An Economic Impact Analysis of the U.S. Biobased Products Industry

2023 Update

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About the Authors

Jay S. Golden, Ph.D.
Contact: JGolde04@syr.edu

DYNAMIC SUSTAINABILITY LAB™
AT SYRACUSE UNIVERSITY

Dr. Jay Golden is the Pontarelli Professor of Environmental Sustainability and Finance at Syracuse University in the Maxwell School of Citizenship and Public Affairs. Golden also founded and directs the Dynamic Sustainability Lab (www.DynamicsLab.org). Golden's research covers sustainable dynamics and systems with a focus on the utilization of Earth's resources and global commerce related to the net-zero carbon economy transition.

Golden received his Ph.D. in Engineering from the University of Cambridge and his Master's degree in Environmental Engineering and Sustainable Development from a joint program of the Massachusetts Institute of Technology and the University of Cambridge. He also holds a Professional Mastery of Project Management Certificate from Stanford University, an MLE in Higher Education from Harvard, and has a B.A. degree in Management.

Golden serves as a technical advisor and consultant to corporations and governments around the world. He is on the Board of Scientific Counselors to the U.S. EPA and is the author of the forthcoming book *Dynamic Sustainability: Implications for Policy, Markets and National Security* by Cambridge University Press.

Robert Handfield, Ph.D.
Contact: Rbhandfi@ncsu.edu

NC STATE Poole College of Management
Supply Chain Resource Cooperative

Dr. Rob Handfield is the Bank of America University Distinguished Professor of Supply Chain Management at North Carolina State University, and he is the Executive Director of the Supply Chain Resource Cooperative (http://scm.ncsu.edu). He also serves as Faculty Lead for the Manufacturing Analytics group within the International Institute of Analytics, and he is on the Faculty for Operations Research Curriculum at NC State University. Dr. Handfield also served as Associate Professor and Research Associate with the Global Procurement and Supply Chain Benchmarking Initiative at Michigan State University from 1992-1999. He received his Ph.D. in Management from the University of North Carolina at Chapel Hill.

Dr. Handfield is the author of several books on supply chain management. His most recent publications include The LIVING Supply Chain, Biopharmaceutical Supply Chains, Supply Market Intelligence, Supply Chain Re-Design, and Introduction to Supply Chain Management (25,000 copies sold and translated into multiple languages). He has co-authored textbooks for MBA and undergraduate courses, including Purchasing and Supply Chain Management 6th revision (with Robert Monczka) and Operations and Supply Chain Management 3rd revision (with Cecil Bozarth). He recently led a global study on the Emerging Procurement Technology: Data Analytics and Cognitive Analytics for CAPS Research, Procurement Analytics for IBM, Global Logistics Trends and Strategies for BVL International in 2013, and a report titled "Future Buy: The Future of Procurement," published by KPMG.

Dr. Handfield is focused on digital supply chains, sustainable procurement, and is a co-author of the four prior biobased products industry economic impact studies. He has worked with over 25 Fortune 500 companies on different aspects of supply chain management, sustainability, and digital analytics.

Jesse Daystar, Ph.D.
Contact: jsdaysta@gmail.com

Dr. Jesse Daystar is an Assistant Adjunct Professor at the Nicholas School of the Environment at Duke University and at the Department of Forest Biomaterials at North Carolina State University. He also serves as the Chief Sustainability Officer and Vice President of Sustainability at Cotton Incorporated. Dr. Daystar has Ph.D. and M.S. degrees in Forest Biomaterials, and he has B.S. degrees in Chemical and Pulp & Paper Engineering from North Carolina State University.

Dr. Daystar is a leader in the field of life cycle assessment of agriculture, textiles, forest biomaterials, and cellulosic biofuels. He has published extensively in these fields in leading peer-reviewed journals and authored a book chapter on life cycle assessment. Beyond publishing research, Dr. Daystar contributes to the academic community by serving on the USDA Biomass Research and Development Initiative awards review panel. He also serves on the Metrics Committee at Field to Market, which convenes diverse stakeholders to work collaboratively to define, measure, and advance the sustainability of food, fiber, and fuel production in the United States.

At Cotton Incorporated, Dr. Daystar develops and implements sustainability strategies, working with industry, academia, and non-governmental organizations across the entire cotton supply chain to drive systemic changes towards more sustainable apparel production.

Steven Pires
Contact: Stevenpires@gmail.com

NC STATE UNIVERSITY

Steven Pires is a PhD candidate at North Carolina State University where he is researching the benefits of biogenic carbon as a mechanism to limit the impacts of climate change. He has over 10 years' experience in sustainability and project management roles focused on helping clients create effective strategies that drive ecological conservation, natural resource efficiency, and sustainable development. Additionally, he has served as vice president and co-founder for an environmental life cycle assessment consultancy. He holds a Master of Science in Forest Biomaterials Science and a B.S. in Environmental Technology and Management both from North Carolina State University.

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Executive Summary

This report was prepared for the U.S. Department of Agriculture (USDA) Rural Development BioPreferred® Program. The conclusions and recommendations are those of the authors and have not been endorsed by the USDA.

This report seeks to address seven important questions regarding the contributions of the biobased products industry in the United States:

(i.) the quantity of biobased products sold,
(ii.) the value of biobased products,
(iii.) the quantity of jobs contributed,
(iv.) the quantity of petroleum displaced,
(v.) other environmental benefits,
(vi.) the economic impacts of biobased exports, and
(vii.) areas in which the use or manufacturing of biobased products could be more effective, including identifying any technical or economic obstacles and recommending how those obstacles can be overcome.

This report is part of a series of USDA reports tracking the impact of the biobased products industry on the U.S. economy. The series includes the October 2014 report, *Why Biobased? Opportunities in the Emerging Bioeconomy*;[1] the June 2015 report, *An Economic Impact Analysis of the U.S. Biobased Products Industry,*[2] and the October 2016,[3] July 2019,[4] and 2021 report updates.[5]

Although there have been several studies on the contribution of the biobased products sector to the global and European economies, this report examines and quantifies the effect of the U.S. biobased products industry from economic, jobs, and environmental perspectives, and provides an important update to past reports. This report is intended to provide a snapshot of available information and a foundation for

[1]Golden, J.S. and Handfield, R.B., "Why Biobased? Opportunities in the Emerging Bioeconomy", USDA BioPreferred® Program website, http://www.biopreferred.gov/BPResources/files/WhyBiobased.pdf.
[2]Golden, J.S., Handfield, R.B., Daystar, J., and McConnell, T.E. An Economic Impact Analysis of the U.S. Biobased Products Industry: A Report to the Congress of the United States of America. A Joint Publication of the Duke Center for Sustainability & Commerce and the Supply Chain Resource Cooperative at North Carolina State University, 2015. https://www.biopreferred.gov/BPResources/files/EconomicReport_6_12_2015.pdf.
[3]Golden, J.S., Handfield, R.B., Daystar, J., Morrison, B., and McConnell, T.E. An Economic Impact Analysis of the U.S. Biobased Products Industry: 2016 Update. A Joint Publication of the Duke Center for Sustainability & Commerce and the Supply Chain Resource Cooperative at North Carolina State University, 2016. https://www.biopreferred.gov/BPResources/files/BiobasedProductsEconomicAnalysis2016.pdf.
[4]Daystar, J., Handfield, R.B., Golden, J.S., and McConnell, T.E. An Economic Impact Analysis of the U.S. Biobased Products Industry: 2018 Update. A Joint Publication of the A Joint Publication of the Supply Chain Resource Cooperative at North Carolina State University and the College of Engineering and Technology at East Carolina University, 2019. https://www.biopreferred.gov/BPResources/files/BiobasedProductsEconomicAnalysis2018.pdf.
[5]Daystar, J., Handfield, R.B., Pascual-Gonzalez, J., McConnell, E., and J.S. Golden (2020). An Economic Impact Analysis of the U.S. Biobased Products Industry: 2019 Update. https://www.rd.usda.gov/sites/default/files/usda_rd_economic_impact_analysis_us_biobased_products_industry.pdf

future efforts as more structured reporting and tracking mechanisms are developed.

This study uses a similar, proven methodology to past reports that took a three-pronged approach to gathering information on the biobased products industry. First, interviewing a broad spectrum of representatives of government, industry, and trade associations involved in the biobased products industry to understand the challenges and future growth potential for biobased products. Second, collecting statistics from government agencies and published literature on biobased products, economics, and jobs. Third, conducting extensive economic modeling using IMPLAN modeling software, developed by the U.S. Forest Service, to analyze and trace spending through the U.S. economy and measure the cumulative effects of that spending.

The IMPLAN model tracks the way dollars injected into one sector are spent and re-spent in other sectors of the economy, generating waves of economic activity, or "economic multiplier" effects. IMPLAN uses national industry data and county-level economic data to generate a series of multipliers, which, in turn, are used to estimate the total implications of economic activity as direct, indirect, and induced effects. Contributions analyses were conducted to assess the effects of specific biobased segments within the U.S. economy.

The seven major sectors covered in this report that represent the U.S. biobased products industry's contribution to the U.S. economy are:

- Agriculture and Forestry,
- Biobased Chemicals,
- Biobased Plastic Bottles and Packaging,
- Biorefining,
- Enzymes,
- Forest Products, and
- Textiles.

This report specifically excludes the energy, livestock, food, feed, and pharmaceuticals sectors.

Within this report, the modeling of the economic and job benefits of the biobased products industry is reported for calendar year 2021, which represents the most current data available as of the writing of this report in 2023.

When viewing results, it is very important to note that the impacts of the global COVID-19 pandemic had implications on the biobased products industry, as it did for the overall domestic and global economies. These impacts will be discussed further in this report.

As presented in Figure 1, the number of people employed in the U.S. biobased products industry in 2021 was 3.94 million people, a drop from the 4.6 million people employed pre-pandemic in 2017.

However, the value added contribution to the U.S. economy grew even through the pandemic, from $470 billion in 2017 to $489 billion in 2021. Each job in the biobased products industry supported an estimated 1.4 jobs in other sectors of the economy.

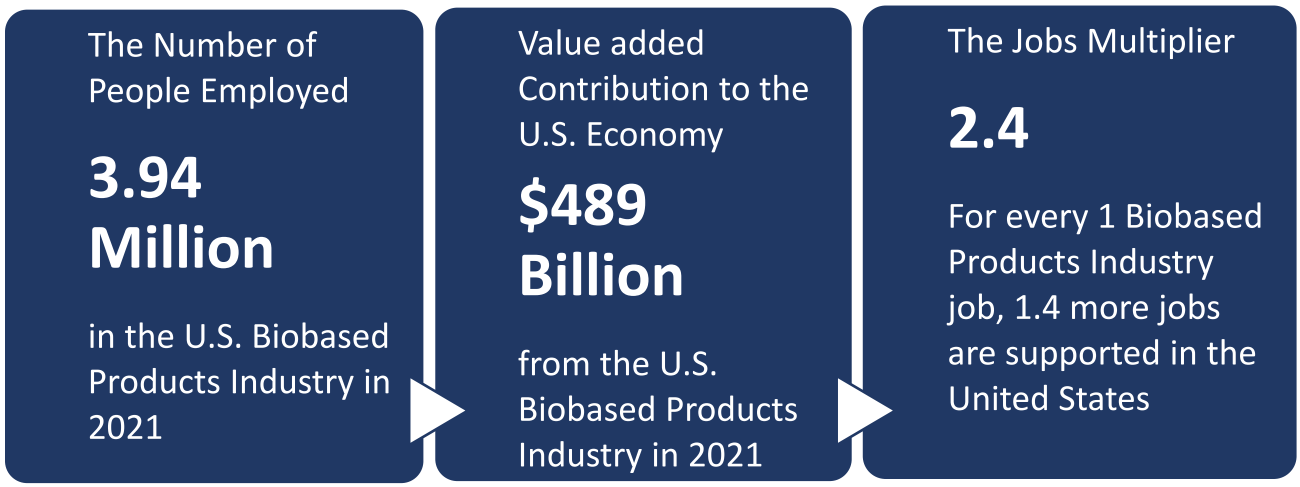

Figure 1: U.S. biobased products industry key findings in 2021.

Figure 2 (below) provides greater insights as to both the employment and value added to the economy by breaking down the numbers by direct, indirect, and induced values.

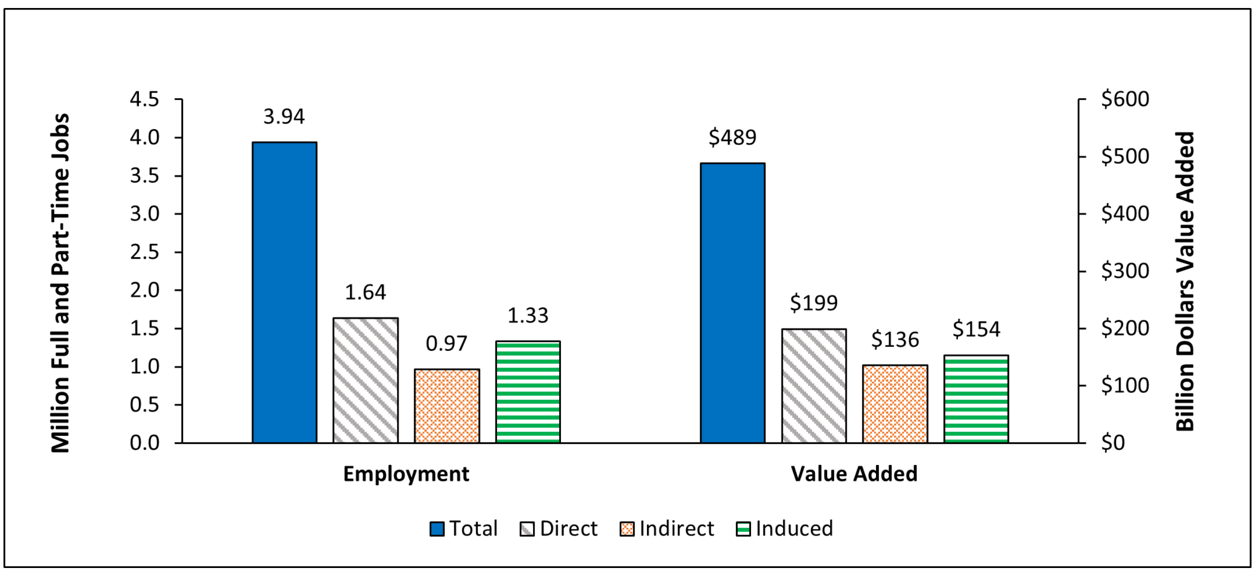

Figure 2: Total employment and value added to the U.S. economy from the biobased products industry in 2021.

Figure 3 shows that the value added to the U.S. economy by biobased products was $489 billion in 2021, up from $464 billion in 2020. This is an increase of $25 billion or a 5.1% increase over 2020. This rebound reflects recovering economies after the economy largely shutdown in 2020. Back modeled data from 2015 is shown for greater context.

Figure 4 shows that employment in the industry decreased slightly from 4.05 million jobs in 2020 to 3.94 million jobs in 2021.

This decrease is likely due in part to challenges in the labor market upon restarting the economy in 2021.

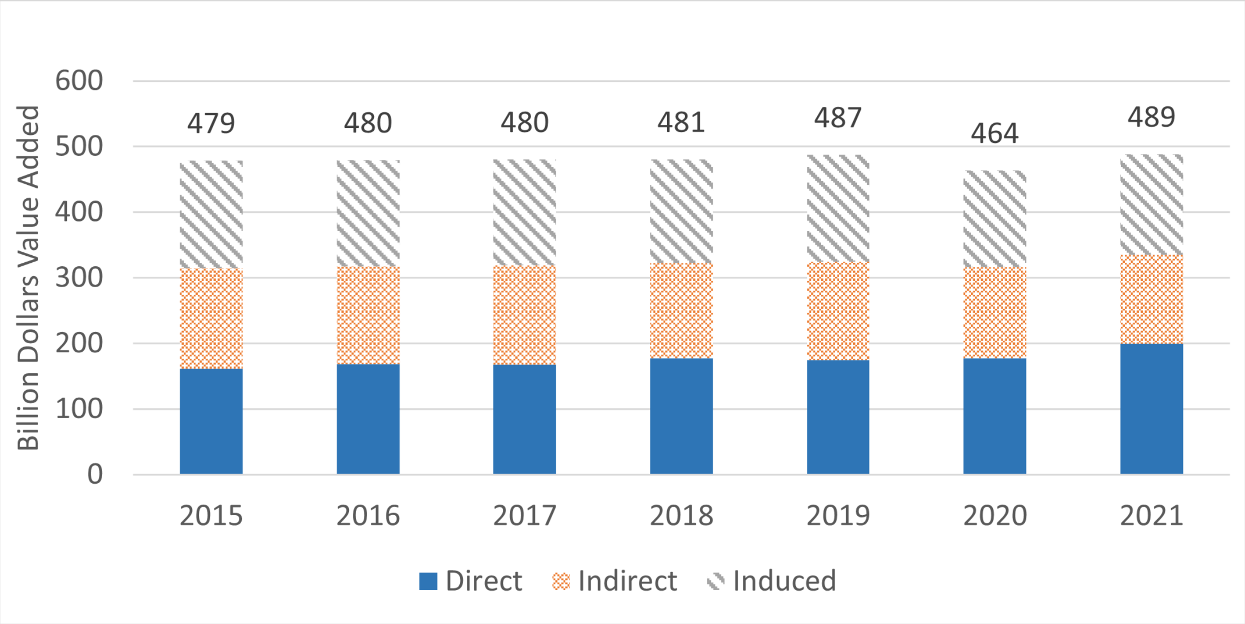

Figure 3: Total U.S. bioeconomy value added by year (all dollars shown in year of impact).

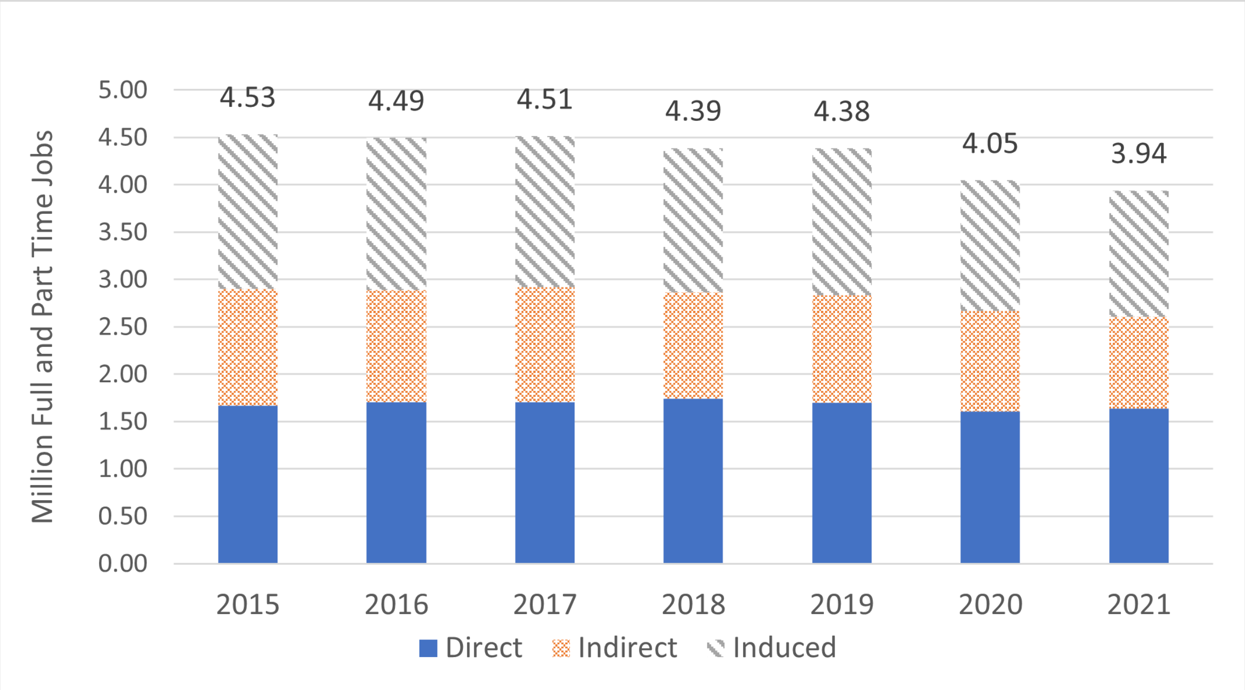

Figure 4: Total U.S. bioeconomy employment by year.

Next, we provide brief responses to the seven questions posed earlier regarding the contributions of the biobased products industry in the United States:

(i) <u>The quantity of biobased products</u>
Despite Congressional mandates to do so,[6] the U.S. Census Bureau has not created North American Industry Classification System (NAICS) codes to track the economic movement and quantity of biobased products sold. The BioPreferred Program has identified about 20,000 biobased products in past research and currently has about 10,000 products in their database. The actual number of biobased products is likely dramatically higher than the number listed in the BioPreferred Program's database as all biobased products do not yet participate in the BioPreferred Program.

Over 40,000 would be a conservative estimate of the total number of existing biobased products as there is no requirement that all biobased products be listed in the BioPreferred Program's database. As is discussed later in this report, the global demand for organizations to meet net-zero carbon emissions is driving demand for biobased products and the number of products available is growing.

(ii) <u>The value of the biobased products</u>
As Figure 3 shows, the value added to the U.S. economy by biobased products was $489 billion in 2021, up from $464 billion in 2020. This is an increase of $25 billion or a 5.1% increase over 2020. This increase reflects recovering economies after the economy largely shutdown in 2020.

(iii) <u>The quantity of jobs contributed</u>
As shown earlier in Figure 4, employment in the U.S. biobased products industry decreased slightly from 4.05 million jobs in 2020 to 3.94 million jobs in 2021. This decrease is likely due in part to challenges in the labor market upon restarting the economy in 2021.

Figure 5 shows the estimated geographic distribution of these jobs at the state level in 2021.

[6] H.R.2 - 115th Congress (2017-2019): Agriculture Improvement Act of 2018. Sec. 9002. Biobased Markets Program. (f) (1). (2018, April 12). https://www.congress.gov/bill/115th-congress/house-bill/2/text

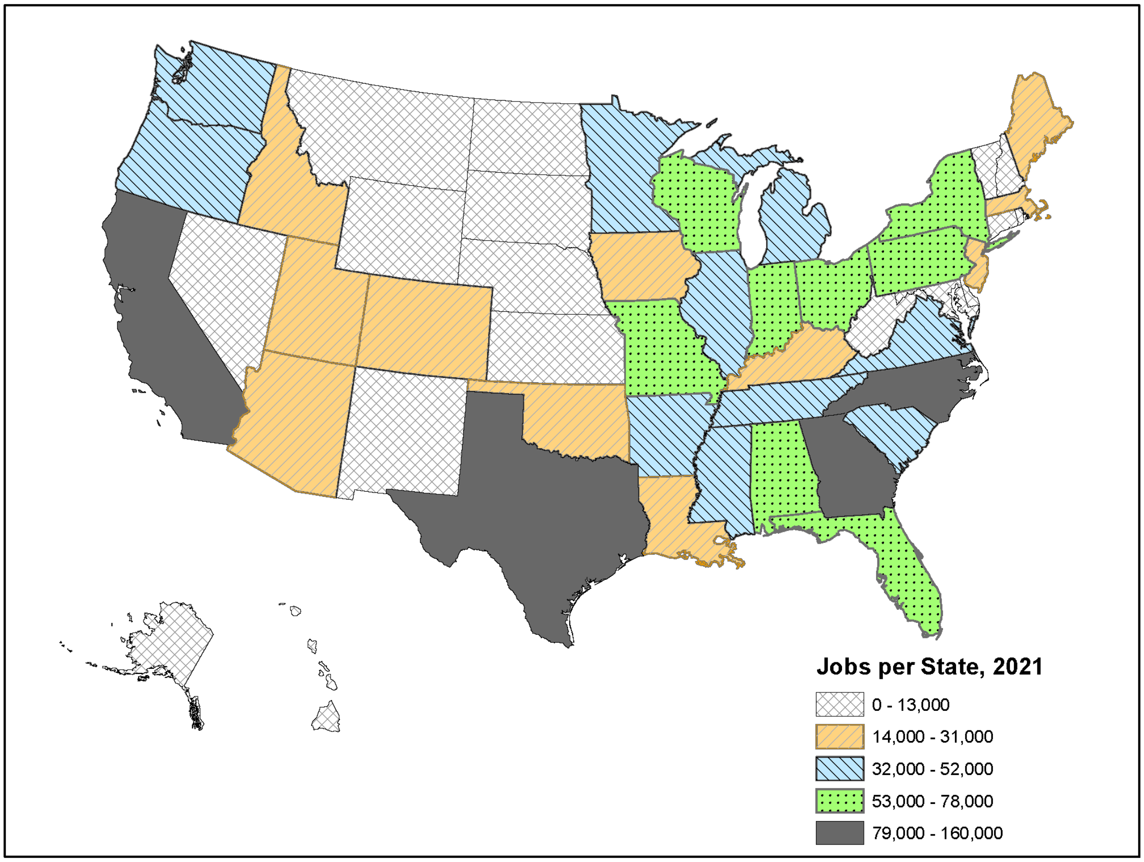

Figure 5: Direct jobs contributed by the biobased products industry in each state and the District of Columbia. For more information, see Section 2.

(iv) <u>The quantity of petroleum displaced</u>
The use of biobased products reduces the consumption of petroleum equivalents by two primary mechanisms. First, chemical feedstocks from biorefineries have replaced a significant portion of the chemical feedstocks that traditionally originate from crude oil refineries. Biorefineries currently produce an estimated 150 million gallons of raw materials per year that are used to manufacture biobased products. Second, biobased materials are increasingly being used as substitutes for petroleum-based materials, which have been used extensively for many years. An example of petroleum displacement by a biobased material is the use of natural fibers in packing and insulating materials as an alternative to synthetic foams. In this report, we updated the oil displacement values from the previous report to reflect economic growth. In 2017, the estimated oil displacement is estimated to be as much as 9.4 million barrels of oil equivalents. In 2021, the displacement grew to 10.7 million barrels of oil equivalents using an 80% petroleum reduction value for biobased products.

(v) <u>Other environmental benefits</u>
While only limited lifecycle analyses (LCA) of the production of biobased products have been conducted, the key environmental

benefits of manufacturing and using biobased products are 1) reducing the use of fossil fuels and 2) reducing the associated greenhouse gas (GHG) emissions. The previous paragraph presents an estimate of the petroleum displacement associated with the biobased products industry. The authors also estimated the GHG emission reductions associated with the production of biobased products as alternatives to petroleum-based products. This number was calculated for the 2017 report and is updated in this report to reflect economic growth. A literature review showed that there are a wide range of GHG reductions resulting from the use of biobased products as an alternative to petroleum-based products. Using the upper range of GHG emissions reductions potential at an assumed 60% reduction, the analysis indicates that up to 5.4 million metric tons of carbon dioxide (CO_2) equivalents may have been reduced in 2021. Given the increasing interest in and use of biobased products, it is essential to conduct additional analyses of their potential impacts on water quality, water use, land use, and other environmental impact categories.

(vii) Areas in which the use or manufacturing of biobased products could be more effective, including identifying any technical and economic obstacles and recommending how those obstacles can be overcome

National and regional policies continue to incentivize the use of biobased feedstocks and the procurement of biobased products. Additionally, business-to-business programs continue to increase biobased supply chains and product offerings to customers.

For example, the 2018 U.S. Farm Bill (Agriculture Improvement Act of 2018), signed on December 20, 2018, legalized the industrial use of hemp. The new bill allows hemp cultivation where in the past it was limited to pilot projects. Already there has been a significant increase in companies developing a new generation of products and rural companies manufacturing hemp fibers for numerous products including prosthetics, flooring, construction materials, and apparel.

In the private sector, Smithfield Foods, the world's largest pork producer, publicly announced that it was going to implement a "manure-to-energy" policy across 90% of its facilities. This process has the potential to create significant volumes of renewable biogas to produce biobased chemicals and products in rural parts of the United States.

While these public and private policy examples continue the positive momentum and expansion of biobased products and benefit the rural parts of the United States, there still exist a number of near-term and long-term opportunities to further advance the biobased products industry. These opportunities include creating production credits, increasing the visibility of the BioPreferred Program's USDA Certified Biobased Product label, and the expansion of other related USDA programs.

Glossary of Terms

Bagasse: The fibrous remains after crushing sugarcane or sorghum stalks and extracting the juice. It serves as a source of biofuel in the production of ethanol, and it also can be used in the manufacture of pulp and building materials.

Biobased: Related to or based out of natural, renewable, or living sources.

Biobased chemical: A chemical derived or synthesized in whole or in part from biological materials.

Biobased content: The amount of new or renewable organic carbon in a material or product as a percent of the material or product's total organic carbon. The standard method ASTM D6866 is used to determine this amount.

Biobased product: A product determined by USDA to be a commercial or industrial product (other than food or feed) that is:

(1) Composed, in whole or in significant part, of biological products, including renewable domestic agricultural materials, renewable chemicals, and forestry materials; or

(2) An intermediate ingredient or feedstock.

Biobased products industry: Any industry engaged in the processing and manufacturing goods from biological products, renewable resources, domestic or agricultural or forestry material. The USDA excludes food, feed, and fuel when referring to the biobased products industry.

Biodegradability: A quantitative measure of the extent to which a material can be decomposed by biological agents, especially bacteria.

Bioeconomy: The global industrial transition of sustainably utilizing renewable aquatic and terrestrial resources in energy, intermediates, and final products for economic, environmental, social, and national security benefits.

Biomass: Material derived from recently living organisms, which includes plants, animals, and their byproducts. For example, manure, garden waste, and crop residues are sources of biomass. It is a renewable energy source based on the carbon cycle, unlike other natural resources, such as petroleum, coal, and nuclear fuels.[7]

Biodegradable Plastic: Plastics that completely degrade into carbon dioxide, methane, water, and biomass through biological action in a defined environment and on a defined timescale. Examples of types of biodegradability include compostable, anaerobically digestible, and marine and soil biodegradable.

Biorefining: Process of producing heat, fuels, electricity, or chemicals from biomass. For example, production of transportation fuel such as ethanol or diesel from natural

[7]Khan, F.A. (2015). Biotechnology Fundamentals: Second Edition, (Boca Raton: CRC Press), 336.

sources, such as vegetable oil and sugarcane.

Byproduct: Substance, excluding the principal product, generated during the manufacturing of the principal product. For example, a byproduct of biodiesel production is glycerin, and a byproduct of ethanol production is distiller's dried grains with solubles.

Cellulose: Fiber contained in the leaves, stems, and stalks of plants and trees.

Compost: A valuable soil amendment made from organics and compostable packaging.

Compostable: A product or waste that can be organically broken down into compost.

Co-product: Product that is jointly produced with another product, which has a value or use by itself. For example, paraffin wax is a co-product during the refining of crude oil to derive petroleum products.

Direct effects: Effects generated by the industry of interest through employment, value added, and industrial output to meet final demands.

EIO-LCA: Economic input-output life cycle assessments quantify the environmental impact of a sector of the economy.

Emissions: Gases and particles that are released into the air or emitted by various sources.[8]

Employment: Considered in this report as full and part-time jobs in an industry.

Engineered wood products (EWPs): Wood composite products comprised of wood elements bonded together by an adhesive. EWPs are manufactured with assigned stress values for use in engineering applications.

Enzyme: A macromolecular that facilitates and speeds up chemical reactions. Enzymes act as catalysts for reactions that convert specific reactants into specific products with greater efficiency relative to the uncatalyzed reaction.

Ethanol: Produced from fermenting any biomass that contains a high amount of carbohydrates. It is typically made from starches and sugars, but advanced generation technologies allow it to be made from cellulose and hemicellulose.[9].

Feedstock: Raw material used in an industrial process, such as the production of biobased chemicals.

Hemicellulose: Groups of complex carbohydrates that surround the cellulose component of the cell wall in plants. Like cellulose, hemicellulose also functions as supporting material in the cell wall.

IMPLAN: Originally developed by the U.S. Forest Service and currently owned and operated by IMPLAN Group LLC (Huntersville, NC). The IMPLAN database and software system can be used to measure the economic effects of a given change or event in a region.

Indirect effects: The result of all sales by the supply chain of the industry of interest.

[8] U.S. Environmental Protection Agency (EPA). (2016, June 8). "Air Pollution Emissions Overview", U.S. EPA, https://www3.epa.gov/airquality/emissns.html.

[9] International Energy Agency (IEA). (2022, April 4). "Glossary", *IEA*, https://www.iea.org/articles/oil-market-report-glossary.

Induced effects: The changes produced from the purchasing of goods and services by households because of changes in employment and/or production levels.

NAICS: Acronym for the North American Industry Classification System. A classification system for grouping businesses by similarity of production process.

Non-Renewable Resources: Raw materials, such as fossil fuels, which cannot be replenished as fast as they are being consumed.

Output: An industry's gross sales, which includes sales to other sectors (where the output is used by that sector as input) and those to final demand.

Qualified biobased product: A product that is eligible for the BioPreferred Program's mandatory Federal purchasing initiative because it meets the definition and minimum biobased content criteria for one or more of the 139 designated product categories.

Recyclable: A product made from valuable materials that can be shredded, melted, or otherwise reduced to their raw forms and reformed into something new.

Renewable Resource: A raw material or energy form, such as agricultural products or solar energy that can be replenished at a rate similar to the rate at which it is used.

Switchgrass: Prairie grass native to the United States and known for its hardiness and rapid growth, often cited as a potentially abundant feedstock.

Total effect: The sum of the effects of all sales generated by all sectors, supply chains, and influence of employees' spending within the study region. The sum of the direct, indirect, and induced effects.

Type I multiplier: The sum of direct and indirect effects, divided by the direct effect.

Type Social Accounting Matrix (SAM) multiplier: The Type SAM multiplier considers portions of value added to be both endogenous and exogenous to a study region. It is the sum of the direct, indirect, and induced effects divided by the direct effect. Type SAM multipliers generally are the preferred multipliers used in input-output analysis.

USDA Certified Biobased Product: A biobased product that has met the BioPreferred Program's criteria to display the USDA Certified Biobased Product label.

Value Added: Composed of labor income, which includes employee compensation and sole proprietor (self-employed) income, other property type income (includes corporate profits, capital consumption allowance, payments for rent, dividends, royalties, and interest income), and taxes on production and imports, less subsidies (primarily consist of sales and excise taxes paid by individuals to businesses through normal operations). A sector's value added is its contribution to the study area's Gross Regional Product.

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1 Introduction

1.1 Background

There are six significant, recent events that make this year's 2023 update report uniquely timely.

1.1.1 Event #1: The Farm Bill

This report comes at an important time when Congress is undertaking hearings and deliberations regarding the five-year reauthorization of the omnibus Farm Bill. Dating back to the 1930s, the Farm Bills set national agriculture, nutrition, conservation, and forestry policies. The current Farm Bill, known as the Agriculture Improvement Act of 2018, is set to expire in 2024. That bill included twelve titles, which covered:

1. Commodities, including prices and income support for farmers.
2. Conservation, implementing natural resource conservation efforts.
3. Trade, covering food export subsidies and international food aid programs.
4. Nutrition, defining the Supplemental Nutrition Assistance Program.
5. Credit, managing federal loan programs.
6. Rural Development, promoting rural economic growth through business and community development programs.
7. Research, Extension and Related Matters, authorizing funds and identifying research and development priorities.
8. Forestry, focusing on conservation efforts.
9. Energy, accelerating the expansion of biobased fuels and renewable energy.
10. Horticulture, supporting fruit, vegetables, and organic farming.
11. Crop insurance, providing programs protecting Americas farmers.
12. Miscellaneous, covering other related issues.

1.1.2 Event #2: The Inflation Reduction Act

This report is very timely because the 177th Congress of the United States passed the Inflation Reduction Act of 2022 (IRA), which was then signed into law by President Biden. The $750 billion act provided nearly $40 billion for agriculture, forestry, and rural development, including $14 billion for renewable energy and biofuels. This funding will benefit the U.S. biobased products industry as the infrastructure and biobased chemical constituents will be used in the biobased products sectors.

1.1.3 Event #3: Climate-Smart Commodities

On September 14, 2022, Secretary Vilsack announced the unprecedented support of a newly designated Climate-Smart Commodities program by the USDA. By 2023, USDA had announced that the program was funding $3.1 billion in awards to 141 projects. The goal of the program is to expand markets for America's climate-smart commodities, which include biobased product feedstocks, reduce greenhouse gas emissions, develop economic benefits, and create jobs across the country, including for underserved producers and communities.

1.1.4 Event #4: The Economic Impacts of the Covid-19 Pandemic

In January 2020, the U.S. Center for Disease Control announced the appearance of a novel coronavirus outbreak, dubbed COVID-19, and the Washington State Department of Health announced the first cases of COVID-19 in the United States. Then on March 9, 2020, the S&P 500 index declined by 7%, triggering a Level 1 market-wide circuit breaker, halting all trading. Trading halts occurred again throughout March 2020.[10] The economic impacts of the COVID-19 pandemic lasted far beyond the spring of 2020 and had significant implications for the U.S. economy and biobased products industry.

As presented in Figure 6, crude oil prices dropped dramatically during the pandemic. In turn, this depressed the demand and production of biobased fuels (Figure 7), thus impacting feedstocks for biobased products.[11,12]

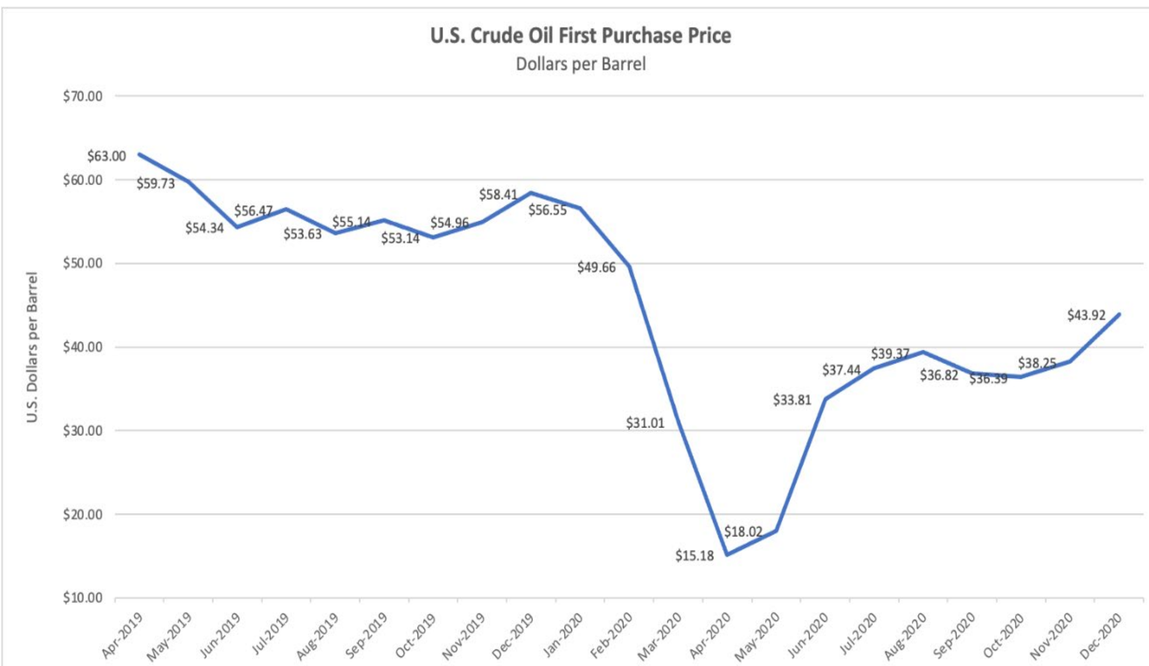


Figure 6: Impacts of Covid-19 on U.S. Crude Oil Prices.

[10]Cox, Jeff (2020, March 9). The market triggered a 'circuit breaker' the kept stocks from falling through the floor. CNBC. https://www.cnbc.com/2020/03/09/sp-500-futures-are-frozen-after-tanking-5percent-heres-what-happens-when-circuit-breakers-kick-in.html

[11]US EIA (2023, May 1). U.S. crude oil first purchase price (dollars per barrel). US EIA. https://www.eia.gov/dnav/pet/hist/LeafHandler.ashx?n=PET&s=F000000__3&f=M.

[12]US EIA (2023, April 28). Fuel Ethanol Production. April 2023 Monthly Energy Review. US EIA. https://www.eia.gov/totalenergy/data/monthly/pdf/mer.pdf

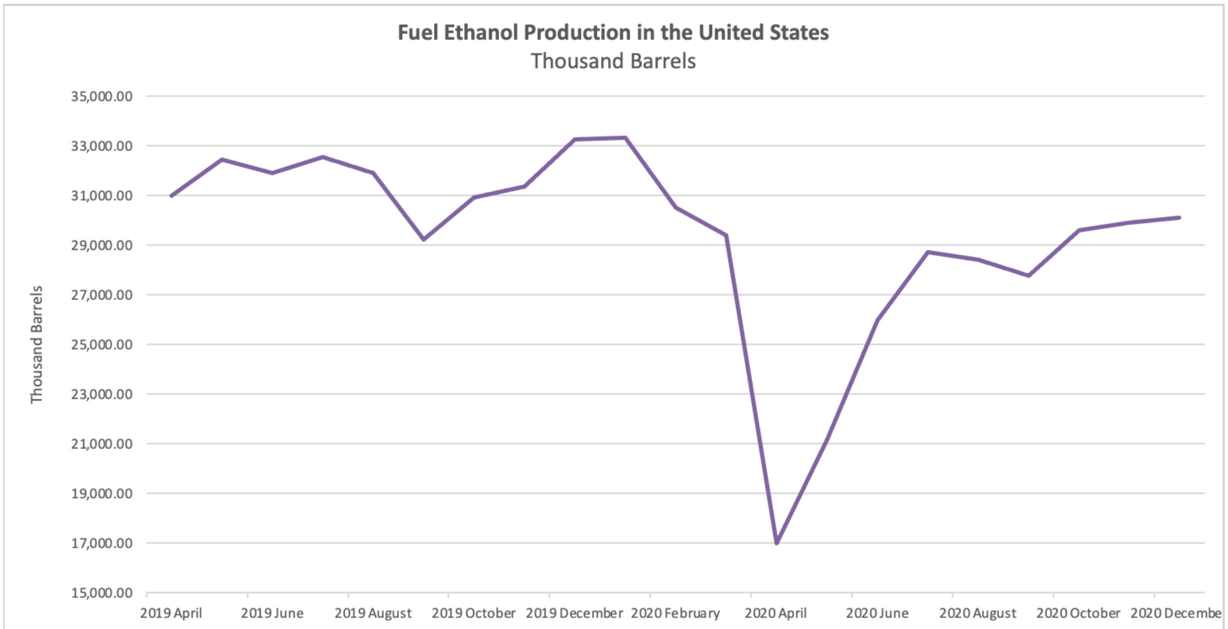


Figure 7: Impacts of Covid-19 on Fuel Ethanol Production in the U.S.

1.1.5 Event #5: Net-Zero Carbon Transition

As further detailed in Chapter 5 of this report, American and global businesses during the last two years have unified in their public commitments to transition to net-zero carbon emissions no later than 2050 and most between 2035 to 2040.

While transitions and increased reliance on electrification from renewable resources will certainly be one of the more predominant and early strategies to lower greenhouse gas emissions, companies are seeking new and novel climate-smart commodities and biobased products to replace legacy petroleum-based chemicals, packaging, and products. This will give rise to greater research, development, and investments to bring these products to market to support global net-zero commitments.

1.1.6 Event #6: Executive Order 14081, Advancing Biotechnology and Biomanufacturing Innovation for a Sustainable, Safe, and Secure American Bioeconomy

On September 12, 2022, President Biden released a new Executive Order (EO) on Advancing Biotechnology and Biomanufacturing Innovation for a Sustainable, Safe, and Secure American Bioeconomy.[13] The EO aims to accelerate the domestic bioeconomy by boosting sustainable biomass production and biobased products purchasing. The order focuses on reducing greenhouse gas emissions and the impacts of climate change. The EO places a large emphasis on expanding market opportunities for biobased products. For example, the EO instructs the Secretary of Agriculture to develop a plan supporting and

[13]Exec. Order No. 14081, 87 Fed. Reg. 56849 (Sept. 12, 2022). https://www.whitehouse.gov/briefing-room/presidential-actions/2022/09/12/executive-order-on-advancing-biotechnology-and-biomanufacturing-innovation-for-a-sustainable-safe-and-secure-american-bioeconomy/

encouraging domestic biomanufacturing to advance the U.S. biomass supply chain.

Section 6 of the EO discusses several initiatives on biobased products procurement, including:

- Within 1 year of the order, when new biobased product categories become commercially available, the Secretary will designate new product categories for Federal procurement purchasing preference.

- By 2025, procuring agencies should aim to increase the amount of biobased product obligations or dollar value of biobased-only contracts.

As specified in the Federal Register, "*The Chief Statistician of the United States (CSOTUS) in the Office of Management and Budget (OMB) was charged with improving and enhancing Federal statistical data collection designed to characterize and measure the economic value of the U.S. bioeconomy. The CSOTUS was also charged with establishing an Interagency Technical Working Group to recommend bioeconomy-related revisions for the North American Industry Classification System (NAICS) and the North American Product Classification System (NAPCS). The bioeconomy refers to a segment of the total economy utilizing or derived from biological resources, and includes manufacturing processes, technologies, products and services. These may encompass, wholly or in part, industries and products including fuel, food, medicine, chemicals, and technology*" (Exec. Order 14081, 2022).[14]

In the 2018 report to Congress, we identified the need to develop specific codes within the NAICS to better track the economic impacts of the U.S. biobased products industry. The project team listed the call for new NAICS codes for biobased products as one of the key findings and recommendations. Further, the 2018 Farm Bill mandated the creation of NAICS codes for biobased products.

We proposed that the USDA could work with key industry segments and the US Department of Commerce in developing suggested biobased products related NAICS codes as well as the rationale and benefit to US companies and policy makers in having such codes implemented. Our recommendations built on earlier conversations with major retailers, brands, and manufacturers who expressed the desire to better track biobased product purchasing and biobased feedstock utilization but who are at a disadvantage due to the lack of biobased NAICS codes. Despite numerous overtures to the U.S. Department of Commerce by USDA and industry, the Congressional directives regarding NAICS codes have not been followed.

1.2 USDA Rural Development BioPreferred® Program Background

Established by the Farm Security and Rural Investment Act of 2002 and strengthened by the Food, Conservation, and Energy Act of 2008, the Agriculture Act of 2014, and the Agriculture Improvement Act of 2018 (2018 Farm Bill), the USDA Rural Development BioPreferred Program is charged with transforming the marketplace for biobased products and creating jobs in rural America. The BioPreferred Program's mandatory

[14]Ibid.

Federal purchasing initiative and voluntary labeling initiative have quickly made it one of the most respected and trusted drivers in today's biobased marketplace.

1.2.1 Strategic Goals

The mission of the BioPreferred Program is to facilitate the development and expansion of markets for biobased products. To carry out this mission, the Program has two broad strategic goals: 1) increasing awareness of biobased products through certification and labeling and 2) creating a market for biobased products through government-wide purchasing requirements.

1.2.2 Mandatory Federal Purchasing

Public and private purchasers look to the BioPreferred Program to ensure that their purchases are biobased and renewable. Beginning in 2005 with its first designations of six product categories, the Program has now designated 139 product categories representing more than 8,700 products that are included in the mandatory Federal purchasing initiative. By providing a central product registry through its online catalog, accessible at www.biopreferred.gov, the BioPreferred Program enables purchasers to locate and compare products, such as cleaners, lubricants, and building materials, including carpet and insulation, from all participating manufacturers, thereby encouraging manufacturers to compete to provide products with higher biobased content. With the Federal Government spending about $54 billion in the 2023 fiscal year on goods and services,[15] there is an extraordinary opportunity to increase the sale and use of biobased products, as required by federal law.

1.2.3 Voluntary Consumer Label

USDA introduced the BioPreferred Program's voluntary labeling initiative to the consumer market in February 2011. Through this initiative, manufacturers can apply to display the USDA Certified Biobased Product label, shown in Figure 8, on their biobased products. To date, more than 7,800 products have been certified to display the USDA Certified Biobased Product label and the number of applications continues to increase. With a web-based application process, the BioPreferred Program makes it simple for manufacturers to apply for the label and track their applications. The BioPreferred Program offers purchasers of biobased products a universal standard to assess a product's biobased content.

Figure 8: Sample USDA Certified Biobased Product label.

[15]GSA. (2023, July 30). FY 2023 Summary. GSA. https://www.usaspending.gov/agency/general-services-administration?fy=2023

1.3 Structure of this Report

The structure of this 2023 report is similar to previous reports.[16] In this report we provide the most up-to-date data available, modeled to reflect the economic and job benefits of the domestic U.S. biobased products industry.

This year's report provides greater granularity at the state level where we quantify the effects of the U.S. biobased products industry on each of the 50 states and the District of Columbia. We also provide information regarding the environmental benefits of the U.S. biobased products industry. Additionally, we discuss an option for a standardized label showing biobased products' carbon intensity as market needs evolve.

Finally, as we have done before, we present case studies from various industry sector businesses.

1.3.1 Economic Data

Section 2 of this report provides both national and state-level modeling results, including the value added by exports for each sector of the biobased products industry. The methodology is consistent with prior reports that incorporate interviews of a broad spectrum of representatives of government, industry, and trade associations involved in the biobased products industry so that we could understand the challenges and future growth potential for biobased products. The team also collected statistics from government agencies and published literature on biobased products. Finally, the most up to date data was incorporated into the IMPLAN modeling software developed by the U.S. Forest Service to analyze and trace spending throughout the U.S. economy and measure the cumulative effects of that spending.

When examining the economic contributions of an industry, IMPLAN generates five types of indicators:

- **Direct effects:** effects of all sales (dollars or jobs) generated by an industry.
- **Indirect effects:** effects of all sales by the supply chain for the industry being studied.
- **Induced effects:** a change in dollars or jobs within the study region that represents the influence of the value chain employees' spending wages in other industries to buy services and goods.
- **Spillover effects:** the sum of the indirect and induced effects.
- **Total effect:** the sum of the direct, indirect, and induced effects.

Appendix A describes the IMPLAN modeling framework in detail. The greatest limitations of the findings in this report relate to the percentages of biobased sectors within the larger economic sectors, such as biobased chemicals within all chemicals. To provide conservative estimates of the biobased products sectors, we consistently used lower

[16]Golden, J.S., Handfield, R.B., Daystar, J., and McConnell, T.E. (2015). An Economic Impact Analysis of the U.S. Biobased Products Industry: A Report to the Congress of the United States of America. A Joint Publication of the Duke Center for Sustainability & Commerce and the Supply Chain Resource Cooperative at North Carolina State University. https://www.biopreferred.gov/BPResources/files/EconomicReport_6_12_2015.pdf

percentages within the ranges we modeled, with ranges varying from 1% to 100% biobased depending on the sector. These estimates are based on published literature and information gathered through interviews.

Section 2 also defines and describes the seven sectors of the biobased products industry and the economic impact by sector, which supplies data on economic activity, value added, and jobs by sector, reports on the value added by exports in each sector and discusses the potential for economic growth in the industry.

1.3.2 Environmental Benefits

Section 3 of this report explores the environmental benefits of the biobased products industry. We specifically explore the GHG emissions reductions achieved because of transitions made to biobased feedstocks and products from legacy fossil fuel-based feedstocks.

1.3.3 Carbon Intensity Labeling

As is detailed in Section 4 of this report, business and policy drivers may lead to a continued and accelerated demand for biobased products in the U.S. and around the world. Specifically, we examine the recent commitments by industry to transition to a net-zero carbon economy that require the development and deployment of biobased alternatives as part of a larger transition strategy.

The authors lay out the rationale to adapt to these institutional needs and consider the development of a carbon intensity label that meets industry and government needs for communicating the climate impacts of biobased products.

1.3.4 Industry Perspectives

As we have done with great interest and positive response in our prior reports, we have undertaken case studies over the course of this study, as presented in Section 5.

The studies include a spectrum of private sector, public sector, state, and local government initiatives that are driving the success and growth of the biobased products industry through innovation, policies, incentives, and technological breakthroughs. These case studies are important illustrations of how the biobased products industry is both a source of economic growth and a technological success story.

1.3.5 Recommendations

Finally, in Section 6, The authors supply a set of policy recommendations based on our on-going research and outreach efforts in the biobased products industry sectors.

1.3.6 Appendices

Appendices at the end of this report provide the reader with more information on the IMPLAN model (Appendix A) and BioPreferred Program product categories (Appendix B) mentioned in this report.

2 Economic & Jobs Analysis

2.1 Total U.S. Biobased Products Industry

This section offers a detailed examination of the key sectors within the U.S. biobased products industry. Each sector's raw materials, processing steps, intermediate products, and end products are discussed. The provided data encompasses leading U.S. and global firms, the total economic value added in 2021, and the count of direct, indirect, and induced jobs that the sector supports in the U.S. The distribution of economic value and employment across subsectors is also included.

Figure 9 illustrates the comprehensive impact of the biobased products industry on employment and Gross Domestic Product (GDP) in the U.S. in 2021. The industry's total contribution to the U.S. economy in 2021 was $489 billion in value added, and it supported 3.94 million jobs. Each job within the biobased products industry supported an additional 1.4 jobs in other sectors. The figure supplies a detailed breakdown of these numbers: the 1.64 million direct jobs in the biobased products industry resulted in 0.97 million indirect and 1.33 million induced jobs, amounting to 2.3 million spillover jobs. These jobs include indirect roles in related industries and induced jobs resulting from the consumption of goods and services generated by the direct and indirect jobs. Figure 10 provides a comparison of the jobs supported and value added impacts of the biobased products industry from 2018 to 2021.

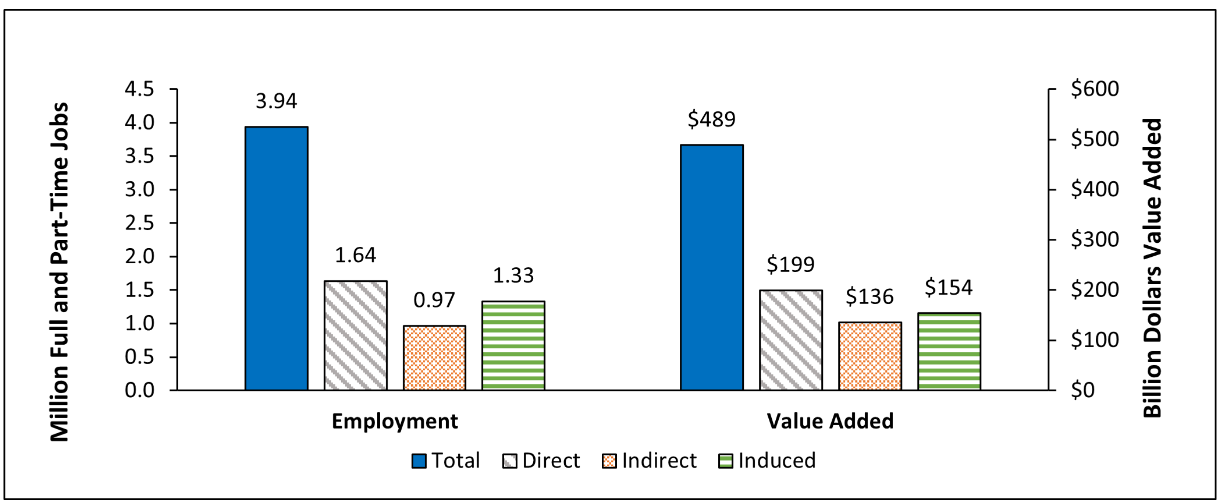


Figure 9: Biobased Products Industry Contributions to U.S. Employment and Value Added in 2021.

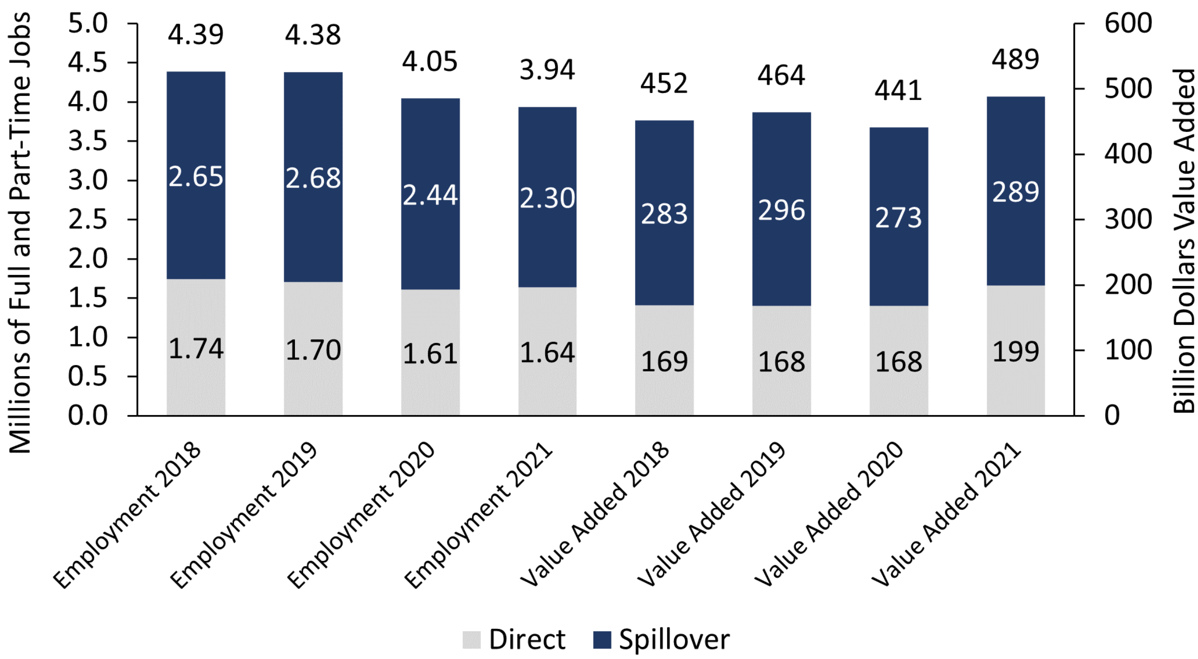


Figure 10: Biobased Products Value Added and Employment Trends: 2018-2021.

Figure 11 illustrates how the value added produced by the biobased products industry is allocated across each state (using an approximated range), and Figure 12 shows the number of jobs the biobased products industry supports by state; Table 1 shows the data for the top 10 states. The biobased products industry affects every state in the nation, not just states where agriculture is the main industry.

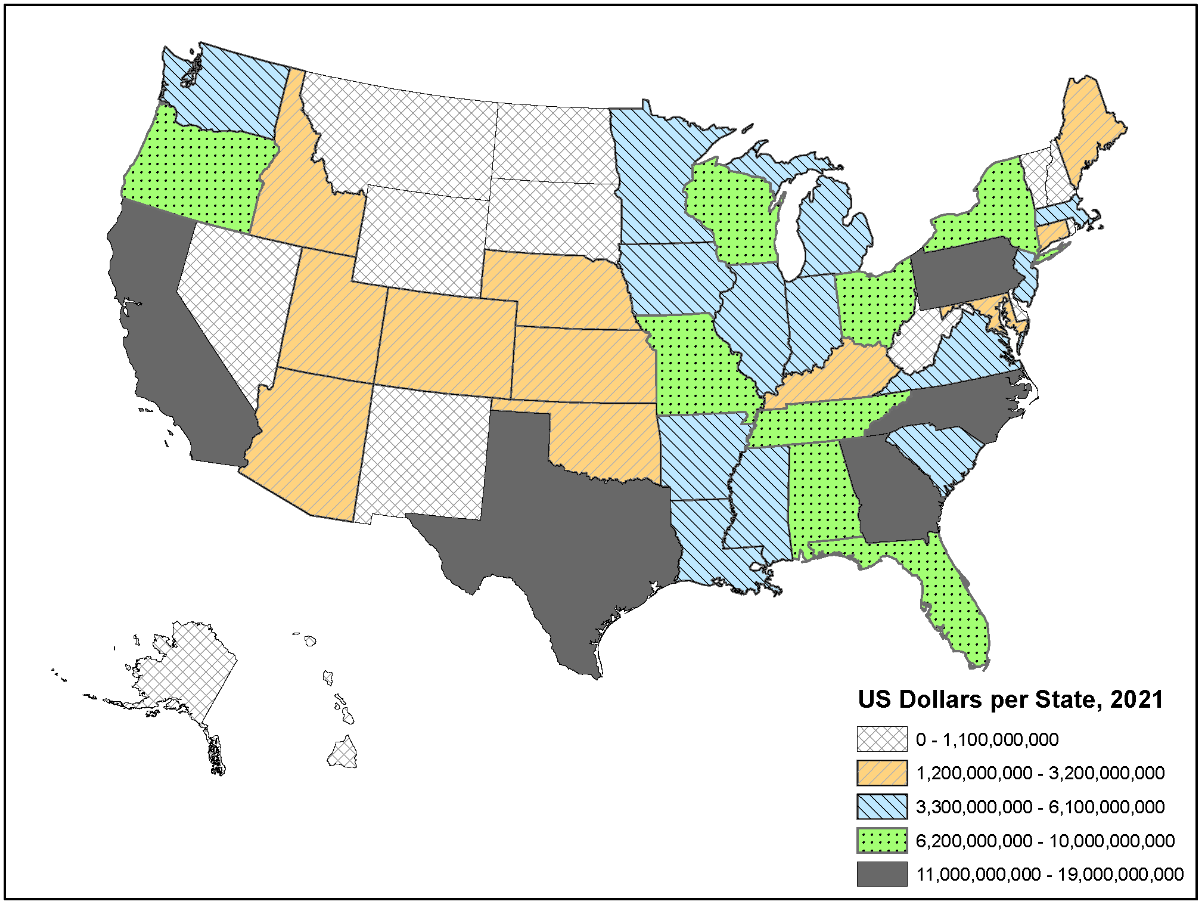


Figure 11: Direct Value Added Contribution by the Biobased Products Industry in Each State and the District of Columbia in 2021.

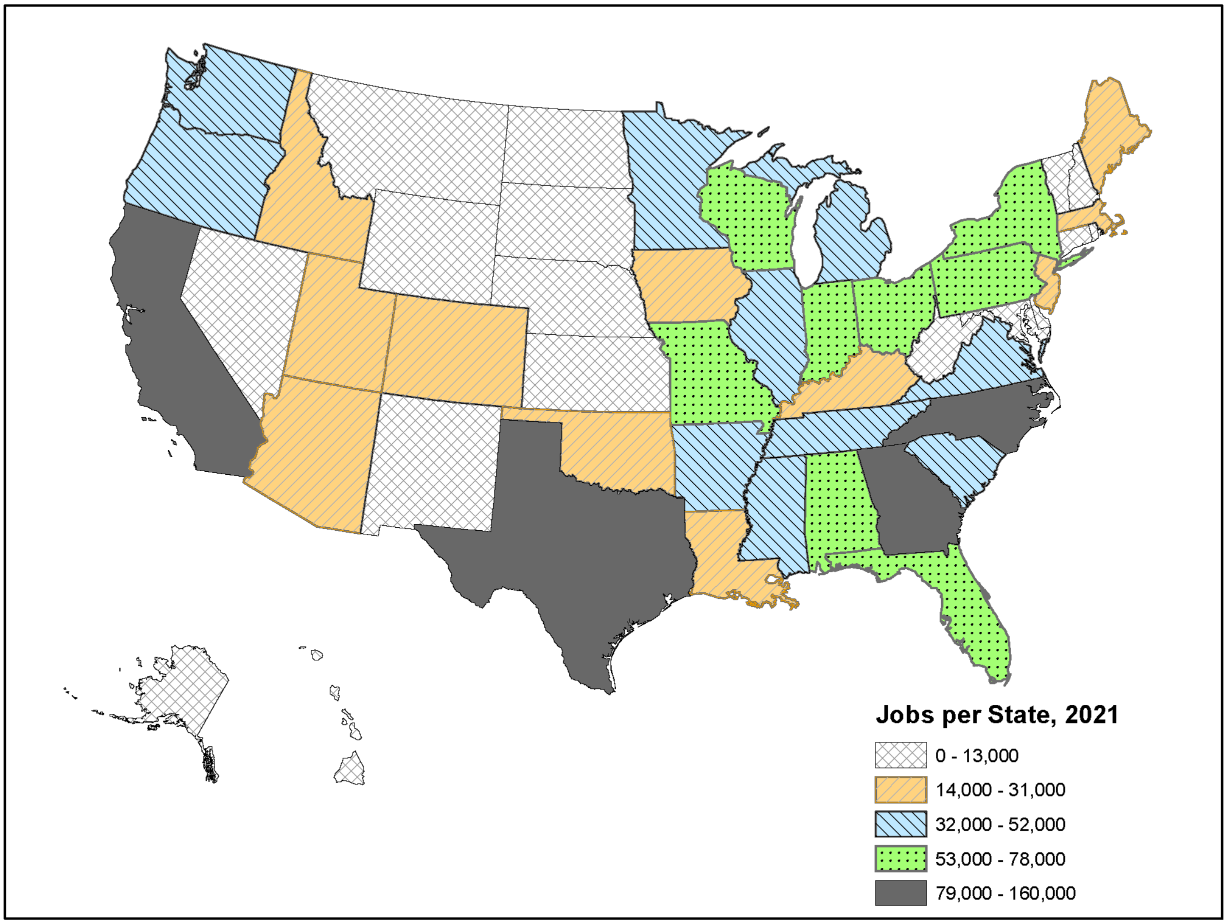


Figure 12: Direct Jobs Contributed by the Biobased Products Industry in Each State and the District of Columbia in 2021.

Table 1: Top 10 states based on Value Added for 2021.

	State	Employment (Number of Jobs)	Value Added ($ Million)
1	California	280,029	$34,863
2	Texas	272,158	$31,334
3	North Carolina	207,670	$22,278
4	Georgia	200,115	$23,541
5	Pennsylvania	154,441	$20,025
6	Wisconsin	152,792	$18,838
7	Ohio	146,614	$16,569
8	Missouri	144,903	$15,905
9	Florida	113,517	$12,267
10	Alabama	106,981	$12,177

2.2 Defining the Biobased Products Industry

The bioeconomy is "the global industrial transition that utilizes biotechnology in creating renewable terrestrial and aquatic resources in energy, intermediates, and final products to the benefit of economic, environmental, and social concerns."[17] This transition within the U.S. economy also aims to create and support national security through renewable resources and energy. This report focuses on the biobased products industry, a part of the bioeconomy. The biobased products industry includes the following seven major sectors of the U.S. economy:

- Agriculture and Forestry
- Biorefining
- Biobased Chemicals
- Enzymes
- Biobased Plastic Bottles and Packaging
- Forest Products
- Textiles

These analyses specifically exclude energy, livestock, food, feed, and pharmaceuticals. One of the limitations of undertaking this research is that, at present, no NAICS codes have been set up specifically for biobased products. NAICS is the standard used by federal agencies in classifying business establishments for the purpose of collecting, analyzing, and publishing statistical data about U.S. businesses. The Department of Commerce has not fulfilled Congressional directives to create NAICS codes specific to biobased products yet. Despite the lack of specific data on biobased products, the authors developed an extensive database of applicable NAICS codes that stand for the associated sectors. For instance, while there is no NAICS code for "biobased chemicals," there is an exhaustive listing of "chemical" subsectors, such as paints and adhesives, other basic chemicals, plastics, and artificial fibers. These subsectors are segments of the biobased chemicals U.S. biobased products industry sector. There is a complete listing of all the modeled NAICS codes used at the beginning of the section on each sector.

Next, the authors developed an estimate for the biobased percentage of each sector. For example, what percentage do biobased chemicals form of the total chemical sector? To conduct this task, the authors analyzed peer-reviewed literature, domestic and international reports, related literature from industry and trade organizations, and market intelligence reports. The authors also conducted interviews of representatives from industry, various organizations, academia, and the government. The estimated percentage of each sector made up of biobased products is in Table 2.

[17]Golden J.S. and Handfield R.B., (2014, July 25.) "Why Biobased? Opportunities in the Emerging Bioeconomy", USDA BioPreferred® Program website, http://www.biopreferred.gov/BPResources/files/WhyBiobased.pdf.

Table 2: Percentages of biobased products in each sector of the U.S. economy in 2021.

Sector	Percent Biobased	Source
Agriculture and Forestry		
Cotton Farming	100	N/A
Forestry, Forest Products, and Timber Tract Production	100	N/A
Commercial Logging	100	N/A
Corn	4.0	USDA ERS 2022/2023 Feed grains yearbook tables - recent (calculated from Table 31)
Oil Seed Farming to Glycerin	0.4	USDA Economic Research Service
Sugar	1.7	Godshall, M.A. Int. Sugar J., 103, 378-384 (2001)[18]
Support Activities	14.4	Based on percentage of all agriculture, excluding food, ethanol, and livestock
Biorefining		
Wet Corn Milling	4.0	Scaled to include only agriculture biobased products
Processing Soybean and Other Oilseeds	0.4	Scaled on agriculture biobased percentage
Refining and Blending Fats and Oils	0.4	Scaled on agriculture biobased percentage
Manufacturing Beet Sugar	1.7	Scaled on agriculture biobased percentage
Sugar Cane Mills and Refining	1.7	Scaled on agriculture biobased percentage
Textiles	74	USDA ERS; USDA NASS
Forest Products	100	N/A
Chemicals	1.9	https://www.statista.com/statistics/302081/revenue-of-global-chemical-industry/ and https://www.fortunebusinessinsights.com/bio-based-chemicals-market-106586
Enzymes	100	N/A
Plastic Packaging and Bottles	0.28	European Bioplastics, Institute for Bioplastics and Biocomposites, nova-Institute (2014)[19]

Note: Where multiple biobased percentage estimates were available, the authors chose to use the lower, more conservative estimate.

[18] Godshall, M.A. "Sugar and Other Sweeteners", in Kent J. (eds) *Handbook of Industrial Chemistry and Biotechnology*, (Boston, MA: Springer, 2012), 378-384.

[19] European Bioplastics. (2016). *Bioplastics Facts and Figure.* European Bioplastics. http://docs.european-bioplastics.org/2016/publications/EUBP_facts_and_figures.pdf.

The following paragraphs discuss the approach used to develop the percentages for three of the seven sectors that are presented in Table 2.

2.2.1 Agriculture and Forestry

The Support Activities category in Table 2 includes cotton ginning, soil testing, post-harvest activities for crops, timber valuation, forest pest control, and other support services for forestry as determined by the U.S. Census Bureau. The average figure of 14.4% for support activities across all sectors is based on the total support activities and output of corn, timber, and other products as a percentage of total agricultural production creating biobased products. The authors assumed all sectors used the same support services equally.

2.2.2 Biorefining

Biorefining accounts for approximately seven percent of the total refining capacity in the United States. The authors estimate that approximately one percent of the output from this sector is used to manufacture biobased products, and the remainder is used for fuel. This estimate is based on the primary feedstock sources input into the refining sector, which includes wet corn milling, soybeans, fats and oils, sugar beets, and sugarcane milling. Biorefining from these sources accounts for a capacity of approximately 6.508 billion barrels per year.

2.2.3 Textiles

About 74% of textiles are produced from biobased feedstocks, including cotton and rayon. In 2021, approximately forty-five million tons of biobased fibers were produced.[20]

[20]Textile Exchange. Preferred Fiber & Materials Market Report. October 2022. https://textileexchange.org/app/uploads/2022/10/Textile-Exchange_PFMR_2022.pdf

2.3 Agriculture and Forestry

Figure 13 illustrates how the value added produced by the Agriculture and Forest sector industry is distributed across each state (using an approximated range), and

Figure 14 shows the number of jobs the Agriculture and Forest sector supports by state; Table 3 shows the data for the top 10 states. Figure 15 shows the employment and value added changes between 2018 and 2021 in the Agriculture and Forestry sector.

Approximately 2.01 million farms contribute to America's rural economy. About 98% of U.S. farms are run by families, i.e., individuals, family partnerships, or family corporations, which, in many cases, are suppliers to companies, such as the major firms listed below. [21]

Major U.S.-Based Firms [22, 23]

Archer Daniels Midland Company (Illinois)
Tyson Foods, Inc. (Arkansas)
Cargill, Incorporated (Minnesota)
Bunge Limited (Missouri)
Deere & Co. (Illinois)
FMC Corporation (Pennsylvania)
Mosaic Co. (Florida)
Corteva Agriscience™ (Indiana)
Eastman Chemical Company (Tennessee)

Global Firms with Large U.S. Operations [27, 28]

Bayer CropScience AG (North Carolina)
BASF Corporation (North Carolina)
Syngenta Crop Protection AG (Minnesota and North Carolina)
Dow Chemical Company (Michigan)

Economic Statistics

Total value added to the U.S. economy in 2021: $39 billion.

Type SAM Economic Multiplier in 2021: 2.2.

Employment Statistics

Total number of Americans employed due to industry activities in 2021: 497,000.

Type SAM Employment Multiplier in 2021: 1.6

Table 4 displays these economic and employment statistics.

Nutrien Ltd. (Colorado)

[21]U.S Department of Agriculture Economic Research Service. (2023, March 14). *Farming and Farm Income*. USDA ERS. https://www.ers.usda.gov/data-products/.

[22]Murphy, A. & Tucker, H. (Eds.) (2023, June 8*). Forbes Global 2000 in 2022.* Forbes. http://www.forbes.com/global2000/list/.

[23]IBISWorld. (2023, February 15). *IBISWorld Industry: Agriculture, Forestry, Fishing and Hunting in the US.* (Report No. 11). IBISWorld.

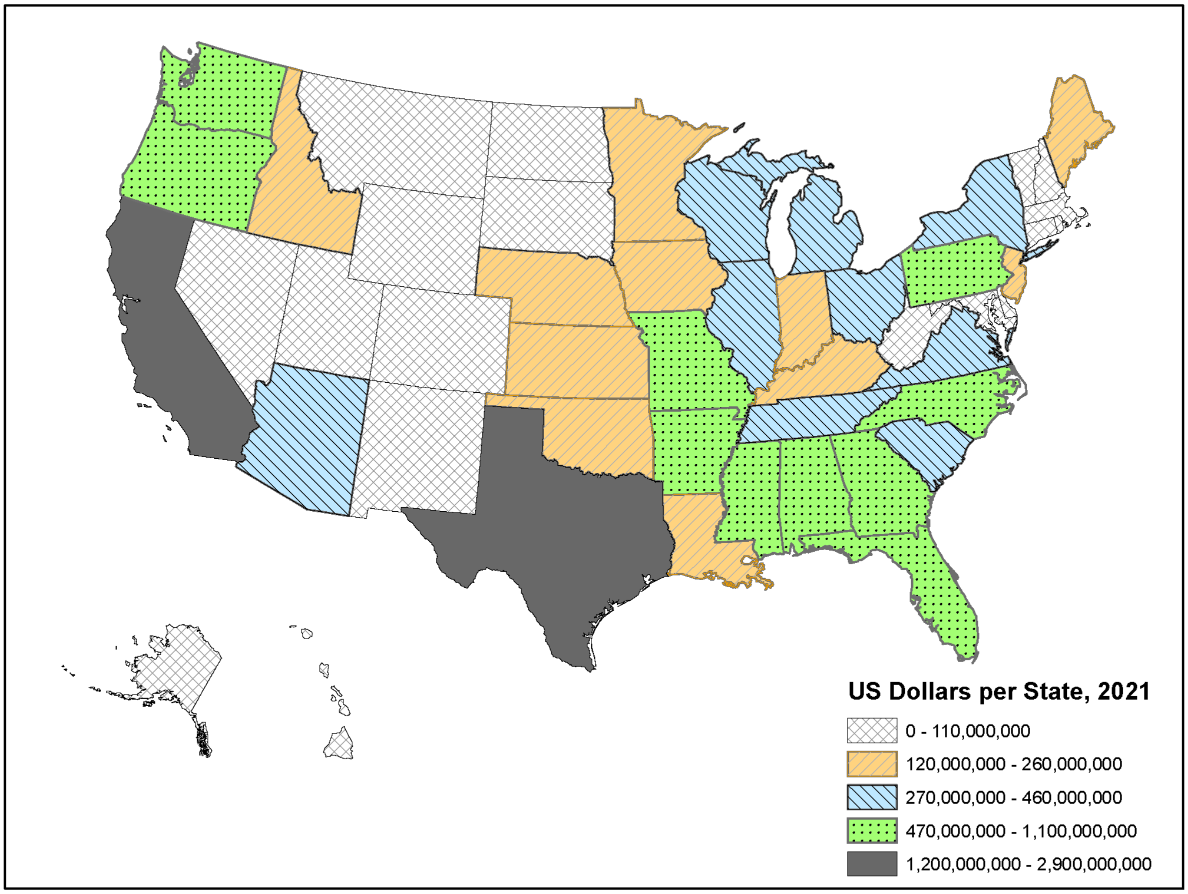


Figure 13: Total Value Added Contributed by the Agriculture and Forestry Sector in Each State and the District of Columbia.

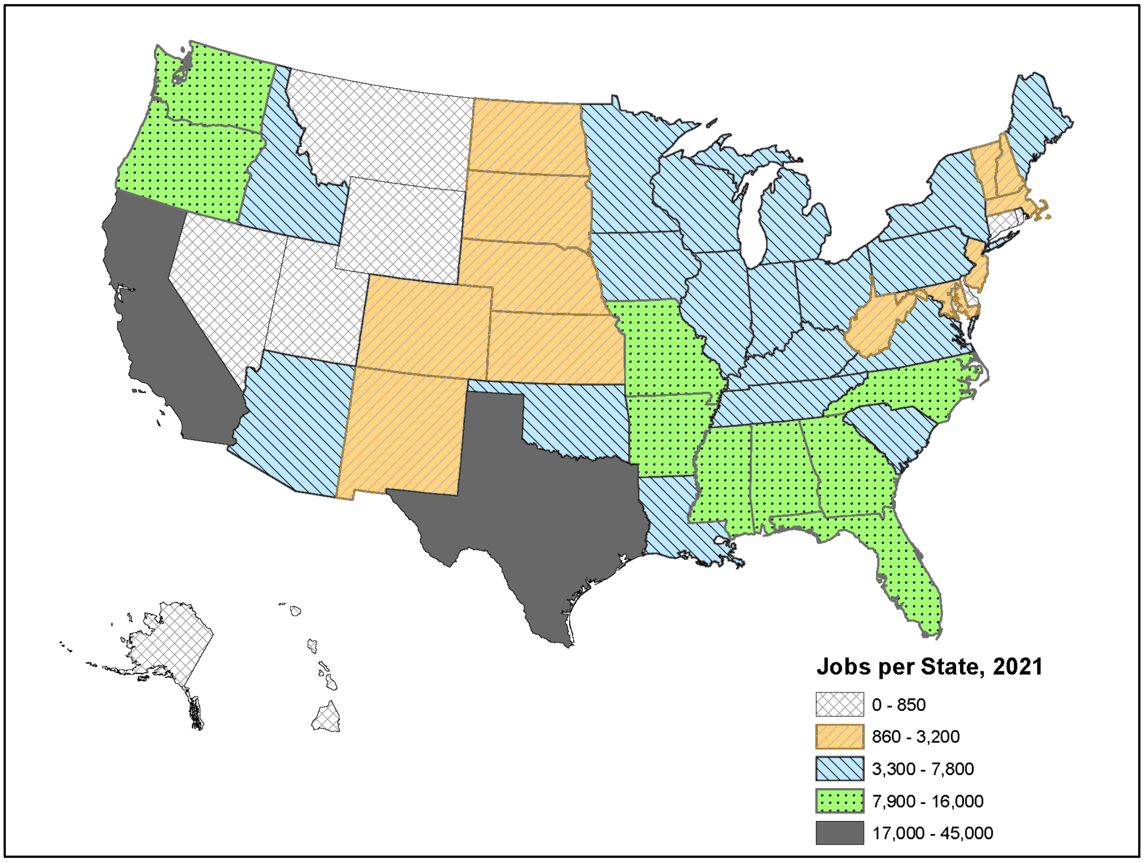


Figure 14: Total Jobs Contributed by the Agriculture and Forestry Sector in Each State and the District of Columbia.

Table 3: Top 10 States for Direct Value Added to the Agriculture and Forestry Sector in 2021.

Rank	State	Employment (Number of Jobs)	Value Added ($ Million)
1	California	44,700	2,901
2	Texas	40,400	2,100
3	Georgia	15,700	1,058
4	Oregon	11,000	857
5	Washington	10,300	741
6	Missouri	14,200	740
7	Florida	12,200	633
8	Alabama	9,500	558
9	North Carolina	10,300	541
10	Arkansas	12,500	515

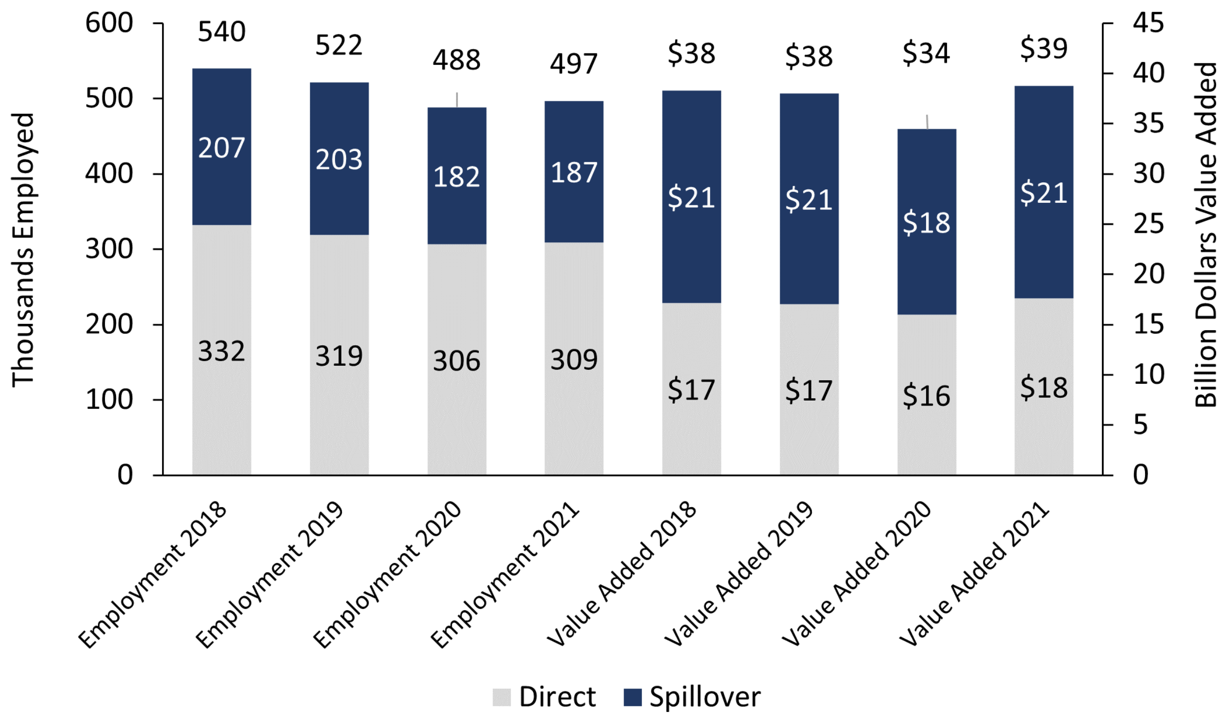


Figure 15: Agriculture and Forestry Sector Contribution to Employment and Value Added 2018-2021.

Table 4: Distribution of Direct Value Added and Employment by Agriculture and Forestry Subsectors.

IMPLAN Code	NAICS Codes	Description	Employment	Value Added
16	113310	Commercial logging	109,332	$6,763,262,519
19	11511, 11531	Support activities for agriculture and forestry – excluding animal production	101,806	$4,259,545,908
8	111920	Cotton farming	62,622	$4,056,542,388
15	113110, 113210	Forestry, forest products, and timber tract production	21,356	$1,728,479,111
2	111150	Grain farming – only corn included	13,522	$624,499,580
1	11111	Oilseed farming	422	$145,206,105
9	111930, 111991	Sugarcane and sugar beet farming	223	$18,683,000
		Totals	**309,283**	**$17,596,219,527**

2.3.1 Overview

The Agriculture, Forestry, Fishing and Hunting sector is made of three main subsectors: crop production, forestry and logging, and support activities for agriculture and forestry. The crop production subsector mainly produces crops for fiber, fuel (excluded from this analysis), and feedstocks (food is excluded), and includes industries such as cotton farming, corn farming, sugarcane harvesting, and oilseed farming.

The forestry and logging industry is formed by three principal industries (timber tract operations, forest nurseries and gathering of forest products, and logging), which grow and harvest timber using production cycles of 10 years or more.[24]

Support activities for agriculture and forestry supply essential inputs and as well as power, transportation, and other activities that are the foundation for the production process in each respective industry.[25]

This sector has seen notable growth, with a 4.3% yearly increase over a five-year period, culminating in a valuation of $638.7 billion by 2023. A key driver of this growth was a 14.8% revenue surge in 2021, which can be attributed to the global recovery from the COVID-19 pandemic and the resulting uptick in export demand. Nevertheless, the sector is predicted to experience a 2.4% dip in revenue by 2023 as markets adjust and supply chains regain stability.[31]

Family-owned farms are more than 85% of this sector. To remain competitive against larger corporations, these farms have increasingly embraced cooperative models and resource pooling. The pandemic has hastened this trend, causing rapid adaptation and consolidation within the sector.[31]

By 2022, the industry overcame supply chain disruptions, enabling downstream operators to run at optimal capacity. However, in the coming years, the sector's revenue is expected to decline due to falling agricultural prices and reduced crop revenue, despite rising meat prices and consumption supplying some support. Consequently, the sector's revenue is expected to experience a 0.5% annualized decrease over the next five years, settling at $622.0 billion.[26]

However, climate change mitigation goals and investments may disrupt this decline. In the U.S., significant investments in climate change mitigation were made with both the IRA and USDA's Partnerships for Climate Smart Commodities grants, and these investments could cause positive market disruption over the next five years. As carbon markets evolve, agriculture will play a unique role and is poised to become a critical player in worldwide climate mitigation efforts. With the majority of the world's leading economies, including the United States, committed to climate reduction targets, both demand for and supply of climate-smart commodities are expected to rise. This could lead to heightened demand and growth in the sector overall.

[24]U.S. Bureau of Labor Statistics. (nd). *About the Forestry and Logging Subsector*. U.S. Bureau of Labor Statistics, U.S. Department of Labor. https://www.bls.gov/iag/tgs/iag113.htm.

[25]U.S. Bureau of Labor Statistics. (nd). *Crop Production*. U.S. Bureau of Labor Statistics, U.S. Department of Labor., https://www.bls.gov/iag/tgs/iag111.htm.

[26]IBISWorld Industry Report 11 Agriculture, Forestry, Fishing and Hunting in the US, September 2023.

2.3.2 Crop Production

Cotton Farming

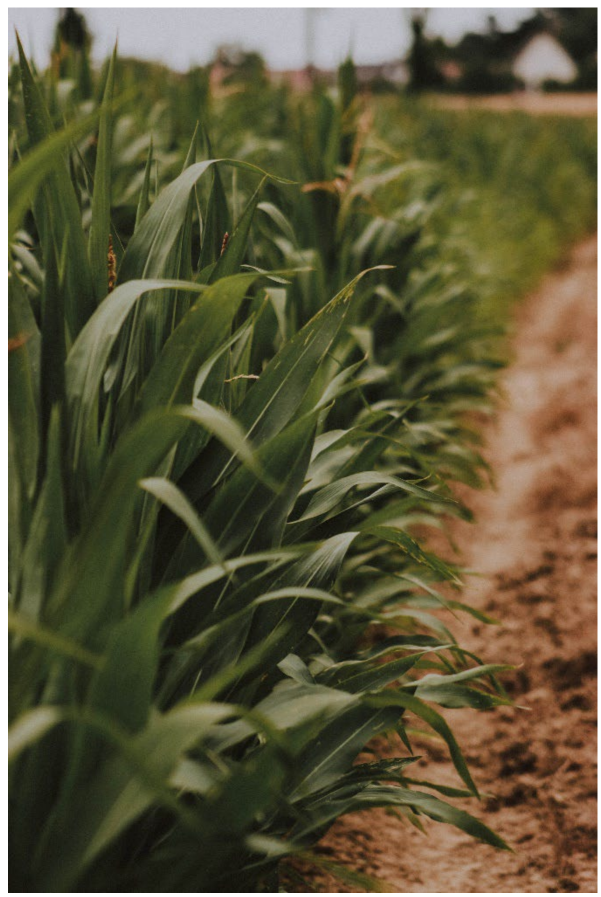
Cotton Farming played a crucial role in 2021 in the country's agricultural economy, ranking among the top global producers and exporters generating approximately $8.59 billion in revenue.[31] Production reached 17.5 million 480 lb. bales, of which Texas and Georgia made 55%. Cotton acreage, totaling 11.2 million acres,[27] was lower than in previous years due to factors like unfavorable weather, low prices, and competition from other crops.

The cotton industry had a significant economic impact, contributing to direct, indirect, and induced effects on employment, income, and tax revenues. It also supported the biobased products industry by supplying raw materials for the textile and apparel industries.

Sustainability and efficiency continued to be a focus in 2021, with initiatives such as the U.S. Cotton Trust Protocol growing in their national support and maturity. This program engages with the producer and promotes best management practices focused on continual improvement and optimized resource use, minimizing environmental impact, and enhancing crop yields. Research and development efforts in the sector focused on improving both fiber and cottonseed quality, developing pest and disease-resistant varieties, automation and robotics, and precision agriculture.

Sugarcane Harvesting

The sugarcane harvesting industry has been stable over the five years prior to 2023 apart from 2021, when COVID-19 affected the entire agricultural sector. Despite weather-related fluctuations and Hurricane Ida's effects, the industry expects a return to growth, with a compound annual growth rate (CAGR) of 1.4%, to reach $1.3 billion by 2023.[28] Over the next five years, this industry is expected to benefit from the bioeconomy as technological developments advance in producing biofuels from bagasse. Bagasse is a byproduct of sugarcane processing and may be a promising feedstock for future biofuel and biobased product manufacturing.



Corn Farming

The corn farming industry has experienced significant volatility in revenue over the past

[27] USDA National Agricultural Statistical Service. (2021). *Quick Stats*. USDA NASS. www.quickstats.nass.usda.gov

[28] IBIS World Industry Report 11193 Sugarcane Harvesting in the US – Market Size 2004-2029, September 2023.

five years due to dramatic fluctuations in corn prices and demand. The COVID-19 pandemic led to a revenue downturn, but surging exports and oil production in 2021 and 2022 caused revenues to soar. Consequently, revenue has grown at an annualized rate of 10.1% to $94.7 billion over the five years prior to 2023, with a 0.3% increase in 2023.

During the pandemic, domestic supply remained stable as production shifts occurred between states. As travel demand increased post-pandemic, oil production rose, and global crop production lagged, leading to higher U.S. corn exports. However, this volatility has negatively impacted production management and profit margins.

In the next five years, revenue is expected to decline slightly due to falling corn prices and increased competition from alternative grains. Although the IRA supports ethanol production, corn may face competition from alternatives like sugarcane. As prices drop, the upcoming Farm Bill will be crucial for corn farmers. Exports will continue to grow at a slower pace, and revenue is projected to decline at an annualized rate of 0.2% to $93.7 billion over the next five years.[29]

2.3.3 Forestry and Logging

Logging

Over the five years prior to 2023, the Logging subsector has experienced declining revenue, due to the pandemic and shifts in downstream subsectors, including nondurable goods manufacturing and construction. Decreased demand for paper products and an initial slowdown in residential construction negatively impacted industry growth. However, a booming real estate subsector and strong demand for softwood lumber mitigated declines in 2020 and 2021. Despite this, industry revenue is expected to decline by 2.6% to reach $15.0 billion in 2023.

In the next five years, industry revenue is projected to rise moderately as prices stabilize and residential construction demand potentially increases if interest rates fall. Consequently, industry revenue is anticipated to grow to reach $15.6 billion by 2028.[30]

Roundwood

Industrial roundwood products are based primarily on the use of the main stem of the tree. This includes pulpwood, sawlogs, and veneer logs, but it excludes wood for residential fuel. Timber grown to make wood pulp for paper production is known as pulpwood, and is usually harvested young, while the trunks still have small diameters. The trees are chipped to prepare the wood for pulping. Pulpwood-sized stems are also used to manufacture engineered wood products, such as structural wood composites. Wood chips and pulp are used

[29] IBIS World Industry Report 11115 Corn Farming in the US - Market Size, Industry Analysis, Trends and Markets (2023-2028), September 2023.

[30] IBIS World Industry Report 11331 Logging in the US – Market Size, Industry Analysis, Trends, and Forecasts (2023-2028), September 2023.

primarily in the production of paper, but they also may be used to produce fiberboard. Larger-sized trees that meet the minimum size requirements for producing lumber or veneer logs to produce plywood are classified as sawtimber. Approximately seven percent of global industrial roundwood is produced in the southern region of the United States. The United States leads the world in the production of timber for industrial products, accounting for approximately 25% of global production.

More than 5,000 types of products are produced from trees. While lumber and paper are easily recognizable, most products are derived from the biobased chemicals within the trees. Historically, these products have been derived from pitch, tar, and turpentine obtained from the pine forests in the southern United States. Currently, these products include rayon fabrics, filters, cosmetics, fragrances, pine oils, and many others.

Timber Tract Services

This industry manages timberland tracts and sells timber downstream to wood, paper, and pulp manufacturers. While growth in residential construction supports the industry, weaknesses in other markets like paper and wood products manufacturing and increased import competition have led to a 1.8% CAGR decline in revenue to $956.5 million in 2023, including a 6.9% decrease in 2023 alone.

Rising wage costs and lumber prices have changed profit growth, attracting new entrants, while institutional investors buying timber holdings may constrain the U.S. timber supply. Forest fires also pose a threat to the industry. Industry revenue is expected to rise slightly in the coming years as sawmill timber prices recover and import penetration falls in wood product manufacturing industries. Construction will likely remain the primary downstream market for timber. Industry revenue is projected to fall at a 0.5% CAGR to $980.4 million from 2023 to 2028.[31]

Crop Services

The Crop Services industry, which aids in various planting, harvesting, and treatment activities, has grown at CAGR of 8.9% to an estimated $38.3 billion over the past five years prior to 2023. Factors such as renewable energy quotas, increasing global population, and stabilizing crop prices have affected the industry. The COVID-19 pandemic initially disrupted operations and reduced demand, but industry revenue is expected to recover, growing an estimated 9.7% in 2023. Over the next five years, crop production is expected to increase. Farmers will likely outsource services due to rising interest rates, resulting in an annualized growth rate of 4.2%, to reach $37.6 billion by 2028.[31]

Forest Support Services

The Forest Support Services industry offers assorted services to downstream forestry markets, including resource estimation, mapping, and firefighting. It is highly fragmented, with most companies being non-employers contracted seasonally. Demand depends on forestry activity and outsourcing trends in downstream industries. Industry

[31]IBIS World Industry Report 11511 Crop Services in the US – Market Size, Industry Analysis, Trends, and Forecasts (2023-2028), February 2023.

revenue has grown due to strong residential construction and lumber demand in recent years. However, recent rising interest rates have caused demand to slow with a CAGR of 0.7%, reaching $3.5 billion in 2023. The industry is expected return to growth over the next five years as consumer confidence and inflations issues resolve, resulting in an estimated annualized 2.1% revenue increase to $3.9 billion by 2028.[32]

[32] IBIS World Industry Report 11531 Forest Support Services in the US – Market Size, Industry Analysis, Trends, and Forecasts (2023-2028), September 2023.

2.4 Biorefining

Figure 16 illustrates how the value added produced by the Biorefining sector industry is distributed across each state (using an approximated range), and

Table 5 shows the data for the top ten states. Figure 18 shows the employment and value added change between 2018 and 2021 in the Biorefining sector.

As of 2021, there were 278 biorefineries in the United States with a nameplate capacity of twenty-one billion gallons per year. Many of these refineries are producing co-products that support the U.S. biobased products industry.[33]

Major U.S.-Based Firms [34]
Cargill, Incorporated (Minnesota)
Archer Daniels Midland Company (Illinois)
Poet LLC (South Dakota)
Valero Marketing and Supply Company (Texas)
Green Plains Inc. (Nebraska)

Economic Statistics
Total value added to the U.S. economy in 2021: $1.6 billion.

Type SAM Multiplier: 6.0 in 2021.

Employment Statistics
Total number of Americans employed due to biobased products industry activities in 2021: 13,025.

SAM Employment Multiplier: 14.5 in 2021.

Table 6 shows these economic and employment statistics.

[33] Buckner, C. & Hill, S. (2021, September 13). *EIA releases plant-level U.S. biofuels production capacity data*. US Energy Information Administration. https://www.eia.gov/todayinenergy/detail.php?id=49516#

[34] Murphy, A. & Tucker, H. (Eds.) (2023, June 8). *Forbes Global 2000 in 2022.* Forbes. http://www.forbes.com/global2000/list/.

Figure 16: Total Value Added Contributed by the Biorefining Sector in Each State and the District of Columbia.

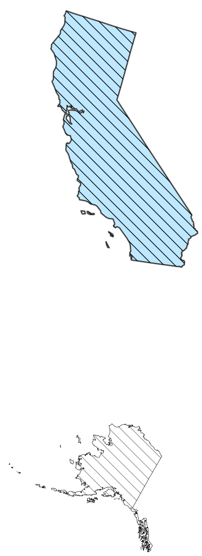


Figure 17: Total Jobs Supported by the Biorefining Sector in Each State and the District of Columbia.

Table 5: Top 10 States for Direct Value Added to the Biorefining Sector in 2021.

Rank	State	Employment (Number of Jobs)	Value Added ($ Million)
1	Illinois	270	88.7
2	Iowa	120	35.1
3	Indiana	60	17.1
4	Louisiana	50	12.5
5	Nebraska	20	12.5
6	Tennessee	20	8.8
7	California	40	8.6
8	Minnesota	40	8.1
9	Missouri	20	7.6
10	Florida	30	5.8

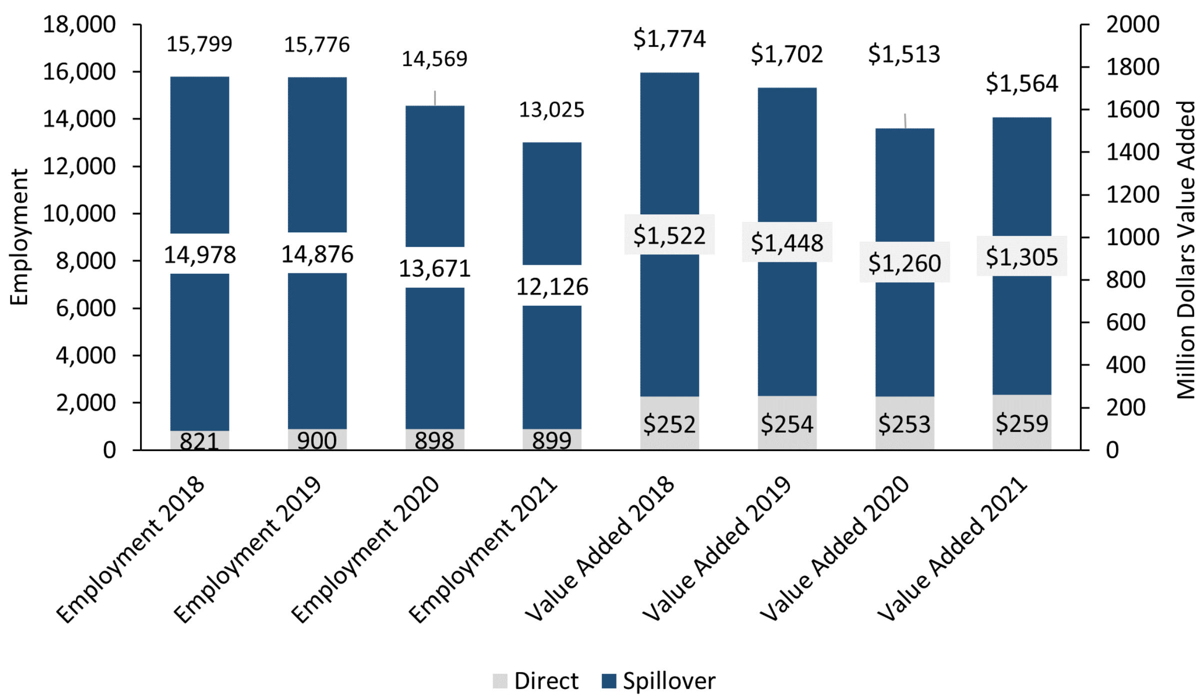


Figure 18: Biorefining Sector Contribution to Employment and Value Trends.

Table 6: Distribution of Direct Value Added and Employment by Biorefining Subsectors.

IMPLAN Code	NAICS Codes	Description	Employment	Value Added
70	311221	Wet corn milling	585	$178,000,000
74	311313	Beet sugar manufacturing	121	$34,000,000
75	311311, 311312	Sugarcane mills and refining	117	$22,000,000
71	311222, 311223	Soybean and other oilseed processing	43	$19,000,000
72	311225	Fats and oils refining and blending	34	$6,000,000
		Totals	**900**	**$259,000,000**

2.4.1 Overview

Biorefining is an innovative alternative to the production of petroleum-based products, and it is an important part of the emerging biobased products industry. The global market for biorefining is expected to increase to nearly $980 billion by 2026, with a compound annual growth rate (CAGR) of 9.8%. North America, China, and Europe lead the world market in production.[35] This positive outlook from industry is due to the volatile prices of fossil fuels. Growth in the sector is limited in that major investment and technological costs are needed to open a new biorefinery, and there is a shortage of biomass suppliers. However, the potential unpredictability in this sector will be stabilized to some extent by increased awareness of sustainability issues and the consequences of burning fossil fuels and the industry's interest in developing biobased products.

Biorefineries are an important pathway to help revive marginalized, rural, agricultural, and industrial economies. Biorefineries can help usher in a new economic engine and support local communities, from farmers to local governments, by creating a steady source of revenue. Biorefineries help farmers keep their land and supply an added base from which they can sell their products. The taxes generated benefit local governments. Further, supporting rural economies with large-scale investments, such as biorefineries, will help reduce the pattern of rural to urban migration that is taking people away from farmlands. Biorefineries establish energy security by reducing the U.S.'s dependence on foreign oil and create steady, well-paying, knowledge-based jobs.

[35]Global Newswire. Global Biorefinery Market to Reach US$979.5 Billion by the Year 2026. January 20, 2022. https://www.globenewswire.com/news-release/2022/01/20/2370040/0/en/Global-Biorefinery-Market-to-Reach-US-979-5-Billion-by-the-Year-2026.html

2.5 Biobased Chemicals

Figure 19 illustrates how the value added produced by the Biobased Chemicals sector industry is distributed across each state (using an approximated range), and Figure 20 shows the number of jobs the Biobased Chemicals sector supports by state; Table 7 shows the data for the top 10 states. Figure 21 shows the employment and value added changed between 2018 and 2021 in the Biobased Chemicals sector.

Over the past five years, chemical manufacturing revenue has grown annually by 3.9%. Looking forward, sector is expected to increase at an annualized rate of 0.4%.[36]

Major U.S.-Based Firms.[37]
The Lubrizol Corporation (Ohio)
Fujifilm Holdings America Corp (New York)
DuPont de Nemours, Inc. (Delaware)
Eastman Chemical Company (Tennessee)
Sherwin-Williams Co. (Ohio)
NatureWorks LLC (Minnesota)
Dow Inc. (Michigan)
Gemtek Products LLC (Arizona)
Gevo, Inc. (Colorado)
Biosynthetic Technologies (California)

Economic Statistics
Total value added to the U.S. economy in 2021: $9 billion.

Type SAM Value Added Economic Multiplier in 2021: 3.5.

Employment Statistics
Total number of Americans employed due to industry activities in 2021: 57,000.

Type SAM Employment Multiplier in 2021: 5.7.

Table 8 shows these economic and employment statistics.

[36] IBIS World Industry Report 32599 Chemical Product Manufacturing in the US – Market Size, Industry Analysis, Trends, and Forecasts (2023-2028), September 2023.

[37] Ibid.

Figure 19: Total Value Added by the Biobased Chemicals Sector in Each State and the District of Columbia.

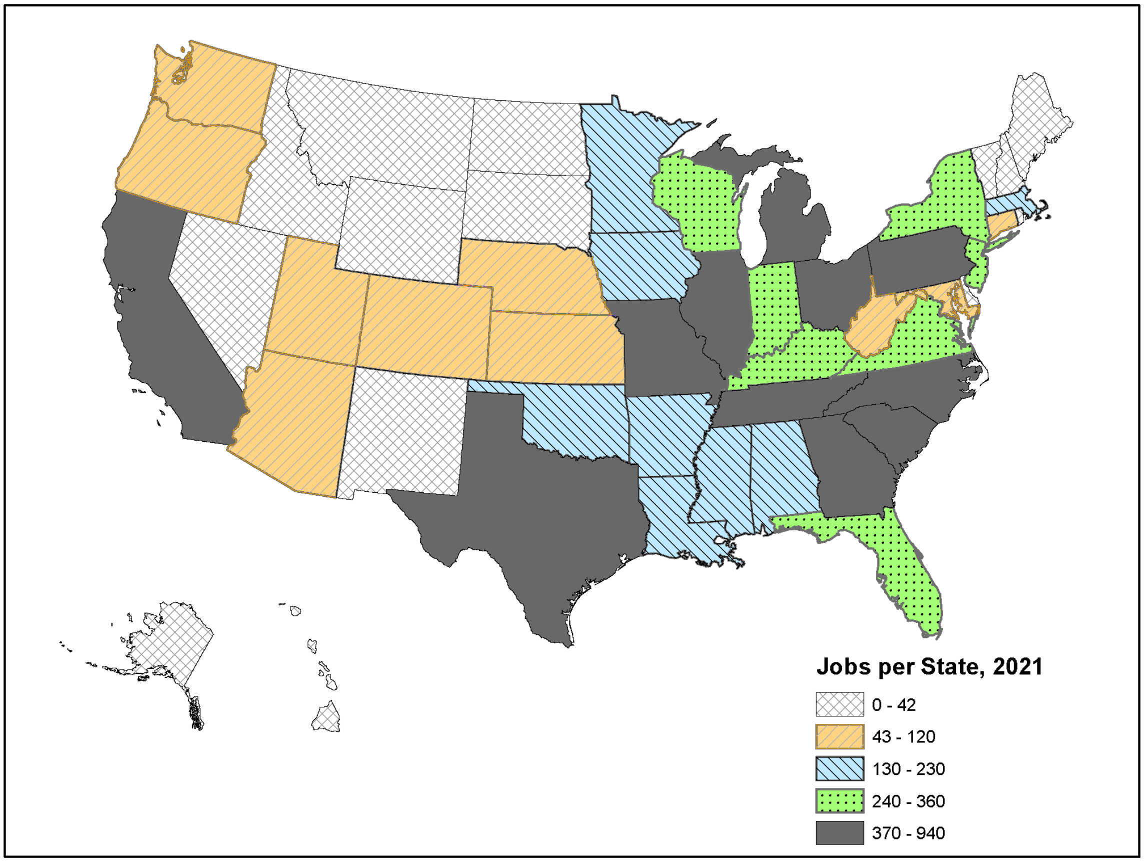


Figure 20: Total Jobs Supported by the Biobased Chemicals Sector in Each State and the District of Columbia.

Table 7: Top 10 States for Direct Value Added to the Biobased Chemicals Sector in 2021.

Rank	State	Employment- (Number of Jobs)	Value Added ($ Million)
1	Ohio	920	294
2	California	710	271
3	Texas	940	251
4	Missouri	610	131
5	Illinois	570	119
6	New Jersey	350	117
7	Michigan	540	111
8	Pennsylvania	490	109
9	North Carolina	580	101
10	Tennessee	570	97

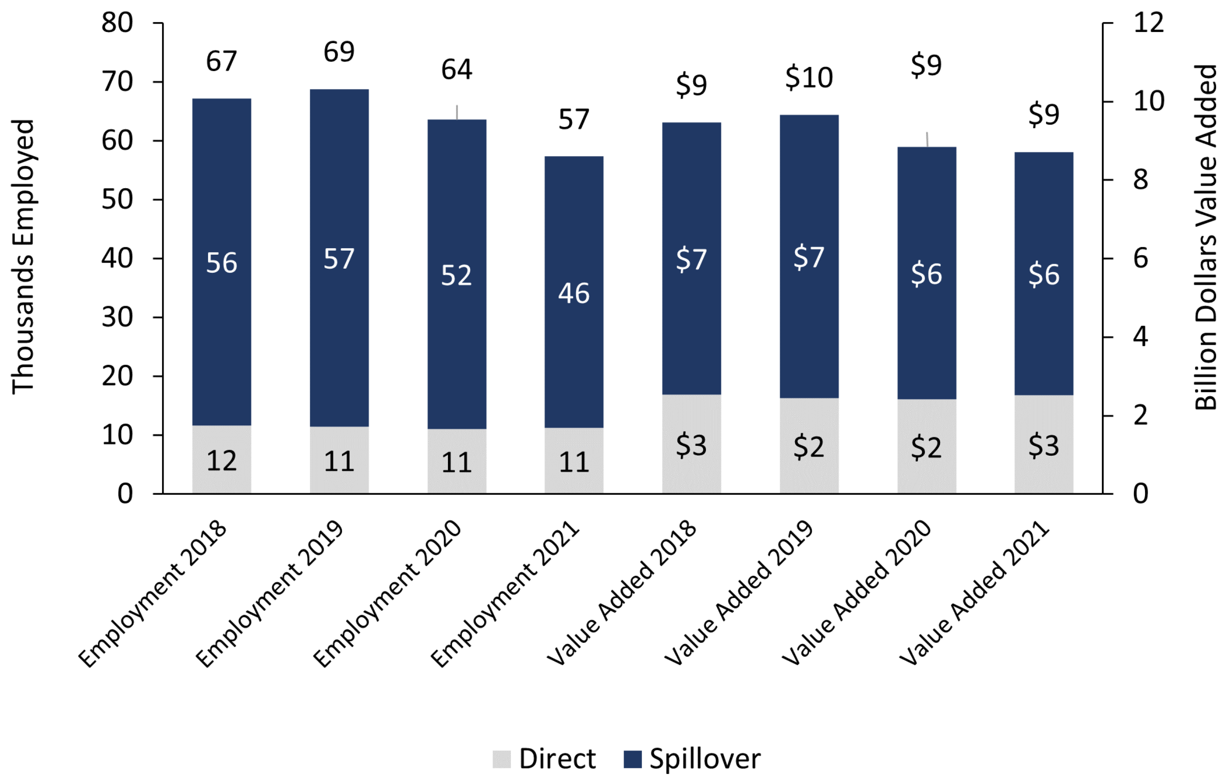


Figure 21: Biobased Chemicals Sector Contribution to Employment and Value Added Trends.

Table 8: Distribution of Direct Value Added and Employment by Biobased Chemicals Subsectors.

IMPLAN Code	NAICS Code	Description	Employment	Value Added
164	325211	Plastics material and resin manufacturing	1,185	$268,000,000
163	32519	Other basic organic chemical manufacturing	1,074	$290,000,000
194	32621	Tire manufacturing	1,051	$109,000,000
180	325620	Toilet preparation manufacturing	1,031	$432,000,000
196	32629	Other rubber product manufacturing	977	$93,000,000
175	325510	Paint and coating manufacturing	805	$212,000,000
185	325998	Other miscellaneous chemical product manufacturing	784	$169,000,000
191	326150	Urethane and other foam product (except polystyrene) manufacturing	703	$80,000,000
190	326140	Polystyrene foam product manufacturing	557	$66,000,000
177	325611	Soap and other detergent manufacturing	546	$311,000,000
178	325612	Polish and other sanitation good manufacturing	483	$116,000,000
166	32522	Artificial and synthetic fibers and filaments manufacturing	466	$79,000,000
176	325520	Adhesive manufacturing	439	$97,000,000
195	326220	Rubber and plastics hoses and belting manufacturing	418	$45,000,000
183	325991	Custom compounding of purchased resins	328	$55,000,000
181	325910	Printing ink manufacturing	139	$17,000,000
184	325992	Photographic film and chemical manufacturing	138	$32,000,000
179	325613	Surface active agent manufacturing	90	$42,000,000
		Totals	**11,214**	**$2,513,000,000**

2.5.1 Overview

Biobased chemicals currently make up a very small segment, estimated at less than 2 percent of the chemical industry. This section and the subsequent sections describe the chemical manufacturing industry, not the biobased chemical manufacturing industry specifically. As such, the authors have covered the developments in the chemical industry by highlighting opportunities for biobased chemicals.

The chemical manufacturing subsector transforms organic and inorganic raw materials into various chemicals. Products that are further processed, such as resins, plastics, and soaps, are categorized uniquely to distinguish them from production of basic chemicals. The primary subsectors within this sector, as defined by their NAICS codes, are basic chemical manufacturing, plastic and resin manufacturing, soap and cleaning compounds, and cosmetic and beauty products.

The United States is a global leader in chemical production, second only to China. After struggling for the past five years, the industry is expected to rebound over the coming five years and grow at an annual rate of 3.9%. Increased demand from downstream consumers signals a return to increased revenue and profits for the industry.[38]

Chemical demand is intrinsically linked to consumer spending and manufacturing since 96% of U.S products need chemical inputs. An uptick in the industrial production index, a measure of mining, manufacturing, and energy industries, consequently, drives chemical demand. Also, the construction industry's health reflects the overall economy and influences chemical manufacturing.

Modest growth in emerging economies is promising for industry exports, despite challenges posed by the trade-weighted index. The future impact of dollar strength on exports is unclear. Profitability is tempered by wage hikes and escalating input prices; even as lower operating costs offer relief.

Chemical prices have seen significant volatility in the past five years, due to fluctuations in crude oil prices, a critical raw material for many industries. The biobased chemical sector offers a sustainable raw material sourcing model, enabling steadier long-term planning for chemical manufacturers. Major players like Dow, DuPont, and Sherwin-Williams have pledged to transition towards this model. The rising demand for eco-friendly products and sustainable business practices is likely to motivate more companies to delve into the biobased chemical sector and invest.

Plastic & Resin Manufacturing

The Plastic and Resin Manufacturing industry has experienced volatile revenue growth due to fluctuating demand. The COVID-19 pandemic led to a revenue decline in 2020,

[38] Ibid.

but rebounding global productivity and increased manufacturing capacity helped the industry grow. Revenue grew at a 0.8% CAGR to $129.1 billion by 2023, though profits declined. Rising costs of raw materials such as crude oil and natural gas increased production expenses. Disrupted supply chains and conflict in Ukraine have elevated energy prices. Through 2028, revenue is expected to fall at a 0.9% CAGR to $123.2 billion, but profit margins will improve as input costs stabilize.[39]

Synthetic Fiber Manufacturing

The Synthetic Fiber Manufacturing industry, which supplies petrochemical-based fibers to discretionary goods producers, has faced challenges due to declines in downstream market demand, pandemic-related disruptions, and increasing crude oil prices. Revenue has fallen at a 4.6% CAGR to $6.1 billion over five years, with profit decreasing as well. Additionally, concerns over emerging macro and microplastic pollution could hinder the industry's growth.

In 2023, a stronger US dollar and a decrease in housing starts will further challenge the industry. However, over the next five years, reduced crude oil prices, a rebound in downstream markets, and growth opportunities will lead to a 1.1% CAGR, increasing revenue to $6.5 billion by 2028, though still below pre-pandemic levels.[40]

Soap & Cleaning Compound Manufacturing

Soap and cleaning compound manufacturers produce various materials, including household staples and commercial products. The COVID-19 pandemic bolstered demand for household soaps, but business disruptions led to meager performance in 2020. High inflation and interest rates have recently challenged the industry, causing revenue to fall at a 1.8% CAGR to $42.7 billion by 2023. From 2023 to 2028, manufacturers will face challenges from declining healthcare demand, increased globalization, and competition from abroad. Despite these hurdles and a predicted 0.8% CAGR decline in revenue to $41.0 billion by 2028, profits are expected to remain stable.[41]

Cosmetic & Beauty Products Manufacturing

Cosmetic and beauty products manufacturing has faced challenges due to rising interest rates and decreasing disposable income, leading to a 2.7% CAGR revenue decrease to $48.8 billion by 2023. However, a growing middle-aged consumer group and rising consumer spending have driven demand for luxury, anti-aging, and innovative products. Exports and online businesses have also supported revenue growth. Over the next five years, increasing consumer confidence, disposable income, and slowing imports will contribute to a 1.2% CAGR revenue growth to $51.8 billion by 2028.[42]

Ink Manufacturing

The Ink Manufacturing industry, which produces printing inks and cartridges, faces challenges due to the shift towards digital media and the decline of traditional print media. The industry is expected to decline at a CAGR of 4.5% to $4.5 billion from 2018 to

[39]IBISWorld. (nd). *Plastic & Resin Manufacturing in the US - Market Size, Industry Analysis, Trends, and Forecasts.* IBISWorld.
[40]IBISWorld. (nd). *NAICS Code 325220 – Artificial and Synthetic Fibers and Filaments Manufacturing.* IBISWorld
[41]IBISWorld. (nd). *NAICS Code 32561 – Soap and Cleaning Compound Manufacturing*. IBISWorld.
[42]IBISWorld (2023, January 25). *Cosmetic and Beauty Products Manufacturing Industry in the US – Market Research Report.* IBISWorld.

2023, with a 3.1% drop in 2023 due to the pandemic's impact. Manufacturers have restructured operations to focus on more profitable segments, but the shift to digital marketing and electronic communication will continue to pressure the industry. As a result, the industry is projected to contract further at a CAGR of 4.4% to $3.6 billion through 2028.[43]

Restructuring continued in the ink manufacturing industry between 2018 and 2022 as it grappled with declining print media, ranging from newspapers to books. Increased consumer spending and the associated labeling and packaging that require inks are one bright spot, but, overall, this industry will continue to shrink at a rate of 1.5%. Exports are also set to decrease by 0.9% due to the increasing competition from foreign producers.

[43]IBIS World Industry Report 32531 Fertilizer Manufacturing in the US – Market Size, Industry Analysis, Trends, and Forecasts (2023-2028), September 2023.

2.6 Enzymes

Figure 22 illustrates how the value added produced by the Enzymes sector industry is distributed across each state (using an approximated range), and Figure 23 shows the number of jobs the Enzymes sector supports by state; Table 9 shows the data for the top ten states. Figure 24 shows the employment and value added changed between 2018 and 2021 in the Enzymes sector.

Enzymes are used in a wide range of industrial sectors, including the production of detergents and biobased chemicals. The global industrial enzyme market was at $6 billion in 2021 and is expected to increase at a CAGR of 4.3% to 2032.[44]

Major U.S.-Based Firms

Archer Daniels Midland Company (Illinois)
Dyadic International, Inc. (Florida)

Global Firms with a Presence in the U.S.

Novozymes A/S (major U.S. sites in North Carolina, California, and Nebraska)
BASF Corporation (major U.S. sites in North Carolina and California)

Economic Statistics

Total value added to the U.S. economy in 2021: $116 billion.

Type SAM Economic Multiplier in 2021: 3.34.

Employment Statistics

Total number of Americans employed due to industry activities in 2021: 698,000.

Type SAM Employment Multiplier in 2021: 7.04

Table 10 shows these economic and employment statistics.

[44] Industrial Enzymes Market Outlook (2022 – 2023). Accessed 2023. https://www.factmr.com/report/industrial-enzymes-market

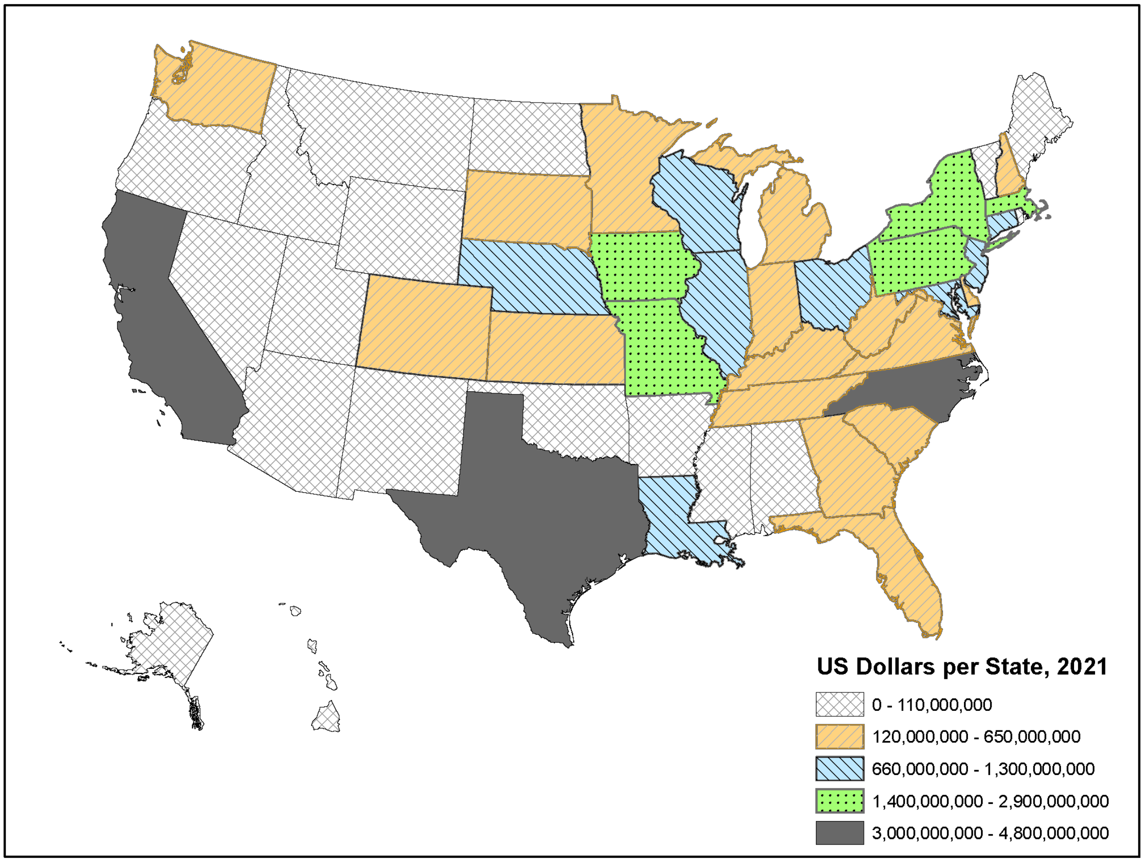


Figure 22: Total Value Added Contributed by the Enzymes Sector in Each State and the District of Columbia.

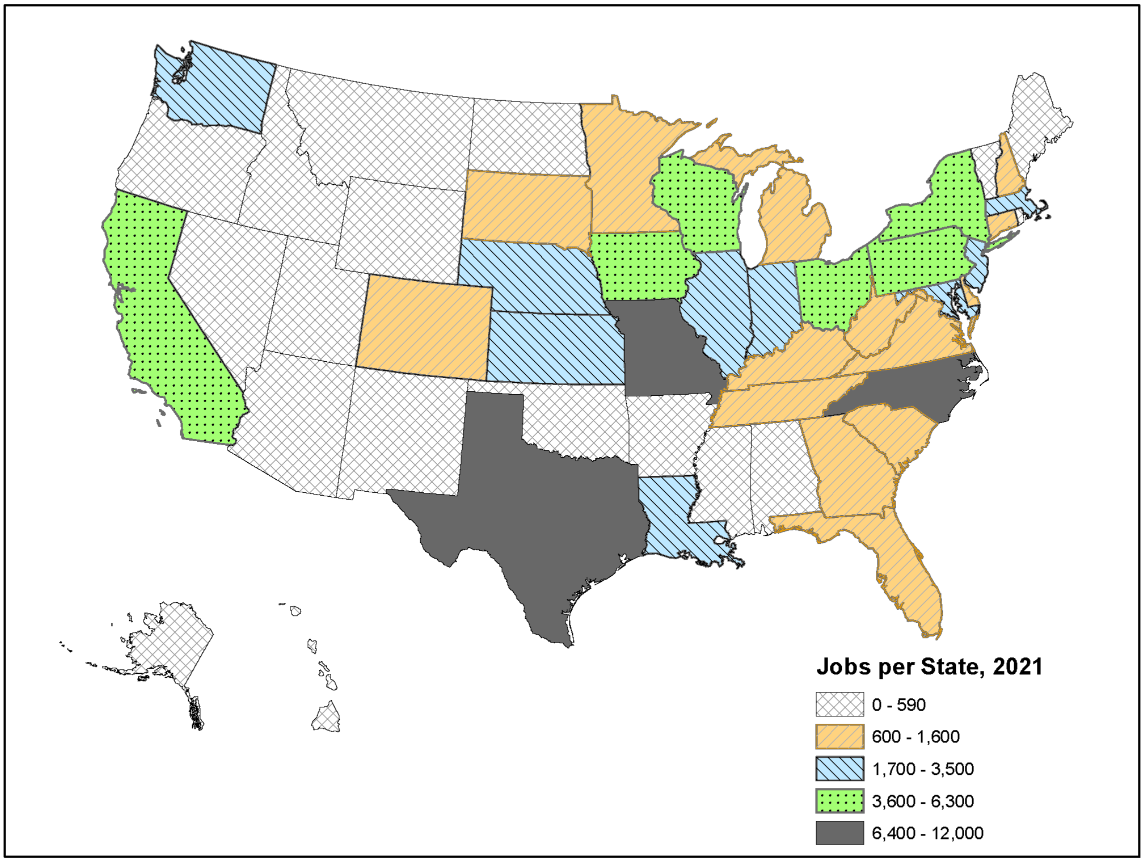


Figure 23: Total Jobs Contributed by the Enzymes Sector in Each State and the District of Columbia.

Table 9: Top 10 States for Direct Value Added to the Enzymes Sector in 2021.

Rank	State	Employment (Number of Jobs)	Value Added ($ Million)
1	North Carolina	12,440	4,786
2	Texas	9,980	3,603
3	California	5,160	3,462
4	New York	6,330	2,910
5	Missouri	8,330	2,379
6	Pennsylvania	4,510	1,941
7	Massachusetts	1,810	1,702
8	Iowa	4,430	1,699
9	Maryland	2,060	1,307
10	Ohio	4,870	1,279

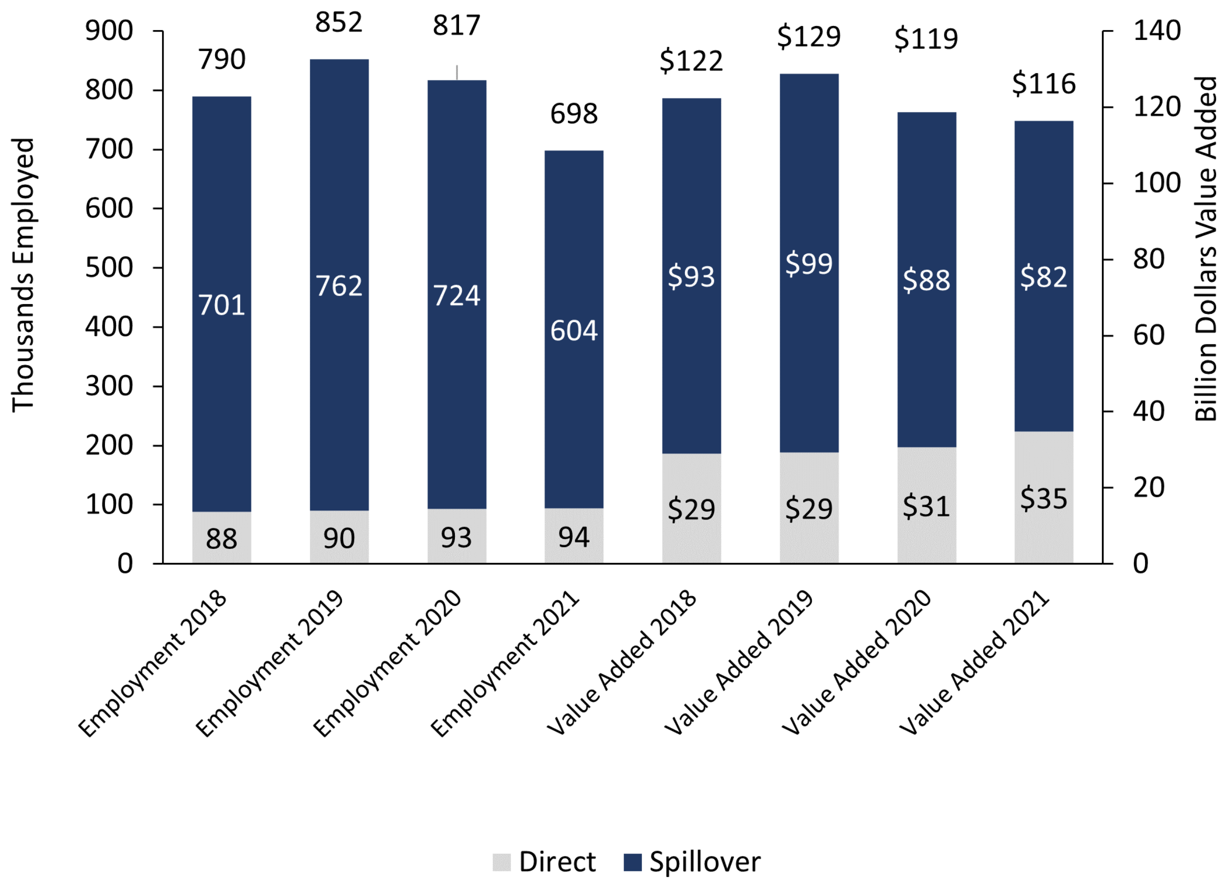


Figure 24: Enzymes Sector Contribution to Employment and Value Added Trends.

Table 10: Distribution of Direct Value Added and Employment by Subsectors.

IMPLAN Code	NAICS Code	Description	Employment	Value Added
165	32519	Other basic organic chemical manufacturing	54,880	$12,222,000,000
176	325414	Biological product (except diagnostic) manufacturing	29,620	$12,598,000,000
		Totals	**84,500**	**$24,820,000,000**

2.6.1 Overview

Enzymes are used in a wide range of industrial sectors, including the production of biofuels, washing detergents, foods and animal feed, and biobased chemicals. Unlike chemical catalysts, enzymes have an active site of specific size and form that will fit only a specific range of substrates for an extremely specific reaction. Enzymes are used as detergents in the textile sector to break down protein, starch, and fatty stains in the finishing of fabrics. They are also used in the biofuels industry in the conversion process of first-generation feedstocks and in the conversion of agricultural wastes (second-generation) into ethanol and in several other industrial sectors, such as paper and pulp, wine making, brewing, and baking.

Globally, the industrial enzyme market contributes to the annual revenue and is a major driver for innovation across several industries. The global industrial enzyme market was estimated at $6 billion in 2021 and is expected to grow at a CAGR of 4.3% to 2032.[45] This positive outlook is owed to a number of factors, ranging from increasing consumer concern for health and growing demand from food and beverage products.[46] The United States and many countries in Europe, including France, Germany, and Sweden have especially supportive policies. The use of enzymes in the production of paper, rubber, photography, and detergents, to name a few, is expected to drive expansion as well.[47]

Enzymes are proteins that promote specific chemical reactions and are the foundation for the metabolism of living organisms. These reactions speed up biochemical processes, making them more efficient by using less energy and resources. Humans have been using enzymes to produce biochemical reactions for thousands of years, with the earliest example being the fermenting of crops into wine and beer. While there are more than 4,000 recognized enzymes in the world, it is estimated that more than 25,000 exist in the natural world. With an estimated 90% of enzymes yet to be classified, this shows an enormous possibility for innovation and growth. Industrial enzymes serve a dual function within the biobased products industry. By helping biochemical reactions, enzymes directly reduce the use of petrochemicals and reliance on fossil fuels. At the same time, enzymes, their feedstocks, and their byproducts are biodegradable, and reduce industrial waste headed to landfills. One area in which there is considerable excitement within the industry is the modification and specialization of existing enzymes. New research into redesigning enzymes will help industrial processes become even more efficient and environmentally preferable.

[45] Industrial Enzymes Market Outlook (2022 – 2023). Accessed 2023. https://www.factmr.com/report/industrial-enzymes-market.

[46] Grand View Research: Enzymes Market by Type, Market Research Report, accessed September 2023. https://www.grandviewresearch.com/industry-analysis/enzymes-industry.

[47] Grand View Research: Enzymes Market by Type, Market Research Report, accessed September 2023. https://www.grandviewresearch.com/industry-analysis/enzymes-industry.

2.7 Biobased Plastic Bottles and Packaging

Figure 25 illustrates how the value added produced by the Biobased Plastic Bottles and Packaging sector industry is distributed across each state (using an approximated range), and Figure 26 shows the number of jobs the Biobased Plastic Bottles and Packaging sector supports by state; Table 11 shows the data for the top 10 states. Figure 27 shows the employment and value added changed between 2018 and 2021 in the Biobased Plastic Water Bottles and Packaging sector.

Concerns about petroleum-based plastics have spurred demand for sustainable biobased plastics. Fluctuating crude oil prices led to the exploration of alternatives, but biobased plastics remain more expensive. Revenue has declined at a 1.5% CAGR over five years, with a 1.2% increase expected in 2023. Environmental awareness and supportive legislation have also bolstered the sector. Over the next five years, a robust economy, new market expansion, and positive legislation will drive growth. Revenue is forecasted to grow at a 1.9% CAGR, reaching $1.2 billion by 2028.[48]

Major U.S.-Based Biobased Plastics Producers

DuPont de Nemours, Inc. (Delaware)
Jamplast Distributions, Inc. (Missouri)
Yield10 Bioscience, Inc. (Massachusetts)
NatureWorks LLC (Minnesota)
Teknor Apex Company (Rhode Island)
Gevo, Inc. (Colorado)
Virent, Inc. (Wisconsin)

Major U.S.-Based Biobased Plastics Users

The Coca-Cola Company (Georgia)
Ford Motor Company (Michigan)
Kraft-Heinz, Inc. (Pennsylvania)
Nike, Inc. (Oregon)
The Procter & Gamble Company (Ohio)

Economic Statistics

Total value added to the U.S. economy in 2021: $1.88 billion.

Type SAM Economic Multiplier in 2021: 3.5.

Employment Statistics

Total number of Americans employed due to industry activities in 2021: 15,000.

Type SAM Employment Multiplier in 2021: 3.1.

Table 12 shows these economic and employment statistics.

[48]IBISWorld. (2023, April 7). *Bioplastics Manufacturing in the US – Market Research Report*. IBISWorld. https://www.ibisworld.com/united-states/market-research-reports/bioplastics-manufacturing-industry/

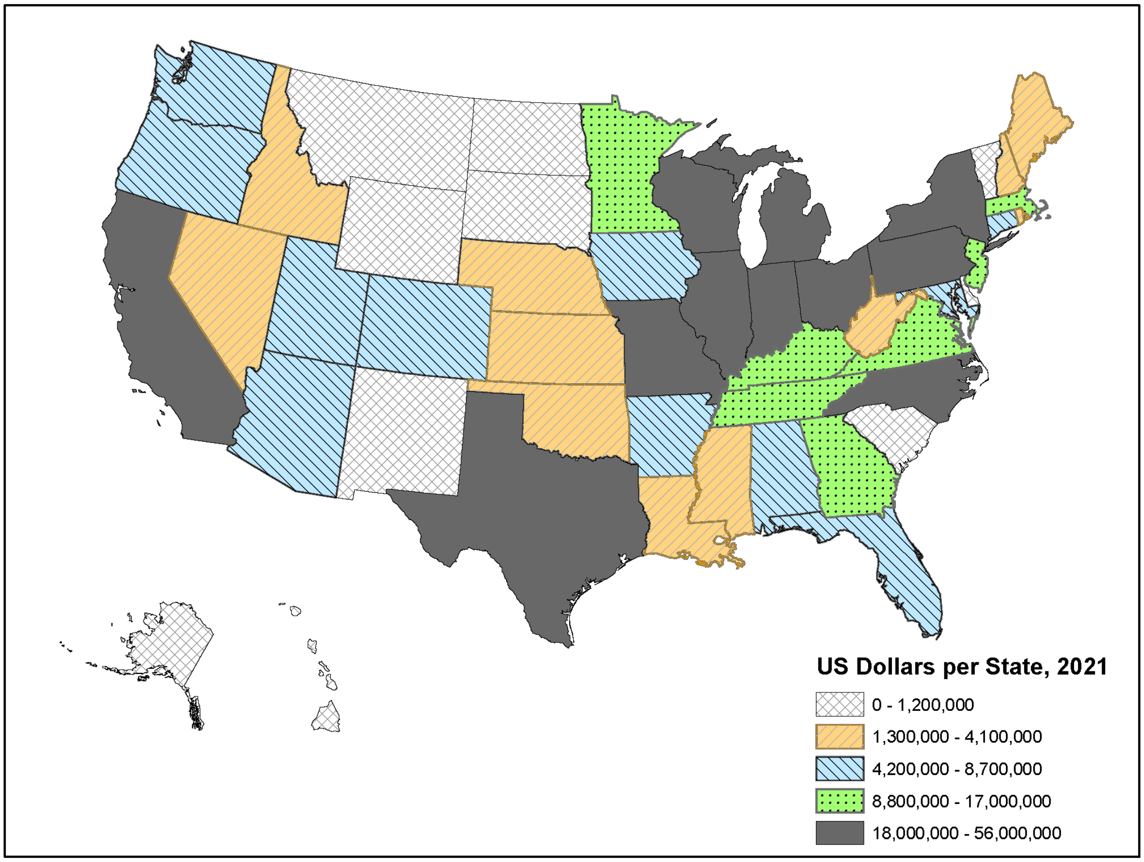


Figure 25: Total Value Added Contributed by the Biobased Plastic Bottles and Packaging Sector in Each State and the District of Columbia.

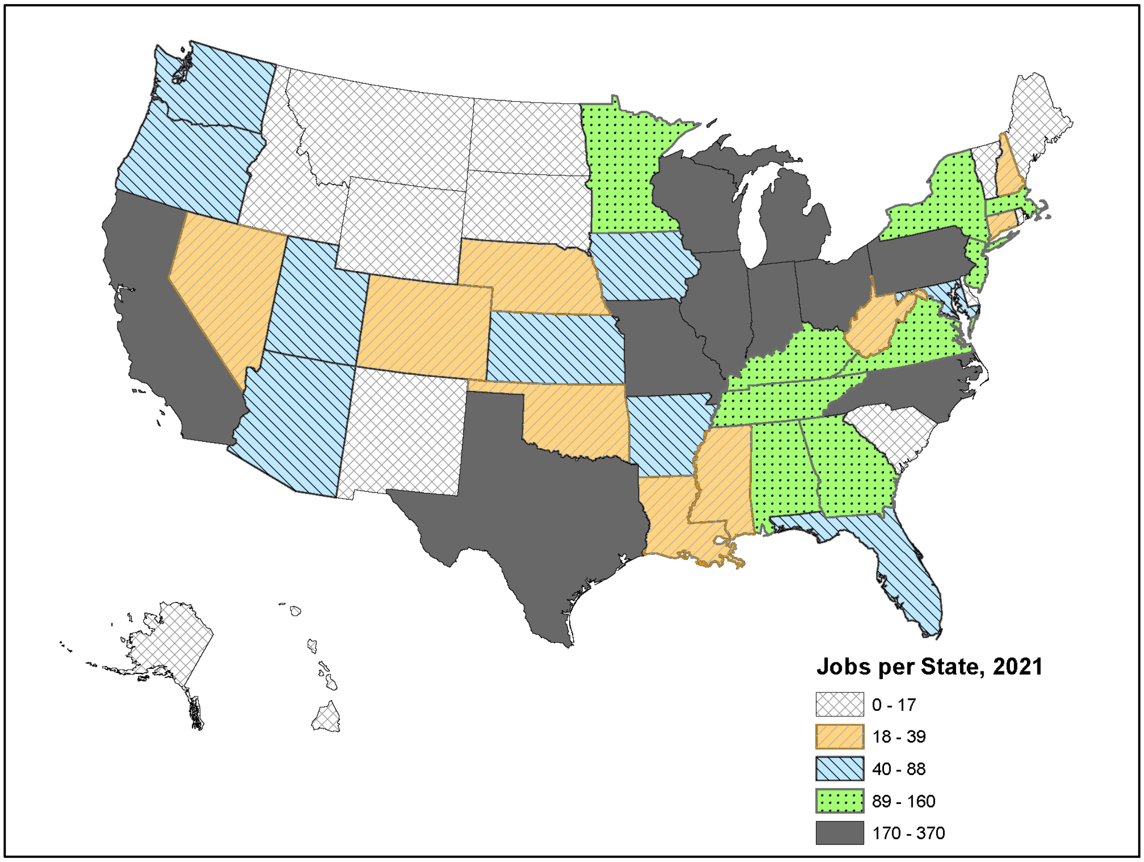


Figure 26: Total Jobs Contributed by the Biobased Plastic Bottles and Packaging Sector in Each State and the District of Columbia.

Table 11: Top 10 States for Direct Value Added to the Biobased Plastic Bottles and Packaging Sector in 2021.

Rank	State	Employment (Number of Jobs)	Value Added ($ Million)
1	Illinois	330	56
2	North Carolina	350	41
3	Ohio	370	41
4	California	320	37
5	Pennsylvania	280	30
6	Missouri	260	29
7	Wisconsin	290	29
8	New York	160	27
9	Texas	260	27
10	Michigan	260	26

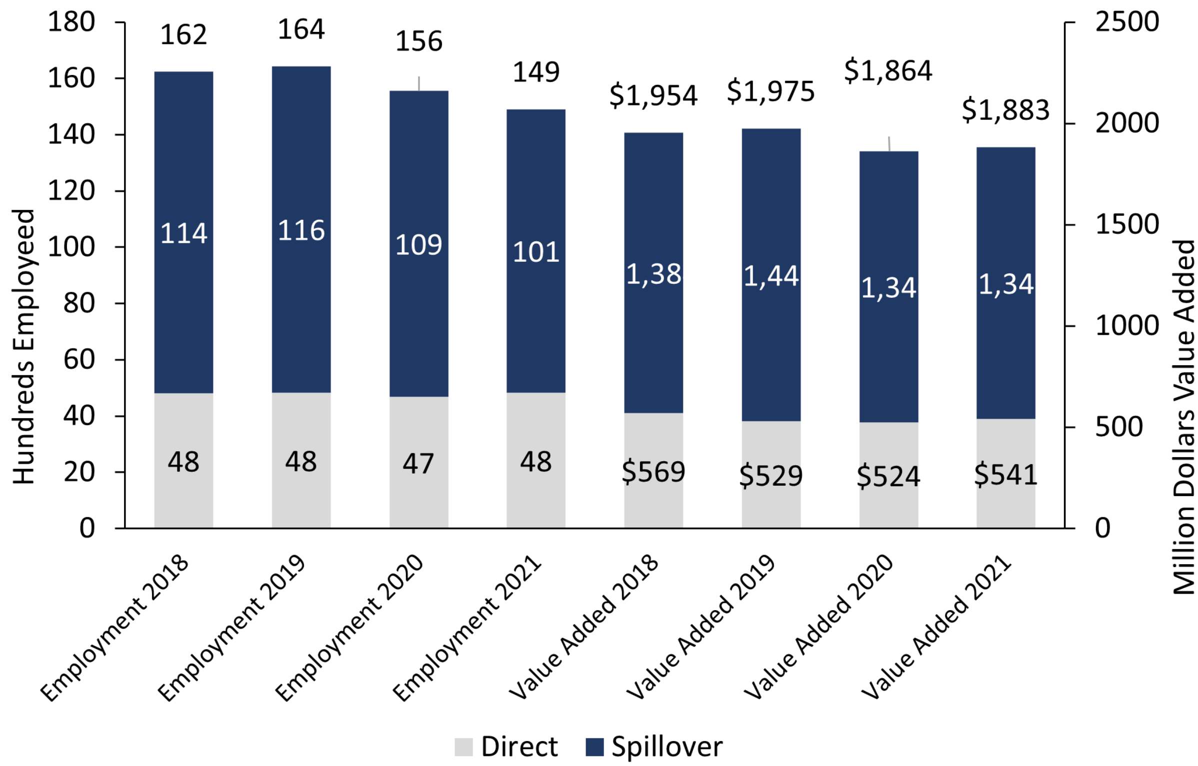


Figure 27: Biobased Plastic Bottles and Packaging Sector Contribution to Employment and Value Added Trends.

Table 12: Distribution of Direct Value Added and Employment by Biobased Plastic Bottles and Packaging Subsectors.

IMPLAN Code	NAICS Codes	Description	Employment	Value Added
193	32619	Other plastics product manufacturing	3252	$342,000,000
186	32611	Plastics packaging materials and unlamented film and sheet manufacturing	986	$120,000,000
192	326160	Plastics bottle manufacturing	363	$41,000,000
187	326121	Unlamented plastics profile shape manufacturing	225	$38,000,000
		Totals	**4,826**	**$541,000,000**

2.7.1 Overview

Within the seven biobased product sectors, biobased plastics is the sector where consumers will most noticeably meet innovative technologies and transformations.

The biobased plastics production sector is nascent, with a marginal growth projection of 1.9% through 2028.[49] This growth is driven by emerging manufacturers, novel products, and expanding markets. Moreover, growing sustainability awareness among producers and consumers fuels innovation and demand.

Support from the U.S. government, particularly the BioPreferred Program, lays the foundation for this sector's expansion. Added supportive legislation would further bolster the industry within a competitive market. Robust global economic conditions are essential for growth. As consumer spending increases, so does the demand for packaged goods. Fluctuations in crude oil prices also prompt growth in biobased plastics, as companies seek alternatives to petroleum-based plastics for more stable pricing. With the rise of environmental consciousness globally, consumer demand will push manufacturers to explore renewable resources further. Industry leaders like Coca-Cola and PepsiCo have voluntarily adopted eco-friendly packaging, created market opportunities, and showed a model for change across industries. As biobased plastics gain popularity, consumers will expect more companies to adopt them, spurring further innovation and technological advancements. This will enable manufacturers to branch into other sectors beyond packaging, such as construction and medical supplies.

Markets

The Bioplastics Manufacturing sector is divided into four prominent categories: starch-based, cellulose-based, glucose-

[49]Ibid.

based, and synthetic-based bioplastics. The contemporary shift towards sustainable solutions has seen bioplastics increasingly being employed in the packaging of various items, including food containers, beverage bottles, and more, even finding applications in niche areas like automobile parts and electronic housings.

Starch-Based Bioplastics:

Starch-based bioplastics, primarily used for crafting food-service tableware, are on a marked rise. Originating from sources like wheat, potatoes, and cassava, they have seen substantial growth, anticipated to cover 54.4% of the industry revenue in 2022, a significant leap from 34.1% in 2017. The uptrend is forecasted to continue till 2027, propelled by increasing environmental consciousness and advancements in sustainable materials.

Cellulose-Based Bioplastics:

Conversely, cellulose-based bioplastics are experiencing a decline. Once popular for packaging CDs, confectionery, and cigarettes, they now grapple with a reduced market share due to the fall in demand for such products. Accounting for 38.2% in 2017, their contribution to revenue is expected to drop to 15.3% in 2022.

Glucose-Based Bioplastics:

Glucose-based bioplastics, made from substances like Polyhydroxybutyrate and polylactides (PLA), find diverse applications, including the production of drink cups, bottles, and other packaging materials. Despite their varied use, their revenue contribution is estimated to be 14.8% in 2022, maintaining a stable but smaller share of the market.

Synthetic and Other Bioplastics:

Lastly, synthetic, and other bioplastics, including those derived from petroleum, make up about 15.4% of the industry demand in 2022. These polymers, despite their synthetic origins, are fully biodegradable and compostable, underscoring the industry's move towards eco-friendly alternatives.

Exports

Exports in the Bioplastics Manufacturing industry predominantly head to nations with significant manufacturing bases or beneficial trade terms with the U.S. Notable recipients of these exports include Mexico (23.4%), Canada (17.6%), China (8.3%), and Belgium (6.3%). Within the five-year span leading up to 2022, the industry foresees a notable surge in exports at an annualized growth of 8.8%, totaling $385.8 million. This increase is propelled by the escalating global demand for alternatives to traditional petroleum-based plastics. In a reflection of this upward trend, exports are predicted to make up 44.6% of the industry's revenue, showing a considerable rise from 32.3% in 2017.

Labor and Research

In 2022, labor costs in the Bioplastics Manufacturing industry are projected to constitute 7.0% of the revenue, marking a slight increase from 6.7% in 2017. Despite its innovative and nascent nature, the industry prioritizes meeting the high-performance standards sought by buyers. This priority necessitates the employment of highly skilled individuals. A significant portion of labor expenses is allocated to the compensation of scientists and engineers. These professionals are essential for conducting research on renewable resources and assessing their potential to replace petrochemical feedstock in the production of plastics. The labor costs in the industry also cover the wages of other employees, including machine operators and supervisors. The average salary in this industry is approximately $73,000 per year.

2.8 Forest Products

Figure 28 illustrates how the value added produced by the Forest Products sector industry is distributed across each state (using an approximated range), and Figure 29 shows the number of jobs the Forest Products sector supports by state; Table 13 shows the data for the top ten states. Figure 30 shows the employment and value added changed between 2018 and 2021 in the Forest Products sector.

A third of the United States, eight hundred million acres, is forested. When considering areas outside of interior Alaska, around 39% of these forestlands are privately owned, 29% belong to the federal government, 19% to corporations, 7% to state governments, 2% to tribal entities, 2% to other private organizations, and 2% to local governments.[50]

Major U.S.-Based Firms [51]

International Paper (Tennessee)
Georgia-Pacific (Georgia)
Weyerhaeuser Company (Washington)
Kimberly-Clark Corporation (Texas)
The Procter & Gamble Company (Ohio)
Boise Cascade Company (Idaho)
WestRock Company (Virginia)

Economic Statistics

Total value added to the U.S. economy in 2021: $413 billion.

Type SAM Economic Multiplier in 2021: 2.9.

Employment Statistics

Total number of Americans employed due to industry activities in 2021: 3.3 million.

Type SAM Employment Multiplier in 2021 3.0.

Table 14 shows these economic and employment statistics.

[50] U.S Forest Service. (2022, November 29). *National Woodland Owner Survey (2022).* USDA Forest Service. https://www.fia.fs.usda.gov/nwos/.

[51] Murphy, A. & Tucker, H. (Eds.) (2023, June 8). *Forbes Global 2000 in 2022.* Forbes. http://www.forbes.com/global2000/list/.

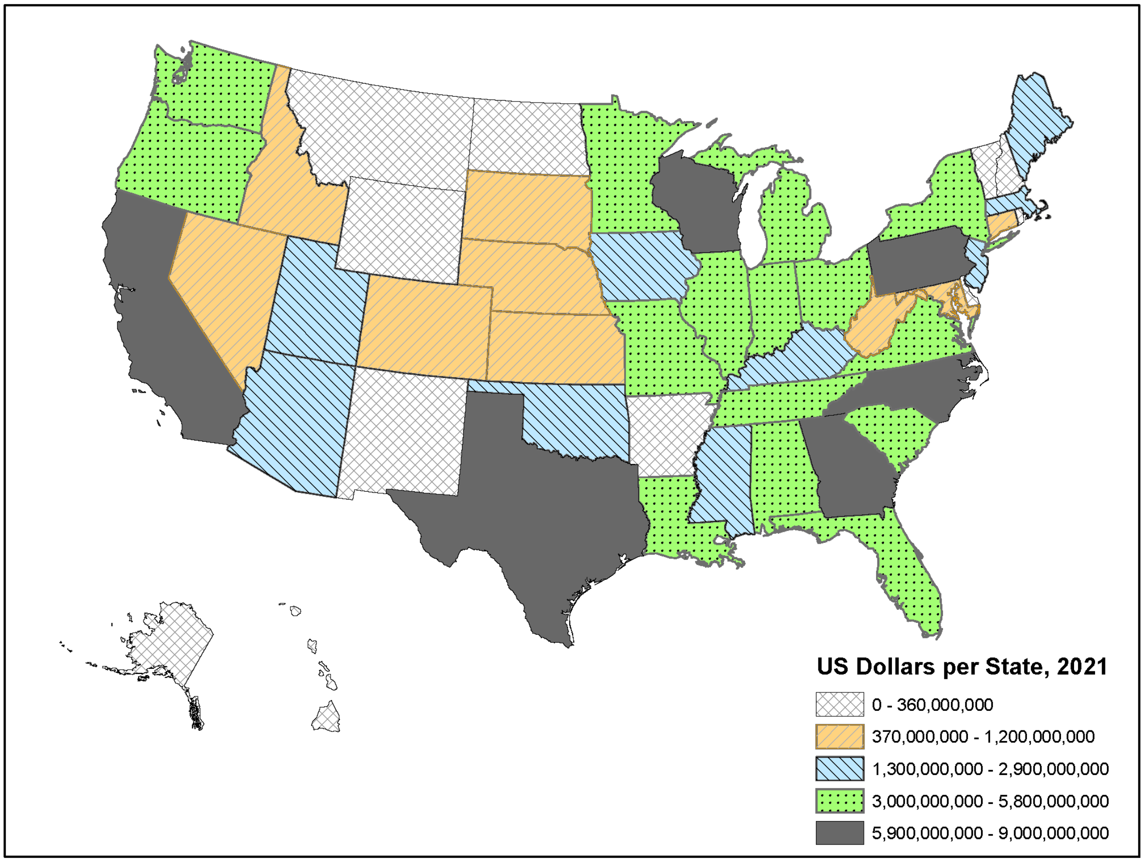


Figure 28: Total Value Added Contributed by the Forest Products Sector in Each State and the District of Columbia.

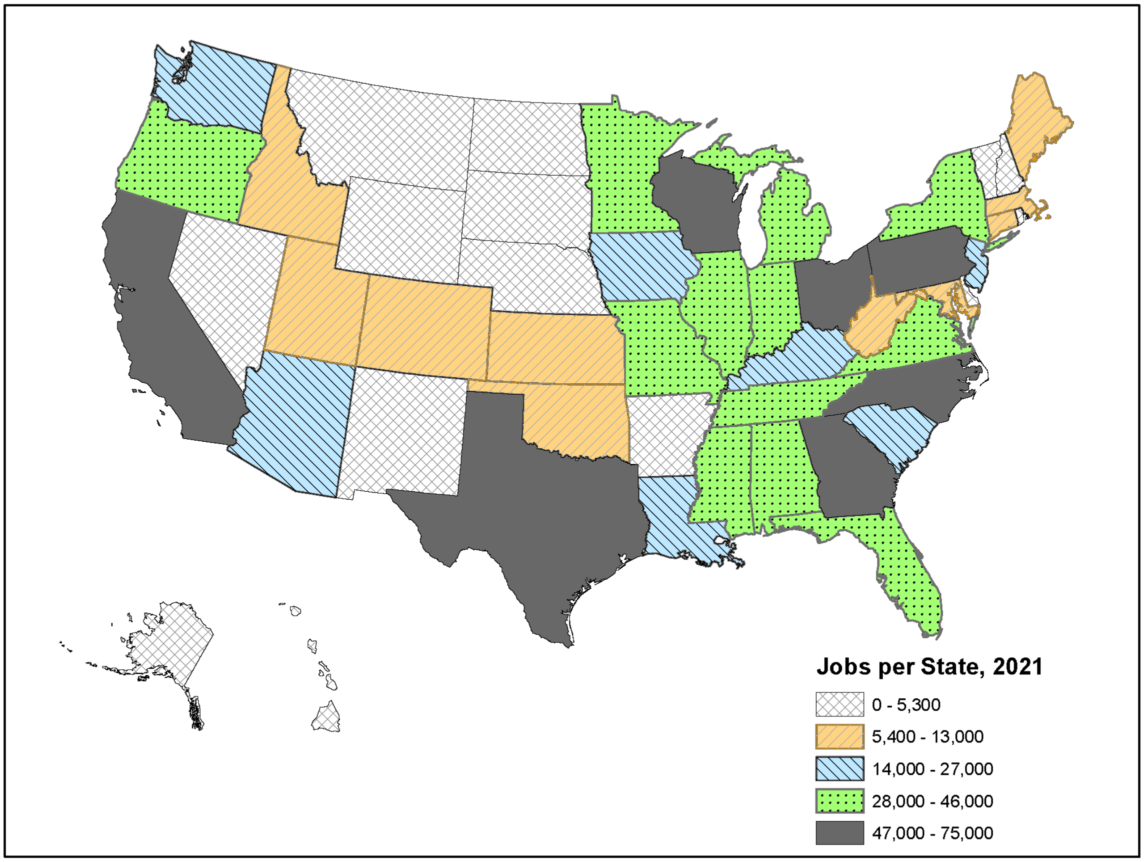


Figure 29: Total Jobs Contributed by the Forest Products Sector in Each State and the District of Columbia.

Table 13: Top 10 States for Direct Value Added to the Forest Products Sector in 2021.

Rank	State	Employment (Number of Jobs)	Value Added ($ Million)
1	California	75,040	9,003
2	Wisconsin	56,850	8,369
3	Pennsylvania	57,750	8,122
4	Georgia	49,310	7,903
5	Texas	66,560	7,743
6	North Carolina	66,370	6,639
7	Alabama	38,390	5,821
8	Oregon	33,350	5,651
9	Ohio	50,540	5,278
10	Tennessee	34,530	5,112

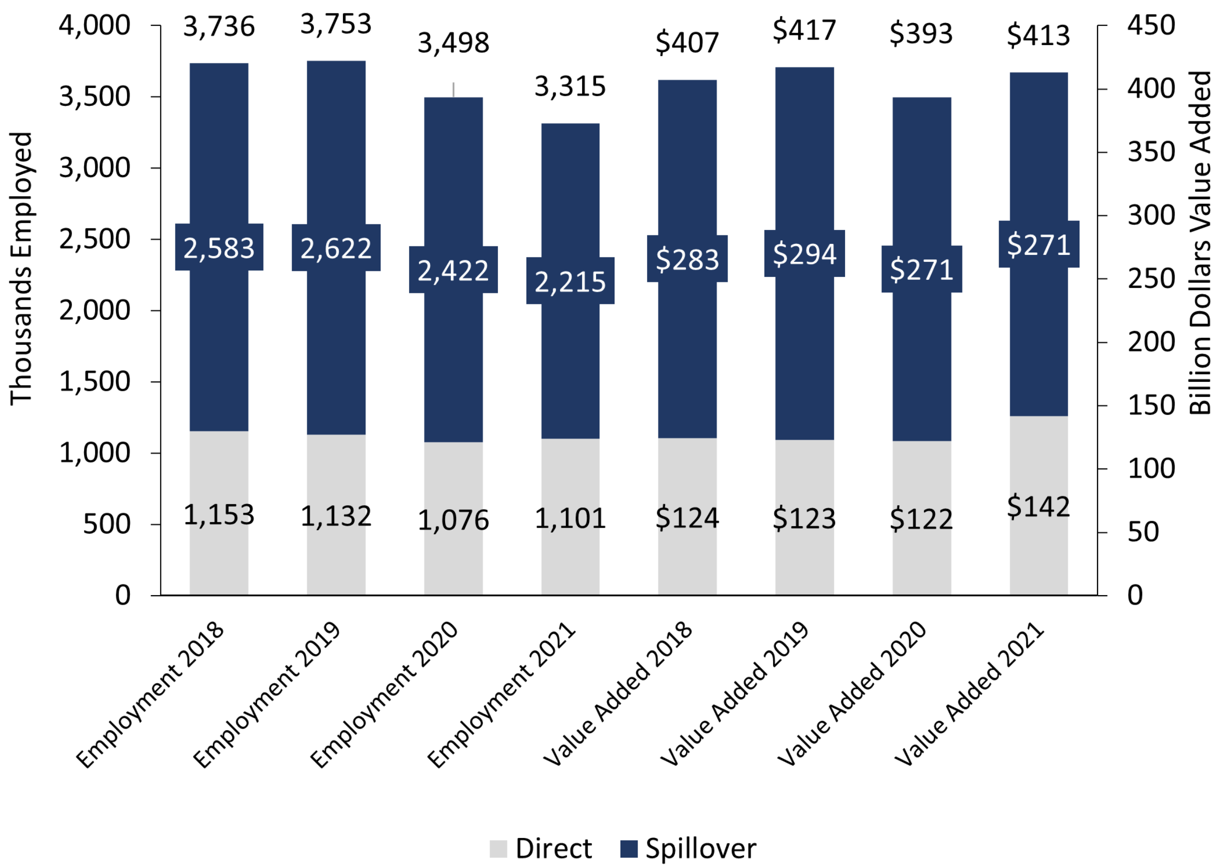


Figure 30: Forest Products Sector Contribution to Employment and Value Added Trends.

Table 14: Distribution of Direct Value Added and Employment by Forest Products Subsectors.

IMPLAN Code	NAICS Codes	Description	Employment	Value Added
147	32221	Paperboard container manufacturing	150,400	$19,638,000,000
365	337110	Wood kitchen cabinet and countertop manufacturing	130,800	$10,159,000,000
132	321113	Sawmills	87,600	$12,876,000,000
140	32212	Paper mills	53,000	$13,312,000,000
137	321920	Wood container and pallet manufacturing	64,800	$4,766,000,000
366	32222	Paper bag and coated and treated paper manufacturing	54,500	$7,692,000,000

IMPLAN Code	NAICS Codes	Description	Employment	Value Added
148	337121	Upholstered household furniture manufacturing	58,500	$3,070,000,000
145	321911	Wood windows and door manufacturing	59,400	$7,255,000,000
135	321918	Other millwork, including flooring	38,400	$4,471,000,000
139	337122	Non-upholstered wood household furniture manufacturing	30,900	$1,856,000,000
141	321211, 321212	Veneer and plywood manufacturing	31,000	$3,946,000,000
146	321213, 321214	Engineered wood member and truss manufacturing	44,500	$5,829,000,000
134	322291	Sanitary paper product manufacturing	27,200	$8,623,000,000
367	322130	Paperboard mills	32,200	$7,850,000,000
371	321999	All other miscellaneous wood product manufacturing	27,400	$3,017,000,000
143	337127	Institutional furniture manufacturing	23,900	$1,495,000,000
150	321991	Manufactured home (mobile home) manufacturing	32,600	$3,624,000,000
369	32223	Stationery product manufacturing	14,600	$1,543,000,000
142	337212	Custom architectural woodwork and millwork	27,400	$1,648,000,000
151	337211	Wood office furniture manufacturing	16,800	$1,462,000,000
370	322299	All other converted paper product manufacturing	17,500	$1,993,000,000
136	321219	Reconstituted wood product manufacturing	16,200	$4,975,000,000
149	321992	Prefabricated wood building manufacturing	18,200	$2,120,000,000
138	321912	Cut stock, re-sawing lumber, and planing	14,400	$2,321,000,000
368	337125	Other household non-upholstered furniture manufacturing	11,600	$1,106,000,000

IMPLAN Code	NAICS Codes	Description	Employment	Value Added
133	321114	Wood preservation	11,400	$4,388,000,000
144	322110	Pulp mills	5,500	$922,000,000
		Totals	**1,013,550**	**$103,135,000,000**

2.8.1 Overview

With the entire forest products sector being biobased, it is the largest of the seven sectors within the study. Forest products industries are made up of three main subsectors: wood product manufacturing, paper manufacturing, and wood furniture. Wood product manufacturing includes sawmills, millwork, and wood production. Paper manufacturing includes pulp mills, paper mills, and paperboard mills. Wood furniture is composed of the manufacturing of cabinets, vanities, and household and office furniture.

There are approximately eight hundred million acres, more than a million square miles, covered by forests in the United States. Almost 70% of the forested acreage in the United States is timberland that produces wood that is suitable for industrial and commercial use. The southern region of the United States has about 40% of this timberland, and the northern and western regions have about 32% and 28%, respectively. [52]

Annually, forest ecosystems in the United States sequester more carbon from the atmosphere than they produce. Forests are the Earth's largest terrestrial carbon sink, and they are a valuable offset for greenhouse gas emissions. The U.S. Forest Service estimates that these systems offset 15% of all emissions.

The U.S. forest products industry employs approximately one million people, making the sector one of the top ten manufacturing industries in the United States. In addition, this industry generates and uses more renewable energy than any other industry in the country.

The United States has ample forest feedstocks and exports the most forest products to China, other countries in Asia, other North American countries, and European countries, as shown in Figure 31.[53]

[52] Shahbandeh, M. (2022, December 20). *U.S. Forest Products Industry – Statistics & Facts*. Statista. https://www.statista.com/topics/1316/forest-products-industry/.

[53] Resource Trade. (nd). *Chatham House Resource Trade Database.* Resource Trade Earth. https://resourcetrade.earth.

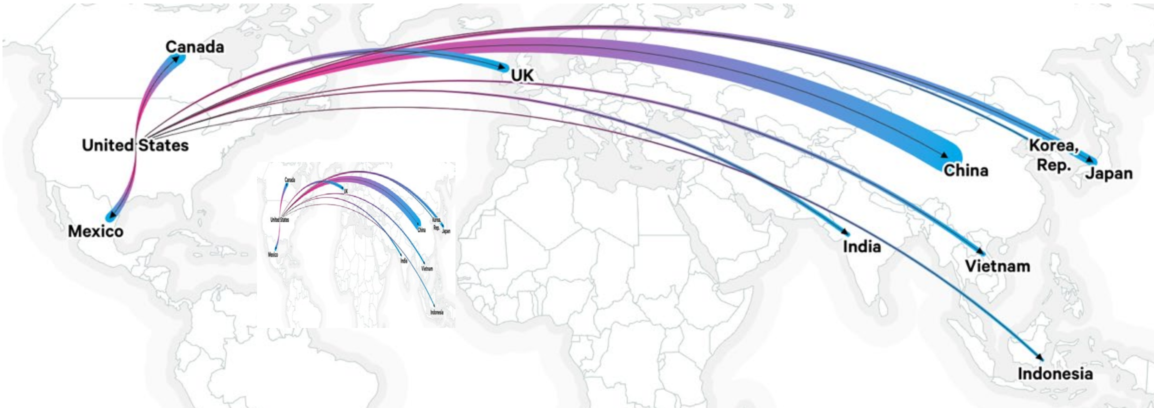


Figure 31: The U.S. Forest Product Global Trade Flows in 2020.

Cardboard Box and Container Manufacturing

The cardboard box and container manufacturing industry is the largest paper-converting industry in the US, and services nearly every economic sector, producing various packaging solutions for many consumer products. It is also the largest industry in the biobased forest products sector.

Heightened demand for online retail during the pandemic helped fuel this industry's growth over the past five years. In the next five years, industry revenue is expected to grow at a CAGR of 2.0% to $90.3 billion.[54]

Paper Mills

The paper mills industry has faced multiple challenges, including growing foreign competition, declining downstream demand for paper products, and the rise of digital media. Over the past five years, industry revenue contracted at a CAGR of 4.0% to $36.1 billion, with a slight decrease of 0.2% in 2023, despite economic recovery.

Increased online business and electronic alternatives have negatively impacted paper demand, while a growing senior population has boosted demand for personal care products like adult incontinence items. The fluctuating world price of wood pulp, the primary feedstock of this sector, has caused volatile profit margins, and high barriers to entry have led to fewer industry operators.

In the coming years, waning demand and a decreasing trade-weighted index will continue to affect the industry. As digitization expands, industry revenue is expected to decline at a CAGR of 6.7% to $25.5 billion by 2028. Industry operators will shift their focus to other business segments or risk losing market share.[55]

Sawmills and Wood Production

The sawmills and wood production industry processes lumber, boards, beams, and other wood products, with demand heavily influenced by construction activity. During the pandemic, rising housing starts and increasing nonresidential construction values boosted industry revenue. Additionally,

[54] IBISWorld. (nd). *NAICS Code 32221 – Paperboard Container Manufacturing*. IBISWorld. https://www.ibisworld.com/classifications/naics/32221/paperboard-container-manufacturing/

[55] IBISWorld. (nd). *NAICS Code 32212 – Paper Mills.* IBISWorld. https://www.ibisworld.com/classifications/naics/32212/paper-mills/

behavior shifts with consumers spending more time at home resulted in increased demand for single use paperware, which supported the sector. However, nonresidential construction declined during the same period, affecting wood usage in industrial and office structures. As a result, sawmills experienced marginal average annual growth of less than 2%, with total sales reaching just under $46 billion in 2023.[56]

Paperboard Mills

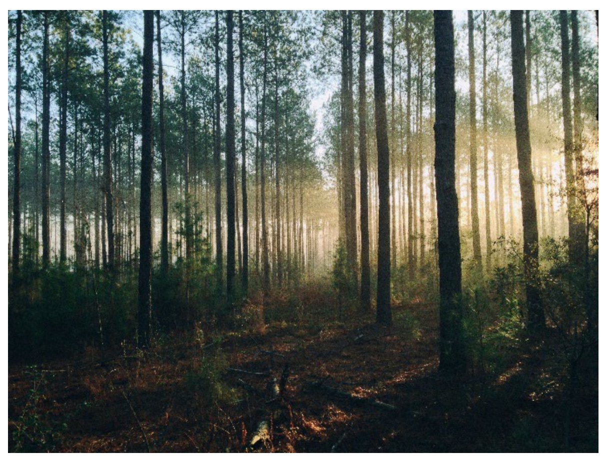
This industry primarily produces paperboard for manufacturing cardboard boxes. It has faced challenges with increased import market penetration and competition from plastic packaging. Over the past five years, revenue has been relatively flat, reaching $41 billion. Despite these challenges, resilient demand from downstream industries like food, beverage, and pharmaceuticals has contributed to growth. In the next five years, revenue is expected to grow at a 1.5% CAGR to $44.1 billion, driven by a stronger economy, increased consumer spending, and investments in automation and recycling facilities.[57]

Millwork

The millwork industry, which produces wood-based architectural products, is closely tied to construction activity. Primarily driven by residential construction, millwork revenue has grown at a 0.6% CAGR to $33.4 billion over the past five years. Historically low interest rates throughout the pandemic stimulated the housing market. However, interest rates have been steadily increasing as the federal reserve attempts to limit inflation and may limit growth. As a result, industry revenue is expected to contract at a 0.4% CAGR to $32.8 billion.[58]

Wood Paneling Manufacturing

This sector's performance is closely tied to new housing starts and home improvements. It has experienced an increase of 4.6% CAGR in revenue over the past five years, reaching $38.6 billion in 2023. Lower interest rates during the pandemic stimulated demand. However, as mortgage rates rise post-pandemic, residential construction is expected to decrease. As a result, a modest decline in industry performance is expected at a 0.1% CAGR to $38.5 billion over the next five years.[59]



[56]IBISWorld. (nd). *NAICS Code 32111 – Sawmills and Wood Preservation.* IBISWorld. https://www.ibisworld.com/classifications/naics/32111/sawmills-and-wood-preservation/

[57]IBISWorld. (nd). *NAICS Code 321330 – Paperboard Mills.* IBISWorld. https://www.ibisworld.com/classifications/naics/322130/paperboard-mills/

[58]IBISWorld. (nd). *NAICS Code 32191 – Millwork.* IBISWorld. https://www.ibisworld.com/classifications/naics/32191/millwork/

[59]IBISWorld. (nd). *NAICS Code 32121 – Veneer, Plywood, and Engineered Wood Product Manufacturing.* IBISWorld. https://img.ibisworld.com/classifications/naics/32121/veneer-plywood-and-engineered-wood-product-manufacturing/

2.9 Textiles

Figure 32 illustrates how the value added produced by the biobased Textiles sector industry is distributed across each state (using an approximated range), and Figure 33 shows the number of jobs the biobased Textiles sector supports by state; Table 15 shows the data for the top ten states. Figure 34 shows the employment and value added changed between 2018 and 2021 in the biobased Textiles sector.

The U.S. apparel market is the largest in the world, forming about 28% of the total global market with a market value of about $315 billion U.S. dollars.

Major U.S.-Based Firms [60, 61]

Nike, Inc. (Oregon)
Gap, Inc. (California)
VF Corporation (North Carolina)
Ralph Lauren Corporation (New York)
Levi Strauss & Co. (California)
Macy's, Inc. (New York)
PVH Corp. (New York)
J. Crew Group, LLC. (New York)

Economic Statistics

Total value added to the U.S. economy in 2021: $62 billion.

Type SAM Economic Multiplier in 2021: 3.4.

Employment Statistics

Total number of Americans employed due to industry activities in 2021: 611,000.

Type SAM Employment Multiplier in 2021: 2.4.

Table 16 shows these economic and employment statistics.

[60]Murphy, A. & Tucker, H. (Eds.) (2023, June 8). *Forbes Global 2000 in 2022.* Forbes. http://www.forbes.com/global2000/list/.

[61]Smith, P. (2022, March 4). *U.S. Revenue of the leading apparel brands in the United States in 2019.* Statista. https://www.statista.com/statistics/978396/leading-apparel-brands-by-revenue-us/

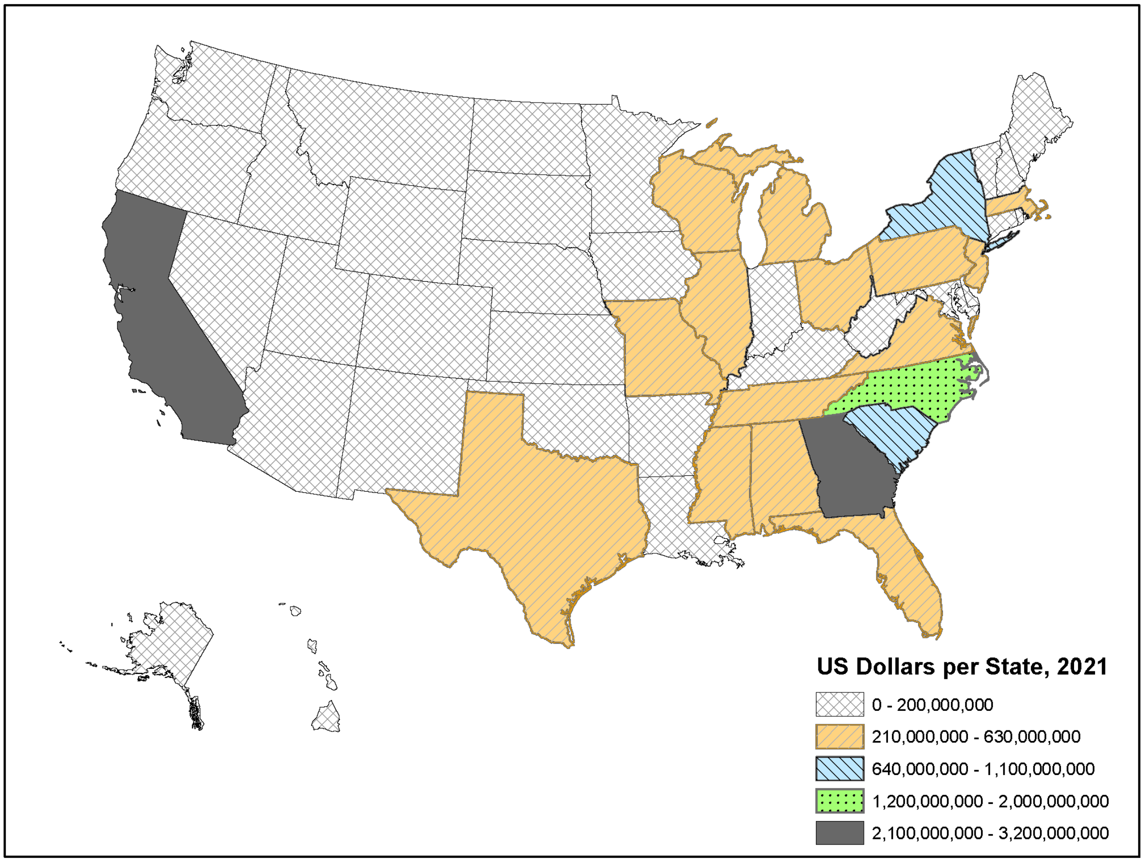


Figure 32: Total Value Added Contributed by the Textiles Sector in Each State and the District of Columbia.

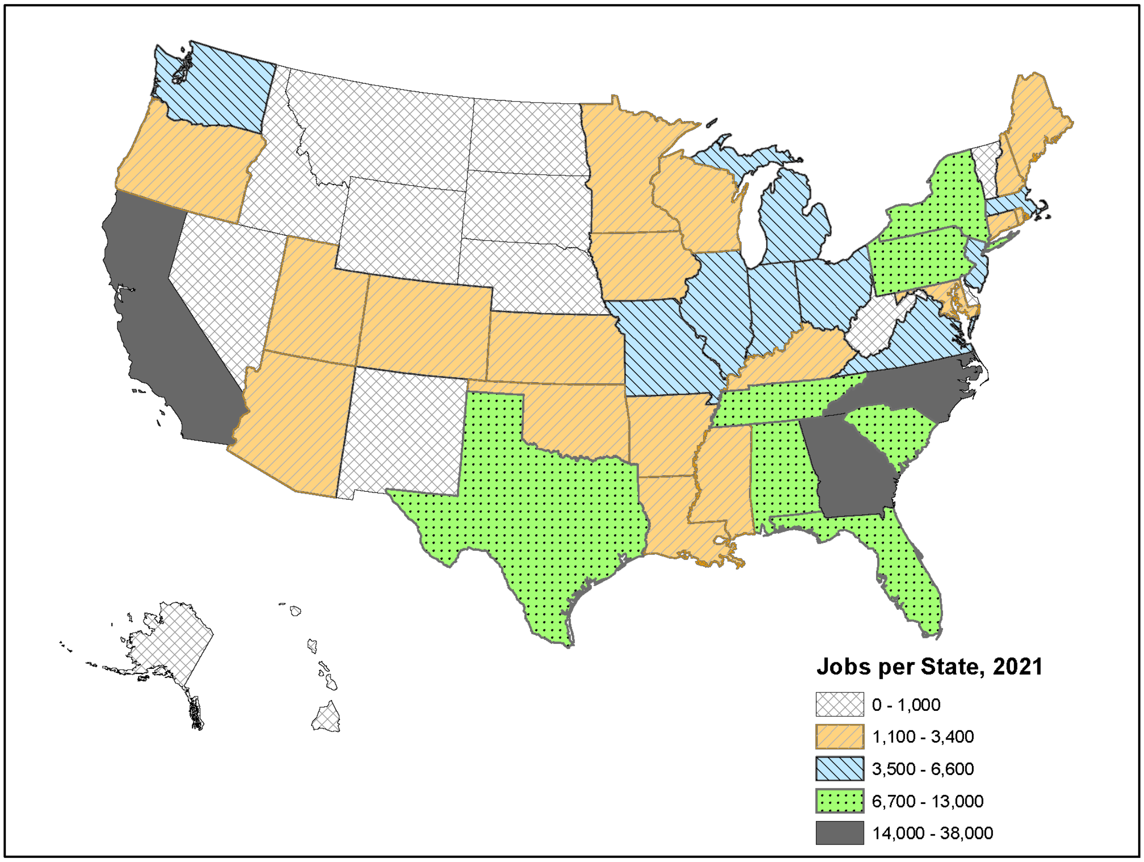


Figure 33: Total Jobs Contributed by the Textiles Sector in Each State and the District of Columbia.

Table 15: Top 10 States for Direct Value Added to the Fabrics, Apparel, and Textiles Products Sector in 2021.

Rank	State	Employment (Number of Jobs)	Value Added ($ Million)
1	Georgia	34,420	3,213
2	California	37,600	2,998
3	North Carolina	27,220	1,975
4	South Carolina	12,780	1,110
5	New York	12,990	930
6	Texas	13,380	634
7	Alabama	8,810	597
8	Tennessee	7,940	528
9	Virginia	5,720	451

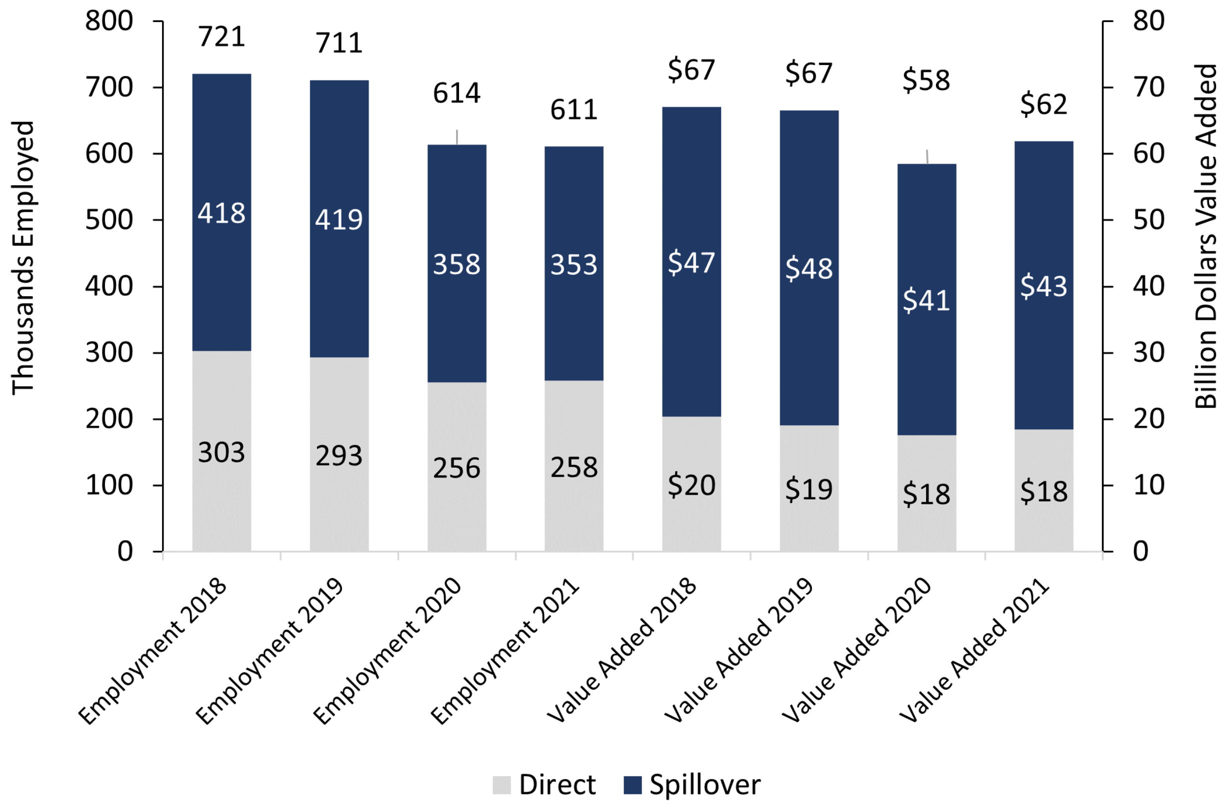


Figure 34: Biobased Textiles Sector Contribution to Employment and Value Added in 2018, 2019, 2020, and 2021.

Figure 32 illustrates how the value added produced by the biobased Textiles sector industry is distributed across each state (using an approximated range), and Figure 33 shows the number of jobs the biobased Textiles sector supports by state; Table 15 shows the data for the top ten states. Figure 34 shows the employment and value added changed between 2018 and 2021 in the biobased Textiles sector.

Table 16 shows these economic and employment statistics.

Table 16: Distribution of Direct Value Added and Employment by Textiles Subsectors.

IMPLAN Code	NAICS Codes	Description	Employment	Value Added
126	31521	Cut and sew apparel contractors	25,600	$1,205,000,000
119	314110	Carpet and rug mills	22,300	$2,176,000,000
123	314999	Other textile product mills	22,300	$1,396,000,000

128	31523	Women's and girls' cut and sew apparel manufacturing	19,400	$1,217,000,000
112	31311	Fiber, yarn, and thread mills	19,600	$1,387,000,000
113	313210	Broad woven fabric mills	15,300	$1,376,000,000
127	31522	Men's and boys' cut and sew apparel manufacturing	21,300	$1,239,000,000
117	31331	Textile and fabric finishing mills	14,500	$1,221,000,000
121	31491	Textile bag and canvas mills	19,600	$1,401,000,000
120	31412	Curtain and linen mills	12,700	$877,000,000
129	31529	Other cut and sew apparel manufacturing	12,100	$626,000,000
115	313230	Nonwoven fabric mills	11,400	$1,648,000,000
130	31599	Apparel accessories and other apparel manufacturing	12,900	$660,000,000
124	31511	Hosiery and sock mills	6,600	$312,000,000
114	31322	Narrow fabric mills and schiffli machine embroidery	4,500	$277,000,000
118	313320	Fabric coating mills	5,200	$516,000,000
116	31324	Knit fabric mills	3,800	$294,000,000
122	314991, 314992	Rope, cordage, twine, tire cord and tire fabric mills	4,200	$373,000,000
125	31519	Other apparel knitting mills	4,300	$226,000,000
		Totals	**197,200**	**$13,180,000,000**

2.9.1 Overview

Within the Textile sector, manufacturers of products like fiber, yarn, fabric, and linen have faced stiff competition from nations with lower labor costs. This has triggered a shift in focus, with firms now increasingly catering to the automobile and home furnishing markets to offset the declining demand from domestic apparel makers. As a result, revenues are set to decrease by 3.6% CAGR to $41.3 billion. The sector is using automation to keep pace, and during the COVID-19 crisis, many mills adjusted their production lines to meet the demand for medical masks and gowns. However, competition from international players is expected to affect profits. By 2028, increased synthetic fiber prices may boost revenues, but they could also deter customers looking for cheaper alternatives. As consumer trends evolve in apparel manufacturing, the industry is projected to see a 1.6% CAGR growth in revenue, reaching $44.8 billion.[62]

[62]IBISWorld. (2023). *Textile Mills Industry in the US – Market Research Report.* IBISWorld. https://www.ibisworld.com/united-states/market-research-reports/textile-mills-industry/

The U.S. Environmental Protection Agency (EPA) estimates that 17 million tons of textiles were thrown away in 2018 in the United States, which is equivalent to 104 pounds per person.[63] As a result of consumer practices and fashion trends, the textile sector is a major user of natural resources, especially fresh water. Growing awareness surrounding environmental impacts and sustainability has caused both consumers' expectations and the textile industry to shift. Currently, the biobased textiles industry has huge opportunities for growth, and an extensive number of technological advances have occurred. Biobased textiles include traditional fibers, such as cotton, wood, and silk, but they also include new, biosynthetic fibers and fabrics. Biosynthetic fibers can be engineered with an array of new features, from performance advantages to the ability to be recycled or biodegrade.

[63] US EPA. National Overview: Facts and Figures on Materials, Wastes and Recycling, accessed September 2023, https://www.epa.gov/facts-and-figures-about-materials-waste-and-recycling/national-overview-facts-and-figures-materials#Generation.

3 Environmental Benefits

3.1 Overview

The global chemical sector is the largest industrial energy consumer and the third largest industry subsector in terms of direct CO_2 emissions. This is largely because around half of the chemical subsector's energy input is consumed as feedstock – fuel used as a raw material input rather than as a source of energy – and contributed 925 $MTCO_2$ in 2021. Emissions are expected to increase, mostly because of global demand for plastics. [64]

Biobased products that use agriculture-based feedstocks in lieu of petroleum-based feedstocks play a vital role in the reduction of GHG emissions. EPA's Greenhouse Gas Reporting Program[65] tracks facility-level emissions but only from the largest U.S. sources of GHGs as presented in Figure 35

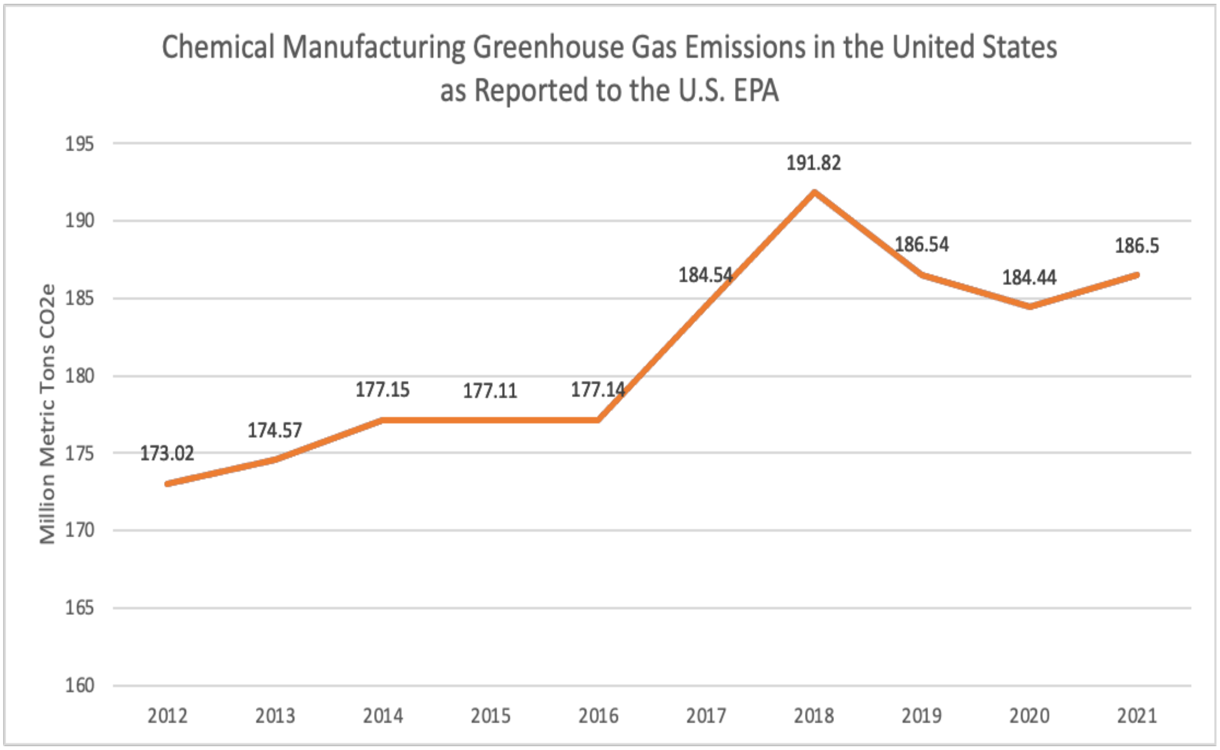


Figure 35: Chemical manufacturing Greenhouse Gas Emissions in the United States as Reported to the U.S. EPA.

[64]IEA. (2022). *Chemicals*. IEA. https://www.iea.org/energy-system/industry/chemicals

[65]EPA. (nd). *Greenhouse Gas Reporting Program (GHGRP).* Environmental Protection Agency. https://www.epa.gov/ghgreporting

3.2 Environmental Trends

One of the most important environmental benefits of the U.S. biobased products industry is the ability to reduce the significant GHG impacts of the chemical sector. Since our earlier reports, there have been both important industry trends to increase the use of biobased feedstocks as well as supporting research on the associated environmental benefits.

One important trend is the push by many of the world's largest plastic bottle manufacturers and users to move from 30% biobased polyethylene terephthalate (PET) produced bottles to 100% biobased PET bottles. In October of 2021, Coca-Cola unveiled their 100% plant-based (excluding the cap and bottle label), recycled PET (rPET) prototype bottle using sugarcane-based feedstocks and commercially scalable technologies.[66]

This follows prior announcements of a three-way partnership between U.S.-based Origin Materials with Nestle and Danone to develop and launch at commercial scale a PET bottle made from biobased materials[67]. The environmental benefits of transitioning to 100% biobased PET have been of recent focus by the scientific community, with the resulting reductions in GHG emissions presented in Table 17.[68]

Another emerging environmentally beneficial biobased solution is the development of 100% biobased polyethylene furanoate (PEF). It is formed by polymerizing sugar-based furandicarboxylic acid (FDCA) with biobased mono-ethylene glycol (MEG). The first commercial FDCA facility is expected to be completed by 2024. PEF is promoted as being a strong biobased solution for food packaging applications, especially those with long shelf-life demands. While a recent life cycle assessment indicated a 33% to 45% GHG emission reduction potential for a PEF compared to an equivalent PET polymers,[69,70] a more recent study by Stegmann et al., (2023), found that biobased PEF would offer 50% to 74% lower life cycle GHG emissions after one recycling trip compared to conventional PET, with some differences based on the waste management option.[71]

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[66]Packaging Gateway. (2023, April 4). *Coca-Cola's 100% Plant-Based Bottle*. Packaging Gateway. https://www.packaging-gateway.com/projects/coca-cola-plant-based-bottle/

[67]AGro & Chemistry (2017, June 3). *Danone and Nestle develop 100% bio-based bottles.* AGro & Chemistry. https://www.agro-chemistry.com/news/danone-and-nestle-develop-100-bio-based-bottles/

[68]García-Velásquez, C., Y. van der Meer. (2022, November 2). *Can we improve the environmental benefits of biobased PET production through local biomass value chains? – A life cycle assessment perspective*. Journal of Cleaner Production. Vol 380, Part 2.

[69]Puente and Stratmann, (2022, February 21). *PEF Bottles- a Sustainable Packaging Material.* Avantium & Nova Institute. https://www.avantium.com/wp-content/uploads/2022/02/20220221-PEF-bottles-%E2%80%93-a-sustainable-packaging-material-ISO-certified-LCA.pdf

[70]Eerhart, A. J. J. E., Faaji, A. P. C., & Patel, M.K. (2012). Replacing fossil based PET with biobased PEF; process analysis, energy and GHG balance. *Energy Environ. Sci.,* 5 (4). P. 6407

[71]Stegman, P., Gerritse, T., Londo, M., Puente, A., & Junginger, M. et. al. (2023). The global warming potential and the material utility of PET and bio-based PEF bottles over multiple recycling trips. *Jour. Clean. Prod*. Vol. 395.

Table 17: Review of environmental benefits for transitioning to 100% Biobased PET.

kg CO_2-eq/kg PET			
Reference	**30% Biobased PET**	**100% Biobased PET**	**Feedstock**
Benavides et al. (2018)	4.1	1.4	Sugar Beet
Chen et al. (2016)	4.20-6.3	4.10-6.5	Mscanthus, sugar beet
Tsiropoulos et al. (2015)	1.93-2.39	Not Reported	Wood, corn, corn stover, switchgrass, wheat straw
Semba et al. (2018)	3.91	1.88	Sugarcane, corn
Akanuma et al. (2014)	Not Reported	4.31-7.10	Corn, wheat stover, poplar, wood
European Commission (2018)	2.19	Not Reported	Surgarcane
European Commission (2018)	2.67	Not Reported	Crop mix of 36% maize, 27% sugar beet and 37% wheat
Garcia-Velasquez and van der Meer (2022)	2.63	2.14	Sugar Beet
Garcia-Velasquez and van der Meer (2022)	2.57	2.11	Miscanthus, Sugar Beet

3.3 Objectives and Methodology

The EIO-LCA methodology was developed by Carnegie Mellon University's Green Design Institute as a method to estimate the material and energy resources required for various activities and the subsequent resulting emissions. The EIO-LCA method is one of several techniques used to examine the environmental impacts of a product over its lifecycle. In contrast to a process LCA, which examines a single process or product by quantifying the flows that are unique to that product, the EIO-LCA process uses "industry transactions," i.e., the purchase of materials by one industry from other industries and information about industries' direct environmental emissions, to estimate the total emissions throughout the supply chain.[72]

The EIO-LCA methodology builds upon the economic impact modeling methods developed by Nobel Prize winner Dr. Wassily Leontief. Dr. Leontief's original work aimed to create a model of the U.S. economy, and it was expanded to include environmental metrics by Carnegie Mellon University. The EIO-LCA model and extensive documentation are available at www.eiolca.net.

The production and use of biobased products have the potential to reduce GHG

[72]Hendrickson, C. T., Lave, L. B., & Matthews, H. S. (2010). *Environmental life cycle assessment of goods and services: an input-output approach*. Routledge.

emissions and the use of petroleum.[73] The reductions in environmental impacts and the use of non-renewable resources depend on the types of products being produced as well as other factors that influence the production supply chain and products' lifecycles. Conducting an LCA for the thousands of biobased products that make up the biobased products industry was not possible for this report. As a way of estimating the potential GHG emissions and reductions in the use of petroleum, a 0 to 100 percent reduction was used to estimate the potential for reductions and compared to the petroleum-based alternatives. Further, additional literature sources provide additional context with specific estimates for GHG and petroleum reductions.

A 0 percent reduction would indicate no difference compared to petroleum-based products, and a 100 percent reduction would indicate that the biobased products used no fossil fuel. In reality, most of the biobased products will lie somewhere between 0 and 100 percent reduction, but it is impossible to determine this for all the products that make up the industrial sectors.

Only the biobased chemicals, biorefining, and biobased plastic bottles and packaging sectors were considered because they can directly replace petroleum-based products. Other industry sectors, such as the production of enzymes, were not examined in this part of the study. In the production of enzymes, it is difficult to identify the chemicals or products that enzymes directly replace, whereas biobased plastics generally displace petroleum-based plastic products. The assumption of direct replacement was required to perform the analysis described in this section.

The environmental metrics of GHG emissions and petroleum use are two key indicators of interest, but there are other important environmental impacts that also should be considered when making policy decisions. In a previous report by Golden et al., the authors examined a broader range of environmental impacts in addition to GHG emissions specific to the biobased products industry.[74] These additional categories of impacts are important to consider, and they are acknowledged here. The scope of this work was limited to the reductions in the GHG emissions and the use of petroleum that result from the use of biobased products as substitutes for petroleum-based products.

Because each biobased product and production process will produce different environmental impacts, the authors did not seek to provide one number that represents all products; instead, ranges of GHG emissions savings and petroleum displacements were determined based on percent reductions compared to petroleum-based materials. The calculated ranges of the reductions also were compared to peer-

[73]Cherubini, F., and Ulgiati, S. (2010), "Crop residues as raw materials for biorefinery systems–A LCA case study", *Applied Energy* 87, no. 1, :47-57.

[74]Golden, J.S., Handfield, R.B., Daystar, J., and McConnell, T.E, An Economic Impact Analysis of the U.S. Biobased Products Industry: A Report to the Congress of the United States of America, A Joint Publication of the Duke Center for Sustainability & Commerce, and the Supply Chain Resource Cooperative at North Carolina State University, 2015.

reviewed literature that describes reductions in environmental impacts. The values used to generate the estimated reductions in impacts were determined using EIO-LCA with the TRACI impact assessment method to calculate the GHG emission equivalents and petroleum use.[75] The economic data used in the environmental analysis were based on 2021 U. S. national data, as reported in previous sections of this report.

3.4 Overview of the Results

The petroleum saved by the biobased products industry was estimated to be as much as 10.7 million barrels of oil. In terms of GHG emissions reductions, the reduction attributable to the biobased products industry was estimated to be as much as 5.4 million metric tons of CO_2 equivalents. The GHG emissions avoided due to the direct replacement of petroleum-based products with biobased products are shown in Figure 36.

3.5 Petroleum Use Avoided

The petroleum use that was avoided by using biobased products was estimated to be as much as 10.7 million barrels of oil assuming an 80% reduction in 2021. The potential petroleum use avoided by direct displacement with biobased chemicals was the largest because the size of the biobased chemicals market is significantly larger than the markets in the other two sectors and makes up 89% of the oil reductions.

Cherubini and Ulgiati (2010) found that biobased chemicals produced at a biorefinery using a switchgrass feedstock reduced fossil fuel usage well beyond 80% compared to the use of petroleum-based chemical production methods, which corresponds to 9.7 million barrels of oil.[76]

The biorefining industry that produces biobased chemicals is reported to use 80% less petroleum than traditional refineries, resulting in a petroleum savings of as much as 841,000 barrels of oil.[77] The potential amount of petroleum use avoided by the biobased plastic bottles and packaging sector was the lowest of the three sectors the authors examined, which also corresponds to the overall market size. Using data from Yu and Chen and Harding et al., the authors calculated that the biobased plastic bottles and packaging sectors' displacements of petroleum-based plastics corresponded to petroleum savings of approximately 120,000 and 160,000 barrels of oil, respectively.[78, 79]

3.6 Avoided GHG Emissions

Using the IMPLAN model environmental dataset, the production of biobased products to replace petroleum-based products had the potential to reduce GHG emissions by as much as 5.4 million metric

[75]Hendrickson, C. T., Lave, L. B., & Matthews, H. S. (2010). *Environmental life cycle assessment of goods and services: an input-output approach*. Routledge.
[76]Cherubini, F., and Ulgiati, S. (2010). "Crop residues as raw materials for biorefinery systems–A LCA case study", *Applied Energy* 87, no. 1, (2010): 47-57.
[77]Ibid.
[78]Yu, J., and Chen, L.X.L., (2008). "The Greenhouse Gas Emissions and Fossil Energy Requirement of Bioplastics from Cradle to Gate of a Biomass Refinery", *Environmental Science & Technology* 42, no. 18, 6961-6966, doi: 10.1021/es7032235.
[79]Harding, K. G., Dennis, J. S., Von Blottnitz, H., & Harrison, S.T.L. (2007). "Environmental analysis of plastic production processes: Comparing petroleum-based polypropylene and polyethylene with biologically-based poly-β-hydroxybutyric acid using life cycle analysis", *Journal of Biotechnology* 130, no. 1, 57-66.

tons of CO_2 equivalents in 2021 assuming a conservative 60% reduction of fossil fuel use. Since the biobased chemicals sector is the largest of the three sectors, it has the highest potential to reduce GHG emissions due to the higher volume of sales. Cherrubini and Ulgiati estimated that biobased chemicals produced from switchgrass at a biorefinery reduced GHG emissions by 49% compared to petroleum-based chemicals, which corresponds to approximately 2.8 million metric tons of CO_2 equivalents per year. The biorefining sector, which has less industrial output than chemical production, has a lower potential to offset GHG emissions. With the same percent reduction of 49%, biorefining has the potential to offset as many as 1.3 million metric tons of CO_2 equivalents per year.[80]

In terms of sales, the biobased plastic bottles and packaging sector was the smallest of the three sectors examined, but it had the highest percent reduction in GHG emissions reported in the literature. Yu and Chen reported an 80% percent decrease in GHG emissions compared to petroleum-based plastics, and Harding et al. reported a 65% decrease compared to petroleum-based plastics.[81, 82] When considering these two percentage reductions in GHG emissions, the reductions from biobased plastics could correspond to 590,000 and 726,000 metric tons of CO_2 equivalents for the 65% and 80% reductions, respectively. The reduction range is shown with the dark blue line in Figure 36.

[80]Cherubini, F., & Ulgiati, S. (2010). "Crop residues as raw materials for biorefinery systems–A LCA case study", *Applied Energy* 87, no. 1, 47-57.
[81]Yu, J., and Chen, L.X.L. (2008). "The Greenhouse Gas Emissions and Fossil Energy Requirement of Bioplastics from Cradle to Gate of a Biomass Refinery", *Environmental Science & Technology* 42, no. 18, 6961-6966, doi: 10.1021/es7032235.
[82]Harding, K. G., Dennis, J. S., Von Blottnitz, H., & Harrison, S.T.L. (2007). "Environmental analysis of plastic production processes: Comparing petroleum-based polypropylene and polyethylene with biologically-based poly-β-hydroxybutyric acid using life cycle analysis", *Journal of Biotechnology* 130, no. 1, 57-66.

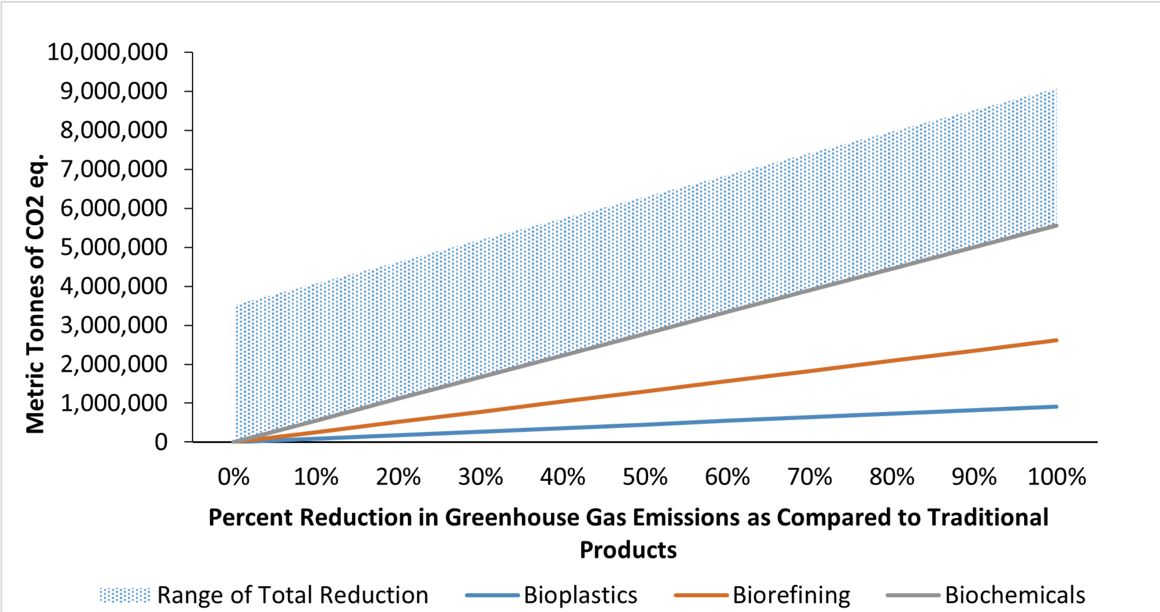


Figure 36: Potential Reductions in Greenhouse Gas Emissions by Biobased Products Manufactured in the United States with a Range of 0% to 100% Reduction in GHG Emissions Compared to Non-Biobased Product Alternatives.

3.7 Limitations

While the EIO-LCA model is useful in many regards, it has some limitations. For petroleum displacement, the data describing the inter-industry transactions were developed from the 2002 benchmark U.S. input-output table, and there likely have been considerable changes since then. In addition, the emissions associated with the various industries have likely changed due to increased regulations of emissions and changing energy production systems. For each of the three sectors examined (biobased chemicals, biobased plastic bottles and packaging, and biorefining), a custom model was developed by entering the adjusted output that could be considered biobased for each of the sector groupings. In addition to the uncertainty surrounding the use of the EIO-LCA model, there is significant uncertainty concerning the percentages of biobased products that make up the total industrial sectors. Because of these uncertainties, the results presented in this study are estimates and should be used cautiously and in context. The aim of this analysis was to supply a range of estimates for GHG emissions and the reductions in the use of petroleum.

3.8 Carbon Storage in Biobased Products

Biobased carbon requires additional accounting methodologies as compared to anthropogenic carbon emissions that originate from the burning of fossil fuels. There are two fundamental methods that can be used to account for biobased carbon:

1. Account for the carbon uptake as an initial negative emission, carbon stored for a period of years, and the later burning or decompositions as a positive emission in the life cycle inventory.

2. Assume that biobased emissions are carbon neutral and are excluded from life cycle inventories.

The benefits and issues related to temporary carbon storage and biobased carbon currently are being debated in the scientific community. There is literature that supports storing carbon for a set period of time to reduce its radiative effects, which warm the Earth. The hypothesis is that this storage over a specified time period has the potential to reduce its global warming potential (GWP) within a given analytical time period.[83]

The benefit created by temporarily removing carbon from the atmosphere depends largely on the analytical time period within which the GWP is calculated, which typically is 100 years. Benefits from storing carbon temporarily would generally be greater for short analytical time periods, and the benefits would decrease as the time period increases. These benefits have been questioned by many scientists on the basis that removing carbon for a period of time will only delay emissions and ultimately increase future emissions. The EPA has recognized the importance of a sound methodology to account for biobased carbon, and it has released a draft regulation setting guidelines for accounting for biobased carbon emissions.

3.9 Land Use Change

Direct land use change (LUC) results from the intentional conversion of land from its current use to a new use. To determine direct LUC emissions, the Intergovernmental Panel on Climate Change has provided guidelines and data that have been incorporated in tools, such as the Forest Industry Carbon Accounting Tool, which was developed by the National Council for Air and Stream Improvement. Direct LUC emissions associated with biobased products must be included according to ISO 14067 and the GHG Protocol Initiative.

There are several methodologies that use an economic equilibrium model to determine market feedback and increases in production yields from agricultural intensification, but they have a high degree of uncertainty because of price elasticity, unknown LUC locations, productivity levels of previously unused land, trade patterns, and the production of co-products. Despite the uncertainty and the issues associated with determining indirect LUC, it is an important factor associated with biobased products.

While increased demand for agriculture products could result in converting forest land into farmland, this has not occurred historically due to productivity growth in crop production (e.g., increased yields, double cropping, and shifts in crop production to more efficient commodities). When land is converted from forest to crop land, a release of substantial forest carbon occurs. Beyond increased carbon emissions associated with LUC, changing from forest to crop land impacts biodiversity, soil loss, water quality and other impact areas. U. S. agricultural and timber production is not driving deforestation in the United States. Authoritative U.S. forest

[83]Levasseur, A., Lesage, P., Margni, M., Deschênes, L., & Samson, R. (2010). Considering time in LCA: Dynamic LCA and its application to global warming impact assessments. 2010/3/19. Environmental Science and Technology, Volume 44, Issue 8, Pages 3169-3174.

and cropland monitoring data indicate overall stability in U.S. forest and cropland areas over the past 10 years. During this time, the largest gains in forest land area have been reversions of agricultural land into forest, with statistically insignificant forest to agricultural land-use shifts due primarily to dynamic cycling on previously cultivated land. Since 2010, forest carbon stocks in the United States have grown by nearly 2,000 MMT C.

3.10 Disposal

Biobased materials may be inherently biodegradable or may be engineered to be biodegradable in landfills. This feature potentially could reduce the amount of land required for landfills. The portion of biobased carbon in products that does not decompose will remain in the landfill indefinitely, so the landfill can serve as a carbon sink. A permanently captured carbon that previously would have gone into the atmosphere has the potential to reduce the GWP of the product over its life cycle. End of life options have been shown to change the conclusions of LCA studies when comparing different biobased products. However, it is difficult to model the future of a product when it is first created.[84] End of life LCA modeling is also sensitive to the biobased accounting methodologies that are used, as discussed earlier.

3.11 Water Use

As a result of the variability of weather and its effects on watersheds, the use of water for agricultural purposes is of constant concern, just as is the use of water for non-renewable energy sources. Researchers and companies now use life cycle techniques to explore and compare the tradeoffs of using certain biobased feedstocks for biobased products and their potential impacts on water usage.

The primary complicating factor is the geographic specificity of water impacts, since individual watersheds and aquifers have very specific characteristics, which can vary greatly.

3.12 Microplastic Pollution

3.12.1 Characteristics

In recent years, there has been growing concern for the environmental and health impacts of microplastics pollution and its abundance in the natural environment. It should be noted that biobased materials such as biobased plastics and cotton are often biodegradable and do not create microplastics particles and fibers that persist for long periods of time. This biodegradability of biobased materials will likely help boost the markets for cotton and other biobased biodegradable materials as they do not create persistent microplastics particles and associated environmental harm.

Microplastics are loosely defined as plastic particles with the largest dimension less than 5mm and take many forms, including pellets, fragments, fibers, and films.[85] Microplastics are also classified into primary microplastics that have been manufactured to its size and secondary microplastics that have formed through the abrasion and degradation of larger plastics. Although not easily

[84] Pawelzik, P., Carus, M., Hotchkiss, J., Narayan, R., Selke, S., Wellisch, M., Weiss, M., Wicke, B., & M.K. Patel (2013). "Critical aspects in the life cycle assessment (LCA) of bio-based materials – Reviewing methodologies and deriving recommendations." *Resources, Conservation and Recycling*: 211-228.

[85] Wright, S., Thompson, R. & Galloway, T. (2013). The physical impacts of microplastics on marine organisms: A review. Environmental Pollution 178 483-492.

identifiable by the unaided eye, microplastics are the most abundant form of plastic debris. Microplastics are transported through several pathways and have been documented in a wide variety of environments, including in canals, rivers, beaches of six continents, seafloor sediments, and ocean surface waters around the world including Polar Regions.[86]

3.12.2 Biological Interaction

Microplastic ingestion in nature has been observed in a variety of aquatic organisms including bivalves, crabs, shrimps, lugworms, zooplankton, seal, and large filter feeders like whales and some sharks.[87] Ingested microplastic particles have been shown to transfer up trophic levels and translocate to tissues and organs of organisms.[88]

[86]Andrady, A. (2017). The Plastic in Microplastics: A Review. Marine Pollution Bulletin 119 12–22. 10.1016.j.marpolbul.2017.01.082

[87]Rehse, Saskia, Kloas, Werner, & Zarfl, Christiane. (2016). Short-term exposure with high concentrations of pristine microplastic particles leads to immobilisation of Daphnia magna. Chemosphere 153 91e99

[88]Andrady, A. (2017). The Plastic in Microplastics: A Review. Marine Pollution Bulletin 119 12–22. 10.1016.j.marpolbul.2017.01.082

4 Carbon Intensity Labeling

4.1 Overview

The BioPreferred Program issues the USDA Certified Biobased Product label, a public facing voluntary label that launched in February of 2011. Manufactures and brands can display the label on their products and/or package as well as product literature, websites, point-of-sale displays, electronic media, and product catalogs. They first must meet prescriptive requirements, including third-party testing and verification of the biobased content of the product using ASTM D6866 Standard Test Methods for Determining the Biobased Content of Solid, Liquid, and Gaseous Samples Using Radiocarbon Analysis (ASTM D6866). The USDA establishes minimum biobased content requirements for categories that are designated to receive a federal procurement preference. Additionally, USDA establishes certification-only categories, which have a minimum biobased content requirement of 25%, for products that do not fall under a designated product category.[89,90] As of September 2023, the USDA has designated 139 product categories and has established more than 100 additional certification-only product categories.

The USDA prescribes the elements that sellers must use to apply the USDA Certified Biobased Product label. The label, as presented in Figure 37, displays the biobased content of the product, packaging, or both. In respect to the label, biobased means, "containing renewable pant, marine, and forestry-based resources not derived from petroleum."[91]

Figure 37: Sample USDA Certified Biobased Product Label.

4.2 Growth of the USDA Certified Biobased Product Label

The BioPreferred Program, including the USDA Certified Biobased Product label, has achieved tremendous growth especially in the most recent years. In 2017, 565 new products received certification. In 2022, more than double that, 1,143 new products received certification.

[89] Lewis, K. (2017, February 21). *USDA Biobased Product Label Launches Today.* USDA Blog. https://www.usda.gov/media/blog/2011/01/20/usda-biobased-product-label-launches-today

[90] USDA. (nd). *Voluntary Labeling Initiative*. USDA BioPreferred Program. https://www.biopreferred.gov/BioPreferred/faces/Welcome.xhtml

[91] USDA (2021). *USDA BioPreferred Program Brand and Marketing Guidelines: How to Display and Promote the USDA Certified Biobased Product Label. Effective March 2021 v4.* USDA. https://www.biopreferred.gov/BPResources/files/BioPreferredBrandGuide.pdf

4.3 Climate Smart Commodities

In 2022, the USDA launched a new program entitled "Partnerships for Climate-Smart Commodities" with the goal of developing and expanding markets for climate-smart commodities with greenhouse gas benefits. The program made an investment of over $3.1 billion to support 141 projects throughout the United States. These projects are estimated to result in a reduction of over 60 million metric tons of CO_2 equivalents.[92] The roll-out of the federal Partnerships for Climate-Smart Commodities program parallels similar efforts to decarbonize commodities undertaken by both U.S. and global businesses as well as certain states in the country. Businesses are rapidly committing to a net-zero carbon transition. The years they are committing to reach net-zero carbon are from 2035 to 2050 with some companies now targeting sooner years to achieve their commitment than they had initially. More than one-third (702) of world's largest publicly traded companies now have net zero targets, up from one-fifth (417) in December 2020.[93] Examples of the some of the commitments by major U.S. retailers and manufacturers is provided in Table 4-1. Examples of U.S. corporate net-zero carbon commitments.

Table 18: Examples of U.S. corporate net-zero carbon commitments.

Company	Commitment
Walmart[94]	Achieving zero emissions in our operations by 2040 and engaging suppliers through Project Gigaton™ initiative to reduce or avoid supply chain emissions by one billion metric tons by 2030.
Procter & Gamble[95]	Achieve net zero greenhouse gas (GHG) emissions across its operations and supply chain, from raw material to retailer, by 2040 as well as interim 2030 goals to make meaningful progress. "To decarbonize our supply chain, we are partnering to advance innovation in materials derived from renewable, bio-based, or recycled carbon across brands including Head & Shoulders, Pantene, Ariel, Tide and Pampers."
Lowe's[96]	Lowe's announced in December 2022 its goal to reach net-zero emissions across the company's scope 1, 2 and 3 greenhouse gas emissions by 2050, in accordance with guidelines from the Science Based Targets initiative (SBTi), the global body enabling businesses to set emissions reduction targets in line with climate science.

[92] USDA (2024, March 4). *Partnerships for Climate-Smart Commodities.* USDA. https://www.usda.gov/climate-solutions/climate-smart-commodities

[93] Net Zero Tracker. (nd). *Data Explorer* Net Zero Tracker. https://zerotracker.net/

[94] Walmart (2023). *Walmart Sustainability Hub: Zero Emissions.* Walmart. https://www.walmartsustainabilityhub.com/climate/zero-emissions

[95] Procter and Gamble. (2021, September 14). *Climate change towards net zero GHG emissions by 2040.* Proctor and Gamble. https://us.pg.com/blogs/net-zero-by-2040/

[96] Lowe's. (2022, December 5). *Lowe's sets goal to reach net zero emissions across scopes 1, 2 and 3 by 2050*. Lowe's. https://corporate.lowes.com/newsroom/press-releases/lowes-sets-goal-reach-net-zero-emissions-across-scopes-1-2-and-3-2050-12-05-22

Ford[97]	Ford Motor Company announced in 2020 that it will achieve carbon neutrality globally by 2050, while setting interim targets to address urgent climate change challenges.
Levi's[98]	In 2021, the company which operates 1,083 retail stores in 37 countries committed to achieving net-zero emissions of greenhouse gases by no later than 2050 and begin the process of submittal to SBTi in 2023.
Nike[99]	NIKE with over 75,000 employees; upwards of one million employees in owned and supplier facilities; over 1,500 physical spaces; and emissions of 11,706,664 metric tons CO2e in FY20 committed to net-zero carbon by 2050.
Dow[100]	By 2030, Dow will reduce its net annual carbon emissions by five million metric tons versus its 2020 baseline (15% reduction). By 2050, Dow intends to be carbon neutral (Scopes 1+2+3 plus product benefits).

To fulfill these public commitments, companies and their suppliers will depend on the availability of lower carbon feedstocks and products, i.e., Climate-smart commodities.

In addition to corporate commitments, multiple states in the US have also made commitments and instituted programs to achieve carbon commitments and greater dependence on biobased and climate-smart commodities.

One such example is the State of New York, which enacted the New York State Climate Act and the Climate Leadership and Community Protection Act (CLCPA) in 2019 which sets up net-zero greenhouse gas emissions goals. Specifically, it requires the state to achieve a reduction of its total GHG emissions of at least 85%, and up to 100%, by 2050. As part of this commitment, the state is looking toward biobased solutions as stated in a recent request for information (5182) that states, "The bioeconomy and nature-based climate solutions provide opportunities to decarbonize across multiple sectors of the economy, with benefits to the environment and resilience."[101]

4.4 Emerging Industry Needs

As a result of the wide-spread and rapid adoption of net-zero carbon commitments by American and global industry, state-led market pull, and gaps in the market, businesses in the US have expressed a need for a verifiable and credible mechanism to quantify the carbon intensity of feedstocks and products throughout the value chain, including a consumer-facing label.

In 2022, the Dynamic Sustainability Lab at Syracuse University in partnership with industry and state government biobased leaders comprising membership of the Alternative Fuels and Chemicals Coalition

[97] Ford (2020, June 24). *Ford expands climate change goals, sets target to become carbon neutral by 2050: annual sustainability report.* Ford. https://media.ford.com/content/fordmedia/fna/us/en/news/2020/06/24/ford-expands-climate-change-goals.html
[98] Levi Strauss & Co. (2021). *Levi Strauss & Co. 2021 Sustainability Report*. https://www.levistrauss.com/sustainability-report/climate/climate-action/
[99] Nike. (2021). *Move to Zero: 2025 and beyond*. Nike. https://www.nike.com/a/sustainability-2025-targets
[100] Dow. (2023). *Accelerating our sustainability commitments and targets*. Dow. https://corporate.dow.com/en-us/science-and-sustainability/commits-to-reduce-emissions-and-waste.html
[101] New York State. (2022). *Innovative Bioeconomy and Nature-based Solutions for New York's Climate Goals. Request for Information RFI-5182.* NYSDERA. https://portal.nyserda.ny.gov/servlet/servlet.FileDownload?file=00P8z000001aJTTEA2

(AFCC) undertook a national survey and research project to explore industry needs in regard to the biobased economy and specifically at the request of industry to develop preliminary insights in regard to the development of a standardized label to communicate carbon intensity. The results of this survey are shown in the following figures.[102]

In the survey, seventy-four percent of the industry respondents indicated that they strongly agreed or agreed that it would be beneficial for their organization to quantify the carbon intensity of products acquired from the supply chain as presented in Figure 38.

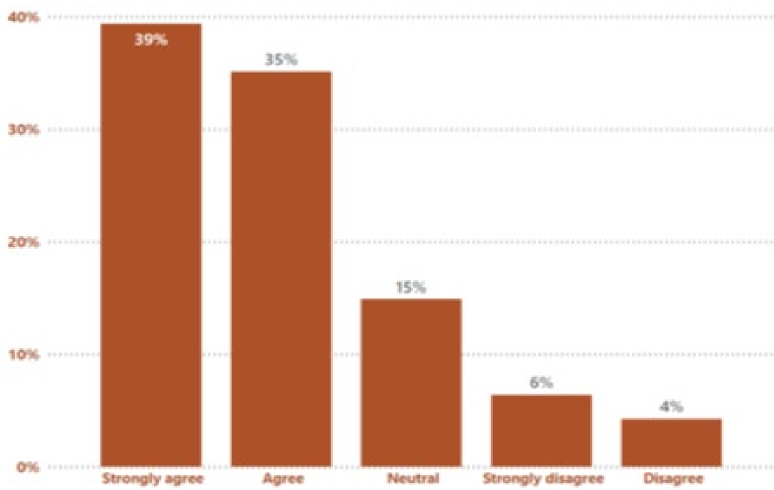


Figure 38: Respondent answers to the question if it would be beneficial for their organization to quantify the carbon intensity of products acquired from the supply chain.

Respondents were asked if it is more effective to have a single and standardized carbon intensity label in the U.S. rather than multiple carbon intensity labels from separate public and/or private organizations. As presented in Figure 39 eighty-two percent of respondents agreed or strongly agreed that a single standardized carbon label is necessary.

[102]Dynamic Sustainability Lab. (2023). A U.S. based carbon intensity label. Technical Bulletin 20230401. www.Dynamicslab.org/allresearch

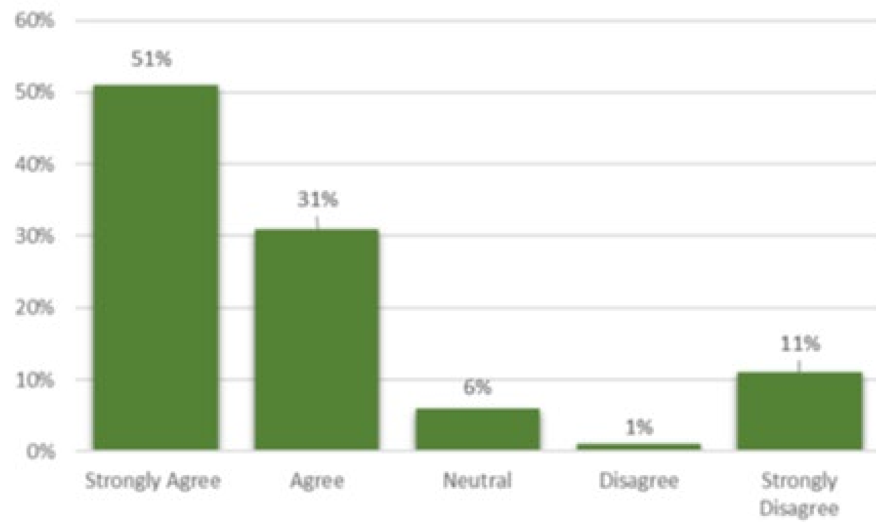


Figure 39: Industry respondent answers to the need for a single and standardized carbon label.

In part, the views of industry are being framed by the emergence of hundreds of various forms of global carbon labels created by individual companies, industry associations, non-governmental organizations, and national and regional governments. Because there is no recognized standard for a carbon intensity label, most of the existing and emerging labels are not consistent in their methodology and many do not transparently publish the methodology used.

The survey asked who industry members believed was the most appropriate organization to develop and manage a carbon label. As presented in Figure 40, the respondents listed an agency of the U.S. government (64%) as the most appropriate organization.

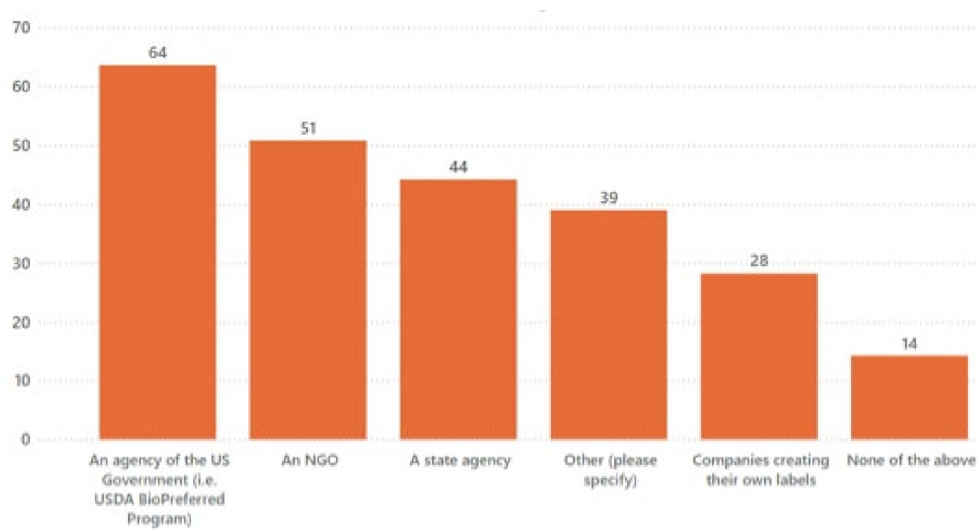


Figure 40: An agency of the U.S. government is identified as the most appropriate organization to develop and manage a carbon label.

While the respondents indicated the need for a carbon label and their desire for an agency of the U.S. government to manage the process, they identified the issues which will be the most important to their organizations in the development of a label.

As presented in Figure 41 the most important factors as part of an index score were the development of technical specifications and standards (73), followed by the cost to the organization (53), and allocation of resources (50), as well as time (46), lack of knowledge (27), and other (12).

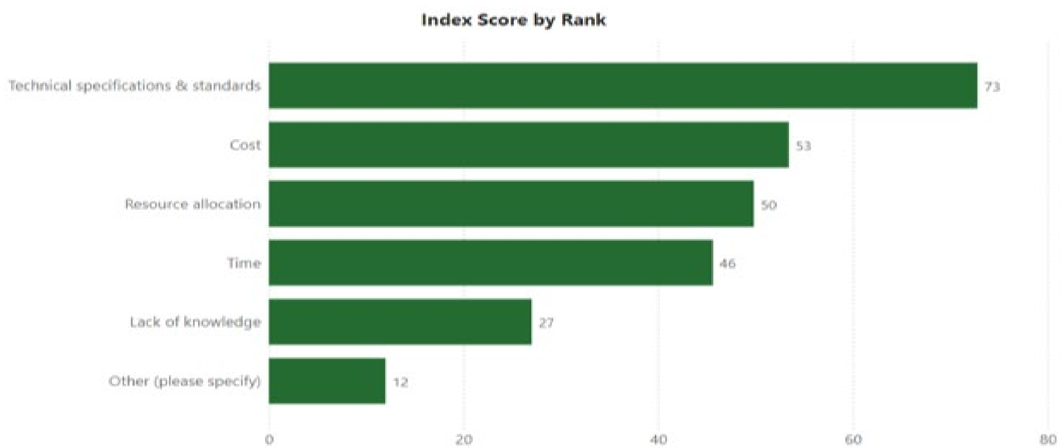


Figure 41: An agency of the U.S. government is identified as the most appropriate organization to develop and manage a carbon label.

4.5 Technical Approach

To address the technical development challenge, the membership of AFCC has engaged with ASTM International, formerly known as American Society for Testing and Materials, an international standards organization that develops and publishes voluntary consensus technical standards for a wide range of materials, products, systems, and services.

ASTM Committee E-62, Industrial Biotechnology and Synthetic Biology Committee, is working to create a trusted, international climate intensity label. Rather than creating new methodologies, the effort references validated, peer-reviewed existing measurement and modeling methodologies (such as Verra, Climate Action Reserve, The Gold Standard, Regrow’s DNDC model, Argonne Lab’s GREET model and others) as well as reputable LCA methodologies. These have validated GHG emission tables for standard fertilizer, tillage, transport, and processing operations to quantify associated carbon dioxide and other GHG data associated with those operations.

The final calculations will yield a value that reflects the carbon pulled from the atmosphere and stored both in the product and the soil in which the biobased feedstock was grown, adjusted for GHG emissions produced throughout the entire production and processing supply chain. This value can be passed down the supply chain to figure out the carbon intensity of the final product at the consumer point-of-purchase.

The goal is to organize and cite the methodology needed to enable and support a trusted consumer facing carbon intensity score that will provide informed and verifiable choices for both institutional buyers and consumers who desire to make purchasing decisions based on carbon intensity.

5 Industry Perspectives

This section presents perspectives on the biobased products industry from a variety of organizations. The companies discussed in this section were selected by the authors because of the nature of their engagement in the biobased products industry and are intended to be a sample of organizations in the industry. These organizations did not ask for inclusion, USDA endorsement, or any sort of compensation for their participation. These case studies are not intended to be an indicator of the USDA's or the authors' endorsement of these organizations in any way. Past reports have contained dozens of case studies that combine to show the breadth and complexity of the biobased products industry.

The companies discussed in this section were selected using the following criteria:

1. Biobased Products Industry Engagement and Availability. The authors had to be able to reach a contact at the company willing to discuss their sustainability efforts during the writing period. Additionally, the companies had to review and provide approval for the information regarding their company before publication. One of the largest hurdles the authors faced in writing this section was reaching companies. The most responsive companies were often found by contacting BioPreferred Program participants or through the authors' personal networks.

2. Industry Representation. The authors sought to include a variety of organizations currently engaged in biobased products industry, including start-ups, laboratories, small businesses, private mid-sized companies, and established publicly traded brands. Case studies include finished retail products, intermediate ingredients, and private label manufacturers.

3. Innovative Sustainability Initiatives. This report seeks to provide examples of the opportunities and challenges facing companies on the forefront of the biobased products industry.

The case studies in this section are for informational purposes only. The USDA does not endorse, recommend, or support any specific companies, products, services, or brands mentioned or referenced in this section or any other sections of this report.

5.1 Greenology: Private Label Contract Biobased Product Development and Manufacturing

Greenology Products, Inc. started out as a niche green organic brand, founded by its CEO Adam McCarthy in 2009. The founder's goal was to create a progressive and innovative line of USDA certified organic household cleaners and detergents—the first of their kind in the U.S.—made with good ingredients to protect the planet, all packaged inside sustainable sugarcane bottles. Greenology created this under their Greenshield Organic® (GO) brand of biobased detergents, wipes, surface cleaners, and baby products. The original GO products are still produced today but are only a small percent of Greenology's business. The bulk of the business today is in private labeling, where customers sell Greenology's products under their own brand names, and contract manufacturing, where customers work with Greenology to develop their desired formulation, for retail groceries and large retailers.

Greenology's mission today is to produce consumer products that are good for people, pets, and the planet. They specialize in formula development and product manufacturing for USDA certified organic, natural, and good-for-you products in the categories of cleaning, laundry, and health and beauty. They partner with retailers through private labeling while also growing their own GO brand products to help drive their mission and promote sustainability in the consumer product industry. Under the Greenshield Organic brand, they manufactured the first line of USDA Certified Organic Detergents and Cleaners in the country.

Greenology has a large portfolio of natural care and cleaning products and has earned the BioPreferred Program's USDA Certified Biobased Product label for more than forty of their products. Participating in the BioPreferred Program is an important part of how Greenology conveys commitment to their mission to make better products for people, the planet, and pets, which is clearly aligned with the goals of the BioPreferred Program as well.

Participating in the BioPreferred Program has allowed Greenology to expand their own brands rapidly and at higher volumes as the USDA Certified Biobased Product label has become a recognized symbol for many brands and has gained a lot of traction in the consumer market as a result. Many private label biobased brands are produced by Greenology, including Kroger, Whole Foods, and others. Typically, private labels do not reveal who the manufacturer is, and so most consumers do not realize that Greenology produces and often develops many products they see in stores. It is difficult for a private niche brand like GO to compete with other products in terms of shelf space. However, by becoming the contract manufacturer for larger private label brands, Greenology can access retail shelves much more easily.
The contract manufacturing process usually begins with a bid issued by the brand. Retailers prefer to have a category grouping of products that all come from the same supplier, which has resulted in significant volume increases for Greenology over the years. For instance, the brand may want to have a private label version of a brand name

laundry detergent in their aisle. Greenology must then propose a chemical solution that comes in at a cost that is at least equal to and performs as well or better than the brand name. That is challenging and requires extensive knowledge of biobased chemistry.

As part of their bid, Greenology offers that the product will have the USDA Certified Biobased Product label attached to it. It is extremely rare that brands ever turn down the label, and many of them explicitly ask for it in the bid. When Greenology wins a bid, they begin by assigning project managers, who connect with the customer and understand the desired product attributes in detail. They will then develop a product prototype and associated pricing for commercializing the product, which must also consider costs and volume forecasts for the new product. Understanding the customer's desires for the "look and feel" of the product packaging is also important. If Greenology provides a solid proposal with all those attributes in mind, they are awarded the bid.

One of Greenology's strengths is that they are willing to customize products to any customer requirements. They have a lengthy list of chemistries that they do not allow in their products, but they are able to customize and deliver different versions of a product for a customer if they want. The minimum biobased content required by the BioPreferred Program is always kept in mind. There are often many different customer attributes that the brand is looking to provide. The product needs to be safe, should delight the senses, have exceptional performance, but also use biobased creams and surfactants that are in the cost range needed. Because of their long history and experience in surfactant formulation, Greenology product developers know where to look for new formulations and can reach out to new suppliers if there is an innovation needed. Collaborating with suppliers on new product development is a core capability of the development team.

Recently, Greenology was tasked with developing an enzymatic liquid dish soap by the end of the year. The mission was to take out the primary surfactant, a derivative of benzene, in the formulation. The challenge was that the benzene derivative was a high performing surfactant; the new product had to be less expensive and had to have the same performance or better than the original.

To address this issue, Greenology partnered with an enzyme supplier and developed a less expensive, higher performing biobased dish soap. Both the enzymatic and nonenzymatic products were presented to the customer, and the product was introduced in North America as a result. Greenology continues to partner with the enzyme supplier, and the two have partnered on multiple customer projects. The supplier likes working with Greenology as well, noting that they can produce private label formulations for Greenology on fast timelines, a necessity when working with private label brands and something other suppliers are not able to do. Another product developed recently was a dehydrated cleaning product line that cuts out water and plastic.

Depending on the volume and customer requirements, Greenology will either produce products in-house or outsource them. For most of their liquid fills (if they are not too thick), this can be completed in

Greenology's on-site facility. For products that require equipment that is not in-house, contract manufacturers are used. Often though, projects can originate with an idea, scale up in the lab, and then to go into commercial line production, all in the same facility.

All sourcing of raw materials to internal production is managed by Greenology, as well as distribution of product to retailer distribution centers. The brands will often supply their own private label artwork and ship these to the production sites. However, Greenology is also able to supply sustainable post-consumer recycled (PCR) packaging and labeling materials. Because product labels are often very intricate, there is a lot of back and forth with the customer to ensure that the label looks like they want it to when it arrives on the store shelves.

Greenology also works to produce private label personal care products and works with copackers to package and produce these products. This includes skin creams and lotions, shampoos, masks, conditioners, and hair serum.

Personal care products are challenging, as many of them have petroleum-based components that are difficult to replace. There can also be a significant cost disadvantage. For example, a bottle of a well-known brand name soap can be produced for merely cents because of their high volume and the availability of petroleum-derived chemicals. Greenology believes that if cost were not a factor, Greenology would be able to produce products using biobased surfactants that perform as well or better than petroleum-based products. However, Greenology acknowledged that biobased components do not have the same economies of scale as petroleum-based components, and the resulting cost gap makes it difficult to produce some biobased products competitively.

Testing being done by both Greenology and third parties is showing that biobased products are actually performing better than petroleum-based products in personal care. The challenge comes in educating consumers about this. Consumers must see the products' performance for themselves, rather than reading about it on a label before perspectives begin to shift more rapidly. While there may not be many green surfactants, Greenology is optimistic about the future for biobased products. As suppliers are beginning to see the impact of biobased alternatives, they are starting to come out with multiple new biobased surfactants every year. This means these chemicals will be more accessible to Greenology, allowing them to pick from more options for their customers. As this shift occurs over the next five to ten years, the availability of biobased products will increase, allowing costs to decrease, and the technology will evolve significantly.

Greenology is seeing that growth occur. In the past few years, their private label biobased volume has grown by thirty to thirty-five percent annually and is continuing to grow, allowing more products to come out onto the market. This will begin to educate consumers and will shift the perception that biobased is more expensive.

Greenology has also begun to collaborate with companies who supply big brands like Target and Walmart. These kinds of opportunities are a result of Greenology's work building their private label portfolio, which shows potential private label customers that Greenology's biobased products can meet their needs. Building a base of private label customers has allowed Greenology to prove they can create high quality biobased products, which allows them more opportunities to grow and expand into new areas.

There are always a lot of challenges. One of the questions Greenology is always asked is how they can quantify the value of a biobased product formulation. When developing a product, typically Greenology reaches out to their suppliers who have a great process that relies on a "bioprocess index." This index helps Greenology estimate the percentage of biobased material in the product that is needed. When this index is not available, Greenology must estimate those percentages. While estimating the percent of biobased product is always a challenge, it is part of the innovation process, and it is something that helps Greenology stand out from the competition. Greenology can innovate and create new biobased applications and can prove that these applications perform better than petroleum-based products, using third party testing. The BioPreferred Program helps to back up Greenology's claims by showing customers that they are not greenwashing their products. Greenology believes that there is no other industry standard that allows them to back up what they say and do.

5.2 Danone's Journey to Circular Economy Packaging

Kory Nook is enthusiastic about packaging innovation. Many people do not understand how critical a role supply chain end-to-end packaging plays in consumer behavior, product design, supply chain outcomes, profitability, and sustainability, but Nook makes it his business to educate others on his team and in his circle of professionals just how critical that role is. As Vice President of Packaging for Danone, he spends every day thinking about how to contribute to the circular economy.

Danone is best known for its dairy products (yogurts such as Activia, Oikos, Danone, and creamers such as International Delight), but also produces water brands (Evian, Volvic, Aqua), and specialized nutritional products. All these products require packaging. Nook is on a mission to ensure that all of Danone's packaging is circular, meaning that it can be reused or recycled and not end up in landfill.

This is a massive challenge, and Danone began this journey just a few years ago. One of the biggest challenges is cost, but infrastructure and material investments as well as regulatory requirements that are current and coming soon also present significant challenges. All these elements require looking at the problem differently and changing the conversation about how packaging is viewed. Nook noted that transitioning to circular packaging is a huge undertaking. It requires abiding by laws, building a community of consumers and stakeholders, and building a future. Despite these hurdles, Nook believes making the transition will help meet business goals and achieve social goals due to the part circular packaging can play in decarbonization.

Nook is an engineer who admits he "fell into" the field of packaging and loved it at once. Packaging protects tangible objects and requires design thinking and collaboration with marketing and other groups. Nook recalls spending a lot of time working with big consumer packaged goods (CPG) companies. Over the course of his time working with these CPG companies, the idea of recyclable packaging became more important as a measurable outcome, along with optimizing cost, sales, and utility. The goal became to rid the world of waste and to become more innovative about circular models, which required working with planning teams in supply chain, studying product portfolios, and moving to build strategic partnerships with suppliers.

Nook recalls that while Danone is one of the biggest food packaging companies in the world when he came onboard, they were not in a great place in terms of sustainable and efficient operations. He explained that Danone was shipping empty HTPE bottles to bottlers to be filled, while their suppliers and competitors were producing bottles in-house using PET and circular materials, thus reducing their carbon footprint. Danone now has projects in Jacksonville to begin moving bottle production in-house, and moving that through their facilities, taking full weighted-out containers of plastic off the planet. Nook emphasized that this effort required a lot of collaboration, from connecting people from packaging, research and development, and operations, to redesigning the product and using a special technology for dispensing. This has created big bottom-line savings from blowing plastic in-house. Nook noted that because HTPE is a higher cost material, Danone buys pre-forms and ships bottles using pallets. Danone can feed plastic to their plants in a much more efficient way that lowers the carbon footprint.

Technology for biobased PET for water bottles is also being developed by Danone. In the meantime, Danone is moving towards a polyethylene bottle. These bottles are more recyclable, and they are currently being used for some of the Evian product line. The company is also trying to lightweight their bottles and is making capital investments that run the new material while also using more recycled content in the bottles. These efforts are largely being driven by a law in California that required a plastic recycled content standard of 15 percent beginning January 1, 2022, increasing to 25 percent in 2025 and 50 percent in 2030.[103] Nook noted that these types of law are important, and abiding by them is driving supply chains to change as companies shift their portfolios to unlock the circular economy, rather than proliferating other new virgin materials.

Yogurt cups are another big packaging project. The challenges of packaging yogurt are significant, but Nook is focused on better understanding the carbon impacts and costs, as well as the packaging redesign. Yogurt lines in Europe have converted from polystyrene to PET, but polystyrene is still used in the US. Danone is seeking to convert more than twenty lines over the next few years, which is complicated to do without shutting down production. The company is exploring how to convert assets, including existing molds, cutting tools, and other investments, and all of that requires money. One challenge with using a biobased material is that the capital expenditures needed to work with the material (which is more difficult to cut and manipulate) will cost more, making a difficult business case. However, to meet the requirements for recyclable material mandated by California, Danone is looking to drive this innovation in this space. Nook asserted that the costs of dealing with a class action lawsuit due to non-compliance must be weighed against the cost of innovating, which is driving companies to evaluate returns on investments differently. Today, a PET yogurt cup is not recyclable, and these materials will only become more widely recyclable by working with a consortium and communities to create new recycling value streams.

The same goes for recycling PET water bottles. Colored PET bottles are not easily recyclable and must be put into special bales, which changes how they are sorted in conveyors. This may require different capital investments, different types of programming, and the technical challenges of recycling colored PET must be pushed upstream to Danone's marketing groups, so they understand how to keep the company's downstream recycled content healthy.

Nook explained that while moving towards a more circular economy is a positive thing, it requires big companies like Danone to

[103]CalRecycle. (2023). *Plastic Minimum Content Standards (AB 793)*. https://calrecycle.ca.gov/bevcontainer/bevdistman/plasticcontent/

partner with government organizations to inform and educate the consumer about the value of circular products so that they will care. Who pays for the cost to offset switching to recyclable bottles is an open question. Nook contends that while companies like Danone can make some investments, government, consumers, and retailers will need to be part of the solution.

Like the costs associated with moving toward using recycled materials, there are also costs associated with transitioning to using biobased materials. Nook stated that, in terms of moving to an entirely biobased package, there are many big costs that must be overcome. It will start with some PET drop-ins, Nook contends, but the only pathway to more biobased material will require setting up new business models and shifting consumer behavior significantly. Nook said that this is very complicated and will require a lot of change. Today, most PET is petroleum-based because of costs and unsustainable margins. Nook believes that biobased packaging will be another two to three years out, where the first stage will be to move everything to PET. The transition process will have to be driven by innovation and an underlying savings program, which will allow the move to biobased materials. Today, Danone is investing in the infrastructure to get the savings needed to make that move. Nook noted that it is one of Danone's long-term goals, and the company is exploring how prices can be brought down with biobased materials like sugarcane and using more pre-formed cups in-house.

When considering all the different elements of value—sustainability, biobased, branding, sizing, demographics, and others—the trend is moving away from single use plastics. Nook explained that Danone hopes to help consumers make better decisions at the grocery store, and to do that, sustainability cannot be seen as flashy and expensive. Only some consumers will pay more for sustainability. Nook believes that Danone is moving in the right direction and does not want to be the last to adopt biobased materials. "Our product brand has only got us so far, and we need to link this effort back to our goal, which is about creating the right products to feed the world," emphasized Nook.

Legislation is also playing a key role in moving toward sustainability. Nook noted that in some of Danone's product cost models, they have used European legislation as a proxy for what the cost impacts will be if they do not start to move the needle on biobased products. Nook believes that the U.S. needs to pay attention to European markets as the move toward sustainability is having a significant impact there. The European Union does not agree on some topics, but they are completely aligned on some elements. For example, there is a global push to move away from polystyrene in food packaging. Looking at all these forces, Nook believes a complete biobased packaging platform is about five to ten years away.

5.3 Colonial Chemistry Leads the Way in the Biobased Chemicals Sector

Colonial Chemical

Colonial Chemistry is a privately held specialty manufacturer based in Tennessee right outside of Chattanooga. The company has been in business for 35 years and was organized originally as a distribution agent for other chemical manufacturers. Eventually, the company began their own manufacturing operations, which began with the development of innovative technologies.

The company began working on developing technologies that were biobased, biodegradable, and based on environmentally benign chemicals. A large segment of the chemical industry involves surfactants and reagents, and Colonial serves several markets that use these types of chemicals. A large part of their revenue involves personal care products, and other major sectors for Colonial include household and industrial cleaning as well as lubricant additives and metal working.

The personal care sector is especially focused on naturally derived products. Dennis Abbeduto is a product development engineer who was brought on to develop applications around Colonial's innovative materials for personal care and other end markets. His goals were to develop more in-house products, develop sample formulations, and help customers work with Colonial's products efficiently. Prior to working at Colonial, Abbeduto worked in several large CPG companies in personal care and was attracted to the role at Colonial because he viewed it as a "different" specialty chemicals company.

Abbeduto explained the challenges in developing biobased chemicals:
"Generally, there is a huge uptick in amino acid surfactant chemistry, as well as proprietary surfactants that have relatively high biobased content and low toxicity. These chemicals are essentially replacements for some of the chemicals that consumers are seeking to avoid, especially in personal care products. The industry as a whole is moving towards naturally-derived products, a trend that began about ten years ago, which has escalated today."

Colonial has focused on developing biobased technologies, looking to keep petrochemicals to a minimum and to avoid toxic materials. Colonial has developed several patented chemistries over the last two decades and continues to work on research and development projects with a team of chemists, focused on synthesis and analytical capabilities.

In many cases, customers will come to Colonial and inquire about the development of specific formulations targeted for biobased applications. Many companies come to Colonial because of their legacy and reputation as a developer of biobased materials. In addition to being biobased, customers also are seeking performance attributes for the targeted application. The challenge of meeting biobased and performance metrics is one that Colonial relishes.

One of the biggest challenges with many new biobased materials is cost. Market demand for biobased content, which is often limited by the cost of the materials, is a major hurdle in the adoption of new biobased materials. This is especially true in the personal care space, where the performance of the product that is applied to people's bodies is especially important. Colonial produces the foundation upon which products are constructed, and the extracts, oils, and additives are then added to the foundation and become the ingredients that are highlighted in marketing claims. The base components are not noted in the marketing of the formulation, and as such, there is little tolerance for high-cost biobased products.

Typical personal care items are for daily use, including cleansing and treating hair, hands, bodies, and faces, in the form of creams and lotions. Colonial has also started to move into oral care products. Colonial has several important chemistry patents, and a lot of the emerging celebrity brands in baby care use their technology, with a high biobased content and a low irritation potential. Some of the common brands using this include Hello Bello and Kylie Baby.

Colonial was a winner in the 2021 EPA Green Chemistry Challenge Awards Program, which recognizes innovators who develop new and innovative green chemistry technologies that supply solutions to significant environmental challenges and spur innovation and economic development. Colonial was recognized for developing their Suga®Boost surfactant blends, which use more environmentally friendly chemicals than traditional surfactants. Suga®Boost surfactants consume less energy to create, are biodegradable, and are derived from plant-based materials, with performance that is as good or better than their traditional petroleum-based counterparts.

Abbeduto believes that biobased chemicals will continue to grow in the household and industrial products categories. In the future, he also believes that the market for biobased products will become more important in new markets such as metalworking and oil production equipment, which are not making a lot of effort towards using biobased products. In industrial markets, there is not the same connection with consumers in the same way there is in personal care and CPGs. In CPG industries, the customer is the every-day consumer, using the products on their skin or in their home, and consumers have a personal stake in trying to be more environmentally friendly. Although the CPG segment started out slowly a few years ago and moved slowly, it has exploded in the last two years.

The foundation for Colonial's products is the oleochemicals market, which are surfactants that are both water soluble and insoluble. The water-soluble surfactants come from a variety of sources and are used in several different applications. For instance, daily cleansing lotions do not have a domestic crop in North America with the volume to meet the demand for high foaming materials. Lauric and myristic acids are the primary key building blocks for foaming surfactants. These fatty acids are rare in nature. Coconut is a major source and has a positive consumer connotation, so for that reason many products are derived from these fatty acids. In the past, the seed or nut of the African oil palm was the dominant source globally of these fatty acids. Babassu is another palm species native to South America that offers a similar fatty acid profile as coconut or palm kernel oils, but it is seldom used.

Some personal care products can use more domestic vegetable oils, especially in lotions and emulsifiers. Colonial has had a partnership with the United Soy Board to develop soybean oil and develop products from high oleic soy oils.

Abbeduto noted that one of the biggest barriers to producing biobased products is being subject to the whims of upstream feedstock suppliers. Feedstocks such as ethanolamine and dimethylaminopropylamine, two nitrogen-containing chemicals, are commonly used in manufacturing surfactants, but they are typically petroleum-based. These types of feedstocks could potentially be converted to biobased sources, and the biobased content could be confirmed through testing done by the BioPreferred Program. However, there are more environmental concerns related to nitrogen-containing chemicals, as these chemicals are produced from ammonia derived via the Haber-Bosch process using petroleum-based methane.

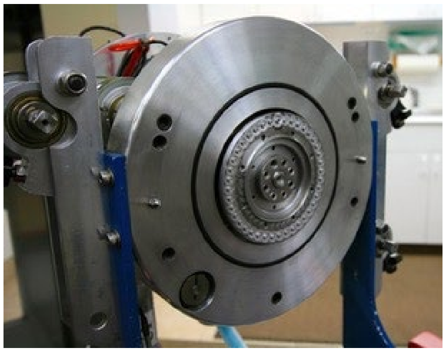
One possible easy substitution for nitrogen-based chemicals is the use of methanol; however, methanol supply chains are not set up for biobased feedstocks and are primarily using petroleum-based feedstocks. Other intermediary supply chains are starting to consider biobased feedstocks but are not yet set up to do so yet. Colonial has been successful in converting one of their intermediates, which has employed proprietary technology, to move to 100% biobased products. The BioPreferred Program provides an important venue for certifying that it indeed has a higher biobased content.

In effect, Abbeduto noted that the BioPreferred Program's USDA Certified Biobased Product label is a valuable tool for educating people on the sources of feedstocks. The USDA Certified Biobased Product label shows that the product's ingredients have been vetted through a third-party analysis, which increases customer trust.

The USDA Certified Biobased Product label is growing in popularity, especially in the CPG category, with companies such as Seventh Generation, P&G, and others choosing to become certified and display the label. When Colonial was awarded the Green Chemistry Challenge Award in their 20th year, Abbeduto was struck by how increasing renewable content is still a nascent effort in industry. Many biobased products have gained traction only in the last five to ten years, but the biobased products market is moving away from being just a niche market.

Personal care products are the most transparent about telling consumers everything that goes into them, but often that information does not tell the whole story. Abbeduto contends that is why the BioPreferred Program is so important. There are often petrochemical products within many personal care products, yet there is typically little evidence they are even present on the product label. The USDA Certified Biobased Product label is a critical communication vehicle, informing consumers of the actual content that is biobased. Abbeduto emphasized that the results simply cannot be falsified, and this is a crucial element that ensures the label can be trusted.

5.4 BETA Analytic Testing Laboratories



Beta Analytic, an ISO 17025:2017 accredited laboratory, has been conducting biobased testing since the early 2000s. The lab reports its test results in seven business days or less. The laboratory has been heavily involved in developing the ASTM D6866 standard that is used by the BioPreferred Program in deploying the USDA Certified Biobased Product label.

History

Beta was founded in 1979 by Murry Tamers, Ph.D. (Yale University), D.Sc. (Université de Paris Sorbonne) and Jerry Stipp, Ph.D. (Australian National University), who played a role in the development of radiocarbon dating methodology.

Enactment of the Farm Security and Rural Investment Act of 2002 specifically required federal procurement agencies to purchase products in categories designated by USDA that met minimum biobased content requirements established by USDA. Since biobased content is a measure of present-day carbon versus fossil carbon, only a minor modification in the final calculations was needed to turn a radiocarbon date into a biobased content percentage. This led to Beta's involvement in the biobased products industry.

Beta, along with an ASTM committee and the BioPreferred Program, played a key role in developing the ASTM D6866 standard in the early 2000s. This international standard is used to decide the biobased carbon content of solid, liquid, or gaseous material using the radiocarbon dating (carbon-14) method. Since then, Beta has been offering reliable biobased testing services for various industries, analyzing material such as biobased plastics, packaging, personal care and cosmetic items, household cleaning products, and intermediate chemicals.

How to Measure Biobased Content

Carbon-14, also known as radiocarbon, is a radioactive isotope present in the atmosphere that is absorbed at ground level by living organisms. Living organisms have a known level of carbon-14 while petroleum-derived substances do not have any carbon-14 content. As a result, carbon-14 analysis for biobased testing measures the exact amount of carbon in a material that comes from biomass sources. This measurement is performed according to test methods such as ASTM D6866 using an Accelerator Mass Spectrometer instrument.

Biobased product test results are reported as a ratio of biobased organic carbon to total organic carbon and range from zero percent to one hundred percent biobased. The value is the part of the product's organic carbon that is derived from biobased sources. A product entirely composed of biobased ingredients will yield a result of one hundred percent biobased content while a product that has only petroleum-derived ingredients will result in zero percent biobased content.

A value in between shows that the product has a mixture of biomass and fossil fuels sources.

There has been a surprising increase in the number of new product formulations in the biobased products industry since the USDA Certified Biobased Product label was launched in 2011, a promising indicator that organizations are continuing to innovate with new biobased materials. In addition to U.S. companies, many companies in international regions such as Europe are applying for the USDA Certified Biobased Product label to expand their markets into the U.S. sector.

The USDA Certified Biobased Product label has become recognized as an important indicator of biobased material certification all over the world. However, one of the challenges with the USDA Certified Biobased Product label is that consumers are not always familiar with the term biobased. Because of this, consumer awareness initiatives and educational programs are necessary to help promote the term biobased and ensure that consumers understand what biobased really means. One reason for lack of familiarity with "biobased" is that there is not enough regulation around the term. Education is critical, and to really grow the biobased sector, the U.S. will have to adopt increasing regulations. For instance, in the EU, single-use plastic bags in Italy and France require a minimum amount of biobased content.

In addition, some brands claim they are plant-based without formally testing for biobased content, which may result in greenwashing. There is often confusion around biobased products due to so many different product labels. An important part of the USDA Certified Biobased Product label is that it shows the actual percentage of biobased content in the product as well as in the packaging. Other programs in the EU instead display a range of biobased content on an ecolabel but may or may not say what the actual content of biobased material is. This highlights the significance of educating consumers on what the percentage of biobased content means.

Beta Analytic believes that an important requirement for growing the BioPreferred Program involves conducting consumer awareness programs of biobased products. Education and outreach programs for consumers on what biobased products are will allow consumers to easily find biobased products in the market and make more informed purchasing decisions.

5.5 Seventh Generation: The Green Premium in Consumer Products

Seventh Generation was one of the very first consumer product companies to focus on sustainable products when it was founded more than 30 years ago in 1988 as a mail order catalog. At that time, its founders believed in creating a company whose values were as important as the products it made and created a mission statement to transform the world into a healthy, sustainable, and equitable place for the next seven generations. Its growth in the last year has been strong because of COVID-19 and the increasing demand for cleaning and disinfecting products; its growth has surged into the 20-30% growth rate as a result.

Martin Wolf is a chemist by training, a graduate of the Worcester Polytechnic Institute, and he began working as a chemist at Ceiba Geigy (known as Syngenta today). Wolf then worked at ThermoElectron, after which he helped co-found an environmental lab, Cambridge Analytical Associates, which eventually went public and merged into a larger company. Wolf then began consulting in the chemical industry. One of his clients was Seventh Generation, who invited him to join the company full-time in 2002 and move up to Burlington, Vermont, the location of its headquarters.

At that time, Seventh Generation was a less than $20M company, with half a dozen buyers in New York and a fulfillment center in Vermont. Wolf's first job was to screen any products sold in the catalogue to ensure they were complying with the environmental claims on their label, including validation of claims on recyclable materials and biobased materials.

Today, Wolf's primary role at Seventh Generation as Director of Sustainability & Authenticity is to derive frameworks for more sustainable products, including exploring alternative ingredients and packaging materials. Wolf described the collaboration that is needed for his role, saying that he is constantly trying to figure out how to work with Seventh Generation's value chain partners, industry partners, advocacy organizations, and government agencies to make their products more circular and more sustainable. He emphasized that if the business is not sustainable, Seventh Generation's products cannot be, and if their system of commerce is not sustainable, the business cannot be. Wolf works with the American Cleaning Institute, various civil advocacy organizations, and state regulators to create a more sustainable system of commerce that can thrive.

How is Seventh Generation Using Green Chemicals?

There are two primary approaches that are used to ensure that green chemicals are used in Seventh Generation's products. First, Seventh Generation ensures that stringent raw material standards are in place. For example, apart from microbial preservatives, all chemicals must be biobased and biodegradable and must not be chronically toxic. All companies selling ingredients to Seventh Generation must complete a multi-page screening document that ensures their materials are compliant. One approach Seventh Generation's formulation chemists use to create new products is to replace petroleum-based ingredients with biobased alternatives. For example, a common surfactant is sodium lauryl sulfate, which can be petroleum-based, and Seventh Generation chemists may decide to replace this with a surfactant that is biobased. In other instances, a chemical supplier may approach Seventh Generation having done formulary research and pitch suggestions on how to formulate and create a new product using biobased technology to replace a non-renewable chemical. The result may lead to collaboration and further exploration of innovative technology.

Unilever

The Unilever Buy-Out

In 2016, Seventh Generation became a wholly owned subsidiary of Unilever. Its revenues at the time were in the $300M - $500M range, and the idea of being swallowed up into a massive global consumer conglomerate was daunting at first. Paul Polman, the CEO of Unilever at the time, visited the Seventh Generation headquarters and made a speech to the entire workforce. His message to the employees was very straightforward; he explained that Unilever bought Seventh Generation because of their values and practices. He emphasized that they did not want Seventh Generation to change, and in fact, Unilever wanted to learn from Seventh Generation's practices. Seventh Generation had to adapt to Unilever's IT systems and other shared services such as human resources, hiring practices, and procurement, but they were largely left to continue to pursue their mission to develop their products as they saw fit. And then, two things happened.

Over time, Seventh Generation influenced and changed Unilever, a mammoth consumer goods company. Wolf noted that Unilever is changing as they adapt to Seventh Generation's views. Their view of why it is important to be biodegradable and biobased has influenced Unilever, who has made a commitment to eliminate fossil fuels from their cleaning products by 2030.

Wolf observed that Seventh Generation's packaging was 80% PCR at the time they were acquired, compared to 2% PCR at Unilever. Seventh Generation showed Unilever how to begin to use more PCR in their packaging, and Wolf noted that today Unilever's packaging is more than 25% PCR, and they are committed to move to 100% PCR in their packaging. Wolf explained, "This is a public commitment that they have made – it appears that we have infected the host with our commitment to sustainability!"

The Cost Obstacle

As for all companies in the CPG industry, cost is still a compelling challenge for Seventh Generation. However, Wolf emphasized that a company has many levers to pull to be able to get their product on the shelf at a given cost target. For instance, he noted that Seventh Generation's material costs tend to be higher due to the lack of established capital infrastructure for many biobased chemicals, but notes that there are ways of adjusting packaging and distribution and working with retail customers to enable their products to be on the shelf at a competitive target price. He also conceded that Seventh Generation is not a value brand, and the company recognizes that they will never be the lowest price point for chemical cleaners on the shelf. They recognize that consumers expect a range of prices and an equivalent range performance, and they recognize that they will be on the shelf at a higher price than non-renewable chemicals. However, Wolf noted, it is Seventh Generation's commitment that their products will also perform as a premium-priced product and will be priced comparably to other premium products. For instance, Seventh Generation's laundry cleaner seeks to be comparable to Tide in price and performance and is not going to compete with more economical brands like Arm and Hammer. The same goes for dishwashing liquid, which is priced at the same level as Palmolive and Dawn, two higher priced products. Seventh Generation is also working with retailers to discover other ways to lower costs. For example, they are working with dollar stores and mass merchandizers to ensure their products arrive on the shelf at a lower total cost, using a variety of levers to do so, always recognizing the consumers' expectations and where the product fits on the spectrum of price and performance.

Market research has shown that some consumers are willing to pay a small premium for a sustainable product— ten to fifteen percent. Not all consumers are willing to do so, but if they are skeptical about the performance of a "green" product and they try it and discover it is comparable to a premium brand, then the added benefit of being biobased may be a deciding factor in favor of the "green" product. But it can be tough to get consumers over this first hurdle. Wolf described an analysis from one study that showed the likelihood consumers would buy Seventh Generation brand products based solely on marketing was six to ten percent. If they had heard of the Seventh Generation brand but not of the Seventh Generation mission, that likelihood rose to twenty to thirty percent. However, once consumers knew both the Seventh Generation brand AND their mission, the purchase intent jumped to nearly fifty percent. The more consumers learned, the more willing they were to switch to a sustainable brand.

Sustainable Products: Not Just a Passing Fad

The marketing team at Seventh Generation is seeing consumers' preferences moving towards sustainable products as more than just a passing trend in the cleaning products and personal care sectors. Consumers are increasingly aware of the need to use biobased products and products that use safer chemistries and are free from toxicants. The growth of biobased cleaning products is much faster than non-renewable products in the same category. This is a trend that has not been lost on competitors. Wolf noted that more chemical companies such as Dupont, Dow, and BASF have all made a commitment to becoming more sustainable and recognize that increasing their offerings of biobased materials is a shift that must be made. Wolf explained that there is increasing pressure on petrochemical energy suppliers to cut back due to the decline in demand for global energy, which will result in increasing constraints on petrochemical feedstocks and a general shift towards biobased materials.

Challenges Ahead

While the outlook for the biobased products industry is positive, there are still challenges to overcome. Wolf noted that, at some point, the issue of land use conversion, particularly relative to greenhouse gas emissions, deforestation, and food versus feedstock concerns, may come to a head as the use of starches and carbohydrates as feedstocks competes with the ability of nations to feed people. Further, Wolf said the industry may be impacted by concerns about deforestation in Malaysia, Brazil, and Indonesia, which is driven by poor government oversight over cheap, underutilized land that they are seeking to put to productive use.

There are also major cultural challenges needed in many executive suites. Companies must hear from their executive suite that sustainability, human health, and the environment are at least as important as financial performance. This is essential, as people who work in research and development and the supply chain are highly cost focused in the CPG industry.

Looking to the Future

Wolf emphasized that Seventh Generation is staying focused on sustainability, health, and equity—their original mission. Wolf noted that some focuses this year are creating more sustainable packaging, dealing with plastics to make them less harmful to the environment, and improving the functional ingredients in their products. While Seventh Generation may not be a big enough player on their own that they can make an enormous difference in the market, Wolf hopes that by working with Unilever to also pursue this journey, change will come. Wolf believes that Unilever is large enough to drive suppliers to produce new biobased materials.

In all, Wolf believes that Seventh Generation, working with Unilever, will be able to influence the market, saying, “We have a very rigorous material standard, and require our suppliers to meet that standard, either with a new ingredient or with modification of an existing ingredient. Our company prides itself on always being at the front of the pack when it comes to setting cleaning product sustainability standards, and on bringing the entire industry along through efforts with the Sustainability Consortium, the Ellen MacArthur Foundation, the UN Environmental Program, the American Cleaning Institute, and other forward-thinking organizations.”

5.6 HempWood: An Old Building Material Made New Again

Hemp is a versatile material that has been used in construction and building materials for centuries. It can be formed into fibrous panels, coverings, sheets, and bricks to be used in many aspects of construction. Hemp has been found in the mortar of bridges constructed in the sixth century in the area now known as France, and it is believed the Romans used hemp fiber to reinforce structural mortar. As the desire for more sustainable building materials grows, hemp is becoming a workable substitute, and it has been proven to exhibit thermoacoustic and sustainable qualities.[104]

Hemp was made illegal by many nations, who imposed legal barriers to prohibit the use of hemp as a building material. This is because of its misunderstood relationship with marijuana. While hemp and marijuana do belong to the same species (*Cannabis sativa*), they stand as separate classifications with differing assets. Marijuana has higher percentages, up to twenty percent, of tetrahydrocannabinol (THC), the primary psychoactive substance in marijuana, which is found primarily in the plant's flower. Industrial hemp is produced for its seeds, fibers, and stem, and is made up of no more than 0.3% THC.

For almost a century the U.S. made industrial hemp illegal until an amendment to the 2014 version of the Farm Bill changed all of that by allowing the growth of industrial hemp by state-run research programs.[105] Since then, an increasing number of states have begun allowing larger scale industrial hemp facilities to begin operations.

Greg Wilson founded HempWood® using his experience working for a bamboo flooring company. In a 2020 interview with COOL HUNTING®, an independent publication that focuses on innovations and intersections in design, culture, and technology, Wilson noted that he began researching the viability of using hemp as a raw material while working for a materials company in China that focused on bamboo. His team's research went unused for years until after the 2014 Farm Bill legalized the research and development of hemp technologies.[106]

Wilson created HempWood and its parent company Fibonacci, LLC, with the vision of creating a brighter future for our planet and stimulating American manufacturing by introducing sustainable building materials with a negative carbon footprint.[107] In his interview with COOL HUNTING®, Wilson said, "Hemp checks all of those boxes. It is eco-friendly; it grows really, really fast while pulling carbon out of the air."[108]

[104]Building Designers Association of Australia. (2023). *Hemp Concrete: The Past, Present and Future of Construction.* https://bdaa.com.au/hemp-concrete-the-past-present-and-future-of-construction/#:~:text=Hemp%20is%20also%20a%20classic,fiber%20to%20reinforce%20structural%20mortar.

[105]O'Connell, Kit. (2023, May 16). *2018 Farm Bill Could Fully Legalize Industrial Hemp in USA*. Ministry of Hemp. https://ministryofhemp.com/2018-farm-bill/

[106]Graver, David. (2020, October 21). *Interview: HempWood Founder Greg Wilson*. Cool Hunting®. https://coolhunting.com/design/interview-hempwood-founder-greg-wilson/

[107]Fibonacci, LLC. (2020). *HempWood: About the Company*. https://hempwood.com/about-the-company/

[108]Graver, David. (2020, October 21). *Interview: HempWood Founder Greg Wilson*. Cool Hunting®. https://coolhunting.com/design/interview-hempwood-founder-greg-wilson/

Headquarters

After an exhaustive search for the right location for its headquarters, HempWood decided on a brand new 16,500 sq. ft. pilot plant in Murray, Kentucky. The state and local officials were incredibly supportive of their endeavor and were eager to see the economic benefits that the new facility would bring to the area.[109] The local mayor of Murray stated that "This product is innovative, sustainable and should have good prospects for growth. We are proud to have them in our area."[110]

Wilson detailed the reasoning for establishing HempWood in Western Kentucky in his interview with COOL HUNTING®. He noted that, historically, more than eighty percent of the U.S. hemp was grown in Kentucky before hemp was regulated, which inspired him to bring the industry back to the area.[111] Two years later, HempWood built a second factory in Murray, KY and currently employs 22 people.

In addition to setting up manufacturing facilities in Murray, HempWood partnered with Murray State University to conduct research on hemp and materials engineering, focusing on sustainable innovations. As a company, HempWood is committed to producing building materials that have a positive impact on the environment and local communities.

What is HempWood?

HempWood transforms hemp fibers and protein-based bonding agents using a patented process, biomimicry to create a workable wood substitute for anything solid oak can be used for.[112]

The process of creating HempWood Organic Flooring starts in the field. All hemp is sourced within one hundred miles of the factory from local Kentucky farmers. After the hemp is collected, a plant-based adhesive is used to bind full-length fiber hemp stalks. After the hemp stalks and plant-based adhesive are combined, the material is compressed and baked to form HempWood Blocks, and then veneers are cut for the top layer of the engineered flooring.[113]

Next, the HempWood veneer is adhered to Purebond® Plywood, an ethically sourced plywood that uses soy adhesives from Columbia Forest Products, and a tongue and groove profile is cut into the flooring. The boards are then sanded, finished, and surveyed for any defects. HempWood's quality control team hand-checks each board and to ensure that the flooring upholds their standards of hardness, durability, and beauty.[114]

HempWood Flooring also recently won a Top 10 green building products prize from BuildingGreen. BuildingGreen's editorial

[109] Fibonacci, LLC. (2020). *HempWood: About HempWood*. https://hempwood.com/about-hemp-wood/

[110] ttps://www.lanereport.com/116395/2019/08/fibonacci-cuts-ribbon-on-5-8m-25-job-hempwood-manufacturing-plant-in-calloway-county/#:~:text=Company%20leaders%20selected%20Murray%20because,Agricultural%20Hemp%20the%20same%20month.

[111] Graver, David. (2020, October 21). *Interview: HempWood Founder Greg Wilson*. Cool Hunting®. https://coolhunting.com/design/interview-hempwood-founder-greg-wilson/

[112] Fibonacci, LLC. (2020). *HempWood: About HempWood*. https://hempwood.com/about-hemp-wood/

[113] Fibonacci, LLC. (2020). *HempWood® Organic Flooring*. https://hempwood.com/flooring/

[114] Fibonacci, LLC. (2020). *HempWood® Organic Flooring*. https://hempwood.com/flooring/

team hand-selects the Top 10 products, highlighting those that significantly improve upon "business-as-usual" practices to transform the building industry. HempWood was selected as a winner because of their innovative use of industrial hemp, which grows quickly, sequesters carbon, requires no fertilizer and little water, fixes nitrogen in the soil, and can replace more polluting and/or slower-growing materials such as cotton or wood.[115]

Organic Growth

Wilson noted that he prefers to avoid venture capitalist funding, instead relying on his own money and funding from friends and family to grow organically. HempWood continues to expand its product line, using lumber panels to produce furniture and cabinetry. It is also working with Oregon State University to produce plastic with sawdust. Wilson noted that their product's biggest competitors are OSB (Oriented Strand Board) and LVL (Laminated Veneer Lumber), which are made from inexpensive materials such as wood chips combined with isocynites and waxes. Wilson contends that, while sustainable construction is a trending topic, the reality is that many big construction companies still forgo making sustainable changes, instead continuing the path of the lowest cost and the highest profit. Wilson noted that, despite some government agencies supplying support for sustainable products, the commercial market still prefers using the cheapest material, unless there is a specific request otherwise.

Wilson emphasized that the most difficult part about running HempWood has been that the market is still very new. A major hurdle, according to Wilson, is public perception of hemp, with many people associating it with marijuana or CBD products rather than seeing it as a legitimate agricultural crop. Despite this hurdle, HempWood has thrived under Wilson's direction. "We have doubled every year reaching $1.5M last year, our fourth year."

[115]BuildingGreen, Inc. (2023). *BuildingGreen Announces Top 10 Products for 2023*. https://www.buildinggreen.com/product-review/buildinggreen-announces-top-10-products-2023

5.7 Braskem: The Pursuit of Green Plastics

Braskem is the largest polyolefins producer in the Americas and the world's leading biobased polymer producer. The company is doing well, partnering with a number of different known global brands to enable greater use of its biobased polymers. Braskem's I'm green™ polyethylene (PE) is a biobased polymer made from sugarcane ethanol, a renewable and sustainable resource produced from Brazilian sugarcane. I'm green™ PE retains the same properties, performance, and application versatility of fossil fuel-derived PE, making it an ideal drop-in substitute for conventional oil-based PE.

Cultivation of sugarcane used in the production of I'm green™ PE captures carbon dioxide (CO_2) and releases oxygen (O_2), which means Braskem’s biobased plastic has a negative carbon footprint. From a cradle-to-gate life-cycle perspective, every ton of I’m green™ PE used in the production of packaging equates to 3.09 tons of CO_2 captured from the atmosphere, in addition to reducing the use of petroleum.[116]

Braskem has made a commitment to become carbon neutral by 2050, in part through expanded development of the I’m green™ portfolio. To date, around 200,000 tons of biopolymers per year are produced in Brazil which expanded to 260,000 tons in 2023. In 2030, this amount is expected to increase to one million tons.[117]

In January 2023, the company announced a project to evaluate an investment in producing carbon-negative biobased polypropylene (PP) in the U.S. The project would use Braskem's proven, proprietary technology to convert bioethanol into physically segregated biobased PP. Braskem is exploring partnership opportunities for this project with several clients, brand owners, and suppliers.[118] When Braskem made this project public, brand owners, OEMs, and PP processors began asking more about green PP. This is a long-term project for Braskem that is currently in the scoping phase and is projected to move toward delivery in 2027.

In a press release, Mark Nikolich, Braskem America CEO, explained, “We are actively evaluating a project to produce the world's first biobased PP on an industrial scale to deliver tangible solutions to our clients […]. This new U.S.-based project would not only serve a growing market for sustainable solutions but also reduce Braskem's reliance on fossil feedstock. Expanding our portfolio to include biobased PP supports Braskem's goal of 1MM tons of biopolymers capacity by 2030 and becoming carbon neutral by 2050.”[119]

[116]Braskem. (2020, November 10). *Braskem Affirms Commitment to Circular Economy and to Achieve Carbon Neutrality by 2050*. https://www.braskem.com/usa/news-detail/braskem-affirms-commitment-to-circular-economy-and-to-achieve-carbon-neutrality-by-2050

[117]Braskem. (2022, October 21). *Braskem Invests in Capacity Expansion and Partnerships for the Production of Biobased Plastics*. https://www.braskem.com.br/usa/news-detail/braskem-invests-in-capacity-expansion-and-partnerships-for-the-production-of-biobased-plastics

[118]Braskem. (2023, January 17). *Braskem Announces Project to Evaluate Production of Biobased Polypropylene*. https://www.braskem.com.br/usa/news-detail/braskem-announces-project-to-evaluate-production-of-bio-based-polypropylene

[119]Braskem. (2023, January 17). *Braskem Announces Project to Evaluate Production of Biobased Polypropylene*. https://www.braskem.com.br/usa/news-detail/braskem-announces-project-to-evaluate-production-of-bio-based-polypropylene

The U.S. is home to the largest ethanol industry production in the world and has ample technology, infrastructure, and supply availability for a project in the polymers' value chain. Braskem's biobased PP would be a drop-in solution that has the same technical properties and recyclability found today in Braskem's current PP portfolio, with the added benefit of a negative carbon footprint. As the largest PP producer in the Americas and using its proven technology at an industrial scale, Braskem's biobased PP would be a first-of-its-kind solution to address brand owners' and OEMs' transition to a more sustainable future.[120]

The authors interviewed Gustavo Lombardi and Stacy Torpey in Braskem's North American headquarters based in Philadelphia and learned more about the exciting push for Braskem to grow its biobased polymers presence. Braskem has a goal to reach one million metric tons of biobased polymers by expanding its production globally. Lombardi noted that this goal is driven not by the need to simply reach one million metric tons, but to prove to the industry, and all users of biobased polymers, that biobased content in the chemical industry is a helpful solution for multiple polymers, not just one.

Braskem is also dedicated to circularity, which, combined with renewable biobased polymer content, can become a fully sustainable value chain.

Domestic biobased ethanol is very established in the United States, and fifty-five percent of all biobased ethanol used is produced here in the USA, making it a very sustainable industry. Most of the focus in the past has been on biobased fuel, but instead of simply burning it in cars, Braskem is looking to make it fully recyclable by using it to produce PP, thus investing in the future. Instead of capturing CO_2 through photosynthesis to be released later when burned as fuel, it will be encapsulated in a stable form.

Braskem has its origins in Brazil, where it pioneered the production of biobased polymers using sugarcane. Lombardi explained that there is no difference in the process when using corn-based ethanol here in the U.S. The quality of ethanol is the key variable, and since it is a commoditized market for fuel production, it is readily available. When talking with potential suppliers of ethanol and showing them the required specifications, Lombardi said suppliers see right away they can meet those requirements. Lombardi added that Braskem is focused on responsible manufacturing, using local suppliers with access to the right corn, which is all about a sustainable supply chain.

Green PE has taken off in Asia and Europe; Lombardi noted that Braskem has been running at full capacity and sold out of green PE in these markets over the past four years. Lombardi added that in the past five years, Braskem has seen the traction for green PP grow significantly, even here in the U.S.

[120]Braskem. (2023, January 17). *Braskem Announces Project to Evaluate Production of Biobased Polypropylene*. https://www.braskem.com.br/usa/news-detail/braskem-announces-project-to-evaluate-production-of-bio-based-polypropylene

More U.S. industry customers are contacting Braskem for information, and, Lombardi noted, the government also supports biobased plastic as a good environmental solution.

Lombardi noted that it is important to be careful with definitions. Biodegradable, compostable, and recyclable are different circular economy references. Green PP and green PE are recyclable, but not biodegradable. The two pillars of the Braskem solution are that their products are produced from renewable content, and they are one hundred percent segregated and fully recyclable. Moving forward, it will be important to set up PP recycling systems that can mimic systems for recycling of high-density PE, which comes with its own challenges. However, industry participants understand that there is value and consumer demand for switching to green products, that evolving technology is making such a switch possible, and that this is a goal to be achieved. Therefore, industry participants are motivated to make PP as efficient as high-density PE.

Today Braskem's product portfolio serves home care, personal care, food and beverage packaging, personal hygiene, automotive, and compounding industries. They provide a complete portfolio with technical solutions that are recyclable. Lombardi noted that, over time, the companies that want to scale and reduce their carbon footprint and de-fossil their products are growing. This will involve using a biobased, one hundred percent segregated product without losing the functional properties of fossil-based plastic. Lombardi explained that customers often do not want to change the color of their package or slow down their production rates, so Braskem's solution must be a drop-in at the same price. Lombardi added that these companies have public commitments on carbon neutrality to achieve a certain percent lower carbon footprint and reduce carbon content, and that is where Braskem can help them achieve those goals.

The last three years have seen a major uptick in U.S. demand for green polymer plastics. Lombardi noted that European industries want a perfect solution that does not exist. Conversely, Lombardi explained that U.S. industries want to understand Braskem's concepts and ability, the risks and processes involved, and the value proposition. Braskem educates people with facts rather than convinces them to make a sale. Because of this approach, Lombardi believes the American public is gradually understanding the technical solutions for managing waste, plastic, and biobased content, as well as the circularity argument. Lombardi added that the USDA Certified Biobased Product label is helping Braskem to make this case and is having an impact.

Braskem also has projects to reuse plastic waste through advanced recycling. Plans are to connect green PP by following the flow in the value stream of waste to work towards advanced recycling. For Braskem, reducing their carbon footprint is all about reducing waste and moving to circularity by capturing CO_2 and reducing their waste streams.

Scope 3 emissions are another important part of Braskem's value chain. The team is very diligent in working with suppliers to ensure it is the right corn and the right ethanol. An LCA is conducted to capture all data, and this is passed on to partners to ensure transparency, so they know what the scope three emissions are upstream.

5.8 The Biomimicry Institute: The Role of Biomimicry in the Textile Industry

No material has zero environmental impact, and the textile industry is notorious for not being environmentally responsible. Harvesting the raw materials needed to produce biobased fabric can contribute to deforestation and increased carbon footprints. Conversely, synthetic fibers make up the bulk of cheap clothes and have revolutionized our wardrobes, but they have come at a cost: oil byproducts are unsustainable, take vast amounts of toxic chemicals and fresh water to produce, and are not biodegradable. What would the textile (and greater materials) industry look like if it truly functioned as an ecosystem?

In an interview Beth Rattner, Executive Director of the Biomimicry Institute and contributor to the report the Nature of Fashion, discussed the current state of the textile industry and ways that existing textile ecosystems can be altered to reduce pollution as well as boost biodiversity, build soil, and support communities. [121]

The Nature of Fashion report examines the current state of the textile industry and explores how the industry could become more sustainable through adopting nature's lessons. The current textile system is tied to fossil-fuel based energy and materials at every step in a textile product's lifecycle, from raw materials to consumption and disposal. First, according to the report, about sixty percent of fibers used to create textiles are derived from petroleum-based chemicals and are processed using fossil-fuel based energy. Next, current consumer habits mean that textile products are typically disposed of at the end of their lifecycle, resulting in synthetic fibers becoming waste that accumulates in soil, air, and water as pollution. Finally, the current fashion system lacks the means to recover and reuse materials due to the use of blended fibers. Composting and thermal energy recovery are rare exceptions that can return materials to basic building blocks; however, they cannot guarantee the full breakdown of hazardous textile chemistries into innocuous forms.[122]

The Nature of Fashion report argues that there is no alternative to the phasing out of non-compostable materials like polyester, and next-generation fibers. Further, the report notes that while recyclable textile fibers may be considered a practical way to replacing traditional materials, they should not be developed as they have no feasible decomposition pathways for end-of-life.[123]

The Transition To 100% Biocompatible Fibers: Primary Production

Even though synthetic, petroleum-based fibers dominate the textile industry, naturally occurring polymers make up thirty-eight percent of global fiber production, primarily in the form of cotton and manufactured cellulosic fibers. Based on research by the Biomimicry Institute, experts believe that the industry can both meet global apparel needs—including desired performance characteristics—and readily transition to one hundred percent compostable fibers from three sources:

[121]Biomimicry Institute. (2020, June 30). *The Nature of Fashion: Why It's Time to Leave Petroleum Behind*. https://biomimicry.org/the-nature-of-fashion-why-its-time-to-leave-petroleum-behind/

[122]Ibid.

[123]Ibid.

naturally occurring fibers, next-gen cellulosic feedstocks, and fermentation products. Making such a shift will require collaboration with industry partners.[124] The goal is not to incentivize further deforestation or global mono-cropping, but to circulate existing materials. Additionally, consumption patterns must change to transition to a more sustainable textile industry; even if textiles are designed to be biodegradable and decomposition pathways are designed, overconsumption is still a problem.

As discussed in the Nature of Fashion report, the Biomimicry institute believes that the future of sustainable fashion lies in establishing a circular fashion economy in which materials are kept in use as long as possible to slow their release into the environment. In this future system, diverse feedstocks, including fiber crops combined with compatible materials made via fermentation and powered by renewable energy, would replace petroleum-based fibers. The industry would use biobased and recyclable materials to create textiles. Reuse, remanufacturing, and recycling would be helped by an improved recovery infrastructure. This would allow scalable decomposition and return all textiles to their basic building blocks.[125]

In our interview with Beth Rattner and Lauren Bright from the Biomimicry Institute, we learned a lot about how this effort will require a multi-stakeholder initiative. Rattner noted that accountability is key to their efforts. Rattner believes that the fashion industry needs to be asking what they are going to do with all the materials that have been generated. These materials cannot simply be burned or sent to a landfill anymore, as the impacts of those actions are accumulating. Instead, Rattner believes the solution will be for the fashion industry to consider how they can start using the current amount of clothing waste as the next generation of feedstocks, not only in a non-depletive manner, but also in a restorative and resilient manner.

Lauren Bright has worked for many years in the textile industry with several apparel and footwear brands and is exploring new ways of applying these concepts to chemistry, materials, and products. She noted that the Nature of Fashion report provides a model to understand how the fashion system *could work* and requires individuals to explore how much people and anthropogenic systems are involved to make this new reality possible. Additionally, Bright explained that the report was the basis for a series of global pilots as proof points for a new, biomimetic system.

One of the pilots, in partnership with Yale's Center for Green Chemistry and other industry leaders, is exploring the environmental fate of materials. The pilot will guide the industry on how to interpret the concepts of biodegradation science, persistence, and toxicity as it relates to both chemistry and materials, shedding light on how they can become food for an ecosystem. But this means understanding the implications of end-of-life product strategies. The goal is to utilize different types of testing, both at the micro and macro level, to accurately interpret how toxicity and biodegradation potential are affected in relation to a product's chemical structure, then feed those conclusions back

[124]Ibid.

[125]Ibid.

to industry formulators, material developers, and the like to inform a more holistic understanding of material life cycles.

More pilot proof points, contextualized to the Global North and Global South, are about recognizing that most textiles (in the current state) do not make their way back into a technological system and end up polluting the environment. Most fibers and fiber blends used in present-day textiles do not fit the criteria for “small loop recycling,” and even the brands that are at the forefront of change in material and product design are in the first stages of this transition. This means we must begin this effort at the beginning of the product creation process. While some companies are now investing in “design for circularity,” which involves design principles that affect product materialization and assortment, many are still not making products that can be reclaimed through the narrow pathways that exist for textile recycling and remanufacturing. Chemical recycling technologies are being commercialized around cotton, polyester, and cotton-polyester blends, but this makes it difficult to achieve the complex coordination needed to collect and sort clothing through this channel. There is currently not sufficient infrastructure to accommodate the local reclamation of textile waste in the Global North, even accounting for a good amount of waste that is being pushed into the markets of the Global South.

The goal of Biomimicry Institute is to understand the new pathways that can connect different technologies through industrial ecology and transform textile waste into non-toxic and biocompatible end products. For instance, one line of research is to push mixed textile waste into a myco-remediation process, using fungi that produce enzymes, which break down the material into value added outputs. This is easy for cotton, but fungi need to be trained to consume biologically incompatible (or evolutionarily “recent”) polymers, such as polyester(s). This will require more work going forward.

The path forward will require notable change in industry, municipalities, and the systems in which textiles flow through global markets. The Biomimicry Institute has laid out this pathway, which begins with 1) investing in local cycles, 2) building restorative and regenerative textile systems, 3) reducing overconsumption, and 4) incentivizing the creation of new biocompatible materials. The long-term vision may look like the intercropping of food and fiber systems to buoy security for both industries and using bacteria to create silk-like fibers. In either case, these creative, local, and climate-focused solutions that respect our planet’s ecological carrying capacity will require the adaptability and resiliency of all humankind.

5.9 AllBirds: The Evolution of Footwear

Allbirds was founded in 2016, by Tim Brown, a former New Zealand soccer player, and Joey Zwillinger, an engineer and renewables expert. Together, the two created their first wool fabric made specifically for footwear and launched a style called the "Wool Runner" shown below.

Evolution of a Low Carbon Company

In discussing the evolution of Allbirds with Aileen Lerch, Senior Manager of Sustainability, it is clear that Allbirds has been on a mission to produce footwear made with naturally sourced materials from its origins. Following the Wool Runner, Allbirds began exploring other natural materials that could be used in the footwear industry. Zwillinger, coming from the biofuels industry, began exploring the variety of biobased materials that were available. The company moved forward with an increasing focus on sustainability and reducing emissions intertwined with the use of natural materials.

Historically, about fifty-seven percent of footwear and sixty-four percent of apparel is made from synthetic materials, which are in turn produced from petroleum-derived plastics. While synthetic fabrics were not widely used in apparel until the 1980s, they have accelerated in use, along with increased negative impacts on waste, biodiversity, and more.[126]

From the beginning, the Allbirds team has been focused on replacing petroleum-based synthetic materials whenever possible. A defining moment came in 2018, when a partnership with Braskem led to the development of a resin made from sugarcane, as part of the I'm green™ brand.[127] The sugarcane-based midsole, which Allbirds calls SweetFoam™, provides increased comfort, flexibility, lightness, and resilience, while meeting the need for a sustainable renewable material.

Allbirds is also a certified B corporation. The company's sustainability practices include producing shoes with a low carbon footprint; using natural, renewable raw materials; using recycled materials when possible; using minimal and recycled packing and shipping materials; and investing in carbon offsetting projects. In 2021, the company went public.

[126]Allbirds (2023). Sustainable Practices: Renewable Materials. Allbirds. https://www.allbirds.com/pages/renewable-materials

[127]Braskem. (2018, August 1). *Braskem Launches New Renewable Resin in Allbirds Shoes*. https://www.braskem.com.br/news-detail/braskem-launches-new-renewable-resin-in-allbirds-shoes

Biobased Materials

Allbirds has gone on to use other sustainable materials as well. The Plant Pacer shoe uses a plastic-free alternative leather upper, called Plant Leather, and the Canvas Pacer has an organic cotton or organic cotton/recycled polyester upper, depending on the color. The Plant Leather is made by Natural Fiber Welding (they call the material MIRUM™), a startup out of Peoria, IL that received early venture backing from Allbirds, Ralph Lauren, and BMW Ventures. The Tree shoe collection has an upper made with TENCEL Lyocell, which has a cooling effect by wicking away moisture. TENCEL is a manufactured tree-based fiber, mainly sourced from eucalyptus. On June 27, 2023, Allbirds also revealed the historic M0.0NSHOT shoe, which has a landmark net 0.0 kg CO_2 equivalent carbon footprint, compared to a standard sneaker that has about 14 kg CO_2 equivalents. Going a step further, Allbirds has shared their detailed methodology in the hope of pushing the industry as a whole toward being more sustainable.[128] The shoe will be made available commercially in 2024.

Most of Allbirds' original line focused on casual shoes, and the company has also created active shoes, including jogging and running shoes, which leverage similar materials. A new training shoe has an outsole made with natural rubber and uses the other previous materials for the midsole.

For the M0.0NSHOT project, Allbirds company is not just focused on using biobased materials, but they also consider the entire life cycle of the shoe. In addition to the SuperLight Foam midsole that has seventy percent biobased content, the company uses carbon-negative biobased plastic trim for the M0.0NSHOT shoe. This biobased plastic is made from microorganisms that convert methane into a polymer that can be molded like plastics, but without the corresponding carbon footprint. Even the packaging has been designed with the net zero carbon goal in mind. The carbon-efficient packaging, which reduces the space and weight needed for transport, is produced with sugarcane-derived, carbon-negative, Green PE. Finally, even green logistics is part of the journey; Allbirds uses carbon-conscious transportation featuring biofuel powered ocean shipping and electric trucking from port to warehouse.[129]

Decarbonizing the Supply Chain

The company is also focused on activities that occur far up the supply chain, including agriculture. For instance, modern agricultural practices such as the use of fertilizers, pesticides, and tilling are notorious for stripping carbon from the soil. Today, the industrialization of the agriculture industry has led to it becoming responsible for about twenty-five percent of global greenhouse gas emissions. For all these reasons, Allbirds embraces regenerative agriculture as an opportunity to reverse climate change. Additionally, Allbirds believes using regenerative agriculture techniques provides added benefits to local communities, biodiversity, ecology, and long-term viability of the land. Allbirds is working with their Merino wool supply chain to increase the supply of

[128]Allbirds. (2023, June 27). *M0.0NSHOT: The World's First Net Zero Carbon Shoe*. https://www.allbirds.com/pages/moonshot-zero-carbon-shoes

[129]Allbirds. (2023, June 27). *M0.0NSHOT: The World's First Net Zero Carbon Shoe*. https://www.allbirds.com/pages/moonshot-zero-carbon-shoes

regenerative wool, while also creating innovative financing models to incentivize them to use their land to store carbon.[130]

The Allbirds M0.0NSHOT project is a push to examine every aspect of its supply chain for sustainable opportunities, including using biobased materials for the shoe itself, using green biobased PE for packaging, using renewable electricity to power the manufacturing of finished goods, and working with its partner GoodShipping to decarbonize ocean shipping emissions. Allbirds is also keen to share their knowledge and spread the word. They have open-sourced their Carbon Footprint Life Cycle Assessment tool to the rest of the footwear and apparel industry.[131] They produce an annual "Flight Status" report, Allbirds' version of a sustainability report, which documents its annual carbon reductions per unit. The 2022 Flight Status report indicates Allbirds' average product carbon footprint was 7.12 kg CO_2 equivalents in 2022, compared to the industry average of 14 kg CO_2 equivalents.[132] Allbirds' goal is to cut that in half by 2025, and then approach zero by 2030.

[130]Allbirds. (2022). *Regenerative Agriculture*. https://www.allbirds.com/pages/regenerative-agriculture
[131]Allbirds. (2022). *Carbon Footprint Calculator*. https://www.allbirds.com/pages/carbon-footprint-calculator
[132]Allbirds. (2022). *Allbirds 2022 Flight Status*. https://www.allbirds.com/pages/sustainable-practices

6 Recommendations

6.1 Overview

The recommendations presented in this section are those of the authors and are not to be interpreted as recommendations from the USDA. The recommendations are based on the multiple years of research and outreach undertaken by the authors and aided by interviews with industry and government officials engaged with the Biobased Products industry.

6.2 Recommendation #1: Measuring the Bioeconomy

The authors have recommended the U.S. government develop annual measurements of the biobased products industry multiple times. Specifically, we have called for the development of NAICS codes[133] for the biobased products industry similar to what exists for the rest of the domestic economy. Despite numerous overtures to the U.S. Department of Commerce by USDA and industry, the outreach to carry out Congressional directives regarding NAICS codes was repeatedly rebuffed.

Executive Order 14081 was issued on September 12, 2022, and entitled, "Advancing biotechnology and biomanufacturing innovation for a sustainable, safe, and secure American bioeconomy.[134] The EO directed the U.S. Bureau of Economic Analysis (BEA) to assess "the feasibility, scope, and costs of developing a national measurement of the economic contributions of the bioeconomy."

The conclusions of the BEA as stated in their report completed in just 180 days stated, "*Developing a bioeconomy satellite account using a broad, comprehensive definition of the bioeconomy appears to be technically feasible and would correspond to similar efforts by the EU and other international organizations. However, developing a consistent, ongoing bioeconomy satellite account broken down along the lines of specific areas of the bioeconomy, such as biotechnology, is likely infeasible at this time due to both a lack of existing data on which to base such an account and a lack of a general consensus on practical definitions. While it is not uncommon for BEA to develop practical definitions suitable for economic measurement as part of developing a satellite account, the conclusion of this report is that even if an operational definition could be developed, there is a dearth of reliable, timely, and consistent source data needed to produce an official bioeconomy satellite account that focuses on specific areas of interest. Given how widespread and prolific bioeconomy activity is throughout the U.S. economy, ranging from agriculture to manufacturing to software, it seems unlikely that government data alone will be the answer to the source data issue. Especially with regard to new innovations and products, such as consumer products like genetic testing*

[133] NAICS Association. (nd). *Search for Codes by Industry.* NAICS Association. https://www.naics.com/search-naics-codes-by-industry/

[134] Executive Order 14081, 3 C.F.R. Page 25711-25715 (2022).

services and lab-grown meats, source data would likely need to come from private sector reports or data sources that currently do not exist on a comprehensive scale. In addition to specialized data, identifying where new, emerging activity is occurring across all industry sectors in the economy would likely require significant, ongoing help from external experts to achieve."[135]

We strongly recommend that Congress and/or the Administration direct the USDA take the lead in coordination with the Department of Commerce to organize a Technical Advisory Council in some form that goes beyond prior work of a single agency to include technical experts from industry, academia, government and NGOs to develop a pathway for the Federal Government to develop the tracking of the economic impacts of the U.S. biobased products industry.

6.3 Recommendation #2: Carbon Intensity Label

Companies around the country are rapidly deploying a variety of low carbon labels that, at best, are confusing the U.S. consumer and, at worst, could be misleading and lacking technical validity.

Recently, the IRA directed and appropriated funding to the EPA to develop Environmental Product Declarations (EPDs) and Ecolabels for building and construction materials to support and promote those products that provide low carbon alternatives.[136] To achieve this, the Agency received $41.5 billion in appropriated funds and is expected to receive an additional $11.7 billion in future revenue from reinstating the Superfund Tax on oil and gas production.

It is the collective recommendation of the authors, without input from the USDA, that the 118th Congress of the United States in conjunction with the 2023 reauthorization of the Farm Bill should explore how best to align the leadership of the BioPreferred Program with the recent emergence of both the climate-smart commodities partnership and industry's rapid commitment and transition to a net-zero carbon economy.

The authors believe that the USDA should be both authorized by Congress with funds appropriated in-line with EPA's $50+ Million to take the leadership role to develop consensus on an approach for the standardization of a technical approach for a national carbon intensity label.

However, time is of the essence if both the American farmer and industry can realize the benefits as opposed to facing a multitude of often unregulated and divergent labels.

[135]Highfall, T. & Chambers, M. (2023). *Developing a National Measure of the Economic Contributions of the Bioeconomy.* U.S. Department of Commerce. https://www.bea.gov/system/files/papers/bea-bioeconomy-report.pdf

[136]Inflation Reduction Act of 2022, H.R. 5376, 117th Congress, (2022). https://www.congress.gov/117/plaws/publ169/PLAW-117publ169.pdf

Appendix A: IMPLAN and the Economic Input-Output Model

The Economic Input-Output Model

IMPLAN is an economic impact modeling system that uses input-output analysis to quantify economic activities of an industry in a predefined region. IMPLAN was designed in 1976 by the Minnesota IMPLAN Group, Inc. under the direction of the U.S. Forest Service to help meet the reporting requirements for the Forest Service's land management programs. Currently, IMPLAN is used extensively to quantify the economic impacts of various industrial activities and policies. The IMPLAN system is managed by IMPLAN Group LLC of Huntersville, North Carolina.

IMPLAN quantifies the economic impacts or contributions of a predefined region in terms of dollars added to the economy and jobs produced (IMPLAN Group LLC 2004).[137] Data are obtained from various government sources, including agencies and bureaus within the Departments of Agriculture, Commerce, and Labor.

Currently, the IMPLAN system's input-output model defines 536 unique sectors in the U.S. economy, which are North American Industry Classification System [NAICS] sectors with the exception of some cases in which aggregates of multiple sectors are used. The IMPLAN system's database is used to model inter-sector linkages, such as sales and purchases between forest-based industries and other businesses. The transactions table quantifies how many dollars each sector makes (processes to sell) and uses (purchases). The table separates processing sectors by rows, and it separates purchasing sectors by columns; every sector is considered to be both a processor and a purchaser. Summing each row quantifies an industry's output, which includes sales to other production sectors and those to final demand. The total outlay of inputs, which are the sums of the columns, includes purchases from intermediate local production sectors, purchases from local value added, and imports (both intermediate and value added inputs) from outside the study region. Using the transactions table, a sector's economic relationships can be explained by the value of the commodities exchanged between the industry of interest and other sectors.

Leontief (1936) defined the relationship between output and final demand as shown in Eq. 1:

$$x = (I - A)^{-1} y \qquad (1)$$

where x is the column vector of industrial output, I is an identity (unit) matrix, A is the direct requirements matrix that relates input to output on a per dollar of column vector. The term $(I - A)^{-1}$ is the total requirements matrix or the "multiplier" matrix. Each element of the matrix describes the amount needed from sector i (row) as input to produce one unit of output in

[137] IMPLAN, Computer Software, IMPLAN, IMPLAN Group LLC, http://www.implan.com.

sector j (column) to satisfy final demand. The output multiplier for sector j is the sum of its column elements, i.e., sector j's total requirements from each individual sector i. Employment and value added multipliers also are derived by summing the respective column elements.[138]

Employment in IMPLAN is represented as the number of both full-time and part-time jobs within an industry that are created to meet final demand. Value added is composed of labor income, which includes employees' compensation and sole proprietor (self-employed) income, other property type income (OPI), and indirect business taxes (IMPLAN refers to value added in this context as "total value added"). OPI in IMPLAN includes corporate profits, capital consumption allowance, payments for rent, dividends, royalties, and interest income. Indirect business taxes primarily consist of sales and excise taxes paid by individuals to businesses through normal operations. Output is the sum of value added plus the cost of buying goods and services to produce the product.

Key terms:

- Value added: Value added describes the new wealth generated within a sector and is its contribution to the Gross Domestic Product (GDP).
- Output: Output is an industry's gross sales, which includes sales to other sectors (where the output is used by that sector as input) and sales to final demand.

When examining the economic contributions of an industry, IMPLAN generates four types of indicators:

1. Direct effects: effects of all sales (dollars or employment) generated by a sector.
2. Indirect effects: effects of all sales by the supply chain for the industry being studied.
3. Induced effects: Changes in dollars or employment within the study region that represent the influence of the value chain employees spending wages in other sectors to buy services and goods.
4. Total effect: the sum of the direct, indirect, and induced effects.

Economic multipliers quantify the spillover effects, i.e., the indirect and induced contributions. The Type I multiplier describes the indirect effect, which is described by dividing the sum of the direct and indirect effects by the direct effect.[139] For example, a Type I employment multiplier of 2.00 means that one additional person is employed in that sector's supply chain for every employee in the industry of interest.

Type II multipliers are defined as the sum of the direct, indirect, and induced effects divided by the direct effect. Type II multipliers differ by how they define value added and account for any of its potential endogenous components. A particular Type II multiplier, the Type SAM multiplier, considers portions of value added to be both endogenous and exogenous to a study region. These multipliers indicate the extent to which activity is generated in the economy due to the

[138]Horowitz, K. J. & Planting, M. A. (2006) (Ed. 2009). *Concepts and Methods of the U.S. Input-Output Accounts*. U.S. Department of Commerce. http://www.bea.gov/index.php/system/files/papers/WP2006-6.pdf.
[139]U.S. Department of Commerce Bureau of Economic Analysis (BEA), Interactive Data Application, BEA website, http://www.bea.gov/itable/index.cfm, accessed April 2015.

sectors being studied. For example, a Type SAM value added multiplier of 1.50 indicates that $0.50 of additional value added would be generated elsewhere in the economy by other industries for every $1.00 of value added produced in the industry being studied.

Contributions Analyses of Biobased Products Sectors

A contributions analysis describes the economic effects of an existing sector, or group of sectors, within an economy. The results define the extent to which the economy is influenced by the sector(s) of interest. Changes in final demand, which generally are marginal or incremental in nature, are not included here as they were in the traditional impact analysis. Based on the number of sectors within each industry group, multiple sector contributions analyses were conducted using IMPLAN's National model. The model was constructed using the Supply/Demand Pooling Trade Flows method, with the multiplier specifications set to "households only." Output was used as the basis for assessing the contributions, but it had to be adjusted to discount internal sales and purchases to the sectors in order to avoid double counting. This required the following four steps using IMPLAN and Microsoft Excel: 1) compile the matrix of detailed Type SAM output multipliers for the groups' sectors; 2) invert the matrix; 3) obtain the direct contributions vector by multiplying the inverted contributions matrix by the groups' sector outputs in IMPLAN's study area data; and 4) build "industry change" activities and events within IMPLAN's input-output model using the values from the calculated direct contributions vector at a local purchase percentage of 100%. Using this method avoided the structural changes that resulted from the customization of the model, and it simultaneously preserved the original relationships in the modeled economy's transactions table.

$$\frac{Direct\ Effect + Indirect\ Effect + Induced\ Effect}{Direct\ Effect} = Type\ SAM\ Multiplier$$

Appendix B: BioPreferred Program Product Categories - 2023

Designated for Preferred Federal Procurement	Eligible for USDA Certified Biobased Product Label	**Category**
✓	✓	2-Cycle Engine Oils
✓	✓	Adhesive and Mastic Removers
✓	✓	Adhesives
✓	✓	Agricultural Spray Adjuvants
✓	✓	Air Fresheners and Deodorizers
✓	✓	Aircraft Cleaners
	✓	Allergy and Sinus Relievers
	✓	Animal Bedding and Litter
✓	✓	Animal Cleaning Products
✓	✓	Animal Habitat Care Products
	✓	Animal Medical Care Products
✓	✓	Animal Repellents
	✓	Animal Skin, Hair, and Insect Care Products
	✓	Anti-Slip Products
	✓	Anti-Spatter Products
	✓	Aromatherapy
	✓	Art Supplies
✓	✓	Asphalt and Tar Removers
✓	✓	Asphalt Restorers
	✓	Asphalt Roofing Materials: Low Slope
✓	✓	Automotive Care Products
	✓	Automotive Tires
	✓	Baby and Kids
	✓	Baby and Kids - Diapers
	✓	Baby and Kids - Oral Care Products
	✓	Baby and Kids - Durable Tableware and Cutlery
	✓	Baby and Kids - Lotions, Moisturizers, and Oils
	✓	Baby and Kids - Sun Care Products
	✓	Baby and Kids - Bath Products

	✓	Baby and Kids - Dishwashing Products
	✓	Baby and Kids - Baby Wipes
	✓	Baby and Kids - Surface and Toy Cleaners
	✓	Baby and Kids - Laundry Products
	✓	Barrier Fluid
✓	✓	Bath Products
✓	✓	Bathroom and Spa Cleaners
✓	✓	Bedding, Bed Linens, and Towels
	✓	Biodegradable Foams
✓	✓	Bioremediation Materials
✓	✓	Blast Media
✓	✓	Boat Cleaners
	✓	Body Powders
✓	✓	Candles and Wax Melts
✓	✓	Carpet and Upholstery Cleaners - General Purpose
✓	✓	Carpet and Upholstery Cleaners - Spot Removers
✓	✓	Carpets
✓	✓	Chain and Cable Lubricants
✓	✓	Cleaning Tools
	✓	Clothing
	✓	Clothing - Utility Gloves
✓	✓	Composite Panels - Acoustical
✓	✓	Composite Panels - Countertops and Solid Surface Products
✓	✓	Composite Panels - Interior Panels
✓	✓	Composite Panels - Plastic Lumber
✓	✓	Composite Panels - Structural Interior Panels
✓	✓	Composite Panels - Structural Wall Panels
✓	✓	Compost Activators and Accelerators
✓	✓	Concrete and Asphalt Cleaners
✓	✓	Concrete and Asphalt Release Fluids
✓	✓	Concrete Curing Agents
✓	✓	Concrete Repair Materials - Concrete Levelling
✓	✓	Concrete Repair Materials - Concrete Patching
✓	✓	Corrosion Preventatives
	✓	Cosmetics
	✓	Cosmetic Tools and Applicators
✓	✓	Cuts, Burns, and Abrasions Ointments
✓	✓	De-Icers

✓	✓	Deodorants
	✓	Desk Accessories and Workspace Organizers
✓	✓	Dethatchers
✓	✓	Diesel Fuel Additives
✓	✓	Dishwashing Products
	✓	Disinfectants
✓	✓	Disposable Containers
✓	✓	Disposable Cutlery
✓	✓	Disposable Tableware
✓	✓	Durable Cutlery
✓	✓	Durable Tableware
✓	✓	Dust Suppressants
✓	✓	Electronic Components Cleaners
✓	✓	Engine Crankcase Oil
✓	✓	Epoxy Systems
✓	✓	Erosion Control Materials
✓	✓	Expanded Polystyrene (EPS) Foam Recycling Products
✓	✓	Exterior Paints and Coatings
	✓	Eyewear
	✓	Fabric Dyes
	✓	Fabric Stain Preventers and Protectors
✓	✓	Facial Care Products
✓	✓	Feminine Care Products
✓	✓	Fertilizers
✓	✓	Films - Non-Durable
✓	✓	Films - Semi-Durable
	✓	Filters
	✓	Fingernail/Cuticle Products
✓	✓	Fire Logs and Fire Starters
	✓	Fire Retardants
✓	✓	Firearm Cleaners, Lubricants, and Protectants
✓	✓	Floor Cleaners and Protectors
✓	✓	Floor Coverings (Non-Carpet)
	✓	Floor Finishes and Waxes
✓	✓	Floor Strippers
✓	✓	Fluid-Filled Transformers - Synthetic Ester-Based
✓	✓	Fluid-Filled Transformers - Vegetable Oil-Based
✓	✓	Folders and Filing Products

✓	✓	Foliar Sprays
✓	✓	Food Cleaners
✓	✓	Foot Care Products
	✓	Footwear
✓	✓	Forming Lubricants
✓	✓	Fuel Conditioners
	✓	Furnace Filters
✓	✓	Furniture Cleaners and Protectors
✓	✓	Gardening Supplies and Accessories
✓	✓	Gasoline Fuel Additives
✓	✓	Gear Lubricants
✓	✓	General Purpose Household Cleaners
✓	✓	Glass Cleaners
✓	✓	Graffiti and Grease Removers
✓	✓	Greases
✓	✓	Greases - Food Grade
✓	✓	Greases - Multipurpose
✓	✓	Greases - Rail Track
✓	✓	Greases - Truck
	✓	Greases - Wheel Bearing and Chassis Greases
✓	✓	Hair Care Products - Conditioners
✓	✓	Hair Care Products - Shampoos
	✓	Hair Removal - Depilatory Products
	✓	Hair Styling Products
✓	✓	Hand Cleaners and Sanitizers - Hand Cleaners
✓	✓	Hand Cleaners and Sanitizers - Hand Sanitizers
	✓	Heat Transfer Fluid - Additive
✓	✓	Heat Transfer Fluids
✓	✓	Heating Fuels and Wick Lamps
✓	✓	Hydraulic Fluids - Mobile Equipment
✓	✓	Hydraulic Fluids - Stationary Equipment
✓	✓	Industrial Cleaners
	✓	Industrial Enamel Coatings
✓	✓	Ink Removers and Cleaners
✓	✓	Inks - News
✓	✓	Inks - Printer Toner (Greater Than 25 Pages Per Minute)
✓	✓	Inks - Printer Toner (Less Than 25 Pages Per Minute)
✓	✓	Inks - Sheetfed (Black)

✓	✓	Inks - Sheetfed (Color)
✓	✓	Inks - Specialty
	✓	Insulation - Other
✓	✓	Interior Paints and Coatings - Latex and Waterborne Alkyd
✓	✓	Interior Paints and Coatings - Oil-based and Solventborne Alkyd
	✓	Interior Paints and Coatings - Other
	✓	Interior Wall and Ceiling Patch
✓	✓	Intermediates - Binders
✓	✓	Intermediates - Chemicals
✓	✓	Intermediates - Cleaner Components
✓	✓	Intermediates - Fibers and Fabrics
✓	✓	Intermediates - Foams
✓	✓	Intermediates - Lubricant Components
✓	✓	Intermediates - Oils, Fats, and Waxes
✓	✓	Intermediates - Paint & Coating Components
✓	✓	Intermediates - Personal Care Product Components
✓	✓	Intermediates - Plastic Resins
✓	✓	Intermediates - Rubber Materials
✓	✓	Intermediates - Textile Processing Materials
	✓	Jewellery
✓	✓	Kitchenware and Accessories
	✓	Laboratory Chemicals
✓	✓	Laundry Products - General Purpose
✓	✓	Laundry Products - Dryer Sheets
✓	✓	Laundry Products - Pretreatment/Spot Removers
	✓	Lavatory Flushing Fluid
✓	✓	Leather, Vinyl, and Rubber Care Products
✓	✓	Lip Care Products
	✓	Lithographic Offset Inks (Heatset)
	✓	Loose-Fill and Batt Insulation
✓	✓	Lotions and Moisturizers
	✓	Lumber, Millwork, Underlayment, Engineered Wood Products
	✓	Masonry and Paving Systems
	✓	Massage Oils
	✓	Mattresses, Mattress Toppers, and Pillows
	✓	Medical Supplies

✓	✓	Metal Cleaners and Corrosion Removers - Corrosion Removers
✓	✓	Metal Cleaners and Corrosion Removers - Other Metal Cleaners
✓	✓	Metal Cleaners and Corrosion Removers - Stainless Steel
✓	✓	Metalworking Fluids - General Purpose Soluble, Semi-Synthetic, and Synthetic Oils
✓	✓	Metalworking Fluids - High Performance Soluble, Semi-Synthetic, and Synthetic Oils
✓	✓	Metalworking Fluids - Straight Oils
✓	✓	Microbial Cleaning Products - Drain Maintenance Products
✓	✓	Microbial Cleaning Products - General Cleaners
✓	✓	Microbial Cleaning Products - Wastewater Maintenance Products
✓	✓	Mulch and Compost Materials
✓	✓	Multipurpose Cleaners
✓	✓	Multipurpose Lubricants
	✓	Oral Care Products
	✓	Oral Care Products - Toothpaste and Mouthwash
	✓	Oral Care Products - Oral Care Tools
	✓	Other
	✓	Other Dyes
✓	✓	Other Lubricants
✓	✓	Oven and Grill Cleaners
✓	✓	Packing and Insulating Materials
✓	✓	Paint Removers
	✓	Paper Products - Non-writing paper
	✓	Paper Products - Office Paper
✓	✓	Parts Wash Solutions
✓	✓	Penetrating Lubricants
	✓	Perfume
	✓	Personal Accessories
	✓	Personal Protective Equipment - Gloves
	✓	Pest Control-Fungal-Agricultural
	✓	Pest Control-Fungal-Home and Garden
	✓	Pest Control-Insect-Agricultural
	✓	Pest Control-Insect-Home and Garden

	✓	Pest Control-Insect-Industrial
	✓	Pest Control-Insect-Personal
	✓	Pest Control-Other
	✓	Pest Control-Weeds-Agricultural
	✓	Pest Control-Weeds-Home and Garden
	✓	pH Neutralizing Products
✓	✓	Phase Change Materials
	✓	Plant Washes
	✓	Plastic Cards (Wallet-sized)
✓	✓	Plastic Insulating Foam for Residential and Commercial Construction
	✓	Plastic Products
✓	✓	Playground and Athletic Surface Materials
✓	✓	Pneumatic Equipment Lubricants
	✓	Polyurethane Coatings
✓	✓	Powder Coatings
	✓	Power Steering Fluids
	✓	Printing Chemicals
✓	✓	Product Packaging
✓	✓	Roof Coatings
	✓	Rope and Twine
✓	✓	Rugs and Floor Mats
	✓	Safety Equipment
	✓	Sanitary Tissues
✓	✓	Shaving Products
	✓	Shipping Pallets
✓	✓	Shopping and Trash Bags
✓	✓	Slide Way Lubricants
✓	✓	Soil Amendments
	✓	Solid Fuel Additives
✓	✓	Sorbents
✓	✓	Specialty Precision Cleaners and Solvents
	✓	Stone and Granite Cleaners
✓	✓	Sun Care Products
✓	✓	Surface Guards, Molding, and Trim
✓	✓	Thermal Shipping Containers - Durable
✓	✓	Thermal Shipping Containers - Non-Durable
✓	✓	Topical Pain Relief Products
✓	✓	Toys and Sporting Gear

✓	✓	Traffic and Zone Marking Paints
	✓	Trash Cans & Waste Receptacles
✓	✓	Transmission Fluids
✓	✓	Turbine Drip Oils
	✓	Wall Base
✓	✓	Wall Coverings
✓	✓	Wastewater Systems Coatings
	✓	Water Capture and Reuse
✓	✓	Water and Wastewater Treatment Chemicals
✓	✓	Water Tank Coatings
✓	✓	Water Turbine Bearing Oils
	✓	Window Coverings - Blinds
	✓	Window Coverings - Drapery
	✓	Wipes - Multipurpose
	✓	Wipes - Disinfecting
	✓	Wipes - Skin
✓	✓	Wood and Concrete Sealers - Membrane Concrete Sealers
✓	✓	Wood and Concrete Sealers - Penetrating Liquids
✓	✓	Wood and Concrete Stains
	✓	Woven Fiber Products
	✓	Writing Utensils - Pens