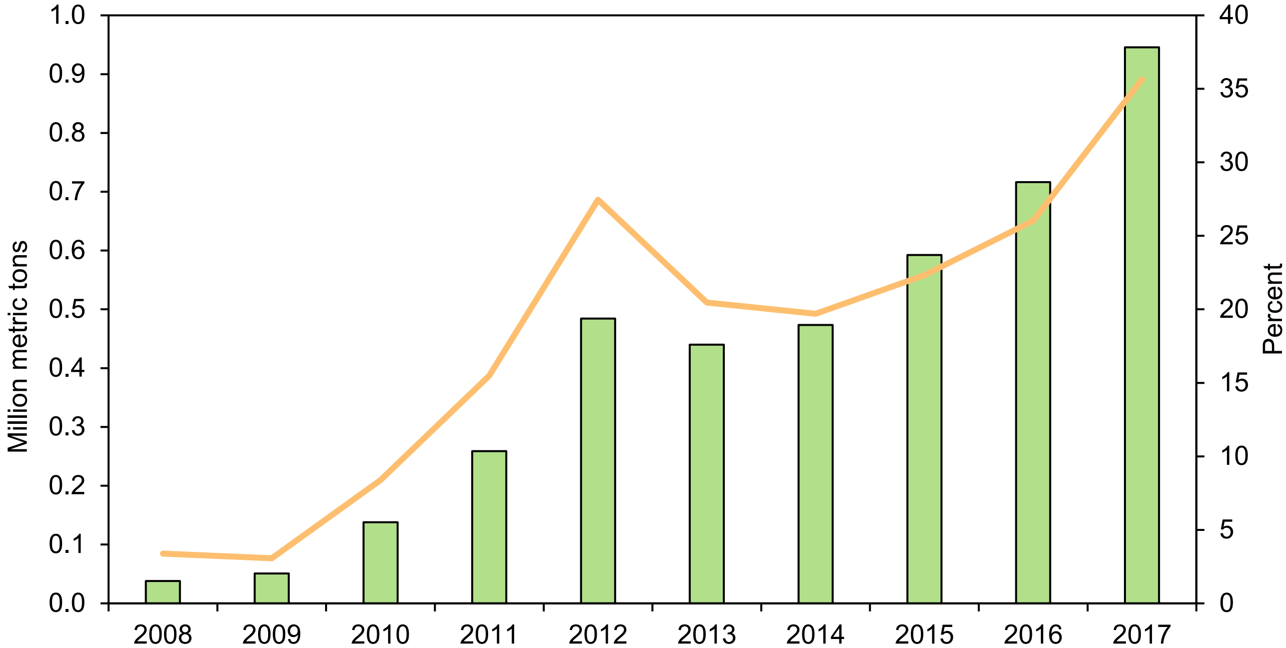

Figure 1.2.7. The bars represent the amount of corn oil processed into biodiesel in the United States from 2009 to 2018 (in million metric tons) (left axis) and the line the percentage of total corn oil production being devoted to biodiesel from 2009 to 2018 (in percentage) (right axis) (7, 8).

Exports of corn were highly affected by the 2012 drought, when they reached a minimum of 19 million metric tons. After that, exports increased significantly with a volume of 52 million metric tons exports in 2018 (Figure 1.2.8).

In 2018, Mexico was the largest market destination for U.S. corn, followed by Japan, with a total of 17 million metric tons and 15 million metric tons exported, respectively.

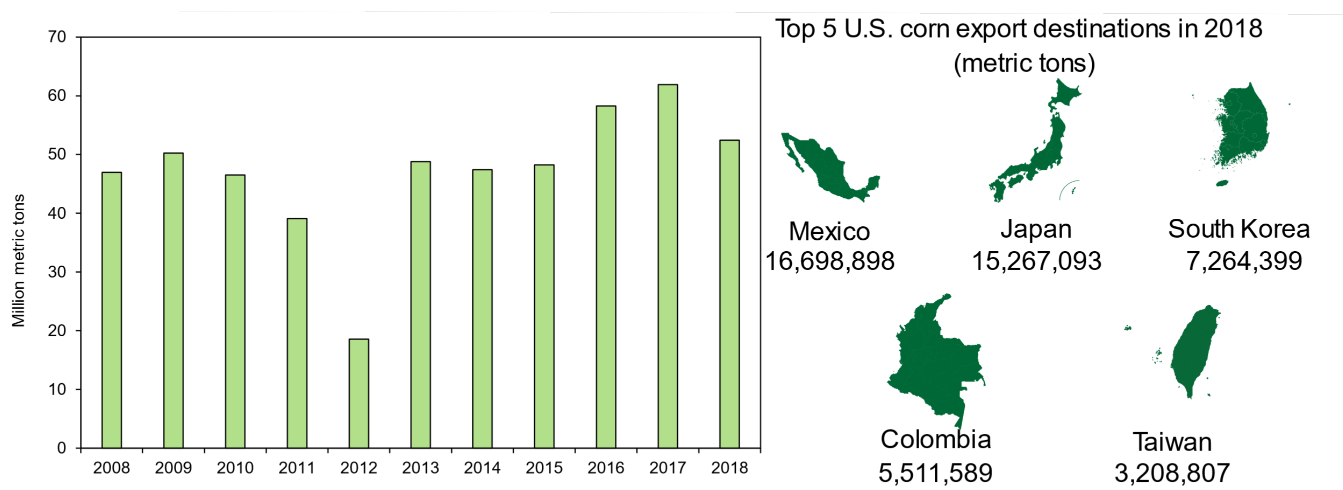

Figure 1.2.8. Exports of corn in the United States from 2008 to 2018 (in million metric tons) (3) and the top 5 United States export destinations in 2018 (in metric tons) (9).

Imports of corn are considerably lower than exports (Figure 1.2.9). In 2012, the year with minimum United States corn production (Figure 1.2.3), imports reached a peak of 4.1 million metric tons. After that, imports were very small, around 1 million metric tons.

Canada was the nation from which the United States imported the most yellow dent corn in 2018 (Figure 1.2.9). Most of the corn imported in the United States is organic corn and seed corn.

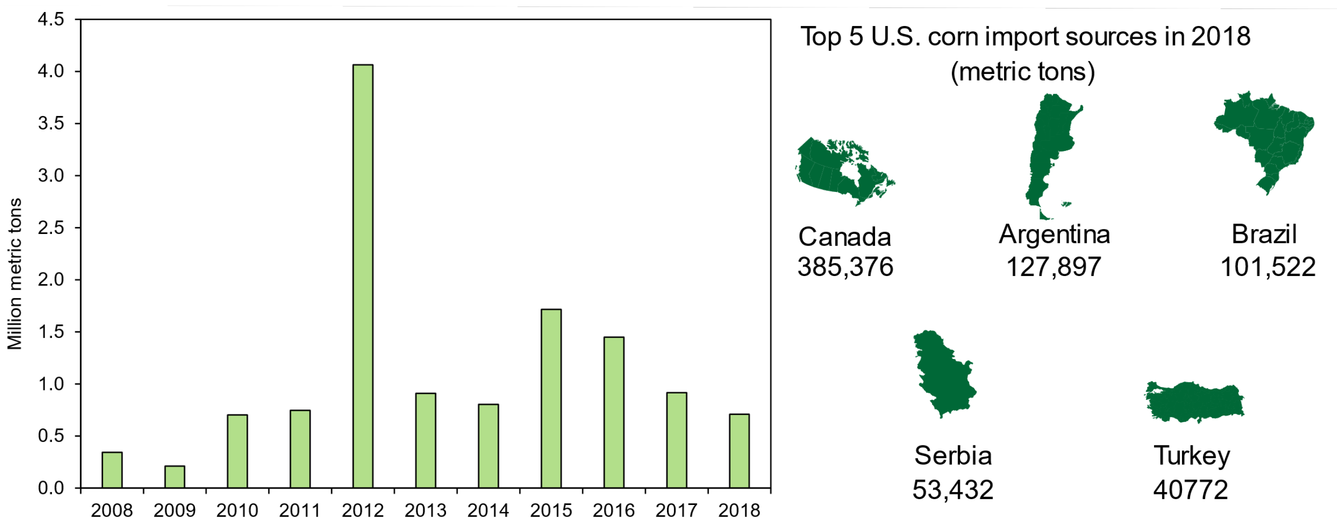

Figure 1.2.9. Imports of corn in the United States from 2008 to 2018 (in million metric tons) (3) and the top 5 United States import sources in 2018 (in metric tons) (9).

Economics

The average farm price of corn has decreased from $162 per metric ton in 2008 to $144 per metric ton in 2018 (Figure 1.2.10). Note that 2012 was the year with the lowest corn production and the highest corn price.

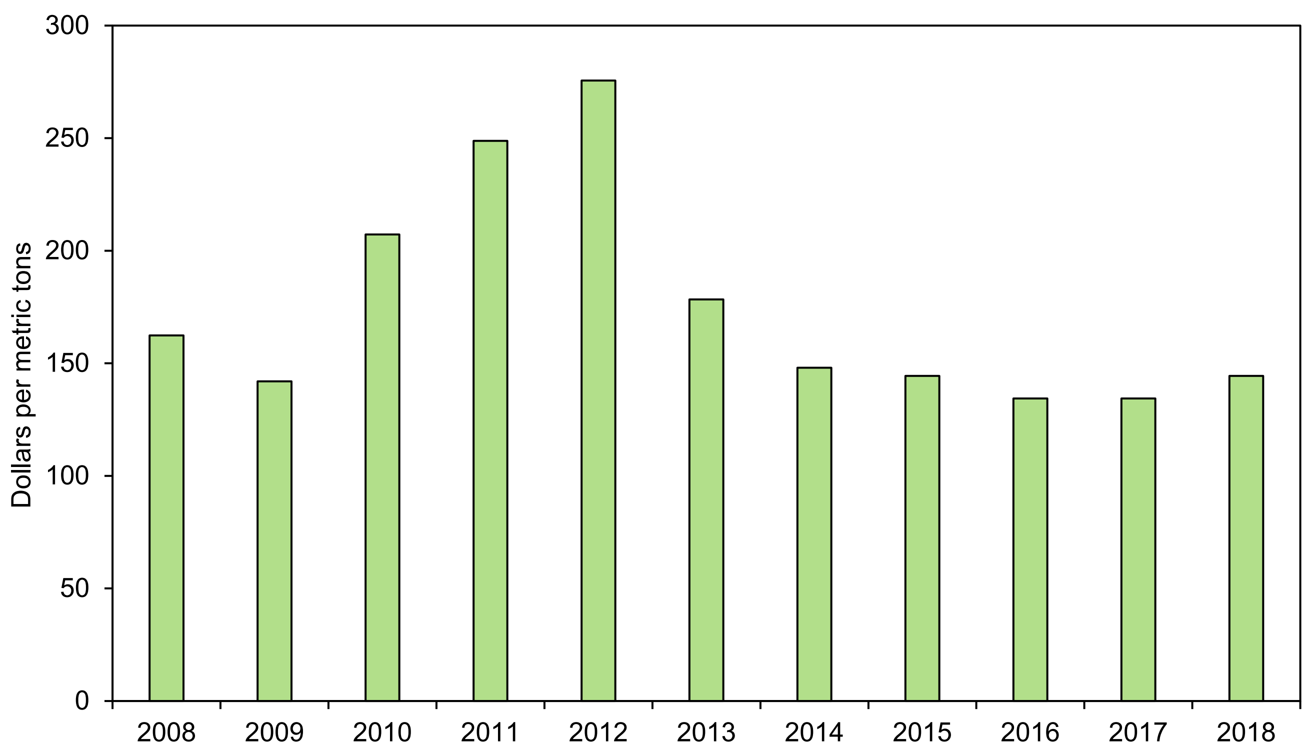

Figure 1.2.10. Farm price of corn from 2008 to 2018 (in dollars per metric ton) (10).

The economic value of corn used for ethanol peaked in 2012 at $34 billion, due to high corn prices. After that, the economic value of corn for ethanol decreased almost 50 percent to $20 billion in 2018 (Figure 1.2.11).

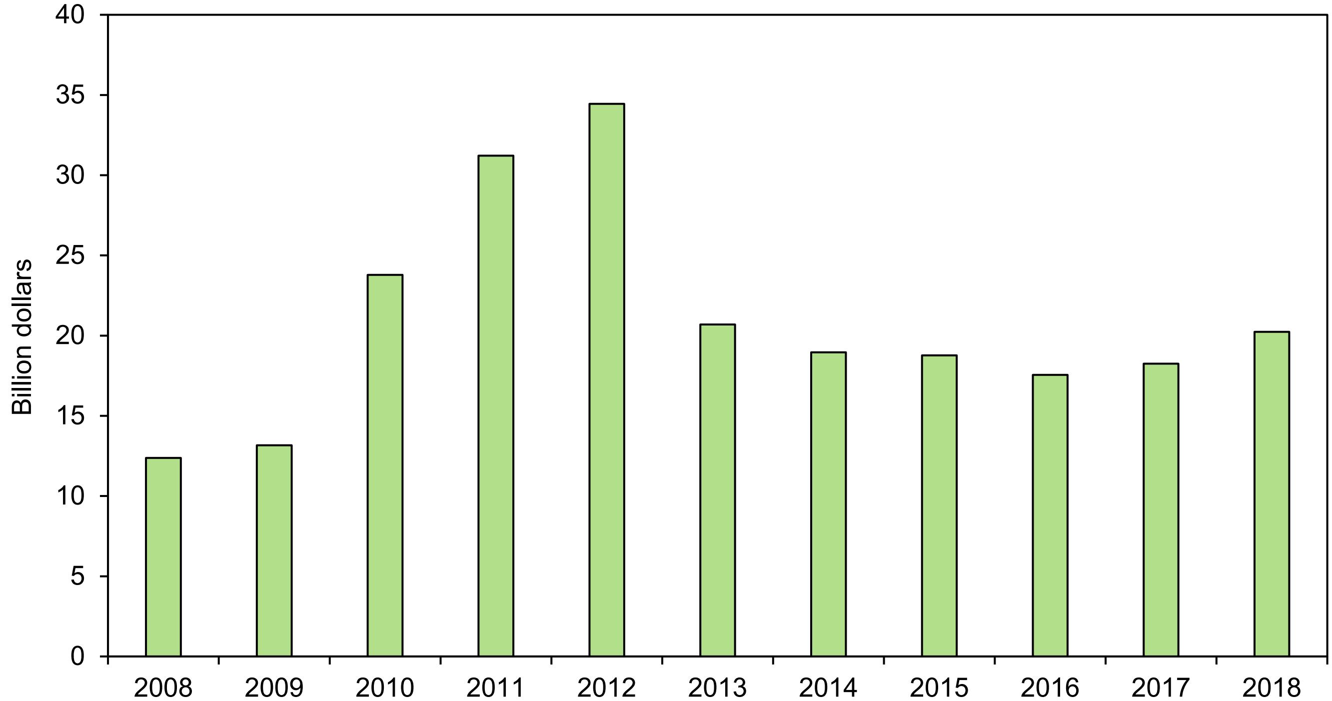

Figure 1.2.11. Economic value of corn being used for ethanol from 2008 to 2018 (in billion dollars) (7, 10).

The value of corn oil used for biodiesel production increased rapidly in the last 10 years, from $28 million in 2009 to $633 million in 2018 (Figure 1.2.12), which is consistent with the increase in biodiesel consumption.

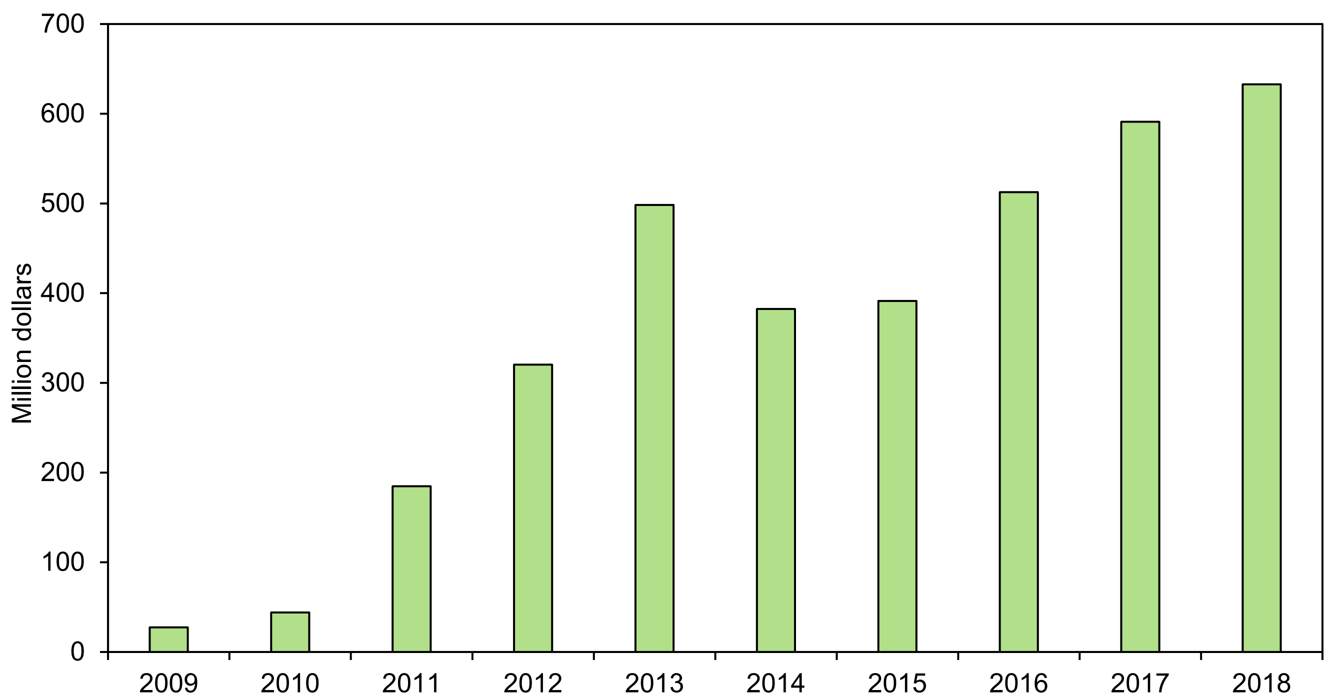

Figure 1.2.12. Economic value of corn oil being used for biodiesel from 2009 to 2018 (in million dollars) (8, 11).

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1.3. Sorghum

Grain sorghum is the third largest grain crop in the United States after corn and wheat. Sorghum is a cereal plant of the grass family and is commonly used in the manufacturing of gluten-free food for human consumption (i.e., flatbreads, cakes, sweetener), as animal fodder, to produce alcoholic beverages and to produce fuel ethanol (1).

Grain sorghum is drought tolerant and produces the same amount of ethanol per bushel as corn. However, no GMO sorghum varieties are available, and field yields are significantly below those of corn.

The land area planted to grain sorghum in the United States is very small and concentrated. Almost 80 percent of sorghum acreage is planted in Kansas and Texas.

The United States is a net exporter of grain sorghum, since production, which has varied significantly in the last decade, is higher than consumption.

U.S. sorghum production has shown a great deal of variability between 2008 and 2018, which is due to several factors but most importantly trade with China. China has gone in and out of the U.S. sorghum market, which has altered farm prices and price expectations. China has a relatively slow approval process for GMO crops that has at times reduced demand for U.S. corn, but GM-free sorghum was available to fill the gap. In addition, China has a Tariff Rate Quota (TRQ) for corn but no such TRQ for sorghum. Finally, the trade war between the U.S. and China had a significant impact on demand for U.S. sorghum that affected farmer production decisions.

Farm revenue from grain sorghum remained nearly constant from 2008 to 2018 despite the variability in production.

In comparison with other crops such as corn, the number of acres of grain sorghum planted is very small and follows a cyclical pattern. The last high point was 8 million acres planted in 2015 with a decline in the years following (Figure 1.3.1).

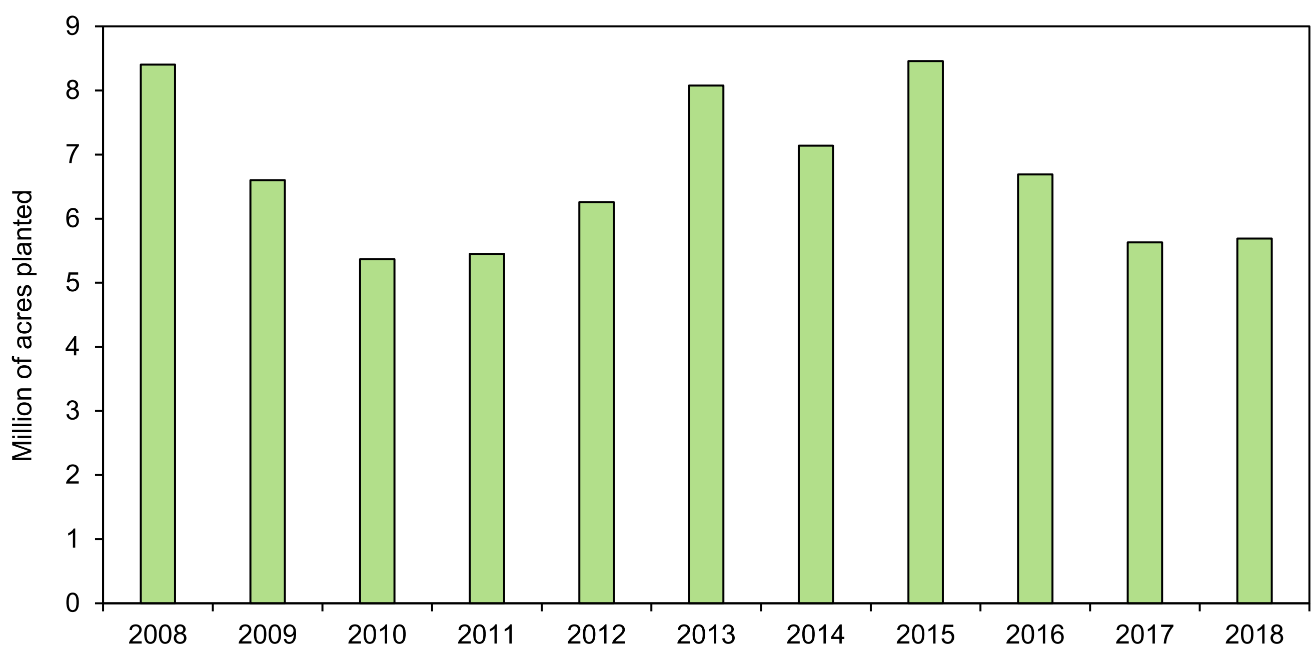

Figure 1.3.1. Acreage of grain sorghum planted in the United States from 2008 to 2018 (in million acres) (3).

Most of the grain sorghum is planted in Kansas and Texas, with 50 and 28 percent of the total acreage, respectively. Colorado, Oklahoma, and South Dakota complete the top five, but the areas planted are an order of magnitude smaller than the top two States (Figure 1.3.2 and Table 1.3.1).

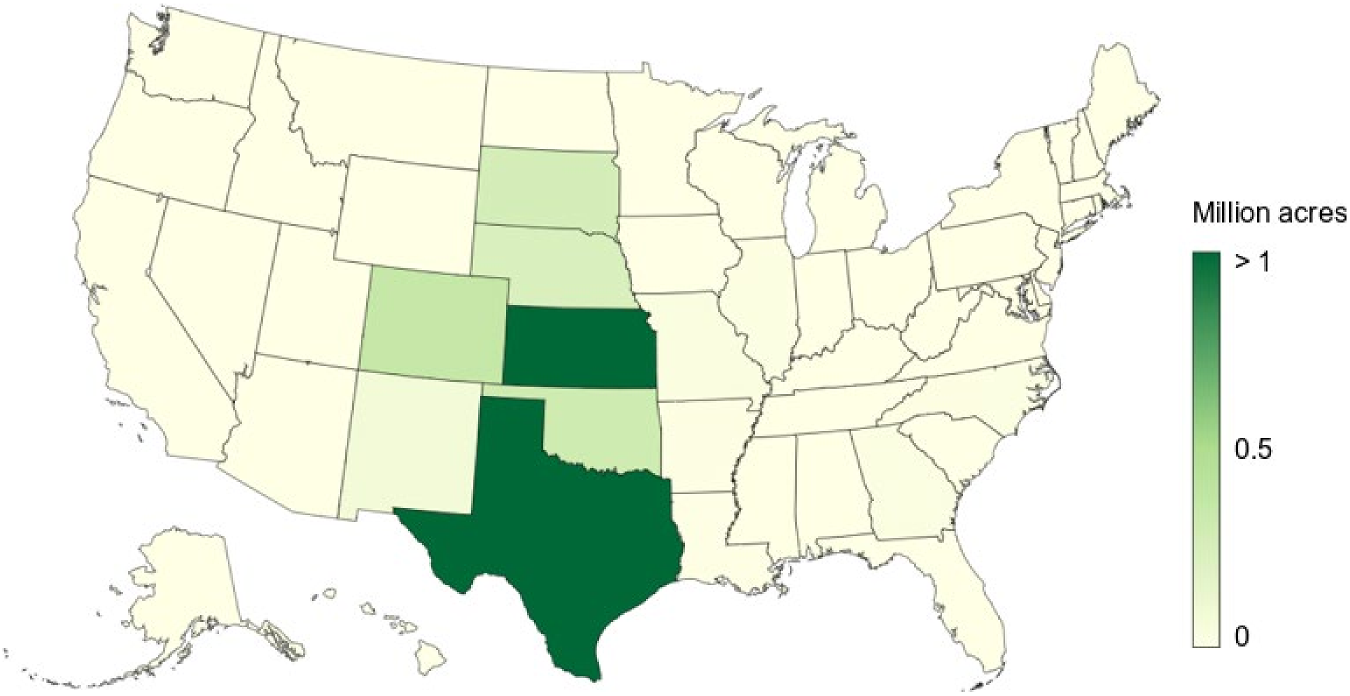

Figure 1.3.2. Total acreage of grain sorghum in the United States by State in 2018 (in million acres) (4).

State	Million Acres	Percentage of acres	Million metric tons
Kansas	2.8	49.8	5.9
Texas	1.6	27.6	1.6
Colorado	0.4	6.3	0.4
Oklahoma	0.3	5.3	0.3
South Dakota	0.3	4.6	0.4

Table 1.3.1. 5 States with largest acreage of grain sorghum in the United States in 2018 (in million acres) (4).

Production

The annual production of grain sorghum varies. From 2008 through 2018, the lowest production recorded was 5 million metric tons in 2011; however, by 2015 production increased threefold, to 15 million metric tons that year. After that peak, the production decreased to 9 million metric tons in 2018 (Figure 1.3.3).

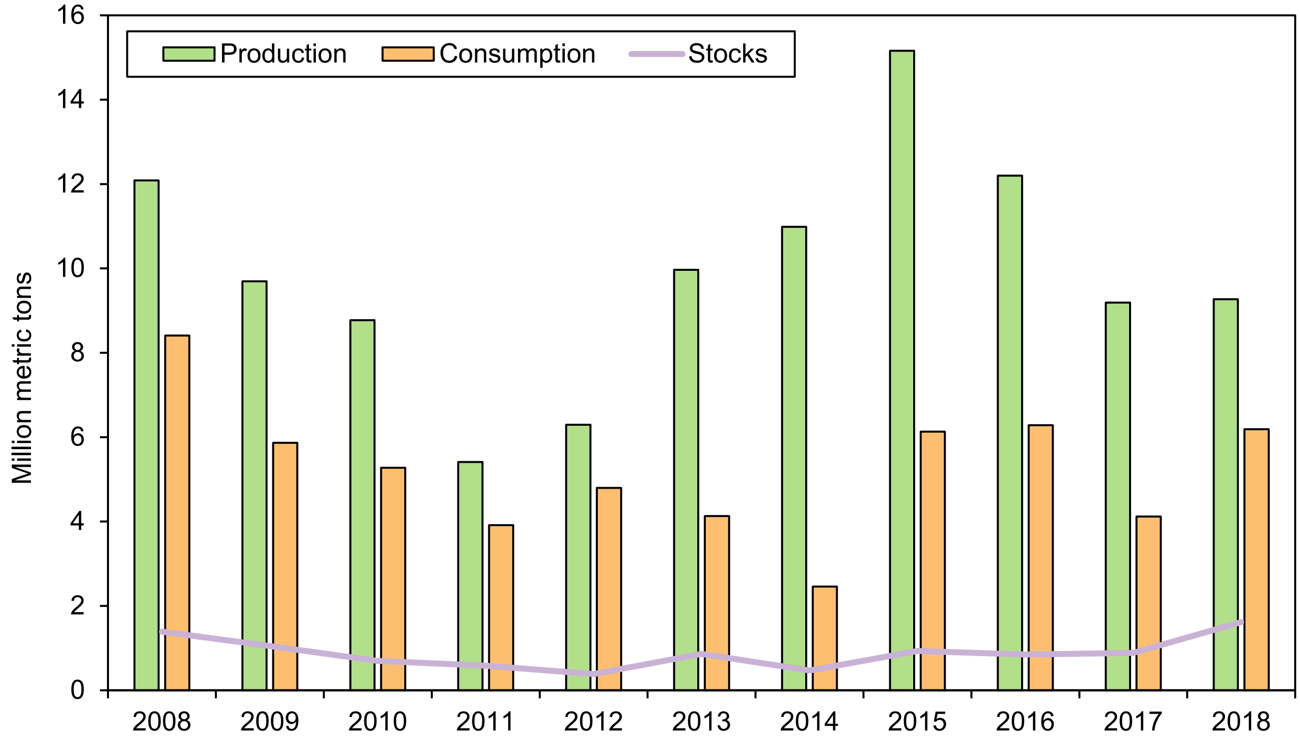

Figure 1.3.3. Total grain sorghum production versus total grain sorghum consumption and ending stocks of grain sorghum in the United States from 2008 to 2018 (in million metric tons) (5).

The economic value of grain sorghum production from 2008 to 2018 is presented in Figure 1.3.4. Grain sorghum production and price (see Figure 1.3.8) are inversely related. Revenue is less variable than production.

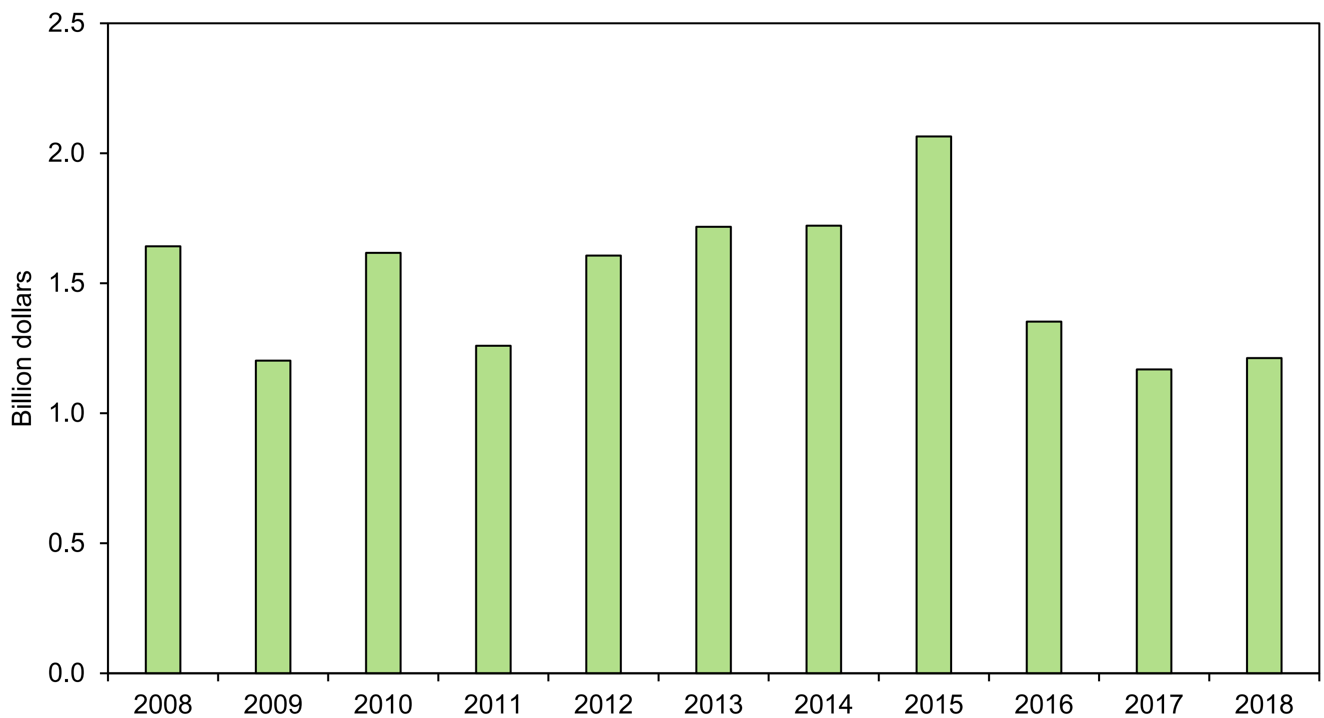

Figure 1.3.4. Production of grain sorghum in the United States from 2008 to 2018 (in billion dollars) (6).

Production of grain sorghum is highly correlated with the acreage planted; therefore, the geographical information and trends of grain sorghum crop production are the same as the acreage trends (Figure 1.3.5 and Table 1.3.2).

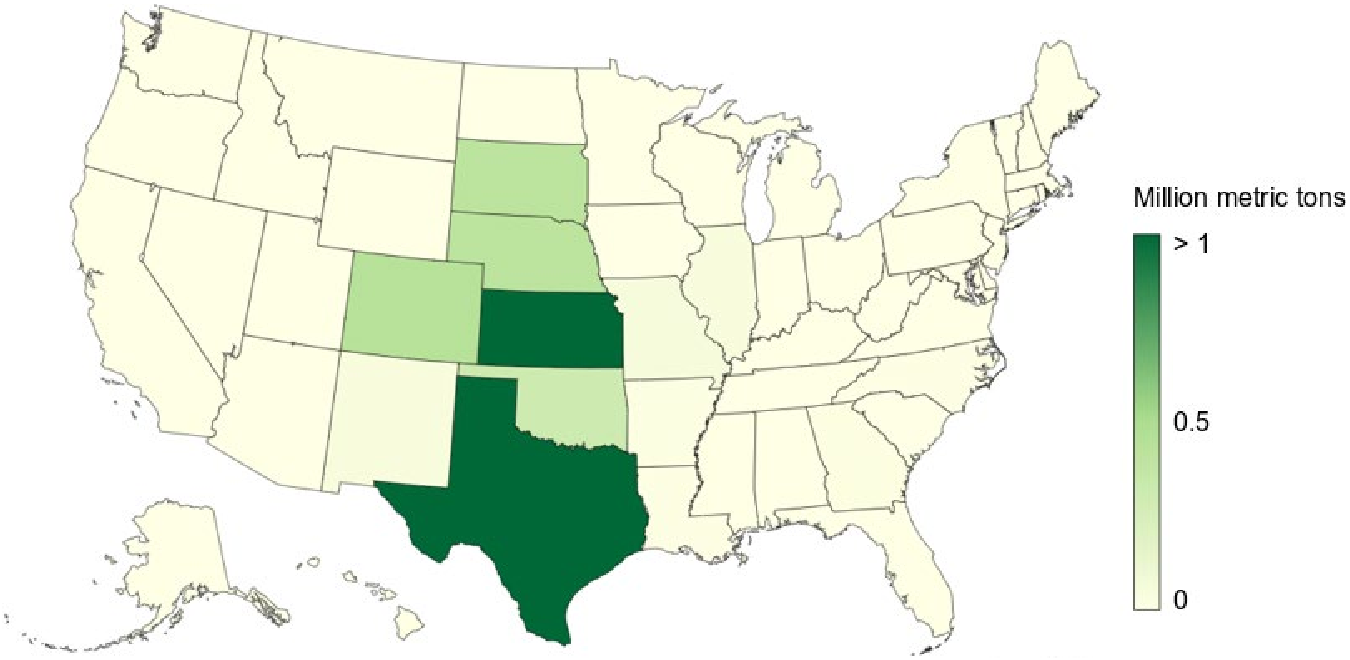

Figure 1.3.5. Total production of grain sorghum in the United States by State in 2018 (in million metric tons) (7).

State	Million metric tons	Percentage
Kansas	5.9	65.1
Texas	1.6	17.3
Colorado	0.4	4.8
South Dakota	0.4	4.5
Nebraska	0.4	4.5

Table 1.3.2. 5 States with highest production of grain sorghum in the United States in 2018 (in million metric tons) (7).

China is the largest market destination for grain sorghum, about 10 times the second-largest importing country, Japan (Figure 1.3.6).

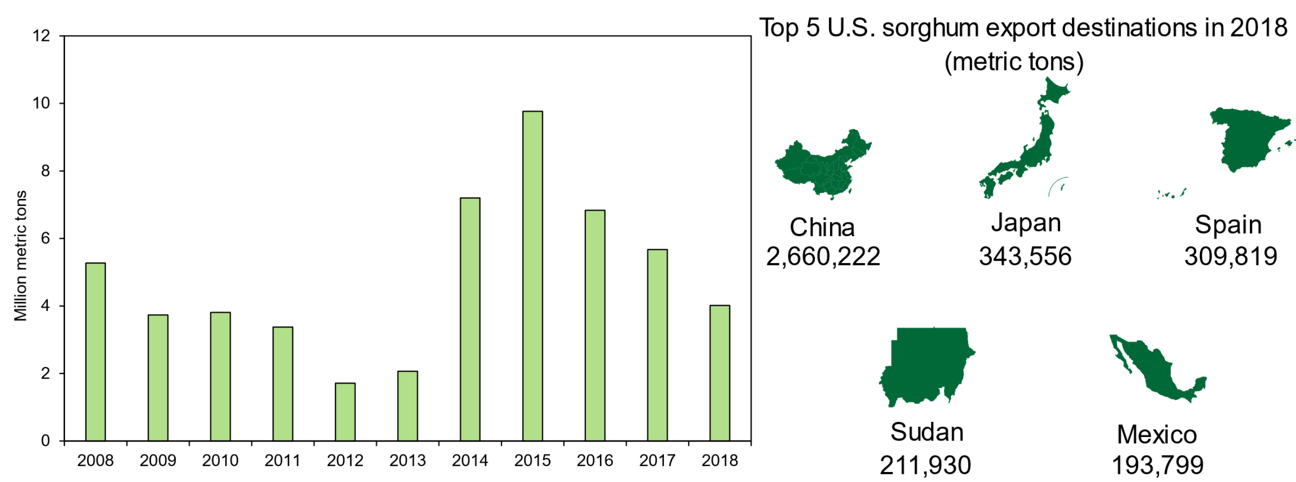

Figure 1.3.6. Exports of grain sorghum in the United States from 2008 to 2018 (in million metric tons) (8) and top 5 United States export destinations in 2018 (in metric tons) (8).

Imports of grain sorghum have been very low over the past 10 years. The largest imports occurred in 2013, when 215,000 metric tons were imported to the United States. In 2018, the United States imported 2,650 metric tons of grain sorghum from Mexico, China, Argentina, and Canada (Figure 1.3.7).

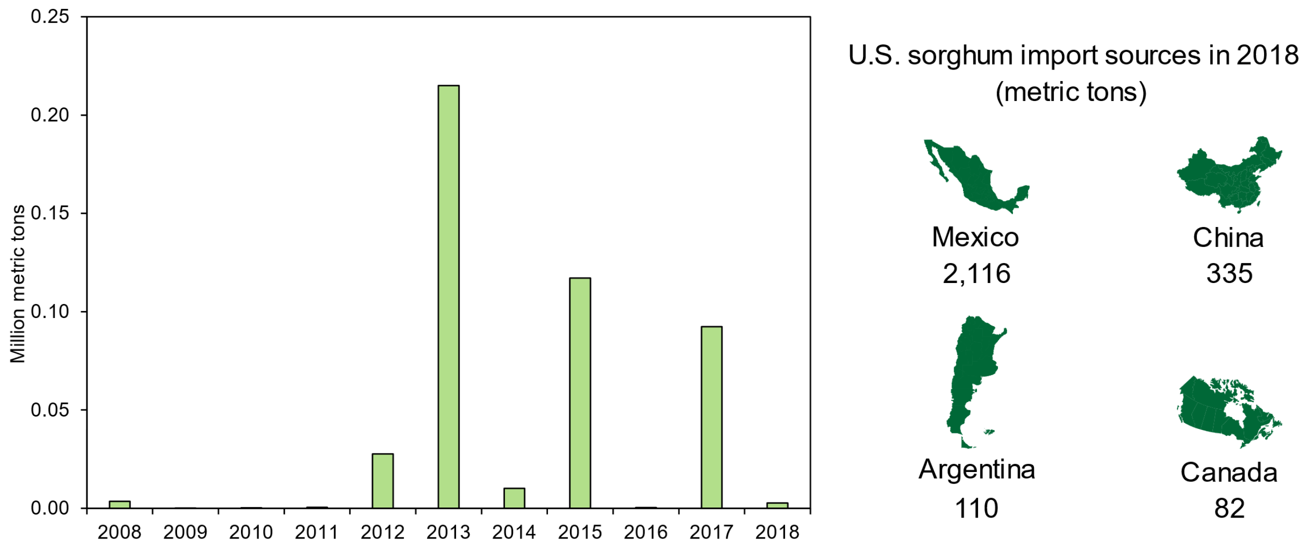

Figure 1.3.7. Imports of grain sorghum in the United States from 2008 to 2018 (in hundred thousand metric tons) (8) and the United States import sources in 2018 (in metric tons) (8).

Economics

The price of grain sorghum varied significantly from 2008 through 2018, reaching a maximum of 245 dollars per metric ton in 2012. The farm price of sorghum increased from 2008 through 2012, and then decreased to $135 per metric tons in 2018 (Figure 1.3.8).

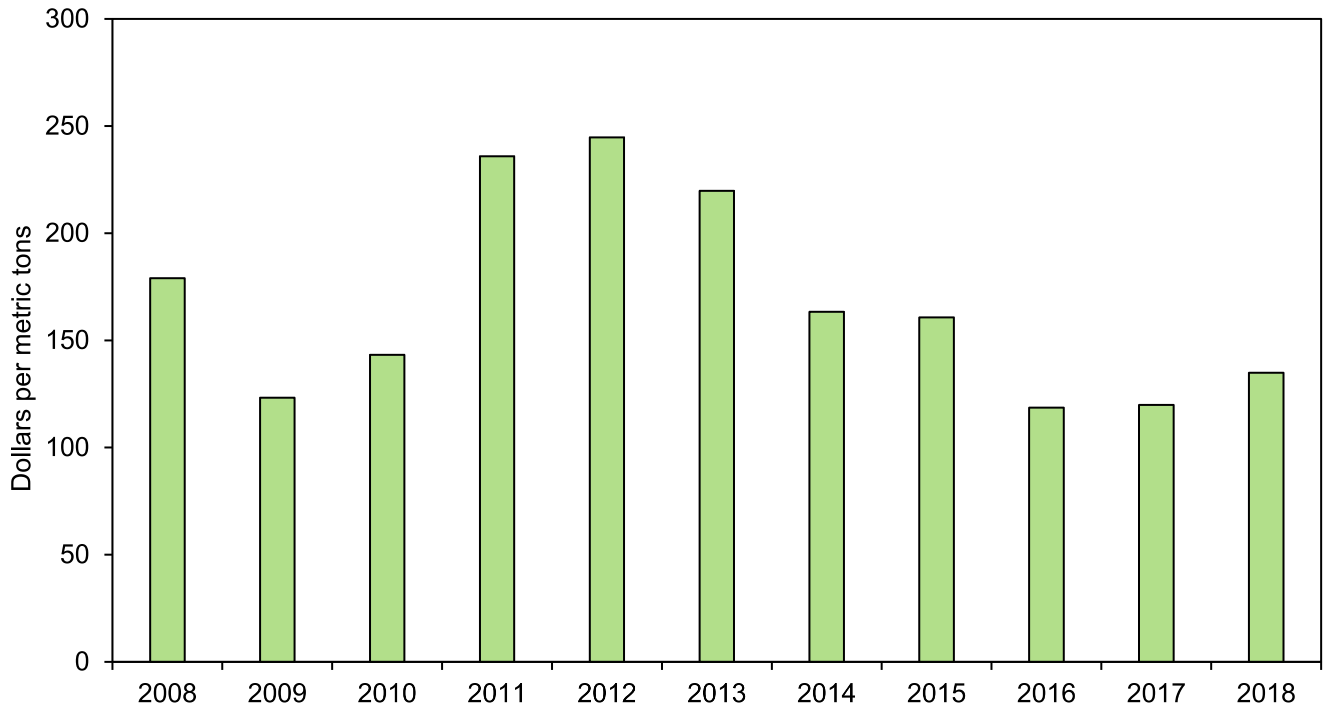

Figure 1.3.8. Farm price of grain sorghum from 2008 to 2017 (in dollars per metric ton) (9).

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1.4. Soy

Soybeans are the world's most prominent oilseed in terms of production. Soy processors separate the oil from the meal; the oil is used for human consumption, biodiesel production, and other industrial uses, while the meal, which is high in protein, is used for animal feed (1).

The production of soy in the United States has increased over the years; soy is the Nation's largest oilseed crop. Its production is concentrated in the Midwestern United States. It is mostly processed into soybean meal and soybean oil through a process known as crushing.

Soybeans and corn are commonly grown in rotation, which makes their production patterns highly correlated. Domestic planted acreage in 2018 was similar between the two crops. Farmer planting decisions between the two crops are based on economic factors and rotational considerations. . Crop rotations can disrupt pest and weed cycles and enhance soil health. Soybeans are a legume and can convert atmospheric nitrogen into fertilizer that can be used by the plant. Short season soybeans are also commonly used in double crop rotations.

The primary feedstock for biodiesel production in the United States is soybean oil. Fifty-four percent of U.S. biodiesel was produced from soybean oil in 2018.

The United States is a net exporter of soy. China, the world's top consumer and largest market destination, imports about 60 percent of its consumption.

Despite the downward trend in soy prices, farm revenue from soy production has increased from 2009 to 2018.

Soy has historically occupied the second-largest acreage among all crops, after corn. However, in 2017, plantings of the two crops converged at 90 million acres each, and this trend continued in 2018 with 89 million acres each (see Figure 1.2.1 and Figure 1.4.1 for more details).

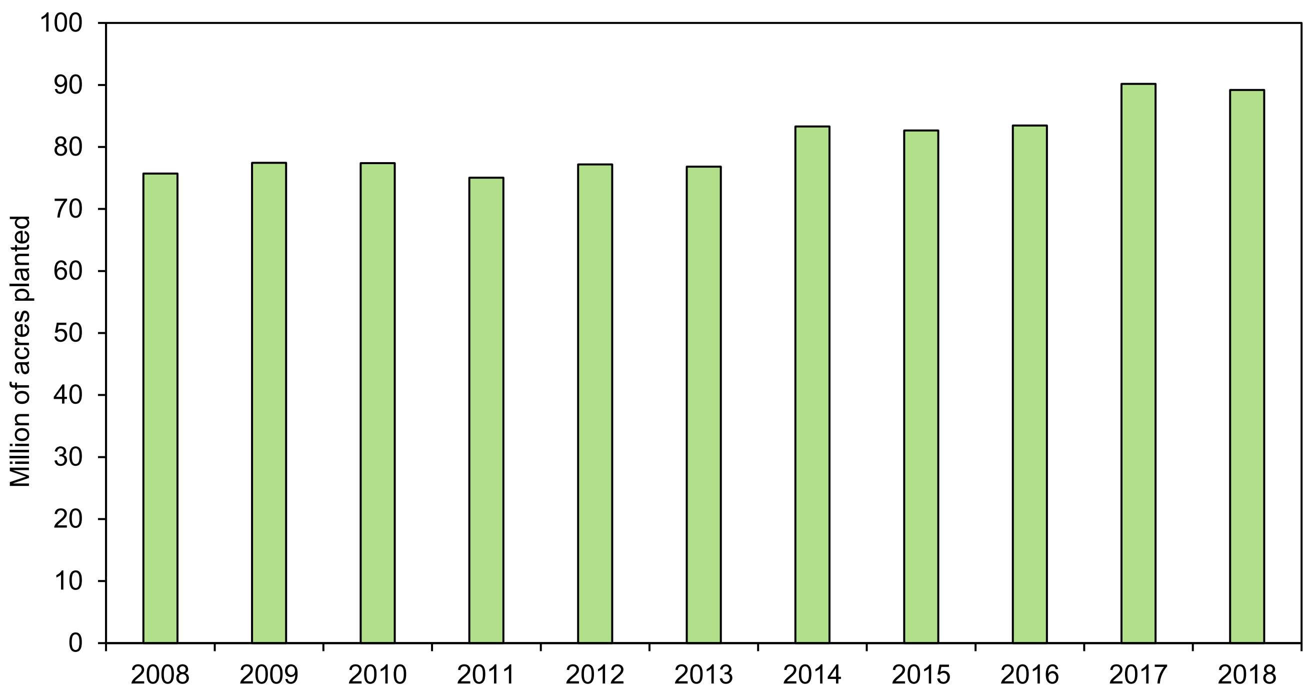

Figure 1.4.1. Acreage of soy planted in the United States from 2008 to 2018 (in million acres) (1).

As happens with corn, most soy is planted in the Midwest. In particular, the Midwestern States encompass 84 percent of soy plantings. The top 5 States for soy acreage are Illinois, Iowa, Minnesota, North Dakota, and Indiana (Figure 1.4.2 and Table 1.4.1).

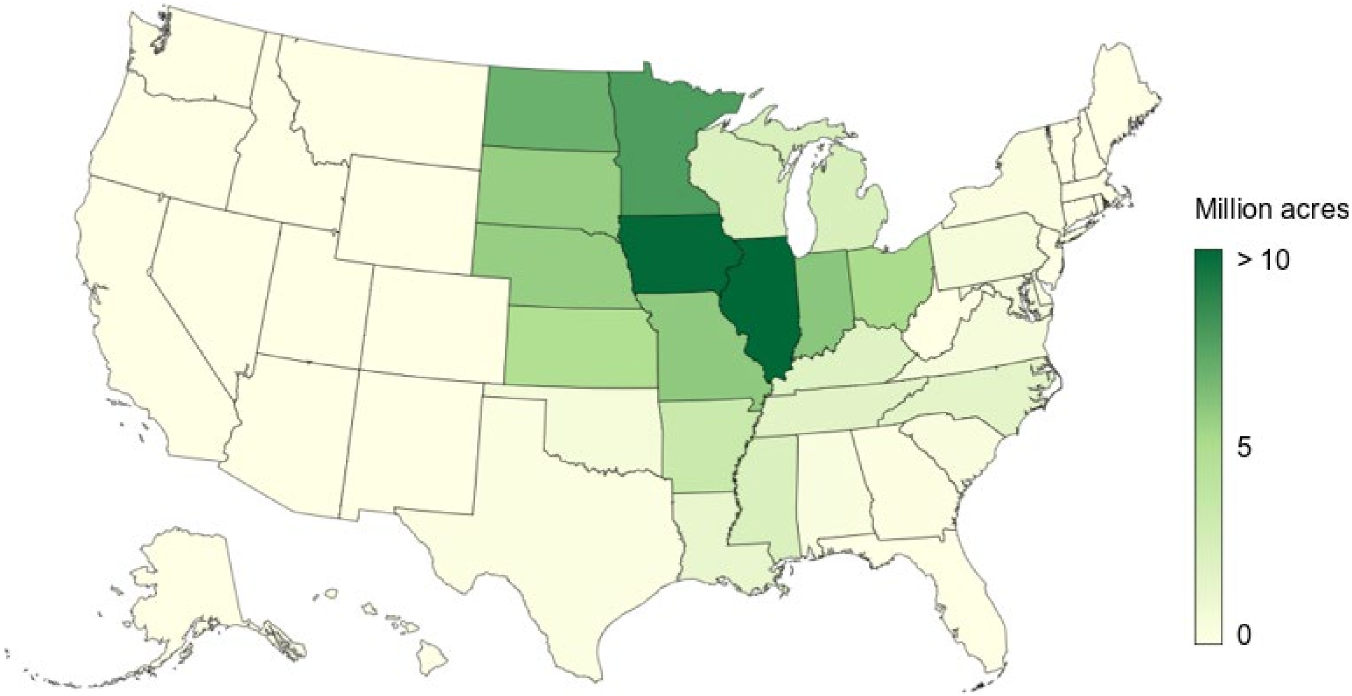

Figure 1.4.2. Total acreage of soybean in the United States by State in 2018 (in million acres) (2).

State	Million Acres	Percentage
Illinois	10.8	12.0
Iowa	10.0	11.0
Minnesota	7.8	8.6
North Dakota	6.9	7.7
Indiana	6.0	6.7

Table 1.4.1. 5 States with largest acreage of soybean in the United States in 2018 (in million acres) (2).

Production

Only 6 percent of soybeans are used whole. The majority is crushed to separate oil and meal. The production and the consumption of soy steadily increased in the last 10 years, from 80 and 48 million metric tons in 2008 to 123 and 60 million metric tons in 2018, respectively (Figure 1.4.3).
The production of soy is higher than the consumption, making the United States a net exporter.

The economic value of soy increased from 2008 to 2012, when it reached a maximum of $44 billion. Revenues remained nearly constant at $39 billion in 2018 (Figure 1.4.4).

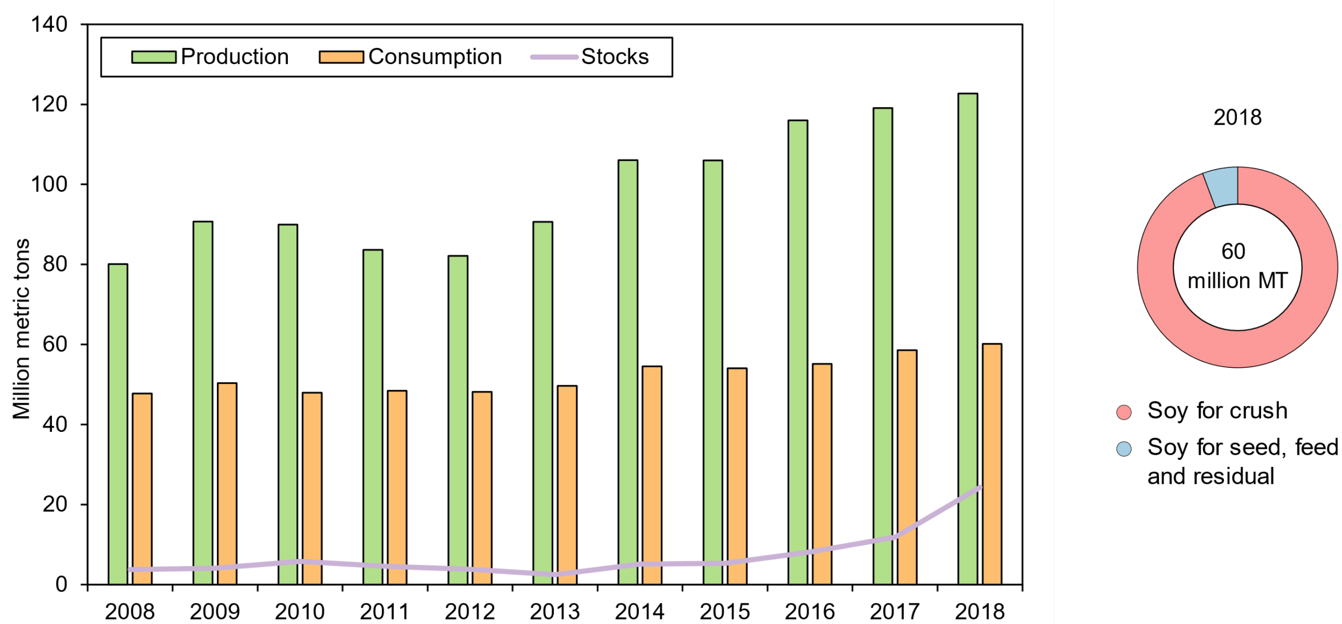

Figure 1.4.3. Total soy production versus total soy consumption and ending stocks of soy in the United States from 2008 to 2018 (in million metric tons) and soy uses in the United States in 2018 (1).

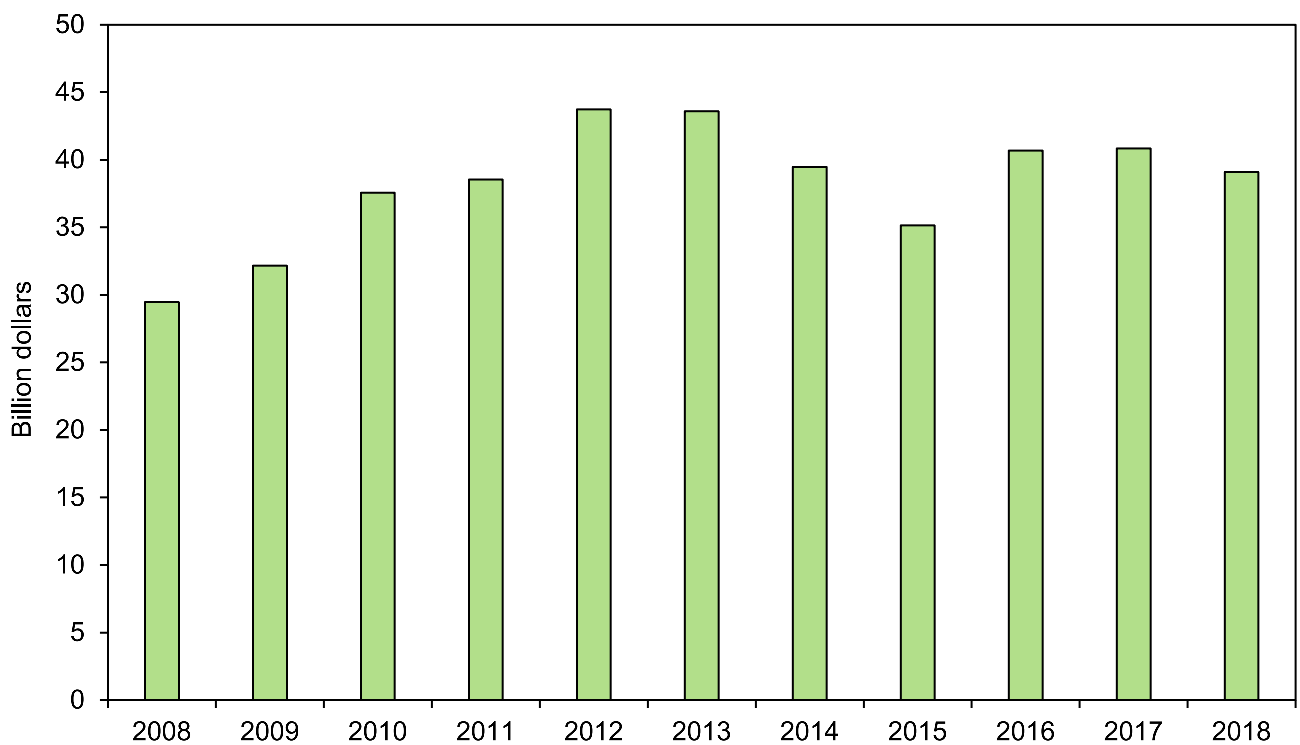

Figure 1.4.4. Total production of soy in the United States from 2008 to 2018 (in billion dollars) (1).

The geographical trends of soy production are the same as those analyzed in the Land Use section (see Figure 1.4.5 and Table 1.4.2).

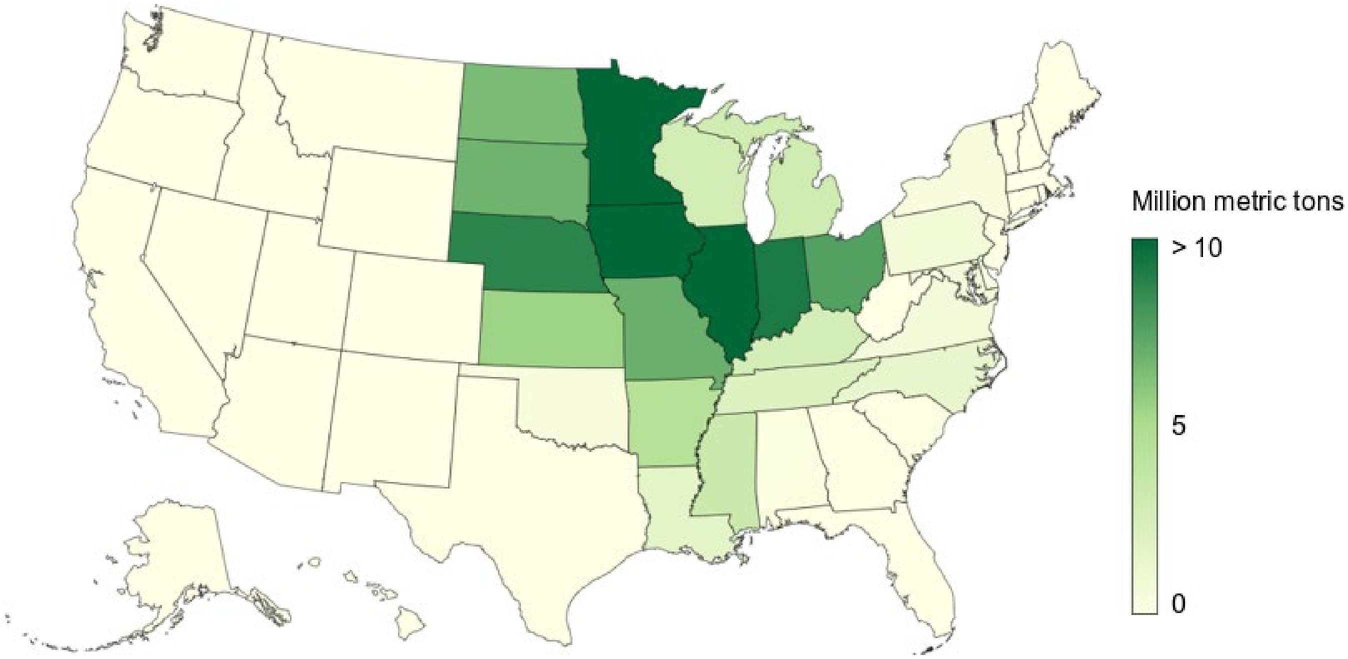

Figure 1.4.5. Total production of soybeans in the United States by State in 2018 (in million metric tons) (3).

State	Million metric tons	Percentage
Illinois	18.0	15.1
Iowa	14.9	12.4
Minnesota	10.1	8.5
Indiana	9.3	7.7
Nebraska	8.8	7.3

Table 1.4.2. Five States with highest production of soybeans in the United States in 2018 (in million metric tons) (3).

Soybean oil is the primary feedstock for biodiesel production. Fifty-four percent of biodiesel was produced from soybean oil in 2018 (4).

The amount of soybean oil used as feedstock for biodiesel production increased with the production of biodiesel (see Figure 2.2.3). In 2018, more than 3.2 million metric tons of soybean oil were used for biodiesel production, compared with just 1.5 million metric tons in 2008; 30 percent of total soybean oil was used for biodiesel production in 2018 (See Figure 1.4.6).

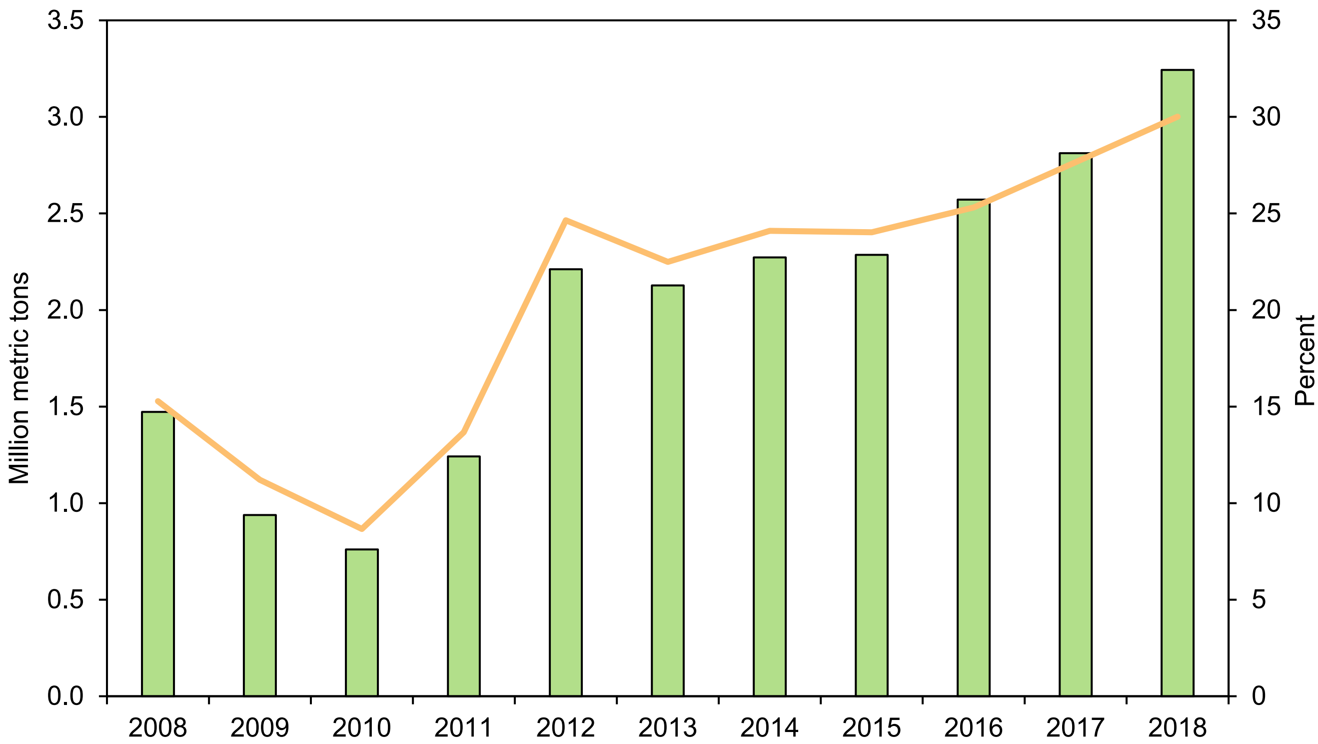

Figure 1.4.6. The bars represent the amount of soybean oil processed into biodiesel in the United States from 2008 to 2018 (in million metric tons) (left axis) and the line the percentage of total soybean oil production being devoted to biodiesel from 2008 to 2018 (in percentage) (right axis) (5).

Exports of soybeans increased by 47 percent in the last decade, from 35 million metric tons in 2008 to 51 million metric tons in 2018. As with corn, the 2012 drought caused U.S. soybean production to decline, which lowered supplies and exports. (Figure 1.4.3 and Figure 1.4.7). The largest market destination for U.S. soybeans is China, receiving twice as much soy as Mexico, the second-largest importing country (Figure 1.4.7).

Exports of soy meal and oil remained nearly constant from 2008 to 2018 around 10 and 1 million metric tons, respectively.

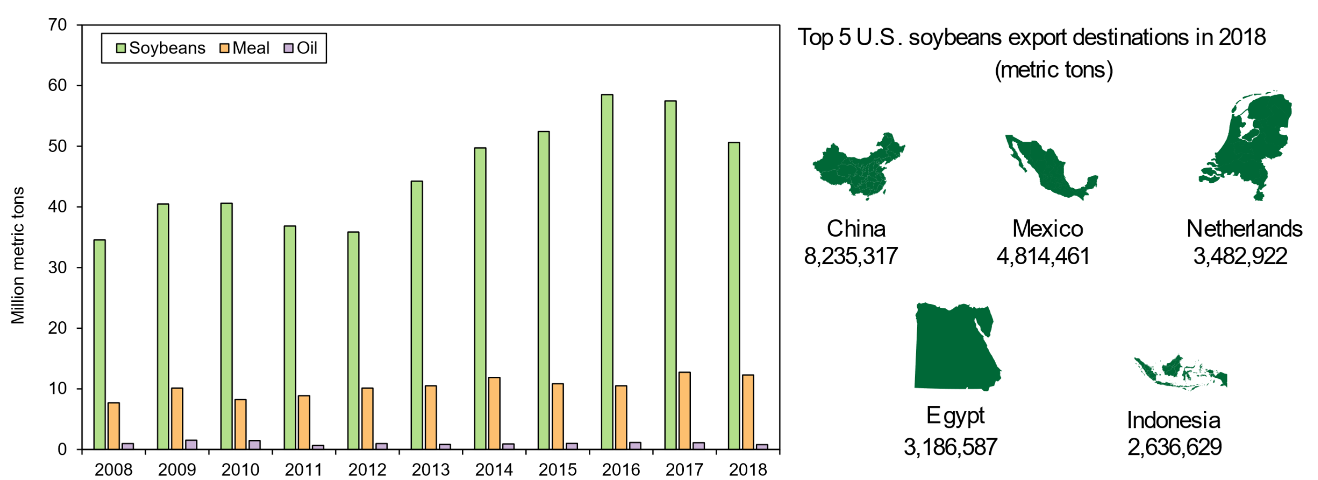

Figure 1.4.7. Exports of soybeans, soy meal, and soy oil from the United States from 2008 to 2018 (in million metric tons) (1) and the top 5 U.S. export destinations in 2018 (in metric tons) (6).

Since the United States is one of the world's major soybean suppliers, soybean imports are tiny in comparison with exports. In 2013 (following the severe 2012 drought when supplies were still tight), soybean imports reached 1.9 million metric tons (compared with 0.5 million metric tons in 2018) due to relatively tight supplies.

Imports of soy meal and soy oil are significantly lower than imports of soybeans. However, they increased by 680 percent and by 345 percent, respectively, in the last decade.

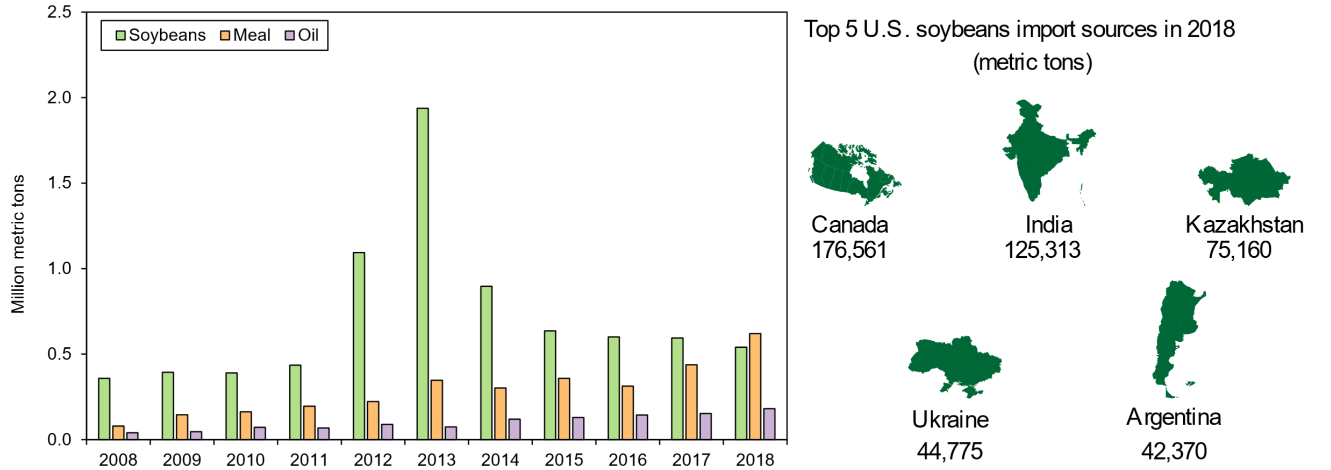

Figure 1.4.8. Imports of soybeans, soy meal, and soy oil in the United States from 2008 to 2018 (in million metric tons) (1) and top 5 United States import sources in 2018 (in metric tons) (6).

Economics

The farm price of soybeans increased considerably from 2008 to 2012 peaking at $533 per metric ton. Once the drought ended, production increased, and prices came down. By 2018, the price had decreased to $319 per metric ton. (Figure 1.4.9)

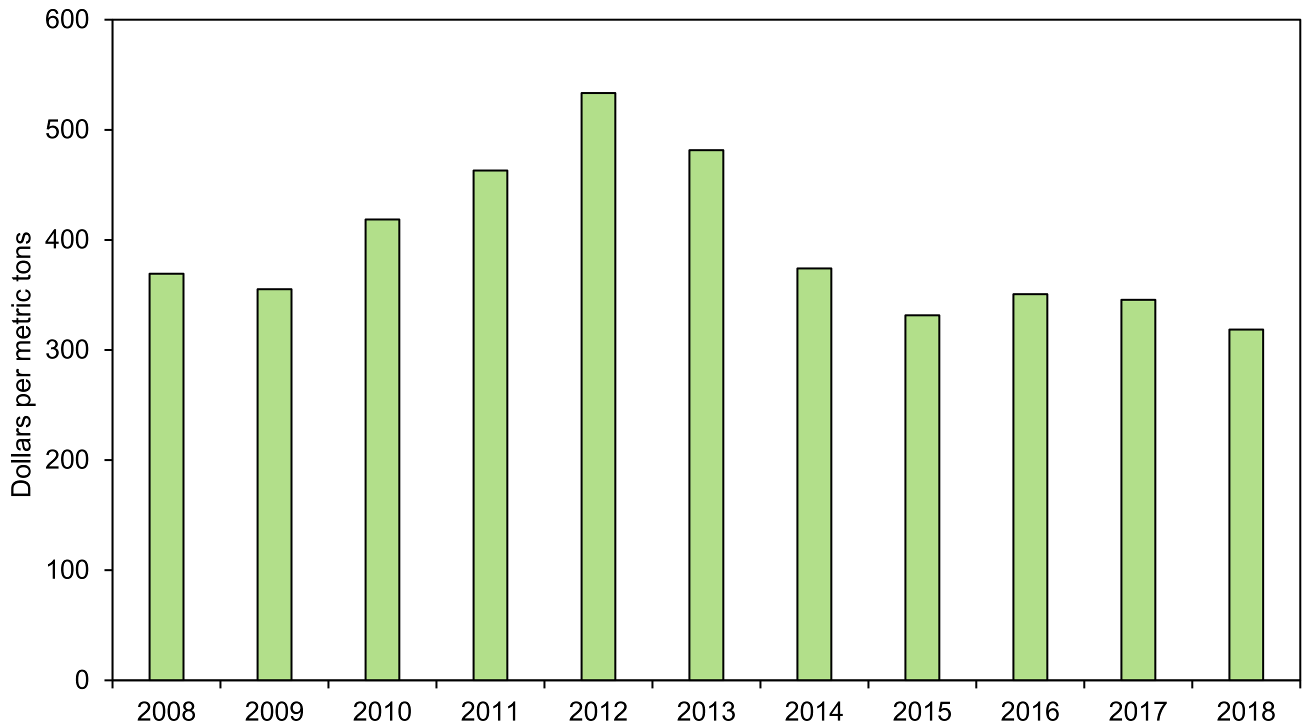

Figure 1.4.9. Farm price of soy from 2008 to 2018 (in dollars per metric ton) (1).

The economic value of soybean oil used for biodiesel production has varied due to the growth in biodiesel production and soybean oil price. The value of soybean oil used for biodiesel production increased from 2008 to 2012 to $2.3 billion--the same years during which biodiesel production and soybean oil prices increased. After 2012, biodiesel production growth offset some reduction in value due to decreasing prices. The value of soybean oil used for biodiesel production in 2018 was $2.1 billion (Figure 1.4.10).

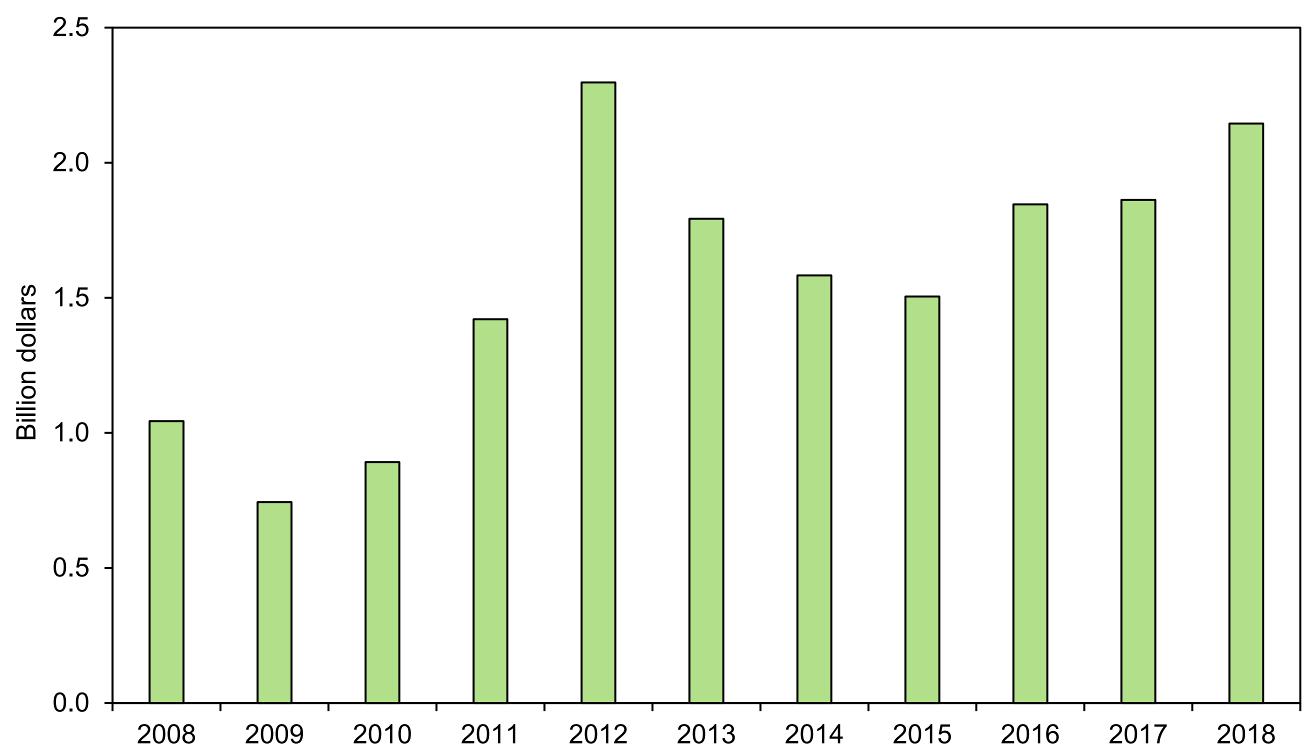

Figure 1.4.10. Economic value of soybean oil being used for biodiesel from 2008 to 2018 (in billion dollars) (5).

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1.5. Canola

Canola is a type of edible rapeseed low in erucic acid and glucosinolates. These characteristics make canola oil useful as a cooking oil, and the meal as a high-quality protein supplement for feedstock. In addition, canola oil is also used as an ingredient in soap and as feedstock to produce biodiesel (1-2).

Demand for canola in the United States increased over the years. There are two drivers behind this increase: the perception that it has heart-healthy properties which lead to an increase in consumption as culinary oil, and the increase of biodiesel production over the last few years which canola is one of its feedstocks. This increase in demand has been satisfied with imports of canola rather than an increase in the domestic production.

Canola oil, along with soy and corn, is used for biodiesel production; 9 percent of biodiesel was produced from canola oil in 2017.

More than 75 percent of canola is planted in just one State, North Dakota, which makes it the most concentrated crop, relative to all field crops.

The domestic price of canola is influenced by events in other rapeseed-producing nations. Most of the canola used in the United States is imported, so local canola growers must compete with farmers in other markets.

The number of canola acres planted has increased from 1.2 million acres to 2.1 million acres in 10 years (Figure 1.5.1), which is a very small acreage in comparison to other oilseeds.

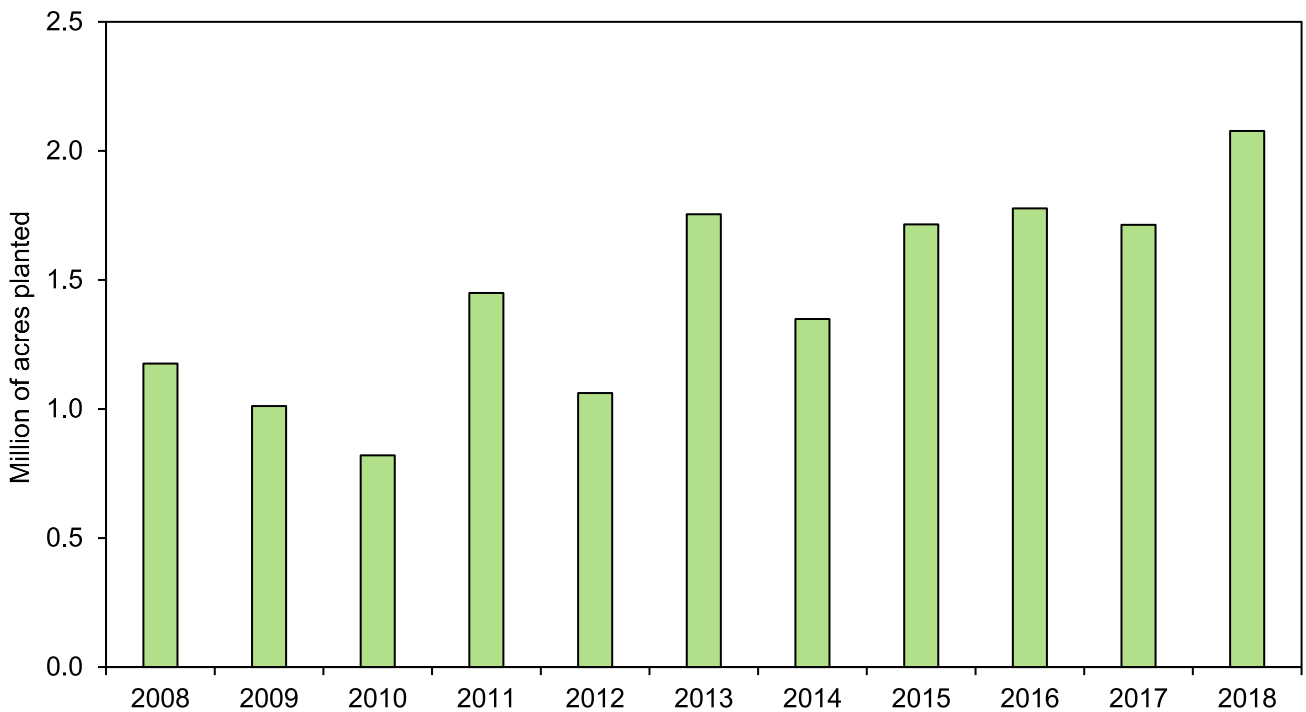

Figure 1.5.1. Acreage of canola planted in the United States from 2008 to 2018 (in million acres) (3).

Canola acreage at the State level is very concentrated; 77 percent of canola is planted in just one State, North Dakota (Figure 1.5.2 and Table 1.15.1).

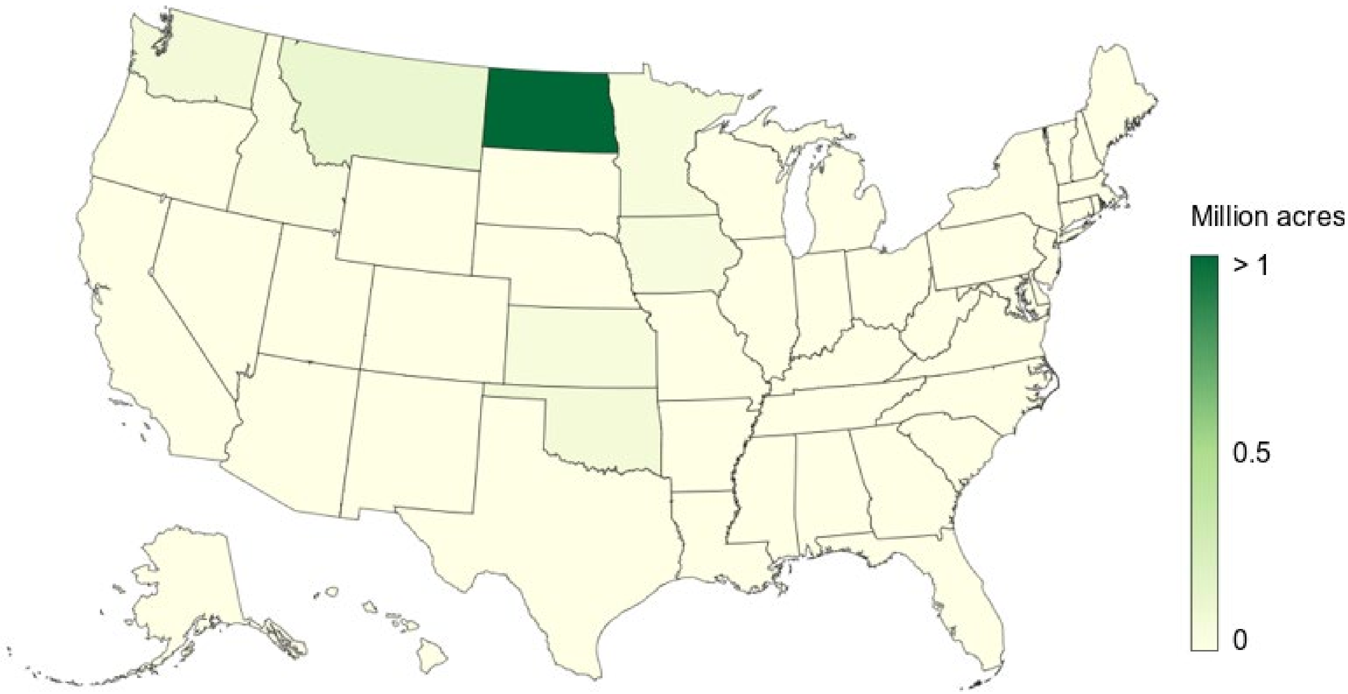

Figure 1.5.2. Total acreage of canola in the United States by State in 2018 (in million acres) (4).

State	Million Acres	Percentage
North Dakota	1.59	76.6
Montana	0.12	5.8
Oklahoma	0.07	3.4
Washington	0.07	3.4
Kansas	0.05	2.3

Table 1.5.1. 5 States with largest acreage of canola in the United States in 2018 (in million acres) (4).

Production

Since 2008, production and consumption of canola in the United States doubled, from 0.6 and 1.1 million metric tons to 1.4 and 1.9 million metric tons in 2018, respectively. Because the consumption of canola is consistently larger than the production, the United States is a net importer (Figure 1.5.3).

Canola is used as a feedstock for biodiesel production; and biodiesel production growth is one factor in the growth of canola consumption.

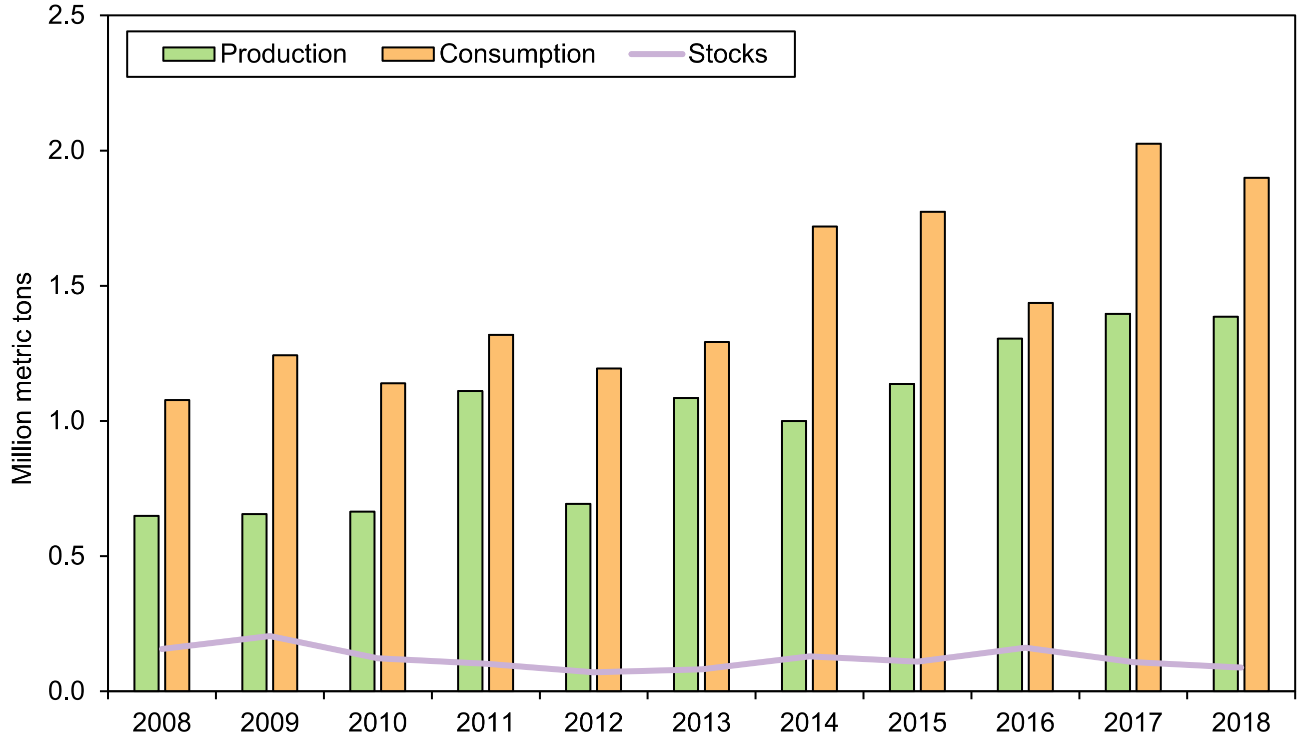

Figure 1.5.3. Total canola production versus total canola consumption and ending stocks of canola in the United States from 2008 to 2018 (in million metric tons) (3).

The year with the highest canola price and greatest farm revenue from canola was 2012 (Figure 1.5.4).

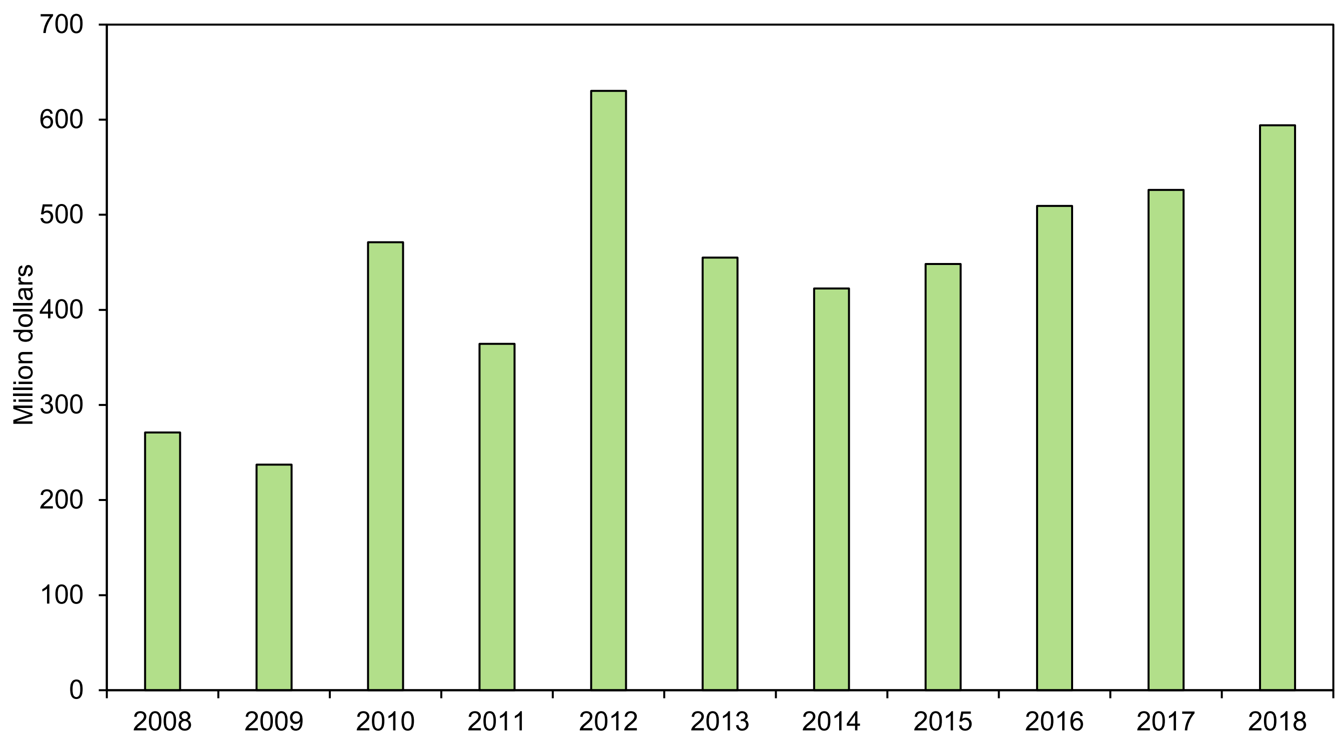

Figure 1.5.4. Total production of canola in the United States from 2008 to 2018 (in million dollars) (5).

Canola production by State is highly correlated with acreage by State; as a consequence, the geographical trends of canola production are the same as those analyzed in the Land Use section (Figure 1.5.5 and table 1.5.2).

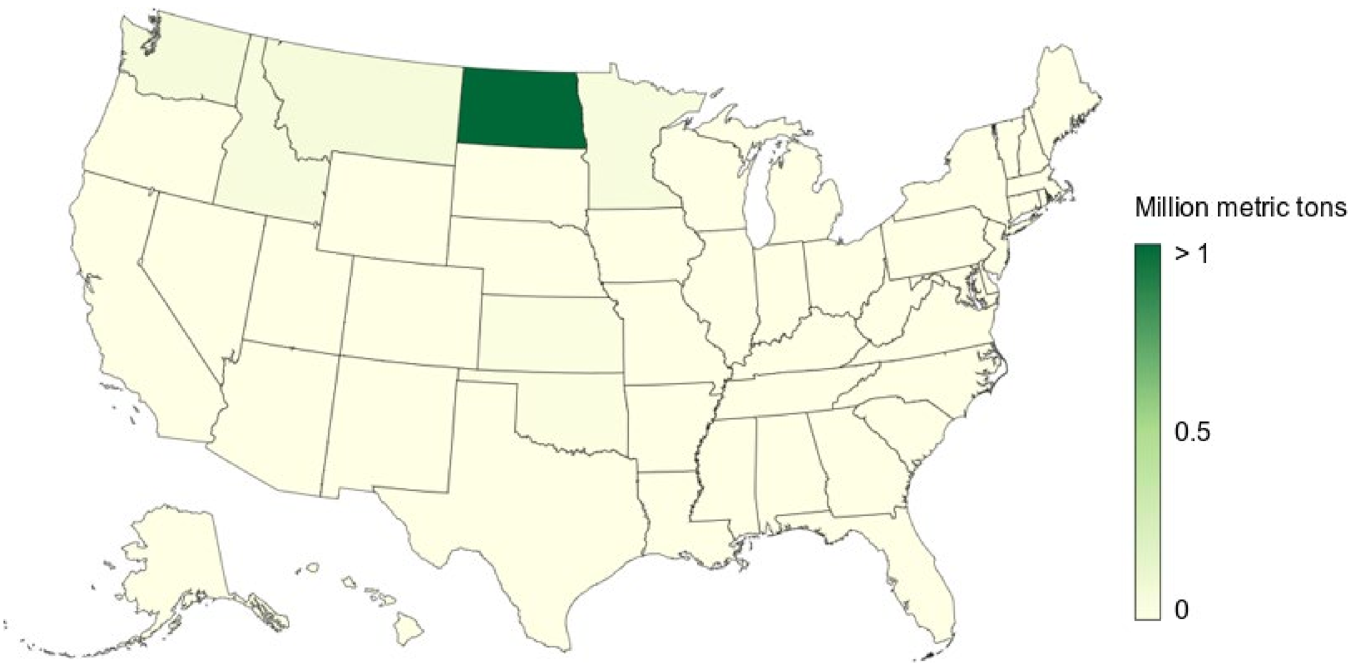

Figure 1.5.5. Total production of canola in the United States by State in 2018 (in million metric tons) (6).

State	Million metric tons	Percentage
North Dakota	1.40	85.7
Montana	0.06	3.6
Washington	0.05	3.3
Minnesota	0.04	2.6
Idaho	0.04	2.4

Table 1.5.2. 5 States with highest production of canola in the United States in 2018 (in million metric tons) (6).

Canola oil is one of the vegetable oils used for biodiesel production, along with corn and soy. Nine percent of United States biodiesel was produced from canola oil according to the Energy Information Administration (7). In 2018, 20 percent of total canola oil produced in the United States was used for biofuels production, compared with just 7 percent in 2010 (Figure 1.5.6).

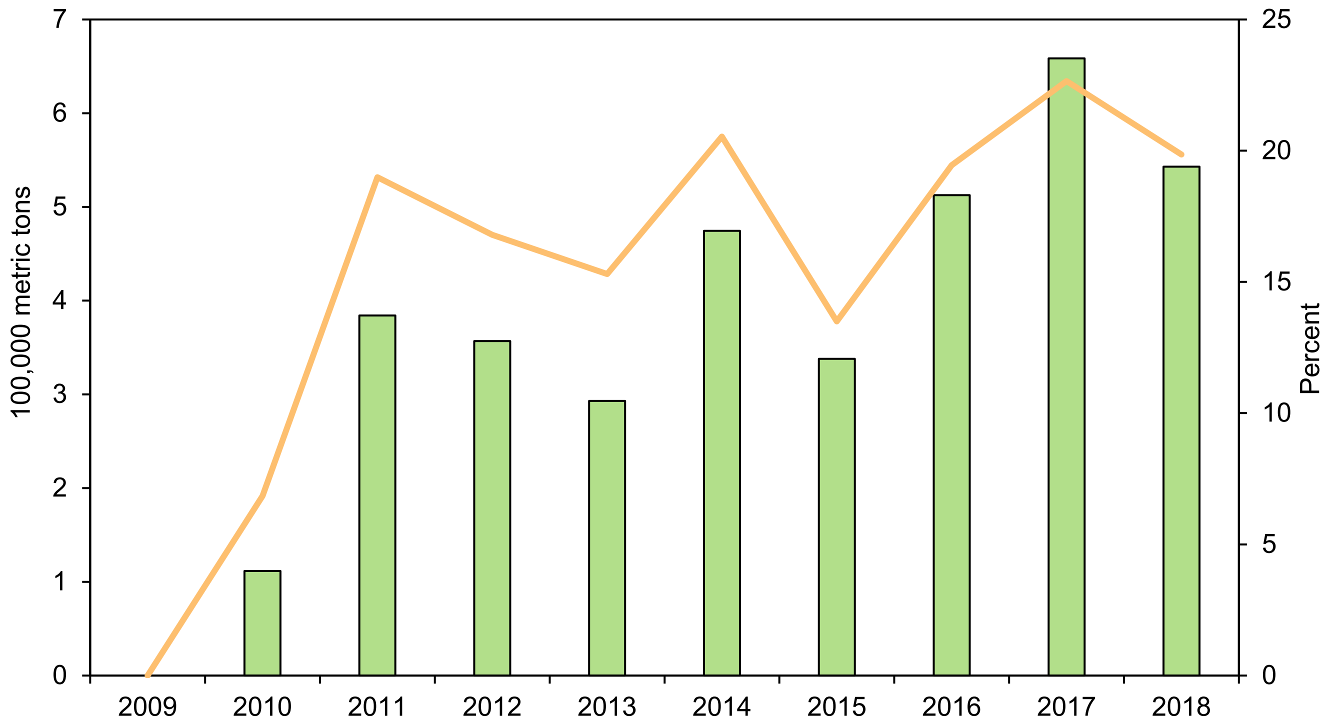

Figure 1.5.6. The bars represent the amount of canola oil processed into biodiesel in the United States from 2009 to 2018 (in 100,000 metric tons) (left axis) and the line the percentage of total canola oil production being devoted to biodiesel from 2009 to 2018 (in percentage) (right axis) (2, 8).

Exports of canola decreased in the last decade from 0.5 million metric tons in 2008 to 0.3 million metric tons in 2018. Most of the U.S. canola was exported as canola oil and canola seed (Figure 1.5.7) (3).

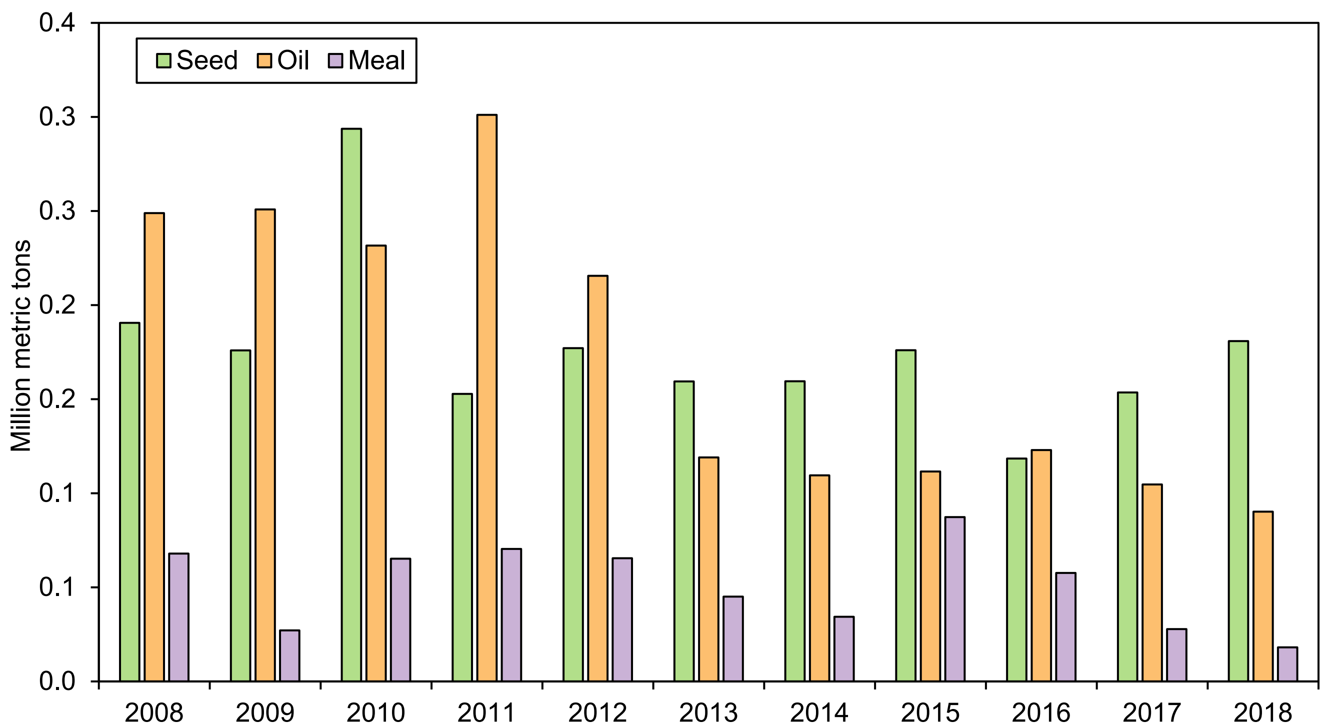

Figure 1.5.7. Total canola exported by the United States from 2008 to 2018 (in million metric tons) (3).

Imports of canola products increased from 3.6 million metric tons in 2008 to 5.6 million metric tons in 2018. In that year, 58 percent of total canola was imported as meal, 32 percent was imported as oil, and 10 percent was imported as canola seed that was crushed in the United States in 2018 (3).

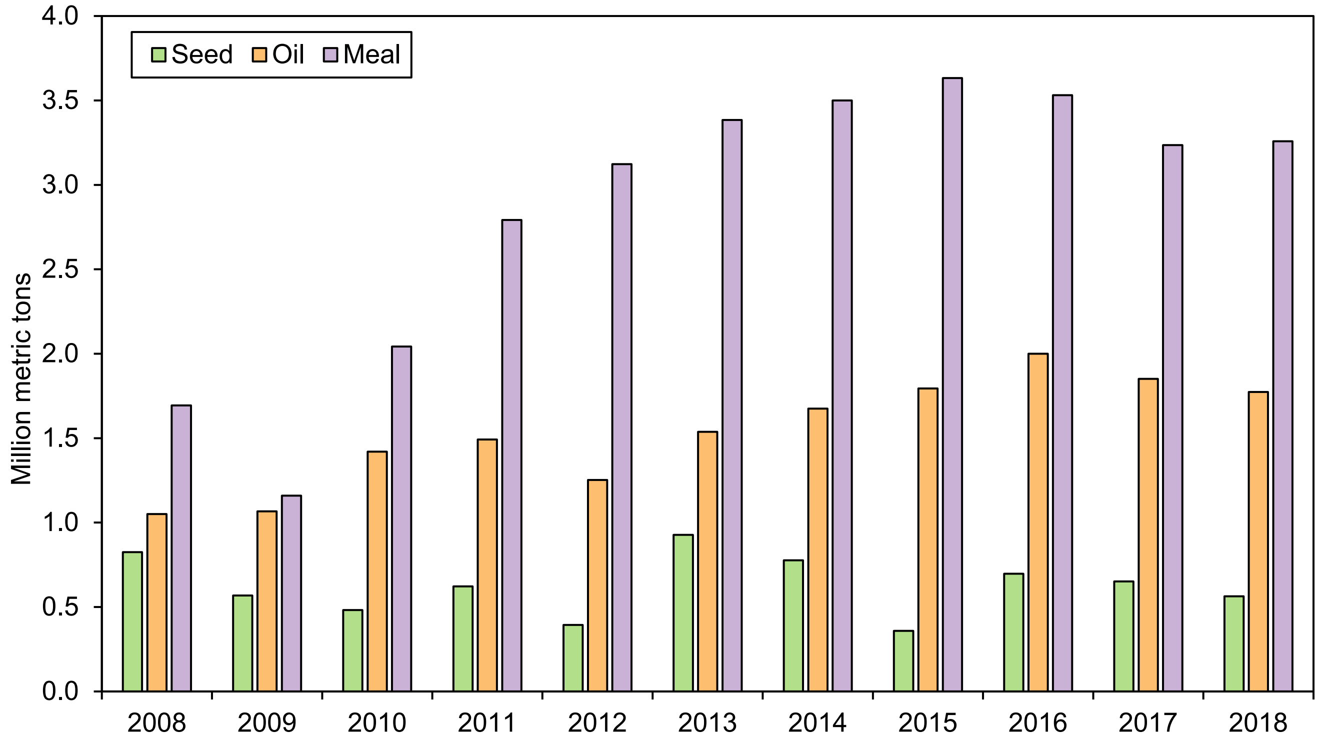

Figure 1.5.8. Total canola imported by the United States from 2008 to 2018 (in million metric tons) (3).

Economics

The price of canola increased from $360 per metric ton in 2008 to $522 per metric ton in 2012. After that, the price decreased to $344 per metric ton in 2018 (Figure 1.5.9.). Since canola imports are a significant portion of total consumption, factors in other producing nations likely influence the price.

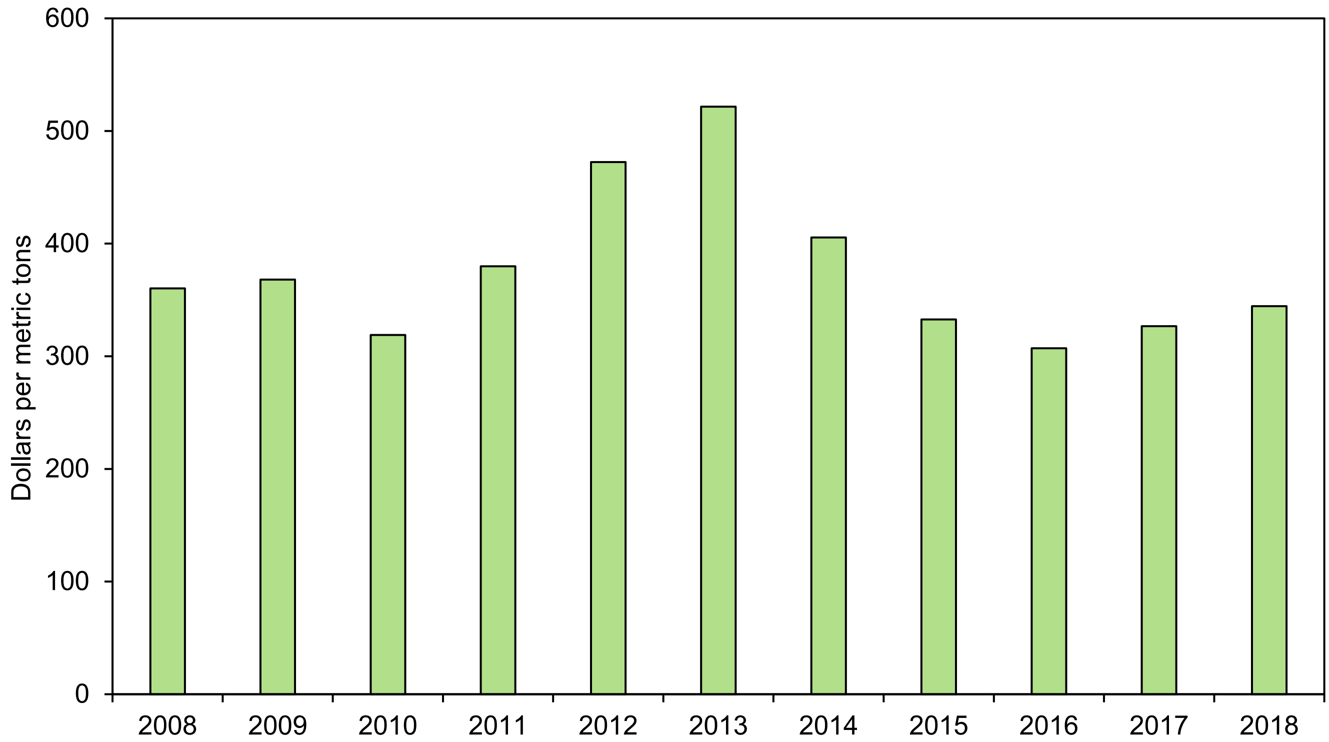

Figure 1.5.9. Farm price of canola from 2008 to 2017 (in dollars per metric ton) (9).

The value of canola oil used for biodiesel jumped in 2011, from $100 million in the prior year to $500 million. After that, the value of canola oil fluctuated between $300 million and $550 million. In 2018, the value of canola oil for biodiesel was $458 million (Figure 1.5.10).

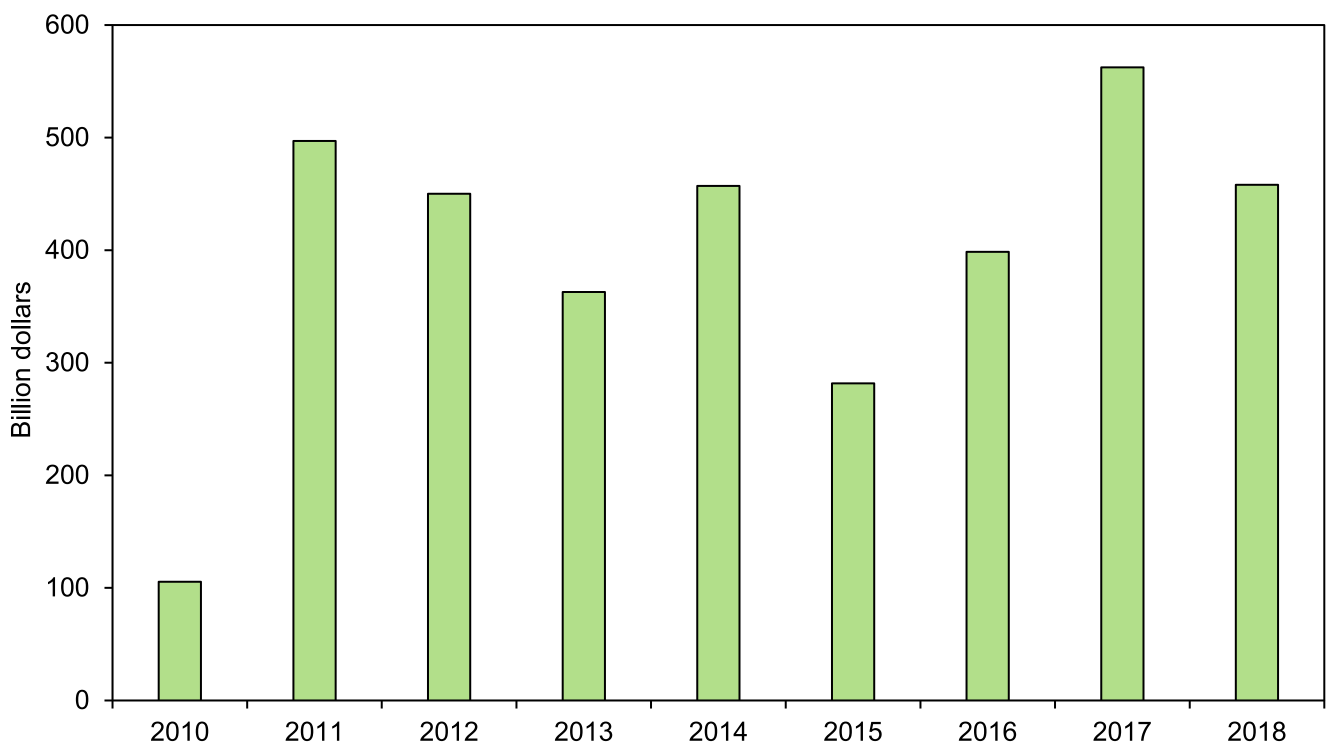

Figure 1.5.10. Economic value of canola oil used for biodiesel from 2010 to 2018 (in million dollars) (8, 9).

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2. BIOENERGY INDICATORS

2.1. Summary

Number of bioenergy facilities in the U.S. ↑ 1% in 2018

TOP 5 TYPES OF BIOENERGY PLANTS

2017	2018
2,527 plants	**2,552 plants**
Biogas [1,999]	Biogas [2,027]
Ethanol [209]	Ethanol [210]
Wood Pellets [148]	Wood Pellets [140]
Biodiesel [95]	Biodiesel [100]
Waste to energy [76]	Waste to energy [75]

Total energy consumed in the U.S. from bioenergy sources ↑ 1.2% in 2018

TOP 5 BIOENERGY SOURCES

2017	2018
4,298 Trillion BTUs	**4,350 Trillion BTUs**
Wood Pellets [2,181]	Wood Pellets [2,261]
Ethanol [1,226]	Ethanol [1,220]
Waste to energy [495]	Waste to energy [487]
Biodiesel [253]	Biodiesel [243]
Biogas [143]	Biogas [139]

ETHANOL

Exports	Imports	Jobs
↑ 23%	↓ 29%	↑ 2.4%
2017 1.4B GALLONS VS 2018 1.7B GALLONS	2017 76M GALLONS VS 2018 54M GALLONS	2017 357,493 VS 2018 366,153

BIODIESEL

Exports	Imports	Direct Jobs
↑ 11%	↓ 58%	↑ 16%
2017: 93M GALLONS VS 2018: 104M GALLONS	2017: 394B GALLONS VS 2018: 167B GALLONS	2017: 62,200 VS 2018: 72,300

WOOD PELLETS

Exports	Imports	Direct Jobs
↑ 16%	↑ 4%	↑ 2.5%
2017: 5.2 MMT VS 2018: 6.0 MMT	2017: 0.21 MMT VS 2018: 0.22 MMT	2017: 24,432 VS 2018: 25,040

2.2. Starch and Cellulosic Ethanol

Ethanol is a renewable fuel derived from plant materials, such as sugar, starches, and cellulosic materials. Figure 2.2.4 shows that 98 percent of ethanol produced in the United States is derived from starchy feedstocks, with corn being the leading crop used as a feedstock for domestic ethanol production (1). Although cellulosic materials are not widely used as a feedstock for ethanol production, they present several potential advantages over starch. One of its main advantages is its higher availability, given that it can be extracted from materials that otherwise would be considered waste (2).

Ethanol is used as a biofuel for transportation. It can be used in several blends with gasoline, in which case, the composition of the fuel is labeled as “E” plus two digits, the two digits being the percentage of ethanol in the fuel. The most common blend is 10 percent ethanol and 90 percent gasoline, which is known as E10. This blend does not require any special modification in the combustion engines as all automakers design their gasoline vehicles to accept blends up to E10. Cars and light trucks built for model years 2001 and later are also permitted by EPA regulations to use 15 percent ethanol blends (E15). Ethanol is also available as E85, also referred to as “flex fuel. E85 fuel contains between 51-83 percent ethanol, depending on geography and season. Flex fuel vehicles are specially designed to run on blends up to E85 (2).

The number of ethanol production facilities in the United States increased between 2010 and 2018, from 204 plants in 2010 to 210 plants in 2018 (3-10). This accounts for almost 370,000 jobs according to the Renewable Fuel Association (3-10). Most of these facilities are located in the Midwest (1).

Ethanol production has been steadily increasing; a record 16 billion gallons of ethanol were produced in the United States in 2018 (11). The United States is the world’s leading ethanol producer, producing 56 percent of total world output in 2018 (12) and exporting 1.7 billion gallons of ethanol in the same year, primarily to Brazil (29%), Canada (20%), and India (9%) (13,14).

Infrastructure

The number of ethanol production facilities has increased in the last 10 years, from 204 plants in 2008 to 210 plants in 2018, as shown in Figure 2.2.1 (3-10). Ninety-seven percent of all ethanol production facilities in the United States use starch as a feedstock (Figure 2.2.2) (1).

In 2018, four ethanol facilities were under construction in the United States, with an additional proposed facility (Table 2.2.1 and Figure 2.2.2) (1).

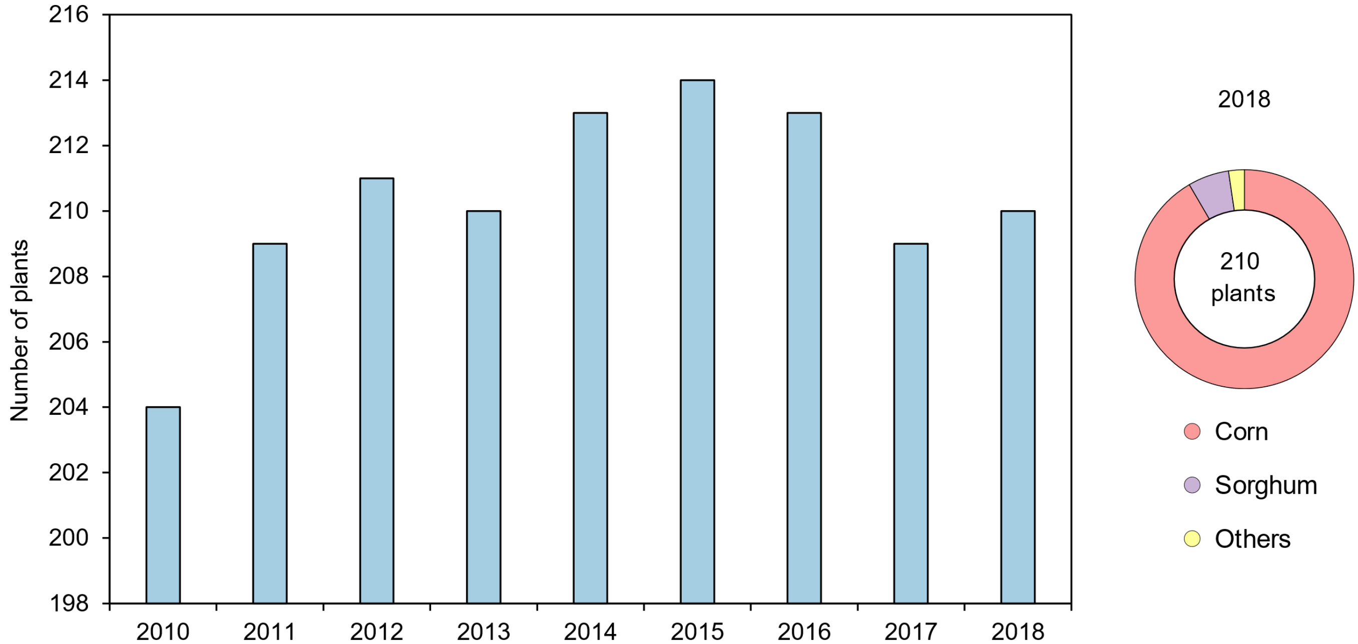

Figure 2.2.1. Total number of ethanol plants in the United States from 2010 to 2018 and ethanol plants by feedstock in 2018 (3-10).

ETHANOL PHYSICAL INFRASTRUCTURE	2010	2011	2012	2013	2014	2015	2016	2017	2018
# of ethanol plants in the United States	204	209	211	210	213	214	213	209	210
# of ethanol plants operational	-	193	194	192	198	199	200	201	204
# of existing plants under construction	-	-	-	7	3	3	3	7	4
# of proposed ethanol plants	-	-	-	-	-	-	-	11	1
# of States that have an ethanol production facility	29	29	29	28	29	29	28	28	27

Table 2.2.1. The physical infrastructure of first-generation ethanol industry facilities in the United States from 2010 to 2018 (3-10).

Existing ethanol production facilities in 2018 by location, capacity, and feedstock are presented in Figure 2.2.2. Most of the production plants are located in the Midwest. Specifically, 22 percent of all existing ethanol production facilities are located in Iowa, 13 percent in Nebraska, and 10 percent in Minnesota (see Table 2.2.2 for additional details) (1). These top three ethanol-producing States are also among the top five corn growing States (see Figure 1.2.2).

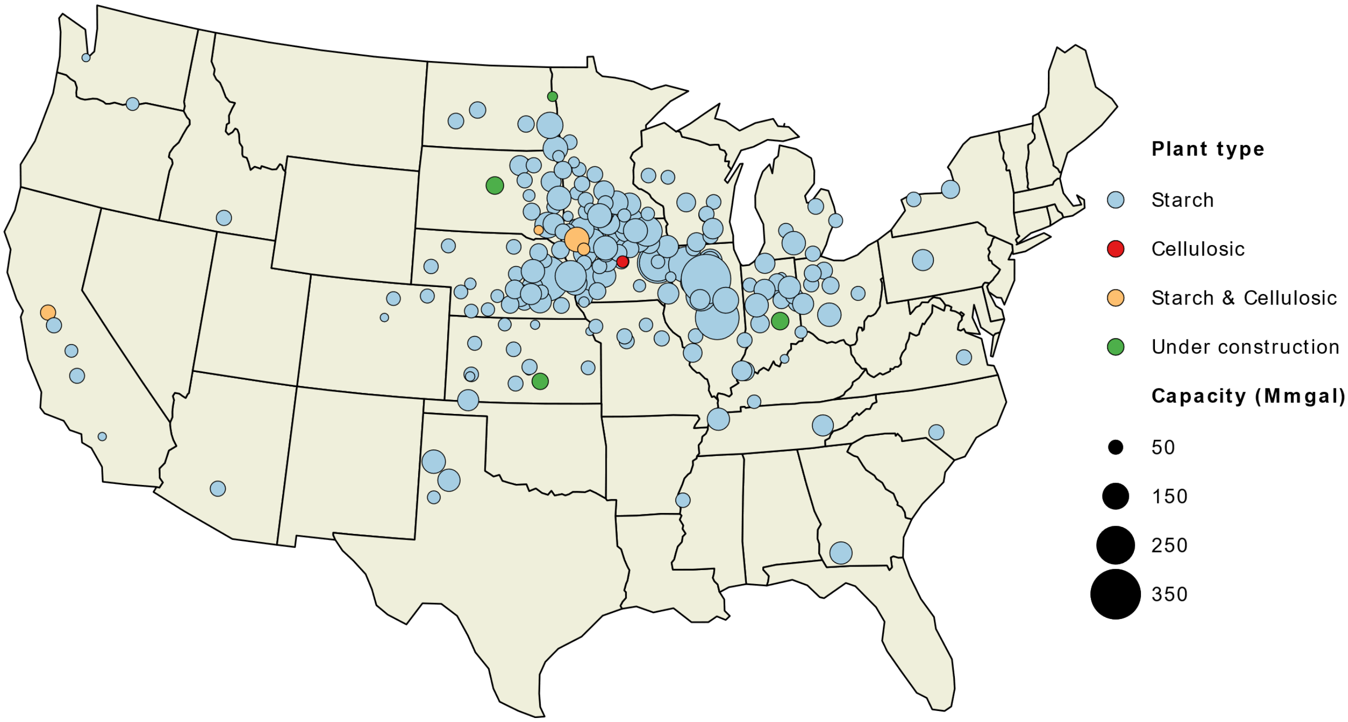

Figure 2.2.2. Ethanol production facilities in 2018 by location, capacity, and type in the United States (in million gallons) (1).

State	Number of ethanol facilities	Percentage of total facilities
Iowa	43	21.7
Nebraska	26	13.1
Minnesota	19	9.6
South Dakota	16	8.1
Indiana	15	7.6

Table 2.2.2. Top 5 States for ethanol production facilities in the United States in 2018 (1).

As shown, starch is the most common feedstock to produce ethanol in the United States. Only one plant in Emmetsburg, Iowa, uses cellulosic materials as unique feedstock for ethanol production, and five facilities use both, starch and cellulosic materials (Figure 2.2.2).

Starch Ethanol

Most of the ethanol produced in the United States is derived from corn starch through dry or wet mill processing. The sugar contained in the starch of sugar rich crops like corn is easy to extract and ferment which makes the production of ethanol affordable (15).

Starch ethanol production requires large amounts of cropland to grow the crops, potentially competing with cropland used for human and/or animal consumption. However, starch ethanol only uses the starch from the parts of the plant that are rich in sugar (for example, the kernel in corn plants). This leaves the remainder of the plant (which contains proteins, fiber, and oil) and the additional protein from yeast to be collected and used as a nutritious, low-cost animal feed (16).

Cellulosic Ethanol

Cellulosic ethanol is ethanol produced by fermenting the sugars contained in cellulose to obtain ethanol. The most common feedstocks used to produce cellulosic ethanol are corn stover, corn kernel fiber, grasses, wood, wheat straw, and municipal solid waste (17).

Production of ethanol from cellulose has the advantage of abundant feedstocks, compared to starch ethanol. It takes advantage of materials that otherwise would be classified as low-value materials in other industries and uses those materials as an energy feedstock. In addition, cellulosic ethanol rates as an Advanced biofuel resulting in a price premium under the California Low Carbon Fuel Standard (LCFS) and the Federal Renewable Fuel Standard (RFS) (2).

Despite its multiple benefits, cellulosic ethanol is not as widely used as starch ethanol. The main driver offered is the higher cost of production. Cellulosic ethanol is more expensive to produce, includes greater technical risk, and higher capital costs. The sugars contained in cellulosic feedstocks are also harder to extract, a property termed biomass recalcitrance (18).

Cellulosic ethanol can be produced following three pathways:

- Biochemical: Enzymes and pretreatment processes deconstruct cellulose and hemicellulose into sugars. Then, microbes are used to ferment sugars into ethanol.
- Thermochemical: Feedstocks are transformed into synthesis gas, comprised of hydrogen and carbon monoxide using heat, and then it is catalytically converted to ethanol, and other intermediates.
- Hybrid: This pathway combines the biochemical and the thermochemical pathways.

As of 2017, seven facilities produced cellulosic ethanol in the United States, with a production capacity of 30 million gallons per year. POET's plant only produced cellulosic ethanol and had a capacity of 20 million gallons per year. The other six are producing cellulosic ethanol from corn fiber at their existing corn ethanol plants (19).

Production

The United States is the world's leading ethanol producer, accounting for 56 percent of global ethanol production in 2018 (12).

Production of ethanol has grown since 2010, with 16 billion gallons of ethanol produced in 2018. Consumption increased from 2010 to 2017 but decreased in 2018 to 14 billion gallons (11). As shown in Figure 2.2.3, ethanol production is greater than consumption, which makes the United States a net exporter of ethanol. Most of the ethanol consumed in the United States is used in the transportation sector (11).

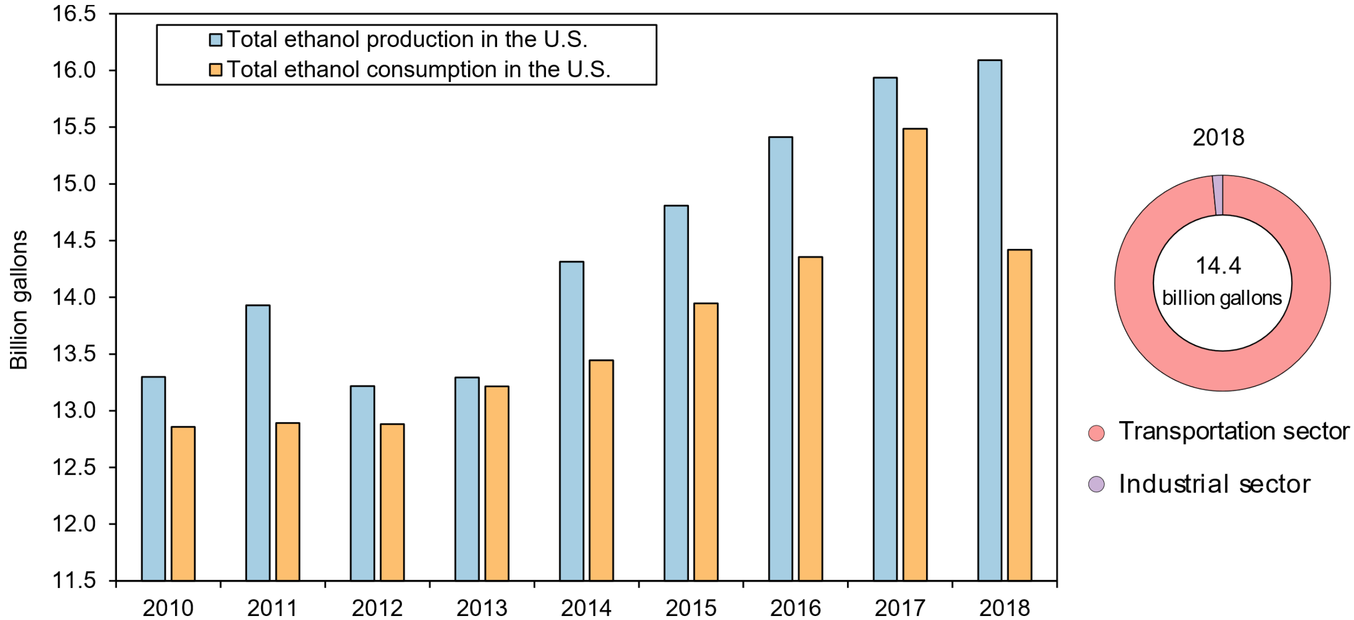

Figure 2.2.3. Left: Total ethanol production and total ethanol consumption in the United States from 2010 to 2018 (in billion gallons). Right: consumption of ethanol by sector in the United States in 2018 (11).

When classified by feedstock, 98 percent of total ethanol produced in the United States is starch ethanol, and 2 percent is cellulosic ethanol (Figure 2.2.4) (1).

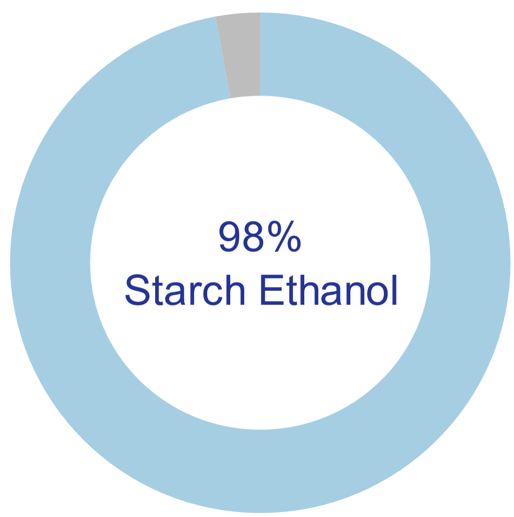

Figure 2.2.4. Percentage of ethanol production in the United States by feedstock in 2018 (1). Starch ethanol depicted in blue, cellulosic ethanol depicted in red.

About 90 percent of ethanol production capacity is located in the Midwest; the top five producing States are Iowa, Nebraska, Illinois, Minnesota, and South Dakota (Figure 2.2.5 and Table 2.2.3) (1).

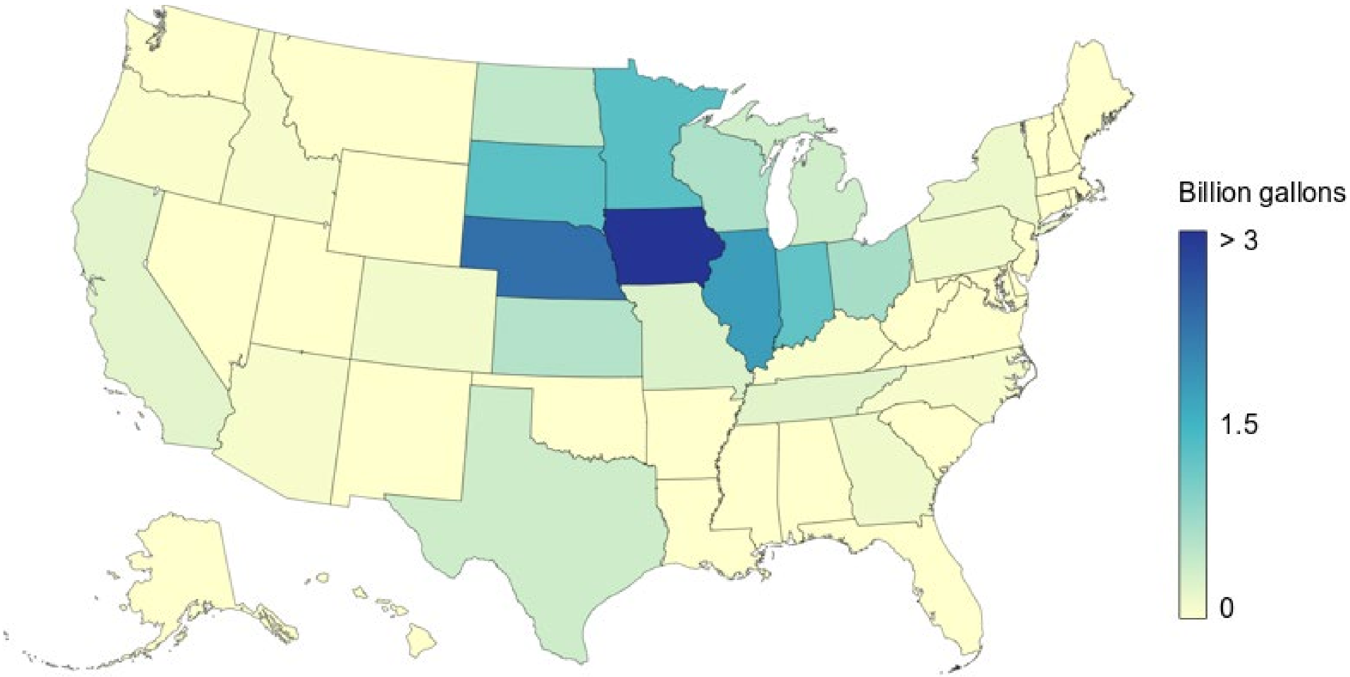

Figure 2.2.5. Total production capacity of ethanol in the United States by State in 2018 (in billion gallons) (1).

State	Billion gallons	Percentage of total U.S. capacity
Iowa	4.6	26.6
Nebraska	2.3	13.5
Illinois	1.8	10.4
Minnesota	1.3	7.6
South Dakota	1.3	7.5

Table 2.2.3. Top 5 States with the highest production capacity of ethanol in the United States in 2018 (in billion gallons) (1).

Exports of ethanol follow the same pattern as domestic ethanol production (Figure 2.2.3): the years with the highest production are also the years with the largest exports. The United States exported 1.7 billion gallons of ethanol in 2018 (13). Brazil, Canada, and India were the top three international markets for the ethanol exports of the United States (Figure 2.2.6).

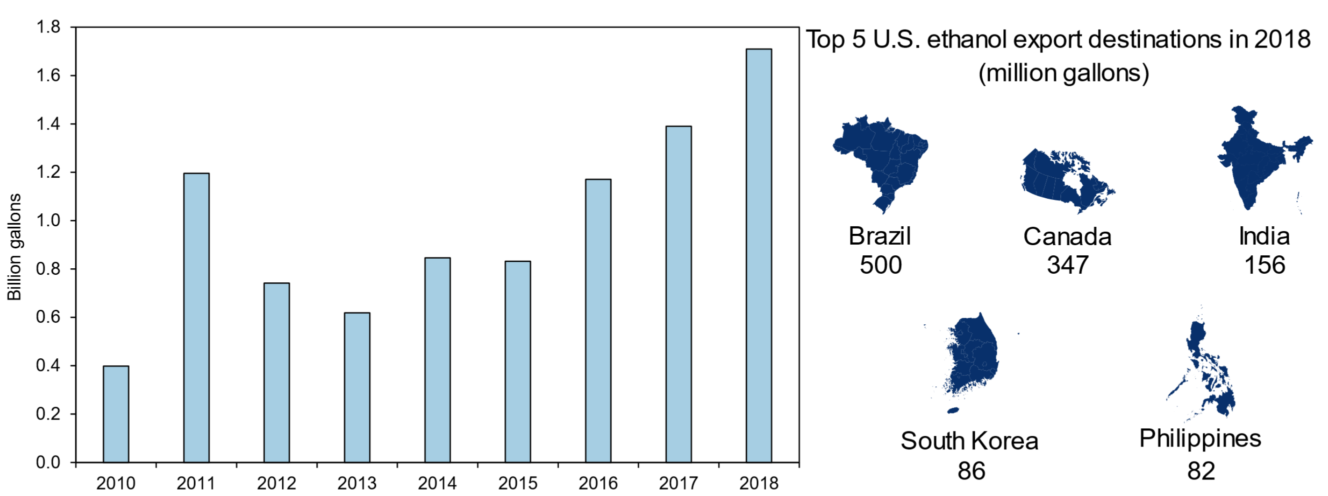

Figure 2.2.6. Exports of ethanol in the United States from 2010 to 2018 (in billion gallons) (13) and top 5 United States exports destinations in 2018 (in million gallons) (14).

Imports of ethanol are very small in comparison with exports. The highest volumes of imports into the United States were in 2012 and 2013, with 500 and 400 million gallons of ethanol imported respectively (Figure 2.2.7); these years also marked the lowest U.S. ethanol production (Figure 2.2.2), which can be attributed to the drought that reduced significantly corn production in those years (20).

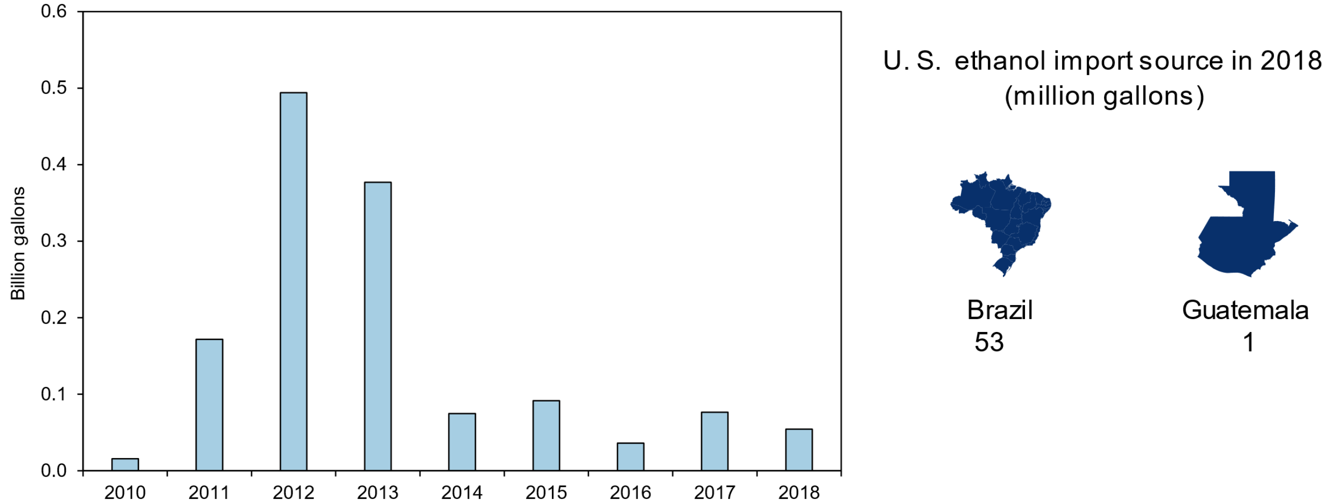

Figure 2.2.7. Imports of ethanol in the United States from 2010 to 2018 (in million gallons) (20) and import source in 2018 (in million gallons) (21).

Economics

The prices of ethanol, E85 and E10, have significantly decreased since 2014, following the same trend as the price of crude oil. In 2018, however, the ethanol price kept decreasing until reaching 1.9 dollar per gasoline gallon equivalent while E85, E10, and crude oil prices increased (Figure 2.2.8) (22-25).

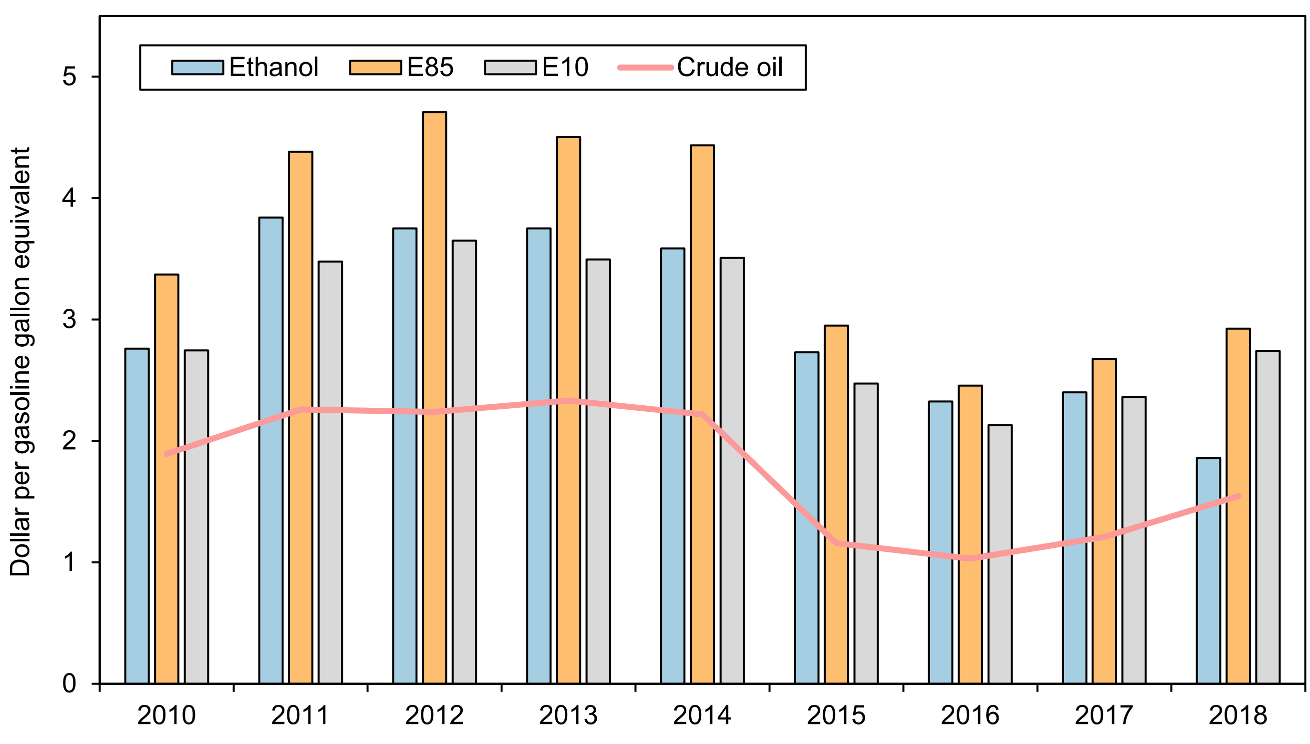

Figure 2.2.8. Evolution of prices for ethanol, E85, E10 and crude oil. Bars represent the relative prices of ethanol, E85 and E10 (blue, orange and grey bars, respectively) from 2010 to 2018 (in USD per gasoline gallon equivalent) (22,23), while the red line depicts the price of crude oil for the same time period (in USD per gasoline gallon equivalent) (25).

The number of jobs related to the ethanol industry remained relatively constant between 2010 and 2018, with a slight decrease in total jobs from 400,000 in 2010 to 366,153 in 2018 (Figure 2.2.9) (3-10).

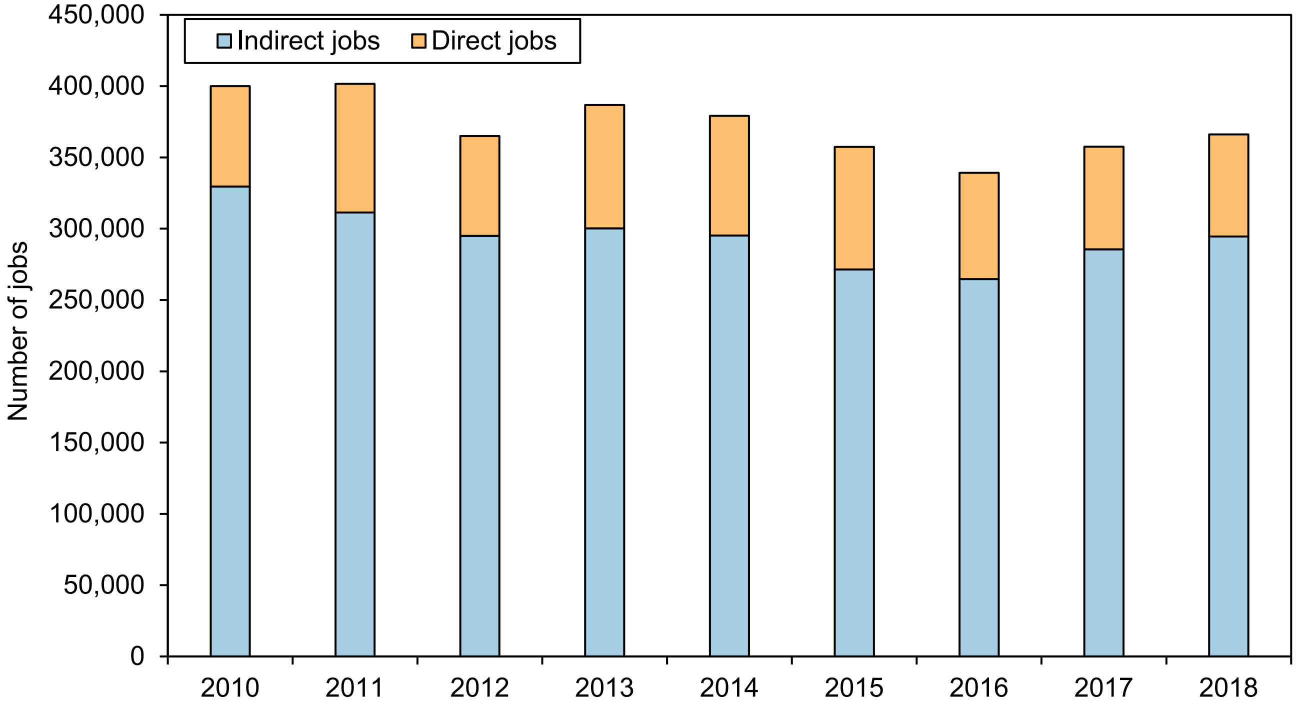

Figure 2.2.9. Number of total jobs generated from the biobased ethanol industry from 2010 to 2018 (3-10).

The ethanol industry in the United States added $46 billion to the U.S. gross domestic product in 2017 (Figure 2.2.10) (3-10). In addition, the ethanol industry generated $25 billion in household income and $10 billion in tax revenue in 2018 (3-10).

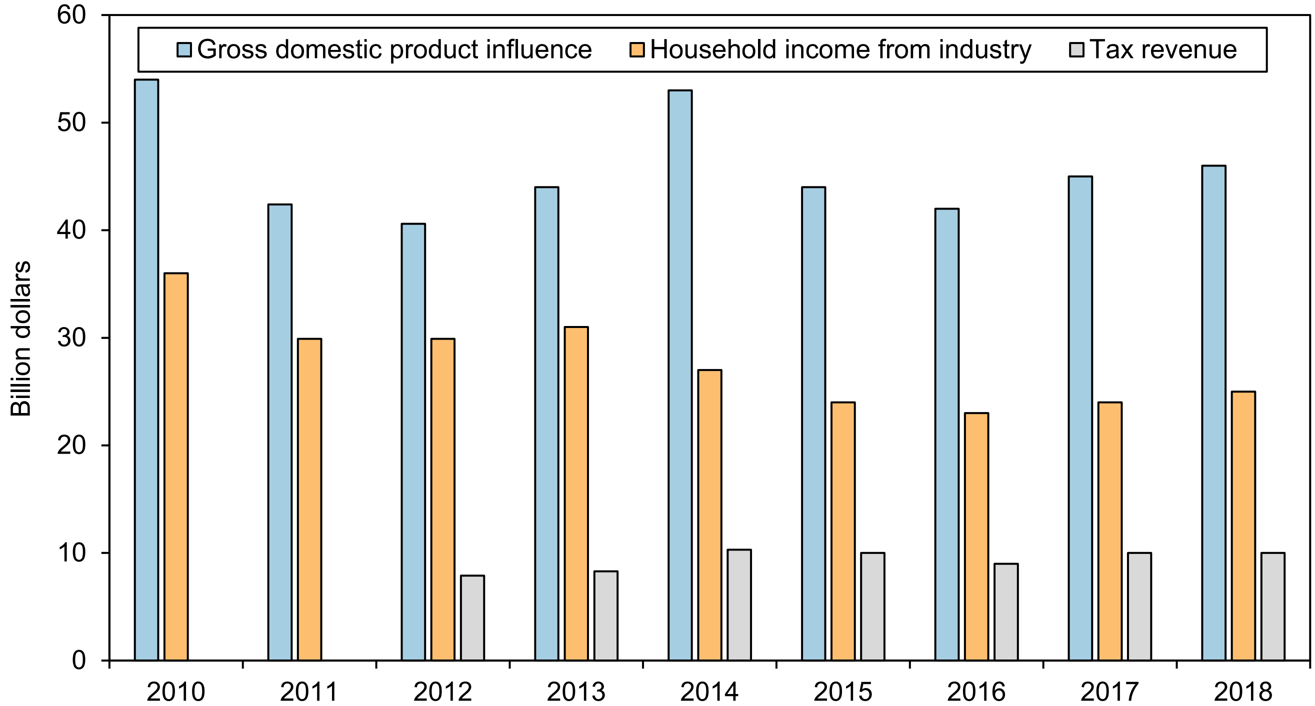

Figure 2.2.10. The ethanol industry's contribution to the U.S. economy from 2010 to 2018 (in billion dollars) (3-10).

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2.3. Biobutanol

Biobutanol is an alcohol produced from the same feedstocks used to produce ethanol. Bio-produced butanol can directly substitute for butanol produced presently from petroleum or natural gas feedstocks. Currently, biobutanol is used as an industrial solvent, as raw material for the synthesis of several chemicals and as fuel in internal combustion engines when blended with gasoline (1).

Biobutanol has several advantages over ethanol. First, the volumetric energy density of biobutanol is almost 20 percent higher than ethanol. Another advantage of butanol is that it resists water absorption, making biobutanol blends easier to transport by pipeline than ethanol blends (1, 2). The water tolerance of butanol blends is also important in gasoline-powered boats, since marine fuel systems are generally not sealed, allowing atmospheric moisture to come into contact with fuel.

Corn is the main feedstock for both biobutanol and ethanol production, which presents a challenge for the biobutanol industry, as more ethanol than biobutanol can be produced from a bushel of corn (2.7-2.8 gallons of ethanol in comparison with 1.5 gallons of biobutanol) (3,4).

As of June 2018, the EPA approved biobutanol blends with gasoline of up to 16 percent of biobutanol content (5). These blends are already being sold in the United States with contents of up to 12.5 percent biobutanol (3).

Infrastructure

Biobutanol is an emerging biofuel and as such its production and commercialization is not common. The first biobutanol plants were achieved by retrofitting existing ethanol fermentation plants (3). Given the advantages of biobutanol over ethanol, this conversion trend is likely to continue (1).

In the United States, two companies are currently manufacturing biobutanol using genetically-modified microbes to obtain isobutanol, Butamax (a joint venture between BP and DuPont) based out of Wilmington, DE; and Gevo based out of Englewood, CO. These two companies have registered their products with EPA for use in on-highway vehicles (3).

Production

The production of biobutanol for fuel has been very small and intermittent since 2013. The EPA reported that approximately 12,000 gallons of biobutanol entered the market in 2013, none in 2014 and 2015, around 125,000 gallons in 2016, and none in the subsequent years (see Figure 2.3.1) (3).

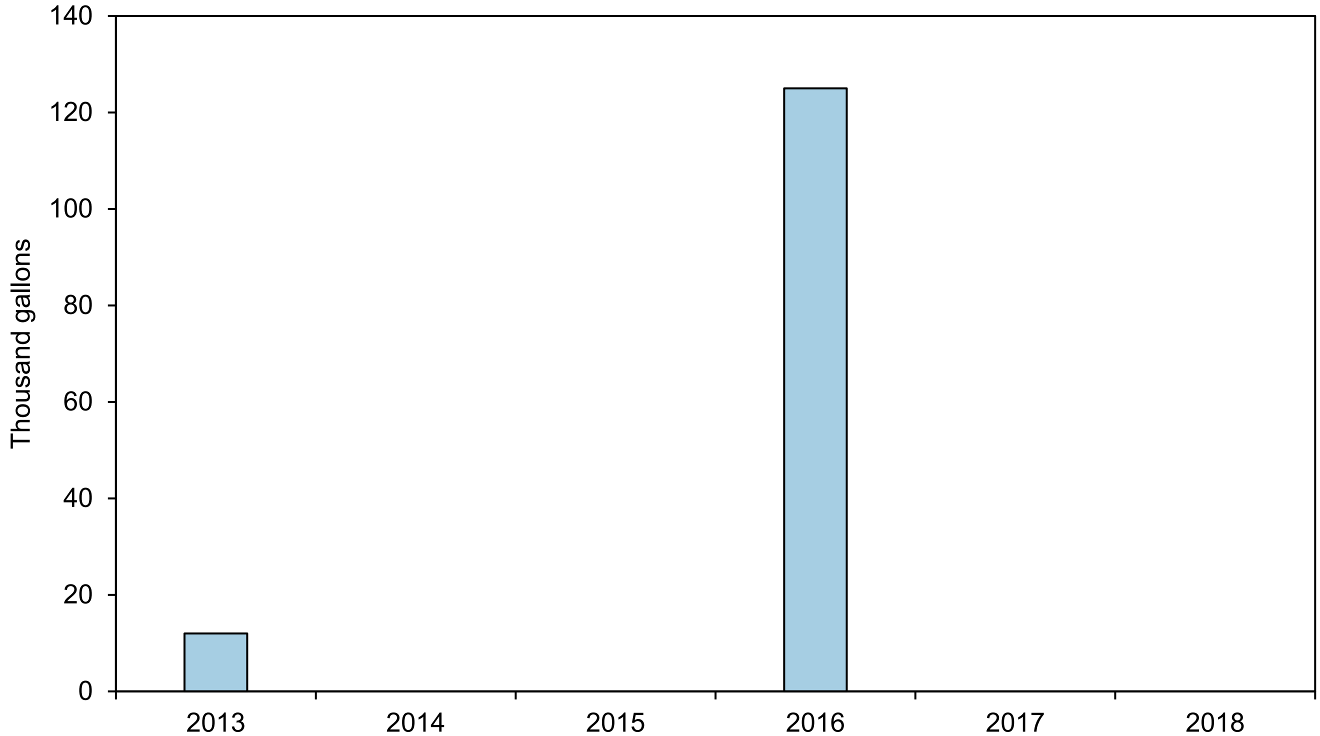

Figure 2.3.1. Production of biobutanol that entered the market from 2013 to 2018 in the United States (in thousand gallons) (3).

Like ethanol, biobutanol can be produced from cellulosic feedstocks such as corn stover instead of corn grain. The United States can produce an estimated 2 billion gallons of biobutanol from corn stover, which is equivalent to 11.8 percent of the total domestic gasoline consumption (2). Considering the amount of corn residues available, 88 percent of the biobutanol production potential is concentrated in the Midwest, with Iowa, Illinois, Nebraska, Minnesota, and Indiana being the top 5 States with highest production potential (2).

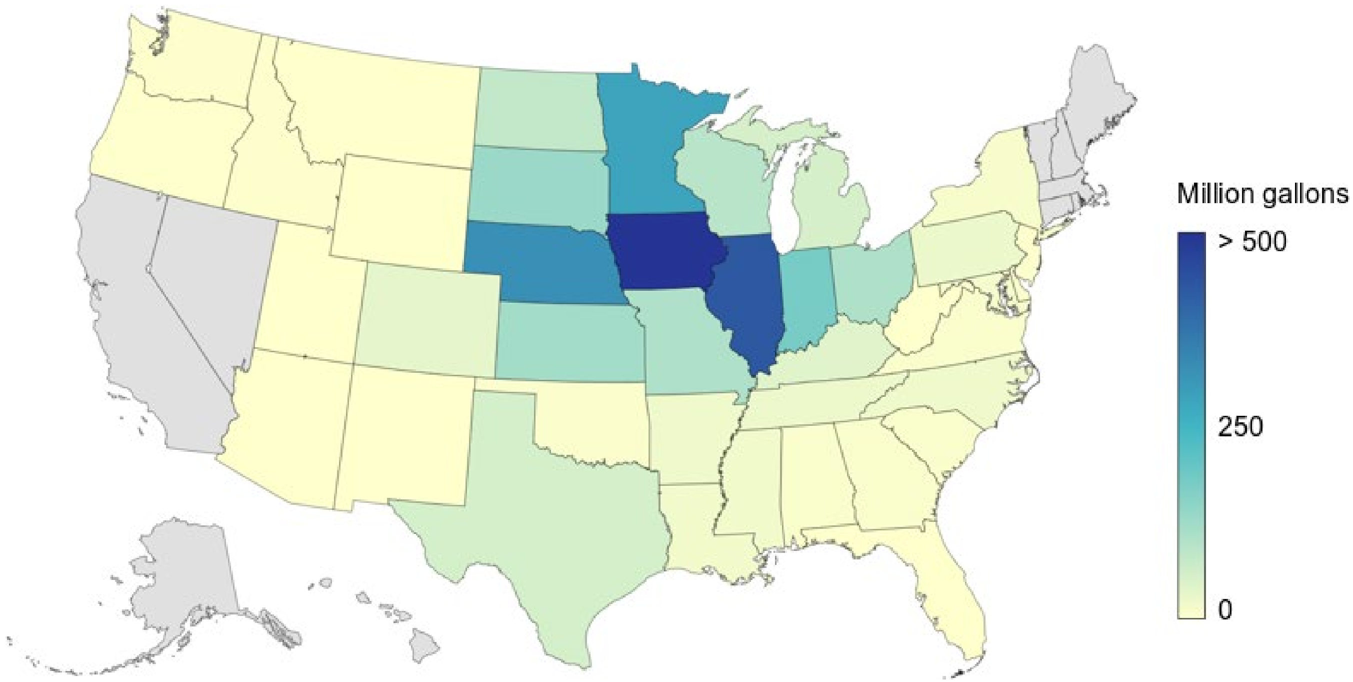

Figure 2.3.2. Biobutanol production potential in the United States (in million gallons) (2).

State	Million gallons	Percentage of total potential
Iowa	509	18.5
Illinois	430	15.6
Nebraska	324	11.7
Minnesota	287	10.4
Indiana	180	6.5

Table 2.3.1. 5 States with highest biobutanol production potential (in million gallons) in the United States (2).

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2.4. Biodiesel

Biodiesel is a renewable fuel used for transportation. It can be found unblended or blended with petroleum diesel. The high-level biodiesel blends are known as B100 (pure biodiesel) or B99 (99 percent biodiesel, 1 percent petroleum diesel). Low-level blends, like B5 (5 percent biodiesel and 95 percent petroleum diesel) and mid-level blends, like B20, (20 percent biodiesel, 80 percent petroleum diesel), are more common than B99/100 due to the lack of regulatory incentives and pricing (1).

Biodiesel can be obtained from vegetable oils, animal fats, or recycled grease (1). In the United States, soybean oil is the leading oil used as a feedstock for biodiesel production (2).

In 2018, the number of biodiesel facilities in the United States increased to 100 plants, from 95 in 2017 (2). The new production facilities are located in Alaska, Iowa, Kansas, Kentucky, Massachusetts and Michigan. The biodiesel industry accounted for more than 72,000 direct jobs in 2018 (3). Most of the biodiesel facilities are located in the Midwest of the United States (4).

Biodiesel production has been steadily increasing in the last decade, from 300 million gallons in 2010 to 1.9 billion gallons in 2018 (2). The consumption almost matched production in 2018, and the trade (i.e., imports and exports) of biodiesel of the United States with other countries was small (5), exporting 104 million gallons and importing 167 million gallons in 2018 (5), with Canada as the main trade partner (6,7).

The number of biodiesel production facilities increased from 95 plants in 2017 to 100 plants in 2018 (Figure 2.4.1) (2). In addition to this increase in biodiesel production plants, in 2018 there were 12 new plants under construction with a total additional capacity of 1.5 billion gallons located in California, Georgia, Illinois, Louisiana, Missouri, North Dakota, New Jersey, Nevada, and South Carolina (Table 2.4.1) (4).

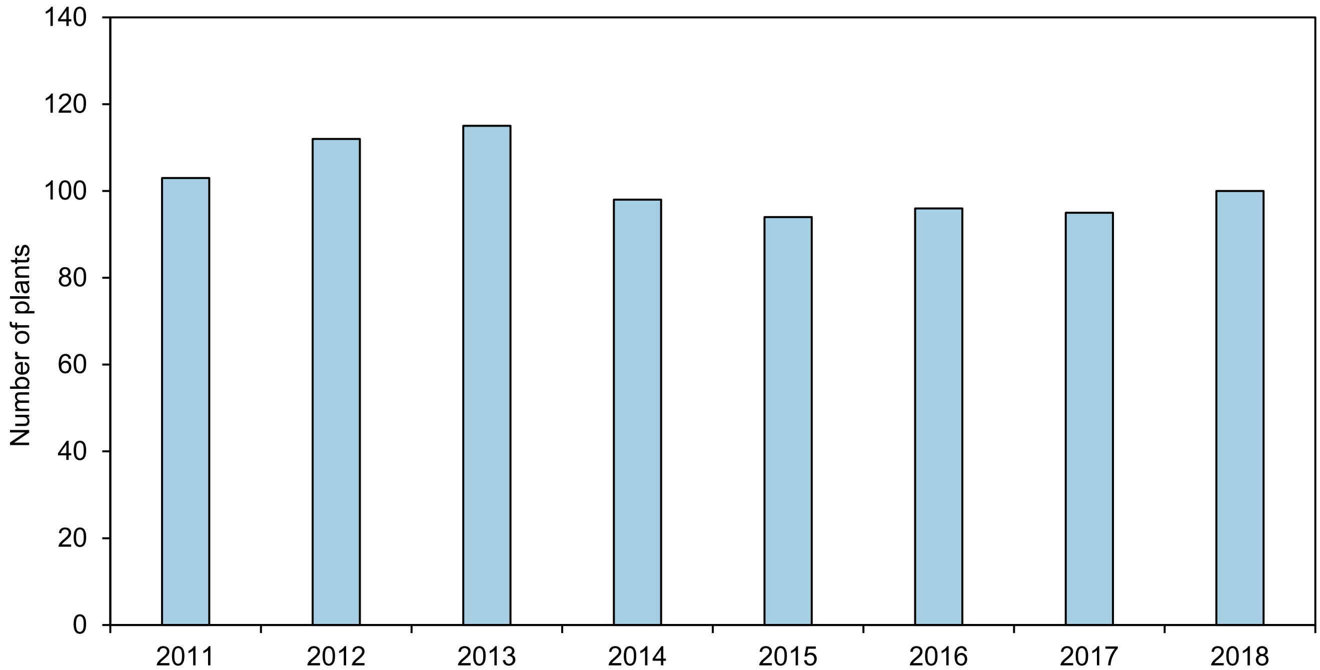

Figure 2.4.1. Total number of biodiesel plants in the United States from 2011 to 2018 (2).

PHYSICAL INFRASTRUCTURE	2011	2012	2013	2014	2015	2016	2017	2018
# of biodiesel plants in the United States	103	112	115	99	94	96	95	100
# of proposed biodiesel plants	-	-	-	-	-	6	0	0
# of existing plants under construction	-	-	-	-	-	15	10	12
# of States which have a biodiesel production facility	35	37	38	35	36	37	36	38

Table 2.4.1. The physical infrastructure of the biodiesel industry in the United States from 2011 to 2018 (2, 4).

Iowa is the State with the most biodiesel plants, accounting for 11 percent of total plants in the United States. Texas with 9 facilities and Illinois with 8 production plants complete the top 3 (Figure 2.4.2 and Table 2.4.2) (4).

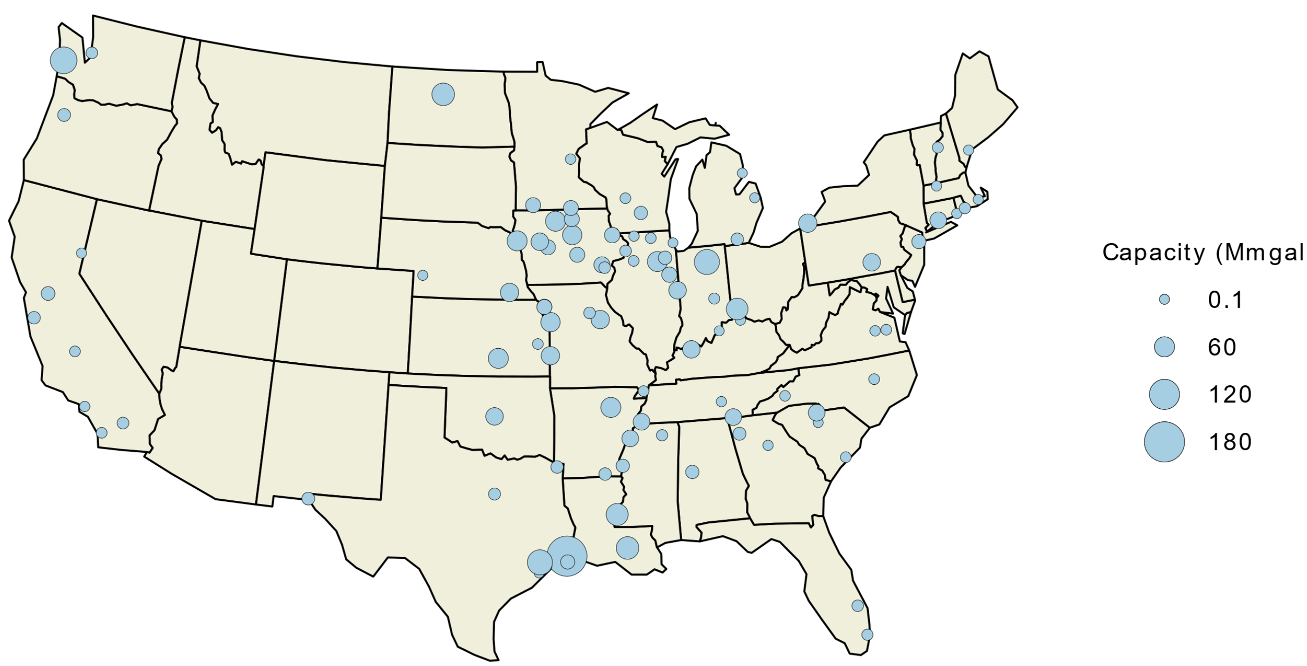

Figure 2.4.2. Biodiesel production facilities location by capacity (in million gallons) in the United States in 2018 (4).

State	Number of plants	Percentage of total plants
Iowa	11	11.1
Texas	9	9.1
Illinois	8	8.1
Missouri	7	7.1
California	7	7.1

Table 2.4.2. Top S States for biodiesel production facilities in the United States in 2018 (4).

The number of B20 and B100 biodiesel fueling stations has remained almost constant over the last decade; there were 681 biodiesel stations in 2018 (Figure 2.4.3) (8).

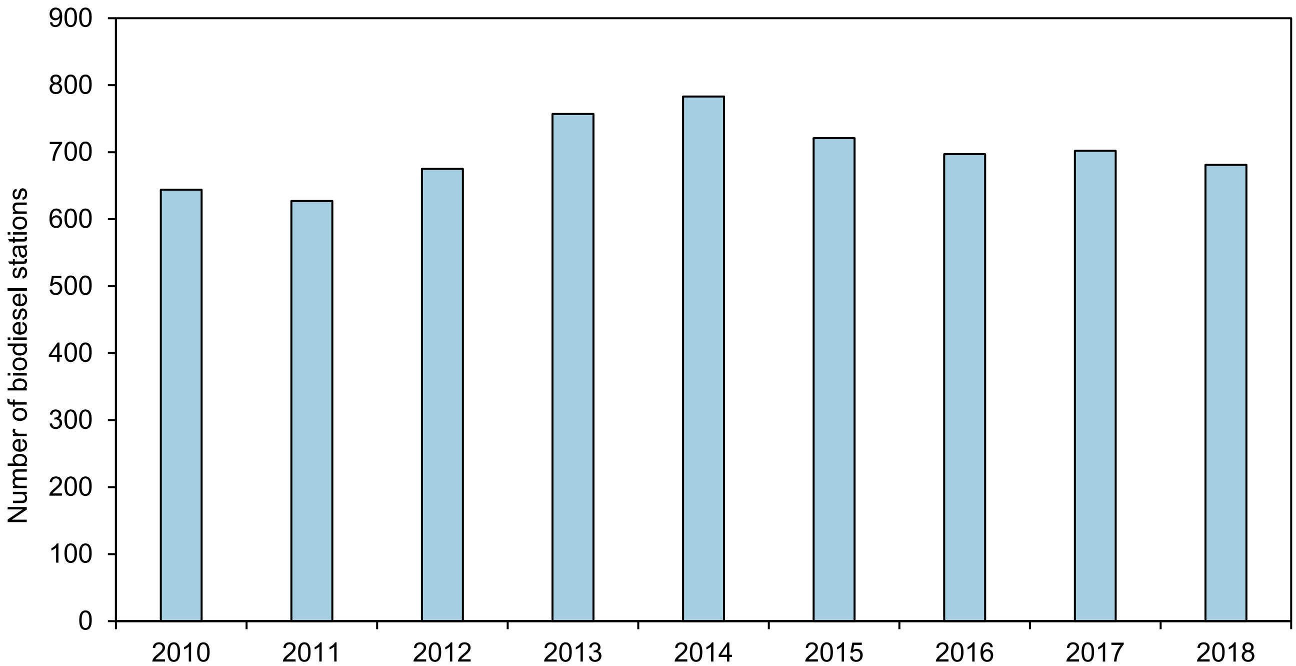

Figure 2.4.3. Number of biodiesel fueling stations in the United States from 2010 to 2018 (8).

Production

Biodiesel production steadily increased in the last years, reaching 1.9 billion gallons in 2018, compared to 300 million gallons in 2018 (2). This is consistent with the increase in the total number of biodiesel plants (Table 2.4.1). In 2018, the production of biodiesel was almost equal to the consumption, and imports and exports of biodiesel were low (Figure 2.4.4) (2, 5).

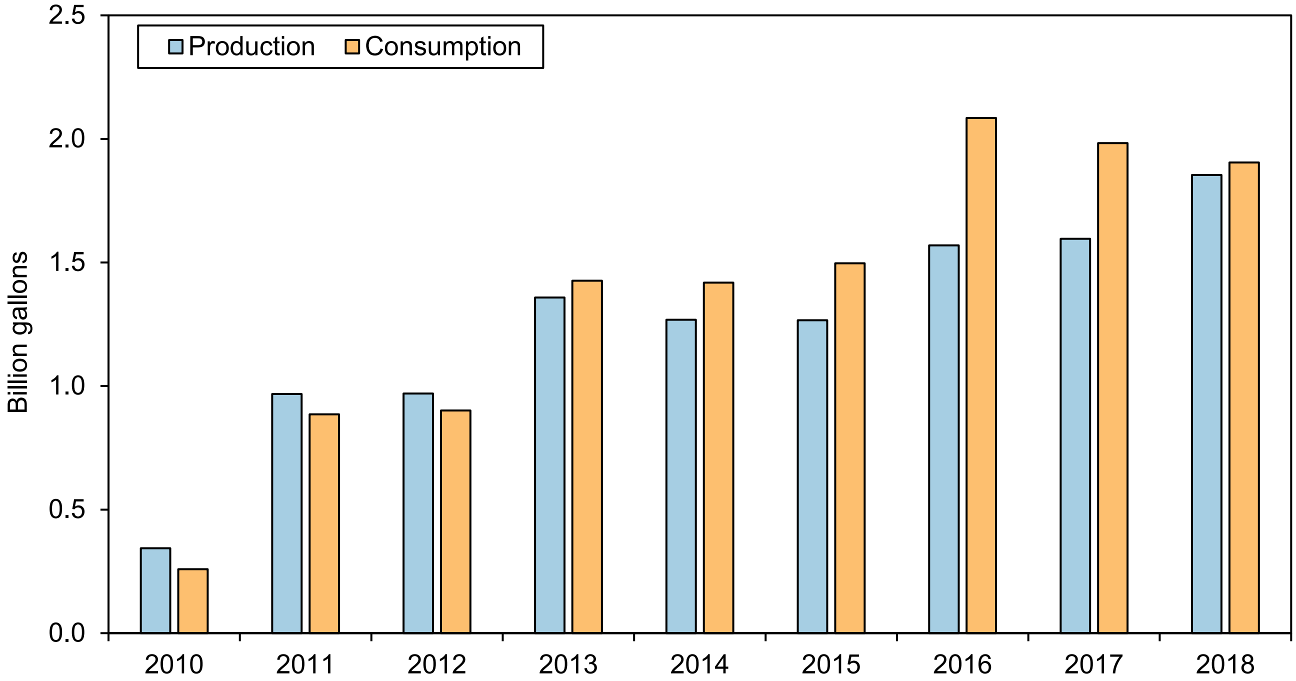

Figure 2.4.4. Biodiesel production and consumption in the United States from 2010 to 2018 (in billion gallons) (2, 5).

Iowa is the State with the highest number of biodiesel plants with 11.2 percent of the United States biodiesel plants, it is also the State with the largest production capacity, with 400 million gallons that represents 15.4 percent of the U.S. capacity. Texas is the second State in in production capacity with 376 million gallons representing 14.5 percent of the U.S. production capacity (Figure 2.4.5 and Table 2.4.3) (4).

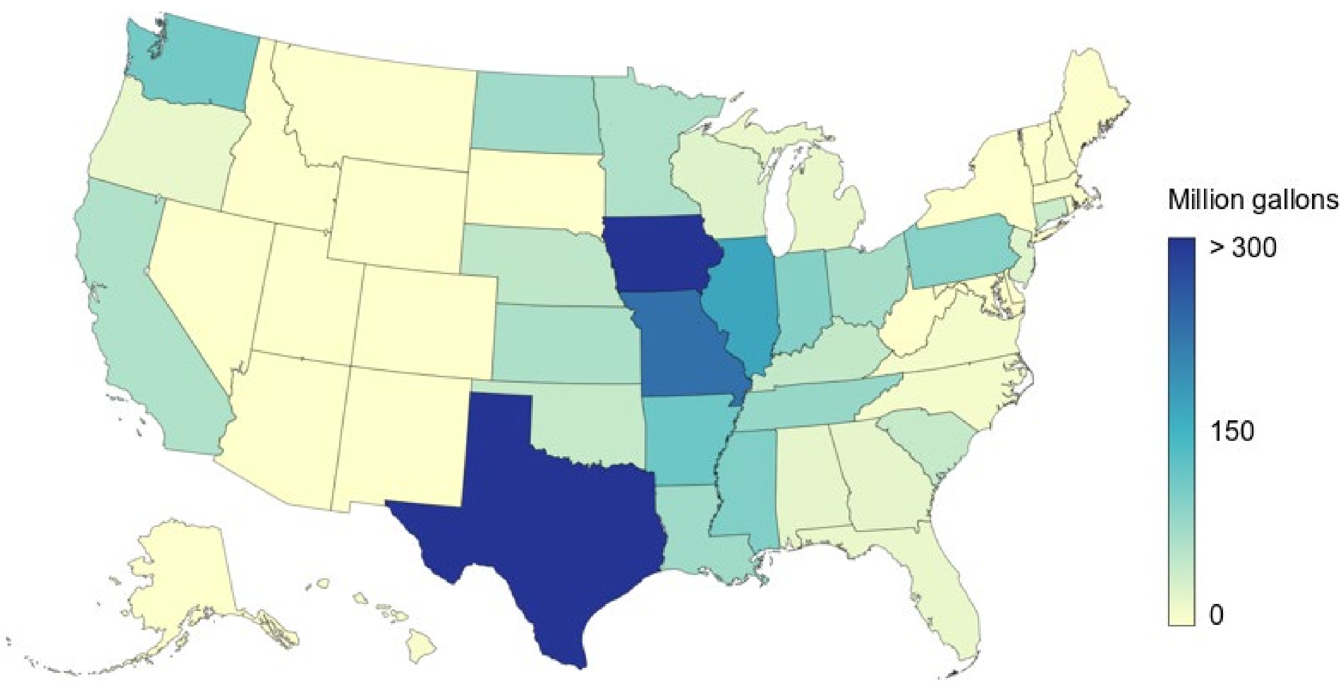

Figure 2.4.5. Total production capacity of biodiesel in the United States in 2018 (in million gallons) (4).

State	Million gallons	Percentage of total capacity
Iowa	400	15.4
Texas	376	14.5
Missouri	231	8.9
Illinois	170	6.6
Arkansas	115	4.4

Table 2.4.3. Top 5 States with highest production capacity of biodiesel (in million gallons) in the United States in 2018 (4).

Exports of biodiesel increased until 2013, reaching a peak of 196 million gallons. In 2014, there was a sudden drop in exports, which have steadily increased again until reaching 104 million gallons in 2018 (5). Eighty percent of total biodiesel exported in 2018 was exported to Canada (Figure 2.4.6) (7).

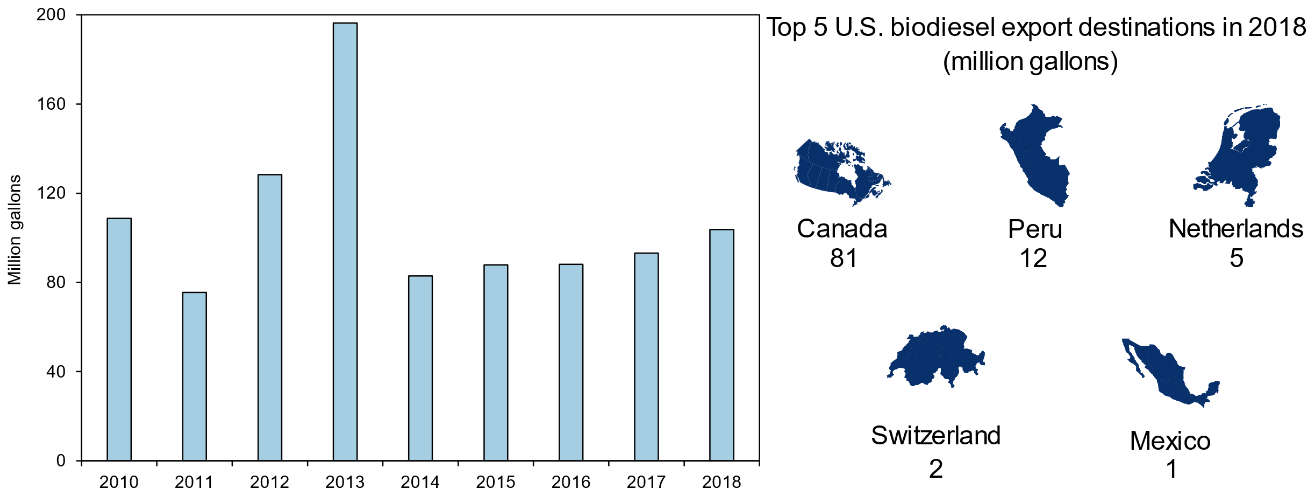

Figure 2.4.6. Exports of biodiesel in the United States from 2010 to 2018 (in million gallons) (5) and top 5 U.S export destinations in 2018 (in million gallons) (7).

In 2018, imports of biodiesel in the United States were very close to exports, reaching 167 million gallons. Eighty-five percent of the diesel was imported from Canada and Germany (Figure 2.4.7) (5, 6).

In 2013 the United States not only became a net exporter of biodiesel, but also increased domestic demand (see Figure 2.4.4). This was driven by two main factors: (1) satisfying the Renewable Fuel Standards targets and, (2) the increase in biodiesel tax credits set to incentivize biodiesel production. However, the amount of biodiesel imported decreased during 2014 due to uncertainty about both the Renewable Fuel Standards targets and the elimination of the tax credits. At the end of 2014, the United States Environmental Protection Agency (US EPA) proposed to keep the Renewable Fuel Standards targets through 2015 and 2016, which resulted in a significant increase in biodiesel imports and consumption. Finally, incentives for biodiesel consumption expired December 31, 2016, which explains the drop of biodiesel imports in 2017 and 2018 (5, 9).

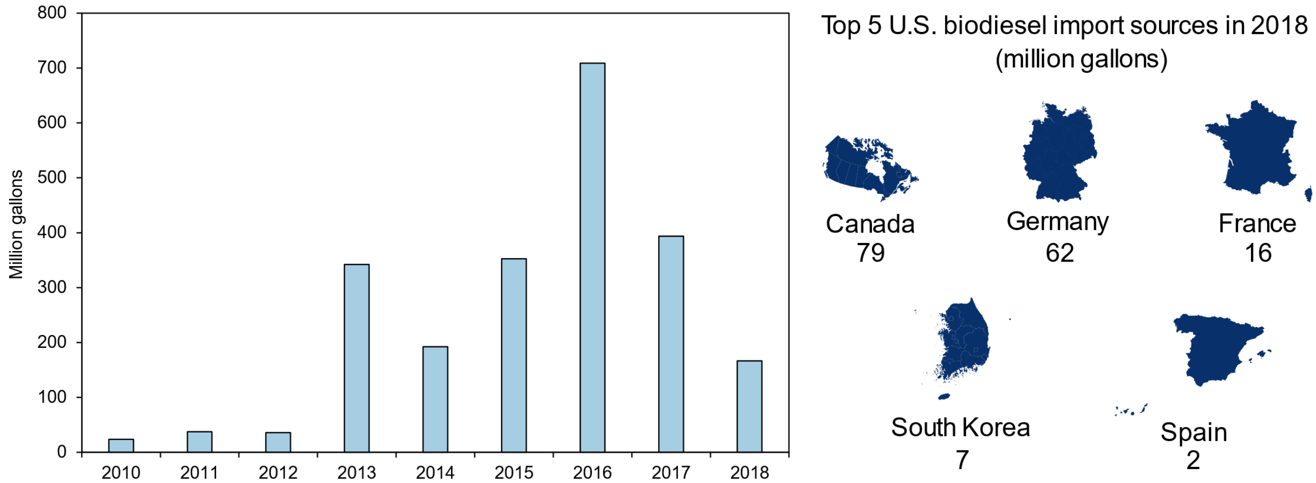

Figure 2.4.7. Imports of biodiesel in the United States from 2010 to 2018 (in million gallons) (5) and the U.S. import sources in 2018 (in million gallons) (6).

Economics

The price of B99/100, B20 and diesel has significantly decreased since 2014, which matches the increase in production and parallels the trend in soy prices (10,11), the main feedstock for biodiesel production. In 2018, for the first time, the price of B20 was slightly lower than the price of diesel, which can lead to an increase in the consumption of renewable fuels (Figure 2.4.8) (10).

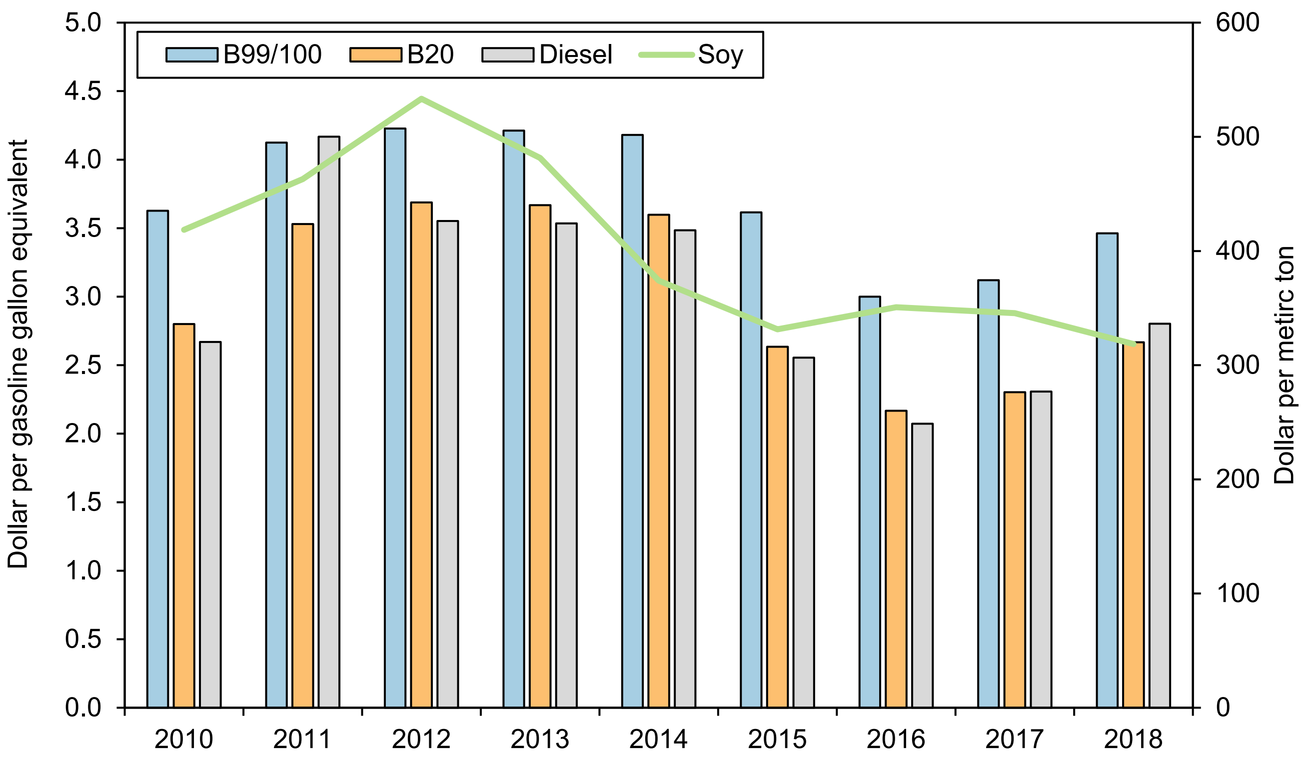

Figure 2.4.8. Prices for two blends of biodiesel, traditional (petro) diesel and soy. Blue, orange and grey bars represent the relative price of B99/100, B20, and diesel respectively, from 2010 to 2018 (in dollar per gasoline gallon equivalent) (left axis) (10). The green line depicts the relative price of soy from 2010 to 2018 (in dollars per metric ton) (right axis) (11).

The number of direct jobs generated by the biodiesel industry has been increasing for the last 5 years, from 50,000 jobs in 2014 to 72,000 jobs in 2018 (Figure 2.4.9) (3). This is consistent with the increase in domestic production (Figure 2.4.4).

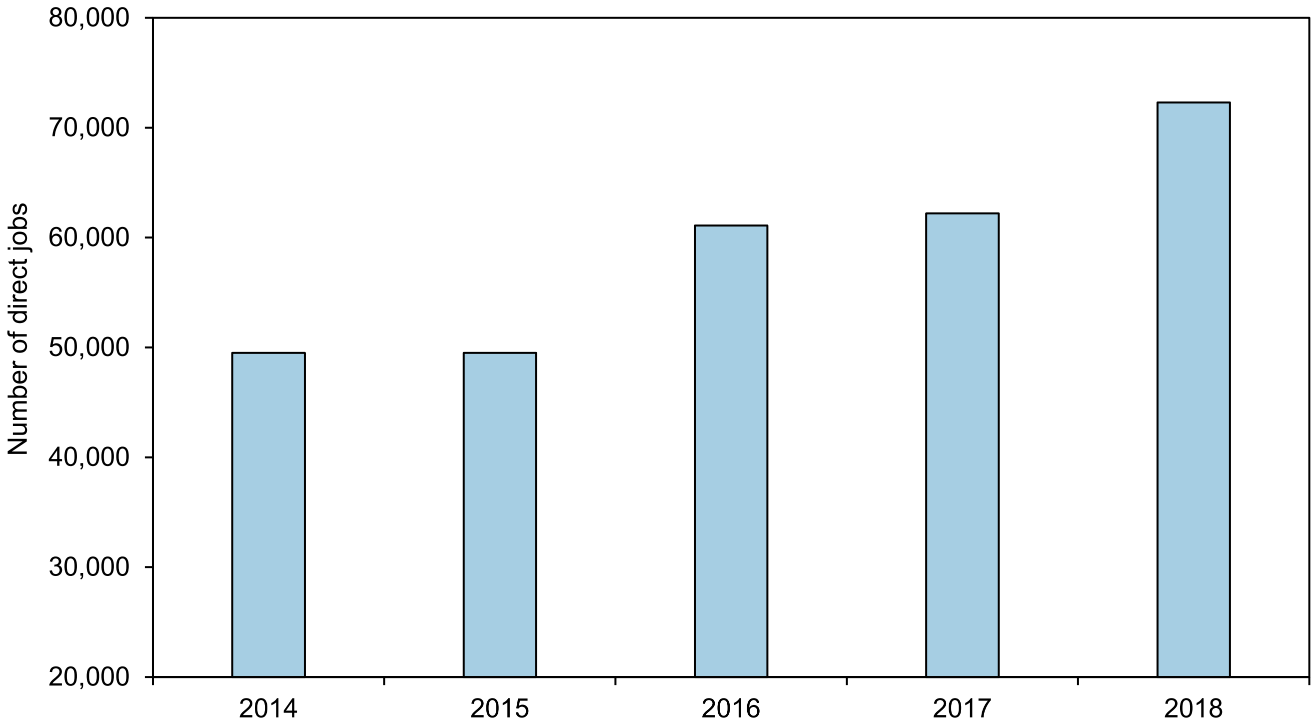

Figure 2.4.9. Number of direct jobs generated from the biodiesel industry from 2014 to 2018 (3).

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2.5. Animal Fats and Recycled Greases

Animal fats and recycled greases can refer to edible or inedible tallow, poultry fat, lard, white grease, yellow grease, and brown grease (1). White grease is grease rendered from animal fat, usually pork fat with less than 4 percent of free fatty acids (FFA) (2). Yellow grease is used grease, primarily restaurant and cooking oil, with no more than 15 percent FFA (3). If the FFA content is higher than 15 percent, it is called brown grease (4).

Animal fats and recycled greases are mainly used for feed and food and for biodiesel production in the United States. According to the U.S. EPA's Renewable Fuel Standards Program Regulatory Impact, animal fats and recycled greases are some of the most environmentally friendly biodiesel feedstocks. Compared to traditional diesel (i.e., petro-diesel), greenhouse gases can be reduced by 86 percent if biodiesel is produced from waste grease (4).

One of the main differences between using oilseed as feedstock for biodiesel production and using animal fats and recycled grease is that while the first group is usually produced in rural areas, animal fats and recycled greases are mostly urban resources since they are recovered from business and industry that use oil for food preparation which are more abundant in urban areas. Even though the processing costs of waste grease are higher than the processing costs of vegetable oil, the feedstock's cost of animal fats and recycled greases is generally lower or even free (4).

Production

The production or collection of animal fats and recycled greases in the United States has remained relatively constant over the years, between 5 to 6 million metric tons per year. In 2018, 47 percent of the total production was tallow, 18 percent was poultry fat, 17 percent yellow grease, 13 percent white grease, and 5 percent other fats (Figure 2.5.1) (5-7).

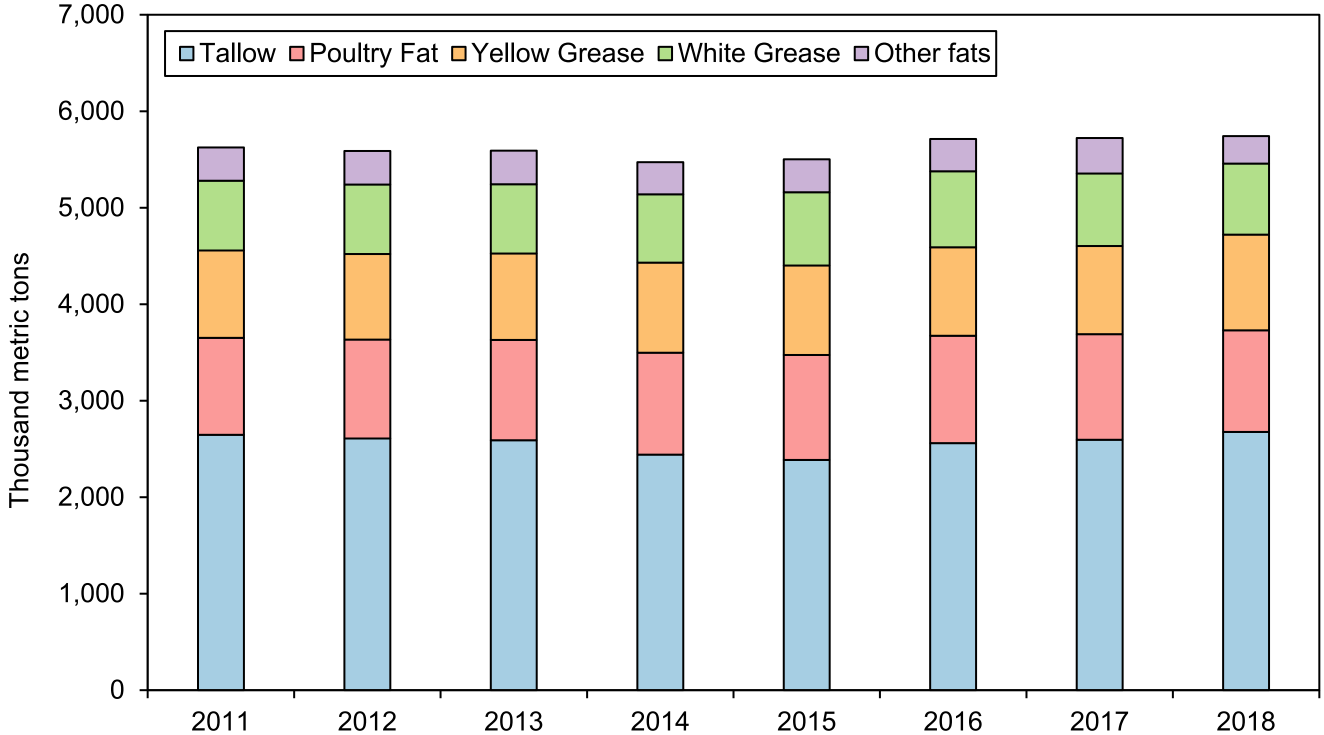

Figure 2.5.1. Total production of animal fats and recycled greases by type in the United States from 2011 to 2018 (in thousand metric tons) (5-7).

The consumption of animal fats and recycled greases slightly increased from 4.1 million metric tons in 2011 to 5 million metric tons in 2018. Although most of the fats are used for feed or food production, the share of animal fats and recycled greases used for biodiesel production increased from 21 percent in 2012 to 28 percent in 2018 (Figure 2.5.2) (5-8).

The increase in the demand for animal fats and recycled greases for biodiesel production is driven by the California Low Carbon Fuel Standard, established by Assembly Bill 32, California Global Warming Solutions Act of 2006. These are products with lower carbon intensity scores under this standard, which makes them more appealing than other feedstocks (5-7).

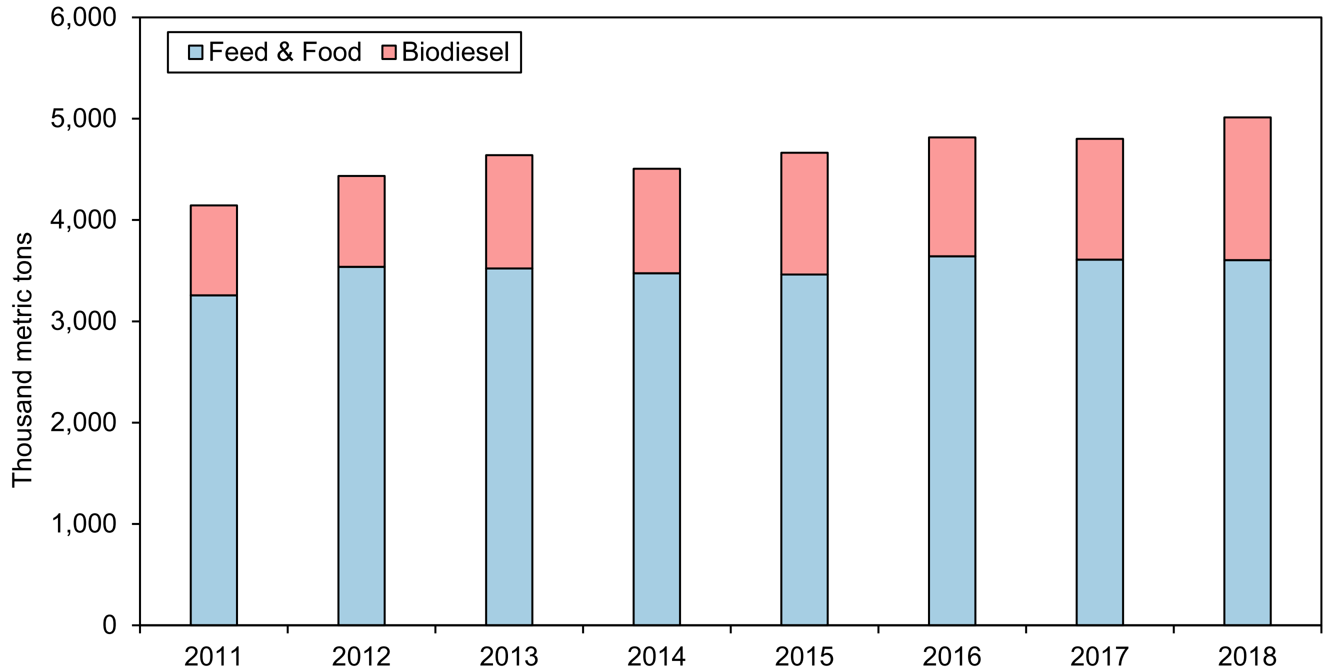

Figure 2.5.2. Total consumption of animal fats and recycled greases by final use in the United States from 2011 to 2018 (in thousand metric tons) (5-8).

A detailed analysis of the type of animal fats and recycled greases by final use is shown in Figures 2.5.3 and 2.5.4. Tallow and poultry fats are mainly used for feed and food production, while yellow and white grease is mostly used for biodiesel production. Note that the amount of animal fats and recycled greases used for biodiesel production increase significantly from 0.9 million metric tons in 2011 to 1.4 million metric tons in 2028 (Figure 2.5.4.) (8).

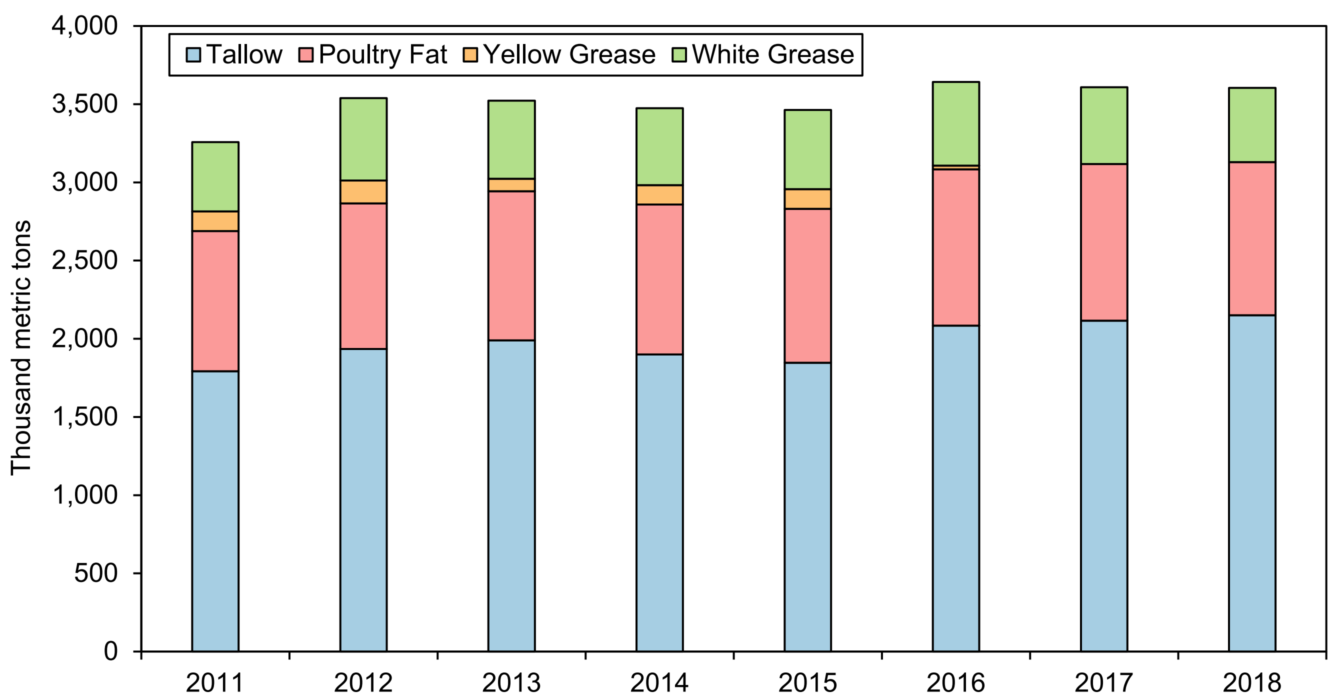

Figure 2.5.3. Total consumption of animal fats and recycled greases for feed and food by type in the United States from 2011 to 2018 (in thousand metric tons) (5-7).

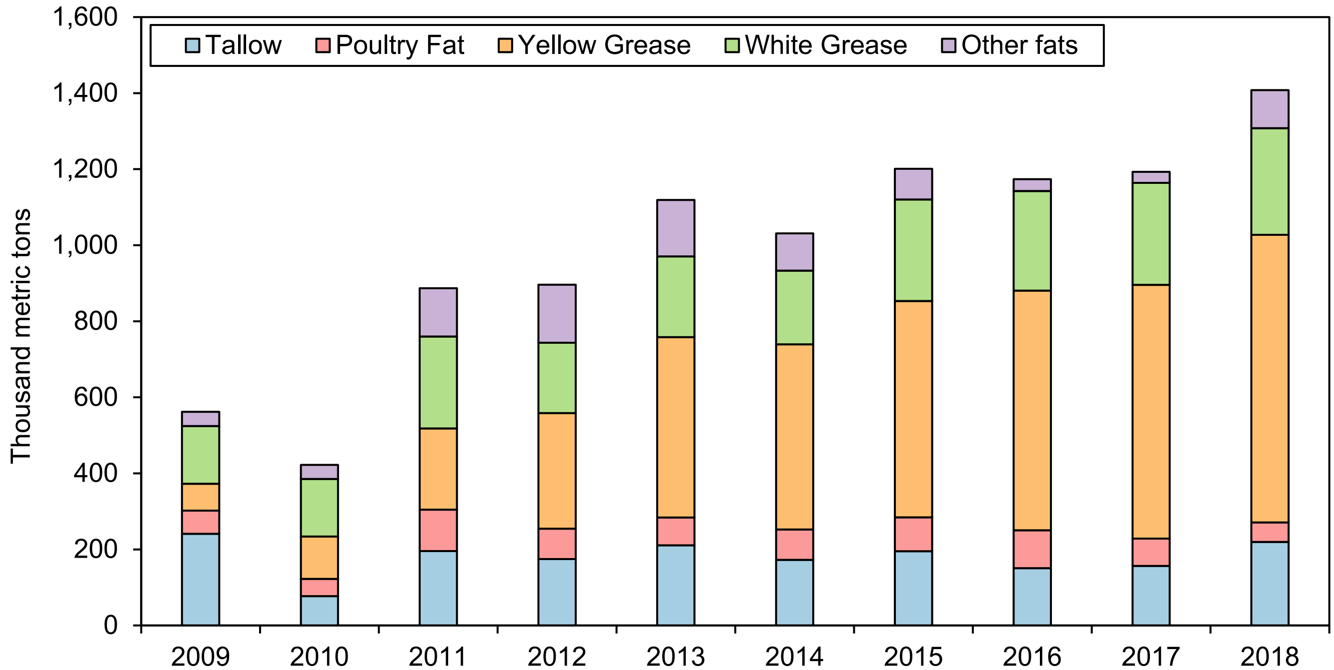

Figure 2.5.4. Total consumption of animal fats and recycled greases for biodiesel production by type in the United States from 2011 to 2018 (in thousand metric tons) (8).

In 2018, in the United States exported over 800,000 metric tons of animal fats and recycled greases, an increase of 13 percent with respect to 2017. Most of these exports were tallow and yellow grease (Figure 2.5.5). Mexico was the top destination for the American tallow in 2018, while the yellow grease was mainly exported to the European Union (5-7). Exports of fats and renewable greases hit a minimum in 2015 but have since rebounded due to the increased demand for biodiesel and renewable diesel production.

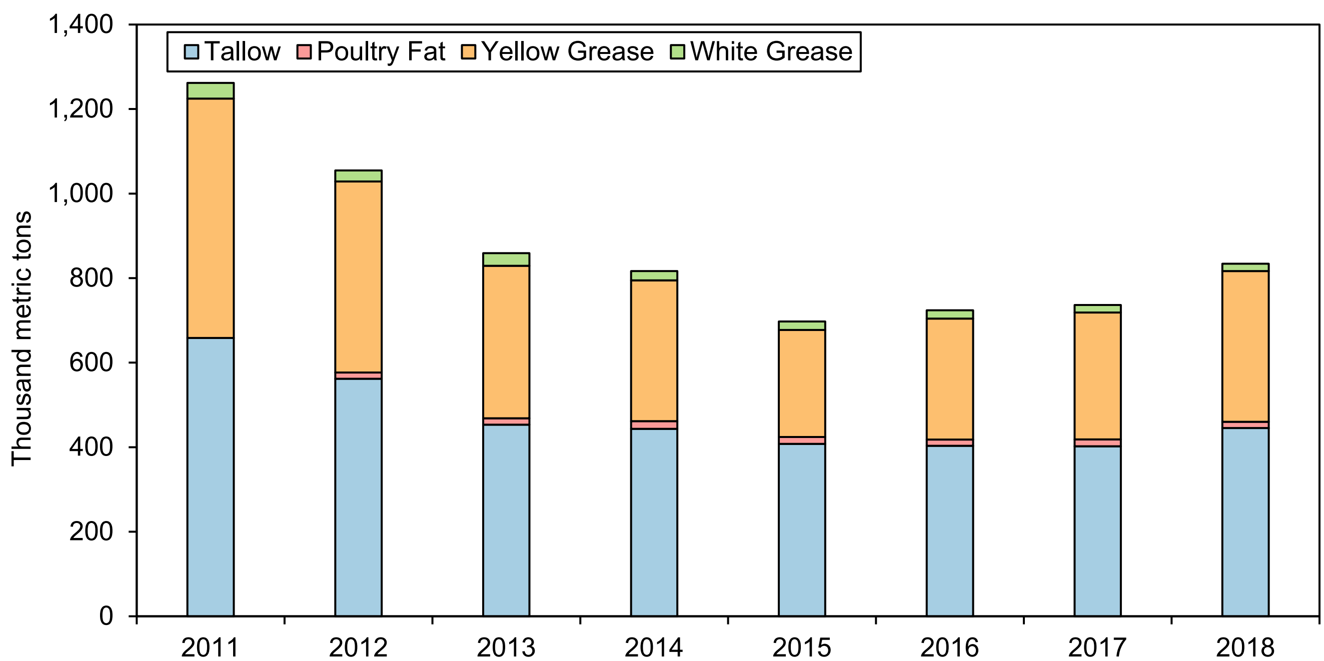

Figure 2.5.5. Exports of animal fats and recycled greases by type in the United States from 2011 to 2018 (in thousand metric tons) (5-7).

Imports of animal fats and recycled greases in the United States significantly increased from 97,000 metric tons in 2012 to 239,000 metric tons in 2018. Tallow, yellow grease and white grease are the main imported fats into the United States (Figure 2.5.6) (5-7).

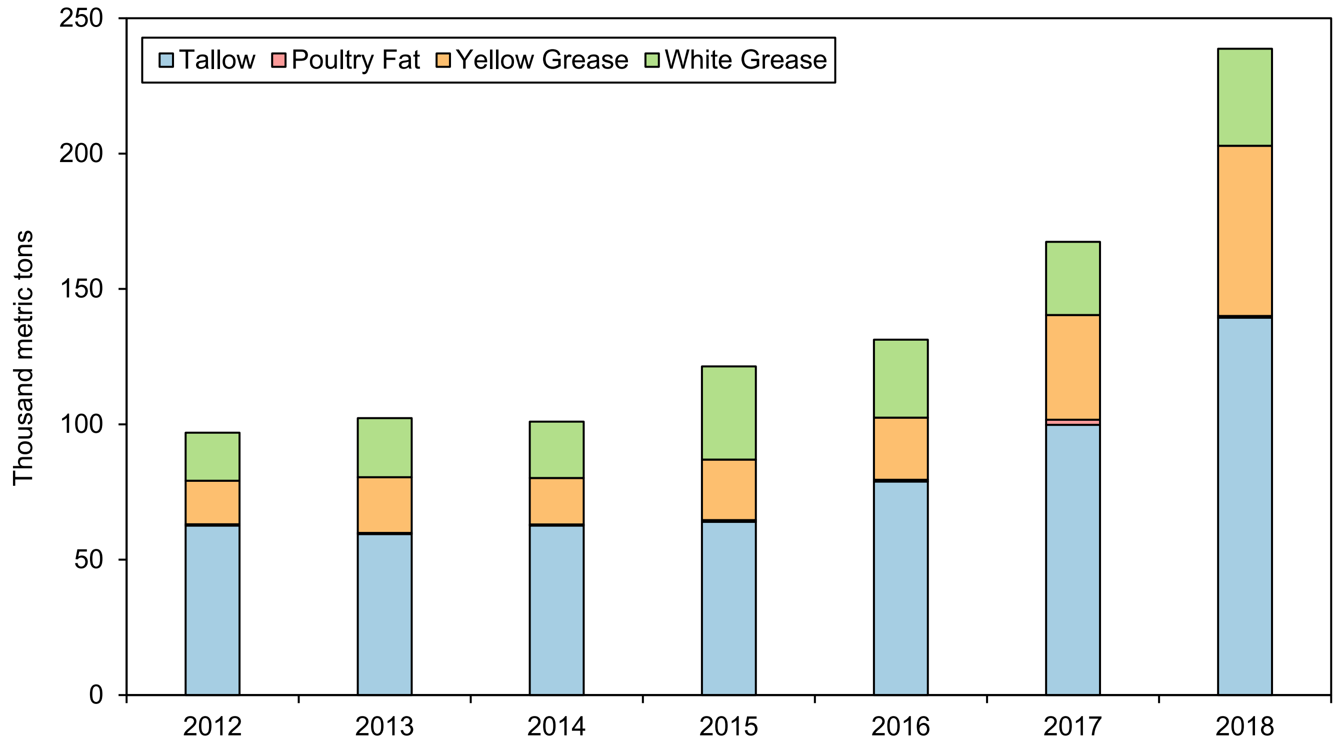

Figure 2.5.6. Imports of animal fats and recycled greases by type in the United States from 2012 to 2018 (in thousand metric tons) (5-7).

Economics

The price of animal fats and recycled greases in the United States decreased on average 50 percent from 2011 to 2018. In 2018, tallow was the most expensive fat with a price of $662 per metric ton, followed by poultry fat ($566 per metric ton), white grease ($463 per metric ton), and yellow grease ($408 per metric ton) (Figure 2.5.7) (5-7).

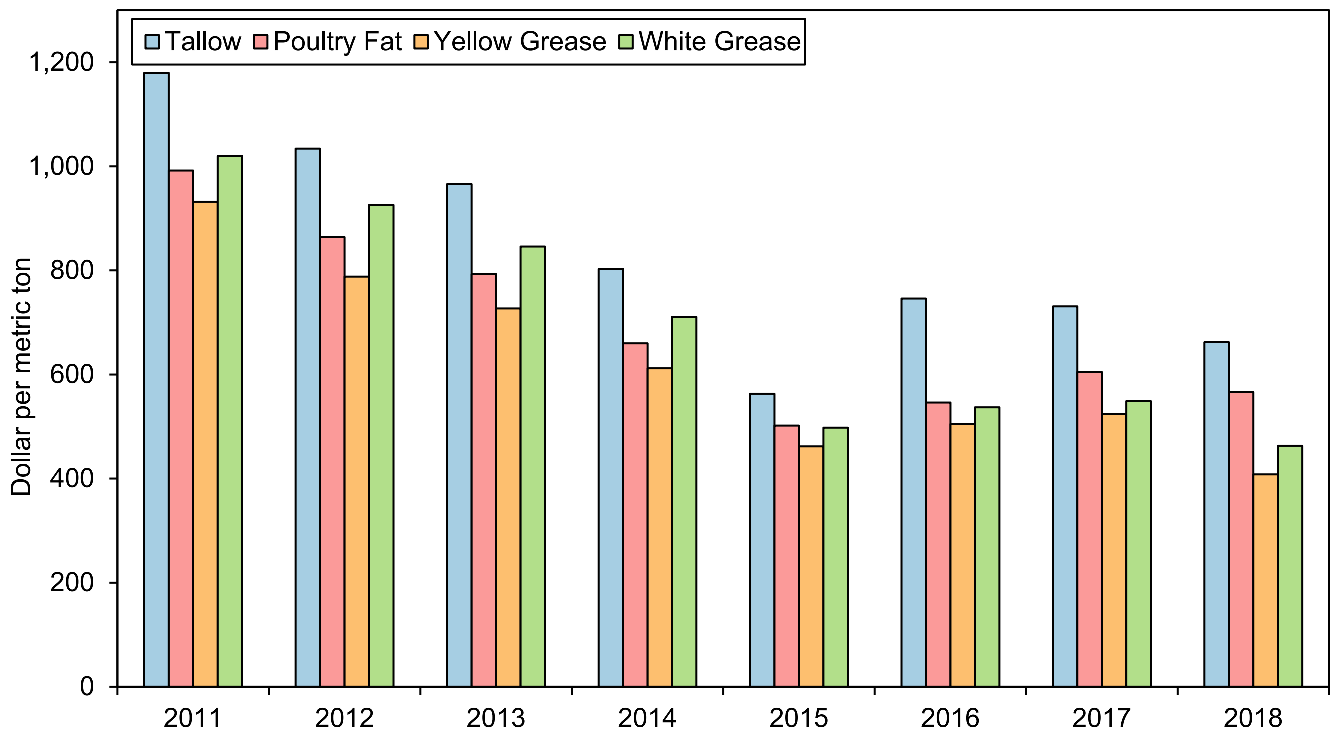

Figure 2.5.7. Relative price of animal fats and recycled greases by type in the United States from 2011 to 2018 (in dollar per metric ton) (5-7).

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2.6. Renewable Diesel

Renewable diesel or green diesel is an emerging biofuel derived from nonpetroleum renewable feedstocks such as agricultural waste, natural fats, vegetable oils, and grease. Although the feedstocks used to produce biodiesel and renewable diesel are similar, processes to produce them are very different. Renewable diesel can be produced through multiple processes, mainly involving traditional hydrotreating of fats, oils, and esters; biodiesel, on the other side, can only be produced through esterification of fats and oils (1,2).

Because of the production method, renewable diesel does not contain oxygen, which eliminates biodiesel challenges regarding freezing temperatures and storage, and it burns cleaner than biodiesel (1).

Renewable diesel is produced using similar processes to conventional diesel production, which makes it chemically identical to petroleum diesel. This means that it can be produced in conventional diesel production facilities, and it can be used in transportation and storage networks and diesel engines without the need for blending or special modifications (2).

Renewable diesel has the potential to reduce carbon emissions between 50 and 85 percent compared to conventional diesel, according to the California Air Resources Board (CARB) (3).

Infrastructure

In 2018, there were four renewable diesel production facilities with a total capacity of 356 million gallons. In addition, one plant is under expansion and two more plants are under construction, which will add 688 million gallons to the total production capacity (2).

Production

Renewable diesel production has continuously increased from 300,000 gallons in 2011 to 306 million gallons in 2018 (4). Consumption has also increased since 2011, reaching 376 million gallons in 2018 (Figure 2.6.1) (4). Despite the large increase in production, it has not been able to match consumption. This imbalance has been satisfied with imports, rendering the United States a net importer of renewable diesel.

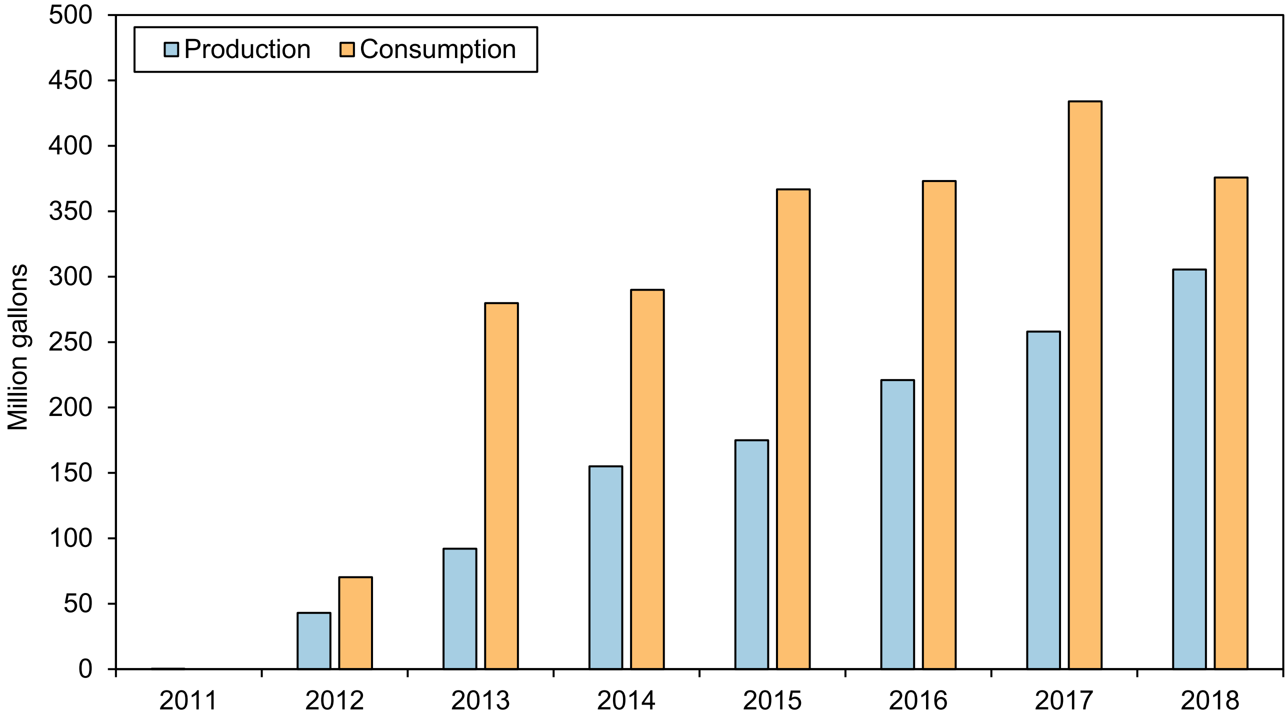

Figure 2.6.1. Renewable diesel production and consumption in the United States from 2011 to 2018 (in million gallons) (4).

Imports of renewable diesel are four times bigger than exports in the United States (Figure 2.6.2.) (4). California is the destination of almost all renewable diesel imported into the United States, mostly from production facilities in Singapore, due to the State's Low Carbon Fuel Standard (2).

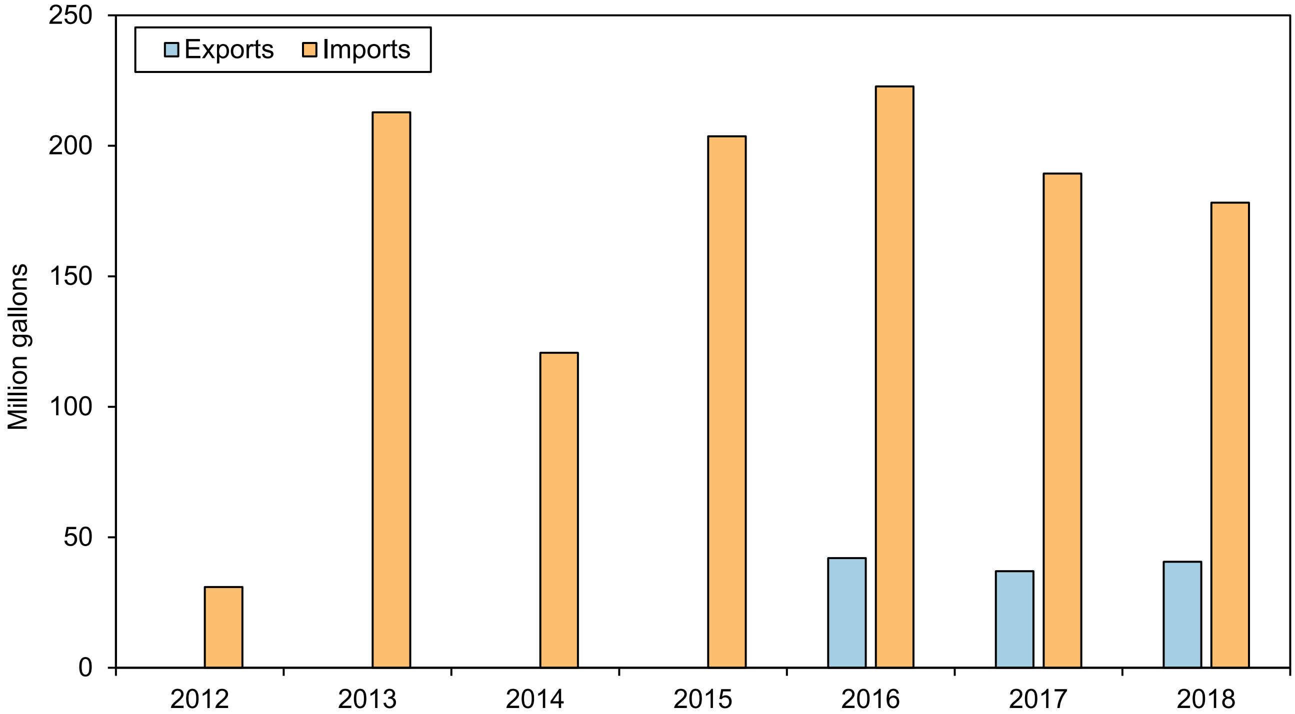

Figure 2.6.2. Renewable diesel exports and imports in the United States from 2012 to 2018 (in million gallons) (4).

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2.7. Renewable Jet Fuel

The International Air Transport Association (IATA) has committed to reducing carbon emissions in the aviation industry to below 50% of 2005 levels by 2050 (1). Blending renewable jet fuel with petrojet fuel will be essential to meet this goal, since 99% of airlines emissions are related to the combustion of jet fuel (2,3).

Renewable jet fuel or sustainable aviation fuel (SAF) is jet fuel produced from renewable feedstocks such as waste oils, agriculture residues or municipal solid waste (4).

Renewable jet fuel presents several advantages over traditional jet fuel. First, the use of renewable jet fuel can reduce greenhouse gas emissions by 90percent compared to conventional jet fuel according to the National Renewable Energy Laboratory (NREL), a national laboratory of the U.S. Department of Energy. Second, renewable jet fuel has higher energy density, which means that the fuel consumption is lower in comparison to petroleum jet fuel. Finally, in conformity with the Renewable Fuel Standard (RFS), renewable jet fuel qualifies for Renewable Identification Number or RIN credits, which reduce impact fuel expenses (4).

The main disadvantages of renewable jet fuel are related to its production costs and logistics. First, they are produced in very small quantities and cannot meet the total demand for jet fuel. Also, renewable jet fuel production facilities are located close to their feedstocks and away from airports and pipelines, therefore increasing transportation costs. Finally, the cost of producing renewable jet fuel is, on average, three times higher (5.00$/gallon) than the cost of producing conventional jet fuel ($1.70-$1.90/gallon). RINs and California Air Resources Board's Low Carbon Fuel Standard (CARB's LCFS) credits can help to address this challenge, which could decrease production costs from $5.00/gallon to $0.95/gallon of renewable jet fuel (2,4).

The first flight using renewable jet fuel took place in 2008 by Virgin Atlantic. Since then, more than 215,000 flights have used renewable jet fuel globally (5). However, only 5 airports (Bergen, Norway; Brisbane, Australia; Los Angeles, USA; Oslo, Norway and Stockholm, Sweden) have regular renewable jet fuel supply. The global production of renewable jet fuel in 2018 was 4 million gallons, accounting for less than 0.1% of the total jet fuel consumption (2).

Since 2006, U.S. airlines and aviation-related entities have worked to implement the use of renewable jet fuel, presenting several industry commitments and collaborations (Figure 2.7.1).

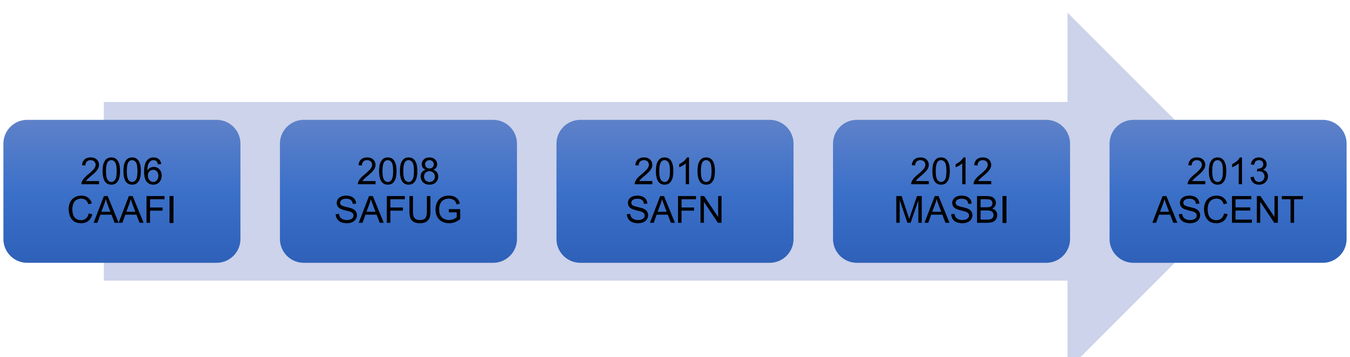

Figure 2.7.1. Timeline of aviation industry collaborations (6-11).

In 2006, the Aerospace Industries Association (AIA), Airports Council International-North America (ACI-NA), the Airlines for America (A4A), and the Federal Aviation Administration (FAA) created the Commercial Aviation Alternative Fuels Initiative (CAAFI). CAAFI is a coalition of airlines, aircraft and engine manufacturers, energy producers, researchers, international participants, and U.S. Government agencies committed to promote the development and deploy of renewable jet fuel (6). CAAFI is focused on four areas: (1) certification and qualification of fuels; (2) research and development; (3) sustainability; and (4) business (7).

In 2008, the Sustainable Aviation Fuel Users Group (SAFUG) was created by a group or airlines, representing more than 15percent of the industry, and the support of environmental organizations such as the Natural Resources Defense Council and the Roundtable on Sustainable Biomaterials (RSB). SAFUG is focused on accelerating the development and commercialization of renewable jet fuels (8).

In 2010, the Sustainable Aviation Fuel Northwest (SAFN) was created by Alaska Airlines, Boeing, Port of Seattle, Port of Portland, Spokane International Airport, and Washington State University. SAFN works to produce renewable jet fuel in the Pacific Northwest (9).

In 2012, American Airlines, Boeing, Honeywell's UOP, the Chicago Department of Aviation and the Clean Energy Trust created the Midwest Aviation Sustainable Biofuels Initiative (MASBI). MASBI connects representatives from across the biofuel's value chain, with focus on five main goals: (1) become national leaders in the market of renewable jet; (2) bring economic development and job growth to the Midwest; (3) diversify jet fuel supply; (4) promote U.S. energy security; and (5) reduce environmental impact (10).

In 2013, the FAA, NASA, the U.S. Department of Defense, Transport Canada, and the Environmental Protection Agency founded the Aviation Sustainability Center (ASCENT). ASCENT is co-led by Washington State University and the Massachusetts Institute of Technology, and its mission is to reduce the environmental impact of the aviation industry (11).

After years of testing, the Department of Defense approved the use of renewable jet fuel from two different pathways in tactical vehicles. Together with the Department of Energy, both agencies co-funded the construction of three biorefineries that will supply the U.S. Navy and the U.S. Airforce with renewable military grade jet fuel (12).

Production

Currently, five renewable jet fuel production methods are approved (Table 2.7.1) by ASTM International, the international standards organization that establishes jet fuel specification requirements. All approved jet fuels must be drop-in, which means that can be used in a blend with conventional jet fuel without modifications to the aircraft or its engine (2,13). From these, only the hydroprocessed esters and fatty acids synthetic paraffinic kerosene (HEFA-SPK) are currently commercialized (2).

Production Process	Year of approval	Feedstock	Blending Limit
Fischer-Tropsch Synthetic Paraffinic Kerosene (FT-SPK)	2009	Biomass (forestry residues, grasses, municipal solid waste)	Up to 50%
Hydroprocessed Esters and Fatty Acids Synthetic Paraffinic Kerosene (HEFA-SPK)	2011	Oil-bearing biomass (e.g. algae, jatropha, camelina, carinata)	Up to 50%
Hydroprocessed Fermented Sugars to Synthetic Isoparaffins (HFS-SIP)	2014	Microbial conversion of sugars to hydrocarbon	Up to 10%
FT-SPK with aromatics (FT-SPK/A)	2015	Renewable biomass (municipal solid waste, agricultural waste, forestry residues, wood and energy crops)	Up to 50%
Alcohol-to-jet Synthetic Paraffinic Kerosene (ATJ-SPK)	2016	Agricultural wastes products (stover, grasses, forestry slash, crop straws)	Up to 30%

Table 2.7.1. Approved renewable jet fuel production pathways (13,14).

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2.8. Wood Pellets

Wood pellets are a biofuel derived from various wood feedstocks, including tops and limbs, commercial thinning, and sawmill residues. Wood pellets can be used for both electricity generation and heating (1).

The total number of wood pellet plants in the United States decreased from 2017 to 2018, from 148 production plants to 140 (2-7). These facilities account for about 25,000 direct jobs (8), mostly located in the southeast of the United States (9).

The United States accounted for 20 percent of the global production of wood pellets in 2018, ranking first in terms of production (10). The production increased from 3.2 million metric tons in 2012 to 7.5 million metric tons in 2018 (10).

In the United States, wood pellets are primarily used for heating and their consumption has remained constant in the last decade at around 2,200 trillion BTUs (11). The domestically consumed ratio varies with winter temperatures and growth in exports.

Exports of wood pellets increased from 1.9 million metric tons in 2012 to 6 million metric tons in 2018 (10). Most of the domestic production of wood pellets, 83 percent, was exported to the European Union in 2018 (12).

At a global scale, wood pellets are primarily used for electricity generation. One of the drivers is the European Union's target of 20 percent renewable energy use by 2020. In this context, to obtain electricity, wood pellets are primarily used in coal-fired power plants, such as the Drax power station in the United Kingdom, for electricity generation (13).

Infrastructure

The number of wood pellet production facilities steadily increased from 2013 to 2017, reaching a peak of 148 plants in 2017. After that, it slightly decreased to 140 plants in 2018 (2-7). Four new plants were already under construction by 2018, with an additional capacity of 702,500 metric tons of wood pellets per year (Figure 2.8.1 and Table 2.8.1) (2-7).

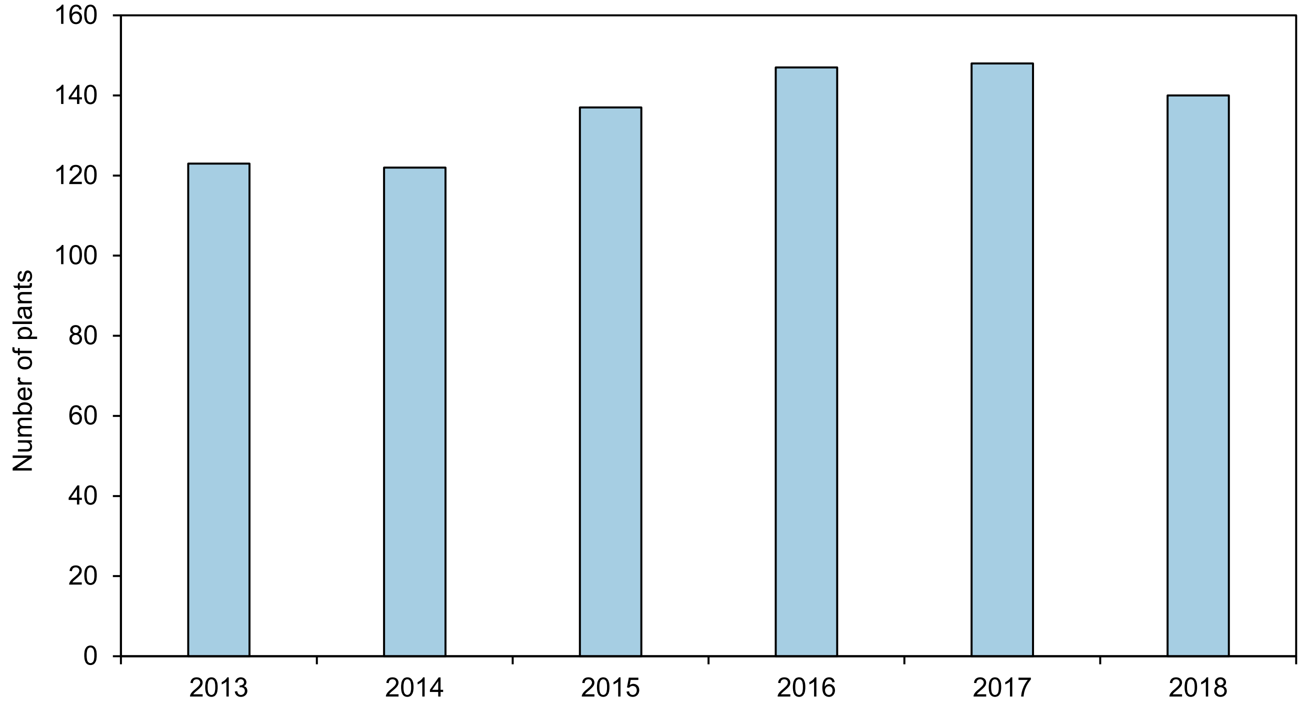

Figure 2.8.1. Total number of wood pellet production plants in the United States from 2013 to 2018 (2-7).

INFRASTRUCTURE	2013	2014	2015	2016	2017	2018
# of wood pellets plants in the United States	123	122	137	147	148	140
# of existing plants under construction	7	9	9	11	4	4
# of proposed wood pellet plants	11	15	22	18	7	0
# of existing plants that were put on standby	-	-	-	13	11	6
# of States that have a wood pellets production facility	36	36	36	38	37	40

Table 2.8.1. Infrastructure of the wood pellet industry in the United States from 2013 to 2018 (2-7).

Although wood pellet production plants are scattered across the country, the southeastern area of the United States concentrates most of the total production (Figure 2.8.2 and Table 2.8.2) (9).
In 2018, the majority of the production facilities used softwood and/or hardwood as feedstock.

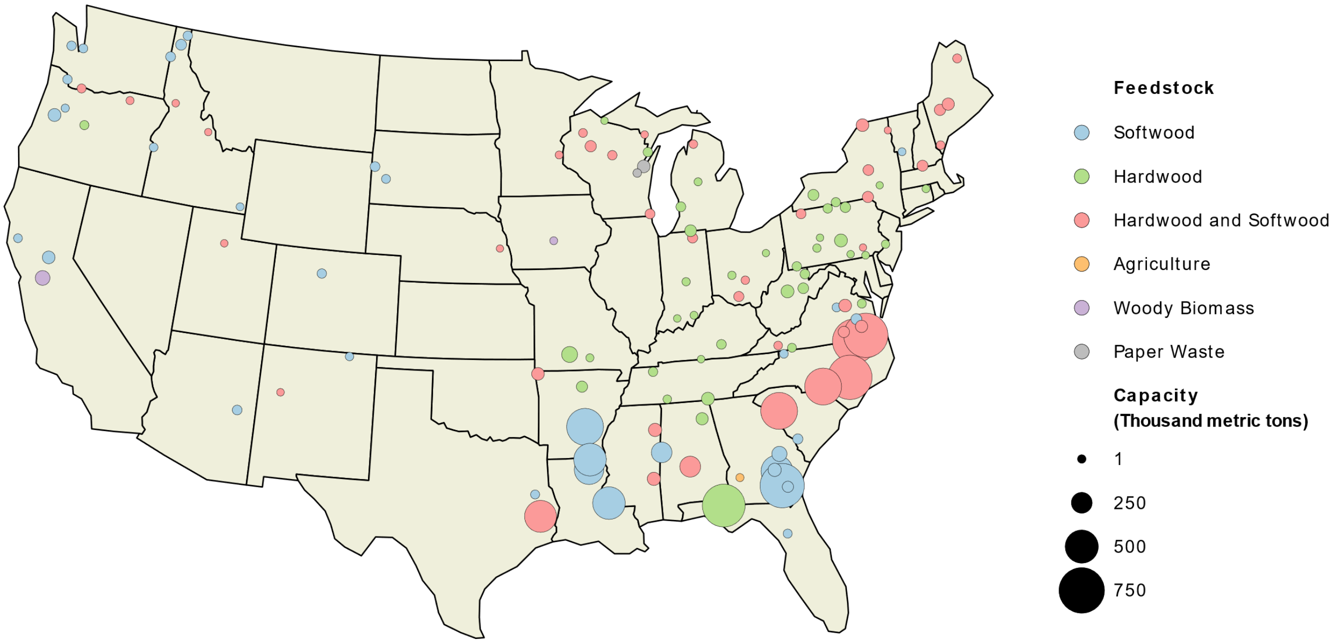

Figure 2.8.2. Wood pellet production facilities in the United States in 2018, sized according to their capacity (in thousand metric tons) and colored by feedstock (9).

State	Number of plants	Percentage of U.S. plants
Pennsylvania	11	8.7
Virginia	9	7.1
Georgia	8	6.3
Wisconsin	8	6.3
New York	7	5.6

Table 2.8.2. Top 5 States ranked according to the number of wood pellets production facilities in in 2018 (9).

Production

The United States is the world's leading producer of wood pellets. Production of wood pellets in the United States accounted for 20 percent of total worldwide production in 2018, with a production of 7.5 million metric tons of wood pellets (see Figure 2.8.3 and Table 2.8.3) (10).

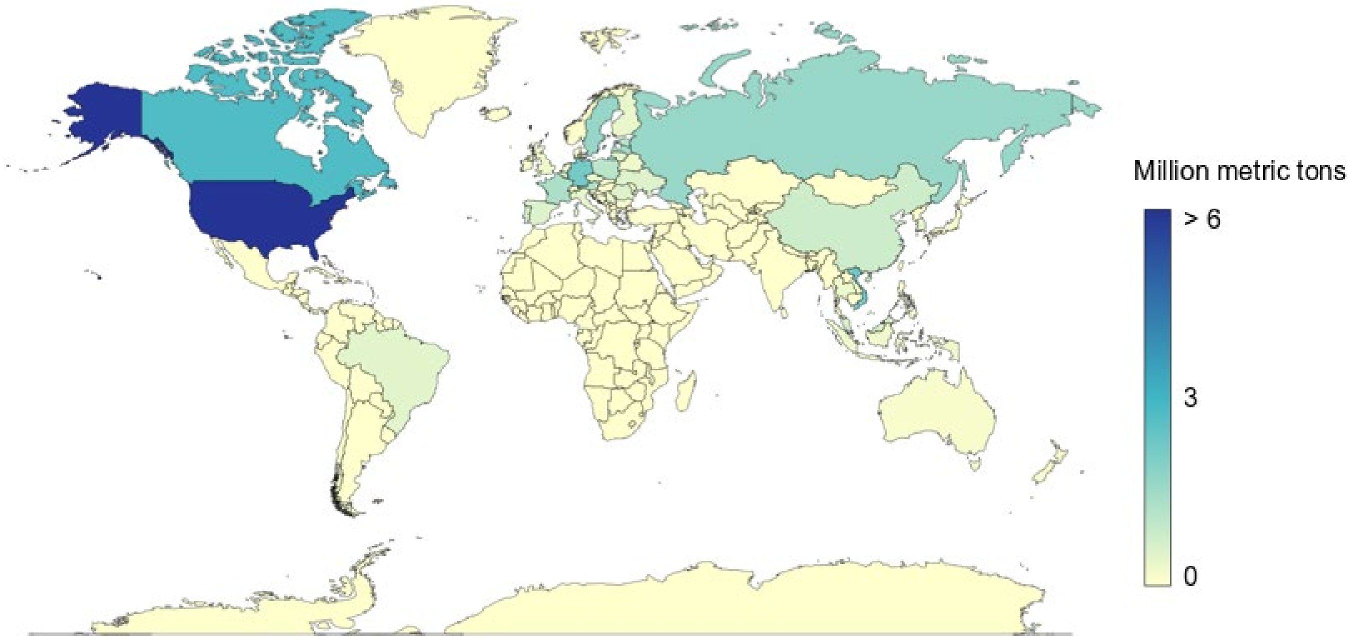

Figure 2.8.3. Wood pellet production worldwide in 2018 (in million metric tons) (10).

Country	Million metric tons	Percentage of total production
United States	7.5	20
Canada	2.8	8
Vietnam	2.3	7
Germany	2.2	6
Sweden	1.7	5

Table 2.8.3. Top 5 countries with largest wood pellet production in 2018 (in million metric tons) (10).

The production of wood pellets in the United States increased between 2012 to 2018, from 3.2 million metric tons to 7.5 million metric tons (10). Consumption of wood pellets has been consistently lower than production, and it remained nearly constant at 2 million metric tons per year (Figure 2.8.4) (10).

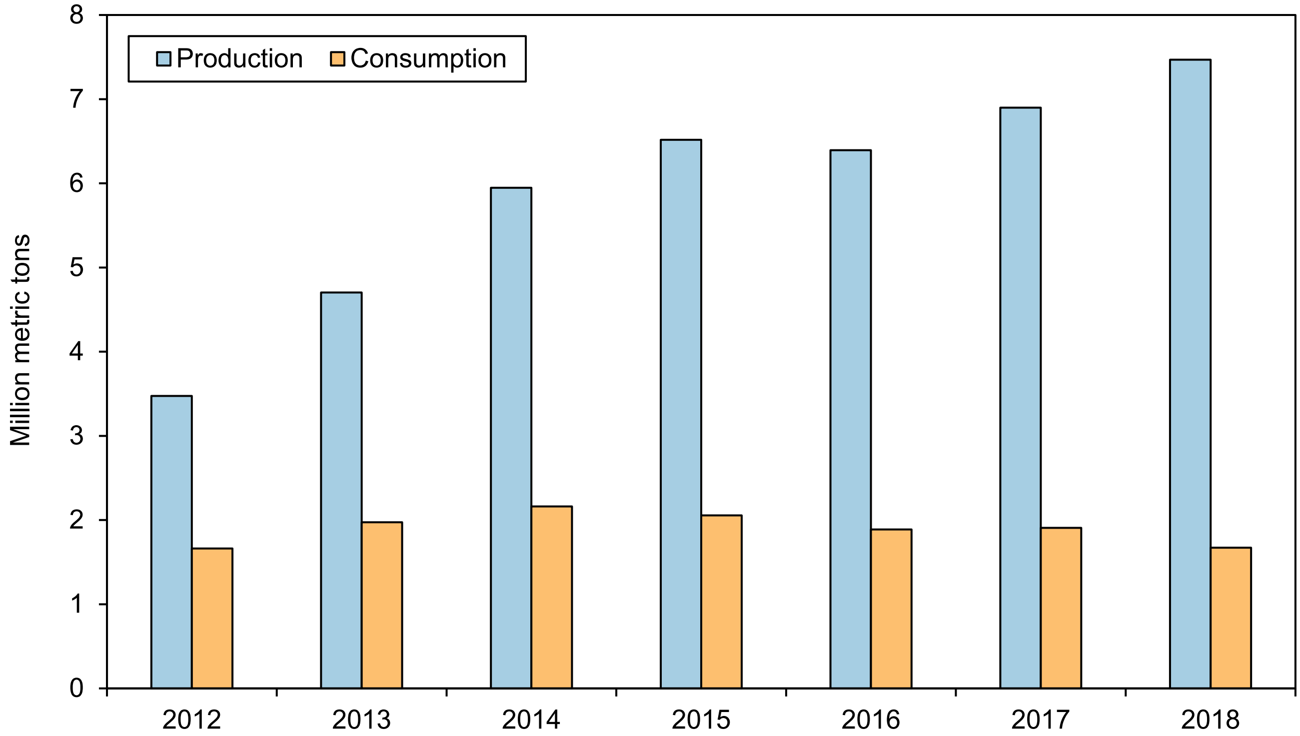

Figure 2.8.4. Total wood pellet production versus total wood pellet consumption in the United States from 2012 to 2018 (in million metric tons) (10).

The southeastern United States concentrates 74 percent of the Nation's wood pellet production capacity. North Carolina and Georgia rank first and second, respectively, in terms of production capacity, accounting for 30 percent of the U.S. production capacity (Figure 2.8.5 and Table 2.8.4) (9).

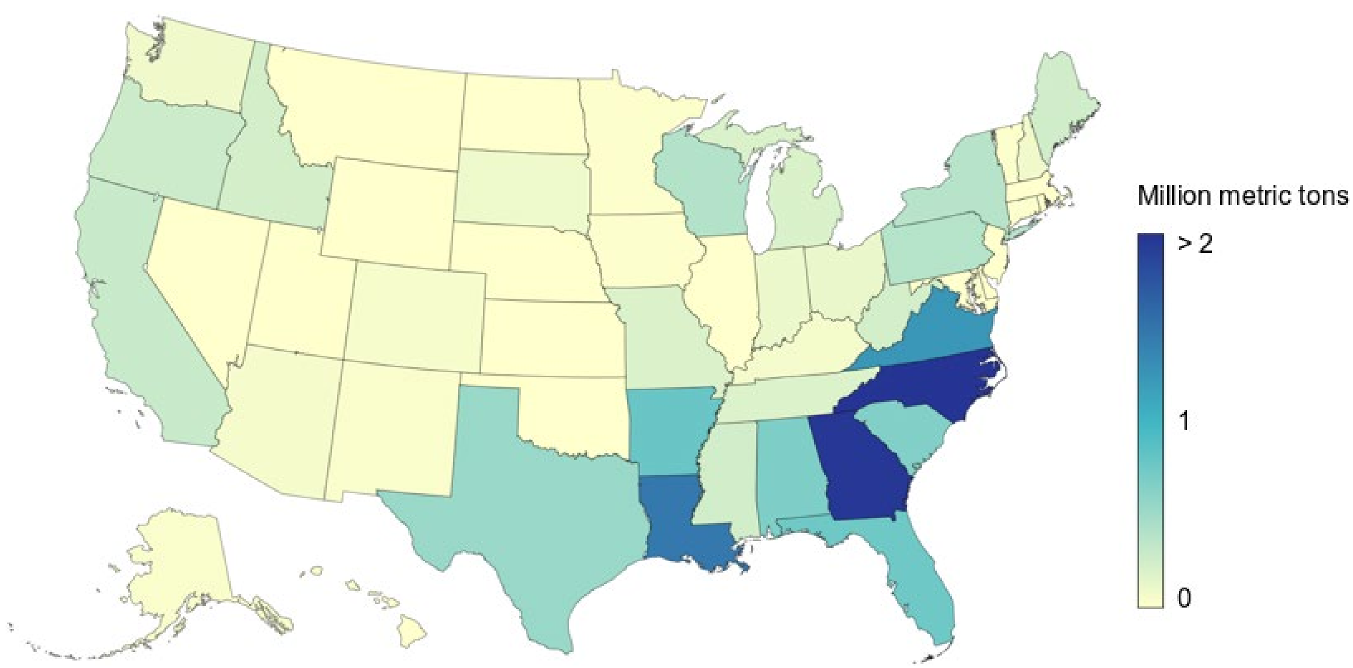

Figure 2.8.5. Wood pellets fuel capacity by State (in million metric tons) in 2018 (9).

State	Million metric tons	Percentage of total capacity
North Carolina	2.6	17.6
Georgia	2.0	13.5
Louisiana	1.5	10.0
Virginia	1.2	8.5
Arkansas	0.8	5.4

Table 2.8.4. Top 5 States with largest wood pellet production capacity in the United States in 2018 (in million metric tons) (9).

Wood pellets can be used for heating and for electricity generation. In the United States, wood energy is primarily used for heating, and its consumption has remained nearly constant in the last 10 years, reaching 2,200 trillion BTUs in 2018 (11). Wood consumption for electricity generation is 20 times lower than for heating. The industrial sector consumes the most wood, followed by the residential sector, the electric power sector and finally the commercial sector (Figure 2.8.6) (11).

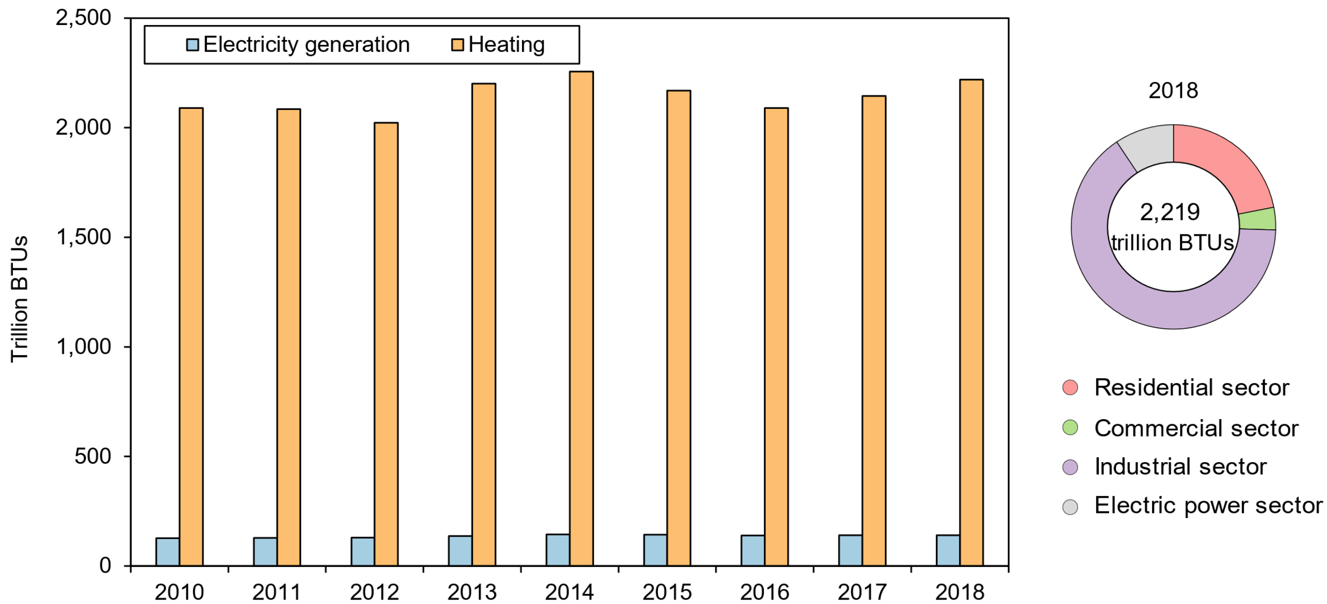

Figure 2.8.6. Energy consumption from wood in the United States by final use and sector from 2010 to 2018 (in trillion British Thermal Units (BTU)) (11).

The United States is the world's leading exporter of wood pellets. Exports of wood pellets increased from 2012 to 2018, from 1.9 million metric tons to 6 million metric tons (Figure 2.8.7) (10). The United Kingdom and Belgium are the two major importers of U.S. wood pellets, with the United Kingdom importing 75 percent of the total production of the United States in 2018 and Belgium importing 15 percent of the total production the same year (see Figure 2.8.7.) (12). Although domestically wood pellets are primarily used for heating, wood pellets exported are used primarily for electricity generation (13).

The European Commission's 2020 climate and energy plan is the main driver for the increase of wood pellet consumption. The plan sets three key targets: 20 percent cut in greenhouse gas emissions (from 1990 levels); 20 percent of the energy consumed in the European Union coming from renewable sources; and 20 percent improvement in energy efficiency (14). Some countries such as the United Kingdom plan to achieve the target by using wood pellets in cofiring (combustion of two different fuels) or by dedicated biomass power plants (13).

The Drax power station, located east of Leeds (United Kingdom), is one of the largest facilities to switch its feedstock from coal to wood pellets, achieving a 75-percent power output through biomass. This power station has a capacity of 3,906 MW and generates 12 percent of the total country's renewable electricity (15).

Nearly 60 percent of Drax's biomass feedstock mix came from the United States. The Drax power station consumes 97 percent of total U.S. wood pellet exports to the United Kingdom and 79 percent of total U.S. wood pellet exports (16).

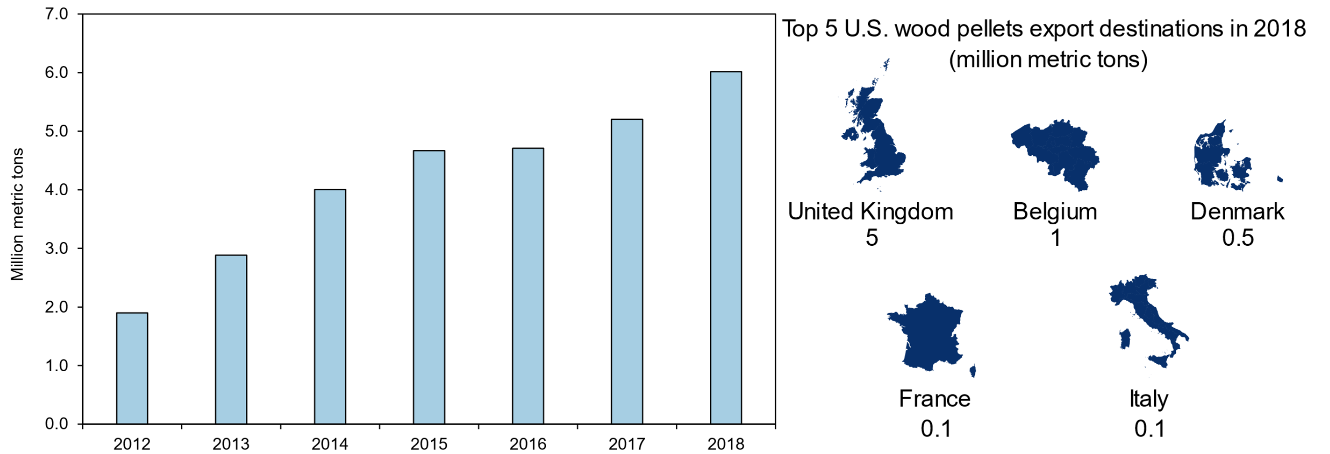

Figure 2.8.7. Exports of wood pellets in the United States from 2012 to 2018 (in million metric tons, left) (10) and top 5 United States exports destination in 2018 (in million metric tons, right) (12).

Imports of wood pellets show a positive trend. In 2014, imports peaked at 220,000 metric tons, and they have remained constant ever since (10). Canada provides 98 percent of wood pellet imports into the United States (Figure 2.8.8) (12).

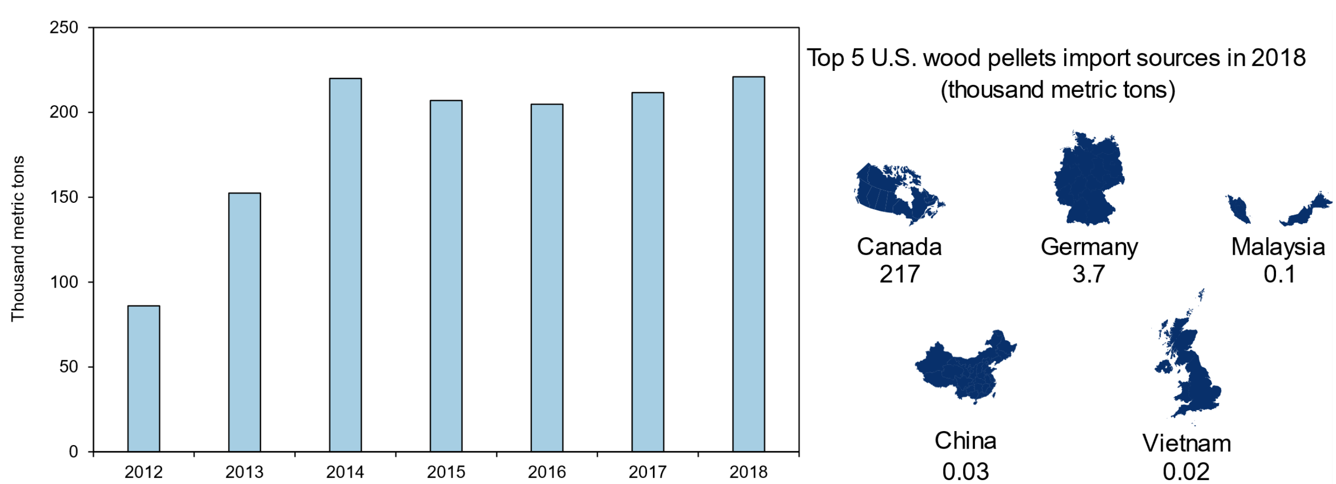

Figure 2.8.8. Imports of wood pellets in the United States from 2012 to 2018 (in thousand metric tons) (10) and top 5 United States import sources in 2018 **(in percent) (12).**

Economics

The number of direct jobs in the economic sector (NAICS code 321999) that includes (but not exclusively) the wood pellet industry has remained approximately constant from 2010 to 2018, with a slight decrease of 5.7 percent between those 2 years (Figure 2.8.9) (8). These small changes are probably driven by the other industries that are compiled under the same NAICS code, as they have more weight in the sector than the wood pellet industry.

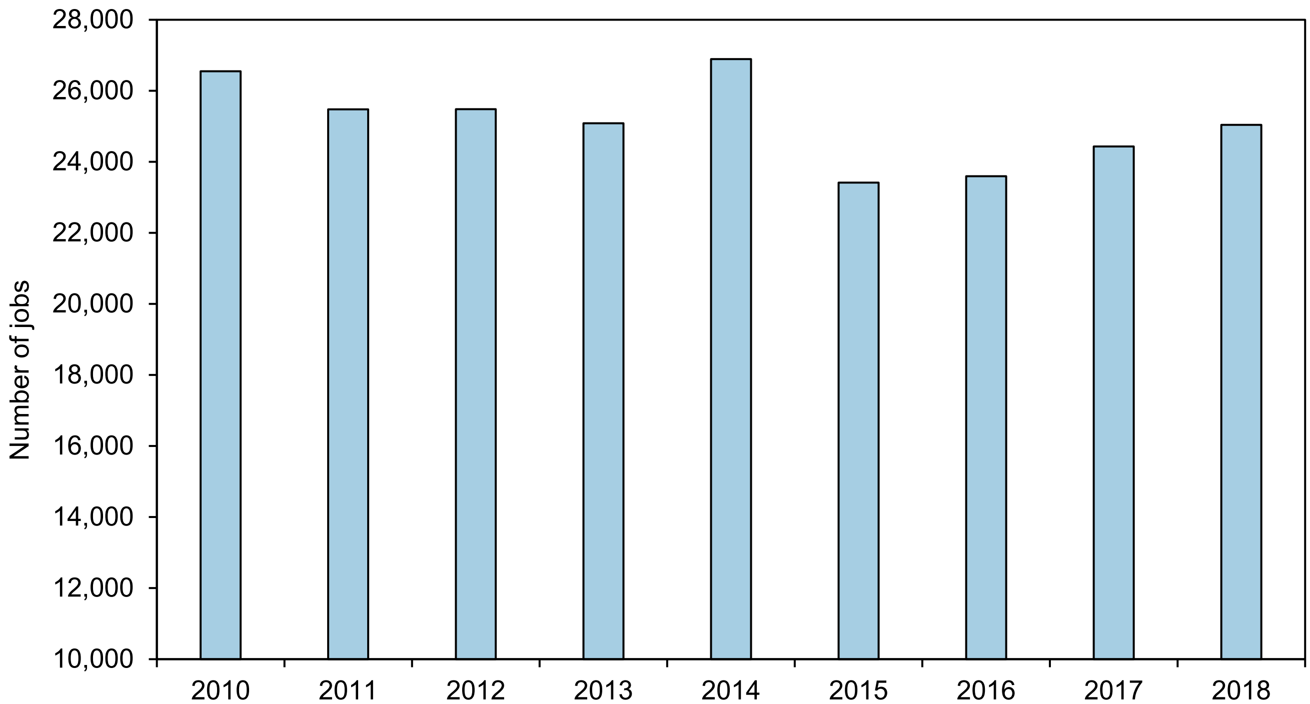

Figure 2.8.9. Number of direct jobs generated in the United States from the miscellaneous wood product manufacturing industry (NAICS 321999) from 2010 to 2018 (8).

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2.9. Waste-to-Energy

Waste-to-energy is the production of energy from waste. There are different types of waste-to-energy plants depending on the technology used to generate energy (1).

In the United States, the most common type of waste-to-energy facility burns municipal solid waste to generate energy (electricity or heat). However, there are other technologies that can generate energy from waste, such as liquid fuel synthesis or biogas recovery from landfills (1).

Municipal solid waste, which includes commercial and household wastes, can be classified into: (1) biogenic materials (i.e., plants or animal based); (2) non-biomass materials (i.e., petroleum based); or (3) noncombustible materials (i.e., glass and metals). Before being burned in a waste-to-energy plant, hazardous and recyclable materials are separated from municipal solid waste (1).

In the United States, the generation of municipal solid waste increased by 7 percent between 2010 and 2017, from 251 million metric tons in 2010 to 268 million metric tons in 2017. Of all this waste, 18 percent is combusted for energy recovery (2).

The number of waste-to-energy plants that incinerate municipal solid waste for energy recovery in the United States decreased in the last 10 years, from 86 plants in 2010 to 75 plants in 2018 (3). Most of these facilities are located in Florida and in the northeastern part of the United States, which is a densely populated region with little land availability for landfills (4).

The total number of jobs and the total economic output generated by the waste-to-energy industry has remained nearly constant over the years, accounting for 13,600 jobs and $5.6 billion in 2018 (3).

Infrastructure

The total number of waste-to-energy facilities decreased in the last decade, from 86 plants in 2010 to 75 plants in 2018 (Figure 2.9.1) (3).

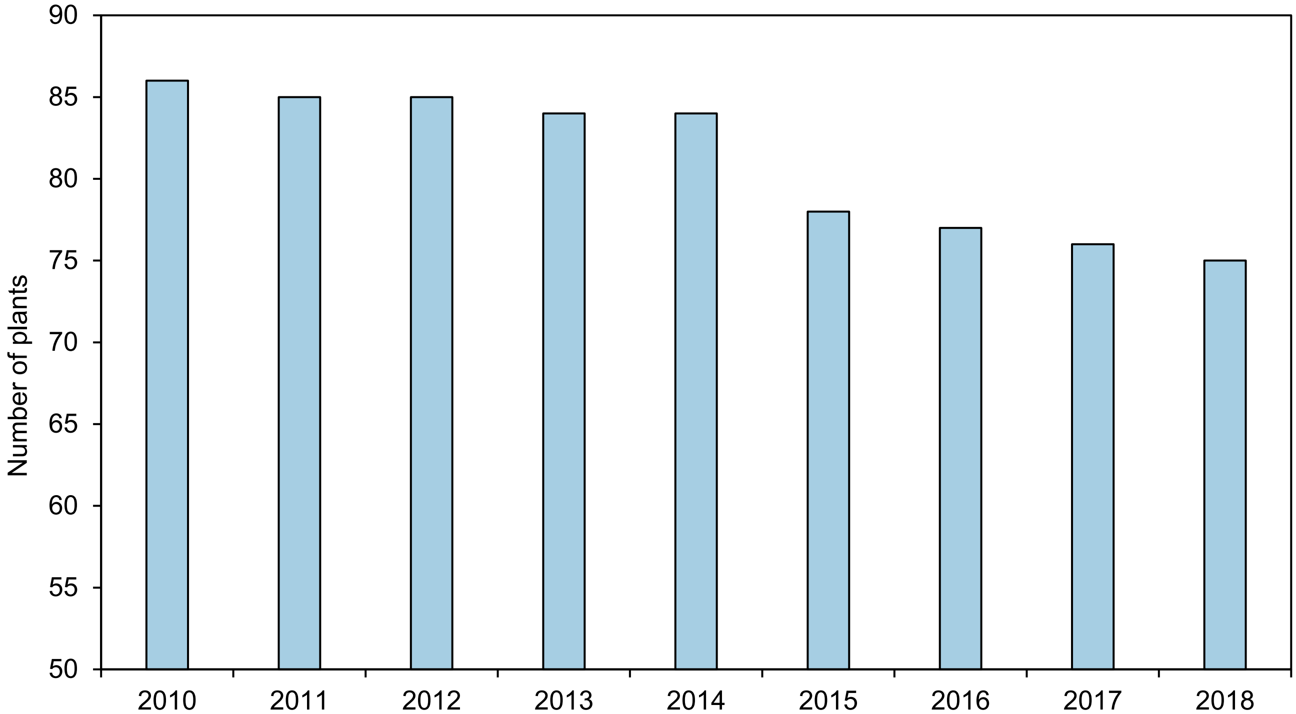

Figure 2.9.1. Total number of waste-to-energy plants in the United States from 2010 to 2018 (3).

In 2018, 20 facilities were closed and 1 was put on standby, and no new plants were proposed to be constructed (Table 2.9.1) (4).

Cities are embracing zero waste policies and renewable energy targets, and therefore shifting away from incineration plants. This is a possible explanation for the reduction in the number of waste-to-energy plants. In addition, these facilities usually face public opposition due to the concern about toxic emissions associated with them and their contribution to climate change (7). As a consequence, companies are using municipal solid waste in co-incineration plants (i.e., plants whose primary purpose is the production of material products or generation of energy) rather than building new waste-to-energy plants (7).

INFRASTRUCTURE	2010	2011	2012	2013	2014	2015	2016	2017	2018
# of waste-to-energy plants in the United States	86	85	85	84	84	78	77	76	75
# of waste-to-energy plants proposed in the United States	2	0	2	2	1	0	0	0	0
# of waste-to-energy existing plants that were put on standby	2	2	2	2	2	2	1	1	1
# of waste-to-energy existing plants that were closed/shut down	11	10	11	13	8	9	11	11	20
# of waste-to-energy fuel switching plants in the United States	20	20	16	13	15	15	15	10	16
# of States which have a waste-to-energy fuel switching production facility	9	9	7	5	7	7	7	8	6

Table 2.9.1. Infrastructure of the waste-to-energy industry in the United State from 2010 to 2018 (3,4).

There are two geographic clusters of waste-to-energy facilities that use municipal solid waste for energy recovery. The first cluster is located in Florida, with 13 waste-to-energy plants. The second cluster is located in the northeastern part of the United States, and comprises New York (10 facilities), Pennsylvania (7 facilities), and Massachusetts (6 facilities) (Figure 2.9.2 and Table 2.9.2) (4,6).

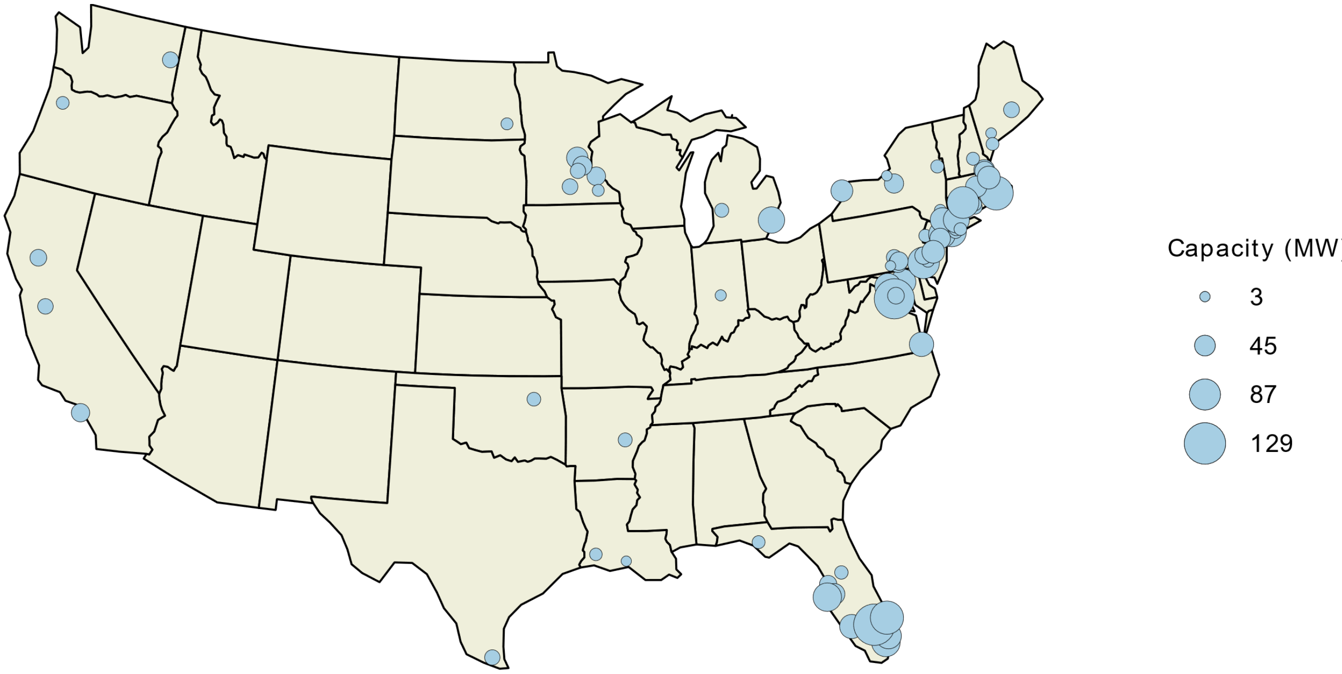

Figure 2.9.2. Waste-to-energy facilities in the United States in 2018, sizes according to capacity (in MW) (4,6).

State	Number of plants	Percentage of total generation
Florida	13	16.9
New York	10	13.0
Pennsylvania	7	9.1
Massachusetts	6	7.8
Minnesota	6	7.8

Table 2.9.2. Top 5 States for waste-to-energy facilities in the United States in 2018 (4,6).

Burning municipal solid waste is a way to generate energy, but it is also a waste management option (1). The concentration of waste-to-energy facilities in the northeastern part of the United States can be explained by its high density of population and high concentration of urban areas, and the lack of space for landfills (6). In addition, both the Florida and the northeastern clusters are located in geographic areas with shallow aquafers may prevent the construction of solid waste / municipal landfills (8,9).

Production

The amount of municipal solid waste generated in the United States increased from 251 million metric tons in 2010 to 268 million metric tons in 2017 (2). In the same year, 52 percent of total municipal solid waste generated was landfilled, 36 percent was recycled and composed, and 18 percent combusted for energy recovery (Figure 2.9.3) (2).

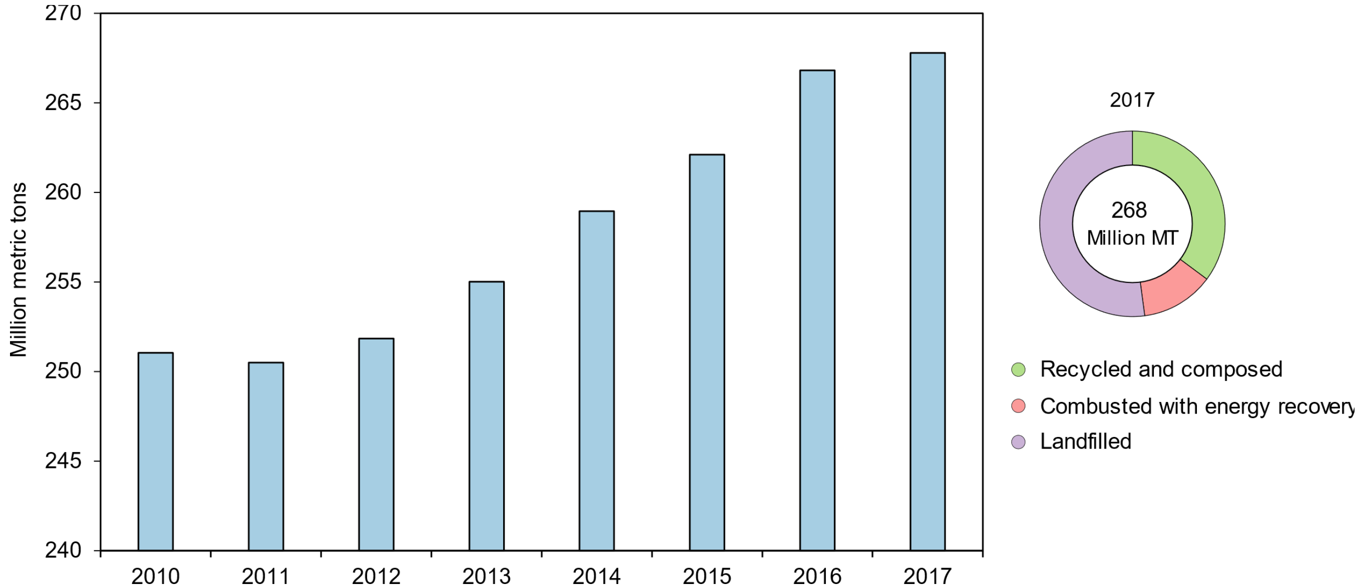

Figure 2.9.3. Total municipal solid waste generation in the United States from 2010 to 2017 (in million metric tons) and end disposal method in 2017 (2).

Municipal solid waste can be classified into (1) biogenic materials (i.e., plant or animal based), (2) non-biogenic materials (i.e., petroleum based), and (3) noncombustible materials. Consumption has remained nearly constant in the last 10 years;17 million metric tons of biogenic municipal solid waste were burned in 2018, which generated 151 BTUs of energy (5). Most of the energy generated from biogenic municipal solid waste is used for electricity generation and consumed by independent power sources (5). Non-biogenic municipal solid waste is not included in the analysis since in 2001 it was reclassified as non-renewable energy source (1).

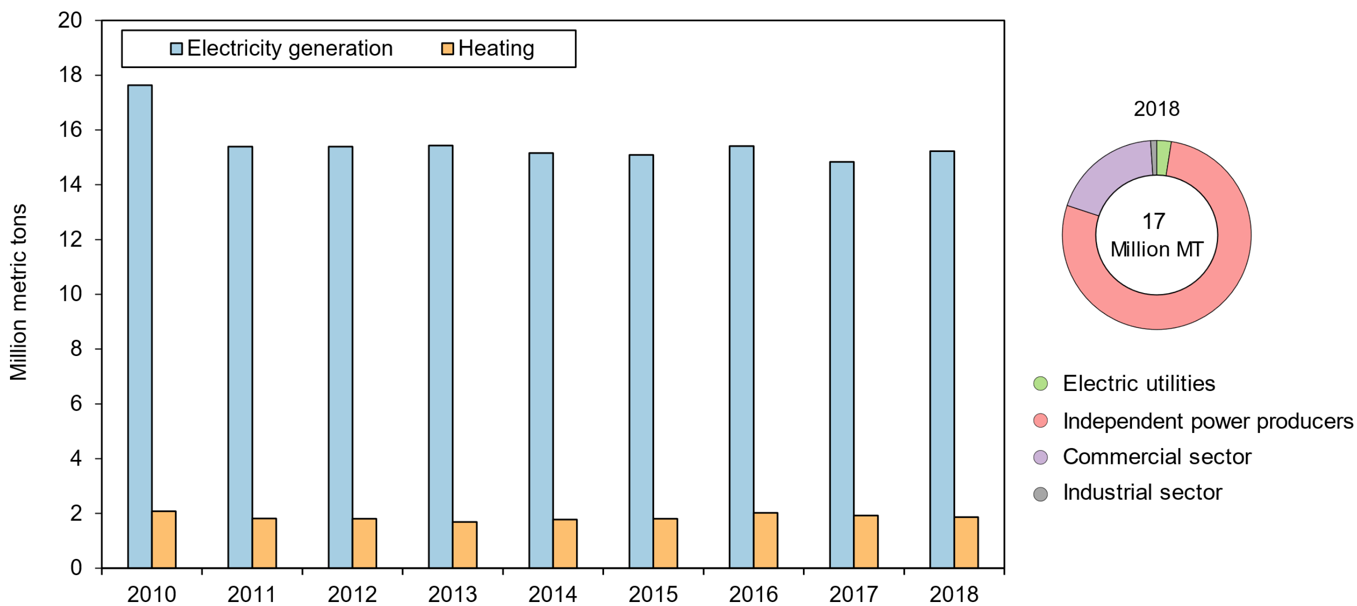

Figure 2.9.4. Biogenic municipal solid waste consumption for energy generation in the United States by final use and sector from 2010 to 2018 (in million metric tons) (5).

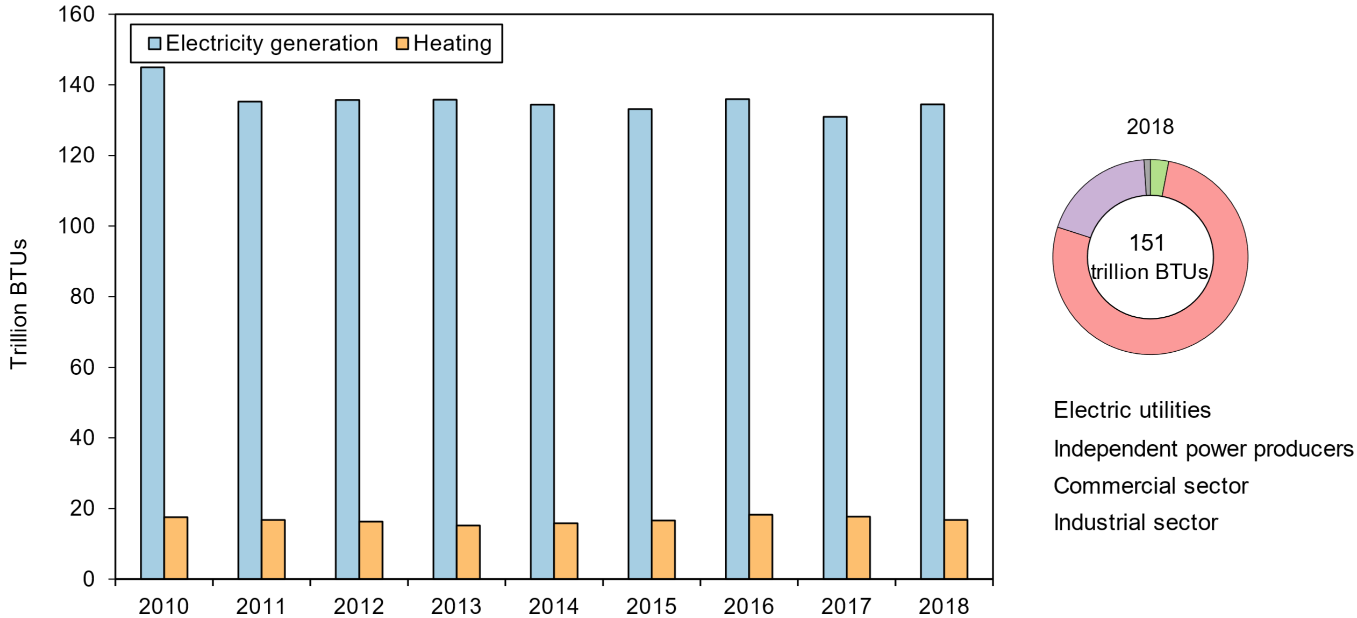

Figure 2.9.5. Energy consumption from biogenic municipal solid waste in the United States by final use and sector from 2010 to 2018 (in trillion British thermal units) (5).

The northeastern cluster concentrates most of the electricity generated from waste (4,6). Florida, New York, Massachusetts, Pennsylvania and New Jersey generated 65 percent of the total waste-generated electricity in 2018 (Figure 2.9.6 ant Table 2.9.6).

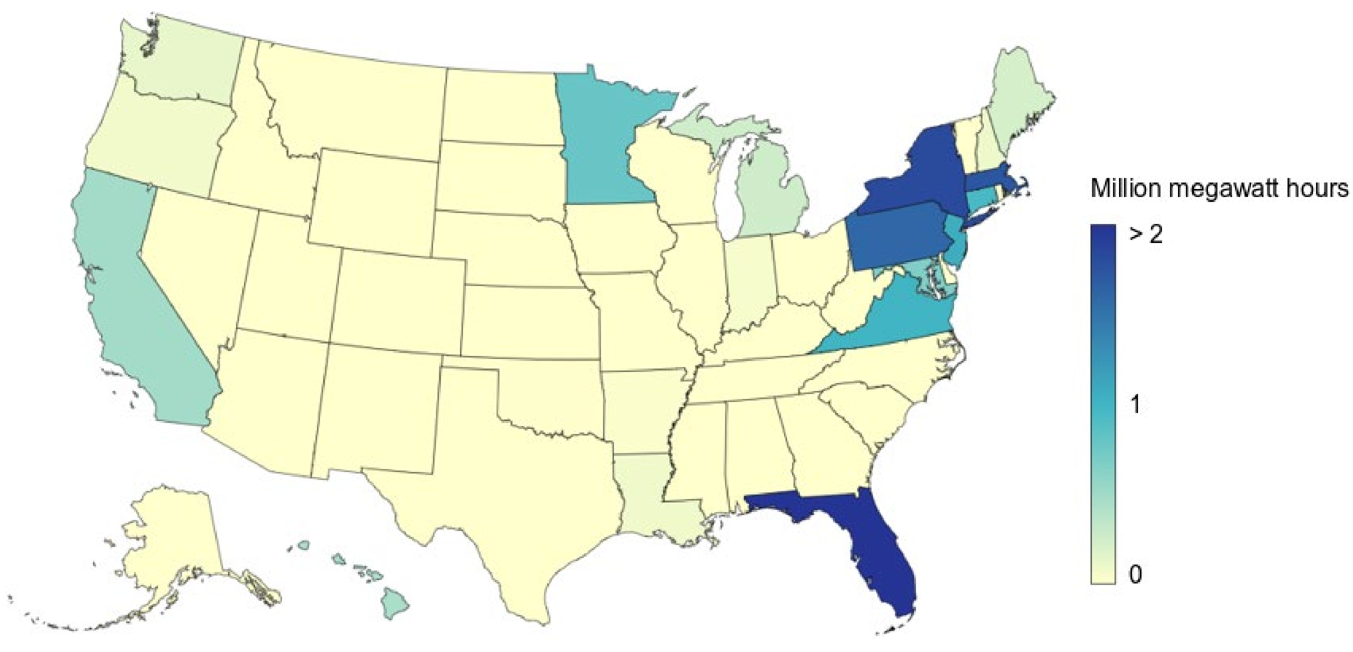

Figure 2.9.6. Electricity net generation from waste-to-energy plants by State (in million megawatt hours) in 2018 (4,6).

State	Million megawatt hours	Percentage of total generation
Florida	3.4	22.8
New York	1.8	12.3
Massachusetts	1.7	11.6
Pennsylvania	1.6	10.7
New Jersey	1.1	7.2

Table 2.9.3. 5 States with highest net generation of electricity from **waste-to-energy plants** in the United States in 2018 (4,6).

Economics

Due to the decrease in the number of waste-to-energy plants (see Table 2.9.1), the revenue from waste-to-energy electricity generation in the United States has significantly decreased from 640 million dollars in 2011 to 54 million dollars in 2018 (Figure 2.9.7) (10).

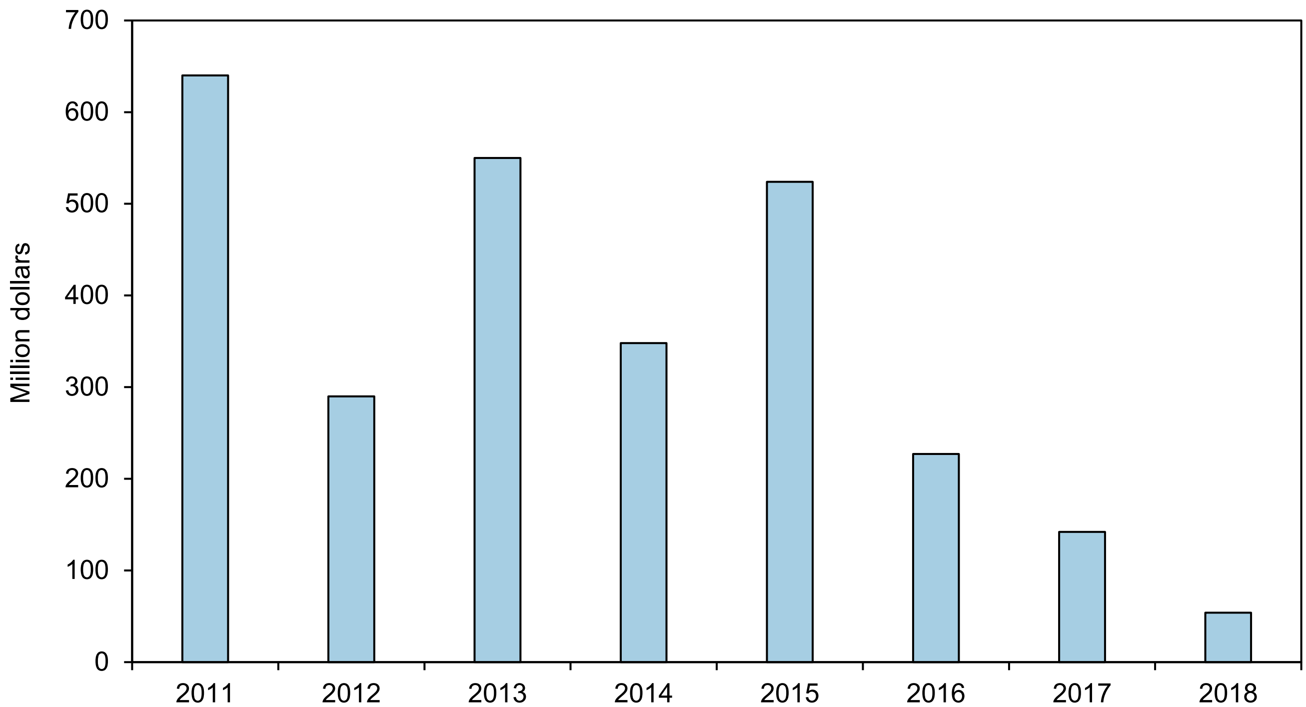

Figure 2.9.7. Revenue from waste-to-energy electricity generation in the United States from 2011 to 2018 (in million dollars) (10).

The total number of jobs (direct, indirect and induced) created by the waste-to-energy industry has remained nearly constant around 14,000 jobs over the years (Figure 2.9.8) (3).

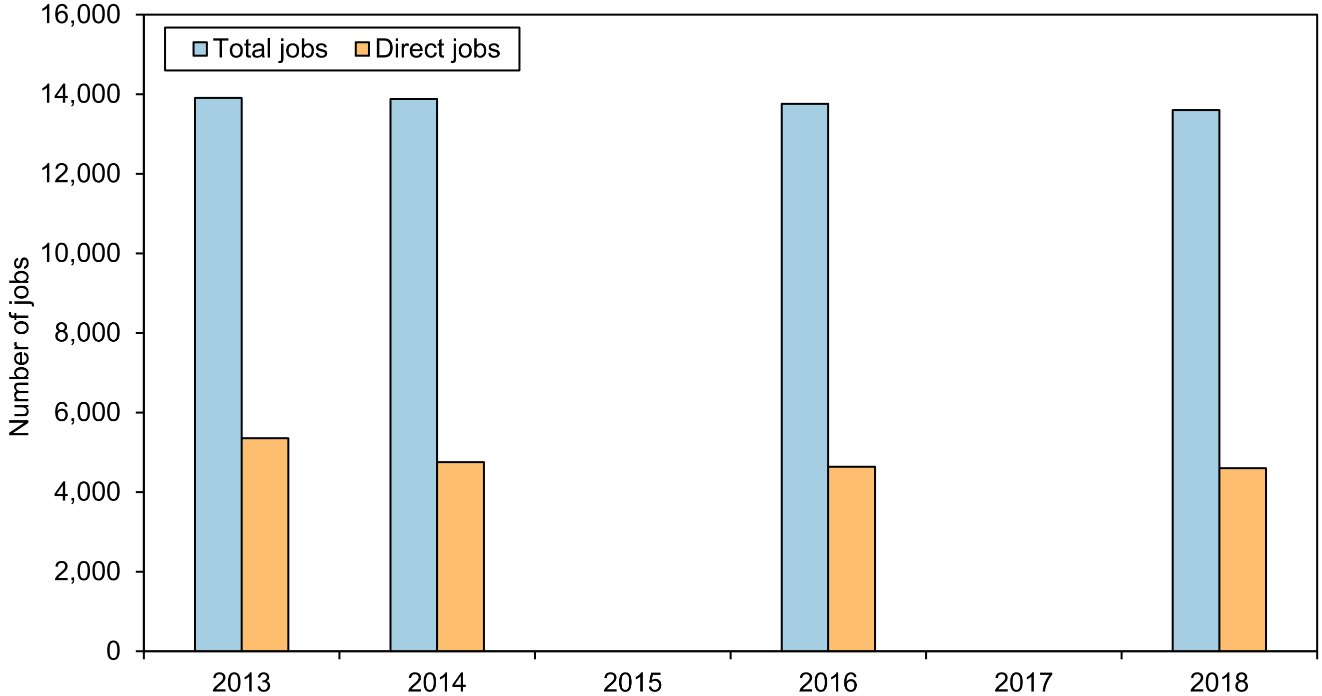

Figure 2.9.8. Number of direct and total jobs (direct, indirect and induced) generated from the waste-to-energy industry from 2013 to 2018 (3).

The total economic output generated by this industry has not significantly change between 2013 and 2018 (Figure 2.9.9) (3).

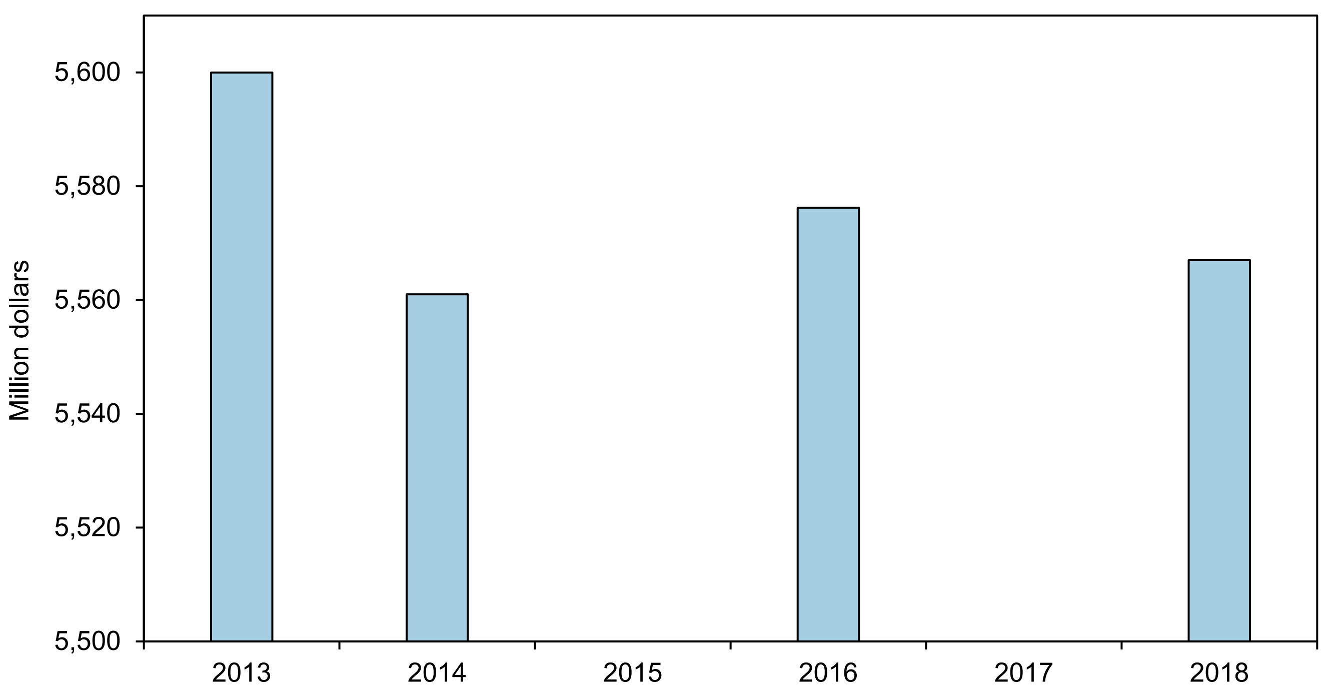

Figure 2.9.9. Total economic output generated from the waste-to-energy industry from 2013 to 2018 (in million dollars) (3).

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2.10. Biogas

Biogas is a renewable energy source produced by anaerobic digestion when organic matter is broken down by bacteria in the absence of oxygen (1). Anaerobic digestion can occur naturally (e.g., in landfills), or it can be optimized using anaerobic digesters (1).

There are different waste sources that can be used to produce biogas, such as landfills, wastewater treatment plants, animal manure and organic waste. Biogas is primarily composed of methane (a flammable gas, also called natural gas) and carbon dioxide (an inert gas). The share of methane in the mixture depends on the biogas source: landfill biogas contains between 40 and 60 percent methane, and farm and wastewater treatment plant biogas contain between 55 and 70 percent methane (2). For distribution via the existing natural gas pipeline system, methane content must be increased through further processing and purification.

Biogas systems capture methane that otherwise would escape into the atmosphere and use it for electricity generation, heating, or transportation fuel.

There were almost 2,000 different sites producing biogas in the United States in 2018: 245 anaerobic digesters on farms; 481 landfills; and 1,268 wastewater treatment facilities (3-5). Most of the plants are located in the midwestern and northeastern parts of the United States (3-5).

In the last decade, the production of biogas increased from 225 billion cubic feet in 2010 to 282 billion cubic feet in 2018 (3, 6). Besides the obvious benefits for the environment, the collection and use of biogas decreases greenhouse gas emissions, as its main component, methane, is a powerful greenhouse gas. In 2018 landfill biogas capture reduced greenhouse gas emissions by 115 million metric tons of carbon dioxide equivalent, and biogas capture form anaerobic digesters in farms reduced greenhouse emissions by 4.3 million metric tons of carbon dioxide equivalent (3, 4).

In 2018, there were 1,994 sites producing biogas in the United States between anaerobic digesters at farms, landfills, and wastewater treatment facilities (3-5). In the last 10 years, the number of biogas recovery systems has significantly increased by 84 percent in farms, and by 43 percent in landfills (Figure 2.10.1 and Table 2.10.1) (3, 4).

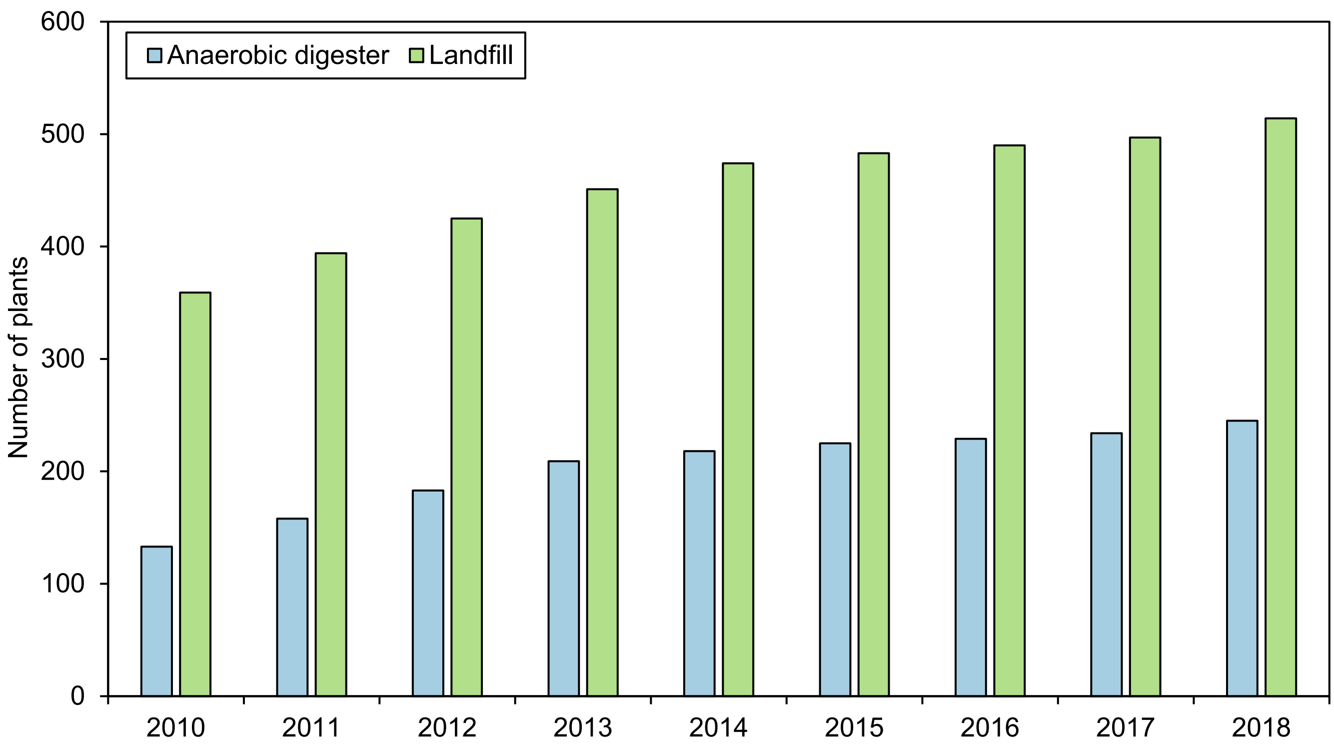

Figure 2.10.1. Total number of anaerobic digesters and biogas collecting landfills in the United States from 2010 to 2018 (3, 4).

INFRASTRUCTURE	2010	2011	2012	2013	2014	2015	2016	2017	2018
# of anaerobic digestion plants	133	158	183	209	218	225	229	234	245
# of anaerobic digesters in livestock farms used for electricity	25	38	50	61	64	65	68	71	75
# of anaerobic digesters in livestock farms used for boiler/furnace	14	14	14	14	14	14	14	14	14
# of anaerobic digesters in livestock farms used for "flare full time"	13	13	13	13	13	13	13	13	13
# of anaerobic digesters in livestock farms used for cogeneration	81	93	106	121	127	133	134	136	143
# of new anaerobic digestion plants that went on line from livestock	19	25	25	26	9	7	4	5	11
# of existing anaerobic digestion plants under construction	0	1	4	1	0	0	0	1	3
# of anaerobic digestion plants that shut down	3	8	1	3	5	4	9	4	2
# of States which have an anaerobic digestion production facility	46	46	48	48	49	49	49	49	49
# of landfill biogas plants	359	394	425	451	474	483	490	497	514

Table 2.10.1. Infrastructure of the biogas industry in the United States from 2010 to 2018 (3, 4).

Almost 60 percent of the biogas facilities in 2018 were in the midwestern and northeastern regions of the United States. California, with 22 anaerobic digester locations, 72 landfill biogas plants, and 156 wastewater treatment facilities, ranked first in number of biogas recovery systems (Figure 2.10.2; Tables 2.10.2 – 2.10.4) (3-5).

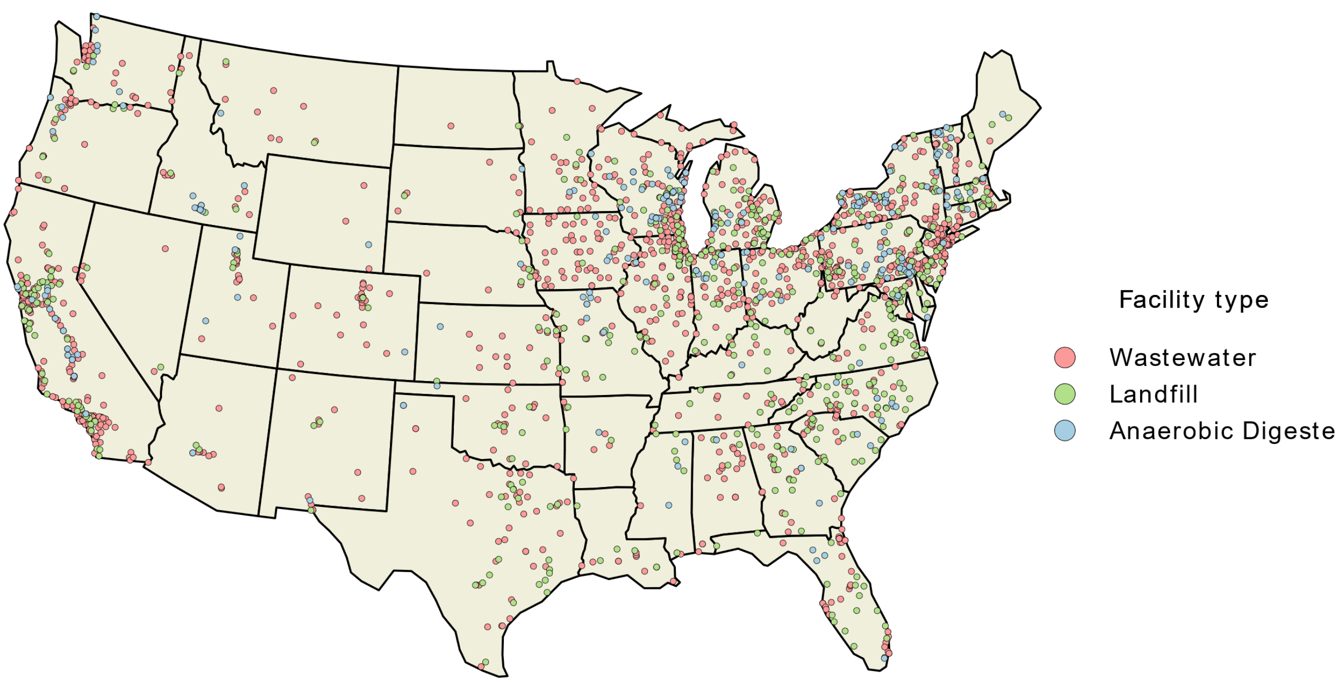

Figure 2.10.2. Biogas facilities locations by type in the United States in 2018 (3-5).

State	Number of plants	Percentage of total facilities
Wisconsin	32	12.9
Pennsylvania	32	12.9
New York	30	12.1
California	22	8.9
Vermont	16	6.5

Table 2.10.2. Top 5 States for number anaerobic digester on farms in the United States in 2018 (3).

State	Number of plants	Percentage of total facilities
California	49	9.9
Michigan	36	7.2
Pennsylvania	32	6.4
North California	29	5.8
New York	23	4.6

Table 2.10.3. Top 5 States for number of biogas recovery systems on landfills in the United States in 2018 (4).

State	Number of plants	Percentage of total facilities
California	156	12.3
New York	118	9.3
Illinois	87	6.9
Pennsylvania	81	6.4
Michigan	65	5.1

Table 2.10.4. Top 5 States for number of biogas recovery systems in wastewater treatment facilities in the United States in 2015 (5).

Production

In the United States, manure generated at animal farms has the largest biogas generation potential, accounting for 1,124 billion cubic feet per year, followed by wastewater treatment facilities, which have a biogas generation potential of 132 billion cubic feet per year, and finally by landfills, with a biogas potential of 125 billion cubic feet per year (Figure 2.10.3 and Table 2.10.5) (4, 7).

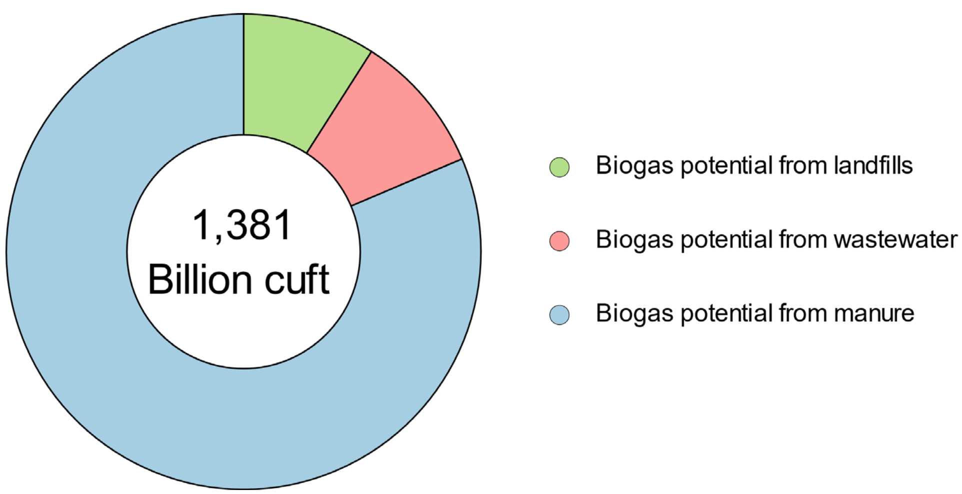

Figure 2.10.3. Biogas potential from different sources in 2018 (in billion cubic feet) (4, 7).

Source	Biogas Potential (billion cubic feet)
Landfills	125
Wastewater	132
Animal manure	1,124

Table 2.10.5. Biogas potential from different sources in 2018 (in billion cubic feet) (4, 7).

Despite farms having the largest biogas generation potential, the volume of biogas captured in landfills is 34 times larger than the biogas captured from farms (3, 6). Biogas captured in landfills increased from 2010 to 2014 until it peaked at 288 billion cubic feet. Since then, the total has slightly decreased to 274 billion cubic feet in 2018 (6). On the other hand, biogas from farms increased from 5 billion cubic feet in 2010 to 8 billion cubic feet in 2018 (Figure 2.10.4) (3).

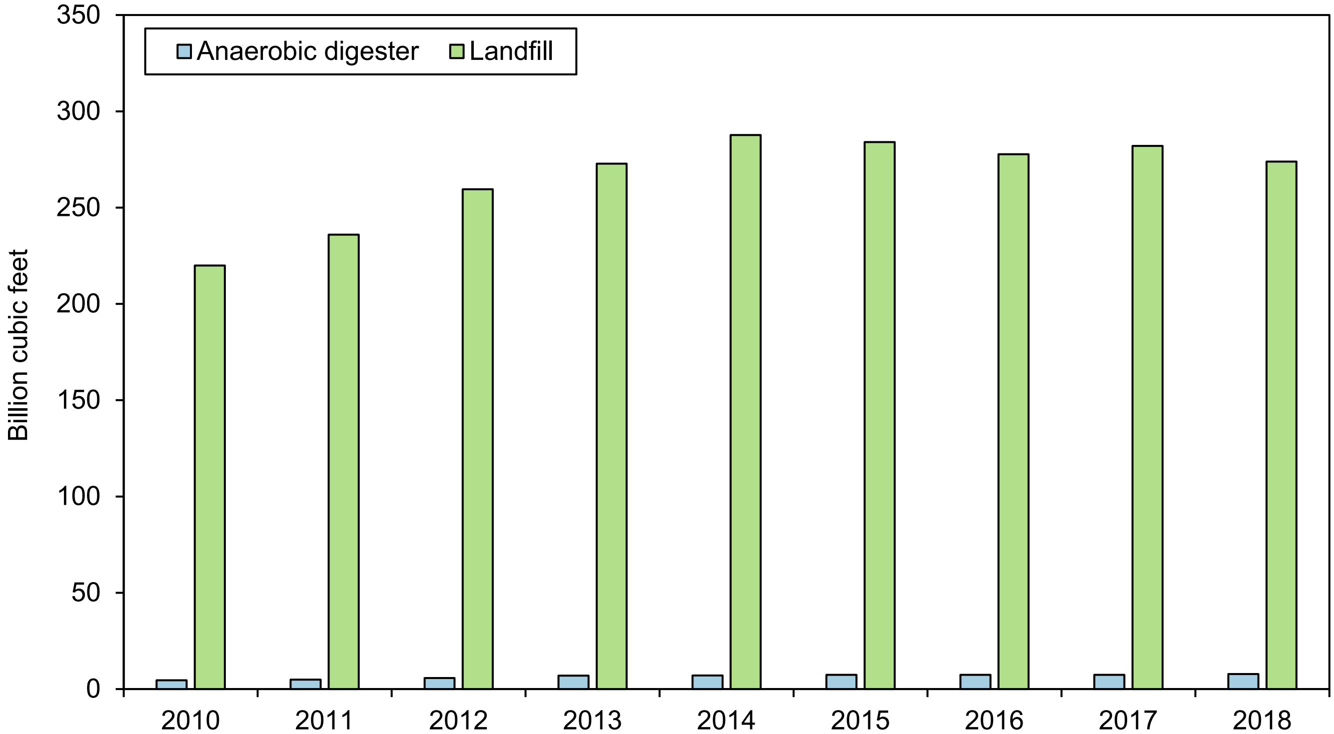

Figure 2.10.4. Total biogas captured by source from 2010 to 2018 (in billion cubic feet) (3, 6).

As of 2018, California, Iowa and North Carolina are the States with the highest biogas potential from animal farms, accounting for more than 20 percent of total U.S. biogas potential in farms (Figure 2.10.5 and Table 2.10.6) (7).

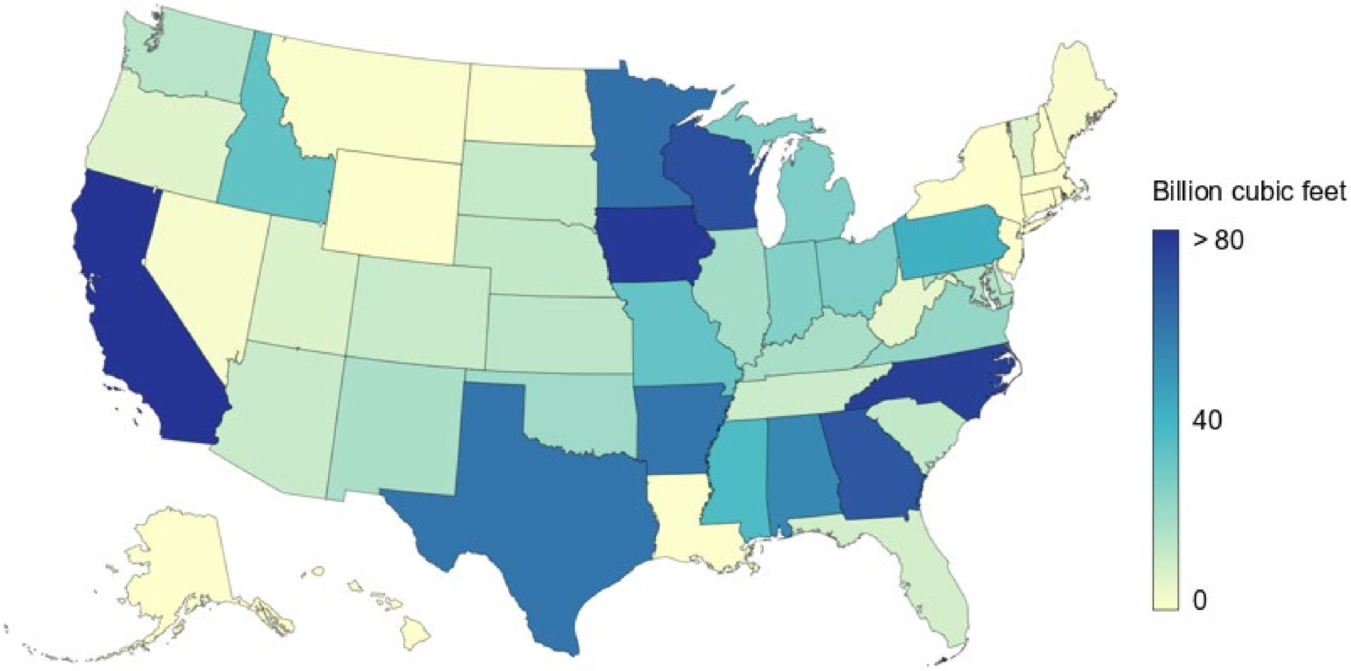

Figure 2.10.5. Biogas potential from anaerobic digesters on farms in the United States in 2018 (in billion cubic feet) (7).

State	Billion cubic feet	Percentage of total
California	96	8.5
Iowa	79	7.0
North Carolina	76	6.8
Wisconsin	72	6.4
Georgia	69	6.1

Table 2.10.6. Top 5 States with the highest biogas potential from anaerobic digesters on farms in the United States in 2018 (in billion cubic feet) (7).

California also has the highest potential for biogas capture from landfills along with Texas, with 13.4 and 13.3 billion cubic feet, representing 21.3 percent of the total biogas potential from landfills (Figure 2.10.6 and Table 2.10.7) (4).

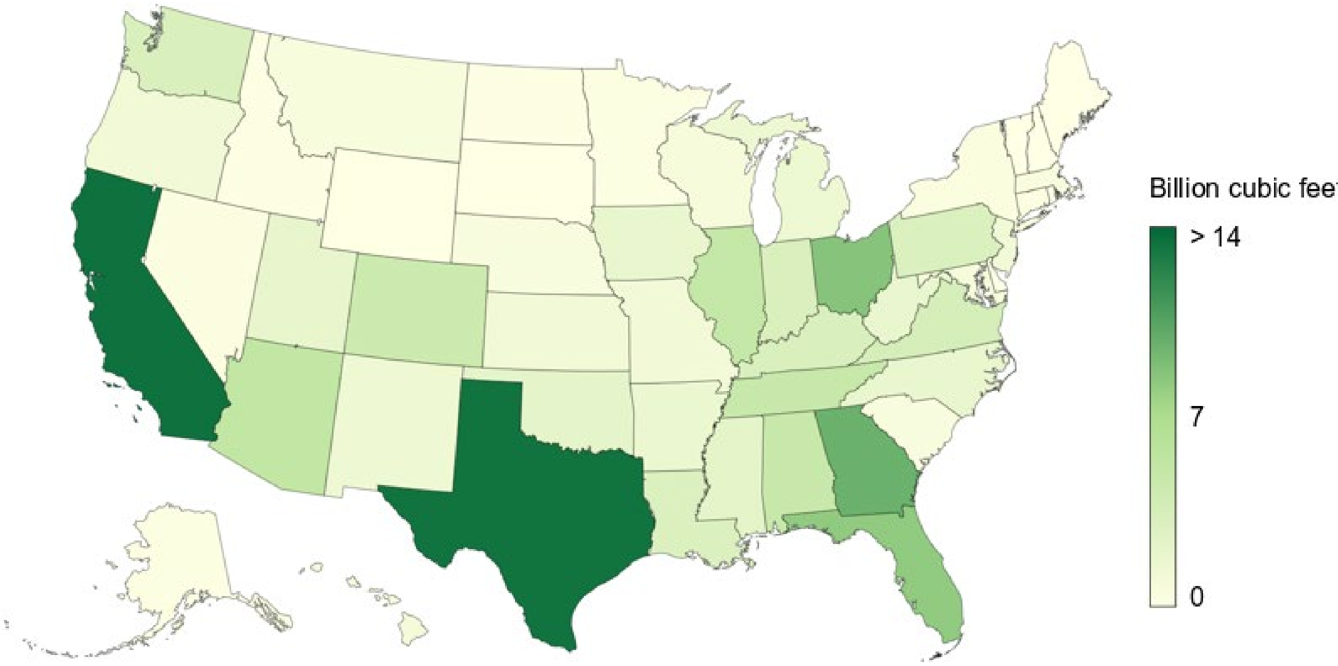

Figure 2.10.6. Biogas potential from landfills in the United States in 2018 (in billion cubic feet) (4).

State	Billion cubic feet	Percentage of total
California	13.4	10.7
Texas	13.3	10.6
Georgia	9.7	7.7
Ohio	8.5	6.8
Florida	8.1	6.5

Table 2.10.7. Top 5 States with the highest biogas potential in landfills in the United States in 2018 (in billion cubic feet) (4).

The biogas generation potential from wastewater facilities is more concentrated than biogas potential from manure or landfills. As with the other sources of biogas, California is the State with the highest potential from wastewater treatment plants, with 19 billion cubic feet, followed by Illinois and Texas with 11 and 10 billion cubic feet, respectively (Figure 2.10.7 and Table 2.10.8).

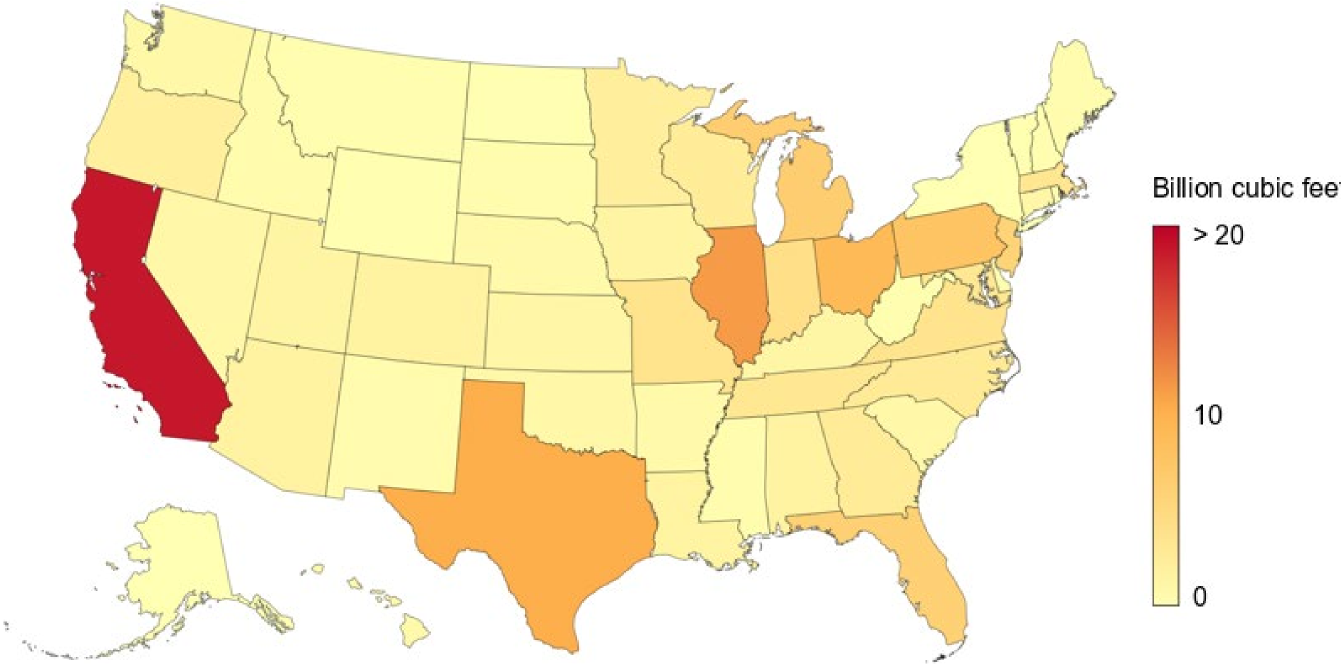

Figure 2.10.7. Biogas potential from wastewater treatment in the United States in 2018 (in billion cubic feet) (7).

State	Billion cuft	Percentage of total
California	19	14.2
Illinois	11	8.6
Texas	10	7.7
Ohio	9	6.7
Pennsylvania	8	5.8

Table 2.10.8. Top 5 States with the highest biogas potential from wastewater treatment plants in the United States in 2018 (in billion cubic feet) (7).

Biogas can be used for electricity generation, for heating, and as a transportation fuel. The total energy generated from biogas in the last decade follows the same trend as the biogas captured by source (Figure 2.10.4). In 2018, landfills generated 136 trillion BTUs of energy from biogas and anaerobic digesters 3.1 trillion BTUs (Figure 2.10.8) (3, 6).

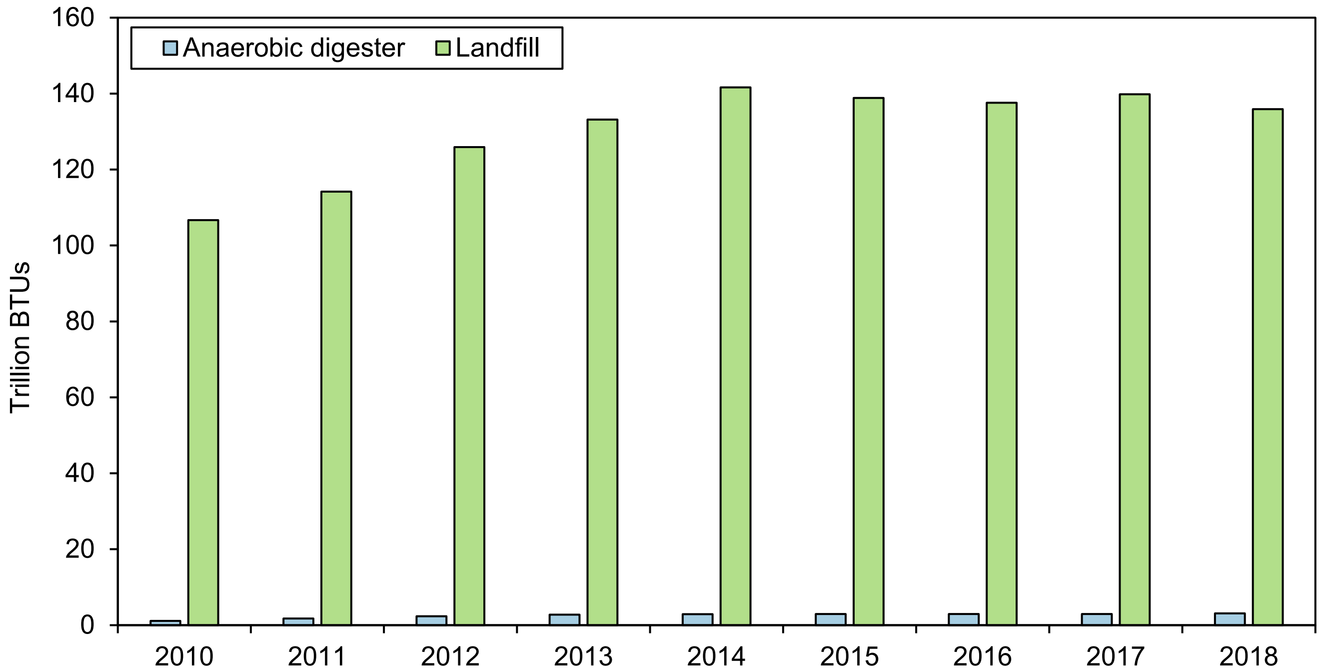

Figure 2.10.8. Total energy generated from biogas by source from 2010 to 2018 (in trillion British Thermal Units (BTU)) (3, 6).

Methane is a valuable source of energy, but it has deleterious greenhouse gas impacts. Global warming potential over 100 years is a measure of the amount of heat that a greenhouse gas traps in the atmosphere; methane's global warming potential is 25 times higher than that of carbon dioxide (8). Capturing methane thus results in a large reduction of carbon dioxide equivalent emissions. In 2018, landfills captured 115 million metric tons of carbon dioxide equivalent, and anaerobic digesters captured 4.3 million metric tons of carbon dioxide equivalent (Figure 2.10.9) (3, 4).

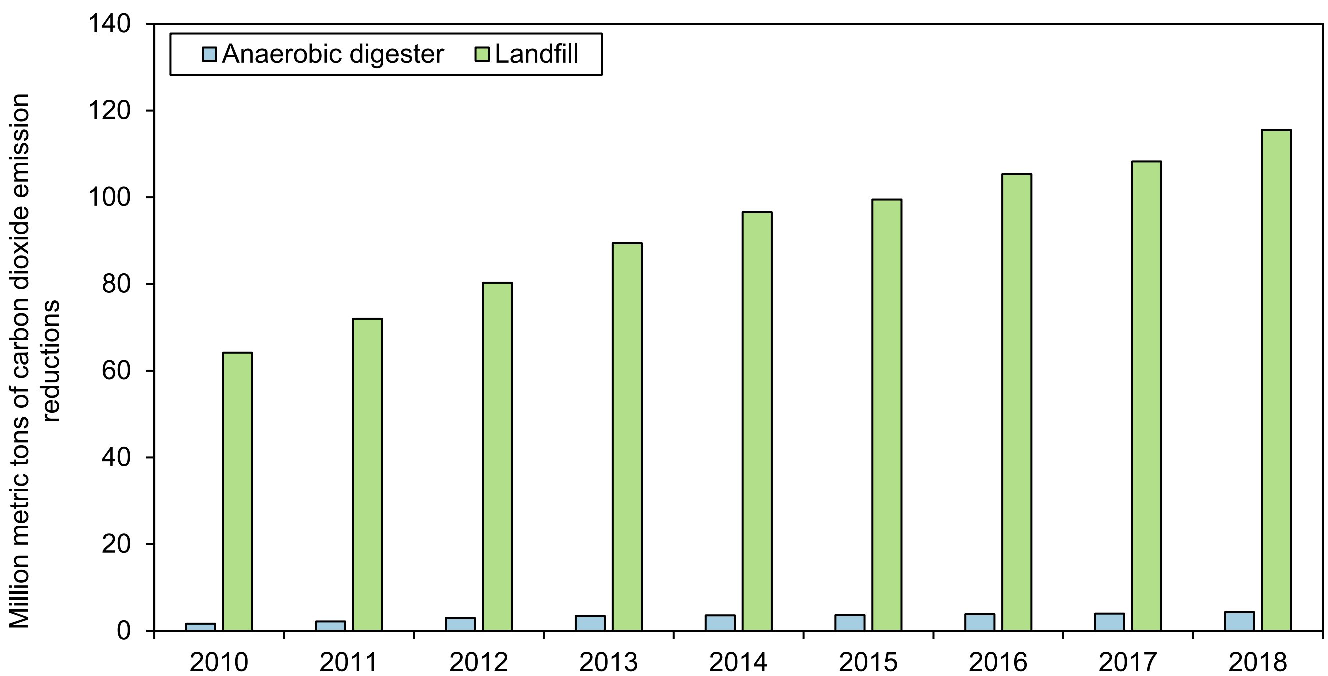

Figure 2.10.9. Methane emissions reductions by source from 2010 to 2018 (in million metric tons of carbon dioxide equivalent) (3, 4).

Methane emissions from waste slightly decreased in the last 10 years, while methane capture from landfills steadily increased (9). In 2017, methane emissions from waste and methane emission reduction from biogas recovery systems on landfill were almost equal, which indicates that to capture all the methane emitted by waste, biogas recovery systems on landfills should double their capacity (Figure 2.10.10) (3,9).

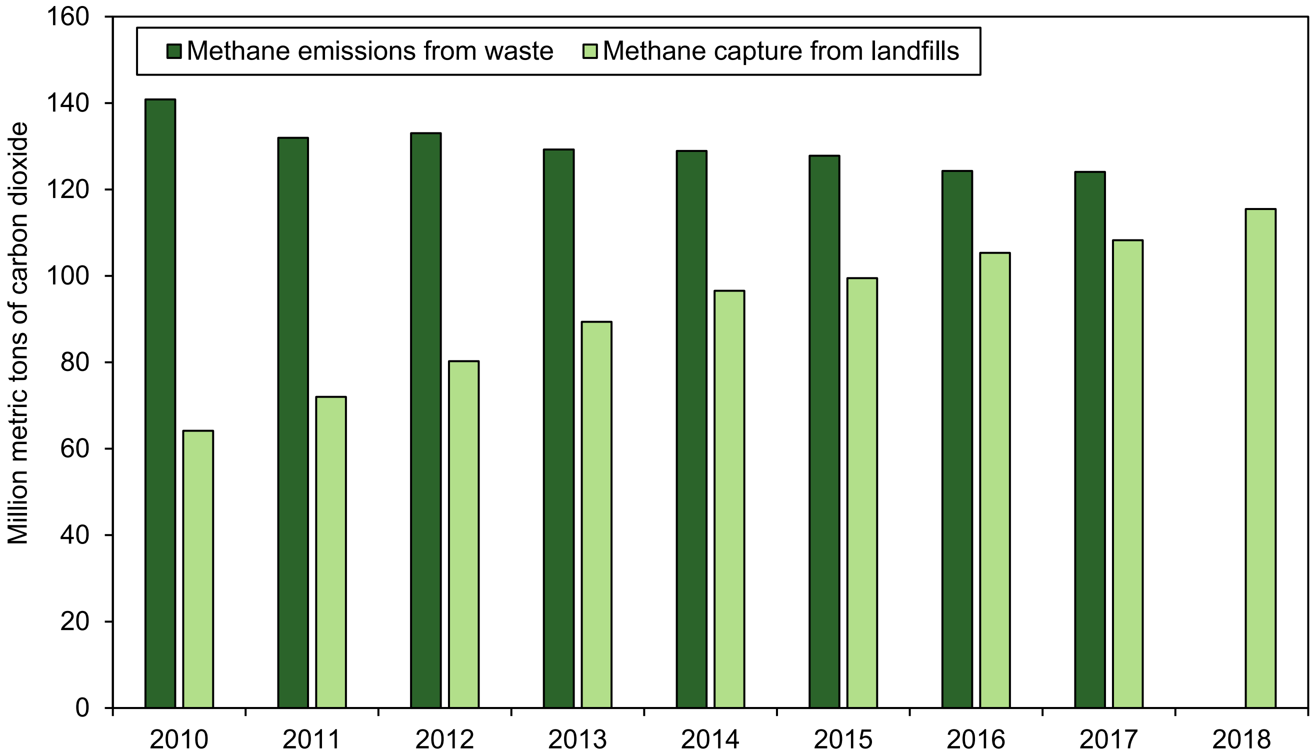

Figure 2.10.10. Total methane emission from waste in the United States from 2010 to 2017 (9) and total methane reductions from biogas recovery systems on landfills from 2010 to 2018 (in million metric tons of carbon dioxide equivalent) (3,9).

Total methane emissions from agriculture have remained constant from 2010 to 2017, which is consistent with the fact that the proportion of farms with an anaerobic digester is very small (9). Methane emissions from agriculture are considerably larger than the amount of methane recovered from farms using anaerobic digesters (Figure 2.10.11) (4,9).

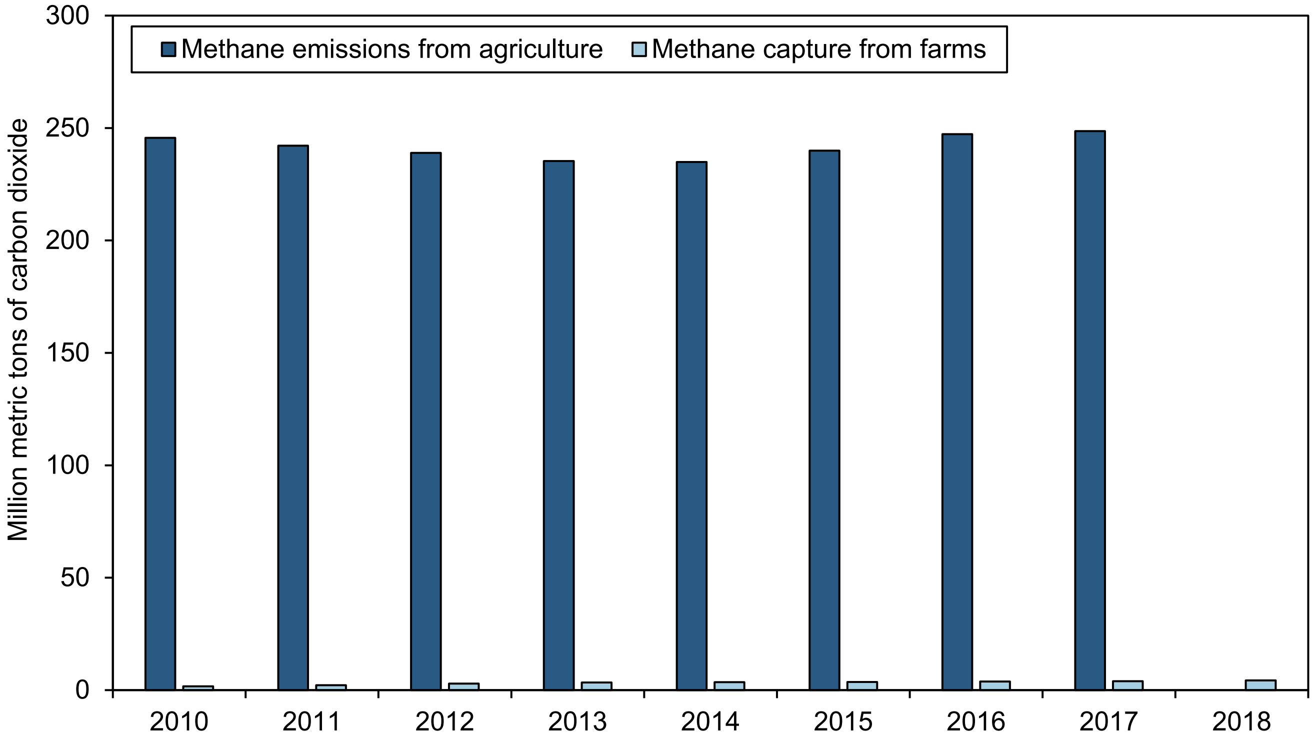

Figure 2.10.11. Total methane emission from agriculture in the United States from 2010 to 2017 (9) and total methane emissions reductions from anaerobic digesters on farms from 2010 to 2018 (in million metric tons of carbon dioxide equivalent) (4,9).

Economics

In 2014, the United States Environmental Protection Agency conducted an industry survey and concluded that building 11,000 biogas recovery systems would result in 275,000 short-term construction jobs and 18,000 permanent jobs. The study also concluded that the market potential from installing digesters on 2,647 dairy operations would be $2.9 billion (1).

In 2018, the American Biogas Council studied the biogas potential and the economic implications by State, being California, Texas and North Carolina, the States with the largest methane production potential from farms, landfills, and wastewater treatment plants (Figure 2.10.12 and Table 2.10.9).

California has the potential to implement 1,294 new biogas projects, which is an increase of 330 percent. Texas can grow by 948 percent, from 86 biogas operational projects to 901 potential biogas projects. Finally, North Carolina can increase its biogas industry by 934 percent, which is equivalent to creating 848 new biogas recovery systems (7). Most of the potential biogas systems are anaerobic digesters in farms.

Constructing the aforementioned projects would generate $3.9 billion in capital investment in California, $2.7 billion in Texas, and $3.1 billion in North Carolina. In addition, that would create 32,342 short-term jobs and 2,148 long-term jobs in California, 22,534 short-term jobs and 1,496 long-term jobs in Texas, and 25,480 short-term jobs and 1,692 long-term jobs in North Carolina (see Table 2.10.9) (7).

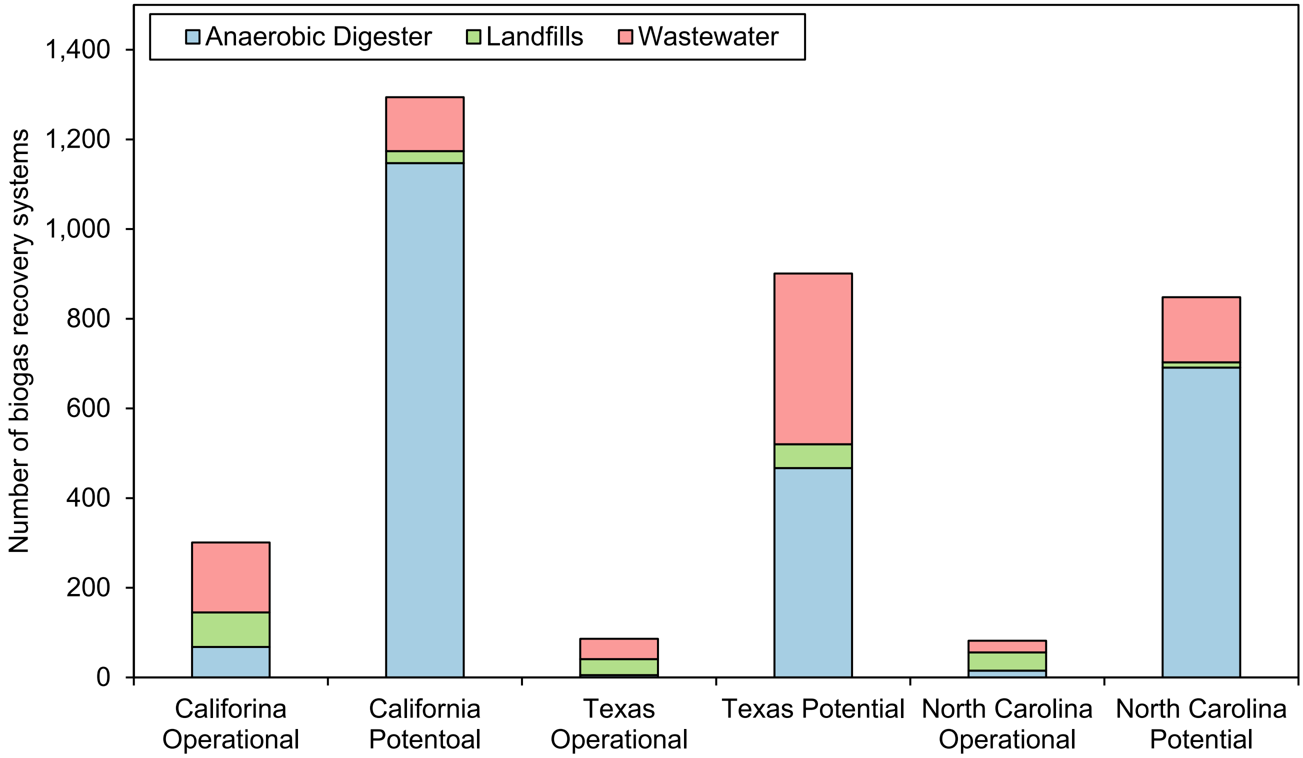

Figure 2.10.12. Operational and potential biogas recovery systems–by type –in California, Texas, and North Carolina in 2018 (7).

	California	Texas	North Carolina
Potential anaerobic digesters in farms	1,147	467	691
Potential biogas systems at landfills	27	53	12
Potential biogas systems at wastewater treatment plants	120	381	145
Capital investment in billion dollars	3.9	2.7	3.9
Short-term jobs	32,342	22,534	25,480
Long-term jobs	2,148	1,496	1,692

Table 2.10.9. Potential biogas recovery systems–by type–in California, Texas, and North Carolina. Economic impact statistics (e.g., jobs, investment) are for the year 2018 (7).

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3. BIOBASED PRODUCTS

3.1. Summary

Number of companies participating in the BioPreferred Program: **>2,200**

TOP 5 STATES BY NUMBER OF BIOENERGY PLANTS

California [276]
New York [222]
Pennsylvania [163]
Michigan [159]
Illinois [147]

The number of products in the BioPreferred catalog is **>3,500**

bioplastics represents **66%** of total products.

Global production of bioplastics in 2018 ↑ **86.3 %**

TOP 5 TYPES OF BIOPLASTICS

2017
3.6 million metric tons

Packaging [1.20]
Textiles [0.22]
Consumer goods [0.15]
Automotive and transport [0.14]
Agriculture [0.11]

2018
6.7 million metric tons

Packaging [5.4]
Textiles [0.45]
Automotive and transport [0.34]
Consumer goods [0.19]
Agriculture [0.14]

Renewable chemical production in the U.S.

⬆ **354%**

2012		2017
0.17 MMT	VS	**0.75** MMT

Value of global market for industrial enzymes

⬆ **4.7%**

2017		2018
5.3 B DOLLARS	VS	**5.5 B** DOLLARS

Forest products represent the largest contribution of renewable source for the biobased products industry .

TOP 5 CATEGORIES

2017

Roundwood [420 Million tons]
Sandwood [80 Million tons]
Paper and paperboard [72 Million tons]
Wood fuel [64 Million m3]
Wood pulp [49 Million tons]

2018

Roundwood [439 Million tons]
Sandwood [82 Million tons]
Paper and paperboard [72 Million tons]
Wood fuel [71 Million m3]
Wood pulp [49 Million tons]

3.2. Bioproducts

Biobased products, or bioproducts, are commercial and industrial products derived in whole, or in significant part, from biological or renewable materials. Such products generally provide an alternative to conventional, petroleum-derived products, such as lubricants, detergents, inks and plastics. The U.S. Department of Agriculture manages the BioPreferred Program, which is intended to increase the purchase and use of biobased products (1). The BioPreferred Program has two major parts: (1) mandatory purchasing requirements for Federal agencies and their contractors, and (2) voluntary labeling initiative for biobased products (1).

Federal law, the Federal Acquisition Regulations, and Presidential Executive Orders require Federal agencies to purchase biobased products in categories defined by the BioPreferred Program. Each category specifies the minimum biobased content for products within the category (1).

In addition, the BioPreferred Program also created a voluntary labeling initiative through which companies can apply for certification to display the USDA certified biobased product (see Figure 3.2.1). This label was created to inform the consumer on whether a given product is indeed biobased (1).

Figure 3.2.1. A sample United States Department of Agriculture Certified Biobased Product label (1).

In this context, the United States Department of Agriculture BioPreferred Program assists companies in identifying products that might qualify for mandatory Federal purchasing and/or might be certified through the voluntary labelling initiative (1).

More than 2,200 companies participate in the BioPreferred Program. California (262 companies) has the largest number of companies participating in the program, followed by Washington (175 companies) and Texas (136 companies) (see Figure 3.2.2 and Table 3.2.1 for further details) (2).

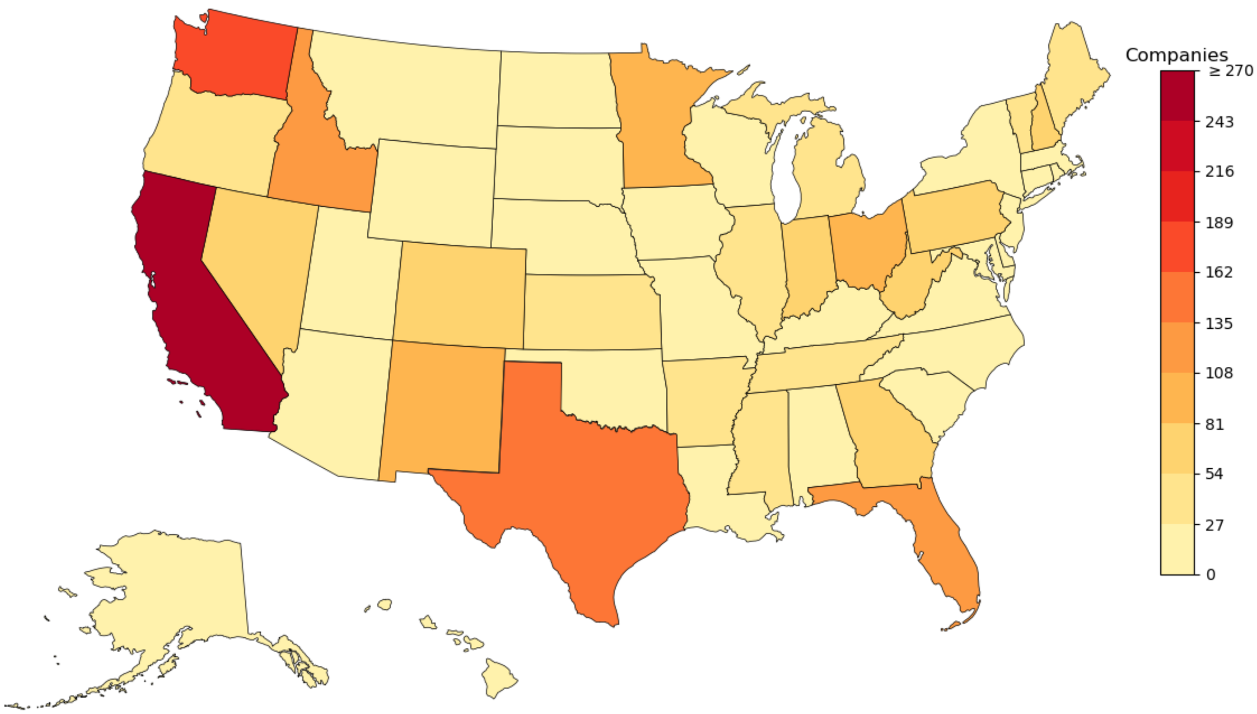

Figure 3.2.2. Number of companies participating in the BioPreferred Program in 2016 (2).

State	Number of companies	Percentage of total companies
California	262	11.8
Washington	175	7.9
Texas	136	6.1
Illinois	123	5.5
Florida	118	5.3

Table 3.2.1. Top 5 States ranked by number of companies participating in the BioPreferred Program in 2016 (2).

Tracking the BioPreferred Program over several years shows the evolution of the biobased economy, given the increase in the number of product offerings within the program (e.g., lubricants, cleaning products, bioplastics). The number of mandatory Federal purchasing offerings increased from just 32 categories in 2008 to 109 categories in 2018. Voluntary labeling offerings increased from 50 categories in 2011 to 100 categories in 2016 (Figure 3.2.3) (1, 2).

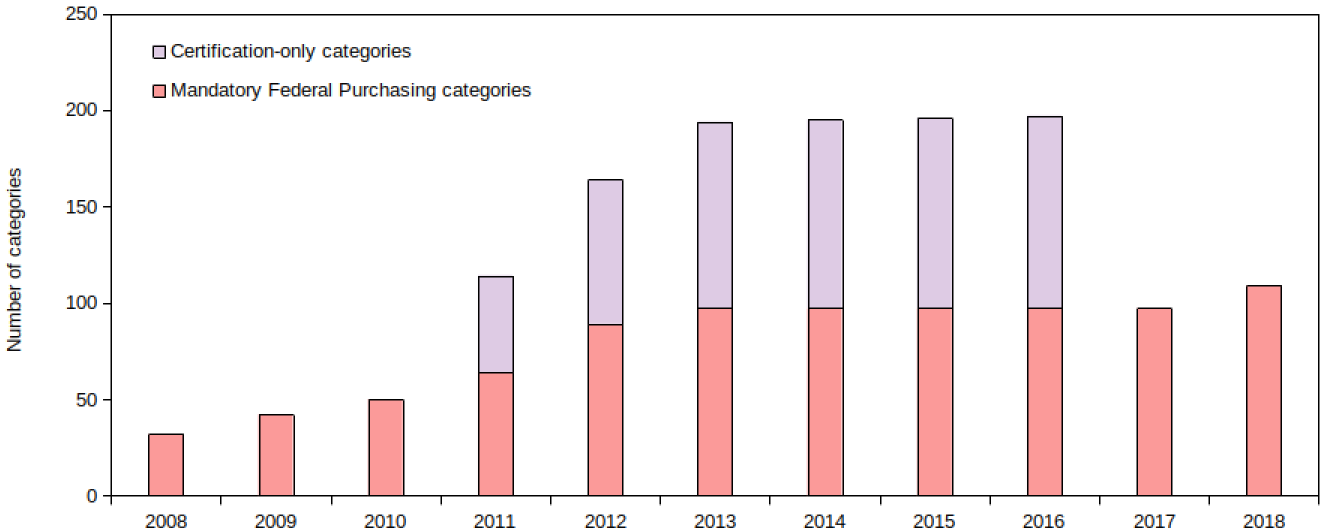

Figure 3.2.3. Number of categories of biobased products for mandatory Federal Purchasing from 2008 to 2018 and certification-only categories from 2011 to 2016 (1).

The BioPreferred Program estimates the total number of biobased products in the United States increased 135 percent in 6 years, from 17,000 products in 2008 to more than 40,000 products in 2014 (1). About 15,000 biobased products are included in the BioPreferred Program. Of these, around 12,400 products qualify for mandatory Federal purchasing initiatives, 900 products are certified but not covered by the purchasing mandates, and 1,700 products qualify for both initiatives (Figure 3.2.4) (1).

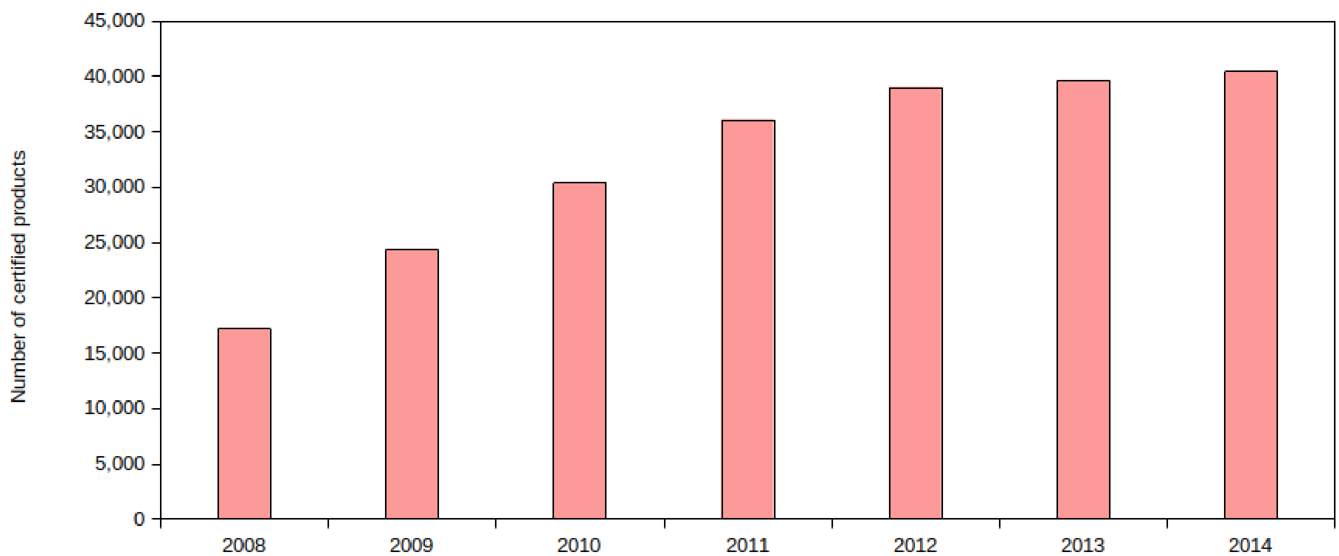

Figure 3.2.4. United States Department of Agriculture's BioPreferred Program estimate of the total number of biobased products in the United States from 2008 to 2014 (1).

Figure 3.2.5 presents the products in the BioPreferred catalog by category in 2016. Bioplastics represent 66 percent of total products in the catalog, followed by enzymes (15 percent of total products) (1).

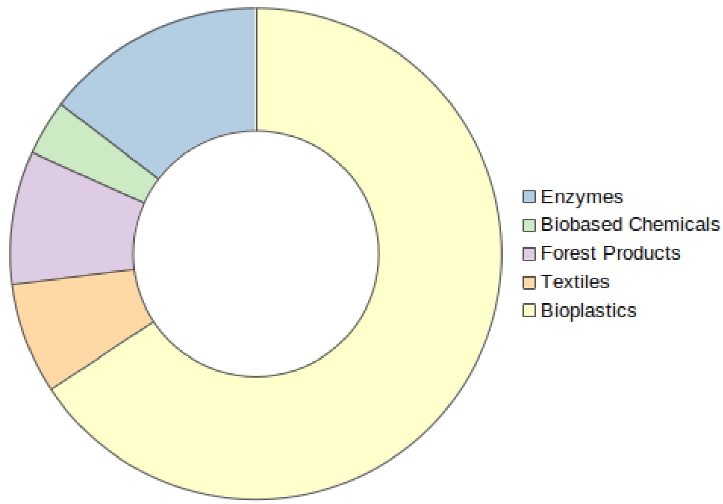

Figure 3.2.5. Federal purchasing products and certified-only products in the catalog by category in 2016 (1).

In 2017 the bioproducts industry directly employed 1.8 million workers in the United States, an increase of 17.1 percent with respect to 2014. The State with the highest number of jobs in the bioproducts industry was California (165,000 jobs), which concentrates 9 percent of all the bioproducts industry jobs in the United States, with an increase of 9 percent from 2014. The second State with the highest number of jobs was Texas (116,000 jobs), followed by North Carolina (110,000 jobs). Both States saw an increase in the number of people directly employed by the bioproducts industry of 6 percent with respect to 2014.

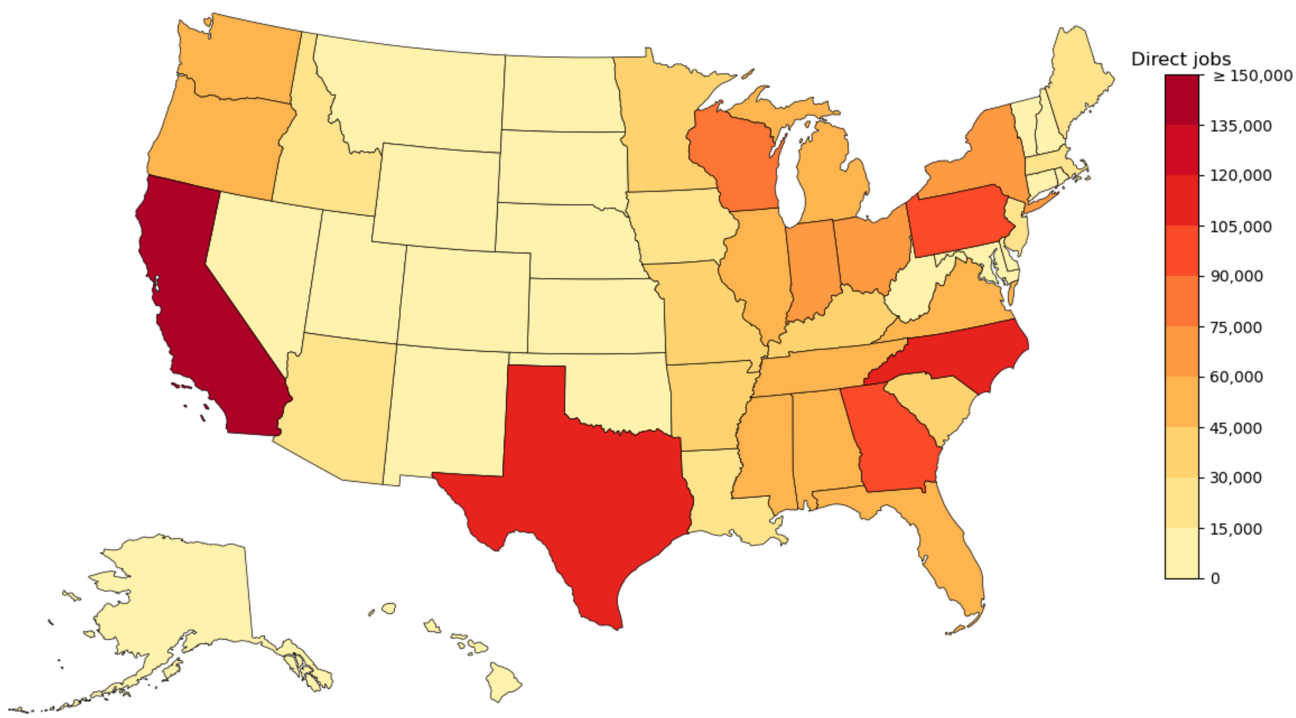

Figure 3.2.6. Number of direct jobs contributed to the United States economy through the biobased products industry in 2017 (2).

State	Number direct of jobs	Percent of total	Percent change from 2014
California	165,260	9.2	9.2
Texas	115,830	6.4	6.4
North Carolina	109,980	6.1	6.1
Georgia	98,620	5.5	5.5
Pennsylvania	90,390	5.0	5.0

Table 3.2.2. Top 5 States with the most direct American jobs from the biobased products industry in 2017 (2).

With the addition of indirect job generation by the bioproducts industry, the figure rises to 3.6 million jobs, an increase of 17 percent with respect to 2014. The top three States in number of total jobs directly or indirectly linked to the bioproducts industry are still California (311,000 jobs), Texas (228,000 jobs) and North Carolina (223,000 jobs).

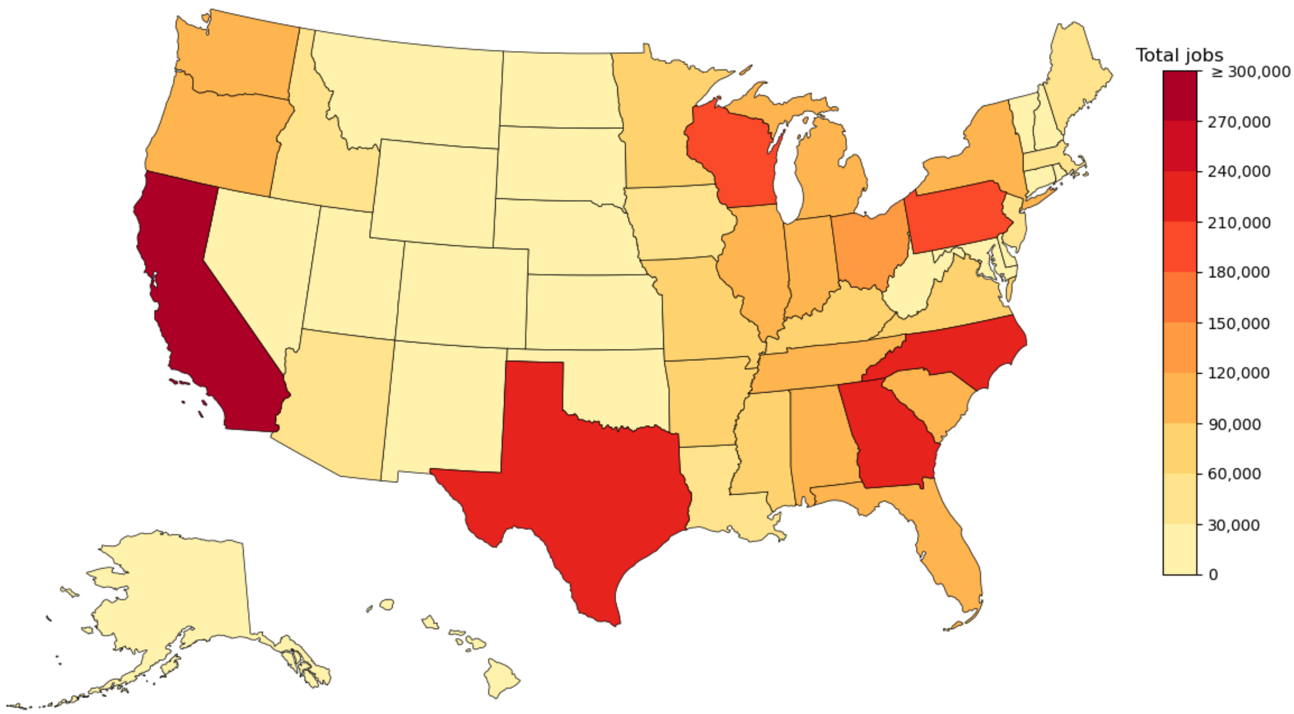

Figure 3.2.7. Total number of jobs contributed to the U.S. economy through the biobased products industry in 2017 (2).

State	Number of jobs	Percent total	Percent change from 2014
California	310,630	8.5	14.7
Texas	228,200	6.3	21.8
North Carolina	222,940	6.1	19.5
Georgia	215,250	5.9	17.3
Pennsylvania	190,670	5.2	20.8

Table 3.2.3. Top 5 States with the most jobs – direct and indirect – from the biobased products industry in 2017 (2).

The bioproducts industry directly added $150 billion to the United States economy in 2017, an increase of 18 percent with respect to 2014. This represents 0.8 percent of the Gross Domestic Product (GDP) of the United States in 2017. California accounted for 8 percent of that number ($12 billion). North Carolina

($10 billion) saw a remarkable increase of 32 percent in its contribution to the economy with respect to 2014. Georgia ($9 billion) ranked first in terms of value-added directly to the economy in 2017.

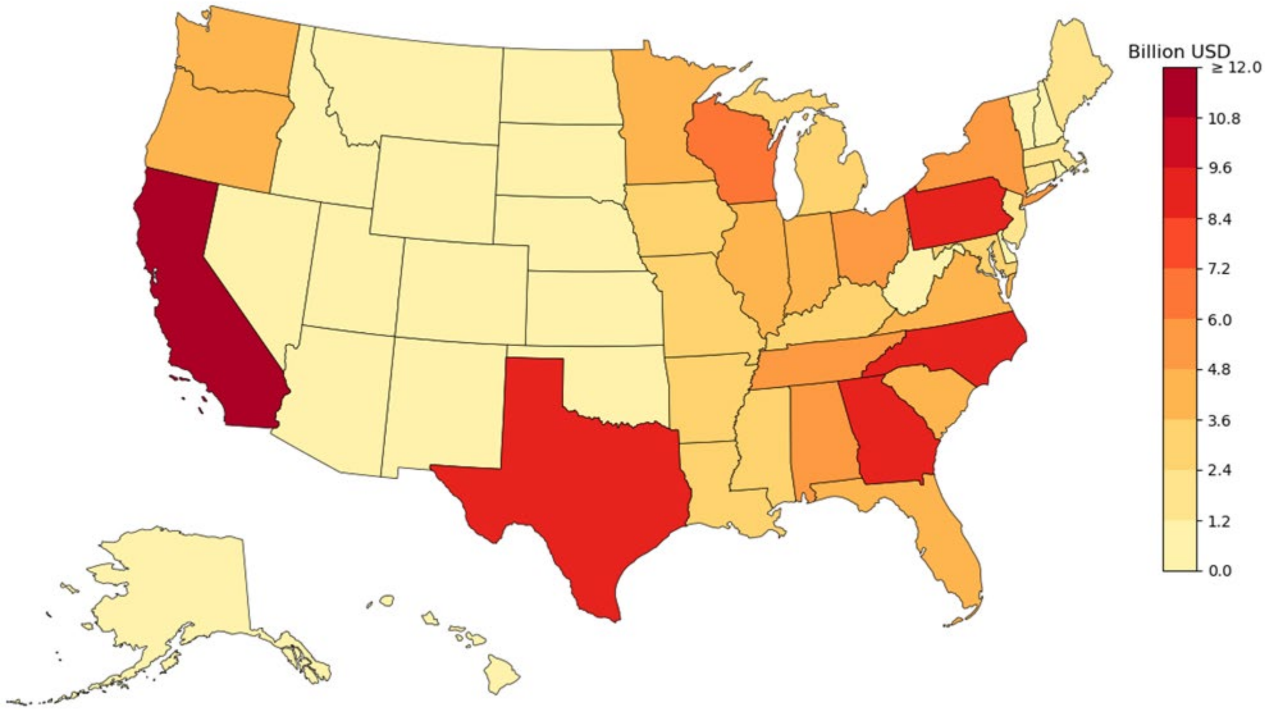

Figure 3.2.8. Direct value-added contribution to the U.S. economy through the biobased products industry in 2017 (in billion dollars) (2).

State	Billion dollars	Percent of total	Percent change from 2014
California	11.9	7.9	17.1
North Carolina	9.5	6.3	32.3
Georgia	9.4	6.2	12.0
Texas	8.9	5.9	23.5
Pennsylvania	8.4	5.6	22.5

Table 3.2.4. Top 5 States ranked by direct value-added contribution to the sU.S. economy through the biobased industry in 2017 (2).

Adding indirect effects to those numbers, the bioproducts industry is responsible (directly and indirectly) for adding $307 billion to the U.S. economy in 2017. California continues to be the State receiving the highest contribution ($26 billion), followed by Texas and Georgia (with $19 billion each).

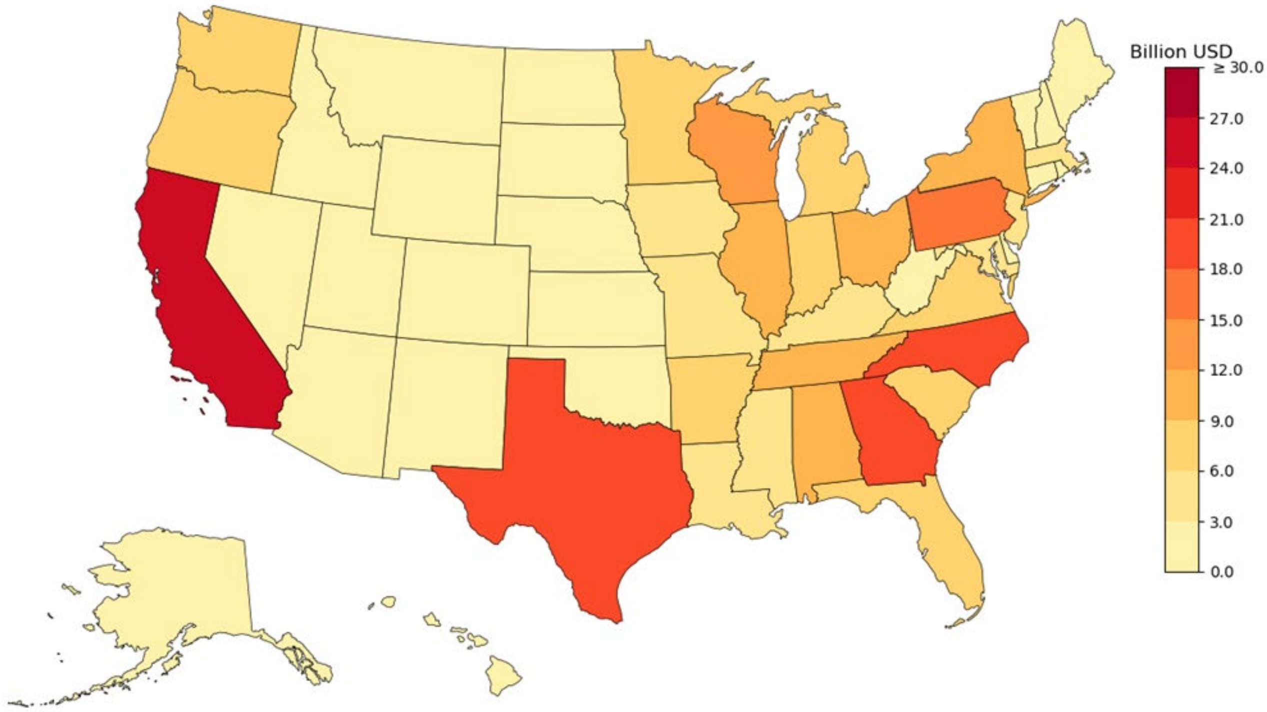

Figure 3.2.9. Total value-added contribution to the U.S. economy through the biobased products industry in 2017 (in billion dollars) (2).

State	Billion dollars	Percent of total	Percent change from 2014
California	26.1	8.5	8.5
Texas	19.4	6.3	6.3
Georgia	19.1	6.2	6.2
North Carolina	18.7	6.1	6.1
Pennsylvania	17.4	5.6	5.6

Table 3.2.5. Top 5 States ranked by total value-added to the United States economy through the biobased industry in 2017 (2).

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3.3. Bioplastics

Bioplastics are a type of plastic that is partially or fully biobased and/or biodegradable. A biobased plastic is produced from renewable resources (e.g., corn, sugarcane, potatoes) as opposed to fossil fuels. Biodegradable plastic can degrade by naturally occurring microorganisms (e.g., bacteria, fungi) in a defined environment and timescale (1). A biodegradable plastic does not need to be biobased to be considered a bioplastic. Conversely, a biobased plastic is considered a bioplastic even if it is not biodegradable (1)

Social and environmental benefits of using bioplastics instead of conventional plastics include the reduction of fossil fuel usage, reduction of carbon footprint, and reduction of global warming potential (1).

The global production of bioplastics grew from 180,000 metric tons in 2008 to 6.73 million metric tons in 2018, an increase of more than 3,500 percent (Figure 3.3.1). In 2008, biodegradable bioplastics represented 97 percent of the total production of bioplastics; since 2010, the production of non-biodegradable bioplastics (i.e. biobased bioplastics) has increased to 83 percent of total production in 2018 (2, 3).

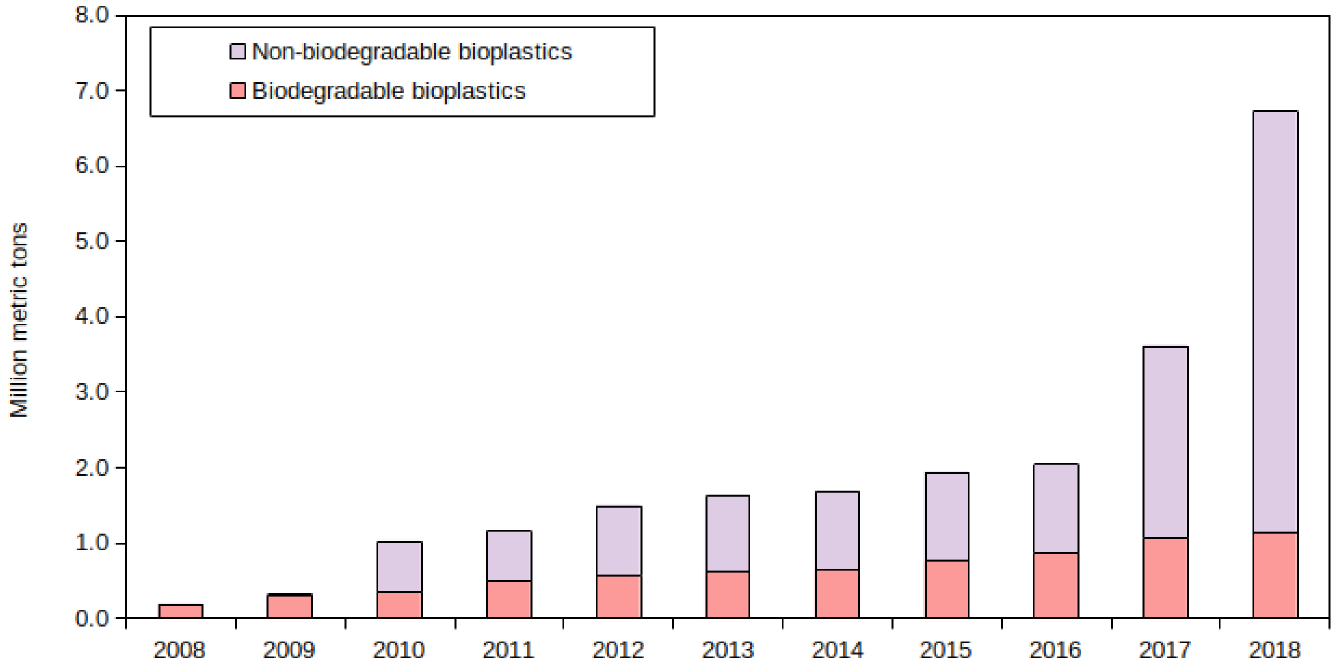

Figure 3.3.1. Global production of bioplastics by type from 2008 to 2018 (in million metric tons) (2, 3).

The vast majority of bioplastics are used for packaging (81 percent of all bioplastics in 2018). Other uses include textiles (7 percent), automotive and transportation industry (5 percent), and consumer goods (3 percent) (Figure 3.3.2) (4).

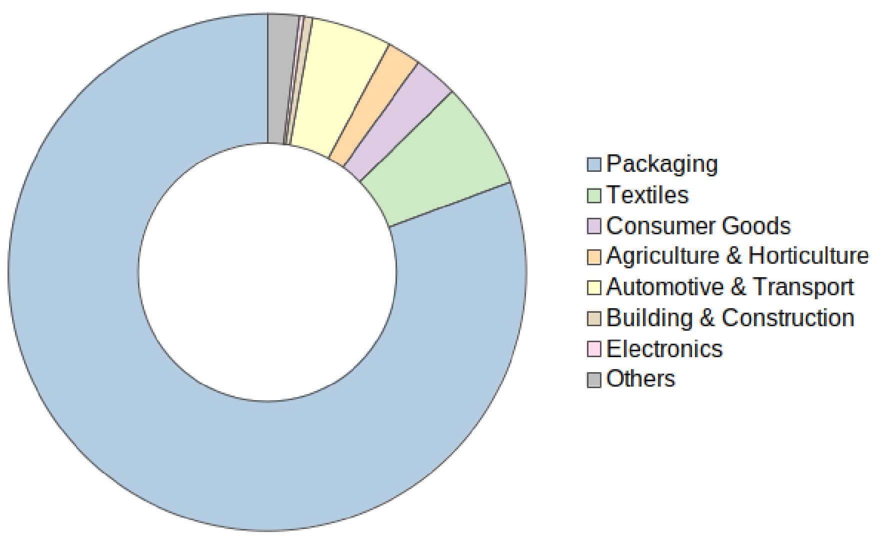

Figure 3.3.2. Final use of bioplastics in 2018 (5).

Asia nations are the main producers of bioplastics, with more than 50 percent the total of global production of bioplastics taking place in Asia. It is followed by Europe with 18 percent of global production. North America ranks third, with 17 percent of the world production of bioplastics (Figure 3.3.3) (5).

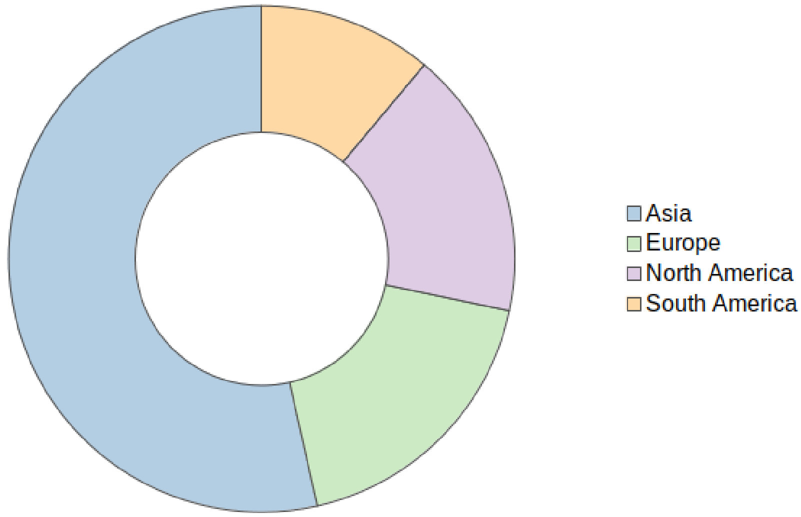

Figure 3.3.3. Global production of bioplastics by region in 2018 (5).

The United States has 38 companies that manufactured bioplastics or fundamental components (monomers), in 53 different production facilities (Figure 3.3.4) (5).

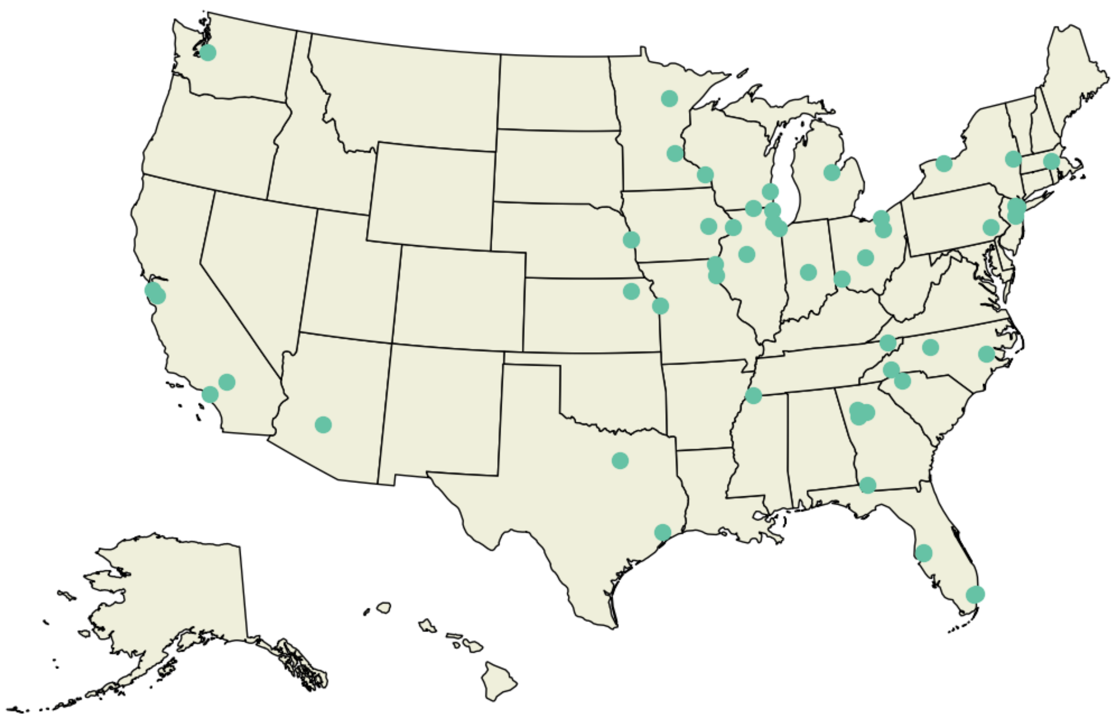

Figure 3.3.4. Production facilities of bioplastics in the United States in 2018 (5).

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3.4. Biobased Chemicals

Biobased chemicals, also known as renewable chemicals, are chemicals totally or partially produced from plants or renewable sources (1).

In 2012, the U.S. renewable chemical production was estimated at 165,000 metric tons. By 2017, this number was estimated to have grown by 354 percent, with total production estimated to be 750,000metric tons. By 2022, total U.S. renewable chemical production is projected to reach 3.2 million metric tons (2). The total job creation in the United States by the renewable chemicals industry is projected to be 19,400 jobs in 2022 (2). This estimate includes both direct and indirect jobs stemming from the production of the renewable chemicals. The value-added to the United States' economy by renewable chemicals is projected to be $3 billion in 2022 (2).

From 2014 to 2017, direct employment in the biobased chemicals industry increased by 4,668 jobs, to a total of 22,360 direct jobs. Over this 3-year interval, direct employment increased by 26 percent. Texas leads this trend with 2,140 direct jobs, followed by Ohio and California, with 1,740 and 1,710 direct jobs, respectively (Figure 3.4.1 and Table 3.4.1).

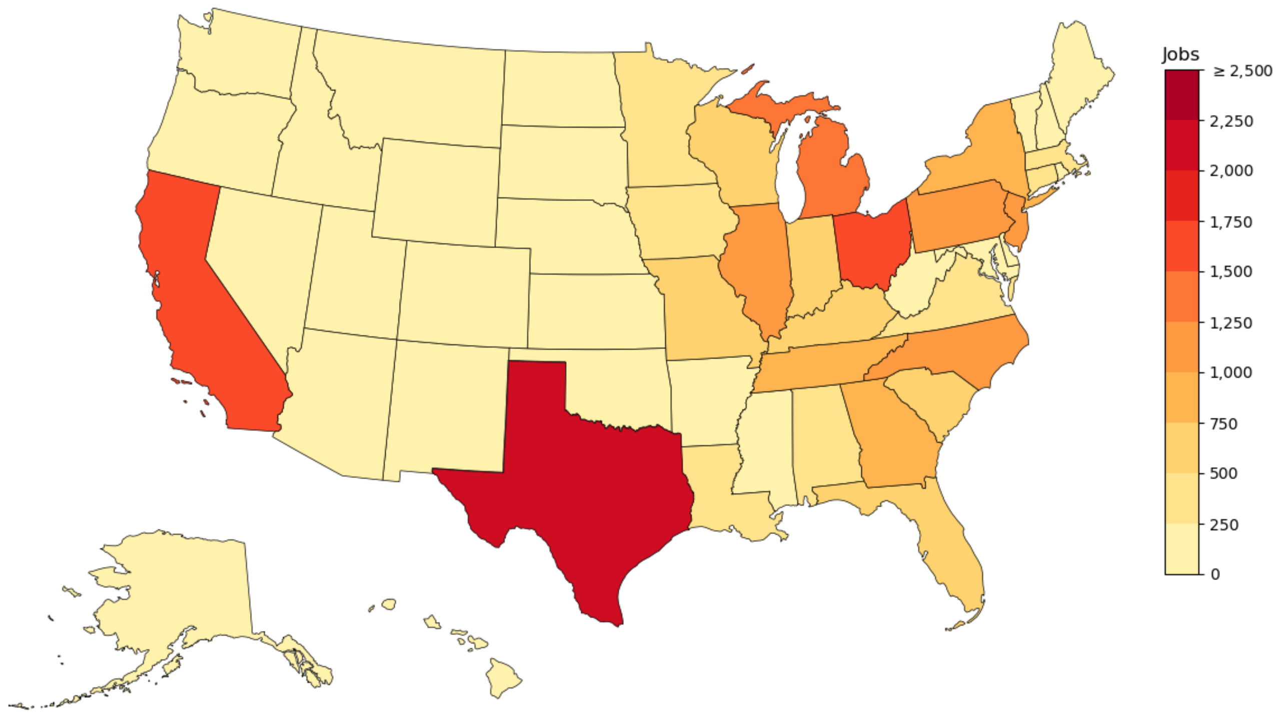

Figure 3.4.1. Number of direct jobs contributed to the United States economy through the biobased chemicals industry in 2017 (3).

State	Number of jobs	Percent of total	Percentage change from 2014
Texas	2,140	9.6	21.6
Ohio	1,740	7.8	25.0
California	1,710	7.7	26.9
Michigan	1,280	5.7	25.6
Illinois	1,210	5.4	17.2

Table 3.4.1. Top 5 States ranked by direct jobs from the biobased chemicals industry in 2017 (3).

The impact of the biobased chemicals industry is even larger when indirect employment is considered. The biobased chemicals industry created 18,000 direct and indirect jobs from 2014 to 2017, for a total of 95,600 jobs in 2017. This represents an increase of 16 percent with respect to 2014. Again, Texas ranks first in number of total jobs (9,730), followed by Ohio (8,700) and California (6,880) (Figure 3.4.2 and Table 3.4.2) (2).

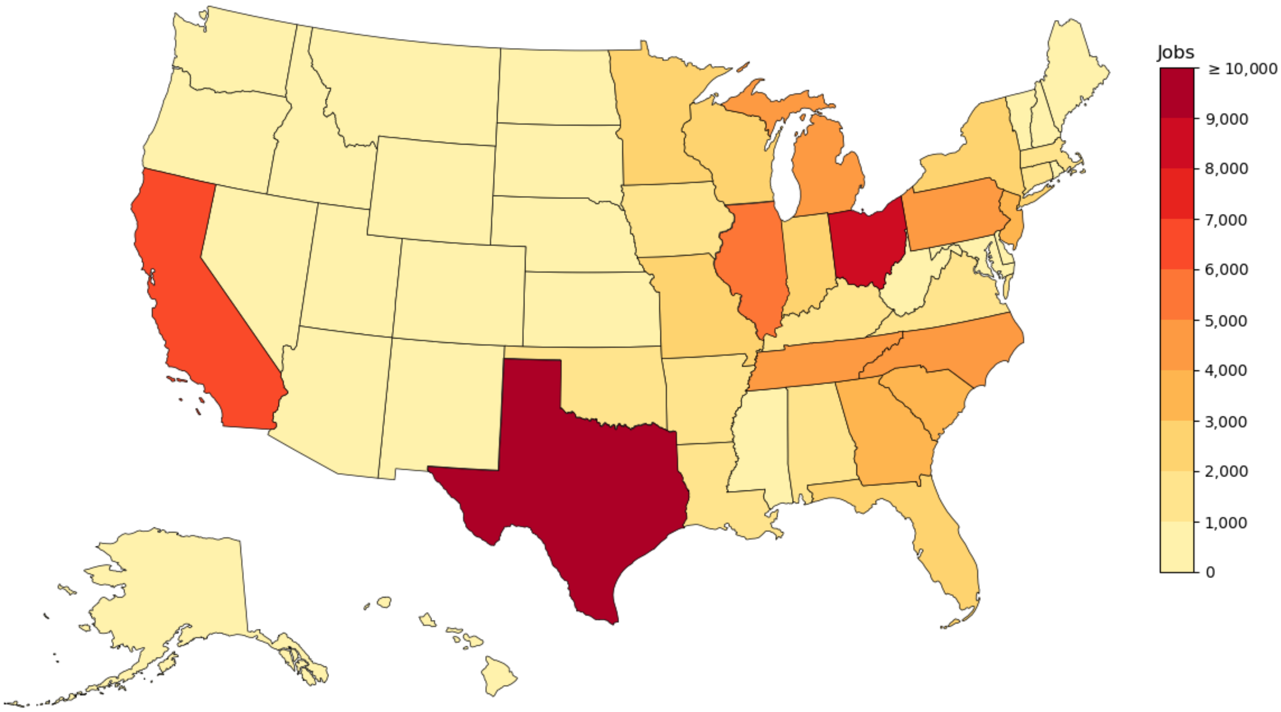

Figure 3.4.2. Number of direct and indirect jobs contributed to the U.S. economy through the biobased chemicals industry in 2017 (3).

State	Number of jobs	Percent of total	Percent change from 2014
Texas	9,730	10.2	17.5
Ohio	8,700	9.1	23.6
California	6,880	7.2	25.9
Illinois	5,310	5.6	16.1
Michigan	4,820	5.0	25.3

Table 3.4.2. Top 5 States ranked by total jobs from the biobased chemicals industry in 2017 (3).

The biobased chemicals industry generated $6.2 billion of direct value-added activity in 2017, a 10-percent increase from 2014. Ohio had the greatest contribution with $630 million, followed by Texas with $568 million and North Carolina with $434 millions. Ohio's direct value-added activity increased by 30 percent from 2014 to 2017 (Figure 3.4.3 and Table 3.4.3).

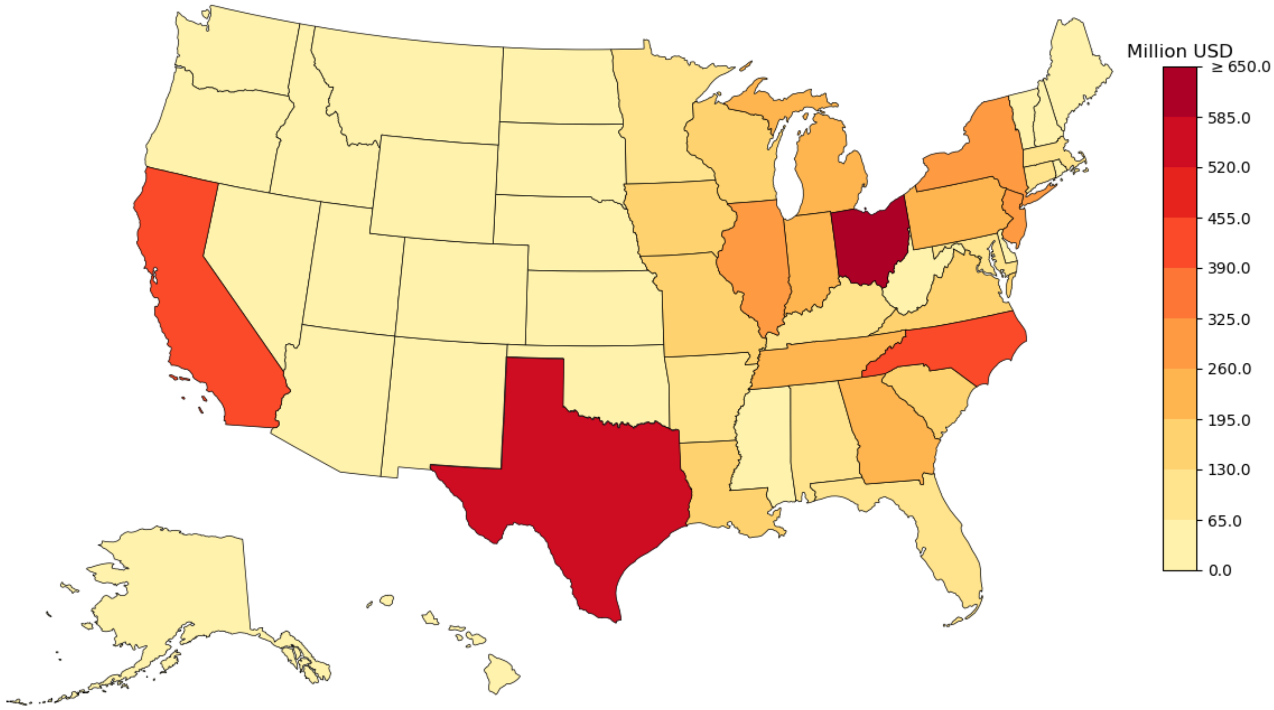

Figure 3.4.3. Direct value-added to the U.S. economy through the biobased chemicals industry in 2017 (in million dollars) (3).

State	Million dollars	Percent of total	Percent change from 2014
Ohio	629	10.2	29.5
Texas	568	9.2	16.9
North Carolina	434	7.0	19.4
California	423	6.8	23.2
New Jersey	287	4.6	24.9

Table 3.4.3. Top 5 States ranked by direct value-added contribution to the U.S. economy through the biobased chemicals industry in 2017 (3).

The direct and indirect contribution of the biobased chemicals industry to the U.S. economy in 2017 amounts to $12.3 billion, 12 percent greater than 2014. Texas contributed $1.4 billion, Ohio came in at $1.2 billion, and California contributed $900 million. Ohio's total contribution increased by 26 percent with respect to 2014, and California saw a 24-percent increase in the same period (Figure 3.4.4 and Table 3.4.4).

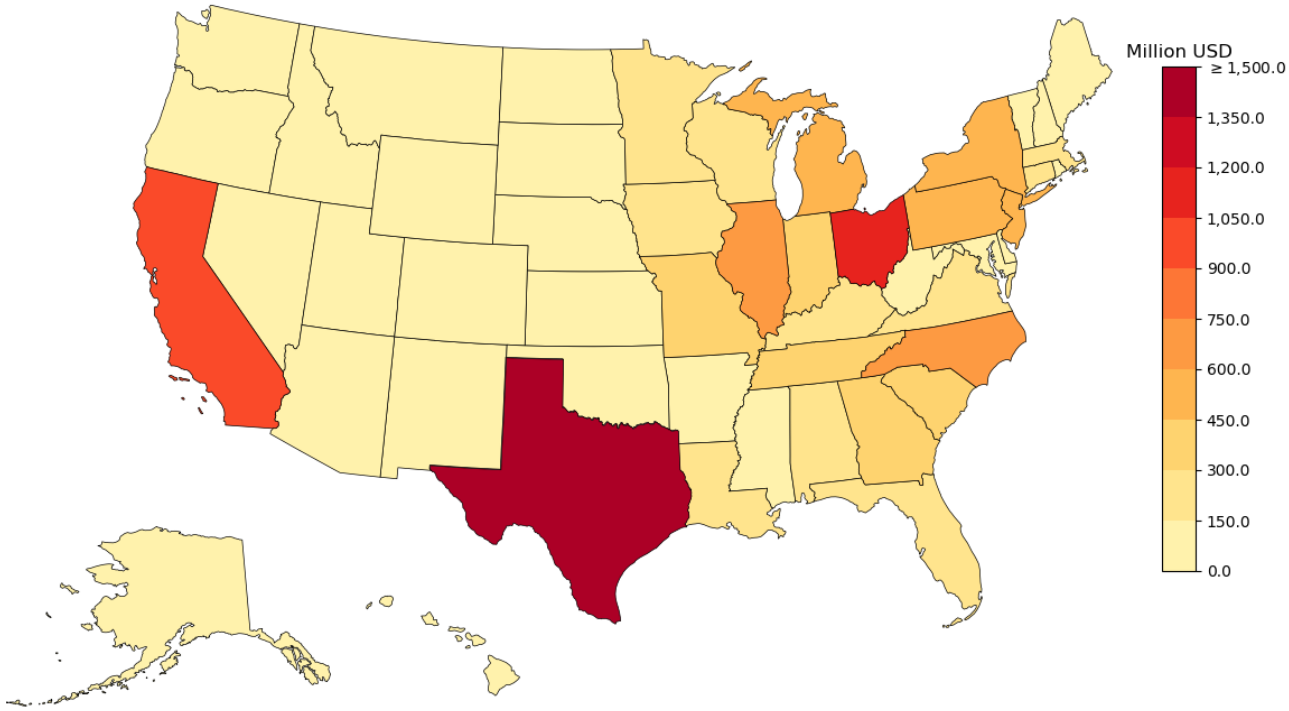

Figure 3.4.4. Total value-added contribution to the U.S. economy through the biobased chemicals industry in 2017 (in million dollars) (3).

State	Million dollars	Percent of total	Percent change from 2014
Texas	1,406	11.4	15.3
Ohio	1,183	9.6	26.1
California	936	7.6	24.3
North Carolina	682	5.5	18.5
Illinois	654	5.3	15.7

Table 3.4.4. Top 5 States ranked by total value-added contribution to the U.S. economy through the biobased chemicals industry in 2017 (3).

References

1. International Energy Agency - IEA - Bio-based Chemicals. Value added products from biorefineries Available at: www.iea-bioenergy.task42-biorefineries.comwww.ieabioenergy.com [Accessed July 2020].
2. United States Department of Agriculture -USDA- (January 2014) Renewable Chemicals & Materials Opportunity Assessment. Available at: https://www.usda.gov/oce/reports/energy/USDA_RenewChems_Jan2014.pdf [Accessed July 2018].
3. An Economic Impact Analysis of the U.S. Biobased Products Industry Available at: https://bioproducts.ecu.edu/ [Accessed September 2020].

3.5. Enzymes

Enzymes are substances of biological origin that enable a specific biochemical reaction. Enzymes serve two purposes: (1) act as a catalyst to facilitate the reaction in industrial processing of food ingredients, feed additives, or other chemicals; (2) as a component in end products such as detergents, laboratory reagents, or digestive aids (1).

The global market for industrial enzymes has increased by 88 percent from 2008 to 2018, from $2.9 billion in 2008 to $5.5 billion in 2018 (2). The main use for enzymes is in the food industry as key elements in fermentation processes such as baking, brewing, and wine and cheese manufacturing. Other uses for enzymes include technical applications in the chemical and pharmaceutical industries and biofuel production (Figures 3.5.1 and 3.5.2) (2).

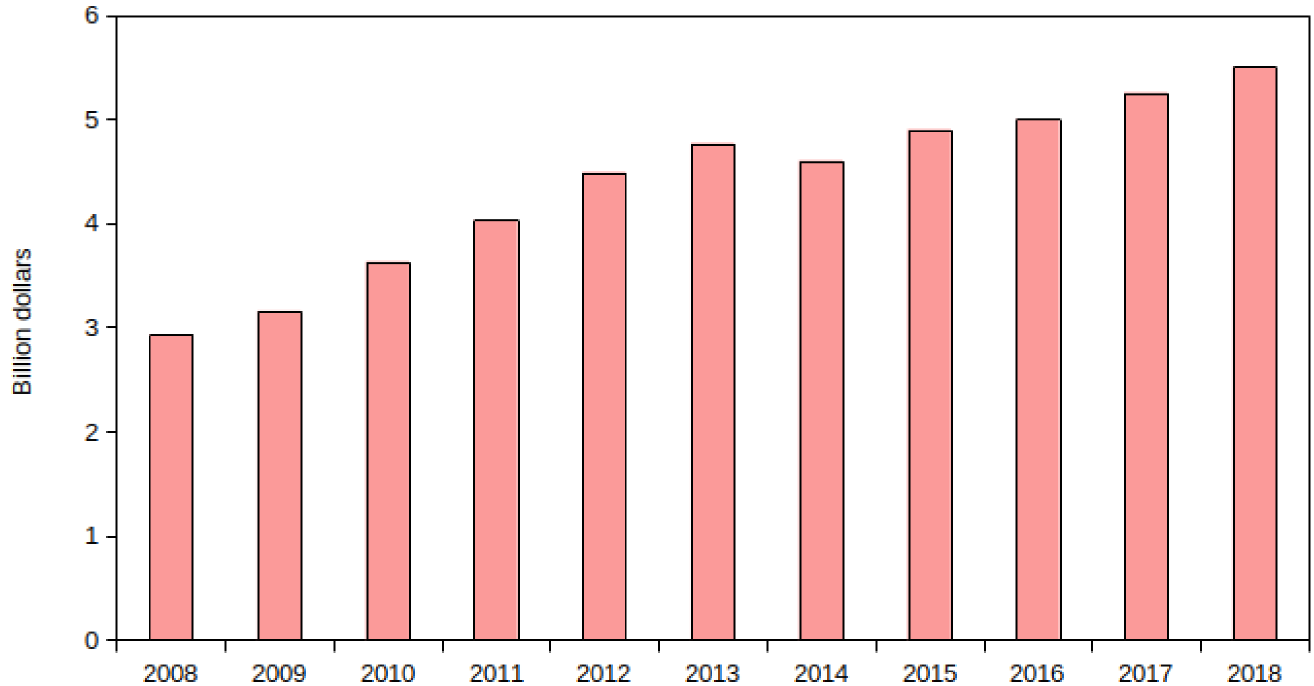

Figure 3.5.1. Global market for industrial enzymes from 2008 to 2018 (in billion dollars) (2).

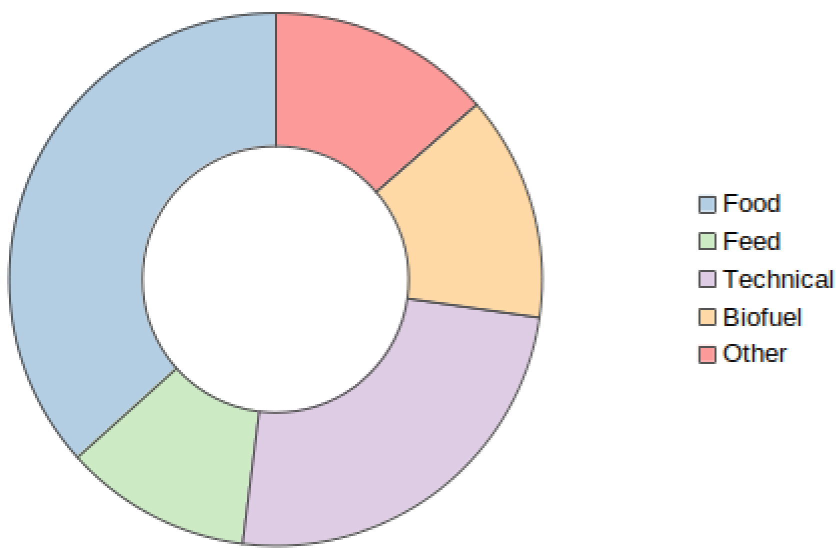

Figure 3.5.2. Global market for industrial enzymes by application in 2017 (2).

Between 2014 and 2017, the enzymes industry created 68,550 direct jobs in the United States. In 2017, direct employment by the enzymes industry was 71,550 workers. A total of 7,160 of those jobs were located in Texas, 5,280 in California and 5,030 in Pennsylvania (Figure 3.5.3 and Table 3.5.1) (3).

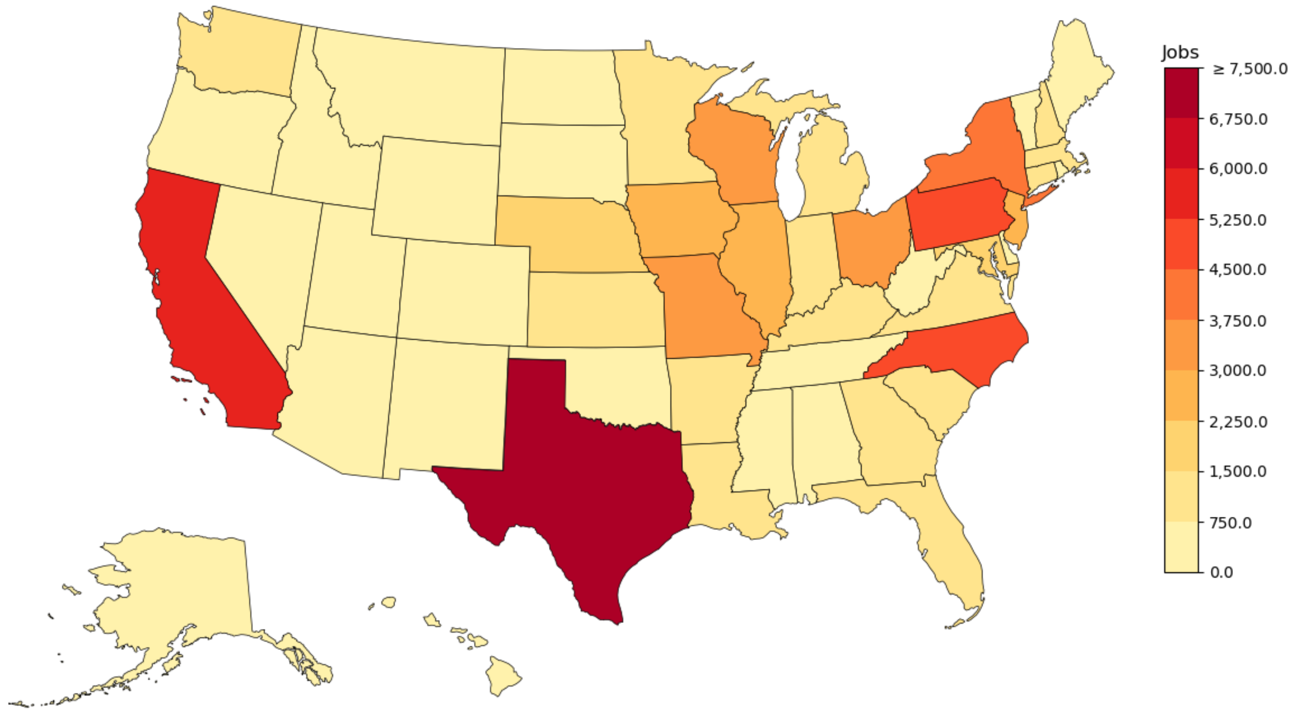

Figure 3.5.3. Number of direct jobs contributed to the U.S. economy through the enzymes industry in 2017 (3).

State	Number of jobs	Percentage of total	Percent change from 2014
Texas	7,160	10.0	95.1
California	5,280	7.4	96.7
Pennsylvania	5,030	7.0	96.5
North Carolina	4,950	6.9	95.7
New York	3,980	5.6	97.1

Table 3.5.1. Top 5 States ranked by direct jobs from the enzymes industry in 2017 (3).

Including indirect jobs, the figure increases to 354,267 total jobs in the United States in 2017. Texas, with 53,580 jobs, Ohio with 24,070 jobs, and California with 21,890 jobs were the top 3 States in terms of total job contribution (Figure 3.5.4 and Table 3.5.2) (3).

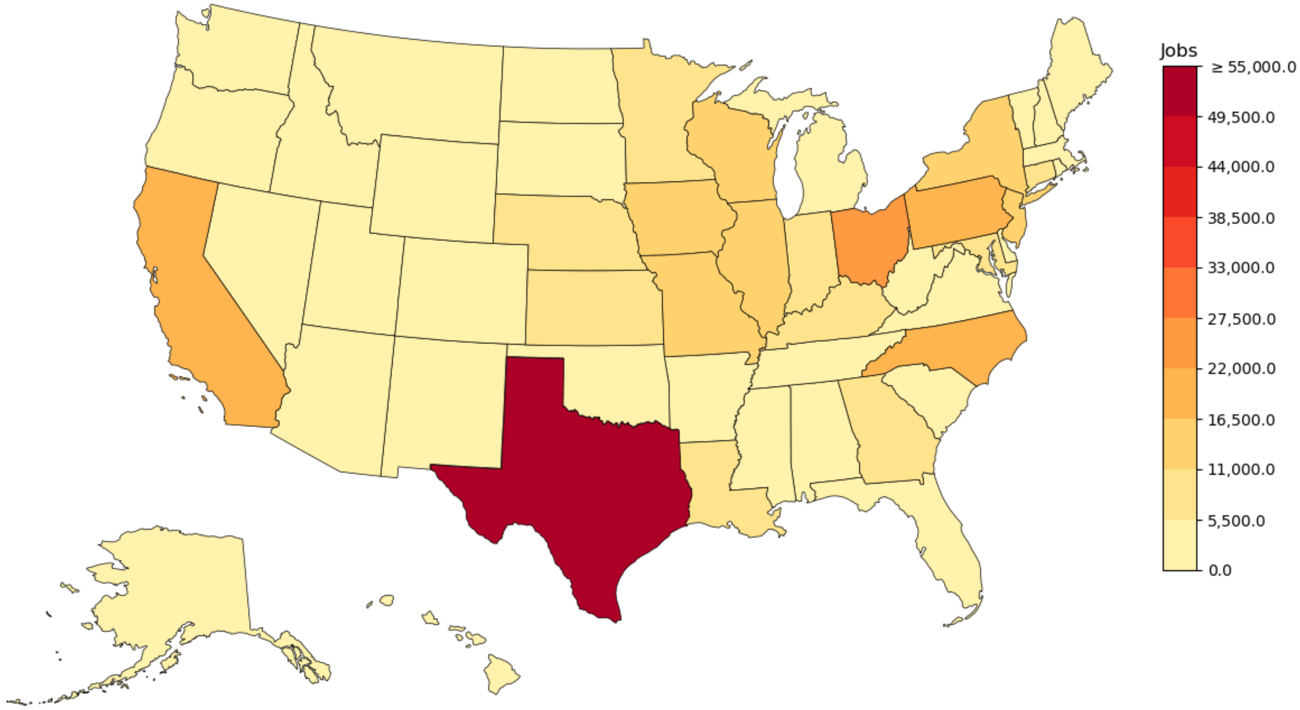

Figure 3.5.4. Number of total jobs contributed to the U.S. economy through the enzymes industry in 2017 (3).

State	Number of jobs	Percentage of total	Percent change from 2014
Texas	53,580	15.1	95.1
Ohio	24,070	6.8	95.2
California	21,890	6.2	96.6
Pennsylvania	20,280	5.7	96.6
North Carolina	18,980	5.4	95.7

Table 3.5.2. Top 5 Sstates ranked by total jobs from the enzymes industry in 2017 (3).

In 2017, the enzymes industry’s direct contribution to the U.S. economy was $21.7 billion, 0.1 percent of the total GDP of the United States in that year. North Carolina directly generated $2.4 billion, Texas generated $2.1 billion, and Maryland generated $1.9 billion (Figure 3.5.5 and Table 3.5.3).

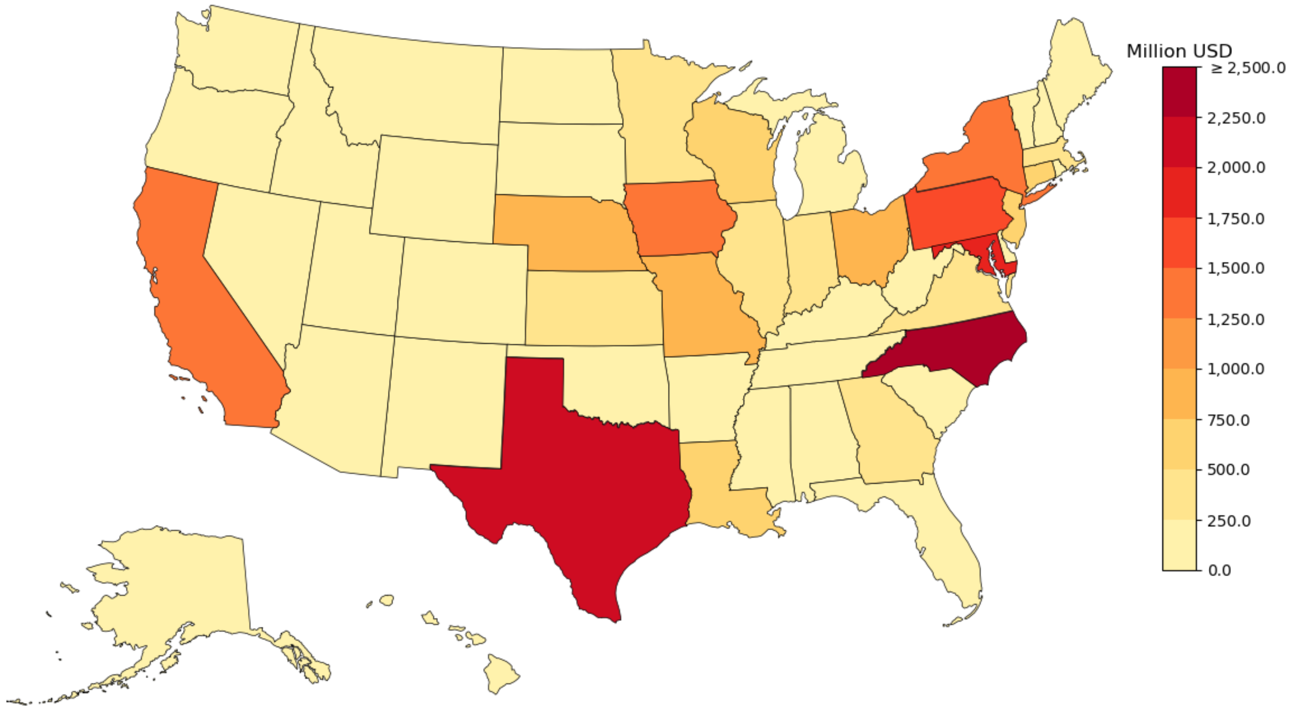

Figure 3.5.5. Direct value-added contribution to the U.S. economy through the enzymes industry in 2017 (in million dollars) (3).

State	Million dollars	Percentage of total	Percent change from 2014
North Carolina	2,440	11.2	95.8
Texas	2,080	9.6	95.1
Maryland	1,870	8.6	97.2
Pennsylvania	1,500	6.9	96.5
Iowa	1,350	6.2	95.2

Table 3.5.3. Top 5 States ranked by direct value-added contribution to the U.S. economy through the enzymes industry in 2017 (3).

Adding the indirect contributions to the economy, the enzyme industry contributed $48 billion in total in 2017. The top 3 contributing States in total value added from industrial enzymes were: Texas, with $7.6 billion (15.7 percent of the total); North Carolina, with $3.6 billion (7.5 percent of the total); and California, with $3.2 billion (6.5 percent of the total) (Figure 3.5.6 and Table 3.5.4) (3).

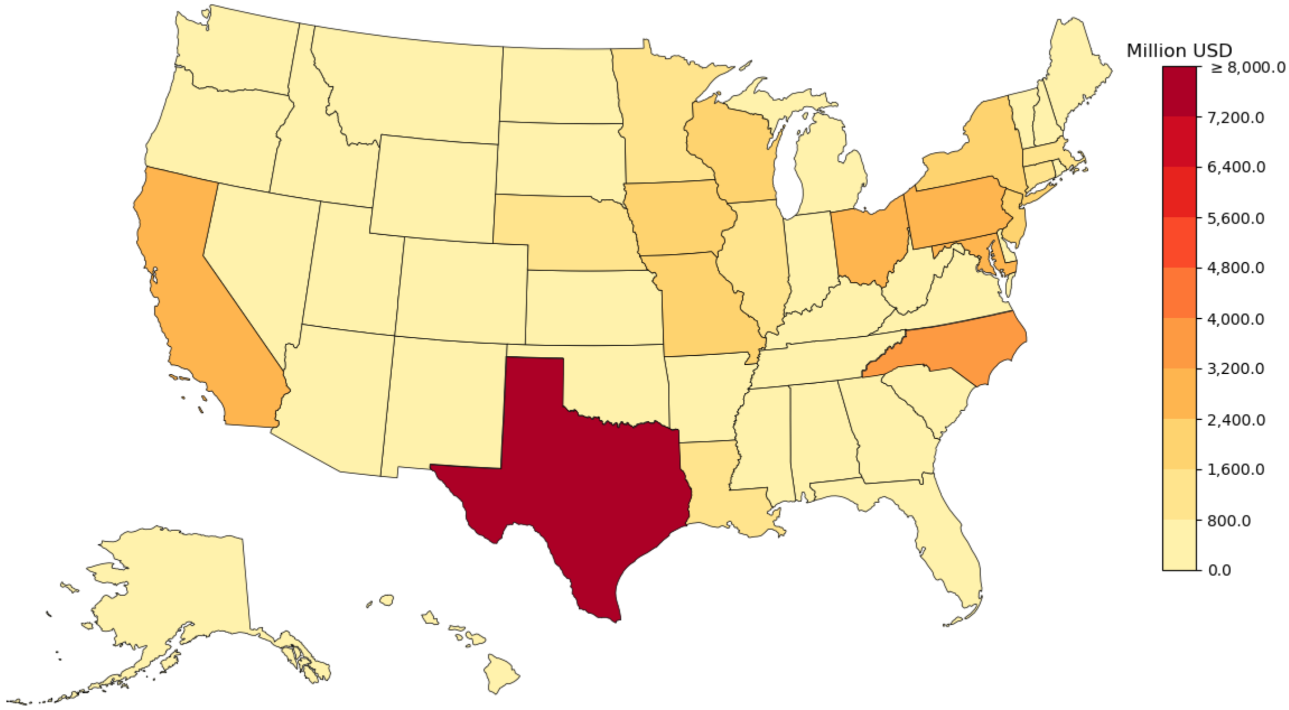

Figure 3.5.6. Total value-added contribution to the U.S. economy through the enzyme industry in 2017 (in million dollars) (3).

State	Million dollars	Percentage of total	Percent change from 2014
Texas	7,620	15.7	95.0
North Carolina	3,650	7.5	95.7
California	3,150	6.5	96.7
Pennsylvania	2,940	6.1	96.6
Ohio	2,680	5.5	95.2

Table 3.5.4. Top 5 States ranked by total value-added contribution to the U.S. economy through the enzyme industry in 2017 (3).

References

1. National Research Council (US) Committee on Biobased Industrial Products. (2000) Biobased Industrial Products: Priorities for Research and Commercialization. Available at: https://iwaponline.com/wst/article/59/5/927/15563/Defining-the-biomethane-potential-BMP-of-solid [Accessed July 2020].
2. BCC Research, Global Markets for Enzymes in Industrial Applications, 2018.
3. An Economic Impact Analysis of the U.S. Biobased Products Industry Available at: https://bioproducts.ecu.edu/ [Accessed September 2020].

3.6. Forest Products

Forest products are the largest source of renewable raw materials for the biobased products industry (1).

From 2008 to 2018, the production of forest products remained nearly constant in the United States. Roundwood was the highest item, with 627 million metric tons of roundwood being produced in 2018. Sawnwood was the second most produced item, with 149 million metric tons produced, followed by wood fuel with 97 million metric tons, and paper and paperboard with 72 million metric tons (Figures 3.6.1 and 3.6.2) (2).

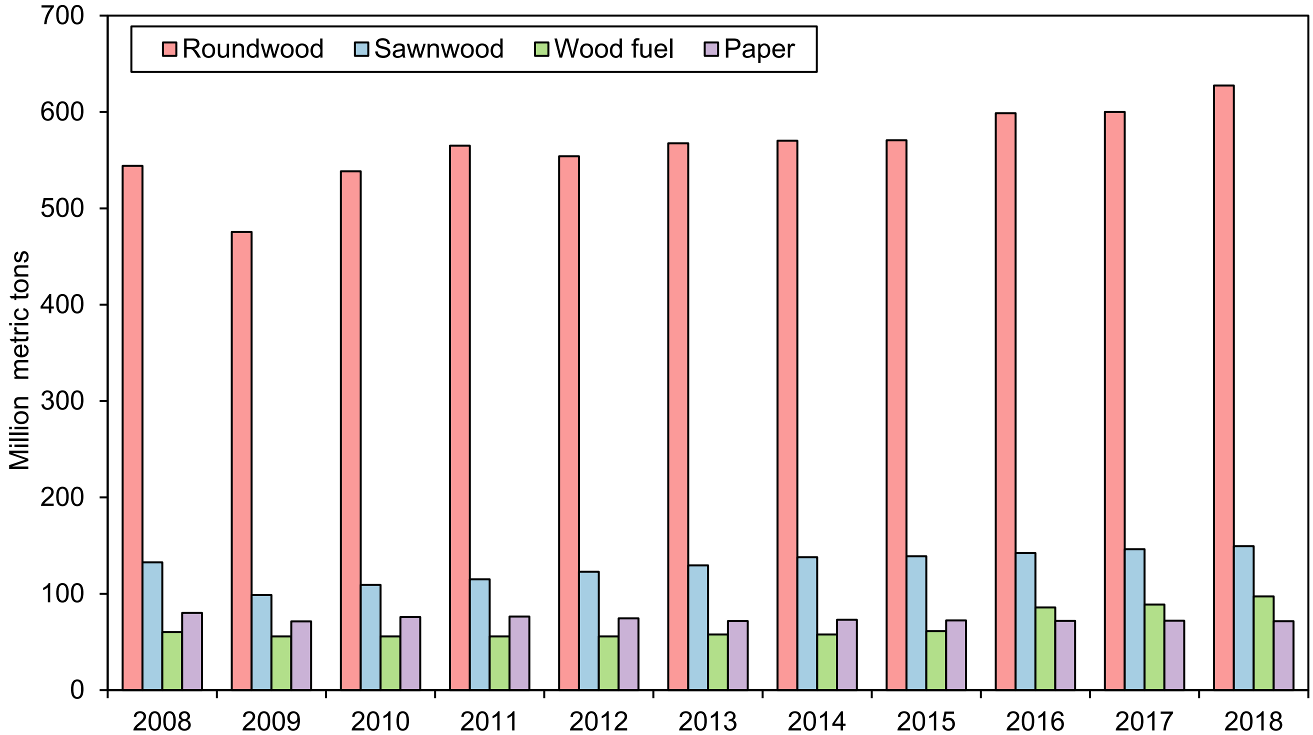

Figure 3.6.1. Production of roundwood, sawnwood, wood fuel, and paper in the United States from 2008 to 2018 (in million tons) (2).

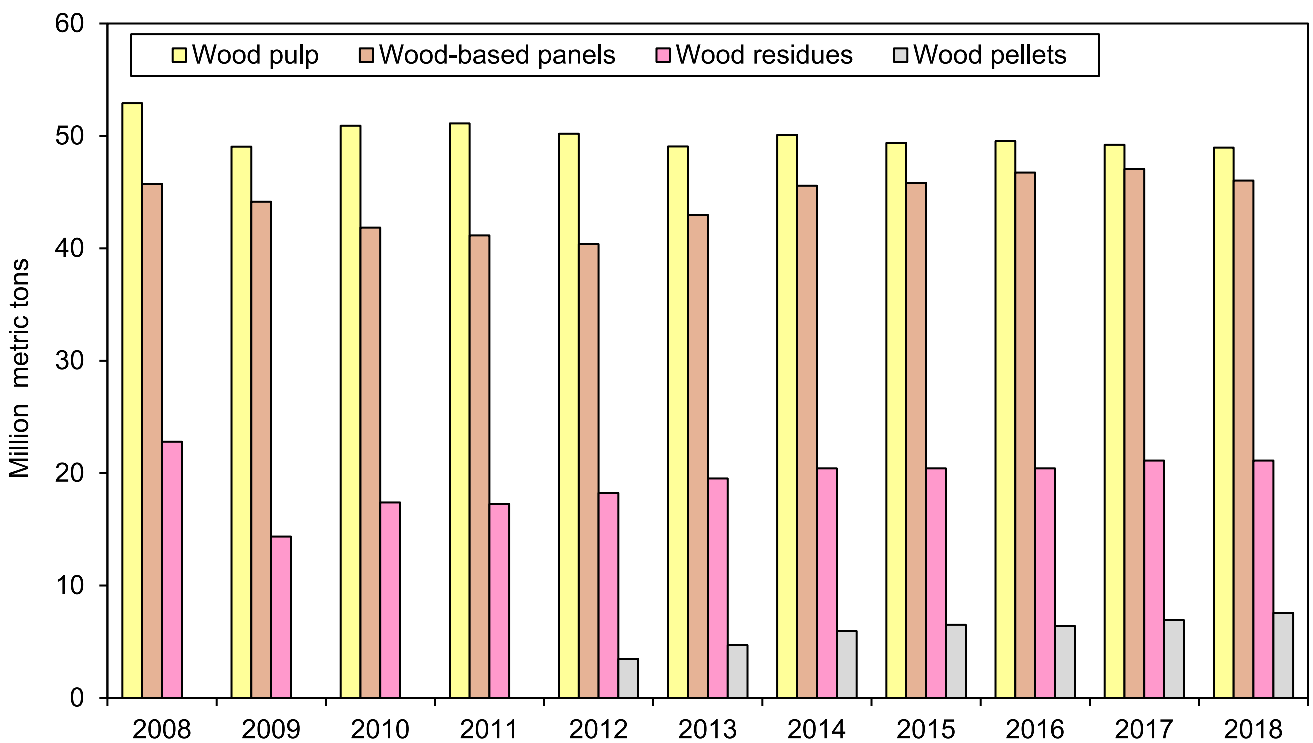

Figure 3.6.2. Production of wood pulp, wood-based panels, wood residues and wood pellets in the United States from 2008 to 2018 (in million tons) (2).

In 2008, the United States was a net importer of forest products. From 2009 to 2018, exports increased and the United Sates became a net exporter (2), with a net export value of $1 billion. Imports and exports of forest products are presented in Figure 3.6.3.

From 2008 to 2018, imports of forest products increased from $24 billion to $27 billion, and exports increased from $21 billion to $28 billion (2).

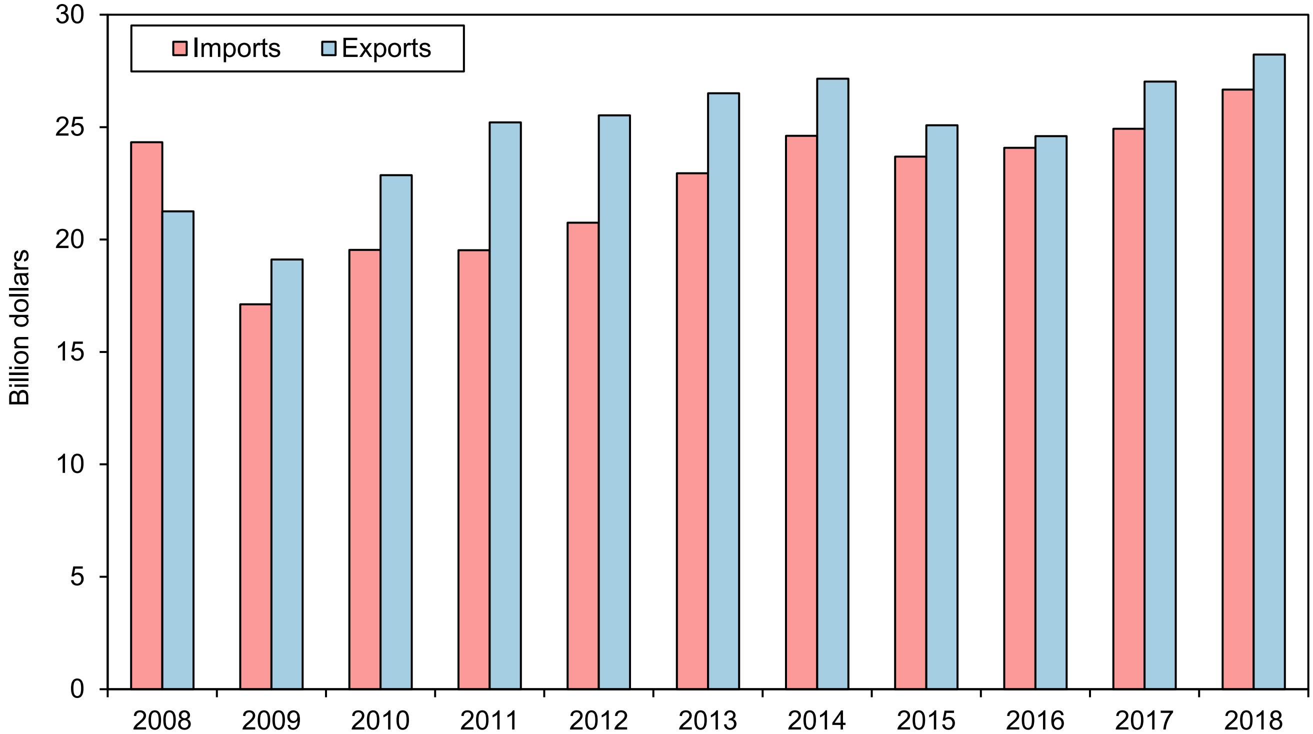

Figure 3.6.3. Imports and exports (in billion dollars) of forest products to and from the United States, 2008 to 2018 (2).

The forest products industry directly employed 1.2 million workers in 2017, an increase of 12 percent from 2014. California is the State to directly employ more people on the forest products industry (87,000) followed by North Carolina (75,000) and Texas (71,) (Figure 3.6.4 and Table 3.6.1) (3).

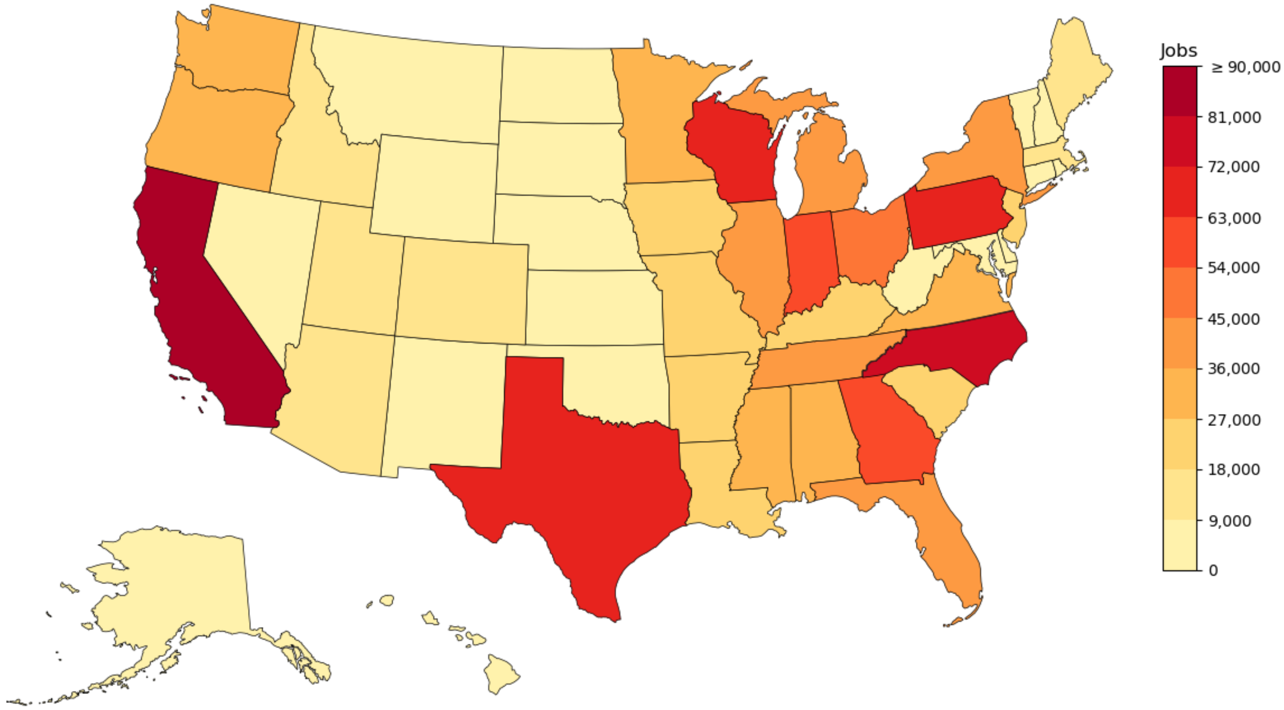

Figure 3.6.4. Number of direct jobs contributed to the U.S. economy through the forest products industry in 2017 (3).

State	Number of jobs	Percentage of total	Percent change from 2014
California	86,930	7.0	17.9
North Carolina	75,190	6.0	17.6
Texas	71,020	5.7	19.7
Pennsylvania	68,480	5.5	14.1
Wisconsin	54,870	5.4	9.8

Table 3.6.1. Top 5 States ranked by direct jobs from the forest products industry in 2017 (3).

The forest products industry generated 2.8 million direct and indirect jobs in the United States in 2017. This represents an increase of 361,000 jobs since 2014, a growth of 16.7 percent. California is the leading State in total number of jobs, with 190,000 jobs, followed by North Carolina and Wisconsin, with 165,000 and 164,000 jobs, respectively (Figure 3.6.5 and Table 3.6.2) (3).

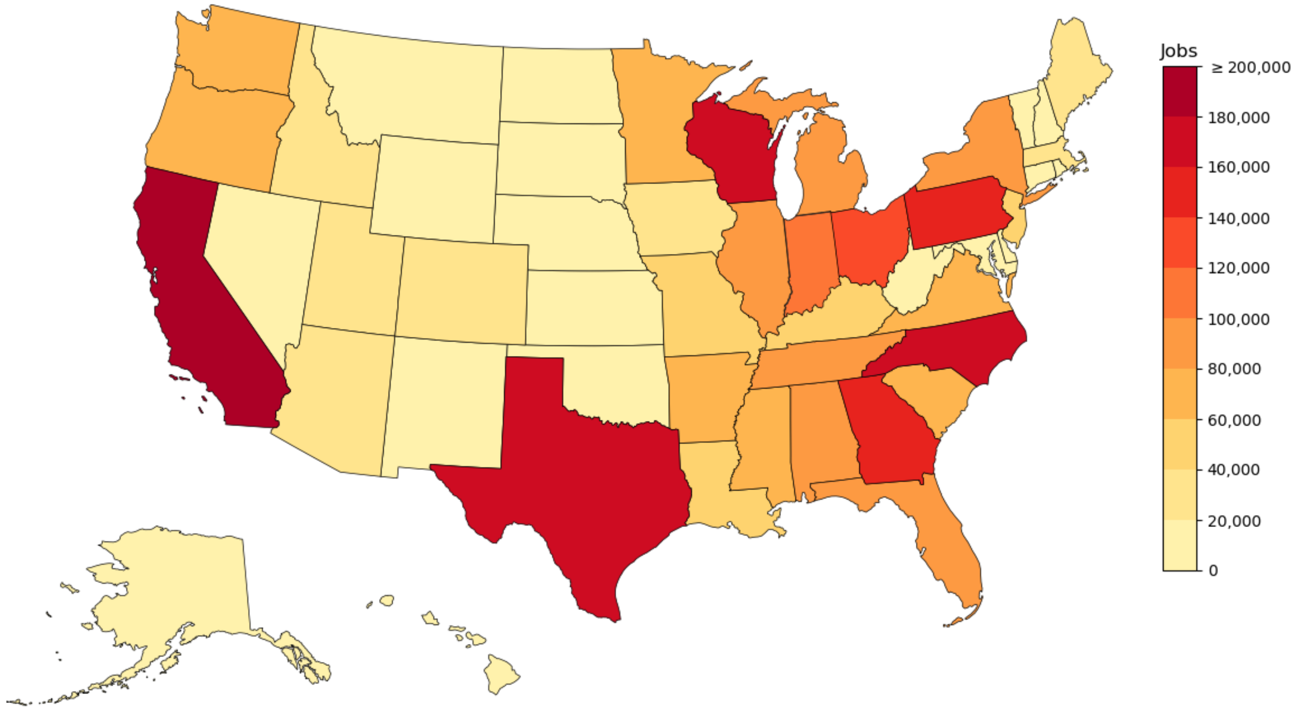

Figure 3.6.5. Number of total jobs contributed to the U.S. economy through the forest products industry in 2017 (3).

State	Number of jobs	Percent of total	Percent change from 2014
California	190,340	6.7	16.7
North Carolina	164,660	5.8	16.0
Wisconsin	164,430	5.8	7.0
Texas	160,820	5.7	17.9
Pennsylvania	154,370	5.4	12.1

Table 3.6.2. Top 5 States ranked by total jobs from the forest products industry in 2017 (3).

The forest products industry directly added $103 billion to the U.S. economy in 2017, representing 0.5 percent of the Nation's GDP in that year. California, Pennsylvania, and Wisconsin were the top contributors, adding $6.7, $6.1, and $6.0 billion, respectively, to the U.S. economy (Figure 3.6.6 and Table 3.6.3) (3).

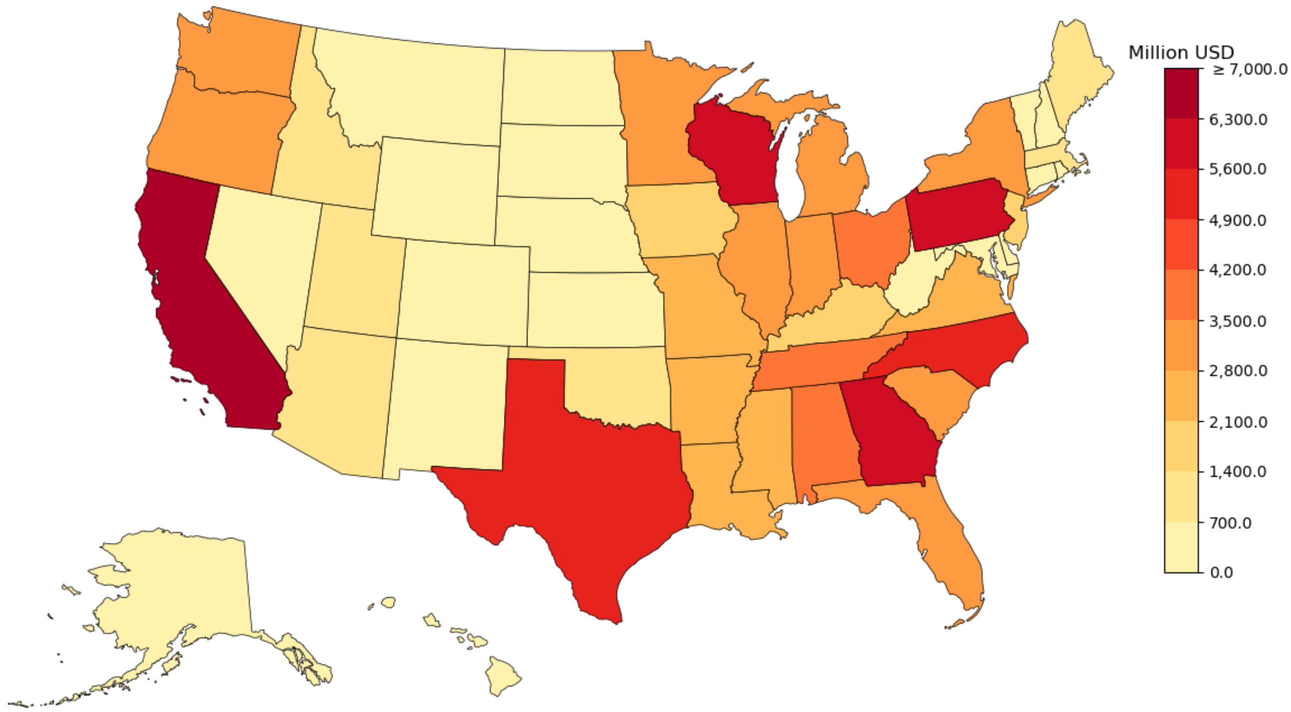

Figure 3.6.6. Direct value-added to the U.S. economy through the forest products industry in 2017 (3).

State	Million dollars	Percentage of total	Percent change from 2014
California	6,720	6.5	15.0
Pennsylvania	6,128	5.9	5.8
Wisconsin	5,952	5.8	3.0
Georgia	5,821	5.6	12.8
Texas	5,227	5.1	14.9

Table 3.6.3. Top 5 States ranked by direct value-added to the economy by the forest products industry in 2017 (3).

Taking into account both direct and indirect contributions to the economy, the forest product industry is responsible for adding $236 billion to the U.S. economy in 2017. California, Pennsylvania, and Wisconsin accounted for $17, $14, and $14 billion, respectively (Figure 3.6.7 and Table 3.6.4) (3).

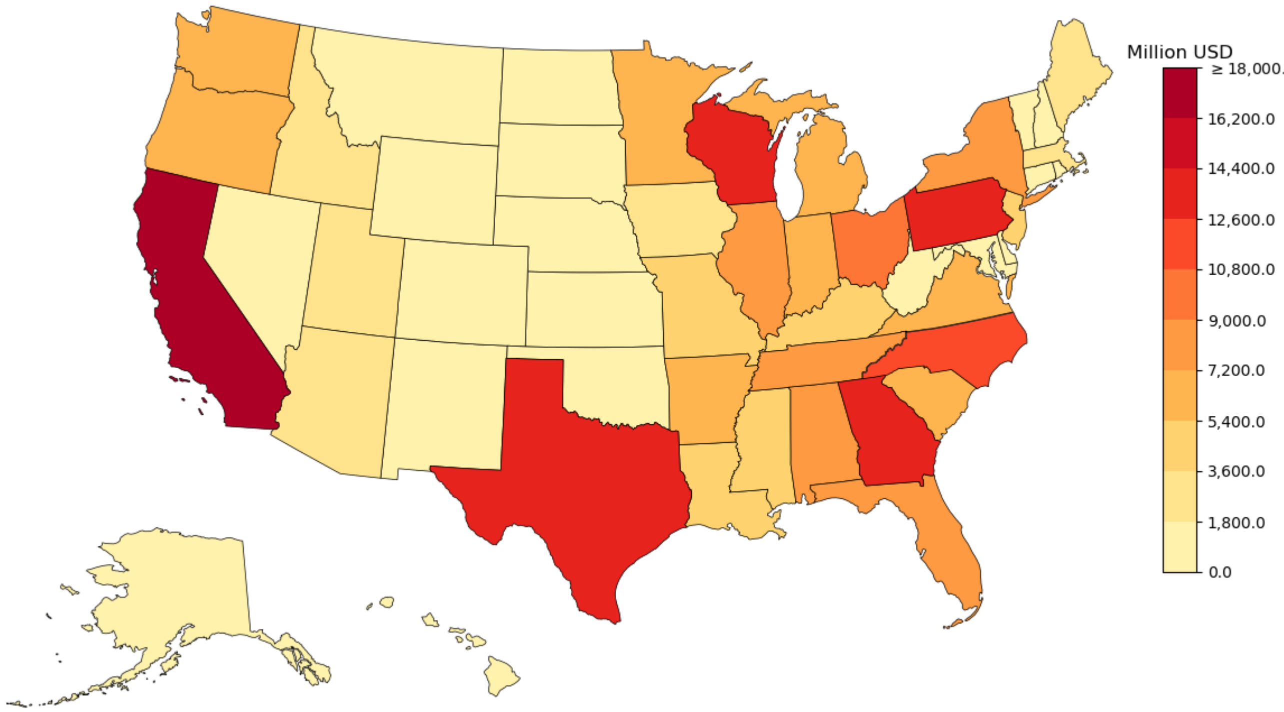

Figure 3.6.7. Total value-added to the U.S/ economy through the forest products industry in 2017 (3).

State	Million dollars	Percentage of total	Percent change from 2014
California	16,780	7.1	15.2
Pennsylvania	13,640	5.8	7.5
Wisconsin	13,550	5.7	3.5
Georgia	13,550	5.7	14.3
Texas	13,430	5.7	15.3

Table 3.6.4. Top 5 States ranked by total value-added to the economy by the forest products industry in 2017 (3).

References

1. National Research Council Committee on Biobased Industrial Products, Biobased Industrial Products: Priorities for Research and Commercialization, 2000. Available at: https://iwaponline.com/wst/article/59/5/927/15563/Defining-the-biomethane-potential-BMP-of-solid [Accessed July 2020].
2. Food and Agriculture Organization of the United States (FAOSTAT), Forestry production and trade, 2018. Available at: http://www.fao.org/faostat/en/#data/FO [Accessed July 2020].
3. An Economic Impact Analysis of the U.S. Biobased Products Industry Available at: https://bioproducts.ecu.edu/ [Accessed September 2020].
4. U.S. Bureau of Economic Analysis, Table 1.1.5 Gross Domestic Product, 2018. Available at https://apps.bea.gov/iTable/iTable.cfm?reqid=19&step=2#reqid=19&step=2&isuri=1&1921=survey [accessed July 2020]

3.7. Textiles

The production, consumption, and trade of biobased textiles are not currently tracked in the United States. The estimated impact that the biobased textile industry has on the U.S. economy is presented in this section.

The biobased textiles industry created 43,160 new jobs between 2014 and 2017, employing 207,530 workers in 2017. Approximately 16 percent of those jobs were located in California (33,860 jobs); Georgia ranks second in direct employment at 28,610 jobs; and North Carolina third at 21,550 jobs (Figure 3.7.1 and Table 3.7.1) (1).

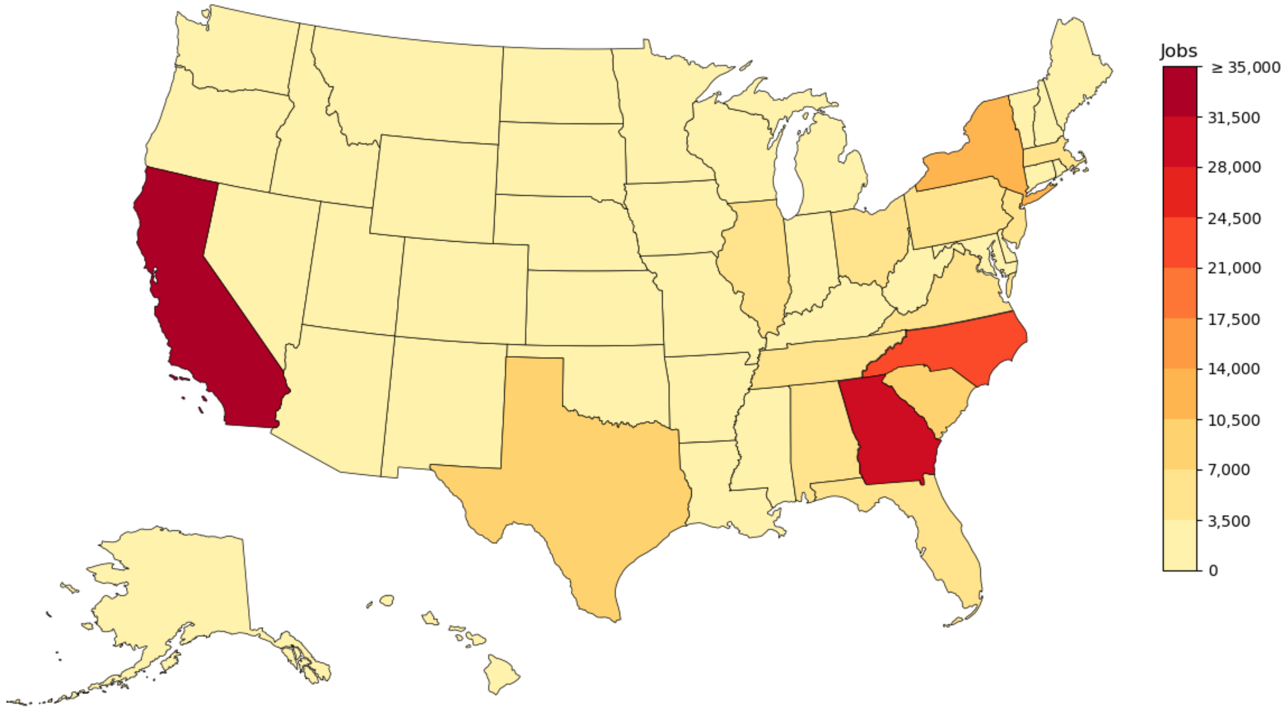

Figure 3.7.1. Number of direct jobs contributed to the U.S. economy through the biobased textiles industry in 2017 (1).

State	Number of jobs	Percentage of total	Percent change from 2014
California	33,860	16.3	8.2
Georgia	28,610	13.8	26.5
North Carolina	21,550	10.4	17.1
New York	12,600	6.4	10.7
South Carolina	10,400	5.0	19.5

Table 3.7.1. Top 5 States ranked by direct jobs from the biobased textiles industry in 2017 (1).

Factoring in the indirect jobs created by the textiles industry, the number of jobs contributed by that industry rises to 2.8 million jobs in the United States in 2017. This represents growth of 361,000 jobs since 2014, an increase of 16.7 percent. California is the leading State in total number of jobs, with 59,000 jobs, followed by Georgia and North Carolina, 55,000 and 40,000 jobs, respectively (Figure 3.7.2 and Table 3.7.2) (1).

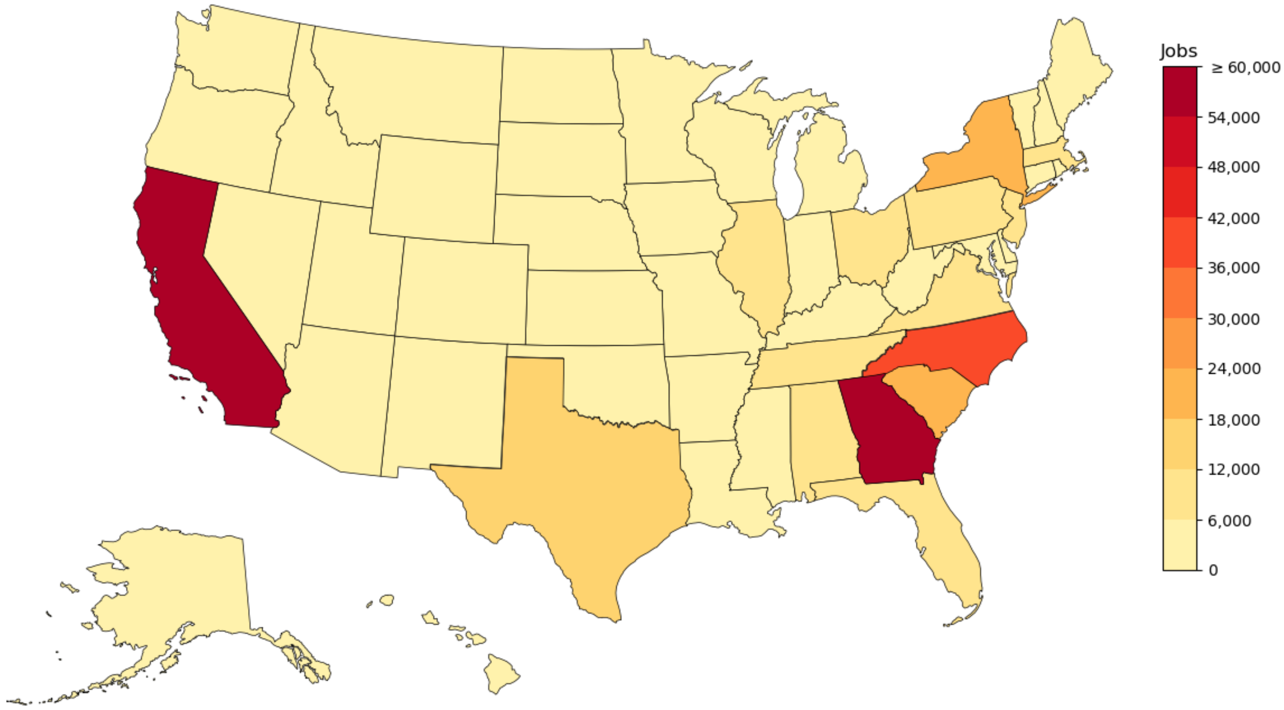

Figure 3.7.2. Number of total jobs contributed to the s economy through the biobased textiles industry in 2017 (1).

State	Number of jobs	Percent of total	Percent change from 2014
California	59,200	16.4	6.6
Georgia	54,580	15.1	26.2
North Carolina	40,040	11.1	18.1
New York	21,190	5.9	12.4
South Carolina	19,210	5.3	19.2

Table 3.7.2. Top 5 States ranked by total jobs from the biobased textiles industry in 2017 (1).

The biobased textiles industry's direct contribution to the U.S. economy in 2017 was $103 billion, an increase of 23 percent with respect to 2014. Georgia, which experienced an increase of 27 percent compared to 2014, California and North Carolina were the top contributors, with direct contributions of $2.2, $1.7, and $1.4 billion, respectively, to the U.S. economy (Figure 3.7.3 and Table 3.7.3) (1).

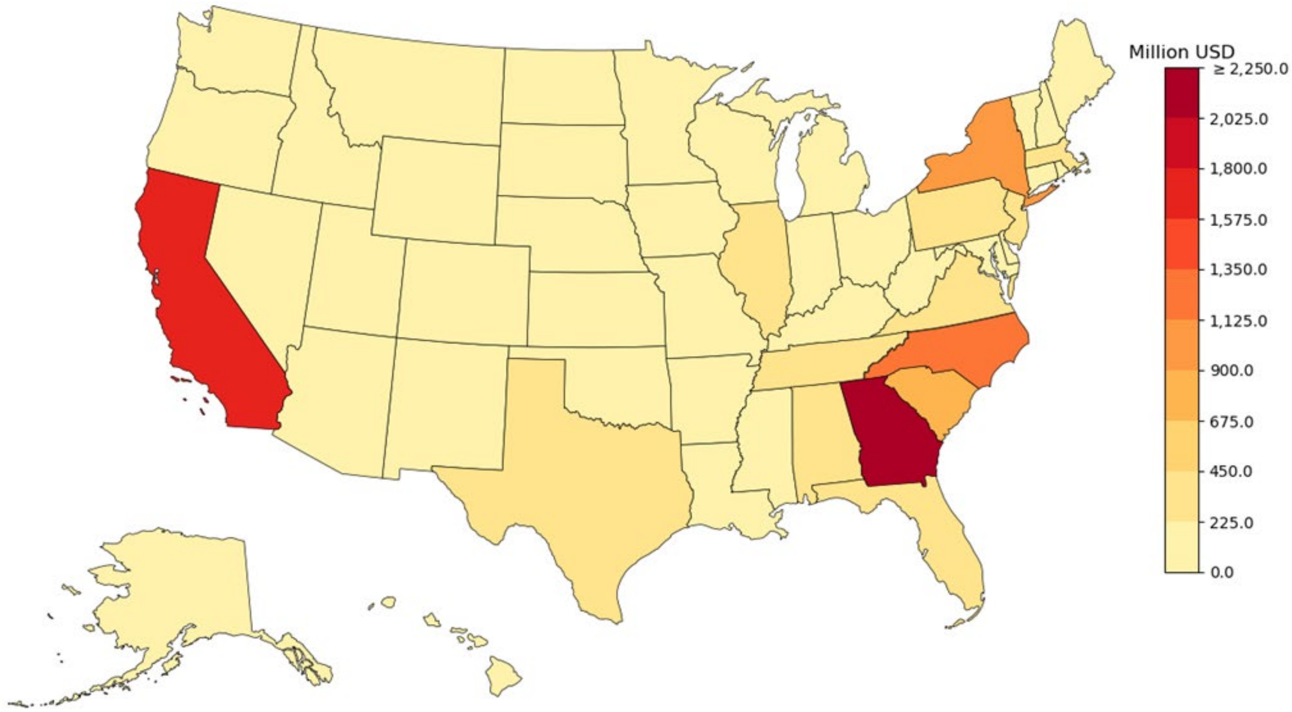

Figure 3.7.3. Direct value-added to the U.S. economy through the biobased textiles industry in 2017 (1).

State	Million dollars	Percentage of total	Percent change from 2014
Georgia	2,160	17.9	26.8
California	1,660	13.8	8.3
North Carolina	1,350	11.2	20.2
New York	970	8.1	14.8
South Carolina	800	6.6	19.6

Table 3.7.3. Top 5 States ranked by direct value-added to the economy by the biobased textiles industry in 2017 (1).

Adding the indirect effects, the biobased textiles industry was responsible for $236 billion in 2017, an increase of $5 billion from 2014 (4). Georgia, California, and North Carolina respectively accounted for $4.2, $4.1, and $2.9 billion (Figure 3.7.4 and Table 3.7.4) (1).

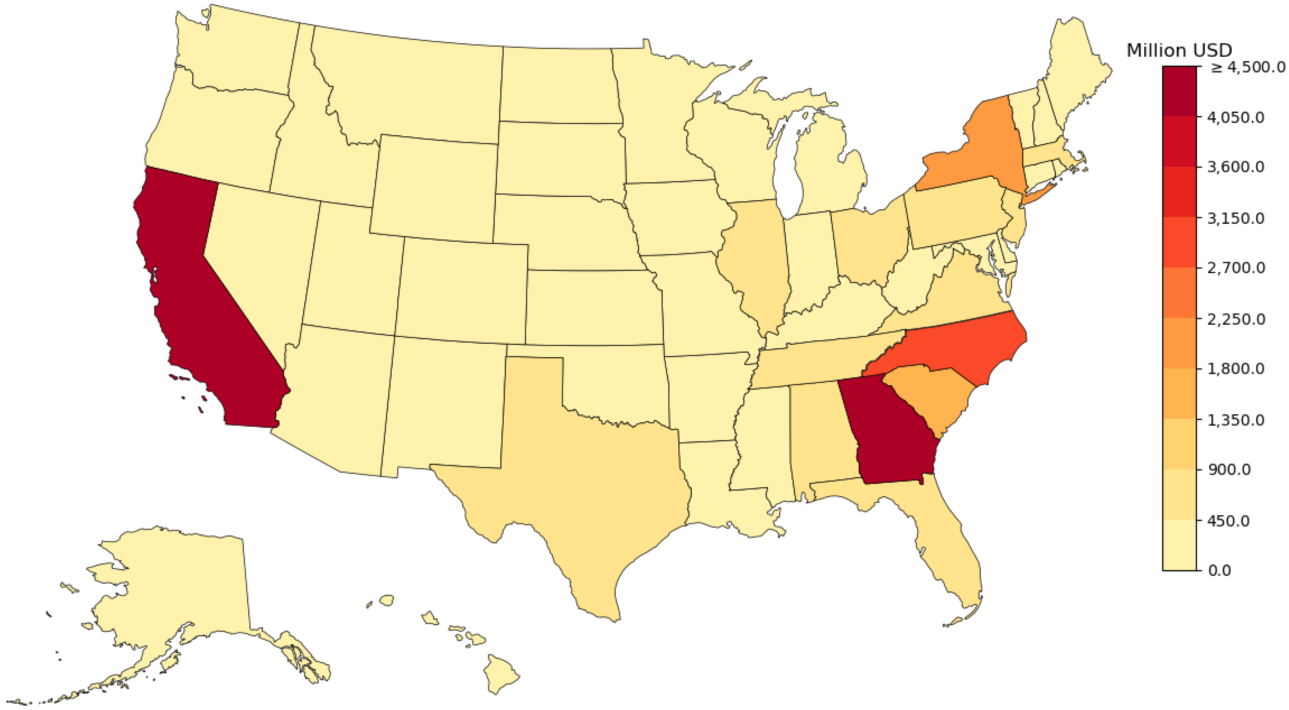

Figure 3.7.4. Total value-added to the U.S. economy through the biobased textiles industry in 2017 (1).

State	Million dollars	Percentage of total	Percent change from 2014
Georgia	4,240	16.9	26.3
California	4,090	16.3	6.7
North Carolina	2,850	11.3	19.8
New York	1,910	7.6	14.4
South Carolina	1,400	5.5	19.4

Table 3.7.4. Top 5 States ranked by total value-added to the economy by the biobased textiles industry in 2017 (1).

References

1. An Economic Impact Analysis of the U.S. Biobased Products Industry Available at: https://bioproducts.ecu.edu/ [Accessed September 2020].