USDA OFFICE OF THE CHIEF ECONOMIST

United States Department of Agriculture

# Indicators and Trends of the U.S. Biobased Economy: 2019 Through 2021

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April 2024

# Executive Summary

This report provides an update on bioindicators of the U.S. economy for calendar years 2019 through 2021 with policy updates that include 2022. This period of 2020 to 2021 represents one of the most tumultuous economic periods in both our society and economy triggered by the global COVID-19 pandemic. But while the overall economy and the biobased economy were negatively impacted by the pandemic, there are numerous longer-term trends and recent public and private policy updates in 2022 and 2023 that provide for a strong positive outlook moving forward as most of the severe impacts of the pandemic are behind us.

As presented in this report, there are a number of both governmental and industry drivers that are key to providing both near-term and longer-term growth for the U.S. biobased economy. Globally, we are witnessing a rapid transition to a net-zero carbon economy, which will be heavily reliant on climate-smart commodities which are derived from agricultural feedstocks i.e. biobased feedstocks.  Both U.S. and global corporations spanning industrial sectors are publicly committing to net-zero carbon no later than 2050 and in most cases far earlier.

American agriculture throughout the country as well as existing and expanding green tech manufacturing provides a strong foundation for the country to realize strong economic and job opportunities including exports of American products to global customers. Further, recent investments by the Federal Government including the Inflation Reduction Act of 2022 will provide the requisite financial and tax incentives to those engaged in the bioeconomy.

And while the transition to electric vehicles will have an impact on longer term ethanol production for passenger cars, we see the emergence of un-met demand for Sustainable Aviation Fuels (SAF) by the global aviation industry. The country will continue to transition away from non-renewable resources to more climate smart biobased renewable resources.

## KEY UPDATES

**1. COVID-19 & THE BIOECONOMY**

The COVID-19 pandemic had a significant impact on the overall bioeconomy both domestically and globally with generally reduced demand for products, slow down in production and new facilities as well as impacts from labor shortages and supply chain interruptions. Additionally, the pandemic made it much more difficult for the research team to acquire updated data in large part due to industry, industry associations, non-governmental associations and some agencies reducing staff or having staff interruptions during and post-pandemic.

**2. RACE TO NET-ZERO WILL ACCELERATE THE BIOECONOMY**

Late 2021 and 2022 saw a precipitous rise in the number of U.S. and global retailers, brands, manufacturers, and financial sectors making public commitments to transitioning to a Net-Zero Carbon Economy, thus generating significant interest and market-pull for low carbon biobased feedstocks, chemicals, energy, and products. Additionally, various States including California, Massachusetts, and New York have promulgated new low carbon policies and commitments with strong drivers for transitioning to biobased products.

**3. RENEWABLE DIESEL DEMAND CONTINUES TO GROW**

This is largely a result of the Renewable Fuel Standard, California's Low-Carbon Fuel Standard, and the U.S. biomass-based diesel blending credit, which currently applies through 2024 and allows qualified taxpayers to claim a credit of $1.00/gallon when the required amount of biodiesel or renewable diesel is blended with petroleum diesel for sale or use in a trade or business.

**4. THE EMERGENCE OF SUSTAINABLE AVIATION FUELS (SAF)**

The global aviation sector came together in 2022 to commit to a net-zero carbon transition by 2050, driving immediate demand and investments for Biobased Sustainable Aviation Fuels. The goal of scaling U.S..SAF production is to reach 3 billion gallons per year in 2030 and 35 billion in 2050—from the current level of 4.5 million gallons per year.

**5. OVER $3B IS BEING INFUSED INTO THE U.S. BIOECONOMY**

The U.S. Government has not only signaled its support for the domestic biobased economy but in 2022 invested over $3.1 billion in over 100 projects across the country to develop and advance Climate Smart Commodities. Additionally, the Inflation Reduction Act of 2022 infused additional capital and tax incentives into the American economy, supporting renewable and biobased solutions to replace legacy energy systems.

## KEY UPDATE #1

## COVID 19 & THE BIOBASED ECONOMY

The COVID-19 pandemic had unprecedented adverse effects on the global and U.S. economy. On January 7, 2020, officials in China announced that they had identified a new virus in the Hubei region. By the end of the month, the virus, designated coronavirus disease 2019 (COVID-19), had spread to other countries in Asia. In February, cases were reported throughout Europe and the United States, prompting the World Health Organization to declare a global emergency. On March 3, the United States followed suit by declaring a national emergency, a move that resulted in lockdowns across the country (BLS, 2020).

In fact, during the 3-day period in March of 2020, stock market selloffs in the United States were so severe that circuit breakers were activated by the Securities and Exchange Commission temporarily halting trading on the New York Stock Exchange The S&P 500 triggered level 1 market wide circuit breakers during the opening hour on March 9, 12, and 16 based on drops of 7percent from the previous close, and tripped later in the day on the 18th. These systems were instituted by the Securities and Exchange Commission in the aftermath of the stock market crash of 1987 to avoid a total meltdown. In total, the Dow Jones Industrial Average lost 37 percent of its value in 2020 while the S&P lost 34 percent (Bloomberg, 2022). One of the direct implications to the bioeconomy was that crude oil prices dropped precipitously in March and April 2020 due to significant declines in demand as well as supply chain impacts, thus making biobased alternatives less competitive in the marketplace. Motor gasoline consumption declined the most in absolute terms. Motor gasoline product supplied averaged 8.9 million barrels per day (MMbbl/d), based on 2020 data through March 13, 2020, and then fell 40 percent to 5.3 MMbbl/d as of the week ending April 17, 2020 (EIA, 2020). Producer prices for crude petroleum declined 34 percent in March and 48.8 percent in April; nearby futures actually went negative for a few days in April. In all, the producer price index (PPI) for crude petroleum fell 71 percent from January to April 2020, two of the largest monthly declines since the index was first published in July 1991. This had a systematic impact on biobased ethanol production and consumption as presented in Figure # ES-1.

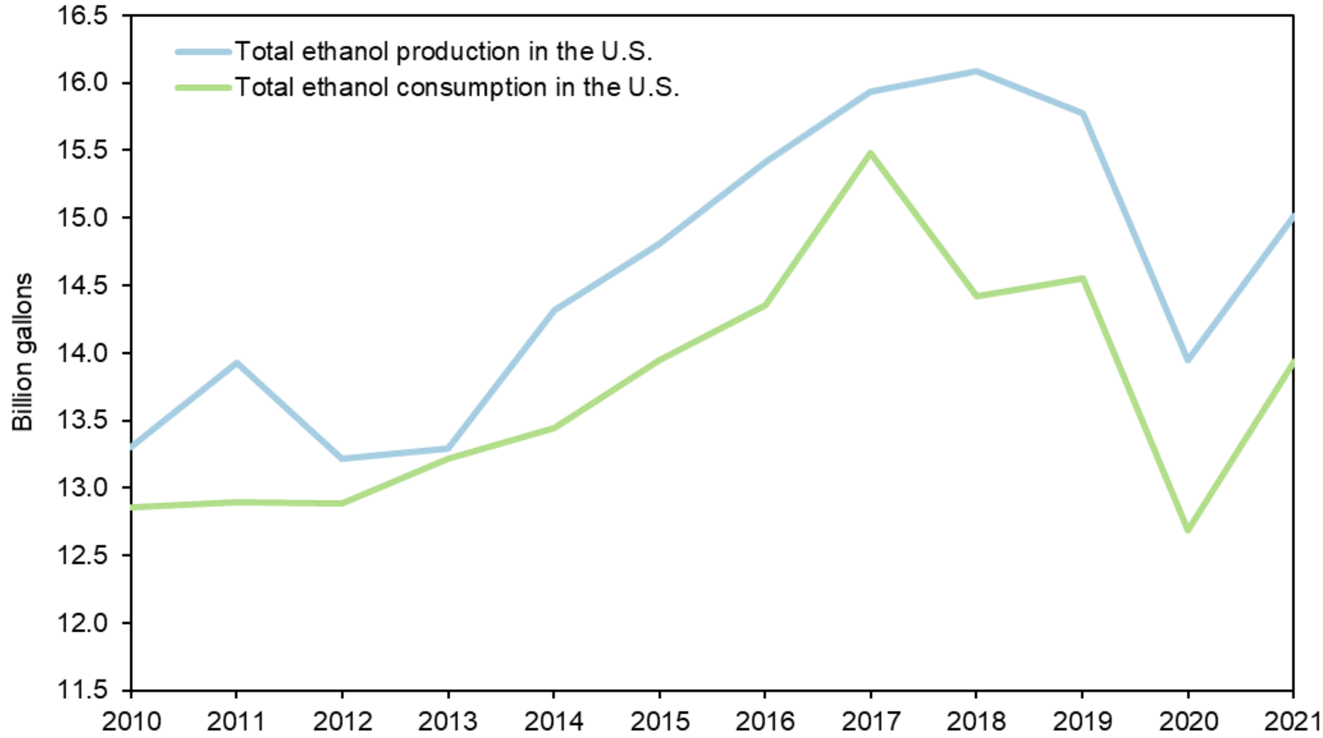


**Figure ES-1.** Total ethanol production and total ethanol consumption in the United States from 2010 to 2021 (in billion gallons) (EIA, 2022).

Additionally, demand for various feedstocks and products also decreased. Total chemical production volume excluding pharmaceuticals fell by 3.6 percent in 2020 (ACS, 2020) and supply chains faltered due to labor and parts shortages, globally. Even renewable diesel demand dropped during the early stages of the pandemic, but rapidly rebounded and grew driven primarily by the State of California's Low Carbon Fuel Standard (LCFS) compliance as presented in Figure # ES-2. Revenues and profits in the broader chemical industry eventually did recover to pre-COVID-19 levels during the fourth quarters of 2020 (Peng et al, 2021)

## KEY UPDATE #2

## RACE TO NET-ZERO CARBON WILL DRIVE THE BIOECONOMY MOVING FORWARD

While the global pandemic took hold over the economy, there was a significant trend by individual companies and groups of companies to commit to net zero carbon emissions by midcentury. Retailers, brands, manufacturers, shareholders, and the financial sectors collaborated on these commitments. The commitment dates generally vary between 2035 to 2050.

In 2019, Amazon was one of the first multi-national companies to commit to a Net-Zero Carbon transition by 2040 when they formed the Climate Pledge (Climate Pledge, 2023). This was followed by a cascade of major and smaller companies also committing to net-zero carbon in years spanning 2035 to 2050. As of 2022, more than one-third (702) of the world's largest publicly traded companies had net zero targets, up from one-fifth (417) in December 2020.The rate of commitments continues to rise as larger companies, shareholders and governments are requiring commitments of their suppliers (Net-Zero Tracker, 2022).

The list of major companies includes Walmart ($559 billion/annual revenue), Apple ($379 billion/annual revenue), Berkshire Hathaway (246 billion/annual revenue), J.P. Morgan Chase ($136 billion/annual revenue), Kroger ($133 billion/annual revenue) and Home Depot ($132 million/annual revenue) among many others (Net Zero Tracker, 2022).

An important pathway for American companies to meet their net-zero carbon commitments and to realize new export business opportunities is to transition away from fossil fuel-based feedstocks and products to lower carbon (climate smart) biobased feedstocks, intermediates, and final products.

## KEY UPDATE #3

## RENEWABLE DIESEL DEMAND CONTINUES TO GROW

Gasoline consumption in the United States during the pandemic and running through 2022 witnessed significant declines. In fact, the 4-week running average for gasoline consumption ending July 31, 2020, was 8.656 million barrels a day, while the average for the week ending July 29, 2022, was 8.592 million. Both are better than the height of the lockdown in April 2020, when just 5.3 million barrels (MMbbl/d) were consumed. This compares to the year 2018 in the United States which had an annual average consumption of 9.329 million barrels per day (MMbbl/d) (API, 2022; EAI, 2023).

Conversely, as presented in Figure ES# 2, renewable diesel demand continued to grow, and grew throughout the pandemic. This is largely a result of the Renewable Fuel Standard, California's Low-Carbon Fuel Standard, and the U.S. biomass-based diesel blender credit, which currently applies through 2024 and allows qualified taxpayers to claim a credit of $1.00/gallon when the required amount of biodiesel or renewable diesel is blended with petroleum diesel for sale or use in a trade or business. Additionally, there is continued market optimism as renewable diesel is compatible with existing distribution infrastructure and engines and the conversion of existing petroleum refineries into renewable diesel refineries (US EIA, 2022; Union Pacific, 2022).

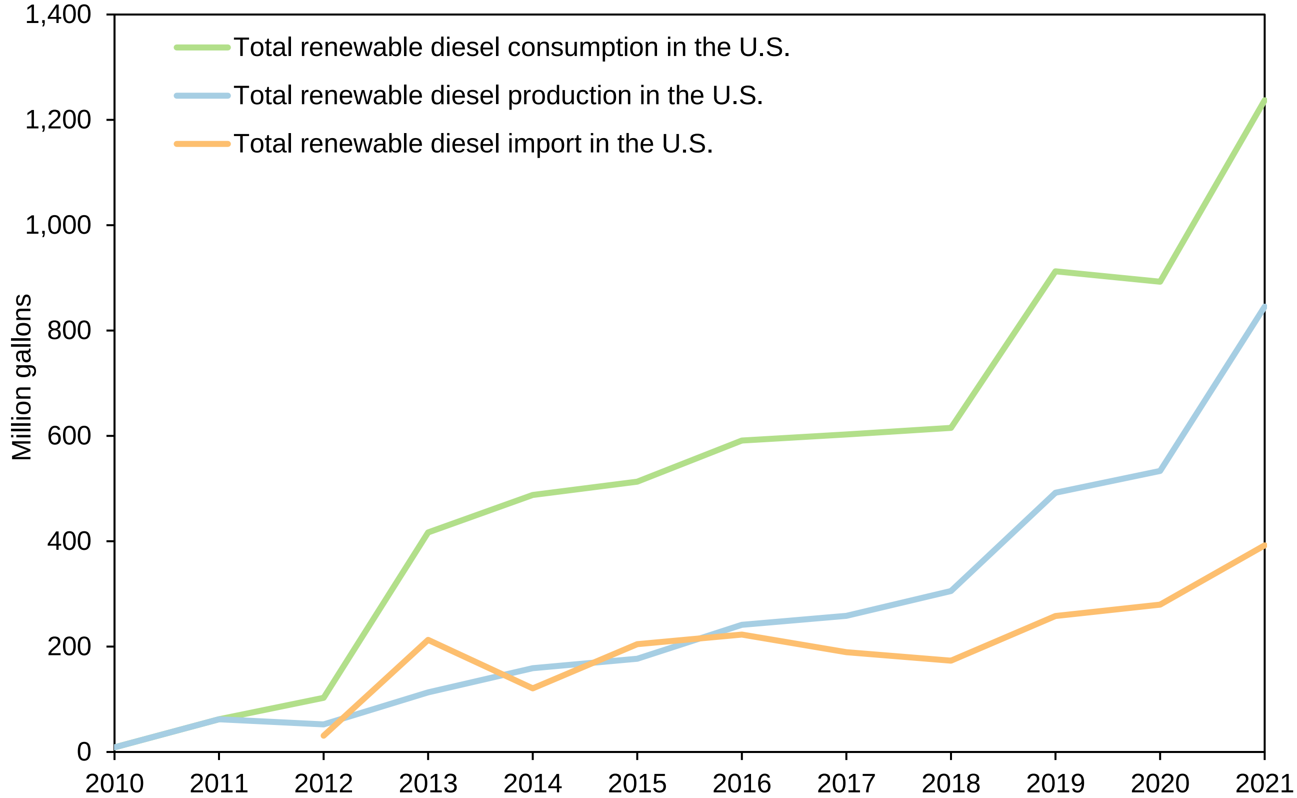


**Figure ES-2.** Renewable diesel production, consumption, and imports in the United States from 2011 to 2021 (in million gallons) (EPA, 2022; EIA, 2022).

## KEY UPDATE #4

## THE EMERGENCE OF SUSTAINABLE AVIATION FUELS.

The international aviation sector (excluding military aviation) accounts for up to 5 percent of global greenhouse gas emissions and is expected to rise post pandemic, possibly tripling by 2050. In response, the industry in September 2021 committed to net-zero $CO_2$ emissions by 2050 and in October 2021, governments from 181 countries came together under the auspices of the International Civil Aviation Organization (ICAO) to adopt the same long-term goal. Additionally, in October 2021, the 77th annual general meeting of the International Air Transport Association (IATA) held in Boston, Massachusetts, approved a resolution for the global air transport industry to achieve net-zero carbon emissions by 2050. This commitment will align with the Paris Agreement goal for global warming not to exceed 1.5°C.

A potential scenario is that 65 percent of this goal will be abated through Sustainable Aviation Fuel (SAF). In the near-term, the bulk of SAF will be developed utilizing biobased feedstocks, including waste feedstocks with uncertainty if the feedstocks will be predominantly domestic supplies or with strong imported feedstocks. Longer-term there is a push to develop carbon-capture and sequestration technologies that will further enhance and lower the greenhouse-gas (GHG) impacts. (Chokshi and Krauss, 2021; IATA, 2022). Additionally, the White House announced a national SAF Grand Challenge in September 2021. The Grand Challenge goal is to supply 3 billion gallons of SAF per year by 2030 and 100 percent of expected domestic commercial jet fuel use by 2050 (GAO, 2023).

SAF is a biobased energy source (i.e., a biofuel with similar properties to conventional jet fuel but with a smaller carbon footprint). An estimated 1 billion dry tons of biomass can be collected sustainably each year in the United States, enough to produce 50–60 billion gallons of low-carbon biofuels. These resources include (DOE, 2023):

- Corn grain
- Oilseeds
- Algae
- Other fats, oils, and greases
- Agricultural residues
- Forestry residues
- Wood mill waste
- Municipal solid waste streams
- Wet wastes (manures, wastewater treatment sludge)
- Dedicated energy crops.

Global SAF production capacity is expected to potentially increase from 41 million gallons per year (MMgal/y) in 2020 to 3,702 (MMgal/y) in 2030. This is based on a slew of projects that are expected to start by 2030. Most of the global SAF production is being planned for standalone renewable fuel refineries. Several crude oil refineries are also being converted into renewable fuel facilities or co-processing facilities for SAF production. The United States is expected to witness SAF production capacity additions of 1,221 (MMgal/y) by 2030 as a result of planned upcoming projects.

**KEY UPDATE #5**

**MORE THAN $3 BILLION IS BEING INFUSED INTO THE U.S. BIOECONOMY**

In 2022, the Congress of the United States passed landmark legislation that provides unprecedented funding that will in part support the biobased economy because of tax incentives, expansion of loan guarantees, investment in R&D for energy and climate-related programs affecting biobased feedstocks and various biobased industrial sectors. Furthermore, on September 14, 2022, USDA Secretary Tom Vilsack announced that the USDA was launching a new initiative entitled "*Partnerships for Climate-Smart Commodities*" which provides pathways for American farmers, producers, manufacturers and brands to take a leading position in the growing global biobased economy. USDA is investing more than $3.1 billion for 141 projects through this effort and all the projects that will be funded require meaningful involvement of small and underserved producers.

This national investment builds upon the Inflation Reduction Act of 2022 which includes $369 billion in spending and tax policies over 10 years to reduce GHG emissions and incentivize expanded production and use of domestic clean energy. One of the measures included in the legislation was an extension of the $1 per gallon biodiesel and renewable diesel blenders tax credit, which was set to expire at the end of December 31, 2022, but extended through 2024. Additionally, a tax credit for sustainable aviation fuel (SAF) ranging from $1.25 to $1.75 per gallon through 2024; clean-fuel production credits starting in 2025 through 2027, which offer incentives based on GHG reductions for clean on-road and aviation fuels; and $20 billion to support climate-smart farming practice adoption on U.S. farms, ranches, and forests.

Additional support for biofuels: The Inflation Reduction Act grants $500 million for blender pumps and other biofuel infrastructure and extends Section 45 of the Renewable Electricity Production Tax Credit for landfill gas construction and maintains a credit of 1.5 cents per kWh (Bipartisan Policy Center, 2022).

**Government Advisory Council**

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This project was supported through a cooperative agreement (58-0111-22-003) issued by the Office of the Chief Economist of the United States Department of Agriculture and the Dynamic Sustainability Lab at Syracuse University.

## How to Cite this Report

Golden, J.S., Ha, H., Pascual-Gonzalez, J., Aguilar-Mogas, A., Brown, T, Otis, A., and A Radich (2023). Indicators & Trends of the U.S. Biobased Economy: 2019 through 2021. U.S. Department of Agriculture, Office of the Chief Economist.

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## Glossary of Terms

| | |
|---|---|
| Anaerobic digestion: | Collection of processes in which organic material is broken down by microorganisms 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. |
| Bioeconomy: | As defined by the Congressional Research Service (2022), the term bioeconomy refers to the share of the economy based on products, |

| | |
|---|---|
| | services, and processes derived from biological resources (e.g., plants and microorganisms). The bioeconomy is crosscutting, encompassing multiple sectors, in whole or in part (e.g., agriculture, textiles, chemicals, and energy). |
| 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 one pound of water at one atmosphere through one degree Fahrenheit. |
| Carbon Intensity: | The ratio of carbon dioxide per unit of energy, or the amount of carbon dioxide emitted as a result of using one unit of energy in production. Emission intensities are also used to compare the environmental impact of different fuels or activities. The related terms - emission factor and carbon intensity - are often used interchangeably. |
| 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 one 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. BROAD MARKET UPDATES

# 1.0 Overview

This version of the *Indicators of the U.S. Biobased Economy* report is unique in that it reports on a period when the broader U.S. economy was significantly impacted due to the global outbreak of COVID-19. The implications of the global pandemic were significant for supply chains, product demand, and inflation, which all affected the bioeconomy as well. Therefore, the presented findings may not be indicative of the longer-term forecasts about the domestic biobased economy.

## 1.1. COVID-19 and the Biobased Economy

Without question, the COVID-19 pandemic had a significant impact on both the global and domestic economy. The United States witnessed historic drops in output and the U.S. GDP fell by 8.9 percent in the second quarter of 2020 (Figure 1.1.1), the largest single-quarter contraction in more than 70 years (BEA 2021).

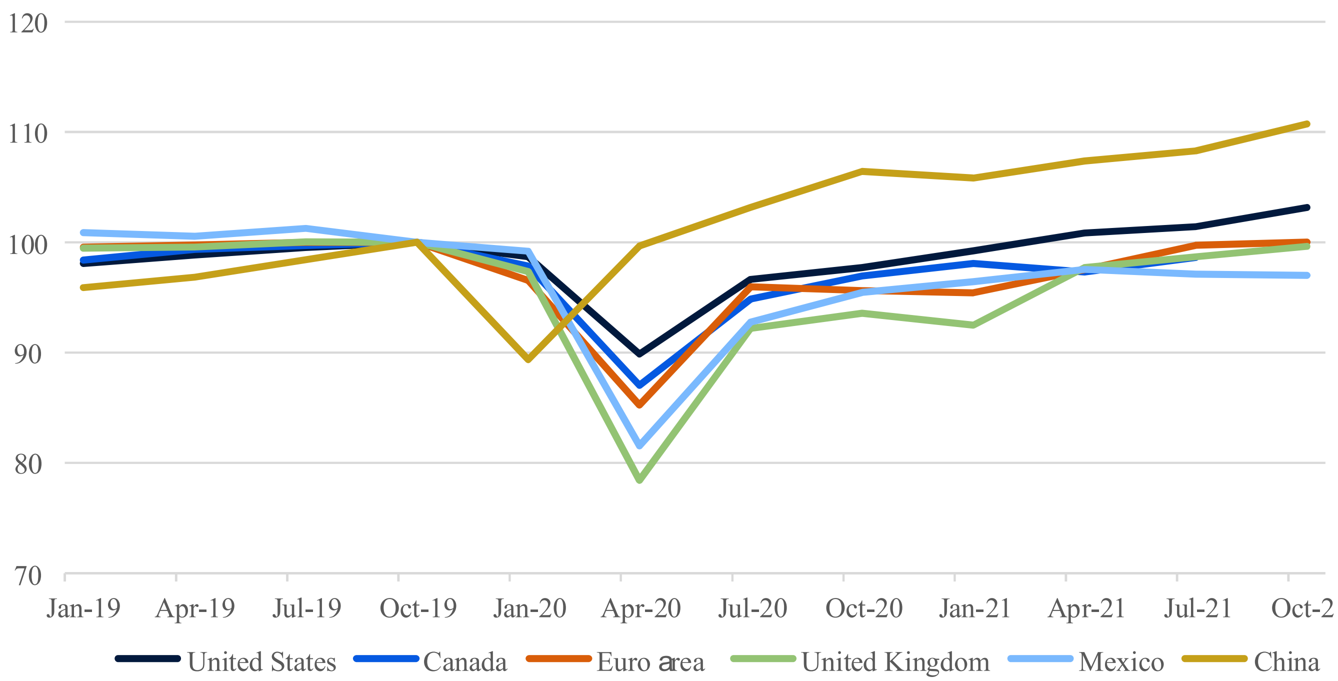


**Figure 1.1.1** Real GDP by Country. Index level: 2019: Q4 = 100. (White House, 2022).

The pandemic resulted in additional impacts to the U.S economy. Inflation rose significantly and the rate of inflation in the United States grew higher than most its trading partners but narrowed in the second half of 2021. Table 1.1.1 presents three different measures of inflation: the change at an annual rate in the personal consumption expenditures (PCE) price index, the core PCE price index (which excludes food and energy) and the consumer price index (CPI). The years 2016-19 covers a recent pre-pandemic period of relative price stability with inflation close to the Federal Reserve's 2 percent target. The next are the years 2020 and 2021. The last one, COVID-19, covers the pandemic period since March 2020 until February 2022.

Inflation through the end of 2021 was significantly higher than before the pandemic, regardless of how it is measured. Inflation was highest in 2021 as defined by the Federal Reserve Bank, as it stayed low throughout 2020 and then accelerated during 2021.

**Annualized Inflation Rates**

| | PCE Price Index | Core PCE Price Index | CPI |
|---|---|---|---|
| **2016-19** | 1.80% | 1.80% | 2.10% |
| **2020** | 1.30% | 1.50% | 1.30% |
| **2021** | 5.80% | 4.90% | 7.10% |
| **COVID-19** | 4.00% | 3.40% | 4.70% |

NOTES: Core PCE excludes food and energy. The COVID-19 period starts in March 2020 and ends in February 2022.

**Table 1.1.1** Tracking inflation in the United States. Source: Federal Reserve Bank of St. Louis (2022).

Additionally, supply chain disruptions also impacted the domestic economy as a whole. In fact, the U.S. Census Small Business Pulse survey, held from May 31 to June 6, 2021, indicated that over 36 percent of small businesses reported delays with domestic suppliers. The manufacturing sector was hit the hardest with over 60 percent of the sector indicating delays due to supply chain interruptions (White House, 2021).

The International Energy Agency (IEA, 2020) reported on the impacts of COVID-19 to the global biofuels industry. As reported, global transport biofuel production in 2020 was estimated to be 144 billion liters (L), equivalent to 2 480 thousand barrels per day – an 11.6 percent drop from 2019's record output and the first reduction in annual production in two decades. This was below the 3 percent growth anticipated for 2020 in their pre-pandemic forecast.

As presented in Figure 1.1.2 ethanol exports from 2010 to 2021 show a continued level of production growth until 2019 when U.S. fuel ethanol exports fell by 14% even though the number of export destinations increased from 34 destinations in 2018 to 39 destinations in 2019. Nearly half of all ethanol was shipped to Brazil despite decreasing their imports of U.S. ethanol by 34%. Brazil, the world's second largest producer and consumer of fuel ethanol, decreased imports of U.S. ethanol for the first year since 2015, dropping to 22,000 b/d in 2019 but still accounting for nearly one-quarter of all U.S. ethanol exports. Exports continued at lower levels due to the on-set of the global pandemic (EIA, 2020).

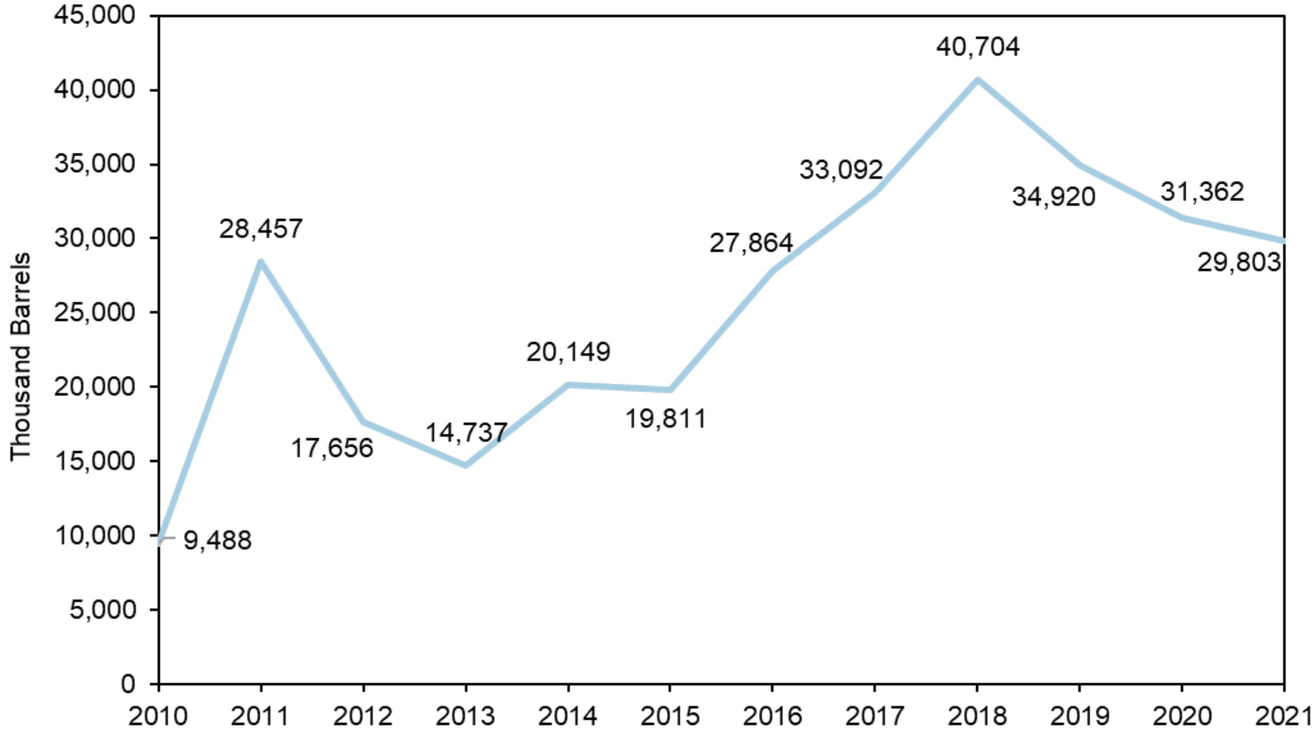


**Figure 1.1.2 U.S**. Exports of Ethanol (EIA, 2022).

In the United States, the production of ethanol in 2019 was 15.7 billion gallons (59.5 billion L). Output fell approximately 40 percent between February and April of 2020, as many plants idled or reduced output in response to the sudden drop in gasoline demand, negative operating margins and constrained storage capacities. Additionally, the ethanol industry in 2019 experienced its first unprofitable year since 2012, thereby ending a run of six consecutive years of positive returns. The estimated loss for a representative Iowa ethanol plant in 2019 was -$1.6 million (Irwin, 2020).

The U.S. Renewable Fuel Reimbursement Program also known as the HEROES Act mitigated the financial impacts to the industry with relief for biofuel producers by providing $0.45 per gallon payment for qualified fuel produced by eligible producers from Jan. 1, 2020, through May 1, 2020 (NCGA, 2020).

### 1.1.1 Pre-Pandemic Trends

Prior to the COVID-19 pandemic the domestic bioeconomy was showing sustained growth. For example, according to the U.S. Energy Information Administration (2020), the consumption of ethanol fuels in the United States in 2000 was 39,367 thousand barrels (Mbbl). By the end of 2019, that number reached 346,468 Mbbl. Similarly, the production of biodiesel in the United States in 2001 was 9 million gallons (MMgal) and by 2019 the production had reached 1,724 MMgal with domestic consumption during that same period accelerating from 10 MMgal to 1,811 MMgal. U.S. renewable diesel production increased from 0.8 MMgal in 2010 to 494 MMgal in 2019 and 847 MMgal in 2021; U.S. consumption in those same years was 0.8 MMgal, 915 MMgal, and 1,318 MMgal, respectively. Innovation has also introduced new biobased fuels to the U.S. market: domestic SAF production (and consumption) began in 2016 at 0.2 MMgal before increasing to 2.4 MMgal in 2019 and 5.1 MMgal in 2021 (US EPA, 2023).

Similarly, non-fuel and energy sectors of the U.S. Biobased Products sector, a subsector of the larger biobased economy witnessed positive impacts both economically and in job creation prior to COVID-19. The most recent analysis by the USDA of the impacts of the U.S. Biobased Products sector (Daystar, Handfield and Golden; 2020) documented that the value-added to the U.S. economy from biobased products rose from $369 million in 2013 to over $459 million in 2016 with employment of full time and part-time individuals increasing by 653,000 persons to 4.65 million.

## 1.2. Mid-Range Economic Outlook

While the COVID-19 pandemic certainly had an impact on the general economy and the biobased economy, there are a number of indicators and policy shifts which, when examined, lead to an optimistic outlook.

### 1.2.1 BioPlastics

In 2019, biobased plastics was estimated to be 2.1 million metric tons or approximately 1 percent of the 359 million metric tons of all plastics produced (European Bioplastics, 2019).

A recent study by the Nova-Institute in Germany (2020) estimated a 36 percent increase in the global bioplastics sector from around 2.1 million metric tons in 2020 to 2.8 million metric tons in 2025. They attribute this growth in large part to new and innovative biopolymers including bio-based PP (polypropylene) and PHAs (polyhydroxyalkanoates). Since PHAs entered the market, the share of this important polymer family continued to grow. Currently, biodegradable plastics account for almost 60 percent of the global bioplastics production capacities. PHA and PLA (Polylactic acid) are bio-based, biodegradable, and feature a wide array of physical and mechanical properties. Packaging remains the largest field of application for bioplastics with almost 47 percent (0.99 million metric tons) of the total bioplastics market in 2020. This includes food wraps, cups, plates, coating for paper and cardboard.

### 1.2.2 Green Chemistry

Green Chemistry is heavily reliant on advances in biobased feedstocks and intermediates. And, in a 2021 report (Golden et al, 2021), it was found that green chemistry is playing a significant role in consumer choices of products. Specifically, between 2015–2019 (pre-pandemic) green chemistry marketed products grew at a much faster rate than their conventional counterparts by 12.6x and faster than the overall market by 5.4x. Clear economic indicators are not readily available due to the lack of NAICS codes developed for both biobased and green sectors of the U.S. economy.

The sector is expected to continue to grow in part because of bi-partisan Congressional action. On January 1, 2021, the National Defense Authorization Act for Fiscal Year 2021 (H.R. 6395) became law. Subtitle E of Title II of the Act includes the text of the bipartisan Sustainable Chemistry Research and Development Act of 2019. Subtitle E will establish an interagency working group led by the Office of

Science and Technology Policy (OSTP) to coordinate federal programs and activities in support of sustainable chemistry also called green chemistry (Golden et al., 2021).

The Act is intended to both support American manufacturing and jobs while also protecting human health and the environment through expanded use of sustainable chemistry technologies. The Act directs the Office of Science and Technology Policy to convene an interagency entity under the National Science and Technology Council with the responsibility of coordinating federal programs and activities in support of sustainable chemistry. The Entity is to be co-chaired by representatives from the Environmental Protection Agency, the National Institute of Standards and Technology, and the National Science Foundation. The Entity is also to develop a working framework of attributes characterizing sustainable chemistry for the purposes of carrying out the Act (Congress.Gov, 2021)

#### 1.2.3 Agricultural Biogas

While the exact numbers of "organic waste" generation in the United States are not detailed, one study (UCS, 2014) estimated that in 2030 the United States could utilize up to 155 million tons of agricultural residues and almost 60 million tons of manure for bioenergy production. More recently, the U.S. EPA (2023) estimates that in 2019, 66 million tons of wasted food was generated in the food retail, food service, and residential sectors, and most of this waste (about 60%) was sent to landfills. An additional 40 million tons of wasted food was generated in the food and beverage manufacturing and processing sectors. The biggest portion of this (42.6%) was managed by anaerobic digestion. Managing agricultural wastes is important as these types of organic wastes generate methane as they decompose which is a powerful greenhouse gas that traps heat in the atmosphere more efficiently than carbon dioxide (EESI, 2017).

#### 1.2.4 Biofuels

Biomass can be converted directly into liquid fuels, called "biofuels," with the three most common types of biofuels being ethanol, biodiesel, and renewable diesel. Ethanol can be derived from various plant materials and is used as a blending agent with gasoline to increase octane and cut down carbon monoxide and other smog-causing emissions. The most common blend of ethanol is E10 (10% ethanol, 90% gasoline), which is approved for use in all conventional gasoline-powered vehicles. Most gasoline powered vehicles can also use E15 (15% ethanol, 85% gasoline). Some vehicles, called flexible fuel vehicles, are designed to run on gasoline or E85 (a gasoline-ethanol blend containing 51%–83% ethanol, depending on geography and season), an alternative fuel with much higher ethanol content than regular gasoline. Roughly 97% of gasoline in the United States contains some ethanol.

The most common types of biobased feedstocks in the United States for ethanol include plant starches (primarily corn) and sugars. The feedstocks are then converted into ethanol via fermentation, where microorganisms are added (e.g., bacteria and yeast) and metabolize plant sugars finally producing ethanol.

Biodiesel and renewable diesel are cleaner-burning replacements for petroleum-based diesel fuel that are produced from renewable biobased sources that can include vegetable oils and animal fats. Biodiesel is nontoxic and biodegradable and is produced by combining alcohol with vegetable oil, animal fat, or recycled cooking grease. Biodiesel can be blended with petroleum diesel in any percentage, including

B100 (pure biodiesel); however, the most common blend is B20 (a blend containing 20% biodiesel and 80% petroleum diesel) (US DOE, 2023). Renewable diesel is produced by reacting vegetable oil, animal fat, or recycled cooking grease with hydrogen rather than alcohol. Renewable diesel has the additional advantage of being chemically identical to petroleum diesel fuel and can be used in any combination with petroleum diesel fuel.

In large part, the demand for biofuels is derived from the Federal Renewable Fuel Standard (RFS), established by the Energy Policy Act of 2005 and expanded in 2007 by the Energy Independence and Security Act. At the State level, the California's Low Carbon Fuel Standard (LCFS) has also done much to increase consumption of biofuels, especially biodiesel, and renewable diesel, and agricultural biogas; in the United States Implemented in 2011, the LCFS resembles the RFS in that both have the objective of decarbonizing transportation fuels. Whereas the RFS mandates volumetric blending targets the LCFS instead establishes unique carbon intensities for participating biofuels and requires transportation fuel suppliers to achieve specific reductions to the average carbon intensity of their supply.

The incentive that an individual low-carbon fuel receives is directly correlated to the carbon intensity reduction that it achieves relative to the fossil fuel baseline. Unlike the RFS, which has been mostly met through corn ethanol blending, renewable diesel became the largest contributor to California's LCFS in terms of both volumes and credits in 2021. Oregon maintains an analogous program and Washington implemented a similar LCFS program in subsequent years to create a "West Coast" regional LCFS (CARB, 2022). Other states are considering the creation of clean transportation standards that would be modeled on the LCFS programs in California, Oregon, and Washington.

There also are emerging policies that are likely to increase the production and utilization of biofuels. In 2018, San Francisco International Airport signed a memorandum of understanding (MOU) with Neste and a group of eight airlines and fuel producers to expand the use of sustainable aviation fuel (SAF) at the airport. The agreement was the first of its kind to include fuel suppliers, airlines, and airport agencies in a collaborative effort to accelerate the global transition to SAF. On December 9, 2020, NetJets, the world's largest private jet company, was the inaugural recipient for the first delivery of SAF in San Francisco. The initial load consisted of over 1,000 gallons that were pumped into a Bombardier Challenger 350. The SAF was from 100 percent renewable and residue materials such as used cooking oil and animal fats resulting in a GHG emission reduction of 80 percent compared to traditional fossil fuels according to the Neste.

One example of other States adopting and/or considering similar programs to the Western States can be found when in 2019 New York State (NYS) passed the Climate Leadership and Community Protection Act (CLCPA), which requires the State to achieve a reduction to its total GHG emissions of at least 85 percent, and up to 100 percent, by 2050. In late 2022, the State finalized a roadmap for the implementation of the CLCPA that, among other things, recommended the creation of a Clean Transportation Standard that would be modeled on the LCFS programs in California, Oregon, and Washington. Legislative action is expected to be taken on the proposal in 2023 (New York State, 2022).

Looking globally, in October 2020, Japan's new Prime Minister Yoshihide Suga called for the country to be carbon neutral in 2050, which comes just after China committed to reduce carbon emissions to zero by 2060 (NY Times, 2020). This follows the European Union which has also committed to carbon neutrality by 2050 (EU, 2020). Japan also recently (2018) adopted a new policy on blending ethyl tertiary butyl ether (ETBE) into gasoline, which, now permits U.S.- produced (corn-based) ethanol to supply up to 44 percent of a total estimated demand of 217 million gallons of ethanol used to make ETBE in Japan. This has the potential to provide exports of 95.5 million gallons of U.S.-produced ethanol annually. ETBE is an ethanol-based oxygenate frequently used in overseas markets. In the past, Japan only permitted sugar cane ETBE (Growth Energy, 2018).

The EU in 2019 rescinded anti-dumping duties that were imposed in 2013 on U.S. ethanol and resulted in a €62.9 per metric ton duty on imports of ethanol from the United States (Agricensus, 2019).

## 1.3. The Changing Landscape in Transportation

While there is great optimism for the continued growth of the Biobased economy in the United States, there are various policies and industry trends that will have negative implications. The most prominent implication to the bioeconomy is the rapid transition to electric vehicles which over time will impact biofuel consumption, especially ethanol.

### 1.3.1 Flex Fuel Vehicles

E85 is a blend of 85 percent denatured and 15 percent gasoline. E85 cannot be used in a conventional, gasoline-only engine. Vehicles must be specially designed to run on it. The only E85-compatible vehicles currently available to U.S. drivers are known as flex fuel vehicles (FFVs) because they can run on E85, gasoline, or any blend of the two. According to DOE, as of 2021, there were more than 27 million FFVs in the United States or 9.6% of the approximately 280 million vehicles registered in the United States (U.S., DOE, 2023; Forbes, 2023). While most new 2021 cars are approved by manufacturers to use E15, there are fewer models now offered in the marketplace as flex fuel vehicles capable of operating on fuel blends containing up to 85 percent ethanol. In fact, as presented in the figure below, while E85 stations and ethanol consumption have continued to increase in the United States, the number of FFV models available has declined since 2014. According to a study by the National Renewable Energy Lab (2023), this decrease is thought to be namely the result to the change in Corporate Average Fuel Economy credits[1], removing the incentive for original equipment manufacturers to produce FFVs.

[1] New CAFE targets went into effect in June 2020 beginning with the 2021 model year, increasing at a rate of 1.5 percent per year, far lower than the nearly 5 percent increase they replace. Additionally, the minimum standard for domestic passenger cars was lowered from the 2020 model year level until the 2023 MY

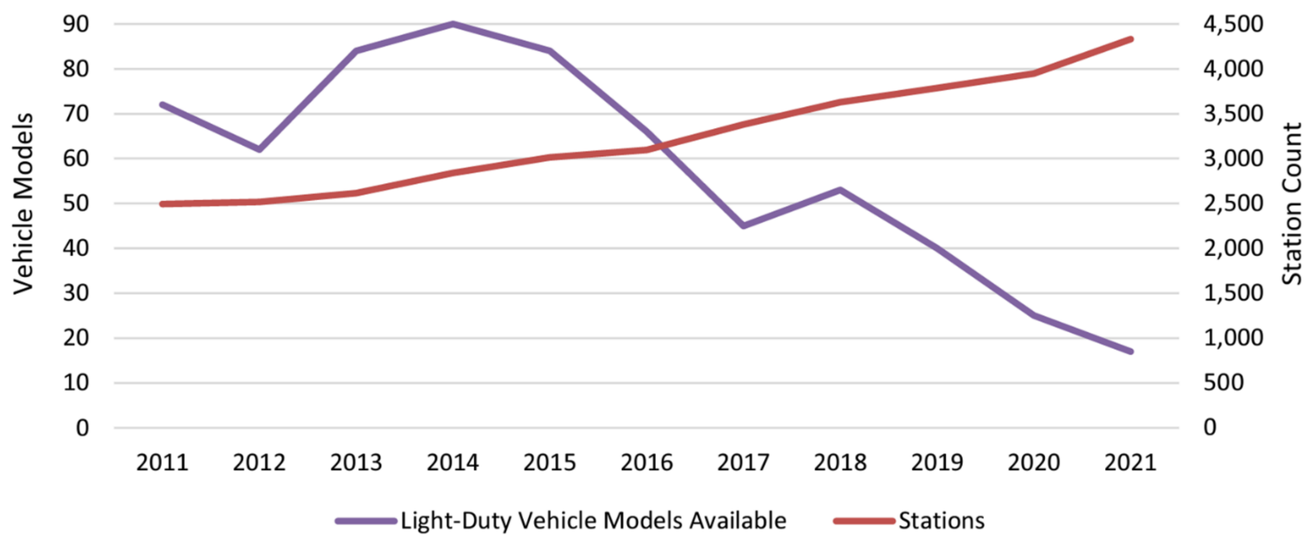


**Figure #1.3.1** XE85 station count and FFV model availability. Source NREL (2023).

In the United States, both Ford and General Motors offered FFVs in 2021. But only 11 models were available as FFVs in 2021, with five of those available only to fleet purchasers. This is down from more than 80 different models from eight manufacturers being available to consumers in 2015 (RFA, 2021). In part, this dynamic is the result of changingFederal policies for vehicle fuel economy standards as well as tax incentives as discussed previously with CAFÉ target reductions.

E-15 is a gasoline blended with 10.5% to 15% ethanol. In 2011, EPA approved E15 for use in light-duty conventional vehicles of model year 2001 and newer. U.S. gas stations are not required to sell E15, but some have started offering E15 due to State and Federal incentives for upgrading equipment and better profit margins when compared with regular gasoline. E15 is available in 31 States at just over 2,500 stations (U.S. DOE, 2023).

### <u>1.3.2 Electric Vehicles</u>

Biofuels including both ethanol and renewable diesel will see long-term decrease in demand as a result of the rapidly expanding transition to electric vehicles which will decrease the utilization of internal combustion engines. The EV transition was strengthened by Congress through the various funding mechanisms in the Inflation Reduction Act. Globally, while EV sales were less than 5% in 2020, by 2022 the percentage had accelerated to 14% of all new cars sold. Electric car sales in the United States – the third largest market behind China and the European Union – increased 55% in 2022, reaching a sales share of 8%. While there exists various models of project market penetration of EVs in the United States, generally the predictions show that with both the Inflation Reduction Act (IRA) and the adoption of California's Advanced Clean Cars II rule by a number of States, EVs in the United States could reach a 50 percent market share by 2030, (IEA, 2023).

In addition to policy drivers, the industry itself is moving towards a manufacturing base predicated on electric vehicles. In 2020, American electric car manufacturer Tesla became the world's most valuable automaker, with a market capitalization higher than the historic Big-3 American auto manufacturers combined (Ford, GM, and Fiat Chrysler) and above the combined value of the six largest U.S. energy companies. Tesla's market cap as of Aug. 28 reached $412.49 billion.

Early in 2021, General Motors (GM) CEO, Mary Barra, publicly announced that her company would sell only zero-emission cars and trucks by 2035 and had already committed to spending $27 billion to introduce 30 electric vehicle models by 2025. GM’s January announcement was quickly followed by Ford in February where they announced they are investing $22 billion in electric vehicles and committed that by mid-2026, 100 percent of Ford’s passenger vehicle fleet in Europe will be zero-emissions capable, all-electric or plug-in hybrid, and will be completely all-electric by 2030.

In part, these decisions were based on evolving policies to address climate change. For example, in September 2020, California Governor Gavin Newsom signed an order to ban the sale of new gasoline and diesel-powered passenger cars by 2035. Put in perspective, California accounts for more than 11 percent of all light vehicles registered in the United States in 2019 (WSJ, 2020). In 2021, New York State adopted a similar ban on non-electric light-duty vehicles that is due to take effect in 2035 (CleanTechna, 2021).

Similarly, in November 2020, the United Kingdom announced it will stop selling new diesel and gasoline cars and vans from 2030 forward as part of their “green industrial revolution.” This accelerates prior plans which had a date of 2040. The government will invest around $1.72 billion for electric vehicle charging infrastructure and an additional funding of about $600 million for grants to lower the cost of an EV purchase (CNBC, 2020).

Current bans on the future sale of internal combustion engines have focused on the light-duty vehicle market due to the unsuitability of existing battery-electric technologies for heavy-duty applications such as long-haul trucking, rail freight, and aviation. Vehicle electrification is expected to displace gasoline and, to a lesser extent, diesel fuel, but not other petroleum products such as aviation fuel, bunker fuel, petrochemicals, etc. It is expensive and, in some cases, impossible to convert gasoline blend stock to these other applications, however, and even the comparatively small percentage of gasoline displacement by ethanol that has occurred to date has caused the prices of non-gasoline petroleum products such as asphalt and petrochemicals to increase relative to the price of petroleum (Brown and Brown, 2017).

## 1.4 Environmental Implications

The biobased economy not only presents economic advantages as described above; it also has a positive impact on the environment. The following sections analyze the benefits of biofuels, bioplastics, and biochemicals.

### 1.4.1 Biofuels

The United States revised Renewable Fuel Standard (RFS2) requires participating biofuels to achieve GHG reductions relative to a fossil fuel baseline of at least 20 percent (corn ethanol) and up to 50 percent (cane ethanol; biomass-based diesel) or 60 percent (cellulosic biofuels) (EPA, 2021).

The amount of GHG emissions reductions depend on the technology and the feedstock used. As an example, ethanol produced by first-generation processes (i.e., easily fermented feedstocks and established technology) reduce GHG emissions by 40 percent for corn starch and 69 percent for sugarcane compared to production from petroleum. Ethanol produced by second-generation processes (i.e., conversion of lignocellulose via emergent technologies) provide still greater environmental benefits, with GHG emission reductions being reported from 70 percent to 96 percent using corn stover as feedstock, and 80 percent using sugar cane and cellulosic material as feedstocks (Hannon et al, 2020).

### 1.4.2 Biobased Chemicals

Biochemicals offer reduced environmental impacts compared to their petroleum-derived counterparts. A life cycle study of eight biochemicals (i.e., propylene glycol, 1,3-propanediol, 3-hydroxypropionic acid, acrylic acid, polyethylene, succinic acid, isobutanol, and 1,4-butanediol) concluded that GHG emissions can be reduced by 39 percent to 86 percent from cradle-to-grave relative to conventional chemicals, and that the energy consumption for their production is lower than for traditional chemicals (Adom, F. et al., 2014).

It is also estimated that replacing 20 percent of petroleum-based chemicals with biobased chemicals could result in a 15 to 66 percent reduction of GHG emissions (IEA 2020). The production of biobased chemicals also minimizes chemical waste and the release of toxic byproducts into the environment.

### 1.4.3 Bioplastics

Assessing the GHG emissions reduction associated to bioplastics production is not straightforward since it depends on the manufacturing path, the raw material used, region of production, and the formulation of bioplastics. However, a study by A.D. La Rosa concluded that compared to petroleum-based plastics, PLA, starch blends, PHAs and cellulosic derivates and regenerates have lower GHG impacts than fossil-based plastics and can potentially reduce GHG emission by 50 percent (A.D. La Rosa, 2016). Another study found that conventional plastics required 80-90 megajoules per kilogram of resin (MJ/kg resin) of fossil energy while bioplastics required just 44-60MJ/kg resin of fossil energy for their production (Yu, J. et al., 2008).

# 2. INDUSTRIAL UPDATES

## 2.1. Transportation Fuels

### 2.1.1 Ethanol

The United States is the world's leading ethanol producer, accounting for 55 percent of global ethanol production in 2022, followed by Brazil (26 percent) and the European Union (5 percent). India is the fourth largest producer of ethanol (4 percent of global production) as it moved toward a national E10 standard. (RFA, 2022). Not surprisingly, the United States is also the biggest corn producer in the world, followed by China, the European Union, and Brazil (USDA, 2019).

Ethanol production represents 0.2 percent of the U.S. GDP equal to the contribution of the forestry and fishing industry, or the rail transportation industry (BEA, 2020). The ethanol industry is responsible for nearly 350,000 jobs, both in direct and spillover employment (RFA, 2011-2022).


**Figure 2.1.1**. Ethanol production facilities in 2022 by location, capacity, and type in the United States (in million gallons) (Ethanol Producer Magazine, 2022).

Even though 2018 saw an increase in the number of projected ethanol plants in the United States, by 2021 just five plants were under construction (RFA, 2011-2022). This has kept the number of ethanol plants approximately constant during the last decade. Still, the refinement of the production processes and the optimization of the technologies involved in the production of ethanol have driven the production capacity up 18 percent from 2010 to 2021 (EIA, 2022).

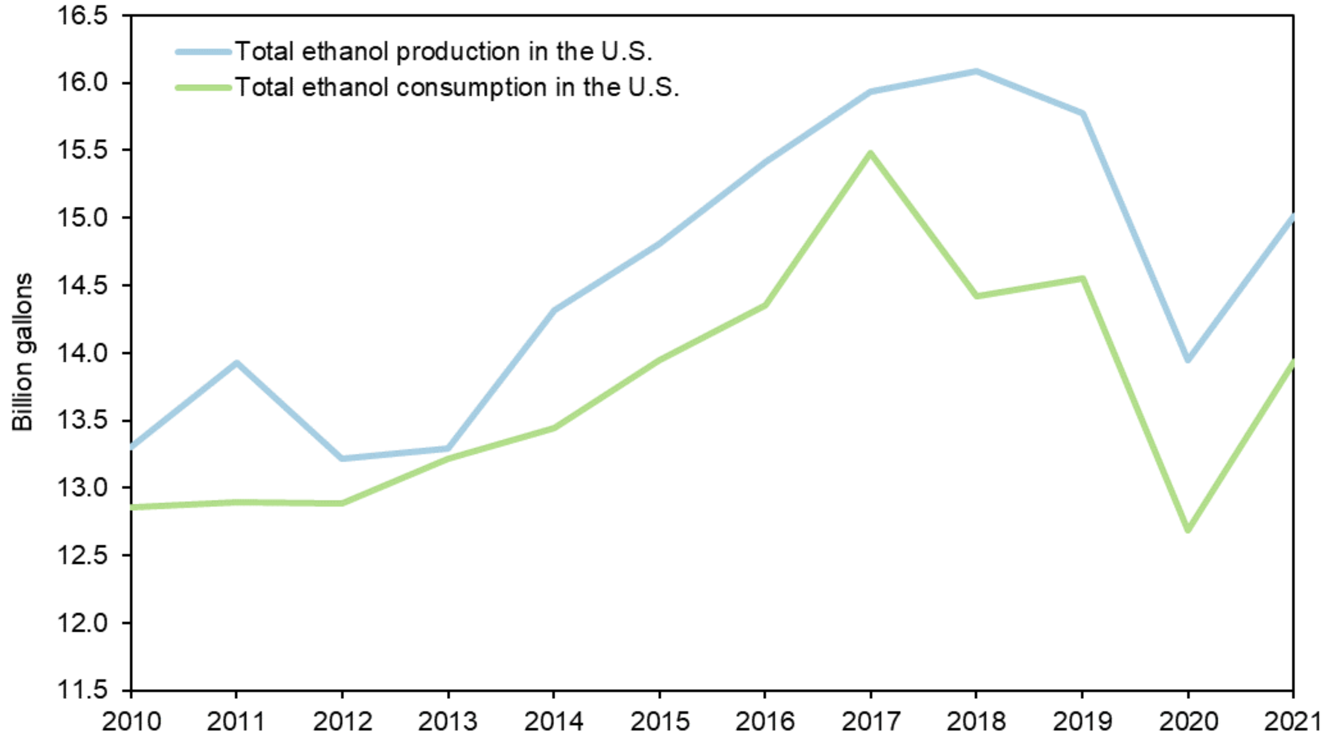


**Figure 2.1.2.** Total ethanol production and consumption in the United States from 2010 to 2021 (in billion gallons) (EIA, 2022).

Consumption of ethanol has also increased during the period of 2010-2021 but at a lower rate than production, effectively rendering the United States a net exporter of ethanol (EIA, 2022). On 2021, the net exports of ethanol were 1.25 billion gallons, a slight decrease from 2020 after years of increase (EIA, 2022). The Covid-19 pandemic and the trade tensions between the United States and China, a major importer of U.S. ethanol, is behind the slight decrease on exports. The current main importer of U.S. ethanol is Canada, followed by South Korea and India. The main domestic consumer of ethanol in the United States is the transportation sector, followed by the industrial sector (EIA, 2022).

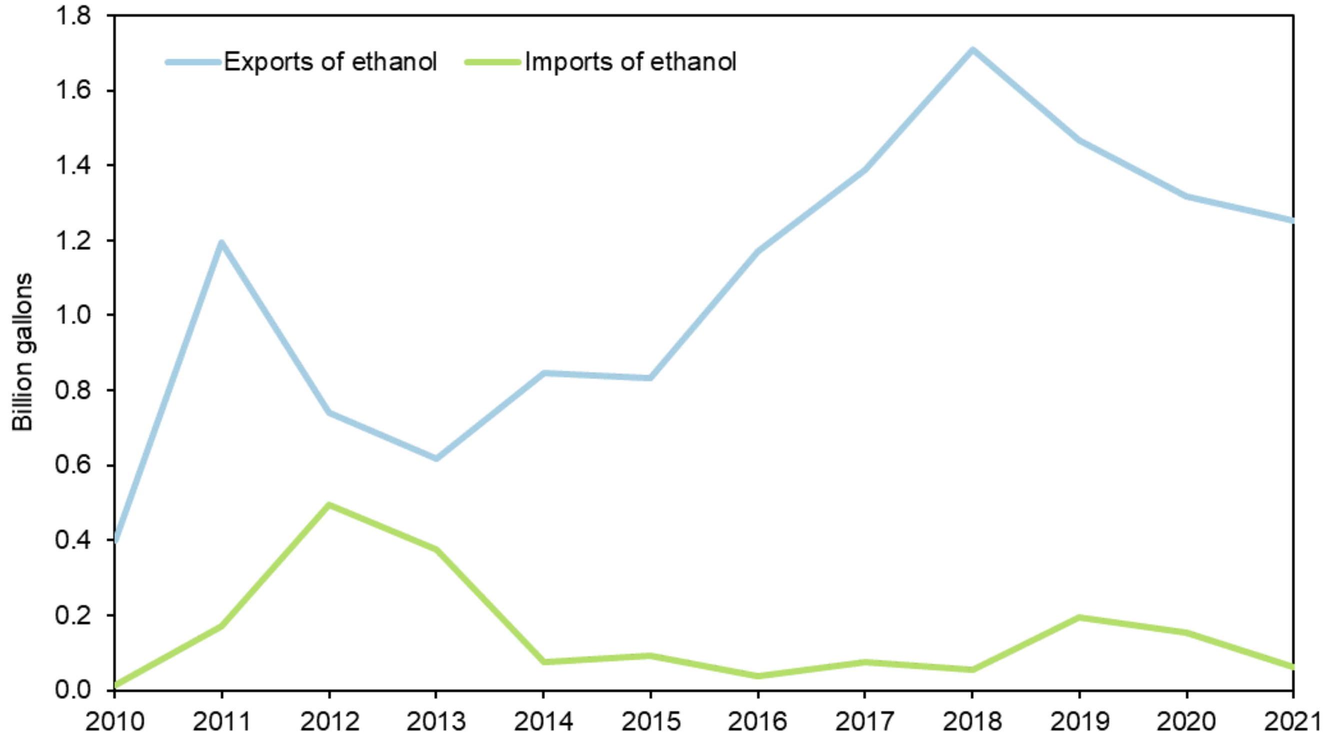


**Figure 2.1.3.** Exports and imports of ethanol in the United States from 2010 to 2021 (in billion gallons) (EIA, 2022).

Some of the drop in exports presented since 2018 was due to both COVID-19 and declining price for Renewable Identification Numbers (RINs, Irwin, S., 2019). RINs are the mechanisms by which U.S. petroleum refiners and product importers comply with the Renewable Fuel Standard (RFS) program administered by the EPA. In 2018, RIN prices experienced a significant drop in their price after the Environmental Protection Agency granted biofuel waivers to oil refiners, exempting them from their obligation to blend ethanol, which increased the prices on fuel blends with high ethanol content like E85 (DOE, 2020).

**2.1.2 Agricultural Biogas - Renewable Natural Gas**

Agricultural crop residues and wastes, manure from dairies and hog farms, sludge filtered from sewage water, municipal solid waste, and food waste can all be used to create renewable natural gas. As organic waste decomposes, it releases a biogas that is 40 percent to 6 percent methane ($CH_4$) which can be captured and refined to remove impurities such as water, $N_2$, $O_2$, $H_2S$, $NH_3$ and $CO_2$ and increase its heat content. The refined biogas, known as renewable natural gas (RNG), is at least 90 percent methane, can be used in place of fossil natural gas (NG) in pipelines, fueling stations, and storage tanks, or as a "drop-in" fuel requiring no engine modifications in NG vehicles.

According to Argonne National Lab (2021) on a lifecycle basis, RNG can reduce GHG emissions by 95percent as compared to diesel and in those instances where biogas would otherwise be released to the atmosphere (e.g., open lagoons), RNG can have a net-negative carbon impact. According to the US EPAs AgSTAR (2023) database as of January 2023, there are 343 manure-based anaerobic digestion systems reducing methane emissions by collecting biogas from the degradation of animal manure. In 2022, manure-based anaerobic digesters reduced greenhouse gas emissions by 10.43 million metric tons of carbon dioxide equivalent ($MMTCO_2$-eq).

Federal and State programs for renewable fuels have provided incentives for projects to convert agriculture biogas into RNG including the Renewable Fuels Standard (RFS) as well as California's and Oregon's Low-Carbon Fuel Standard (LCFS) incentive programs. In the United States, there are more than 2,300 sites producing biogas in all 50 States: 475 anaerobic digesters on farms, 1,269 water resource recovery facilities using an anaerobic digester, 97 stand-alone systems that digest food waste, and 549 landfill gas projects (American Biogas Council, 2023; Ohionline, 2014; U.S. EPA, 2023).

### 2.1.3 Biobutanol

Biobutanol is a second-generation fuel produced from the same feedstocks as ethanol. It is chemically identical to butanol produced from petroleum or natural gas feedstocks. Biobutanol is currently 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 (Biobutanol, 2020).

As an emerging biofuel, biobutanol production and commercialization is not common, while its production and use could increase significantly given the advantages of biobutanol over ethanol (Biobutanol, 2020). The biggest challenge for the biobutanol industry is that corn is the main feedstock for both ethanol and biobutanol production, and more ethanol than biobutanol can be produced from a bushel of corn (DOE, 2020; Wu M. et al., 2007). Nonetheless, biobutanol presents several advantages over ethanol, such as an almost 20 percent higher energy content, better resistance to water absorption, and the better water tolerance of butanol blends (Biobutanol, 2020; Alavijeh. M.K. et al., 2019).

Reflecting such advantages, as of June 2018, the EPA approved biobutanol blends with gasoline of up to 16 percent of biobutanol content (Federal Register, 2018). These blends are already being sold in the United States with contents of up to 12.5 percent biobutanol (DOE, 2020).

The first biobutanol plants were built by retrofitting existing ethanol fermentation plants (DOE, 2020). Two companies are currently manufacturing biobutanol, 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 (DOE, 2020).

Since 2013, the production of biobutanol for fuel has been very small and intermittent in the United States. 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, none from 2017 to 2019, and 440 gallons in 2020 (see Figure 2.1.4) (EPA, 2022).

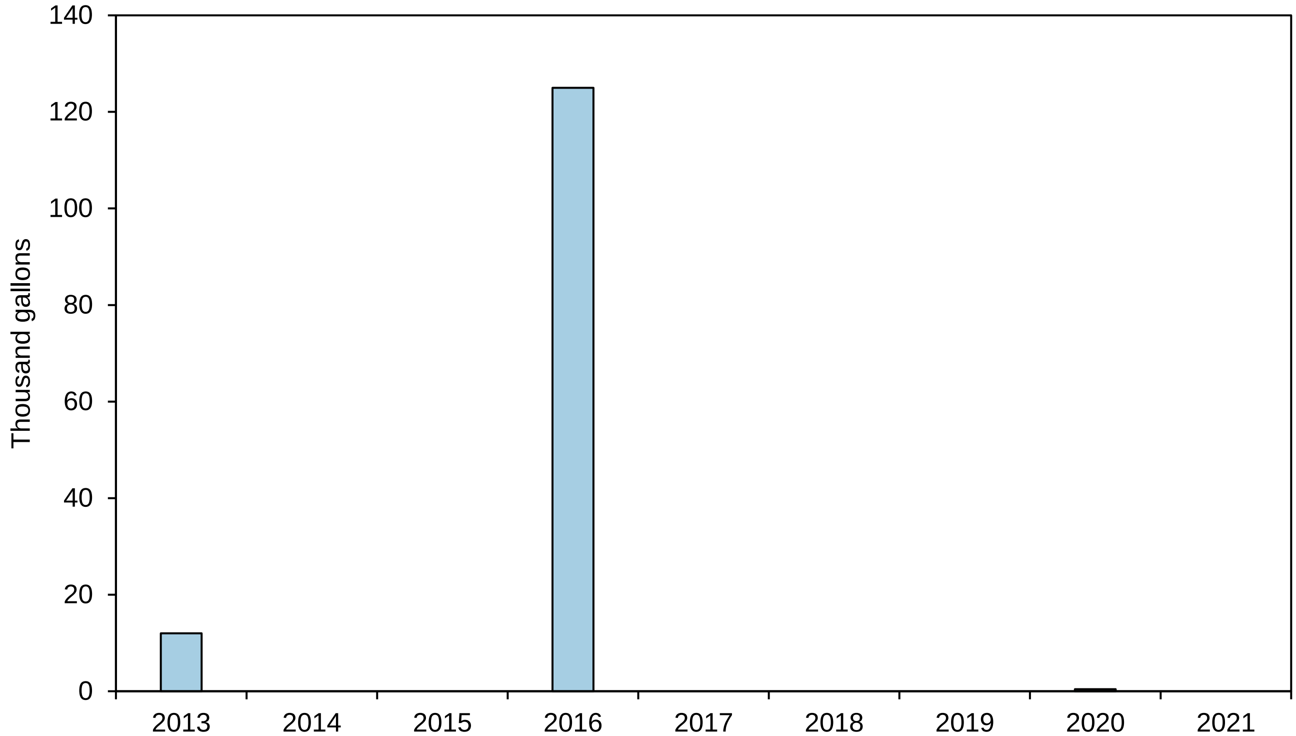


**Figure 2.1.4** Production of biobutanol that entered the market from 2013 to 2021 in the United States (in thousand gallons) (EPA, 2022).

Despite its low production, the potential of biobutanol production in 2020 is estimated to be 2.7 billion gallons, which is equivalent to about16 percent of total domestic gasoline consumption in 2020 (Alavijeh. M.K. et al., 2019; EIA, 2022; USDA, 2022).

Biobutanol can also be produced from cellulosic feedstock such as corn stover. Considering the amount of corn residues available, the Midwest has about 88 percent of total biobutanol production potential, with Iowa (436 million gallons), Illinois (412 million gallons), Nebraska (342 million gallons), Minnesota (277 million gallons), and Indiana (190 million gallons) as the top five States with highest production potential (Alavijeh. M.K. et al., 2019; USDA, 2022). The top five States' percentages of the total biobutanol production potential are 16.5 percent for Iowa, 15.6 percent for Illinois, 12.9 percent for Nebraska, 10.5 percent for Minnesota, and 7.2 percent for Indiana (Alavijeh. M.K. et al., 2019; USDA, 2022).

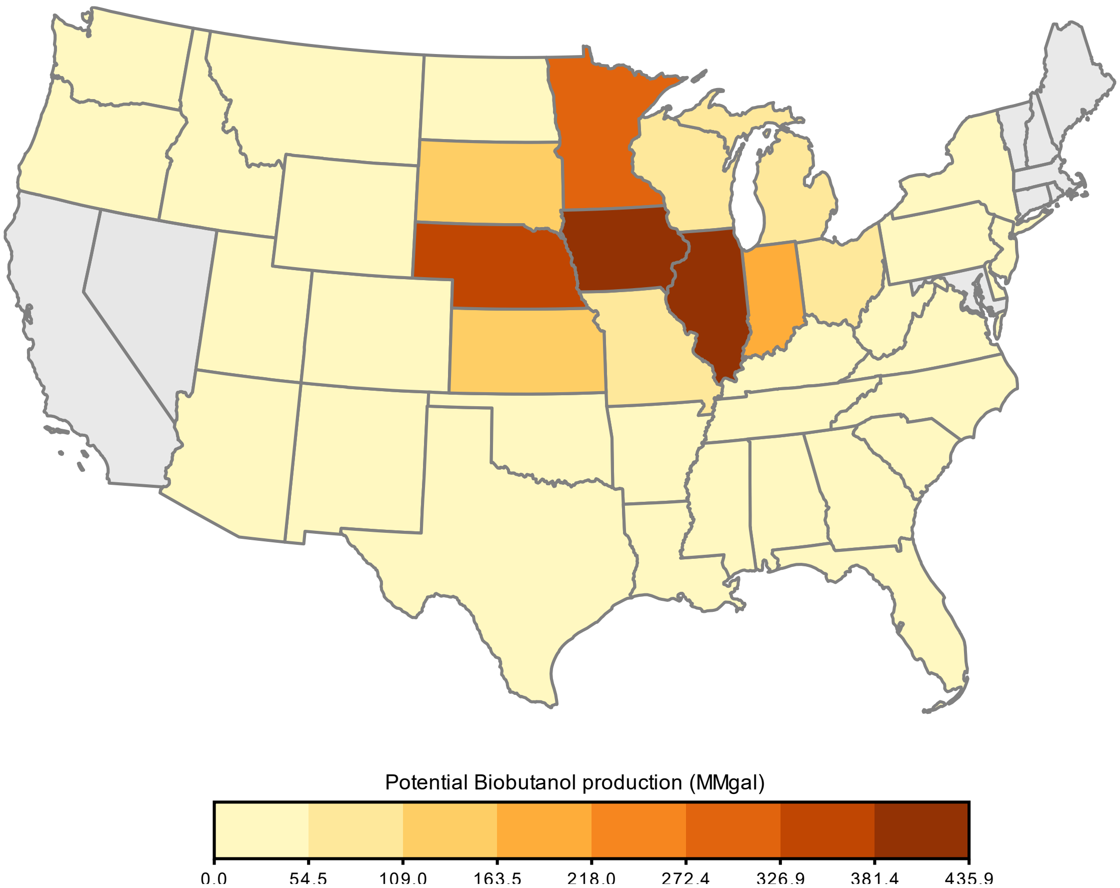


**Figure 2.1.5.** Biobutanol production potential in the United States (in million gallons) (Alavijeh. M.K. et al., 2019; USDA, 2022).

### 2.1.4 Biodiesel

Biodiesel is a biomass-based diesel fuel produced using vegetable oil or animal fats through a process known as transesterification. The most common feedstocks for biodiesel production are soybean oil (57 percent), corn oil (14 percent), recycled greases (11 percent), canola oil (10 percent), and raw animal fats (8 percent). Unlike petroleum-based diesel, or petrodiesel, biodiesel is nontoxic and biodegradable (RFA, 2020; EIA, 2020).

Biodiesel can be found in blends with petrodiesel, with composition ranging from 2 percent (B2) to 100 percent (B100). The most common blends are B5 and B20. As long as the biodiesel blend meets or exceeds the ASTM D6751 standard, it can be used in any diesel engine without special modifications. All engine manufacturers approve the use of B5 blends in their engines, with most also approving the use of B20 blends. For that reason, blends up to 5 percent in biodiesel content do not require a special label at retail pump stations (RFA, 2020).

Because of its composition, biodiesel is cleaner in terms of exhaust emissions than petrodiesel. B20 soybean-based blends, for example, emit 20 percent less carbon dioxide to the atmosphere. Hydrocarbons emissions are also reduced by 20 percent when using that blend, and carbon monoxide and particulate matter emissions are 10 percent lower when compared to petrodiesel emissions. However, nitrogen oxide emissions increase 3 percent when using B20. The reductions are even higher when using pure biodiesel (B100), reaching a reduction of 70 percent in carbon dioxide and hydrocarbon emissions and 50 percent in carbon monoxide and particulate matter compared to petrodiesel (DOE, 2011).

The number of biodiesel production facilities decreased from 91 plants in 2020 to 75 plants in 2021 (EIA, 2022). This led to a reduction in the production of biodiesel of 6 percent (106 million gallons) compared to 2020 (EIA, 2022). Consequently, the consumption of biodiesel dropped by 12 percent (EIA, 2022), which caused the loss of 7,000 direct jobs (Irena, 2022). However, the number of B20 and B100 biodiesel fueling stations increased 2.5 percent between 2020 and 2021 (USDA, 2022).

Despite the reduction of biodiesel production, 14 new renewable diesel plants were under construction in 2021. These new plants have a projected total production capacity of 2.8 billion gallons. Three of these new facilities will be in California, with two more being constructed in Texas. California together with Texas and Louisiana are the three States with a higher concentration of crude oil refineries. Given that soybean and corn are materials that are easier, cheaper, and safer to transport than petrodiesel, it is not uncommon for biodiesel production facilities to be placed close to crude oil refineries and/or fuel blenders. This strategy is partially confirmed by the fact that Texas, the State with the largest number of crude oil refineries, is the second State with the highest number of biodiesel plants (EIA, 2022).

Missouri and Texas are second only to Iowa in number of biodiesel facilities, with Iowa being the largest corn producer and the second largest soybean producer in the United States. Iowa, Missouri, and Texas account for 32 percent of total plants in the United States and 43 percent of total U.S. biodiesel production capacity. The fourth State in terms of number of biodiesel facilities is California. Illinois ranks fifth in number of current biodiesel plants (EIA, 2022).

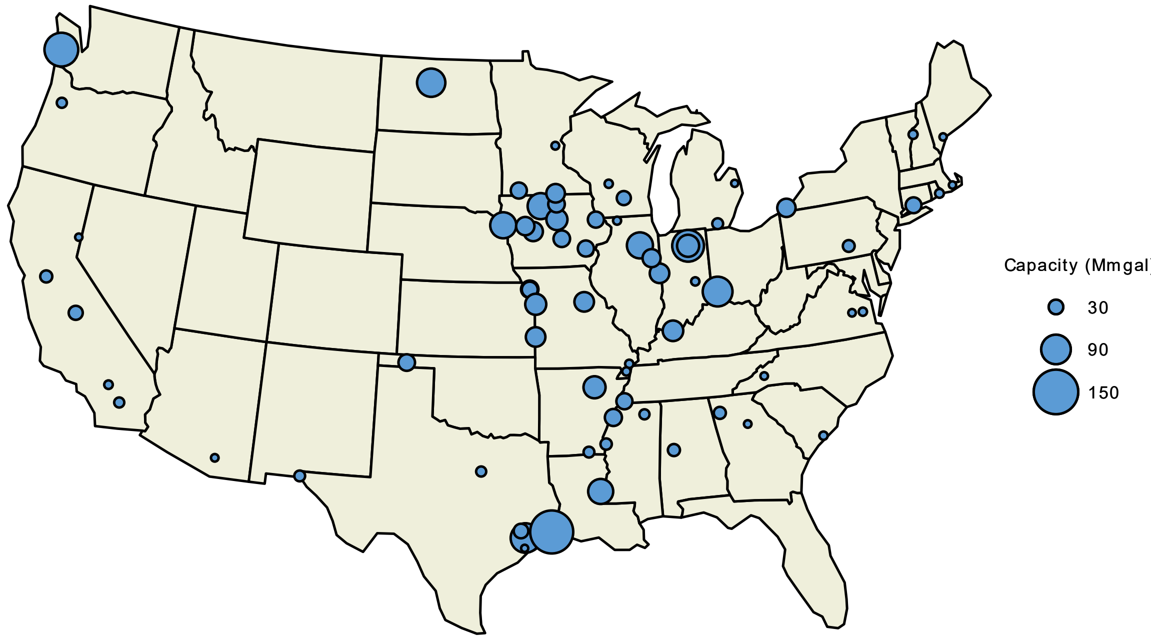


**Figure 2.1.6.** Biodiesel production facilities location by capacity (in million gallons) in the United States in 2021 (EIA, 2022).

Net exports of biodiesel were low during 2021. In 2021, production of biodiesel closely matched consumption resulting in a net export amount of 63 million gallons (EIA, 2022). Production of biodiesel has stayed at the 2018 levels, with a little fluctuation. In late December 2019, the biodiesel tax credit (BTC) incentives were extended retroactively through 2022, which is expected to impact consumption and production of biodiesel and renewable diesel (EIA, 2020).

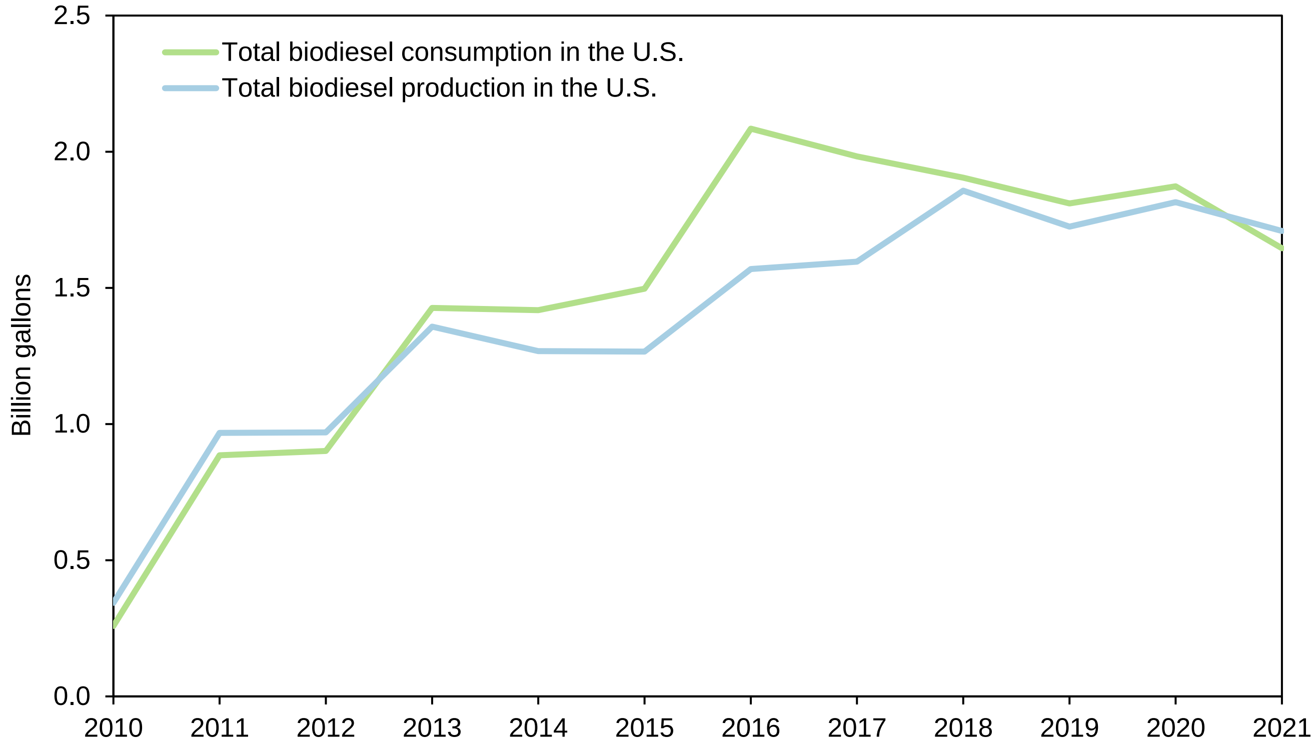


**Figure 2.1.7.** Total biodiesel production and total biodiesel consumption in the United States from 2010 to 2021 (in billion gallons) (EIA, 2022).

Compared to 2020, total exports of biodiesel increased 26 percent in 2021, for a total amount of 182 million gallons of biodiesel exported. Canada was the destination of 76 percent of total biodiesel exports. Imports increased 3 percent between 2020 and 2021, reaching 203 million gallons of biodiesel. Canada and Germany were the source of 74 percent of all the biodiesel imported in 2021 (EIA, 2020).

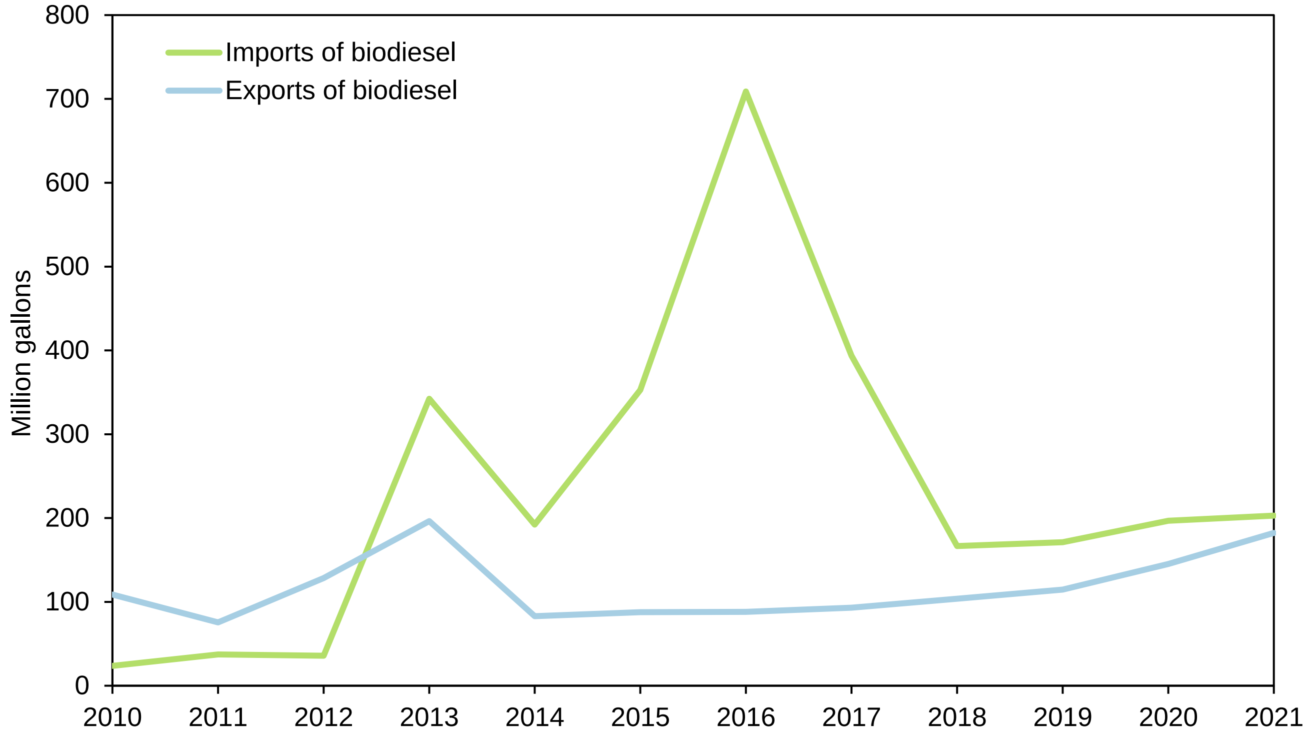


**Figure 2.1.8.** Exports and Imports of biodiesel in the United States from 2010 to 2021 (in billion gallons) (EIA, 2022).

As presented in figure 2.1.8, U.S. imports of biomass-based diesel, which include biodiesel and renewable diesel, grew 3 percent in 2021 to more than 200 million gallons, increasing for the third consecutive year. Imports of biodiesel increased in 2021 because of growing demand to meet government renewable fuel programs. U.S. consumption of biomass-based diesel, unlike demand for other fuels, remained relatively unaffected by responses to COVID-19 during 2021 (U.S. EIA, 2021).

The price of B99/100, B20 and petrodiesel increased 3, 17, and 19 percent in 2021 in comparison with 2020. This parallels the trend in soybean oil prices, one of the main feedstocks for biodiesel production (DOE, 2022) (USDA, 2022).

### 2.1.5 Animal Fats and Recycled Greases

Animal fats and recycled greases can be classified by free fatty acids (FFA) content (Advanced Biofuels USA, 2015; Universal Green Commodities, 2020; Biodiesel Magazine, 2011; Farm Energy, 2019):

- White grease: less than 4 percent FFA. Examples include pork fat, lard, edible or inedible tallow, and some poultry fat.
- Yellow grease: between 4 percent and 15 percent FFA. Obtained mainly from spent cooking oil. Contains low-quality animal fats such as tallow, poultry, or lard.
- Brown grease: over 15 percent FFA. Sometimes also referred to as trap grease, it is a low-quality grease comprised of a heterogeneous mixture of compounds. It can be obtained from grease traps

located at commercial food service operations and domestic septic systems. It requires additional processing to produce biodiesel.

Yellow and white grease are the main sources for biodiesel production, accounting for 80 percent of total feedstocks. According to the U.S. EPA's Renewable Fuel Standards Program Regulatory Impact, if animal fats and recycled greases are used, the greenhouse gases can be reduced by 86 percent in comparison with petrodiesel (EPA, 2002).

The production and collection of animal fats and recycled greases in the United States has remained constant over the last 10 years, with a slight increase of 1 percent since 2020. The largest increase in grease production and collection was in tallow production, which was up by 10 percent with respect to the previous year. Yellow and white greases production remained constant, with a slight decrease of 5 percent in white grease production, from 2020 (The International Magazine of Rendering, 2017-2022). In 2021, 1,535 million metric tons of yellow grease, 0.6 million metric tons of tallow and 0.3 million metric tons of white grease were used as a feedstock for biofuels production. Note that in this case biofuels include fuel ethanol, biodiesel, renewable diesel, renewable heating oil, renewable jet fuel, renewable naphtha, renewable gasoline, biobutanol, and "other" biofuels and bio-intermediates (EIA, 2022).

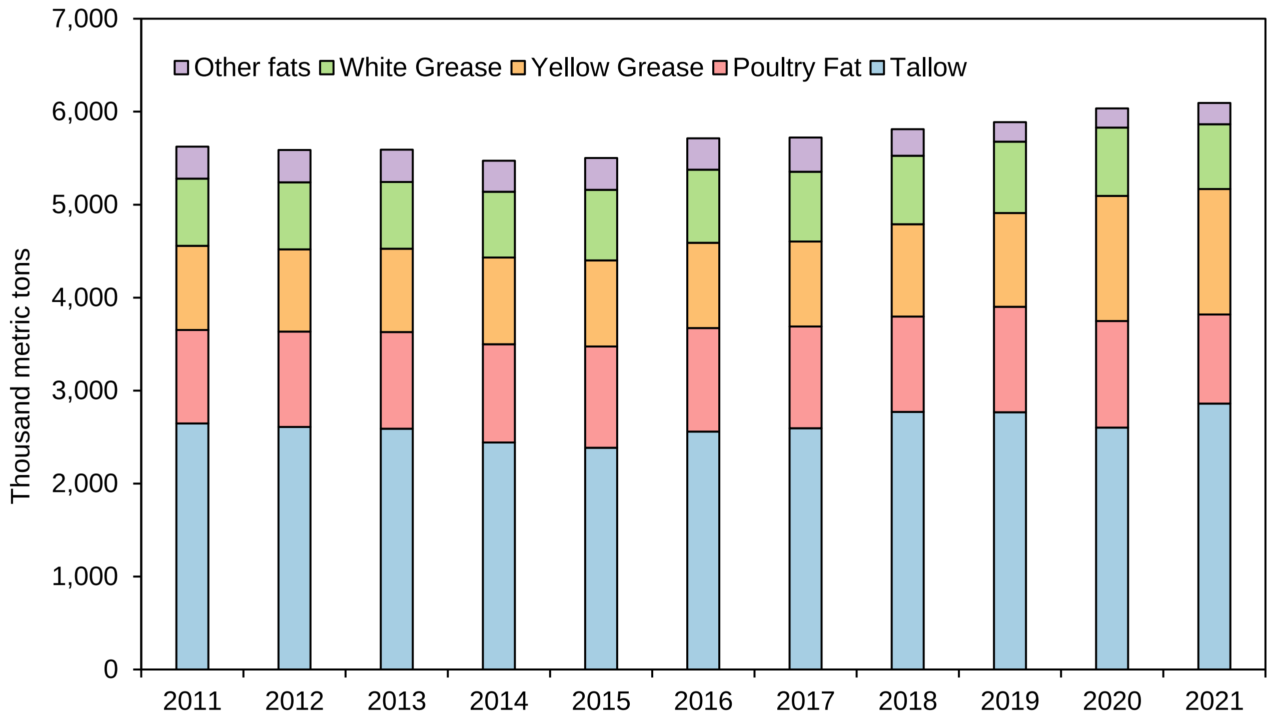


**Figure 2.1.9.** Total production of animal fats and recycled greases by type in the United States from 2011 to 2021 (in thousand metric tons) (The International Magazine of Rendering, 2022)

The consumption of animal fats and recycled greases for biofuels production increased by 158 percent from 2020 to 2021. Note that 2020 data and previous years only captured consumption for biodiesel production and from 2021 on the data includes consumption for fuel ethanol, biodiesel, renewable diesel, renewable heating oil, renewable jet fuel, renewable naphtha, renewable gasoline, biobutanol, and "other" biofuels and bio-intermediates, which explains the difference between the 2 years (EIA, 2022).

Exports of animal fats and recycled greases remained nearly constant between 2020 and 2021, reaching 1,2 million metric tons in 2021. While exports of poultry fat, tallow and yellow grease were reduced by 11, 25, and 1 percent respectively from 2020, white grease exports increased by 240 percent reaching 82,000 metric tons in 2021. Singapore was the top destination for the American yellow grease in 2021, while Mexico continued to be the top importer of American tallow. The total net exports in 2020 amounted to 668,000 metric tons of animal fats and recycled greases (The International Magazine of Rendering, 2017-2022).

The amount of fats and recycled greases imported to the United States is low; however, it follows a positive trend with an increase of 41 percent from 2020 to 2021. Tallow (333.000 metric tons) and yellow grease (130,000 metric tons) are the main fats imported to the United States. Imports of poultry fat decreased 38 percent in 2021 (The International Magazine of Rendering, 2017-2022).

In 2021, the price of animal fats and recycled greases increased considerable in comparison with 2020. Poultry fat ($1,038 per metric ton), tallow ($1,444 per metric ton), white grease ($1,066 per metric ton) and yellow grease ($893 per metric ton) increased their price by 80-100 percent during the last year (The International Magazine of Rendering, 2017-2022).

### 2.1.6 Renewable Diesel

Renewable diesel or green diesel is another type of biomass-based diesel fuel. It can be obtained from natural fats such as vegetable oils, animal fats, and greases and from cellulosic biomass such as crop residues, wood and sawdust, and switchgrass. Unlike biodiesel, renewable diesel is not obtained through transesterification but through various thermochemical processes such as hydrotreating, gasification, and pyrolysis. This makes renewable diesel chemically identical to petrodiesel, and thus meets ASTM D975 specification for petroleum diesel. For this reason, it can be used in existing petrodiesel transportation and storage networks and diesel engines without the need for blending or special modifications. For this reason, it is considered a “drop-in” biofuel. Although it does not require blending with petroleum diesel for its use, it can also be blended with petrodiesel, the most common blends being R5 (5 percent renewable diesel and 95 percent of petroleum diesel) and R20 (20 percent renewable diesel and 80 percent petroleum diesel). In the same way as biodiesel, blinds with a renewable diesel content above 5 percent must be labeled at the pump in retail fueling stations (Government fleet, 2016; DOE, 2020).

Besides the chemical indistinguishability from petrodiesel, other benefits of renewable diesel include:

- Low sulfur content, in the same range or below ultra-low sulfur diesel (ULSD).
- No aromatic compounds, which are toxic and/or carcinogenic.
- Variable cetane number, depending on the production process cetane number can be varied to meet market and regulation requirements.
- No oxygen content, which eliminates biodiesel challenges regarding freezing temperatures and storage.
- Variable cloud point, depending on the production process, which opens the possibility to obtain renewable jet fuel in addition to or instead of renewable diesel.

- By-products obtained in the production of renewable biofuel include naphtha, renewable jet fuel and fuel gas.

Due to its characteristics, renewable diesel meets the requirements of the California Air Resources Board (CARB) and is considered compliant with the strict regulations for diesel fuel in that State. It is also classified as an ultra-low sulfur diesel (ULSD). As it can be obtained from non-edible biomass, renewable diesel is a second-generation biofuel or advanced biofuel (California Environmental Protection Agency, 2020).

Renewable diesel can reduce particulate matter (PM) emissions up to 30 percent, nitrogen oxides ($NO_X$) and carbon monoxide (CO) up to 10 percent, and hydrocarbon (HC) emissions up to 5 percent. Volatile organic compounds (VOCs) and polycyclic aromatic hydrocarbons (PAHs) emissions for renewable diesel are also lower than for petrodiesel. Life Cycle Assessment (LCA) analysis show that greenhouse gas (GHG) emissions for renewable diesel are between 15 to 80 percent lower than for petrodiesel, depending on feedstock source (California Environmental Protection Agency, 2020).

In 2021, there were six renewable diesel production facilities with a combined capacity of 791 million gallons per year. Renewable diesel industry is expected to grow with the resurgence of the economy (EIA, 2022).

Renewable diesel production and consumption have grown continuously since 2010, with an extraordinary increase in 2021 of 58 and 39 percent, respectively, from 2020. Despite the large increase in production, consumption of renewable diesel continues to be higher than production (EPA, 2020). This imbalance in production-consumption has been satisfied with imports. The U.S. imports renewable diesel exclusively from Singapore (99.8 percent) and Netherlands (0.2 percent). In 2021, imports of renewable diesel were 40 percent higher than in 2020. All renewable diesel imports have entered the United States in California, as renewable diesel has one of the lowest carbon intensities of the approved pathways for California’s Low Carbon Fuel Standard (LCFS) compliance. According to the U.S. Energy Information Administration, the United States does not export renewable diesel (EIA, 2022).

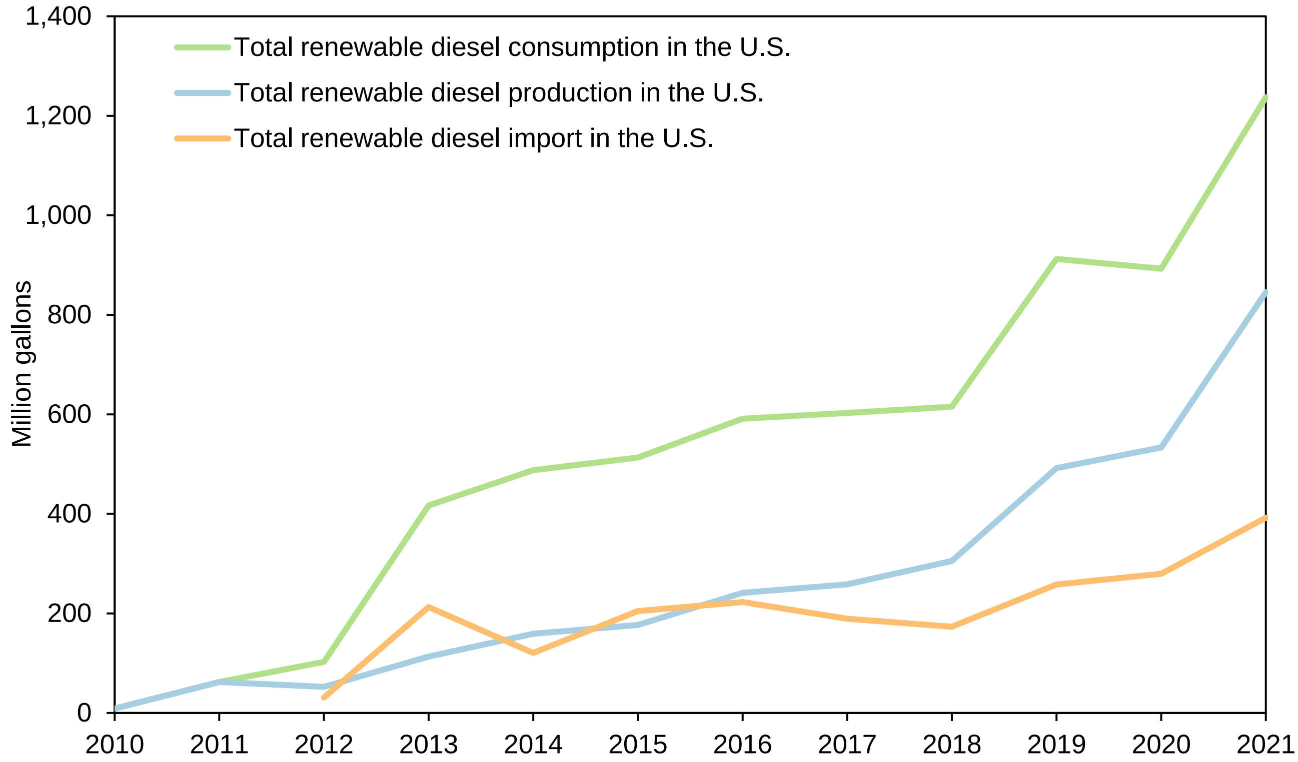


**Figure 2.1.10.** Renewable diesel production, consumption, and imports in the United States from 2011 to 2021 (in million gallons) (EPA, 2022; EIA, 2022).

### 2.1.7 Sustainable Aviation Fuels

Renewable jet fuel or sustainable aviation fuel (SAF) is jet fuel produced from renewable feedstocks such as virgin and waste oils, agriculture residues or municipal solid waste (AFDC, 2023).

Renewable jet fuel has several advantages over traditional jet fuel. According to the United States Department of Energy, greenhouse gas emissions can be reduced up to 94 percent, depending on feedstock and pathway, when renewable jet fuel is used. Also, because it has a higher energy density, the fuel consumption is lower in comparison with traditional jet fuel. Finally, renewable jet fuel allows for more flexibility, since it is a replacement for conventional jet fuel that can be produced using multiple feedstocks and production technologies. (AFDC, 2023).

Like other emerging fuels, the main disadvantages of renewable jet fuel are related to production costs and logistics. Total demand for jet fuel cannot be met with renewable jet fuel since its production is very small and jet fuel market is large and growing. Also, transportation costs are higher since renewable jet fuel production facilities are located close to their feedstocks and away from airports and pipelines. Finally, the cost of producing renewable jet fuel is, on average, more than two times higher ($4.10/gallon) than the cost of producing conventional jet fuel ($1.80/gallon). (DOE, 2023).

The aviation industry has set 3 global goals to address its impact to the climate: improve efficiency by 1.5 percent from 2009 to 2020; stabilize net $CO_2$ emissions at 2020 levels with carbon-neutral growth; and reduce carbon emissions to below 50 percent of 2005 levels by 2050 (IATA, 2020). Blending renewable jet fuel with petrojet fuel will be essential to meet these goals, since almost all of airline emissions are related to the combustion of jet fuel (Aviation Benefits, 2023).

In 2021 and 2022, the European Union and the United States issued different regulations aiming to meet the decarbonization goals of the aviation sector (IATA, 2023; Sustainalytics, 2023).

- **ReFuelEU Aviation:** In July 2021, the European Commission published a package of legislative proposals branded “Fit for 55”. One component of the package is the ReFuelEU proposal which aims to increase production and use of renewable jet fuel. The mandate is expected to start in 2025 with a minimum volume of sustainable aviation fuel at 2percent, increasing in 5-year intervals to ultimately reach a minimum volume of 63percent in 2050, of which 28percent would consist of synthetic aviation fuels.
- **The U.S. Sustainable Skies Act**: The U.S. Congress introduced the Sustainable Skies Act in May 2021, aiming to increase incentives to use sustainable aviation fuel. The credit will start at $1.50 per gallon for blenders that supply sustainable aviation fuel with a demonstrated 50 percent or greater lifecycle GHG savings and rewards higher GHG achievement up to the maximum of $2 per gallon. A complimentary proposal also includes $1 billion in grants over 5 years to expand the number of sustainable aviation fuel producing facilities in the United States.
- **Sustainable Aviation Fuel Tax Credit**: In September 2021, U.S. President Joe Biden proposed a Sustainable Aviation Fuel (SAF) tax credit to help cut costs and increase sustainable aviation fuel

production in the United States. Furthermore, the government will offer up to $4.3 billion in funding opportunities to support SAF projects. This was followed by the announcement in November 2021 of the Aviation Climate Action Plan, which aims to achieve net zero GHG emissions from the U.S. aviation sector by 2050. To meet this target, the production of sustainable aviation fuel will need to increase at least 3 billion gallons per year by 2030.

- **Inflation Reduction Act**: Effective in August 2022, includes $297 million for the Sustainable Aviation Fuel and Low-Emissions Aviation Technology Grant Program.

Since 2016, over 45 airlines have flown using a blend of renewable and traditional jet fuel for more than 490,000 commercial flights in 2023, a significant increase in comparison with 500 flights in 2016 (IATA, 2023). However, in 2021, renewable jet fuel shared less than 0.1 of the world's commercial aviation fuel consumption of 60 billion gallons (IEA, 2021; IATA, 2022).

The ASTM International, the international standards organization that establishes jet fuel specification requirements, has approved nine renewable jet fuel production pathways (Table 2.6.1) and eight other conversion processes are under evaluation as of April 2023. Renewable jet fuel must be drop-in, which means that it can be used in a blend with conventional jet fuel without the need for modifications to the aircraft or its engine. ASTM standards are continuously updated to allow for advancements in technology to produce renewable jet fuel (ICAO, 2023).

| **Production Process** | **Feedstock** | **Blending Limit** |
|---|---|---|
| Fischer-Tropsch Synthetic Paraffinic Kerosene (FT) | Biomass (forestry residues, grasses, municipal solid waste) | Up to 50% |
| Hydroprocessed Esters and Fatty Acids Synthetic Paraffinic Kerosene (HEFA) | Oil-bearing biomass (e.g. algae, jatropha, camelina, carinata) | Up to 50% |
| Hydroprocessed Fermented Sugars to Synthetic Isoparaffins (SIP) | Microbial conversion of sugars to hydrocarbon | Up to 10% |
| FT-SPK with aromatics (FT-SPK) | Renewable biomass (municipal solid waste, agricultural waste, forestry residues, wood and energy crops) | Up to 50% |
| Alcohol-to-jet Synthetic Paraffinic Kerosene (ATJ-SPK) | Agricultural wastes products (stover, grasses, forestry slash, crop straws) | Up to 30% |
| Catalytic Hydrothermolysis Synthesized Kerosene (CH) | Fatty acids or fatty acid esters or lipids from fat oil greases | Up to 50% |
| Hydrocarbon-Hydroprocessed Esters and Fatty Acids (HC-HEFA-SPK) | Algal oil | Up to 10% |
| Fats, Oils, and Greases (FOG) Co-Processing (co-processed HEFA) | Fats, oils, and greases | Up to 5% |
| FT Co-Processing (co-processed FT) | FT biocrude | Up to 5% |

**Table 2.1.1.** Approved renewable jet fuel production pathways (ICAO, 2023).

The EPA reported that 5.1 million gallons of renewable jet fuel entered the market in 2021, which represents more than a 10-percent increase from 2020 (see Figure 2.1.11) (EPA, 2022).

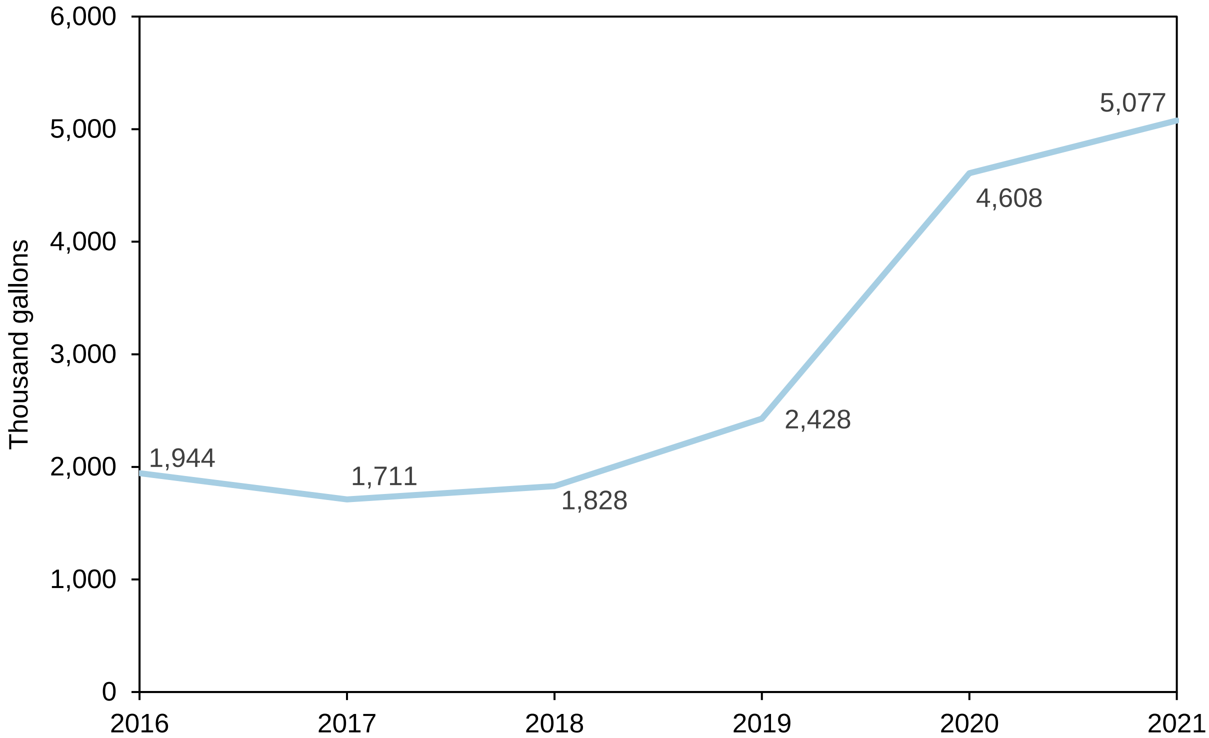


**Figure 2.1.11** Production of renewable jet fuel from 2016 to 2021 in the United States (in thousand gallons) (EPA, 2022).

## 2.2. Primary Energy

### 2.2.1 Wood Pellets

Wood pellets are a bioenergy source derived from various wood feedstocks, including tops and limbs, commercial thinning, and sawmill residues (Golden J.S. & Morrison B., 2017). Raw materials are first milled and then compressed into a cylindrical shape to increase the energy output and the global efficiency of their combustion. Wood pellets can be used for both electricity generation and heating. With a heat of combustion slightly lower than coal (20 MJ/Kg), they present the advantage of being carbon neutral when wood feedstock is harvested under sustainable forestry practices.

In 2021, the number of wood pellet production facilities decreased to 116 plants, making an all-time low. Despite the decrease, three new plants were proposed and four were already under construction, with an additional capacity of 113,800 metric tons of wood pellets per year. The biggest production facilities are located in the southeastern area of the United States, which concentrates 74 percent of the Nation’s wood pellet production capacity. Most of these facilities use softwood and/or hardwood as primary feedstock (Biomass Magazine, 2013-2022).

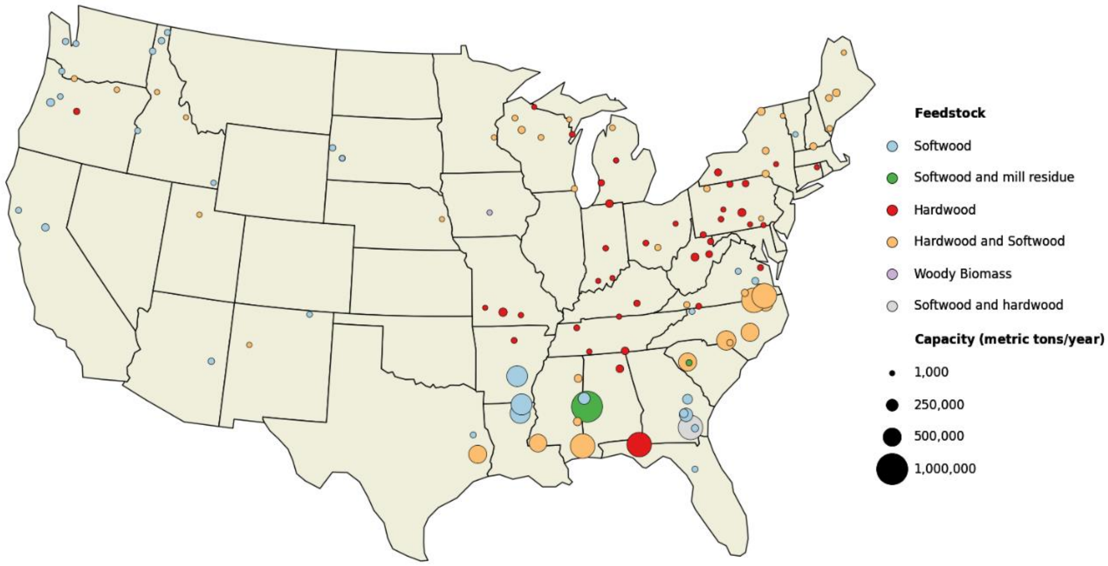


**Figure 2.2.1.** Wood pellet production facilities in the United States in 2020, sized according to their capacity (in thousand metric tons) and colored by feedstock (Biomass Magazine, 2022).

The United States is both the world's leading producer of wood pellets and the world's leading exporter, accounting for 19 percent of total worldwide production in 2022. The production of wood pellets in the United States stayed constant from 2019 to 2020 reaching 8.4 million metric tons (FAOSTAT, 2022).

Consumption of wood pellets in the United States is significantly lower than production, and it remained nearly constant at 0.2 million metric tons per year since 2014 (FAOSTAT, 2022). In the United States, wood pellets are primarily used for heating, where 94 percent of total energy consumption from wood was used for heating and just 6 percent was used for electricity generation in 2020. Consumption of wood pellets for heating has remained constant in the last decade at around 2,000 trillion BTUs (although the domestically consumed ratio varies with winter temperatures and growth in exports). By sectors, 66 percent of total energy consumed from wood in 2020 was consumed by the industrial sector, followed by the residential sector (21 percent), the electric power sector (9 percent), and finally the commercial sector (4 percent) (EIA, 2022).

Exports of wood pellets reached a peak in 2020, with 7.3 million metric tons being exported (Figure 2.2.2). The United Kingdom is the largest importer of U.S. wood pellets, importing 72 percent of total U.S. wood pellet in 2021. Netherlands is the second largest importer with 16 percent of total U.S. exports going to that country (UN Comtrade, 2022).

Although domestically wood pellets are primarily used for heating, wood pellets exported are used for electricity generation (EIA, 2015). One of the drivers was the European Commission's 2020 climate and energy plan. The plan sets three key targets for year 2020: 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 (European Commission, 2020). Countries such as the United Kingdom planned to achieve the target by using wood pellets in cofiring (combustion of two different fuels) or by dedicated biomass power plants.

The Drax power station, located east of Leeds (United Kingdom) and with a generation capacity of 3,906 MW, is one of the largest facilities to switch its feedstock from coal to wood pellets, achieving a 75-percent power output through biomass. Nearly 60 percent of Drax's biomass feedstock mix came from the United States. The Drax power station consumes 97 percent of total United States' wood pellet exports to the United Kingdom (Engineering and Technology, 2018; Drax, 2020).

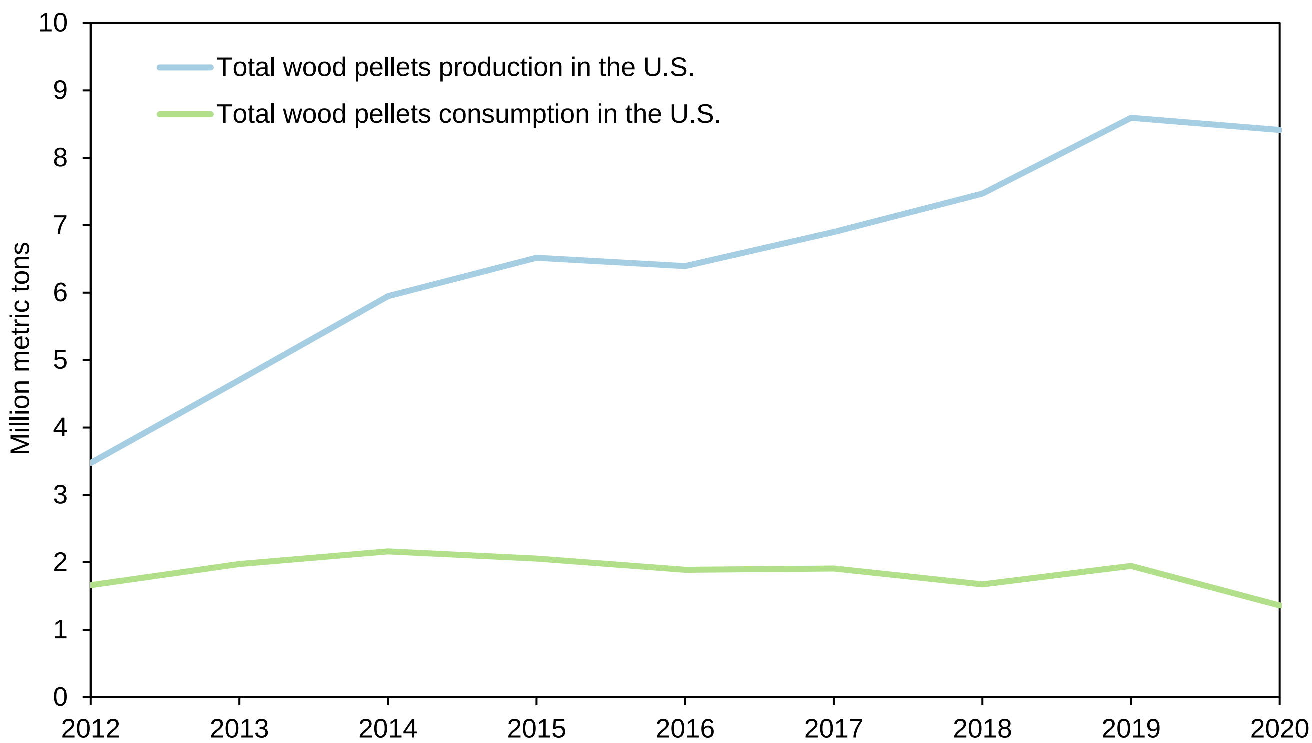


**Figure 2.2.2.** Total wood pellet production versus total wood pellet consumption in the United States from 2012 to 2020 (in million metric tons) (FAOSTAT, 2022).

Imports of wood pellets are significantly lower than exports and they have remained constant at 200,000 metric tons per year since 2013. In 2020, 99.6 percent of those imports were provided by Canada (UN Comtrade, 2022).

The number of direct jobs in the economic sector that includes the wood pellet industry has remained approximately constant in 2019, with a slight decrease of 2 percent in 2020. These small changes are probably driven by the other industries included in the economic sector (U.S. BLS, 2022).

### 2.2.2 Waste-to-Energy

Waste-to-energy is the production of energy from municipal solid waste (MSW). Waste, that would otherwise be sent to landfills, is burned in waste-to-energy plants to generate electricity. Around 85 percent of all MSW can be burned in waste-to-energy plants to produce electricity, with 63 percent of that waste being biomass. Besides the benefits of generating electricity from waste, it also reduces the volume of waste in landfills. Through waste-to-energy plants, the volume of waste can be reduced by up to 87 percent. This is especially beneficial in urban areas with high population densities and little space for landfills (EIA, 2020).

The total number of waste-to-energy facilities that incinerate MSW for energy recovery in the United States increased in 2021 to 98 plants. Most of these facilities are located in two geographic clusters: the first cluster is in Florida, where there are 13 waste-to-energy plants. The second cluster is in the northeastern part of the United States with 30 plants (EIA, 2022).

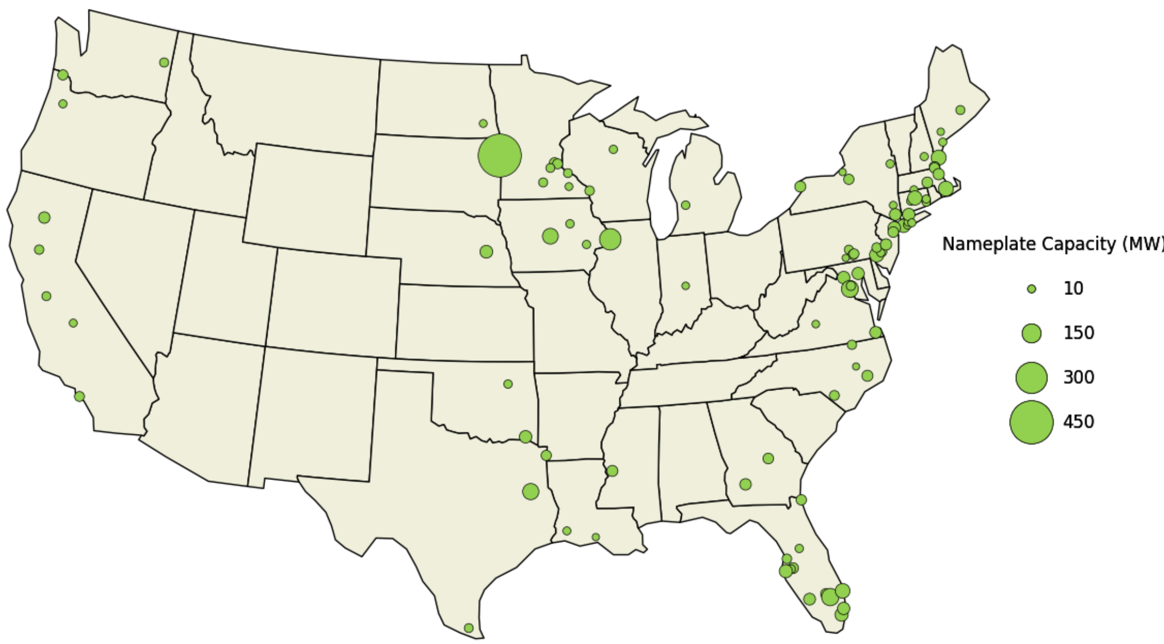


**Figure 2.2.3.** Waste-to-energy facilities in the United States in 2021, sizes according to capacity in MW (EIA, 2020).

The concentration of waste-to-energy facilities in the northeastern part of the United States can be explained by its high population density and high concentration of urban areas, and the limited land for landfills. In addition, both the Florida and the northeastern clusters are located in geographic areas with shallow aquifers that may prevent the construction of MSW landfills (USGS, 2020; Javawardhana et al. 2016).

The number of WTE plants in the United States is trending downward, with a 13-percent reduction in the last decade. A plausible explanation for this reduction is that cities are increasingly embracing zero waste policies and renewable energy targets, and therefore shifting away from incineration 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. As a consequence, companies are using MSW 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 (EPA, 2020).

Consumption has remained nearly constant in the last decade; 15 million metric tons of biomass MSW were burned in 2021, which generated 126 trillion BTUs of energy. Ninety percent of the total energy generated from biomass MSW is used for electricity generation, and it is mostly consumed by independent power producers (78 percent) followed by the commercial sector (19 percent) (EIA, 2022).

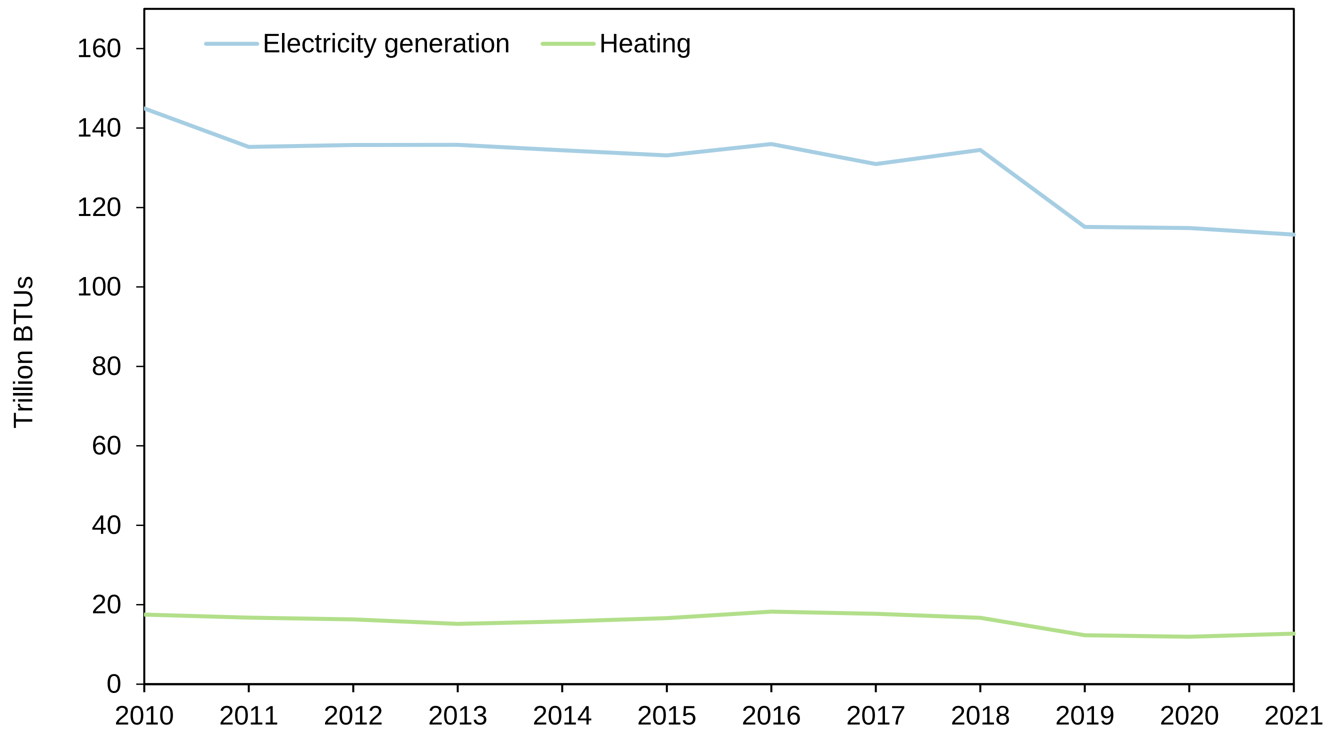


**Figure 2.2.4.** Final use of the energy generated from biogenic municipal solid waste in the United States from 2010 to 2021 (in trillion British thermal units) (EIA, 2022).

According with the Energy Recovery Council, the waste to energy industry creates 5.6 billion of gross economic sales output and supports nearly 14,000 jobs, 5,400 of which are direct jobs, with $890 million of total labor compensation (ERC, 2019).

### 2.2.3 Biogas

Biogas is a mixture of gases produced as the result of organic matter being broken down by microorganisms in the absence of oxygen. This process, which is called anaerobic digestion, can occur naturally in landfills, or it can be optimized using anaerobic digesters (EPA, 2014).

There are different sources of organic matter 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, that is the main component of 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. Another possibility is to increase the methane content of biogas through further processing and purification for distribution via the existing natural gas pipeline system, which upgrades biogas to renewable natural gas (RNG). The upgraded biogas, RNG injected into a natural gas pipeline has a methane content between 96 and 98 percent (EPA, 2023). Biogas systems use biogas for electricity generation, heating or for transportation fuel.

In 2021, the United States had more than 2,500 sites producing biogas: 287 anaerobic digesters on farms; 1,277 wastewater treatment facilities; and 941 organic waste and landfill gas projects. Most of the plants were located in the midwestern and northeastern United States. California is the leading State in number of biogas recovery systems with 301 plants including biogas systems located in landfills, farms, and wastewater treatment facilities (EPA, 2022; Water Environment Federation, 2015).

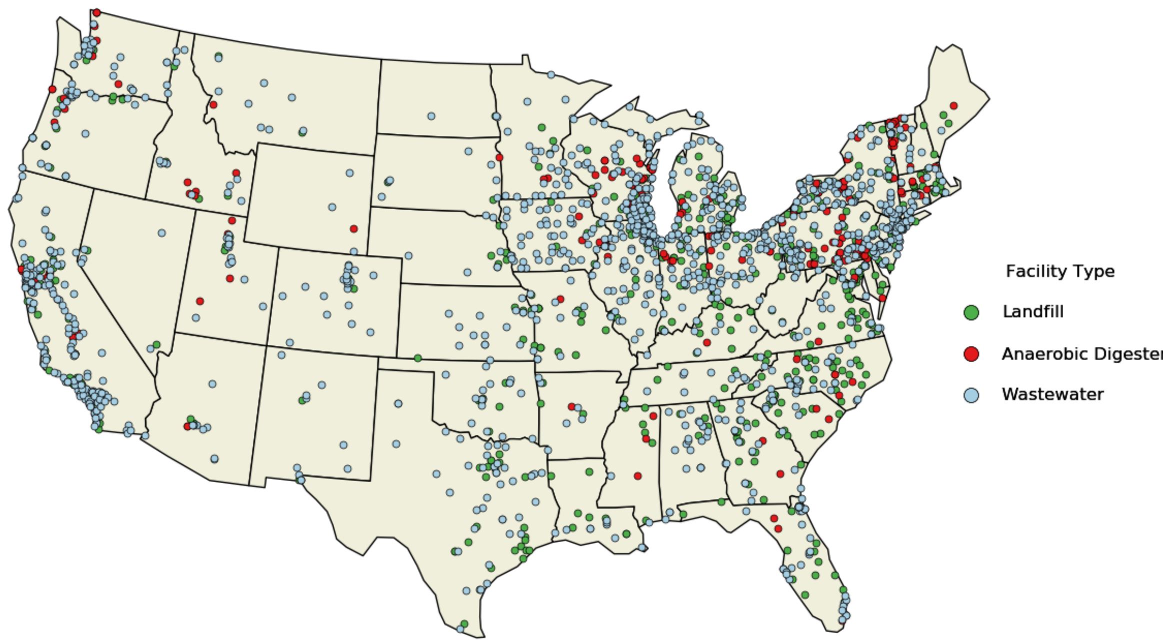


**Figure 2.2.5.** Biogas facilities locations by type in the United States in 2015 (wastewater) and 2022 (landfills and anaerobic digesters) (EPA, 2022; Water Environment Federation, 2015).

Biogas is a growing industry; production of biogas on farms increased by 156 percent, production of biogas at landfills grew by 53 percent from 2010 to 2021. According to the American Biogas Council, the United States has the potential to build more than 15,000 new biogas sites: 8,600 anaerobic digesters in farms; 4,000 wastewater treatment facilities; and 2,000 landfills. If fully realized, these biogas systems could produce up to 103 trillion KWh of electricity each year, which is equivalent to 84 million homes' energy use for 1 year (American Biogas Council, 2022).

California, Texas, and North Carolina are the States with highest overall biogas potential as of 2021, accounting for more than 21 percent of total U.S. biogas potential. California leads in terms of biogas potential in all categories (anaerobic digesters in farms, wastewater treatment facilities, and landfills). California has the potential to install 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. Most of the potential biogas systems are anaerobic digesters in hog farms. Construction of these 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, it 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 (American Biogas Council, 2020).

Despite farms having the largest biogas generation potential, the volume of biogas captured on farms is almost 40 times lower than the biogas captured from landfills. In 2021, biogas captured in farms remained constant at 7 billion cubic feet and biogas captured in landfills slightly decreased by 8 percent in comparison with 2020. Following this reduction in biogas production, the total energy generated from biogas also decreased in 2021. Landfills generated 116 trillion BTUs of energy from biogas and anaerobic digesters in farms generated 2.6 trillion BTUs, a decrease of 9 percent (EPA, 2020; EIA, 2021).

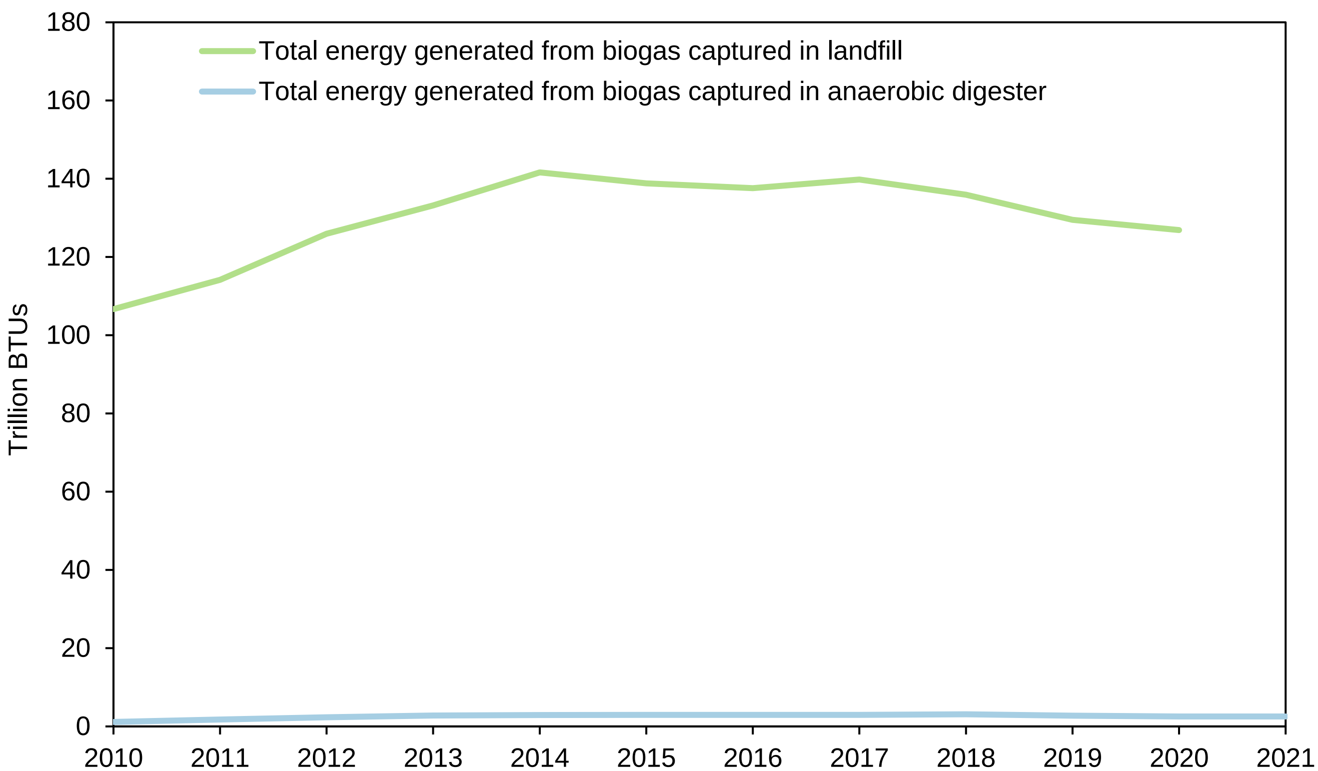


**Figure 2.2.6.** Total energy generated from biogas by source from 2010 to 2021 (in trillion British Thermal Units (BTU)) (EPA, 2022; EIA, 2022).

Since 2017, the agricultural biogas industry has been developed significantly using livestock manure-based anaerobic digestion systems. The number of newly operational digester systems accepting livestock manure increased from 10 new systems in 2017 to 50 new systems in 2021 (EPA, 2022). Along with the trend in agricultural biogas industry, the number of total projects for RNG projects, including pipeline injection and compressed natural gas (CNG) for transportation fuel or other uses, have also increased significantly since 2017. Compared to only seven operating agriculture RNG projects in 2017, the number increased to 97 projects in 2021 and continued to increase to 109 in 2022 (EPA, 2023). During the developments of agricultural biogas industry and agricultural RNG projects, the number of other types of biogas projects such as combined heat and power, electricity generation, and flared full time either decreased or remained the same (EPA, 2022).

Current rapid expansion of RNG projects was driven by the ability for this fuel to generate lucrative credits under RFS and LCFS programs that incentivize renewable, carbon-negative energy (EPA, 2022; Federal Register, 2022). Under the Federal RFS program, RNG in a compressed or liquefied form as transportation fuel is currently characterized under cellulosic (or D3 RINs) or advanced biofuel (or D5 RINs). Like the RFS program, California's LCFS program currently designates manure biogas as a negative emissions fuel, which awards profitable credits for its production (Lazenby, 2022).

The collection and use of biogas decreases greenhouse gas emissions, as its main component, methane, is a powerful greenhouse gas. Methane's global warming potential over 100 years, which is a measure of the amount of heat a greenhouse gas traps in the atmosphere, is 25 times higher than that of carbon dioxide (IPCC, 2018). In 2021, biogas systems in landfills captured 94 million metric tons of carbon dioxide equivalent, and anaerobic digesters in farms reduced greenhouse gases emissions by 5.9 million metric tons of carbon dioxide equivalent (EPA, 2022; EIA, 2022).

Methane emissions from waste were constant in the last decade around 130 million metric tons of equivalent carbon dioxide per year. Since total methane emissions from waste were double the amount of emission captured by biogas recovery systems on landfills in 2020, landfills should double their recovery capacity to capture all the methane. Similar to the emissions from waste, emissions from agriculture remained constant in the last decade at 250 million metric tons of equivalent carbon dioxide per year. To reduce emissions from agriculture, the number of anaerobic digesters in farms should also increase significantly (EPA, 2022).

In 2020, the American Biogas Council estimated that the biogas industry would generate 373,000 short-term construction jobs and 25,000 permanent jobs.

## 2.3.1 Biobased Chemicals

Biobased chemicals, also known as renewable chemicals, are chemicals totally or partially produced from plants and other renewable materials. Examples of biobased chemicals include fermentation products such as ethanol, lysine and citric acid, and sorbitol, glycerol as well as fatty acids (IEA, 2020). In contrast to petroleum-based chemicals, production of biobased chemicals is environmentally, economically, and socially sustainable (IEA 2020; ACME-Hardesty, 2021):

- Emissions of GHG are lower because biobased chemicals are produced from renewable sources. It is estimated that replacing 20 percent of petroleum-based chemicals with biobased chemicals could result in a 15 to 66—percent reduction of GHG emissions.
- Use of raw materials not derived from petroleum ensures a steady production of biobased chemicals with prices not tied to the volatility of oil prices. As new biobased chemicals are being produced in the United States, more jobs are being created.
- Plant-based feedstock means that production processes of biobased chemicals are safer and less harmful than petroleum-based production processes. This in turn also means less special handing and management than traditional chemicals, reducing operating expenses and increasing revenue.

Biobased chemicals are intimately related to green chemistry which is defined as "the design, development and implementation of chemical products and processes that reduce or eliminate the use and generation of hazardous substances" (Anastas and Warner, 1998). Although the focus of green chemistry is placed in the minimization of waste rather than in the use of renewable feedstock, it is evident that the production of biobased chemicals implicitly achieves that goal.

Different metrics exist to quantify the environmental footprint of a given chemical product. One of the most widely used is the E factor, whose value equals the amount of waste generated in a chemical process (waste being everything but the desired product). An E factor of zero would mean that a given chemical process generates zero waste (Sheldon and Woodley, 2018). The EPA has also developed GREENSCOPE, a sustainability assessment tool used to evaluate and assist in the design of chemical processes (Gonzalez and Smith, 2003; EPA 2014). This tool allows for quantifying process sustainability and Life Cycle Inventory (LCI) generation by analyzing the performance of a given chemical process in terms of material efficiency, energy, economics, and environment.

As of 2019, global biobased chemical and polymer production is estimated to be around 90 million metric tons, which represents 21 percent of all the chemicals produced worldwide. Petroleum-based chemicals are widely used over biobased chemicals because currently the production costs of biobased chemicals exceed the cost of petrochemical production (IEA, 2020).

In economic terms, the global market for biobased chemicals was valued at $87 billion in 2022, with North America representing 27.3 percent of that total. The market for biobased chemicals is projected to grow from 96 billion dollars in 2023 to 164 billion dollars by 2030 (Market Research Future, 2022).

### 2.3.1 Biobased Plastics

Bioplastics aka Biobased Plastics are a type of plastic that are derived with biobased feedstocks (e.g., corn, sugarcane, potatoes) as opposed to conventional plastics which are produced from fossil fuels. Bioplastic production usually starts from a biological source and go through a series of modification techniques such as pretreatment, hydrolysis, and fermentation which ultimately produce bioethanol. Bioplastics take many forms including biobased and biodegradable bioplastics which are also biodegradable, such as bio-PLA (Polylactic acid) and bio-PHA (polyhydroxyalkanoate). Materials must meet ASTM Specifications D6400 or D6868 to be called biodegradable and compostable on land and must meet ASTM D7081 specifications for marine environments 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 (Rahman and Bhoi, 2021).

However, not all biobased plastics are biodegradable such as bio-polyethylene (bio-PE), bio-polypropylene (bio-PP), bio-polyethylene-terephthalate (bio-PET), bio-polytrimethylene terephthalate (Bio-PTT), and bio-polyamide (bio-PA). This is why the chemical and plastics industry has a broader definition of bioplastic to mean, "bioplastics are plastics that are (1) biobased, meaning they come from a renewable resource, (2) biodegradable, meaning they break down naturally, or (3) are both biobased and biodegradable. There are durable bioplastics made entirely from sugar cane, and some biodegradable plastics that are derived from nonrenewable resources" (Plastic Industry Association, 2023).

Global production of bioplastics (both biobased and non-biobased but biodegradable) grew 14.5 percent between 2020 and 2021, from 2.11 million metric tons in 2020 to 2.42 million metric tons in 2021. Despite this notable increase in production and a continuing positive trend, bioplastics represent only 0.57 percent of total plastic production (Plastics Europe, 2022). Sixty four percent of the total bioplastics production in 2019 was biodegradable bioplastics, and 36 percent was non-biodegradable biobased bioplastics. The production of non-biodegradable biobased plastics has significantly increased in the last decade, from 6,000 metric tons in 2008 to 864,000 metric tons in 2021 (European Bioplastics, 2022).

The principal market driver behind the growth of bioplastics consumption are brands that want to offer environmentally friendly solutions to customers, who increasingly look for alternatives to petrochemical products. It is estimated that if bioplastics were to be promoted in a similar way as biofuels, annual growth rates of 10-20 percent could be expected (Bioplastics Magazine, 2020).

The main producers of bioplastics are located in Asia, where 50 percent of global bioplastics is produced. It is followed by Europe, with a share of 24 percent of global production. North America ranks third, with 17 percent of the world production of bioplastics in 2021 (European Bioplastics, 2022).

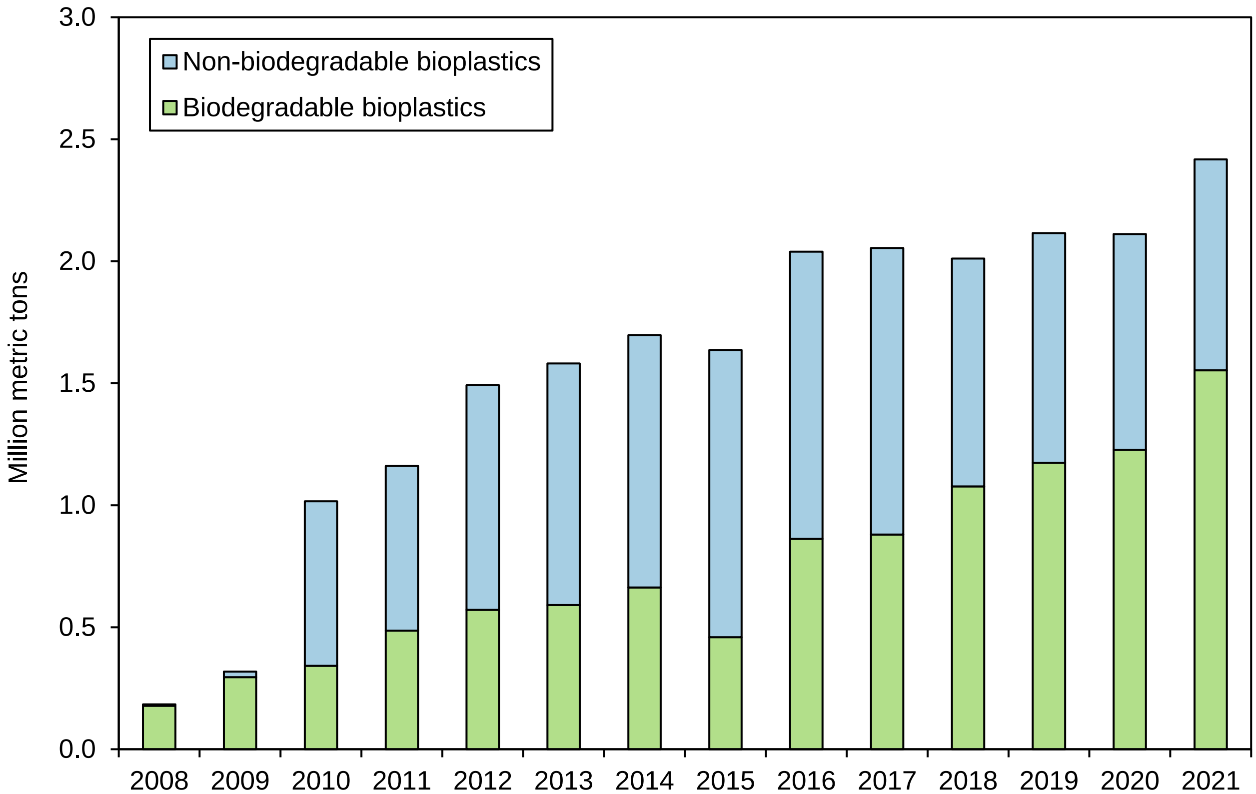


**Figure 2.3.1.** Global production of bioplastics by type from 2008 to 2021 (in million metric tons) (European Bioplastics, 2021).

In 2021, 48 percent of bioplastics produced globally were used mainly for packaging (Figure 2.3.2). Other uses include consumer goods (11 percent), textiles (10 percent), and agriculture (9 percent) (European Bioplastics, 2022).

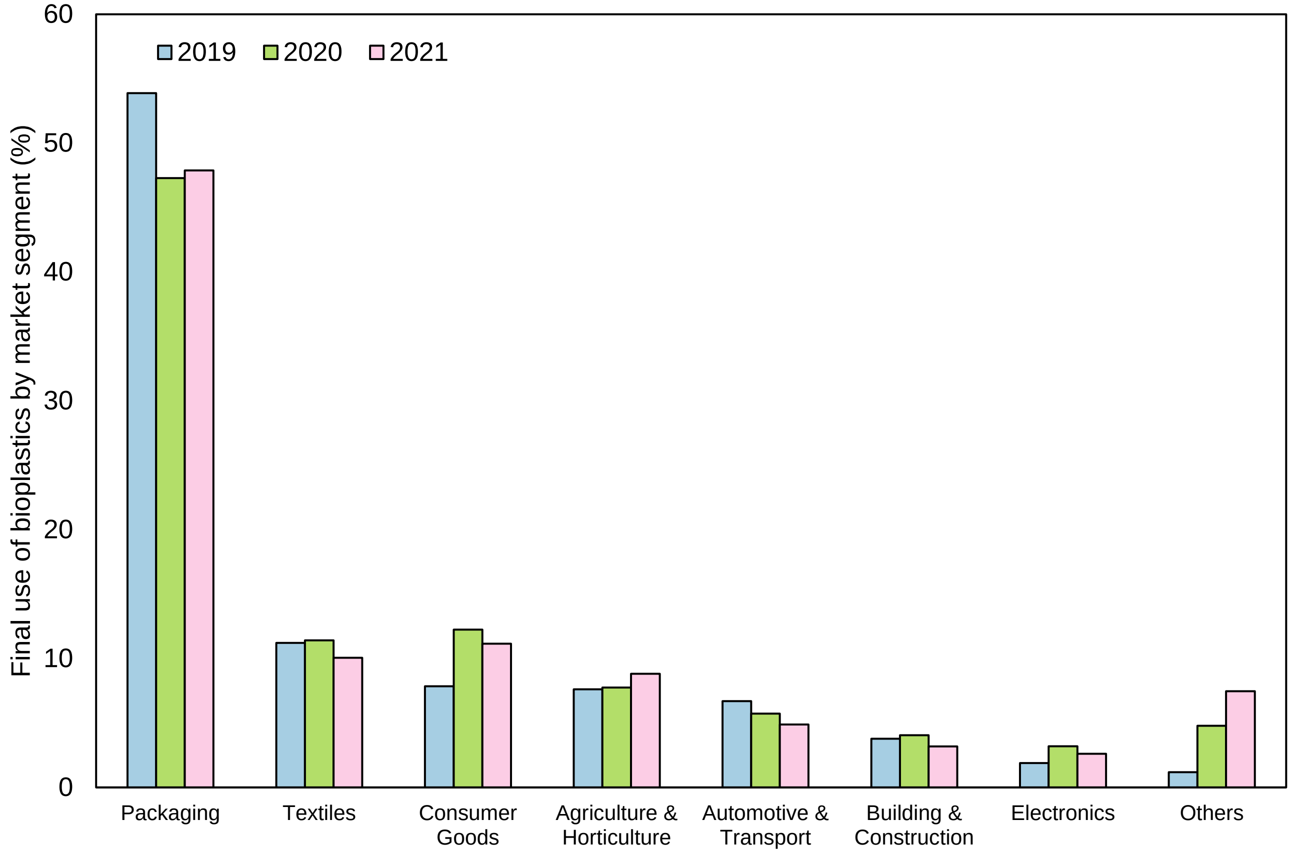


**Figure 2.3.2.** Final use of bioplastics from 2019 to 2021 (European Bioplastics, 2019, 2020, 2021).

## 2.3.2 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 the industrial processing of food ingredients, feed additives, or other chemicals; (2) act as a component in end products such as detergents, laboratory reagents, or digestive aids (National Research Council, 2000).

The global market for industrial enzymes remained almost constant with an increase of 8 percent from 2020 to 2021, reaching $6.4 billion. The main use for enzymes is in the food industry (37 percent in Figure 2.3.4) as key elements in fermentation processes such as baking, brewing and wine and cheese manufacturing. Other uses for enzymes include technical applications (25 percent in Figure 2.3.4) in the chemical and pharmaceutical industries and biofuel production (14 percent in Figure 2.3.4) (BCC Research, 2022).

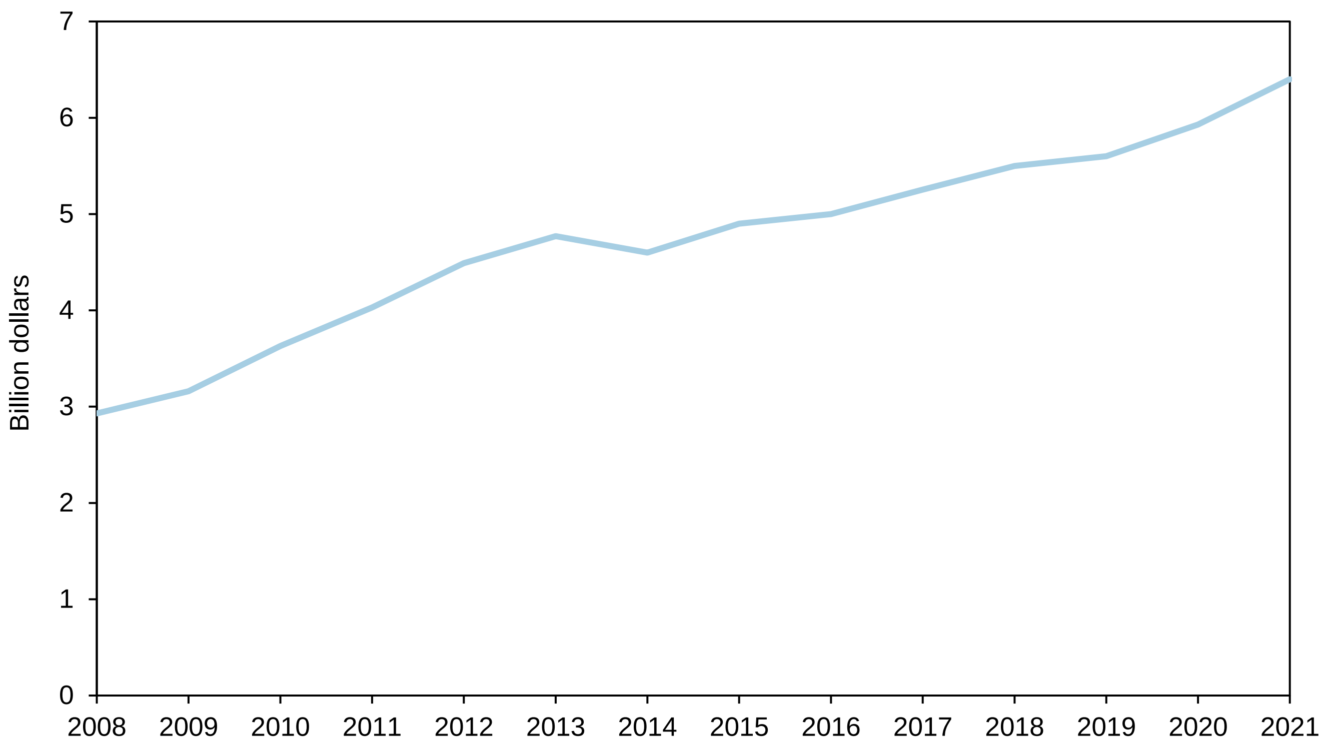


**Figure 2.3.3.** Global market for industrial enzymes from 2008 to 2021 (in billion dollars) (BCC Research, 2021).

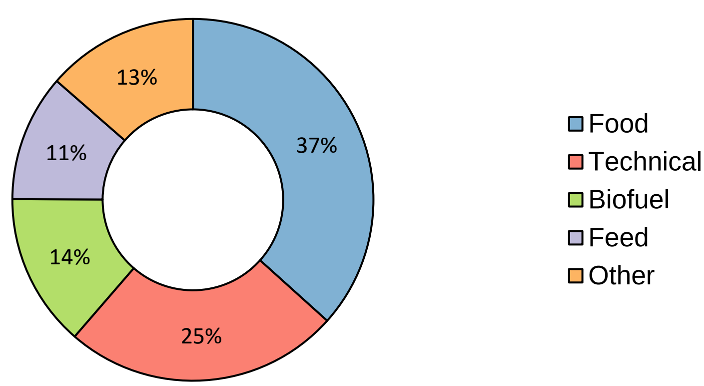


**Figure 2.3.4** Global market share for industrial enzymes by application in 2017 (BCC Research, 2019).

## 2.4 Biobased Products

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.

In an effort to expand and promote the development of biobased products; the U.S. BioPreferred Program was created in 2002 as part of the Farm Bill. It has subsequently been reauthorized and expanded as part of the Agriculture Improvement Act of 2018 (2018 Farm Bill) (USDA, 2020).

The two major parts of the program are:

- Mandatory purchasing of biobased products requirements for Federal agencies and their contractors; and,
- Voluntary labeling initiative for biobased products to increase consumer awareness of the benefits of biobased products (Figure 2.4.1)


**Figure 2.4.1**. A sample United States Department of Agriculture Certified Biobased Product label (USDA, 2020).

The United States Department of Agriculture's BioPreferred Program assists companies in identifying products that might qualify for mandatory Federal purchasing and/or might be certified through the voluntary labelling initiative (USDA, 2020).

About 11,000 biobased products are included in the BioPreferred Program. Of these, 9,800 products qualify for mandatory Federal purchasing initiatives, 1,000 products are certified but not covered by the purchasing mandates, and 7,400 products qualify for both initiatives (USDA, 2022).

As presented in Table 2.4.1, the number of products certified through the USDA BioPreferred Program has exhibited sustained growth as the pull of retailers and consumers for more sustainable products is driving companies to seek certification. Between 2019 and 2022, the number of products certified per year increased by 280 percent (USDA, 2022).

| Catalog Category | 2017 | 2018 | 2019 | 2022 |
|---|---|---|---|---|
| Baby and Kids | 53 | 46 | 58 | 238 |
| Construction | 57 | 106 | 116 | 562 |
| Custodial Services | 148 | 176 | 341 | 821 |
| Films and Packaging | 85 | 106 | 60 | 378 |
| Food Services/Cafeteria | 68 | 88 | 138 | 601 |
| Grounds Maintenance | 110 | 72 | 82 | 414 |
| Household Supplies | 218 | 207 | 404 | 1,130 |
| Intermediates | 157 | 373 | 345 | 2,074 |
| Miscellaneous | 63 | 43 | 114 | 223 |
| Office Supplies | 9 | 21 | 16 | 103 |
| Operations and Maintenance | 164 | 121 | 113 | 783 |
| Personal Care and Toiletries | 160 | 186 | 423 | 1,041 |
| Safety Equipment | 1 | 0 | 0 | 20 |
| Vehicles and Equipment Maintenance | 4 | 5 | 6 | 36 |
| Total Products Certified by Year | 1,297 | 1,550 | 2,216 | 8,424 |

**Table 2.4.1** USDA BioPreferred product certifications by year (USDA, 2022).

## 2.5 Forestry Products

Forest products are the largest source of renewable raw materials for the biobased products industry (National Research Council Committee on Biobased Industrial Products, 2020) and also contribute to primary energy.

The production of forest products in the United States remained constant in 2021 at 1,100 million tons but declined during the COVID-19 pandemic. Roundwood, which represents 58 percent of total production, was the highest item being produced in 2021 (Figure 2.5.1). It was followed by sawnwood (13 percent of total production), wood fuel (9 percent of total production), and paper and paperboard (6 percent of total production) (FAOSTAT, 2022).

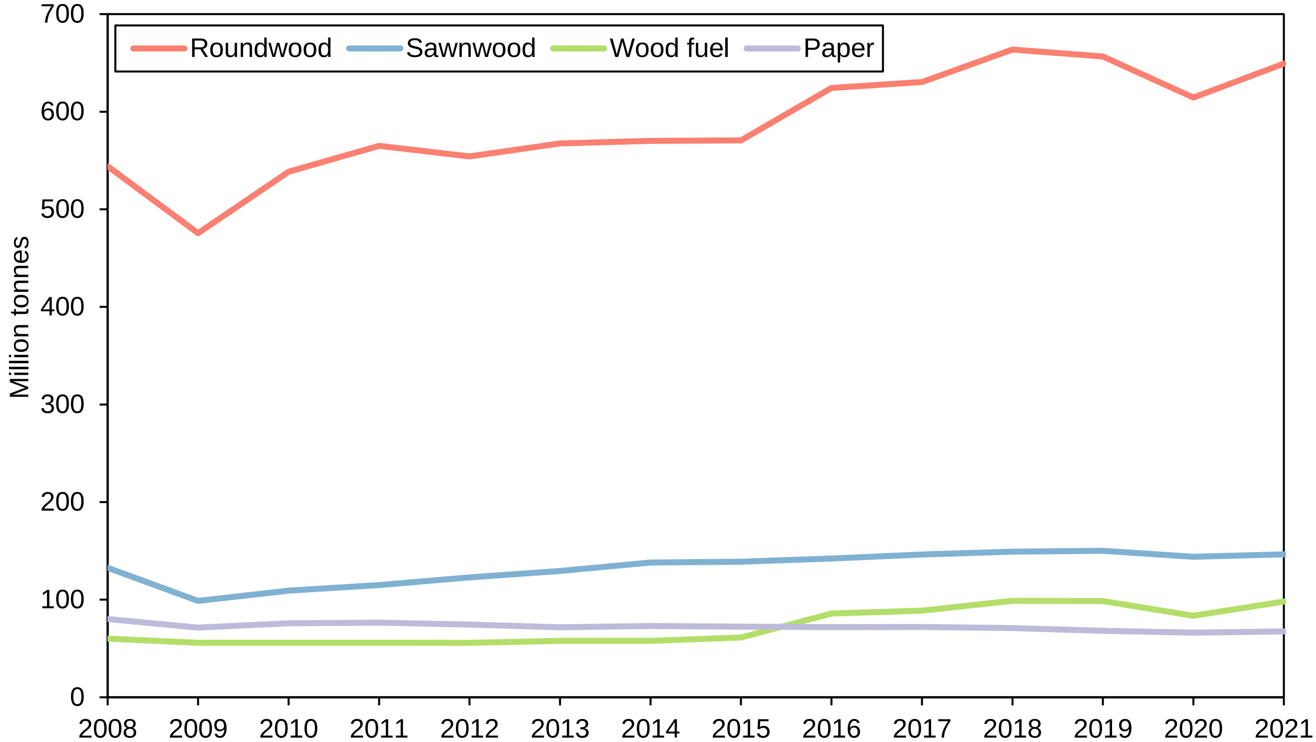


**Figure 2.5.1.** Production of roundwood, sawnwood, wood fuel and paper in the United States from 2008 to 2021 (in million tons) (FAOSTAT, 2022).

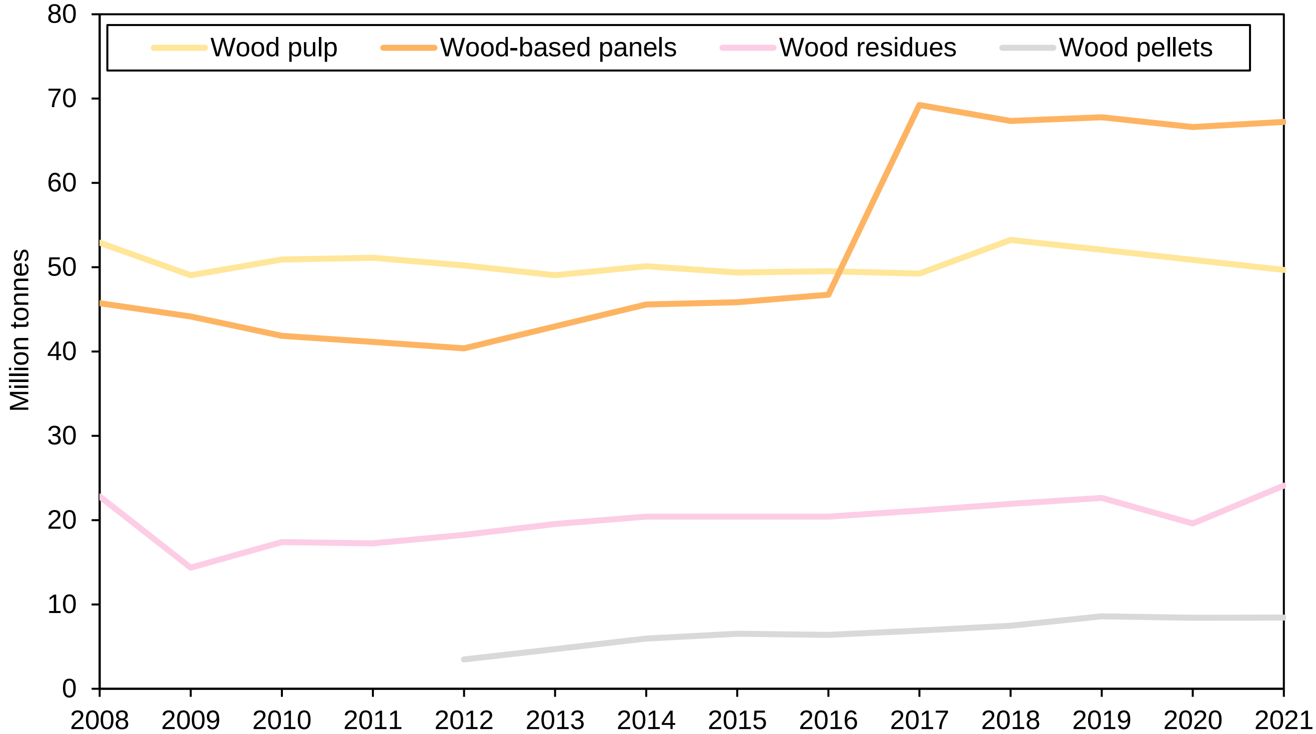


**Figure 2.5.2.** Production of wood pulp, wood-based panels, wood residues and wood pellets in the United States from 2008 to 2021 (in million tons) (FAOSTAT, 2022).

Trade of forest products in the United States increased in 2021 from $27 billion to $41 billion in imports and from $22 billion to $27 billion in exports. After almost 10 years of being a net exporter of forest products, the United States became a net importer in 2018. This trend continued in 2021, with $14 billion of net imports (FAOSTAT, 2022).

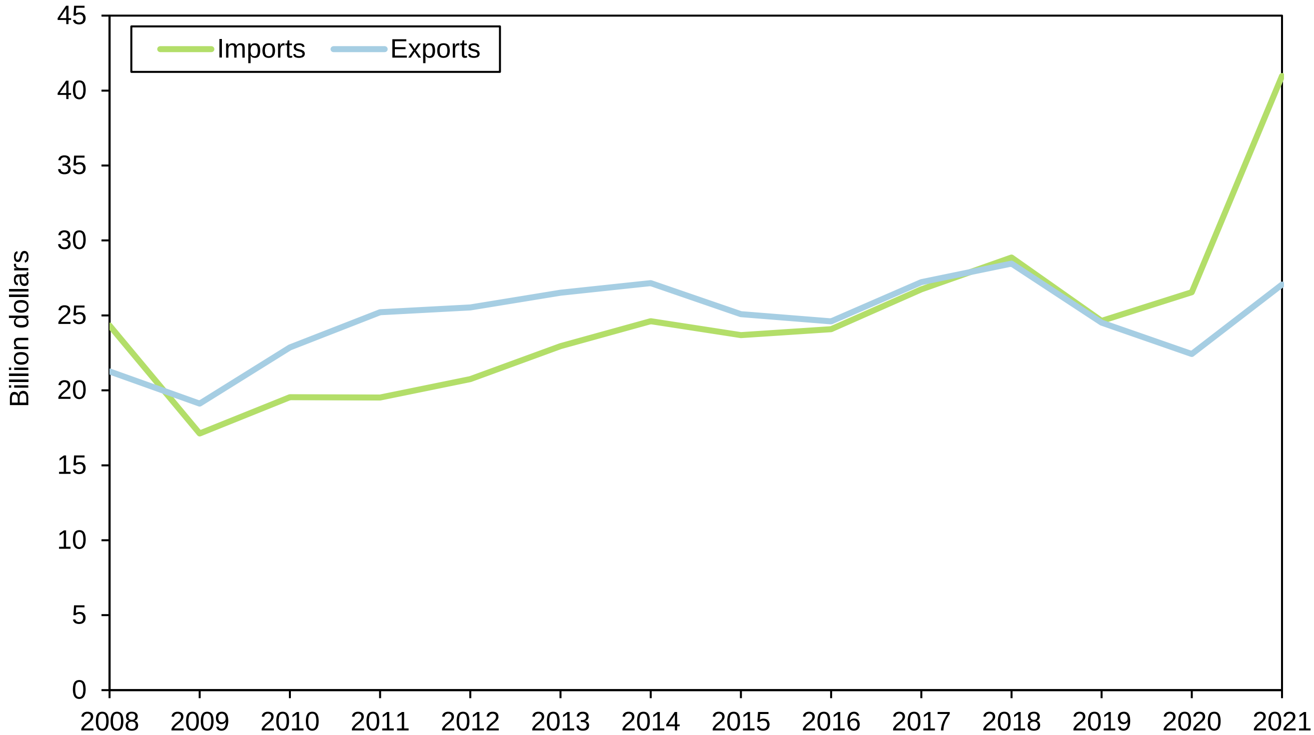


**Figure 2.5.3.** Imports and exports (in billion dollars) of forest products to and from the United States, 2008 to 2021 (FAOSTAT, 2022).

Wood and paper products in the United States represented 0.3 percent of total gross domestic product in 2021. These industries had a value added of $116 billion and employed almost 800 employees (BEA, 2022).

## 2.6 Apparel and Textiles

Apparel and textiles include both biobased and synthetic fibers and dyes. It is estimated that fossil fuel derived polyester is the largest feedstock for the apparel and textiles industry. However, cotton, which is an agricultural product, plays a significant role comprising approximately 30 percent of the global apparel and textile feedstock (CottonUp, 2023).

The United States is a net importer of apparel and textiles. After the Great Recession, the United States apparel global exports increased gradually from $3.9 billion to $ 6.1 billion until 2015. The more recent years' exports from 2015 to 2021 leveled off, except for decrease to $4.9 billion in 2020. In 2021, while the United States. exported over $6 billion in apparel, the Nation imported over $85 billion (Statista, 2023).

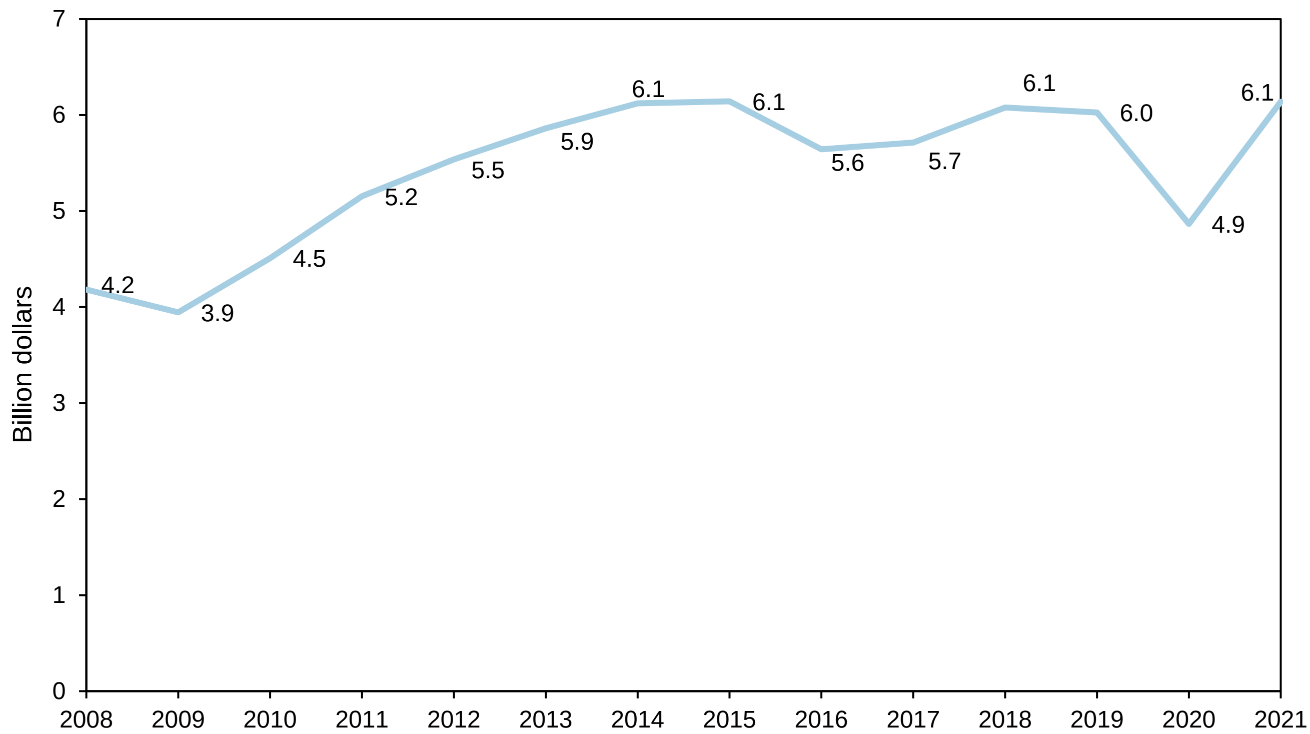


**Figure 2.6.1.** Value of United States apparel global exports by year in U.S. billion dollars (ITA, 2023). Hemp is a domestic crop that is being used in the apparel and textiles industry. Hemp has been documented to be very effective for various consumer product applications because it is resistant to mold and ultraviolet light. Additionally, hemp fibers readily absorb dye, becoming softer and more comfortable with long-term use, making it attractive for the apparel and textiles industry (USDA REIS, 2022). Despite its potential as a biobased feedstock for the apparel and textile industry, in 2022, the production of hemp for fiber in the United States was estimated at 21 million pounds, down 37 percent from 2021 (USDA, 2023).

The 2018 Farm Bill directed USDA to establish a national regulatory framework for hemp production in the United States. USDA published a final rule that provides regulations for the production of hemp in the United States and became effective on March 22, 2021. The final rule builds on the interim final rule published October 31, 2019, that established the U.S. Domestic Hemp Production Program. The final rule incorporates modifications based on public comments and lessons learned during the 2020 growing season. Key provisions of the final rule include licensing requirements; recordkeeping requirements for maintaining information about the land where hemp is produced; procedures for testing the tetrahydrocannabinol (THC) concentration levels for hemp; procedures for disposing of non-compliant plants; compliance provisions; and procedures for handling violations (USDA, 2023).

Industrial hemp production in the United States was reported to be 54,152 acres in 2021 with a value of over $824 million in 2021 (USDA, 2022).

# 3. INVESTMENTS & FINANCE

## 3.1 Loan Programs

The Food, Conservation, and Energy Act of 2008 otherwise known as the 2008 Farm Bill, established the Biorefinery Assistance Program (9003 Program) under Title IX, Section 9003, for making loan guarantees to fund the development, construction, and retrofitting of commercial-scale biorefineries using Eligible technology. This program provides loan guarantees up to $250 million to assist in the development, construction and retrofitting of new and emerging technologies. These technologies are advanced biofuels, renewable chemicals, and biobased products.

A biorefinery is a facility (including equipment and processes) that converts renewable biomass or an intermediate ingredient or feedstock of renewable biomass into any one or more, or a combination, of biofuels, renewable chemicals, or biobased products, and may produce electricity. To be eligible for the 9003 program, the project must be located in a U.S. State or territory, and the total amount of Federal participation (loan guarantee, plus other Federal funding) must not exceed 80 percent of the total eligible project costs (USDA, 2022). The borrower and other principals involved in the project must make a significant cash equity contribution. The 2008 Farm Bill defined eligible technologies as: technology that is being adopted in a viable commercial-scale operation of a biorefinery that produces an advanced biofuel; and technology that has been demonstrated to have technical and economic potential for commercial application in a biorefinery that produces an advanced biofuel.

The 9003 program's authority was continued in the Agricultural Act of 2014 with several specific changes: (1) renamed the program as the Biorefinery, Renewable Chemical, and Biobased Product Manufacturing Assistance Program; (2) revised the purpose statement for the program to include renewable chemicals and biobased product manufacturing; (3) expanded the program to include biobased product manufacturing facilities; (4) added definitions for ''Renewable Chemicals'' and ''Biobased Product Manufacturing;'' and (5) Ensured diversity in the types of Projects approved.

As reported in Golden et. al. (2022) of the 62 unique organizations that have entered the 9003-loan guarantee application process since 2008, seven (7) or 11.3 percent have successfully completed the 9003-loan guarantee process and received financing by a private lender as presented in Table 3.1.1.

| | YEAR | PROJECT NAME | LOAN AMOUNT | TECHNOLOGY | FEEDSTOCK | PRODUCT | LENDER | LOCATION | CURRRENT STATUS |
|---|---|---|---|---|---|---|---|---|---|
| 1 | 2009 | Range Fuels | $80,000,000 | Biomas Gasification | Cellulostic - Wood | Ethanol | N/R | Soperton, GA | Never operated then closed / Sold to Lanza Tech in 2012 for $5.4 M (Freedom Pines Biorefinery)-is operating |
| 2 | 2009 | Sapphire | $43,600,000 | Refining at Dynamics Fuels in Geismar, LA | Algae | various types of transportation fuels | N/R | Columbus, NM | Loan Paid Off. 2017 sold off. Biorefinery closed |
| 3 | 2011 | INEOS Bio | $75,000,000 | gasification and fermentation | Cellulostic Wastes | bioethanol + renewable power | N/R | Vero Beach, FL | Plant constructed and operated. Sold to Frankens Energy in 2017 |
| 4 | 2011 | Fremont Community Digester | $12,825,000 | anaerobic digester | Liquid Organic Wastes | 2.8 MW Renewable Electricity | N/R | Freemont, MI | 2017 aquired by Generate Capital |
| 5 | 2017 | Ryze Renewables | $112,580,000 | Isotherm Hydroprocessing | Non-edible Distillers Corn Oil | Renewable Diesel, Naphtha, Propane | Greater Nevada Credit Union | Storey County, NV | Now known at New Rise Renewables Reno LLC. Project not completed. Entered into ground sale and leaseback with Twain Financial Partners April 2022. |
| 6 | 2017 | Ryze Renewables | $198,000,000 | Isotherm Hydroprocessing | Non-edible Distillers Corn Oil | Renewable Diesel, Naphtha, Propane | Greater Nevada Credit Union | Las Vegas, NV | Pending Update from Greater NV |
| 7 | 2021 | BC Organics | $100,000,000 | Aneorobic Digestion | Dairy Manure & Food Wastes | Renewable natural gas, nutirent stream, and clean water | Live Oak Bank | Greenleaf, WI | Under Construction in 2022 |

**Table 3.1.1** Summary of 9003 loan applicants that were successful in obtaining a USDA conditional commitment and private lender loan since 2009. As of September 2022, two of the approved projects are currently operating and producing renewable energy. Note: N/R represents no record in the 9003 database. (Golden et. al., 2022).

In addition to the 9003 Program, the Real Energy for America Program (REAP) supports agricultural producers and rural small businesses for purchasing and installing renewable energy systems, including but not limited to biomass (e.g., biodiesel and ethanol, anaerobic digesters, and solid fuels) (USDA, 2023). REAP also provides funds for improving their efficiency of existing energy-using operations such as high efficiency heating, ventilation, and air conditioning systems (HVAC).

REAP is a competitive program in which all projects are scored against one another in each State. Scoring is based on eight criteria with different points with a total of 100. In the currently adopted scoring rubric, the highest points of 25 are given to the criterion of energy generated/saved/replaced, while the lowest points of 10 are given to three criteria: commitment of matching funds, environmental benefits, and State director/administrator points (USDA, 2023).

To be eligible for the funds, projects must be located in rural areas with populations of 50,000 residents or less (USDA, 2023). One exception is that agricultural producers' projects can be located in non-rural areas if the project is associated with an on-site production operation. Loan guarantees on loans are available up to 75 percent of total eligible project costs, and the minimum REAP guaranteed loan amount to be provided to a borrower is $5,000 and the maximum amount is $25 million (Federal Register, 2022).

Business and Industry (B&I) Guaranteed Loan Program is designed to assist credit-worthy rural businesses with facilities located in rural areas that save or create jobs. Most types of business are eligible for this program, including those engaged in the manufacturing, wholesale, retail, and service industries. Private-entity borrowers must demonstrate that loan funds will remain in the United States, and the facility being financed will primarily create new or save existing jobs for rural U.S. residents (USDA, 2023). Eligible areas are considered in rural areas not in a city or town with a population of more than 50,000 inhabitants; the borrower's headquarters may be based within a larger city, as long as the project is located in an eligible rural area.

The maximum percentages of guarantee are based on loan size. The scale of maximum percentages is 80 percent guarantee on loans up to and including $5 million; 70 percent guarantee on loans greater than $5 million up to and including $10 million; and 60 percent guarantee on loans greater than $10 million. The average size of B&I loans is about $3 million with a range from $200,000 to $5 million (USDA, 2023).

Loan proceeds may be used for broad business purposes, including but not limited to the following: business acquisitions, construction, conversion, expansion, repair, modernization and development, purchase of equipment, machinery, and supplies. Energy projects can be eligible based on certain conditions, including but not limited to ineligible for REAP, unless sufficient funding is not available under REAP. In particular, energy projects that produce renewable biomass or biofuel as an output must utilize commercially available technologies and have completed two operating cycles at design performance levels prior to issuance of a Loan Note Guarantee (Code of Federal Regulations, 2023).

## 3.2 Research & Development (R&D) Funding

The technologies used to produce biobased products and biofuels are relatively novel when compared to traditional fossil-based production means. As such, these production processes are not yet optimized, and rely mostly on experimental techniques and innovative methodologies. To compensate for the initial low financial outcome when using these new processes to produce biobased products and biofuels, Federal, State and local agencies implement different incentive programs. The most direct approach is the award of research grants to enterprises involving biobased products or biofuels.

The USDA National Institute of Food and Agriculture (NIFA) hosts a database containing awards granted to projects involving biobased products or biofuels (NIFA, 2022), depicted in Figures 3.2.1, 3.2.2, and 3.2.3 From 2008, the number of grants awarded to projects related to conventional biofuels (ethanol, biodiesel, biogas, waste to energy and wood pellets) has been steadily decreasing during the last decade, from 565 research projects in 2008 to just 163 in 2021 (see Figure 3.2.1) (NIFA, 2021). This trend is more accentuated in projects involving ethanol and biodiesel. Although the rest of conventional biofuels (biogas, waste to energy and wood pellets) also show a slight decrease in awards, this trend is not so drastic as with ethanol and biodiesel (Figure 3.2.1) (NIFA, 2022).

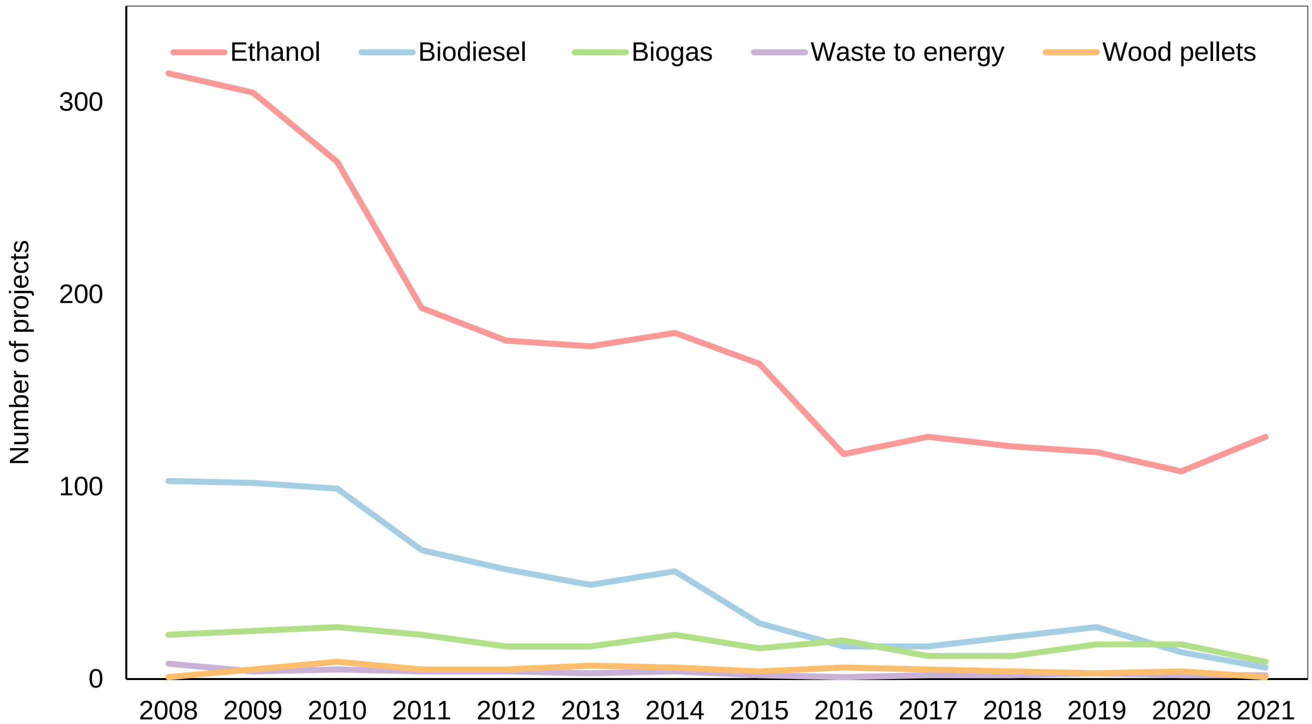


**Figure 3.2.1.** Number of awards to research projects containing conventional biofuel-related keywords in the United States from 2008 to 2021 (NIFA, 2022).

This decrease is more acute for the emergent biofuels, although not as monotonic as with the conventional biofuels (Figure 3.2.2) (NIFA, 2022). Given the emergent nature of these biofuels, and its novelty compound, it is not surprising that their trends are less monotonous and unpredictable than for conventional biofuels. Projects involving recycled greases appear briefly in 2014 and 2017, only to vanish again in 2018 (Figure 3.2.2) (NIFA, 2022).

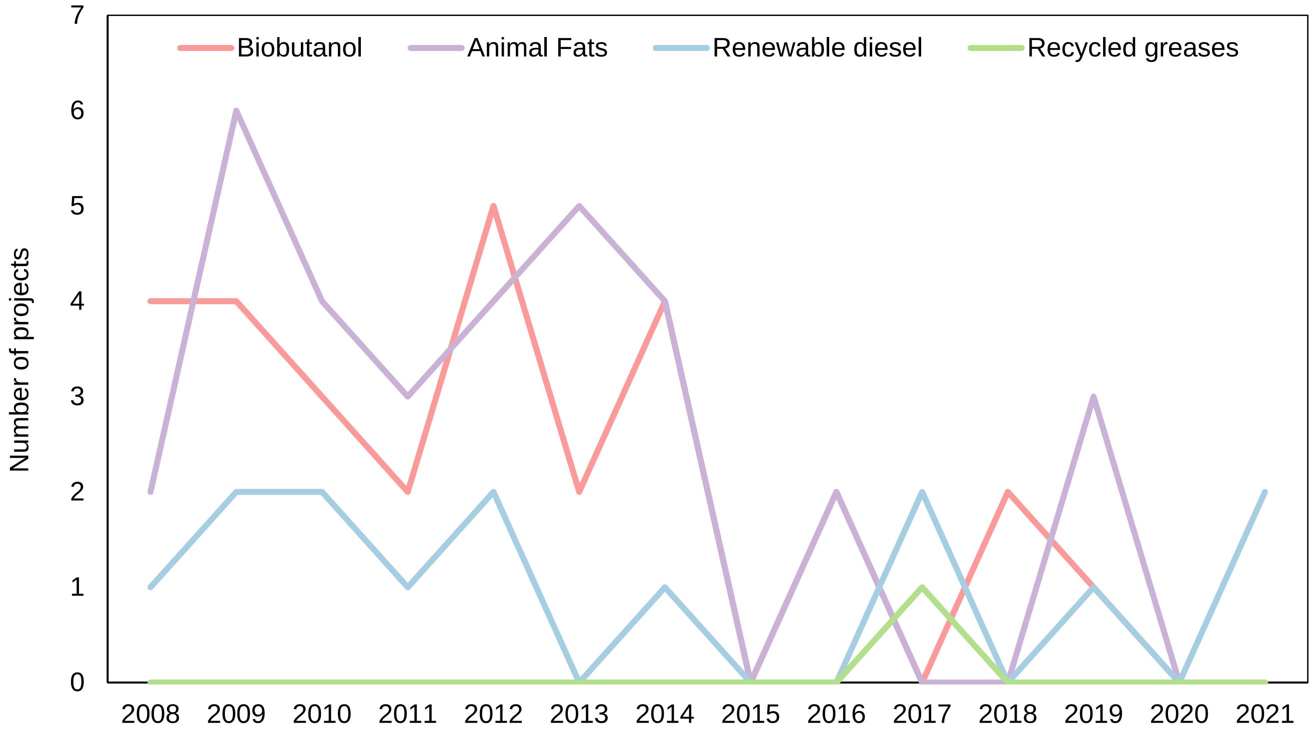


**Figure 3.2.2.** Number of awards to research projects containing emergent biofuels-related keywords in the United States from 2008 to 2021 (NIFA, 2022).

The same downward trend can be seen in research projects related to biobased products. The number of projects containing the keyword "Enzymes" decreased from 343 projects in 2008 to 154 projects in 2021. Projects involving "bioplastics" and "biochemicals" remained nearly constant with 10 research projects each year. Finally, projects related to other "bioproducts" went down 67 percent in the last 10 years from 52 to 17 projects. (Figure 3.2.3) (NIFA, 2021).

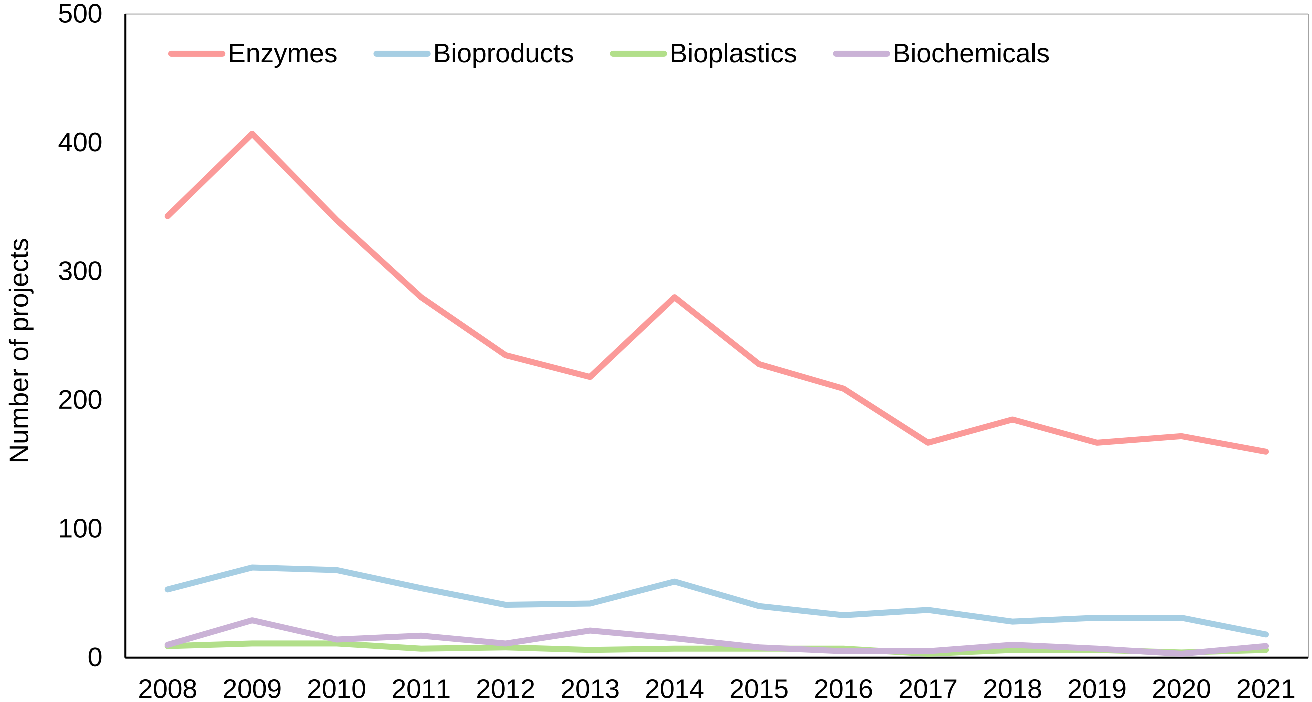


**Figure 3.2.3.** Number of awards to research projects containing keywords related to biobased products in the United States from 2008 to 2021 (NIFA, 2022).

As for the amounts awarded, the vast majority of awards amounted to less than $250,000, both in biofuels (83 percent in 2019 and 72 percent in 2021 of the awards, Figure 3.2.4.) and in biobased products (83 percent in 2019 and 74 percent in 2021 of the awards, Figure 3.2.4.). A noteworthy 2, 3, 2 percent of the biofuel projects were awarded more than $1 million in 2019, 2020, and 2021, respectively, with a similar figure (3, 4, 0 percent in the same periods) for the biobased products projects (Figure 3.2.4).

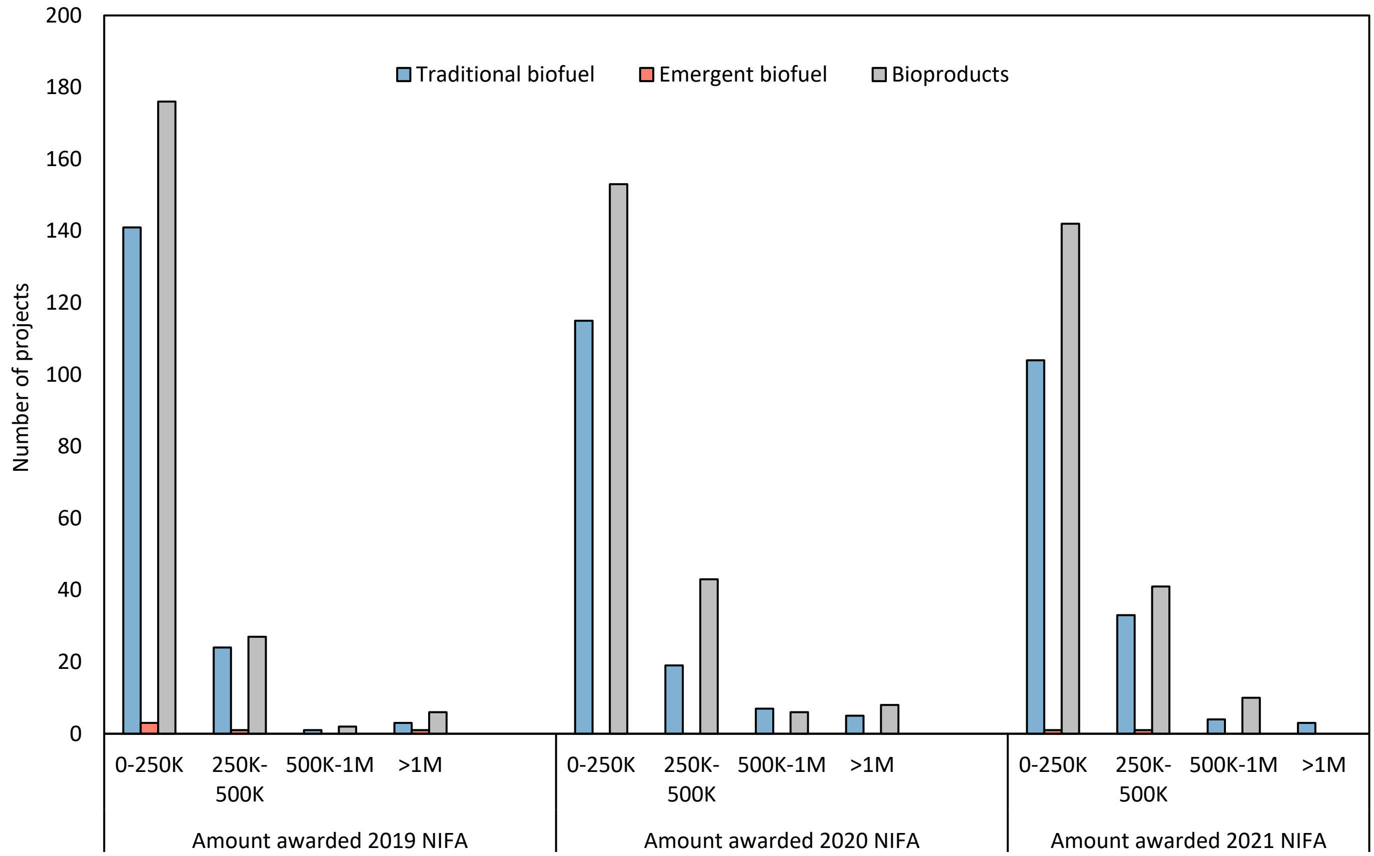


**Figure 3.2.4.** Award amount range in dollars for Biofuels research projects and Bioproducts research projects from 2019 to 2021 in the United States (NIFA, 2022).

Similar to the NIFA website, the National Science Foundation (NSF) hosts a database containing awards granted to projects involving biofuels and biobased products (NSF, 2022), as presented in Figures 3.2.5, 3.2.6, and 3.2.7. Since 2008, the number of grants awarded to conventional biofuels decreased by 55 percent from 58 projects in 2008 to 26 projects in 2021. Projects involving ethanol and biodiesel are the ones showing a bigger decrease in number of awards (see Figure 3.2.5) (NSF, 2021).

The NSF only awarded 17 projects involving emergent biofuels from 2008 to 2021. In 2020 and 2021, three projects were awarded, and no project was awarded in 2019. As described above, trends on emergent biofuels are unpredictable due to their novelty compound (Figure 3.2.6) (NSF, 2022).

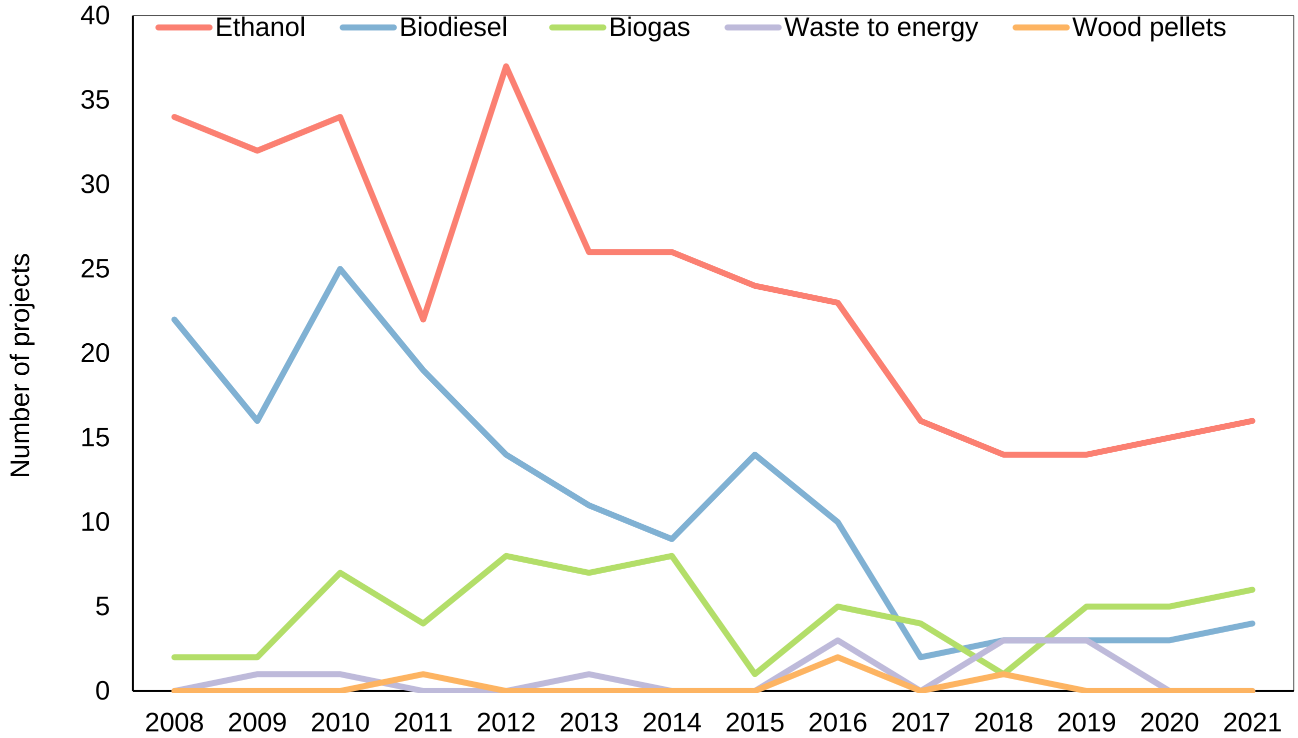


**Figure 3.2.5.** Number of awards granted by the NSF to research projects involving conventional biofuels in the United States from 2008 to 2021 (NSF, 2022).

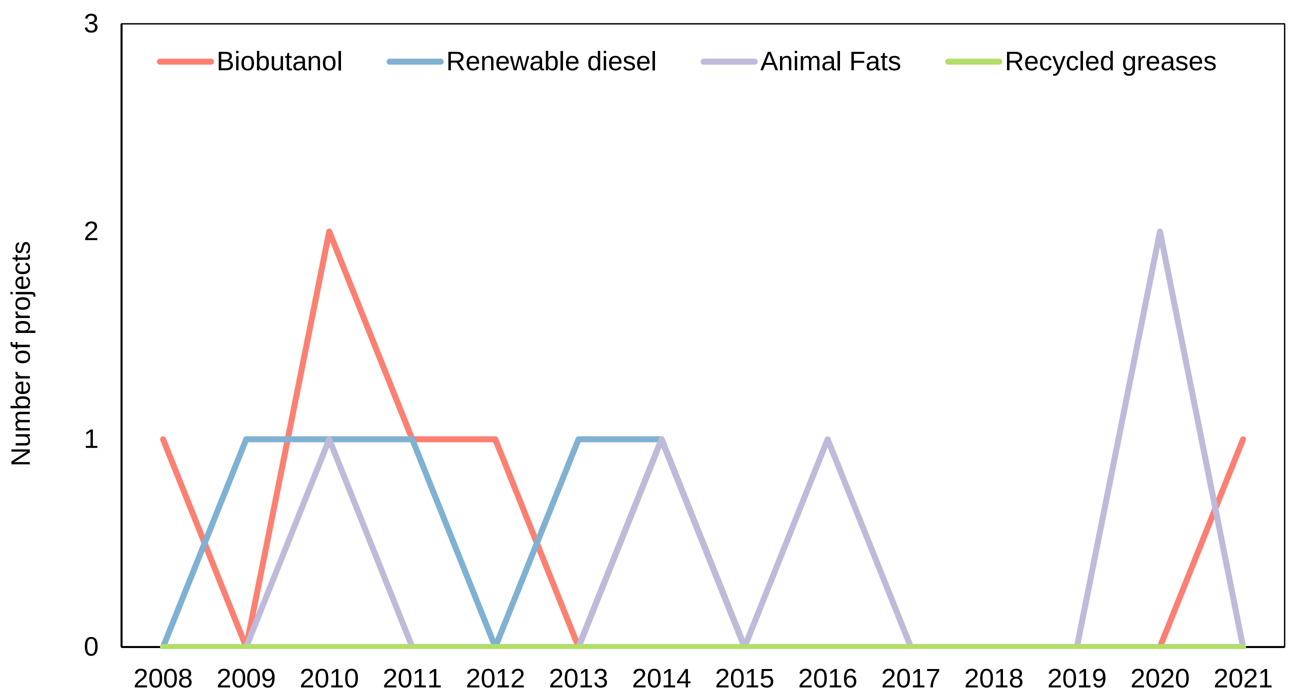


**Figure 3.2.6.** Number of awards granted by the NSF to research projects involving emergent biofuels in the United States from 2008 to 2021 (NSF, 2022).

The number of research projects related to biobased products awarded by the NFS remained nearly constant from 2008 to 2021 with a slight increase of 3 percent. Projects related to enzyme and biochemical research and development represented 98 percent of total biobased products projects in 2021, with 232 and 194 projects, respectively (Figure 3.2.7) (NSF, 2022).

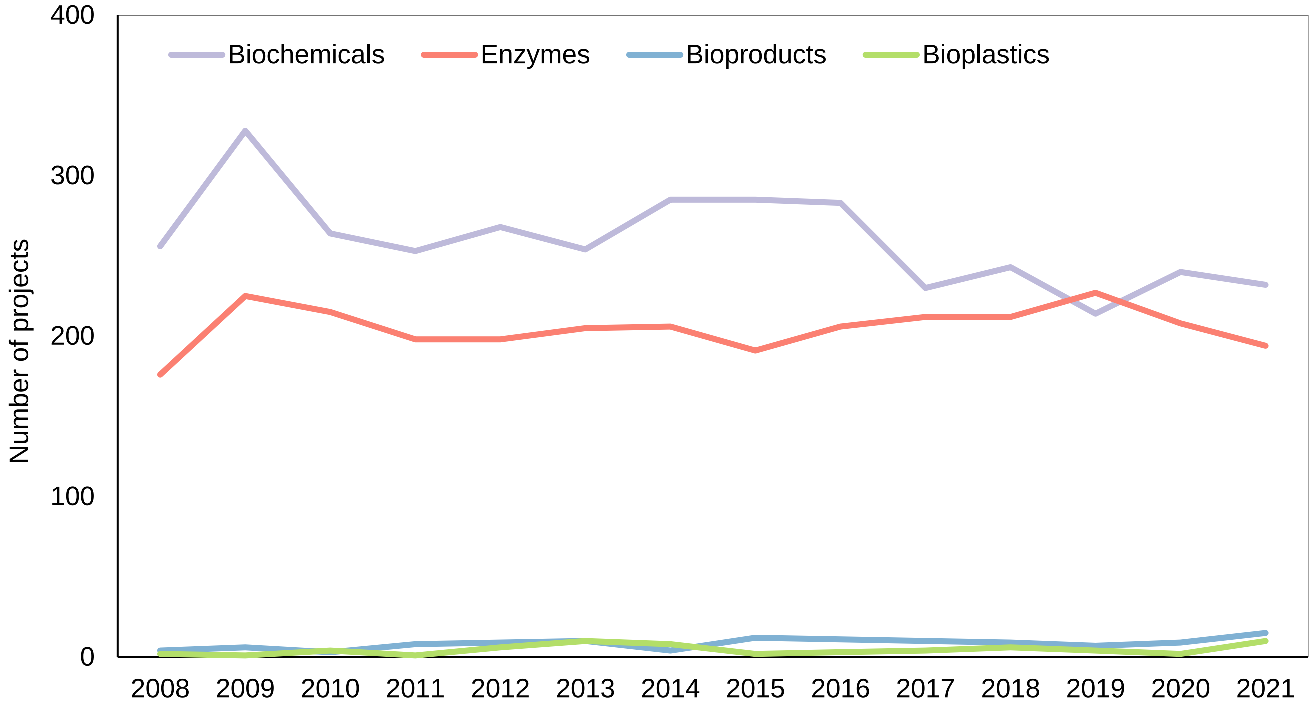


**Figure 3.2.7.** Number of awards granted by the NSF to research projects related to biobased products in the United States from 2008 to 2021 (NSF,2022).

In 2021, less than half of the projects were awarded 100 and 500 thousand dollars, both in biofuels and in biobased products. However, more than half of the projects in biofuels and biobased products were award for 100 and 500 thousand dollars in 2019 and 2020. It is worth noting that 4, 8, and 4 percent of the biofuels (1, 2, and 1 projects) were awarded more than $1 million in 2019, 2020, and 2021, respectively. Biobased products projects (32, 40, and 31 projects) that were awarded more than $1 million showed 8, 10, and 7 percent in 2019, 2020, and 2021, respectively (Figure 3.2.8) (NSF, 2022).

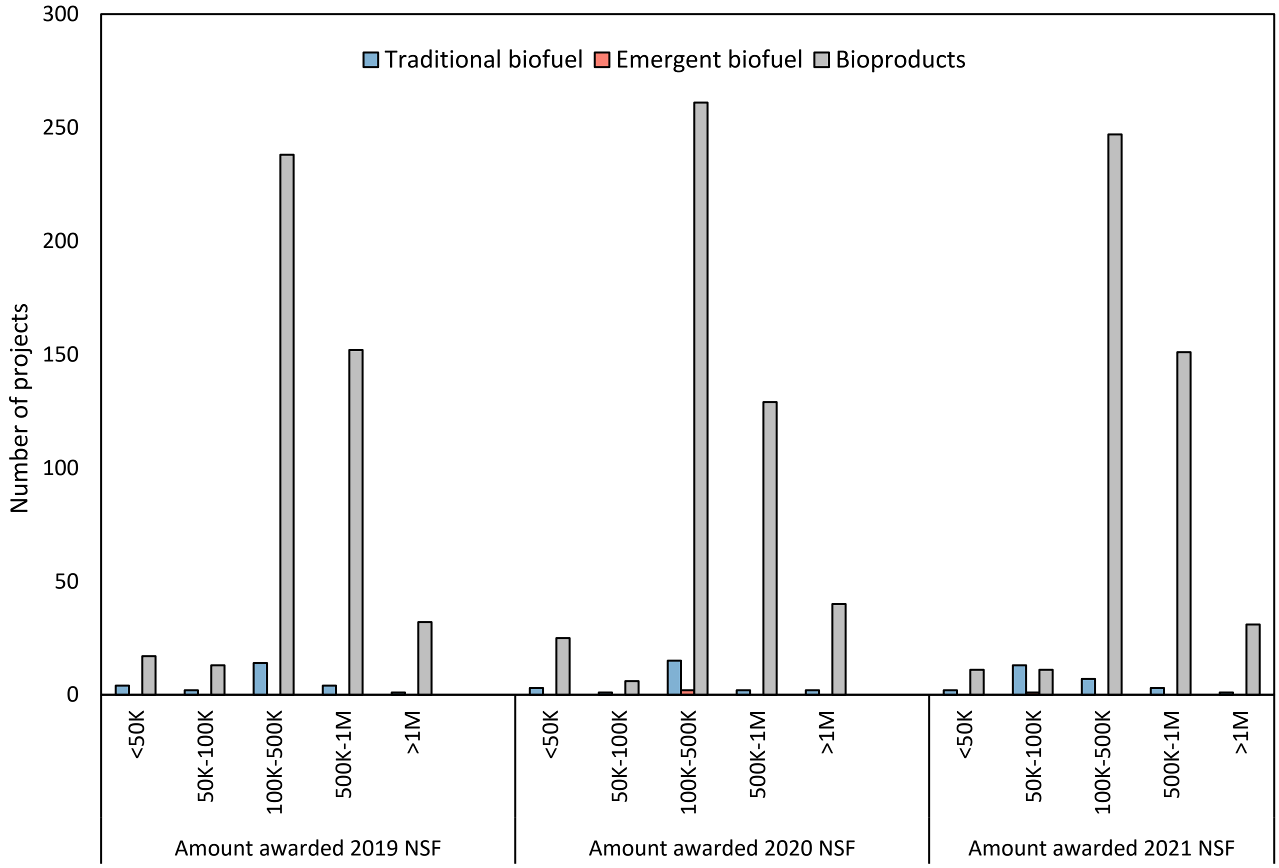


**Figure 3.2.8.** Award amount range in dollars for Biofuels research projects and Bioproducts research projects from 2019 to 2021 in the United States (NSF, 2022).

## 3.3 Capital Expenditure (CAPEX Funding)

### 3.3.1 Energy Investments

There currently exists limited information on investments for the bioeconomy both domestically and globally. The International Energy Agency (IEA) tracks investments for global energy sectors. Worldwide investments in energy declined by 20 percent in 2020, mostly driven by the COVID-19 pandemics impact to the oil and gas sectors. Specifically, renewables for transport and heat of which biobased is an important segment averaged $33.5 billion in investment for the years of 2018 and 2019 (IEA, 2021). During 2019, the United States and China were the two countries with the greatest investment in renewables, yet the United States substantially trailed China investment in overall renewables for transport and for power as presented in figure 3.3.1.

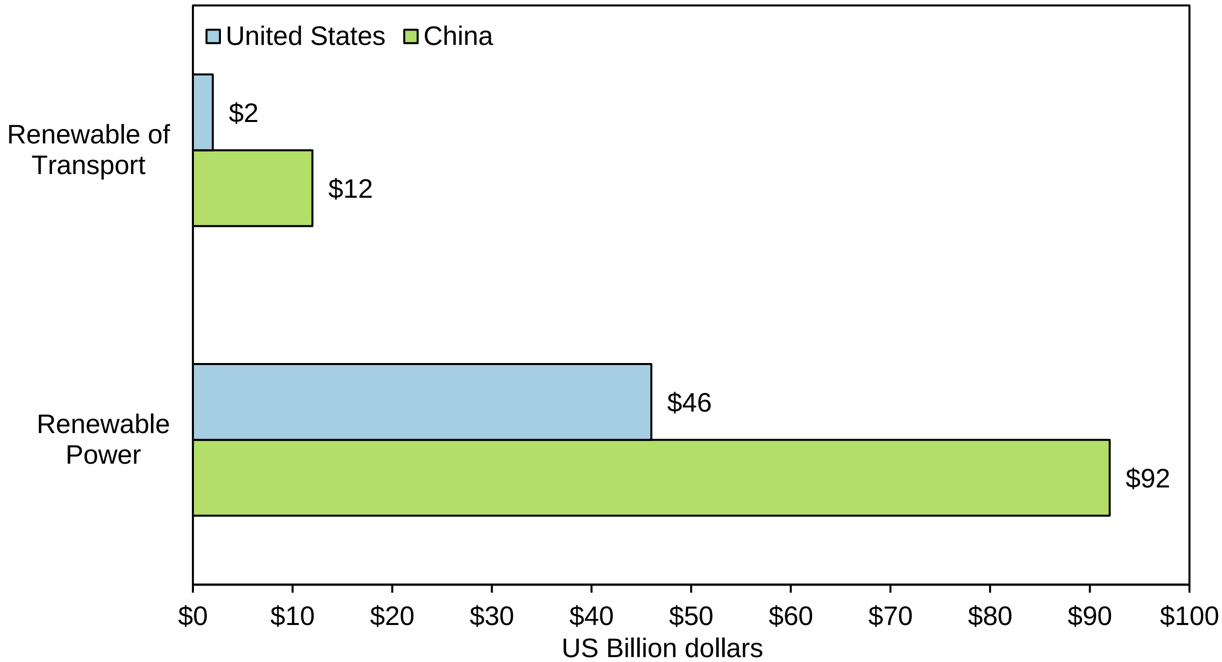


**Figure 3.3.1.** Investments in renewable power and renewable energy for 2019 China vs. United States (IEA, 2021).

### 3.3.2 Biochemicals

Globally, there is increased attention being placed on the plastics industry as public awareness continues to grow of the various adverse environmental impacts from fossil fuel-based plastics which is resulting in new and emerging public policies. As presented below, the market is responding by increasing investments in biochemical and bioplastic start-ups. Investments include grant, equity investment (at various stages), structured loan and private investment in public equity.

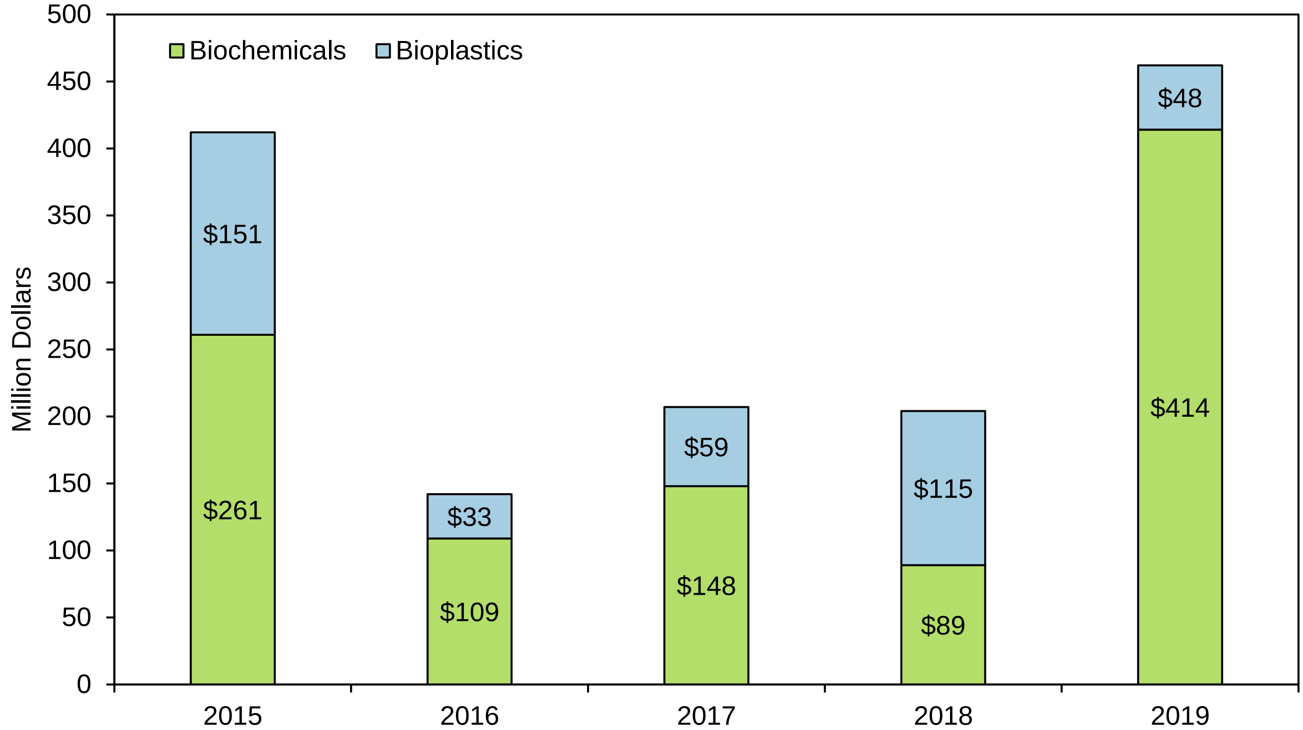


**Figure 3.3.2.** Global Investments in Biochemicals and Bioplastics start-ups, 2015-2020 (IEA, 2021).

### 3.3.3 Biofuels

Globally, investment in biofuels as well as biogas and biomethane has seen a steady decline. This has primarily been driven by national policies and as presented in chapter 1 of this report, the decline is anticipated to continue over the longer term as a result of the electric vehicle transition.

In 2019, there was a global decline in liquid biofuel investments by around 30 percent mostly driven by a dramatic decrease of investments in China which suspended the extension of its 10-percent ethanol blending mandate nationwide to reduce competition for corn production and assure food security.

In the United States, the Renewable Fuel Standard (RFS2) will remain the primary Federal policy driving U.S. biofuel consumption. Consumption increases of biofuels in the United States from 9.99 billion gallons in 2008 to 16.83 billion gallons in 2021 have been greatly contributed by the Federal RFS program (EIA, 2022). The proposed volume requirements for biofuels will gradually increase to 20.82 billion gallons for 2023, 21.87 gallons for 2024, and 22.68 billion gallons for 2025, compared to the 2021 final volume requirement of 18.84 billion gallons (EPA, 2023). As in the past years, the increases in the proposed volume requirements will majorly contribute to consumption of biofuels—ethanol, biodiesel, renewable diesel, and other biofuels including renewable heating oil, renewable jet fuel—that qualify for use in the Federal RFS program (EIA, 2022).

For 2020 and 2021, the COVID-19 crisis resulted in dramatic reductions in gasoline demand which has a cascading impact for the biofuels sectors and interest in investments within the sector (IEA, 2021). In the

United States, the total consumption of biofuels was 15.41 billion gallons in 2020 and 16.83 billion gallons in 2021 that decreased from 17.16 billion gallons in 2019 (EIA, 2022).

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# 5. APPENDIX

## 5.1 Bioindicators Database Structure

The data presented in this report are also available in a separate database. The bioindicators database contains physical, production, trade, and economic data from 2010 to 2021.

### 5.1.1 Database file

"USDA_Bioindicators_2019_2020_2021.xlsx" has a table of contents where the major categories are listed. Each category's name is hyperlinked to the corresponding sheet with the data. When clicking on the hyperlink for the desired category, the sheet with the data for that category is opened. Each data sheet contains the name of the variable, the values of the variable for different years, source name, the link to the reference from which the data was retrieved, and the date of retrieval.

A list of the data included in the database is provided below.

### 5.1.2 Ethanol

Number of ethanol Plants installed in the United States [2010-2021]
Number Ethanol Plants in the United States-Starch [2016-2022]
Number Ethanol Plants in the United States-Cellulosic [2016-2022]
Number Ethanol Plants in the United States-Corn [2018-2022]
Number Ethanol Plants in the United States-Sorghum [2018-2022]
Number Ethanol Plants in the United States-Other (Tobacco, crop residue, waste stream) [2018-2022]
Number of Ethanol Plants Operational in the United States [2011-2019, 2021]
Number of Existing Plants Under Construction [2013-2021]
Number Proposed Ethanol Plants in the United States [2017-2019, 2022]
Number of States which have an Ethanol Production Facility [2010-2021]
Ethanol plant capacities (billion gallons) [2010-2022]
Total Volume of Ethanol Produced in US (billion gallons) [2010-2022]
Total Volume of Ethanol Consumed (billion gallons) [2010-2021]
Total Volume of Ethanol Consumed: Transportation (billion gallons) [2010-2021]
Total Volume of Ethanol Consumed: Industrial sector (billion gallons) [2010-2021]
Total Volume of Ethanol Imported into the US (billion gallons) [2010-2021]
Total Volume of Ethanol Exported from the US (billion gallons) [2010-2021]
Total corn used for Fuel ethanol use (million metric tons) [2010-2021]
Price for Ethanol Per gallon (dollar per gallon) [2010-2022]
Price for Ethanol Per gallon (dollar per gge) [2010-2022]
Price for E85 Per gallon (dollar per gge) [2010-2022]
Price for gasoline Per gallon (dollar per gge) [2010-2022]
Number of direct jobs working with ethanol production [2010-2021]
Number of indirect and induced jobs working with ethanol production [2010-2021]

GDP influence (billion dollars) [2010-2021]
Household income from industry (billion dollars) [2010-2021]
Tax Revenue (billion dollars) [2012-2021]
Crude oil (dollar per barrel) [2010-2021]
Ethanol facilities location by capacity (million gallons) [2019]

### 5.1.3 Biobutanol

Total Volume of Biobutanol entering the commercial market in the US (thousand gallons) [2013-2021]
Biobutanol production estimation (million liters) [2019]

### 5.1.4 Biodiesel

Number of Biodiesel Plants in the United States [2011-2022]
Number of Proposed Biodiesel Plants [2016-2019, 2021]
Number of Existing Plants Under Construction [2016-2019, 2021]
Number of States which have a Biodiesel Production Facility [2011-2022]
Total Production of Biodiesel in US (billion gallons) [2010-2021]
Total Volume of Biodiesel Consumed for Transportation (billion gallons) [2010-2021]
Total Volume of Biodiesel Imported into the US (billion gallons) [2010-2021]
Total Volume of Biodiesel Exported from the US (billion gallons) [2010-2021]
Number of Biodiesel stations [2010-2021]
Price Per Gallon of Biodiesel (dollar per gallon) [2010-2022]
Price Per Gallon of B99/100 (dollar per gge) [2010-2022]
Price Per Gallon of B20 (dollar per gge) [2010-2022]
Price Per Gallon of Diesel (dollar per gge) [2010-2022]
Average Soy Price (dollar per metric tons) [2010-2022]
Number of direct jobs working with biodiesel production [2014-2021]
Biodiesel facilities location by capacity (million gallons) [2019]

### 5.1.5 Animal Fats and Recycled Greases

Total production of Poultry Fat (Thousand metric tons) [2011-2021]
Total production of Tallow (Thousand metric tons) [2011-2021]
Total production of White Grease (Thousand metric tons) [2011-2021]
Total production of Yellow Grease (Thousand metric tons) [2011-2021]
Total production of Other fats (Thousand metric tons) [2011-2021]
Total consumption of Poultry Fat (Thousand metric tons) [2011-2018]
Total consumption of Tallow (Thousand metric tons) [2011-2018]
Total consumption of White Grease (Thousand metric tons) [2011-2018]
Total consumption of Yellow Grease (Thousand metric tons) [2011-2018]
Total consumption of Poultry Going to Biodiesel (Thousand metric tons) [2009-2021]
Total consumption of Tallow Going to Biodiesel (Thousand metric tons) [2009-2021]
Total consumption of White Grease Going to Biodiesel (Thousand metric tons) [2009-2021]
Total consumption of Yellow Grease to Biodiesel (Thousand metric tons) [2009-2021]

Total consumption of Other fats Going to Biodiesel (Thousand metric tons) [2009-2021]
Total exports of Poultry Fat (Thousand metric tons) [2012-2021]
Total exports of Tallow (Thousand metric tons) [2011-2021]
Total exports of White Grease (Thousand metric tons) [2011-2021]
Total exports of Yellow Grease (Thousand metric tons) [2011-2021]
Total imports of Poultry Fat (Thousand metric tons) [2012-2021]
Total imports of Tallow (Thousand metric tons) [2012-2021]
Total imports of White Grease (Thousand metric tons) [2012-2021]
Total imports of Yellow Grease (Thousand metric tons) [2012-2021]
Price for Poultry Fat (dollar per metric ton) [2011-2021]
Price for Tallow (dollar per metric ton) [2011-2021]
Price for White Grease (dollar per metric ton) [2011-2021]
Price for Yellow Grease (dollar per metric ton) [2011-2021]

#### 5.1.6 Renewable Diesel

Total Production of Renewable Diesel in the US (million gallons) [2010-2022]
Total Consumption of Renewable Diesel in the US (million gallons) [2010-2022]
Total Volume of Renewable Diesel Exported from the US (million gallons) [2016-2019]
Total Volume of Renewable Diesel Imported into the US (million gallons) [2012-2021]

#### 5.1.7 Renewable Jet Fuel

Total production of renewable jet fuel (thousand gallons) [2016-2022]

#### 5.1.8 Wood Pellets

Number of WP Plants in the United States [2013-2021]
Number of Proposed WP Plants [2013-2021]
Number of Existing Plants Under Construction [2013-2021]
Number of Existing Plants that Were Put on Standby [2016-2021]
Number of States which have an WP Production Facility [2013-2021]
Wood pellets Production (million metric tons) [2012-2021]
Wood pellets Imports (Thousand metric tons) [2012-2021]
Wood pellets Exports (million metric tons) [2012-2021]
Wood pellets Consumption (million metric tons) [2012-2021]
Electricity Net Generation from Wood (trillion BTUs) [2010-2022]
Electricity Net Generation from Wood (trillion BTUs): Industrial Sector [2010-2022]
Electricity Net Generation from Wood (trillion BTUs): Electric Power Sector [2010-2022]
Heating from Wood in the US (trillion BTUs) [2010-2022]
Energy Consumption from Wood in US (trillion BTUs) [2010-2022]
Energy Consumption from Wood in US (trillion BTUs): Residential Sector [2010-2022]
Energy Consumption from Wood in US (trillion BTUs): Commercial Sector [2010-2022]
Energy Consumption from Wood in US (trillion BTUs): Industrial Sector [2010-2022]
Energy Consumption from Wood in US (trillion BTUs): Electric Power Sector [2010-2022]

Wood pellet production worldwide (million metric tons) [2010-2020]
Average Annual Densified Biomass Capacity (million metric tons) [2016-2022]
Wood Pellets Exported from US (in million $) [2012-2020]
Wood Pellets Imported from US (in million $) [2012-2020]
Total Jobs Created in the Wood Pellet Industry [2010-2021]
Wood pellets facilities location by capacity (metric tons) [2019]
Wood pellets production by country (metric tons) [2019]

#### 5.1.9 Waste to Energy

Number of WTE Plants in the United States [2010-2019]
Number of WTE Plants Proposed in US [2010-2021]
Number of WTE Existing Plants that Were Put on Standby [2010-2021]
Number of WTE Existing Plants that Were Closed-Shut Down [2010-2021]
Number of WTE Fuel Switching Plants in US [2010-2021]
Number of States which have an WTE Fuel Switching Production Facility [2010-2021]
Municipal solid waste generation in the United States (million metric tons) [2010-2018]
Municipal solid waste generation in the United States (million metric tons): Recycled and composted [2010-2018]
Municipal solid waste generation in the United States (million metric tons): Combusted with Energy recovery [2010-2018]
Municipal solid waste generation in the United States (million metric tons): Landfilled [2010-2018]
Biogenic Municipal Solid Waste: Consumption for Electricity Generation (million metric tons) [2010-2021]
Biogenic Municipal Solid Waste: Consumption for Heating Generation (million metric tons) [2010-2021]
Biogenic Municipal Solid Waste: Consumption for Energy Generation (million metric tons) [2010-2021]
Biogenic Municipal Solid Waste: Consumption for Energy Generation (million metric tons): Electric utilities [2010-2021]
Biogenic Municipal Solid Waste: Consumption for Energy Generation (million metric tons): Independent power producers [2010-2021]
Biogenic Municipal Solid Waste: Consumption for Energy Generation (million metric tons): Commercial sector [2010-2021]
Biogenic Municipal Solid Waste: Consumption for Energy Generation (million metric tons): Industrial Sector [2010-2021]
Biogenic Municipal Solid Waste: Consumption for Electricity Generation (Trillion BTUs) [2010-2021]
Biogenic Municipal Solid Waste: Consumption for Heating Generation (Trillion BTUs) [2010-2021]
Biogenic Municipal Solid Waste: Consumption for Energy Generation (Trillion BTUs) [2010-2021]
Biogenic Municipal Solid Waste: Consumption for Energy Generation (Trillion BTUs): Electric utilities [2010-2021]
Biogenic Municipal Solid Waste: Consumption for Energy Generation (Trillion BTUs): Independent power producers [2010-2021]
Biogenic Municipal Solid Waste: Consumption for Energy Generation (Trillion BTUs): Commercial sector [2010-2021]

Biogenic Municipal Solid Waste: Consumption for Energy Generation (Trillion BTUs): Industrial Sector [2010-2021]
Revenue from waste electricity generation in the U.S. (million dollars) [2011-2020]
Jobs in WTE Facilities [2013-2014, 2016, 2018]
Total jobs (direct, indirect, and induced) created by WTE [2013-2014, 2016, 2018]
Total Economic output by WTE (million dollars) [2013-2014, 2016, 2018]
Waste-to-energy facilities location by net generation (MWh) [2019]

### 5.1.10 Biogas

Number of anaerobic digestion (AD) Plants [2010-2022]
Number of anaerobic digestion (AD) Plants used for Electricity [2010-2022]
Number of anaerobic digestion (AD) Plants used for Boiler/Furnace [2010-2022]
Number of anaerobic digestion (AD) Plants used for "Flare Full Time" [2010-2022]
Number of anaerobic digestion (AD) Plants used for Cogeneration [2010-2022]
Number of Existing AD Plants Under Construction [2010-2022]
Number of New AD Plants that Went online from livestock [2010-2021]
Number of AD Plants that Shut Down [2010-2019]
Number of States which have an AD Production Facility [2010-2022]
Number of landfill Plants [2010-2021]
Number of States which have a landfill Facility [2010-2021]
Biogas potential from landfills (billion cubic feet) [2018, 2020]
Biogas potential from wastewater (billion cubic feet) [2018, 2020-2021]
Biogas potential from animal manure (billion cubic feet) [2018, 2020]
Anaerobic digestion: Biogas generated (trillion BTU) [2010-2021]
Anaerobic digestion: Biogas generated (billion cubic feet) [2010-2021]
Anaerobic digestion: Total Methane Emission Reductions (million metric tons of $CO_2$) [2010-2021]
Agriculture: total methane emissions (million metric tons of $CO_2$) [2010-2020]
Landfill gas: energy consumption (trillion BTU) [2010-2021]
Landfill gas: energy consumption (billion cubic feet) [2010-2021]
Landfill gas: Total Methane Emission Reductions (million metric tons of $CO_2$) [2010-2021]
Waste: total methane emissions (million metric tons of $CO_2$) [2010-2021]
Anaerobic digesters in farms location [2019]
Landfill locations [2019]
Wastewater treatment facilities location [2015]
Biomethane production (thousand metric tons) [2019]

### 5.1.11 Bioproducts

USDA BioPreferred product certifications: Total [2017-2019, 2022]
USDA BioPreferred product certifications: Baby and Kids [2017-2019, 2022]
USDA BioPreferred product certifications: Construction [2017-2019 2022]
USDA BioPreferred product certifications: Custodial Services [2017-2019, 2022]
USDA BioPreferred product certifications: Films and Packaging [2017-2019, 2022]

USDA BioPreferred product certifications: Food Services/Cafeteria [2017-2019, 2022]
USDA BioPreferred product certifications: Grounds Maintenance [2017-2019, 2022]
USDA BioPreferred product certifications: Household Supplies [2017-2019, 2022]
USDA BioPreferred product certifications: Intermediates [2017-2019, 2022]
USDA BioPreferred product certifications: Miscellaneous [2017-2019, 2022]
USDA BioPreferred product certifications: Office Supplies [2017-2019, 2022]
USDA BioPreferred product certifications: Operations and Maintenance [2017-2019, 2022]
USDA BioPreferred product certifications: Personal Care and Toiletries [2017-2019, 2022]
USDA BioPreferred product certifications: Safety Equipment [2017-2019, 2022]
USDA BioPreferred product certifications: Vehicles and Equipment Maintenance [2017-2019, 2022]

#### 5.1.12 Bioplastics

U.S. Plastic and Rubber Products Value Added (billion dollars) [2008-2021]
Value Added of Manufacturing US Plastic and Rubber Products as Percentage of GDP ( percent ) [2008-2021]
Gross Output of US Plastic and Rubber Products (billion dollars) [2008-2021]
Compensation of Employees, Value Added of Plastics and Rubber Products (billion dollars) [2008-2020]
Taxes on Production and Imports, Less Subsides of US Plastics and Rubber Products (billion dollars) [2008-2020]
Gross Operating Surplus of Plastics and Rubber Product Products (billion dollars) [2008-2020]
Full and Part Time Employees (thousands) [2008-2020]
Global Plastic Production (million metric tons) [2008-2020]
Global production capacity of biodegradable bioplastics (million metric tons) [2008-2021]
Global production capacity of non-biodegradable bioplastics (million metric tons) [2008-2021]
Global production capacities of biodegradable and non-biodegradable bioplastics: Total (million metric tons) [2008-2021]
Global production capacities of biodegradable and non-biodegradable bioplastics: Packaging (flexible &rigid) (percent) [2017-2021]
Global production capacities of biodegradable and non-biodegradable bioplastics: Textiles (percent) [2017-2021]
Global production capacities of biodegradable and non-biodegradable bioplastics: Consumer Goods (percent) [2017-2021]
Global production capacities of biodegradable and non-biodegradable bioplastics: Agriculture & Horticulture (percent) [2017-2021]
Global production capacities of biodegradable and non-biodegradable bioplastics: Automotive & Transport (percent) [2017-2021]
Global production capacities of biodegradable and non-biodegradable bioplastics: Building & Construction (percent) [2017-2021]
Global production capacities of biodegradable and non-biodegradable bioplastics: Electronics (percent) [2017-2021]
Global production capacities of biodegradable and non-biodegradable bioplastics: Others (percent) [2017-2021]

Global production capacities of biodegradable and non-biodegradable bioplastics: Starch Blends (percent) [2014, 2017-2021]
Global production capacities of biodegradable and non-biodegradable bioplastics: Polylactic Acid (PLA) (percent) [2014, 2017-2021]
Global production capacities of biodegradable and non-biodegradable bioplastics: Poly (butylene adipate-co-terephthalate) (PBAT) (percent) [2014, 2017-2021]
Global production capacities of biodegradable and non-biodegradable bioplastics: Polyethylene (PE) (percent) [2014, 2017-2021]
Global production capacities of biodegradable and non-biodegradable bioplastics: Polyamides (PA) (percent) [2014, 2017-2021]
Global production capacities of biodegradable and non-biodegradable bioplastics: Polyethylene Global production capacities of biodegradable and non-biodegradable bioplastics: Terephthalate (PET) (percent) [2014, 2017-2021]
Global production capacities of biodegradable and non-biodegradable bioplastics: Polytrimethylene (PET) (percent) [2014, 2017-2021]
Global production capacities of biodegradable and non-biodegradable bioplastics: Terephthalate (PTT) (percent) [2014, 2018-2021]
Global production capacities of biodegradable and non-biodegradable bioplastics: Polybutylene Succinate (PBS) (percent) [2014, 2017-2021]
Global production capacities of biodegradable and non-biodegradable bioplastics: Other (percent) [2014, 2017-2021]
Global production capacities of biodegradable and non-biodegradable bioplastics: Polyhydroxyalkanoates (PHA) (percent) [2014, 2017-2021]
Global production capacities of biodegradable and non-biodegradable bioplastics: Polyproprylene (PP) (percent) [2014, 2017-2021]
Percentage of Bioplastic in Total Global Plastic Consumption [2008-2020]
Land Used for Bioplastics (million ha) [2013-2021]
Land Used for Bioplastics/Total Amount of Arable Land (percent) [2013-2021]

**5.1.13 Enzymes**

Global Industrial Enzyme Market (billion dollars): Total [2008-2021]
Global Industrial Enzyme Market (billion dollars): Food (billion dollars) [2011-2017]
Global Industrial Enzyme Market (billion dollars): Feed (billion dollars) [2011-2013, 2016-2017]
Global Industrial Enzyme Market (billion dollars): Technical (billion dollars) [2011-2013, 2016-2017]
Global Industrial Enzyme Market (billion dollars): Biofuel (billion dollars) [2017]
Global Industrial Enzyme Market (billion dollars): Other (billion dollars) [2017]
Global Industrial Enzyme Market (billion dollars): Detergent (billion dollars) [2011-2013, 2016]

**5.1.14 Forest Products**

U.S. Wood Products Value Added (billion dollars) [2008-2021]
Value Added of Manufacturing US Wood Products as Percentage of GDP (percent) [2008-2021]
Gross Output of US Wood Products (billion dollars) [2008-2020]
Compensation of Employees, Value Added of Wood Products (billion dollars) [2008-2020]
Taxes of Production and Imports, Less Subsides of US Wood Products (billion dollars) [2008-2020]
Gross Operating Surplus of Wood Products (billion dollars) [2008-2020]
Full and Part Time Employees of US Wood Products (thousands) [2008-2020]
U.S. Paper Products Value Added (billion dollars) [2008-2021]
Value Added of Manufacturing US Paper Products as Percentage of GDP (percent) [2008-2021]
Gross Output of US Paper Products (billion dollars) [2008-2020]
Compensation of Employees, Value Added of Paper Products (billion dollars) [2008-2020]
Taxes of Production and Imports, Less Subsides of US Paper Products (billion dollars) [2008-2020]
Gross Operating Surplus of Paper Products (billion dollars) [2008-2020]
Full and Part Time Employees of US Paper Products (thousands) [2008-2020]
Total production of Wood fuel (million $m^3$) [2008-2021]
Total production of Wood residues (million $m^3$) [2008-2021]
Total production of Roundwood (million $m^3$) [2008-2021]
Total production of Sawnwood (million $m^3$) [2008-2021]
Total production of Wood-based panels (million $m^3$) [2008-2021]
Total production of Wood pulp (million metric tons) [2008-2021]
Total production of Paper and paperboard (million metric tons) [2008-2021]
Total production of Wood pellets (million metric tons) [2012-2021]
Total production of Forest products Imports (billion dollars) [2008-2021]
Total production of Forest products Exports (billion dollars) [2008-2021]

**5.1.15 Funding**

Number of awards granted by the NIFA to research projects involving Ethanol [2008-2021]
Number of awards granted by the NIFA to research projects involving Biobutanol [2008-2021]
Number of awards granted by the NIFA to research projects involving Biodiesel [2008-2021]
Number of awards granted by the NIFA to research projects involving Renewable diesel [2008-2021]
Number of awards granted by the NIFA to research projects involving Recycled greases [2008-2021]
Number of awards granted by the NIFA to research projects involving Animal Fats [2008-2021]

Number of awards granted by the NIFA to research projects involving Wood pellets [2008-2021]
Number of awards granted by the NIFA to research projects involving Waste to energy [2008-2021]
Number of awards granted by the NIFA to research projects involving Biogas [2008-2021]
Number of awards granted by the NIFA to research projects involving Bioproducts [2008-2021]
Number of awards granted by the NIFA to research projects involving Bioplastics [2008-2021]
Number of awards granted by the NIFA to research projects involving Biochemicals [2008-2021]
Number of awards granted by the NIFA to research projects involving Enzymes [2008-2021]
Number of awards granted by the NSF to research projects involving Ethanol [2008-2021]
Number of awards granted by the NSF to research projects involving Biobutanol [2008-2021]
Number of awards granted by the NSF to research projects involving Biodiesel [2008-2021]
Number of awards granted by the NSF to research projects involving Renewable diesel [2008-2021]
Number of awards granted by the NSF to research projects involving Recycled greases [2008-2021]
Number of awards granted by the NSF to research projects involving Animal Fats [2008-2021]
Number of awards granted by the NSF to research projects involving Wood pellets [2008-2021]
Number of awards granted by the NSF to research projects involving Waste to energy [2008-2021]
Number of awards granted by the NSF to research projects involving Biogas [2008-2021]
Number of awards granted by the NSF to research projects involving Bioproducts [2008-2021]
Number of awards granted by the NSF to research projects involving Bioplastics [2008-2021]
Number of awards granted by the NSF to research projects involving Biochemicals [2008-2021]
Number of awards granted by the NSF to research projects involving Enzymes [2008-2021]
Award amount range by the NIFA for biofuels and bioproducts projects (dollars) [2021]
Award amount range by the NSF for biofuels and bioproducts projects (dollars) [2021]