Rural Development
U.S. DEPARTMENT OF AGRICULTURE

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

Together, America Prospers

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- Okabashi Brands, Inc.
- PepsiCo
- Sealed Air Corporation
- United Soybean Board
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About the Authors

Jesse Daystar, Ph.D.
Contact: Jesse.Daystar@duke.edu

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. 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.

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 wrote a book chapter on life cycle assessment. Beyond publishing research, 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, 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.

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

Dr. Rob Handfield is the Bank of America University Distinguished Professor of Supply Chain Management at North Carolina State University, and also serves as Executive Director of the Supply Chain Resource Cooperative (http://scm.ncsu.edu). He is Faculty Lead for the Manufacturing Analytics group within the International Institute of Analytics and is on the Faculty for Operations Research Curriculum at NC State University. 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.

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" (Prentice Hall, 1999, 25,000 copies sold, and translated into Chinese, Japanese, and Korean). He has co-authored textbooks for MBA and undergraduate courses, including Purchasing and Supply Chain Management 6th Edition (with Robert Monczka) and Operations and Supply Chain Management 3rd Edition (with Cecil Bozarth). He recently led a global study on "Emerging Procurement Technology: Data Analytics and Cognitive Analytics for CAPS Research," "Procurement Analytics for IBM," "Global Logistics Trends and Strategies" for BVL International (2013), and a report titled "Future Buy: The Future of Procurement," published by KPMG International.

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

Jay S. Golden, Ph.D.
Contact: Jay.GoldenPhD@gmail.com

Dr. Jay Golden is the Pontarelli Professor of Environmental Sustainability and Finance in the Maxwell School at Syracuse University. Prior to joining Syracuse, Golden served as faculty chair of the Business and Environment Program and Director of the Center for Sustainability and Commerce at Duke University. He also served in executive leadership positions at East Carolina University and Wichita State University. His research covers sustainable systems and production consumption systems of the earth's resources using systems and lifecycle modeling.

Dr. Golden is regularly called upon by corporations and governments to provide guidance on organizational, policy and technological approaches to sustainability. Golden received his Ph.D. in Sustainable 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 Institute for Management and Leadership in Education (MLE) from Harvard, and has a B.A. degree in Management.

Eric McConnell, Ph.D.
Contact: temc@latech.edu

Dr. Eric McConnell is an Assistant Professor of Agricultural Sciences and Forestry in the School of Agricultural Sciences & Forestry at Louisiana Tech University. He received his B.S. in Forest Management from Louisiana Tech University, and he received his master's and Ph.D. degrees from Mississippi State University in Forest Products and Forest Resources, respectively.

McConnell's research has focused on input-output modeling of the forest products industry, timber and lumber price trends, and production forestry clientele typologies. His Extension program provides information to clientele and stakeholders regarding wood technology, wood products sustainability criteria, economic impacts, and industrial trends. McConnell's professional service includes contributing to the Forest Products Society, the Society of American Foresters, and the Society of Wood Science and Technology.

Janire Pascual-Gonzalez, Ph.D.
Contact: pascualj17@ecu.edu

Dr. Janire Pascual-Gonzalez received her undergraduate degree in Chemical Engineering and her master's degree in Chemical Engineering and Processes in 2011 from the Universitat Rovira i Virgili of Tarragona (Spain). In 2015, she received her Ph.D. in Chemical, Environmental, and Processes Engineering at Universitat Rovira i Virgili of Tarragona (Spain). Since September 2017, Pascual-Gonzalez has been a postdoctoral scholar in the Division of Research, Economic Development, and Engagement at East Carolina University (ECU). Her research focuses on the development of systematic methods to assess and optimize consumption production systems from a sustainable perspective.

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Executive Summary

This report was prepared for the USDA BioPreferred® Program. The conclusions and recommendations are those of the authors and have not been endorsed by USDA. The report is part of a series of reports tracking the impact of the biobased product industry on the U.S. economy including the October 2014 USDA report, *Why Biobased? Opportunities in the Emerging Bioeconomy*;[1] the June 2015 USDA report, *An Economic Impact Analysis of the U.S. Biobased Products Industry,*[2] the October 2016 report, *An Economic Impact Analysis of the U.S. Biobased Products Industry: 2016 Update,*[3] and the July 2019 report, *An Economic Impact Analysis of the U.S. Biobased Products Industry: 2018 Update*.[4] 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;
- **ii.** The value of the 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 and economic obstacles and recommending how those obstacles can be overcome.

Although there have been several other studies on the contribution of the biobased products sector to the global and European economies, this series seeks to examine and quantify the effect of the U.S. biobased products industry from economic, job, and environmental perspectives, and this report provides an important update to past reports. The report is intended to provide a snapshot of available information and a platform upon which to build future efforts as more structured reporting and tracking mechanisms may be developed. This report is focused on biobased products and, as such, does not focus on biobased fuels or other energy sources except when analyzing co-products.

As detailed in this report, we used a similar, proven methodology to past reports that took a three-pronged approach to gathering information on the biobased products sector. The authors interviewed 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. We collected statistics from government agencies and published literature on biobased products, economics, and jobs; and we conducted extensive economic modeling using IMPLAN modeling software—developed by the USDA 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. In turn, these 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.

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[1] Golden, J.S. and Handfield, R.B., "Why Biobased? Opportunities in the Emerging Bioeconomy," USDA BioPreferred® Program website, accessed April 2019, 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.

This report also includes further analysis of the value of U.S. biobased product exports. Exports make important contributions to the Gross Domestic Product (GDP) providing a valuable market channel to support our farmers and growers in the agricultural community. The economic impacts of biobased exports were determined using export data from IBIS World and the IMPLAN economic model. An embedded summary of export growth is reported for each of the seven major sectors discussed next.

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

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

This report specifically excludes the energy, livestock, food, feed, and pharmaceuticals sectors. These sectors are also excluded from participation in the BioPreferred® Program. According to the National Academies of Sciences, the bioeconomy accounted for 5.1 percent of the U.S. gross domestic product in 2016, equating $959.2 billion dollars.[5]

The next three figures show the major findings of this report. As summarized in Figure 1, the total contribution of the biobased products industry to the U.S. economy in 2017 was $470 billion, employing 4.6 million workers. It was estimated that each job in the biobased industry supported 1.79 jobs in other sectors of the economy.

Figure 2 shows these numbers in more detail. The 1.65 million direct jobs supporting the biobased industry supported 2.96 million spillover jobs, including both indirect and induced jobs. Similarly, the $162 billion in direct value added had a spillover value added of $309 billion.

Figure 1: U.S. Biobased Products Industry Key Findings in 2017.

The Number of People Employed	→	Value Added Contribution to the U.S. Economy	→	The Jobs Multiplier
4.6 Million		**$470 Billion**		**2.79**
In the U.S. Biobased Products Industry in 2017		from the U.S. Biobased Products Industry in 2017		For every 1 Biobased Products industry job, 1.79 additional jobs are supported in the United States

[5] National Academies of Sciences, Engineering, and Medicine. "Safeguarding the Bioeconomy." Washington, DC: The National Academies Press, 2020. https://doi.org/10.17226/25525.

Figure 2: Total Employment and Value Added to the U.S. Economy from the Biobased Products Industry in 2017.

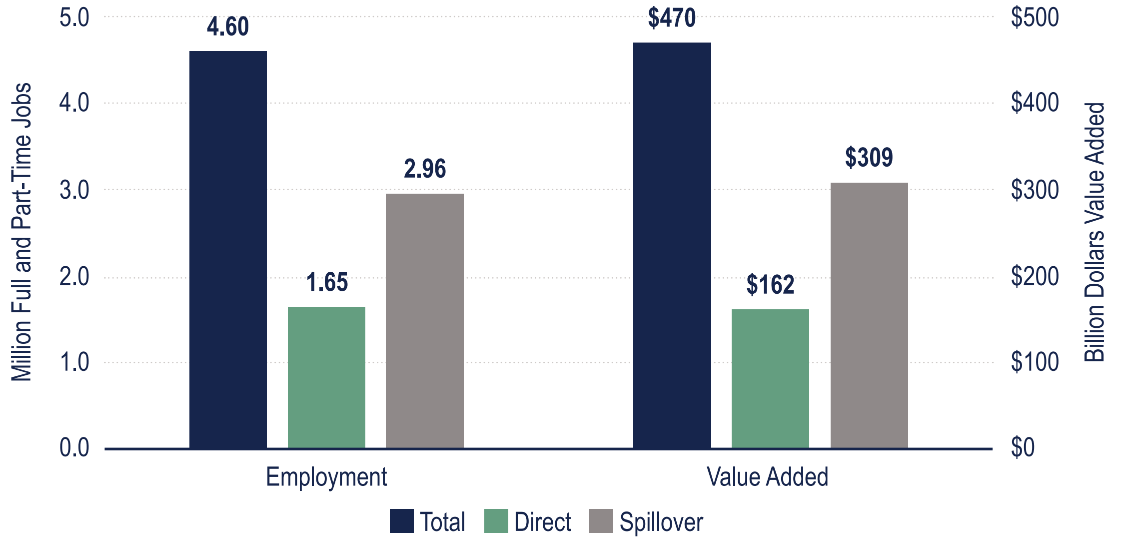
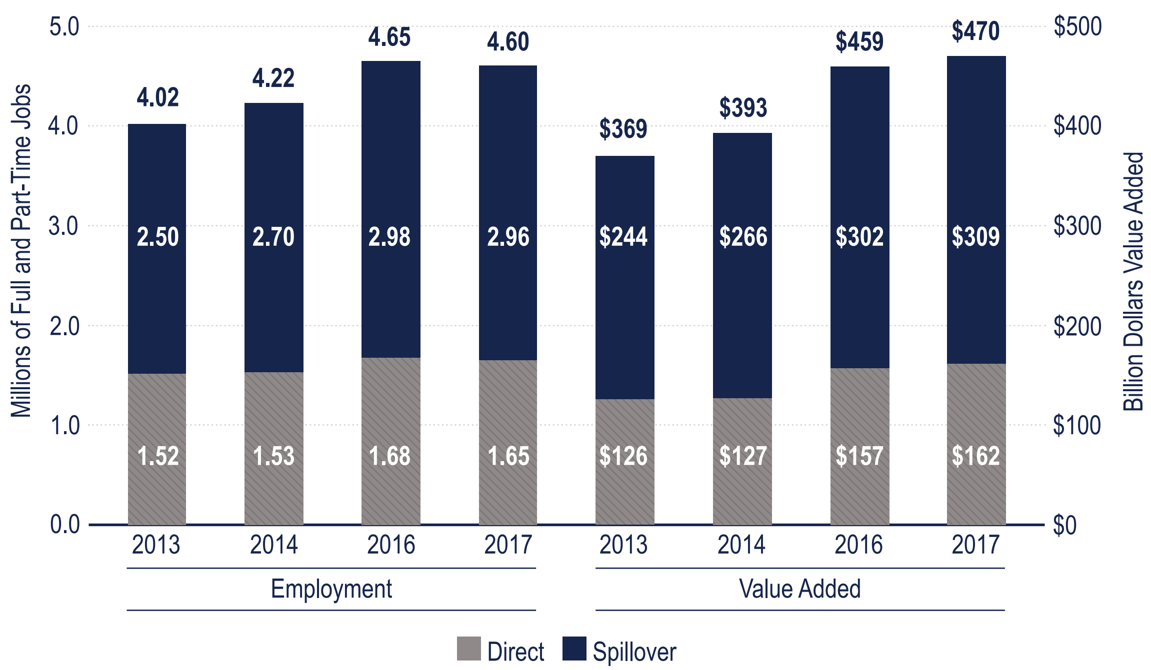


Figure 3 shows the value added to the U.S. economy by biobased products was $470 billion in 2017, up from $459 billion in 2016. This is an increase of $10.9 billion, or a 2.4 percent increase over 2016 levels, and compares favorably with the National Research Council's estimate of $353 billion for 2012. This growth was due in part to the growth of the national economy and the growth of the GDP, but it also suggests that biobased products are a healthy and growing industry.

Contributing to this is the increasing use of biobased materials in several sectors, as consumers are growing more cognizant of the need to use sustainable materials. Figure 3 also shows that employment in the industry decreased slightly from 4.65 million jobs in 2016 to 4.6 million in 2017.

Figure 3: Economic Impacts of Biobased Products Industry in 2013, 2014, 2016, and 2017.



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

i. The quantity of biobased products

While there is no database that tracks the "quantity of biobased products sold," the USDA BioPreferred® Program has identified about 20,000 biobased products. The actual number of biobased products is likely dramatically higher than the number in the BioPreferred® Program's database as there is no requirement that all biobased products be listed in the BioPreferred® Program's database. In terms of jobs created and value added, the forest products segment alone more than doubles the estimates for the remainder of the biobased products sector, which is not well represented in the BioPreferred® Program's database due to the original exclusion of forest products from the program. Thus, 40,000 would be a conservative estimate of the total number of existing biobased products. Sufficient data are not available to estimate the total number of individual "units" of biobased products sold. However, the total value added from direct sales of biobased products was estimated to be in $127 billion 2014 and $162 billion in 2017, suggesting that both the sales and number of biobased products is increasing.

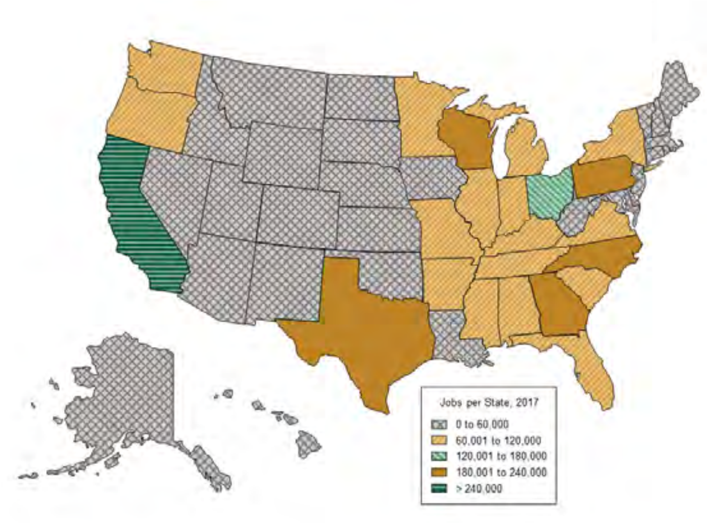
ii. The value of the biobased products

As Figure 3 shows, the value added to the U.S. economy by biobased products was $470 billion in 2017. This includes $162 billion in direct value added and $309 billion spillover value added (direct value added plus induced value added). As mentioned earlier, this is a 2.4 percent increase over the 2016 levels reported in the previous report.

iii. The quantity of jobs contributed

As shown in Figures 1, 2, and 3, the biobased products industry employed more than 4.6 million people in the United States in 2017. This included more than 1.65 million jobs directly in the biobased products industry and 2.96 million spillover jobs (direct jobs plus induced jobs). Figure 4 shows the estimated geographic distribution of these jobs at the state level, based on the distribution of jobs in 2017.

Figure 4: Jobs supported by the Biobased Products Industry by State. Note: Higher numbers reflect a greater number of jobs in the biobased products industry at the state level relative to the U.S. average. For more information, see Section 2.



iv. The quantity of petroleum displaced

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 this petroleum displacement by a biobased material is the use of natural fibers in packing and insulating materials as an alternative to synthetic foams, such as Styrofoam. In this report, we updated the oil displacement values from the 2018 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.

v. Other environmental benefits

While only limited lifecycle analyses 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 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 percent reduction, the analysis indicates that up to 12.7 million metric tons of CO_2 equivalents may have been reduced in 2017. A 60 percent reduction is a conservative estimate based on the emissions reductions potential from the biobased chemicals and biorefining sectors. 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.

vi. The economic impact of biobased exports

Biobased products made in the United States are consumed both domestically and internationally. The economic contribution of biobased product exports calculated using the IMPLAN economic model and industry export data from IBIS World are estimated at 569,000 jobs and $59 billion in value added. The magnitude of these impacts illustrates the importance of biobased products trade to the U.S. economy and to the rural economies that grow the agriculture inputs for the biobased products industry.

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.

Two events with potentially important implications for biobased products occurred in 2018-2019. The 2018 U.S. Farm Bill (Agriculture Improvement Act of 2018) signed by the president on December 20, 2018 legalized the industrial use of hemp (containing no more than 0.3 percent THC). The new bill allows hemp cultivation, where in the past, hemp was limited to pilot projects. Already there has been a significant increase in businesses developing a new generation of products and rural companies manufacturing hemp fibers for numerous products including prosthetics, flooring, construction materials, and apparel.

The second event was an industry led policy program. Smithfield Foods, the world's largest hog and pork producer, publicly announced it was going to implement a "manure-to-energy" project across 90 percent of its facilities. This program has the potential to create significant volumes of renewable biogas to produce biobased chemicals and other 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- and long-term opportunities to further advance the biobased products industry. These opportunities include creating production credits, increasing the visibility of the USDA BioPreferred® Program's USDA Certified Biobased Product label, and the expansion of other related USDA programs. Our key recommendations include the following for the consideration of USDA and other relevant public and private sector organizations:

- Modification of the North American Industry Classification System (NAICS) codes by the Office of Management & Budget (OMB) to include biobased products-specific codes for items such as biobased chemicals and plastics.
- As stated in prior reports, the authors still see the need to improve the ability of the Federal Government, including the GSA and other acquisition departments of Federal agencies, to track the purchase of biobased products in acquisition systems. Currently, it is difficult to accurately determine the use of biobased products by the Federal Government.
- Increase basic and applied research funding to universities for developing biobased feedstocks and products through the National Science Foundation (NSF), USDA, DoD, and the Department of Energy (DOE). This includes developing opportunities for overcoming economic disparities in the rural United States through the expansion of the biobased products industry.
- Increase opportunities for private sector and university collaboration through ongoing NSF, USDA, and DOE grants. Many of the biobased product innovations available today began in university laboratories, and supporting the source of these important developments is vitally important for increasing the growth of the industry.

- Leverage biobased product purchasing goals with the DOE and other Federal agencies. These recommendations all have a common theme of increasing collaboration between multiple industry partners, public sector organizations, academic institutions, consumer-marketing consultancies, and others. The goal is that by working together, the many challenges that exist in growing the biobased products industry can be addressed through alternative and innovative approaches that promote consumer awareness, utilize existing market and supply chain channels in different ways, and develop technologies that promote renewable resources in new and different markets.

As noted above, in addition to collecting data from published sources and government statistics, we interviewed organizations that employ forward-looking leaders in the biobased products industry to better understand the dynamics, drivers, and challenges to continued growth of the sector. The authors conducted interviews with the following organizations:

- Braskem S.A.
- Biodegradable Products Institute
- Biotechnology Innovation Organization
- Croda International, Plc.
- Ecovative Design, LLC
- Green Dot Bioplastics, Inc.
- Sysco Guest Supply, LLC
- Nanosystems, Inc.
- Okabashi Brands, Inc.
- PepsiCo
- Sealed Air Corporation
- United Soybean Board
- U.S. Department of Agriculture (USDA)
- U.S. Department of Labor, Bureau of Labor Statistics
- U.S. General Services Administration (GSA)

Based on those interviews, the report includes case studies on the development, manufacture, and use of biobased products with the following key innovative industrial partners:

- Braskem
- Biodegradable Products Institute
- Croda International, Plc.
- Ecovative Design, LLC
- Green Dot Bioplastics, Inc.
- Sysco Guest Supply, LLC
- Nanosystems, Inc.
- Okabashi Brands, Inc.
- PepsiCo
- Sealed Air Corporation

Glossary of Terms

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 and forestry materials; or
2. An intermediate ingredient or feedstock.

Biobased products industry: Any industry engaged in the processing and manufacturing of 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.

Bioenergy: Renewable energy made available from materials derived from biological sources. In its most narrow sense, it is a synonym for biofuel, which is fuel derived from biological sources. In its broader sense, it includes biomass, the biological material used as a biofuel, as well as the social, economic, scientific, and technical fields associated with using biological sources for energy.

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.[6]

Bioplastics: Plastics that are partially or fully biobased and/or biodegradable.

Biobased Bioplastic: A bioplastic that has some or all of its content produced from renewable biomass sources such as vegetable oil and corn starch. In contrast to conventional plastics made from petroleum-based products, the raw material for biobased plastics is biomass, which can be regenerated.

Biodegradable Plastic: Biobased 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 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. Cellulose is the most abundant organic compound on earth.[7]

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

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

Contribution analysis: The economic effect 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.

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.

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

[7] "The Biofuels Handbook", ed. J. G. Speight (London: RSC Publishing, 2011), 524.

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 that quantify the environmental impact of a sector of the economy.

Emissions: Gases and particles 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 comma between 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.

Forestry materials: Materials derived from the practice of forestry or the management of growing timber.[10]

IMPLAN: Originally developed by the USDA Forest Service and currently owned and operated by IMPLAN Group, LLC, Huntersville, N.C. 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.

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

Intermediate ingredient or feedstock: A material or compound that has undergone processing (including thermal, chemical, biological, or a significant amount of mechanical processing), excluding harvesting operations. It is subsequently used to make a more complex compound or product.[11]

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

Non-Renewable or Finite Resources: Raw materials, such as fossil fuels, that 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 USDA BioPreferred® Program's mandatory Federal purchasing initiative because it meets the definition and minimum biobased content criteria for one or more of the 109 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 rate similar to the rate at which it is used.

Sorghum: A drought-resistant genus of plants in the grass family. Sorghum serves as staple food in several dry and arid regions. It is also used as animal feed and in the production of alcoholic beverages and sweeteners. The high sugar content in sweet sorghum allows it to be fermented for the production of ethanol.

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

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[8] EPA "Air Pollution Emissions Overview," U.S. EPA, accessed June 2019, https://www3.epa.gov/airquality/emissns.html.

[9] International Energy Agency (IEA), "Glossary," *IEA*, accessed May 2019, https://www.iea.org/about/glossary/e/#tabs-2.

[10] U.S. Government Publishing Office (GPO) Electronic Code of Federal Regulations (e-CFR), Title 7 CFR part 3201.2, *e-CFR*, accessed June 2019, http://www.ecfr.gov/cgi-bin/text-idx?SID=c2eba5045067ce569f1d820d6d77b694&mc=true&node=se7.15.3201_12&rgn=div8.

[11] GPO Electronic Code of Federal Regulations (e-CFR), Title 7 CFR part 3201.2, e-CFR, accessed June 2019, https://www.ecfr.gov/cgi-bin/retrieveECFR?gp=391&SID=da89ee8f2dd6cf6bd65afa9d1253b84b&ty=HTML&h=L&n=pt7.15.3201.

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 USDA BioPreferred® Program's criteria to display the USDA Certified Biobased Product certification mark.

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 consists 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 The USDA BioPreferred® Program

Established by the Farm Security and Rural Investment Act of 2002 (2002 Farm Bill) and strengthened by the Food, Conservation, and Energy Act of 2008 (2008 Farm Bill), the Agriculture Act of 2014 (2014 Farm Bill), and the Agriculture Improvement Act of 2018 (2018 Farm Bill) the USDA BioPreferred® Program is charged with transforming the marketplace for biobased products and creating jobs in the rural parts of the United States. The program's mandatory Federal purchasing initiative and voluntary labeling initiative quickly have made it one of the most respected and trusted drivers in today's biobased marketplace. Visit www.biopreferred.gov for more information.

1.1.1 Strategic Goals

The mission of the BioPreferred® Program is to facilitate the development and expansion of markets for biobased products. To accomplish this mission, the program has two broad strategic goals: 1) to advance the biobased products market and, 2) to increase the purchase of biobased products government-wide. As of May 2019, there were more than 15,000 products in the BioPreferred® Program's catalog.

1.1.2 Mandatory Federal Purchasing

Private and public purchasers look to the USDA BioPreferred® Program to ensure their purchases are biobased. Beginning in 2005 with its first designations of six product categories, the program has now designated 139 product categories representing approximately 15,000 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 from all participating manufacturers, thereby encouraging manufacturers to compete to provide products with higher biobased content. With the Federal Government spending about $45 billion annually on goods and services,[12] there is an extraordinary opportunity to increase the sale and use of biobased products, as required by Federal law.

1.1.3 Voluntary Consumer Label

USDA introduced the BioPreferred® Program's voluntary labeling initiative to the consumer market in February 2011. To date, more than 3,500 products have been certified to display the USDA Certified Biobased Product label (shown in Figure 5) and the number of applications continues to increase. With a web-based application process, the USDA BioPreferred® Program makes it simple for manufacturers to apply for the label and track their applications. The program's partnership with ASTM International ensures quality control and consistent results, and offers purchasers of biobased products a universal standard to assess a product's biobased content.

Figure 5: Sample USDA Certified Biobased Product Label.

1.2 About this Report

The availability of data quantifying the biobased products sectors of the economy in the United States is limited. This is the latest in a series of reports that addresses the impact of the biobased products industry on the U.S. economy. The first report in 2015[13] examined the number of jobs supported in the United states, and the value added by the biobased products industry to the U.S. economy. The website for this report received more than 150,000

[12] "GSA Schedule Sale FY 2018 - Government Spending through GSA & VA Schedules," FEDSched, accessed May 2019. https://gsa.federalschedules.com/resources/gsa-schedule-sales-2018/.

[13] 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, accessed May 2019, https://www.biopreferred.gov/BPResources/files/EconomicReport_6_12_2015.pdf.

download requests. The second report in 2016[14] updated the data from the first report and was the first to quantify the effects of the U.S. biobased products industry on each of the 50 states and the District of Columbia. The third report was written in 2018[15] and provided a crucial third data point by which to see national trends in the biobased products industry. This report provides the second set of results at the state level, revealing the interaction between national trends and state level results.

In this report, the authors have updated the national data from previous reports and calculated the value added by exports for each sector of the biobased products industry at the state level. As was the case for the previous reports, we took a three-pronged approach to gathering information for this report. The authors interviewed a broad spectrum of representatives of government, industry, and trade associations involved in the biobased products industry so we could understand the challenges and future growth potential for biobased products. We collected statistics from government agencies and the published literature on biobased products, and we used IMPLAN modeling software developed by the USDA Forest Service to analyze and trace spending through 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 chemicals. To provide conservative estimates of the biobased products sectors, we consistently used lower percentages within the ranges we modeled, varying from 1 - 100 percent biobased, depending on the sector. These estimates were formed based on published literature and information gathered through interviews. Section 2.2 contains more information on this process.

This report is intended to serve as a platform for greater understanding and tracking the progress of the biobased products industry in the United States. It is highly recommended that USDA continue annual efforts to track the progress of the bioeconomy and to support efforts to standardize methodologies and practices to acquire specific biobased products industry economic and jobs data with partner government agencies such as the U.S. Department of Commerce. A good beginning would be to introduce biobased product industry-specific NAICS codes as mandated in the 2018 Farm Bill.

Section 2 defines and describes the seven sectors of the biobased products industry and the economic impact by sector, which provides data on economic activity, value added, jobs by sector, reports on the value added by exports in each sector, and discusses the potential for economic growth in the industry. There are case studies interspersed throughout this section, involving major private sector, public sector, and university initiatives driving the success and growth of the biobased products industry through innovation and technological breakthroughs. These case studies are important illustrations of how the biobased products industry is both a source of economic growth and represents a technological success story.

Section 3 discusses environmental benefits of the biobased products industry. Section 4 describes Federal biobased procurement policies, including the BioPreferred® Program, and how biobased products are tracked in Federal acquisition systems. Section 5 contains recommendations to grow the biobased products industry. Appendix A describes the economic modeling framework using IMPLAN.

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14 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, accessed May 2019, https://www.biopreferred.gov/BPResources/files/BiobasedProductsEconomicAnalysis2016.pdf.

15 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, accessed May 2019 https://www.biopreferred.gov/BPResources/files/BiobasedProductsEconomicAnalysis2018.pdf.

2 Economic Impact Analysis by Sector

2.1 Total U.S. Biobased Products Industry

In this section, we examine in detail the major sectors of the biobased products industry in the United States. For each sector, we discuss the raw materials, processing steps, intermediates, and products introduced into the economy. The data provided includes major U.S. and global firms, total value added to the U.S. economy in 2017, and the number of direct, indirect, and induced jobs supported by the sector in the United States. The distributions of economic value added and employment by subsector are also provided. Case studies and interviews with companies in the forefront of the biobased products industry are interspersed within this section.

Figure 6 shows the aggregate effect of the biobased products industry on employment and gross domestic product in the United States in 2017. The total contribution of the biobased products industry to the U.S. economy in 2017 was $470 billion, and the industry employed 4.6 million workers. Each job in the biobased products industry was responsible for supporting 1.79 jobs in other sectors of the economy. Figure 6 shows these numbers in more detail. The 1.65 million jobs directly supporting the biobased products industry resulted in 2.96 million spillover jobs, which includes indirect jobs in related industries and induced jobs produced from the purchase of goods and services generated by the direct and indirect jobs. Figure 7 compares the economic impact of the biobased products industry from 2013 to 2017.

Figure 6: Biobased Products Industry contributions to U.S. Employment and Value Added in 2017.

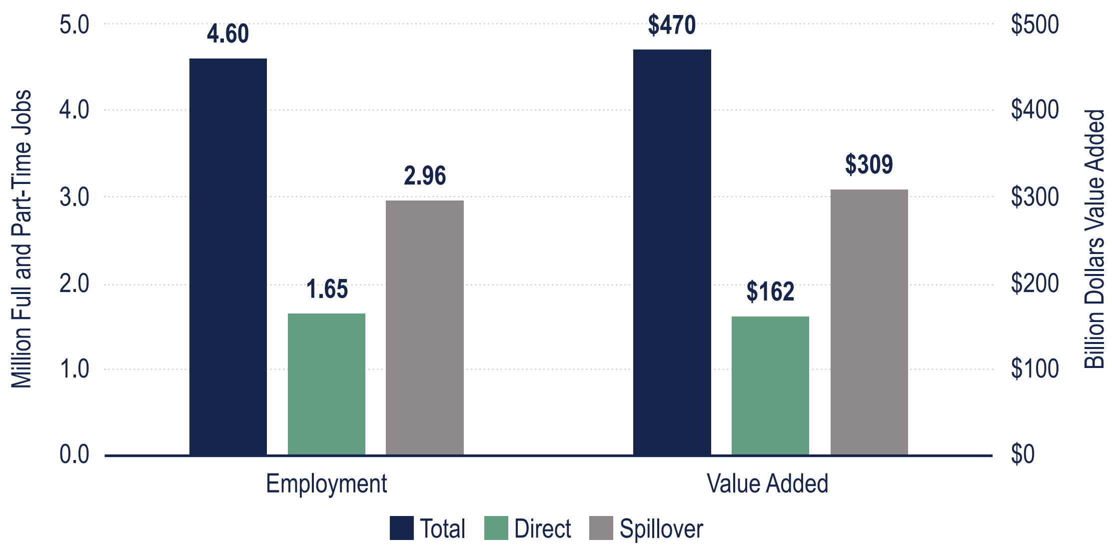


Figure 7: Biobased Products Economic Impacts Growth for 2013, 2014, 2016, and 2017 for Value Added and Employment.

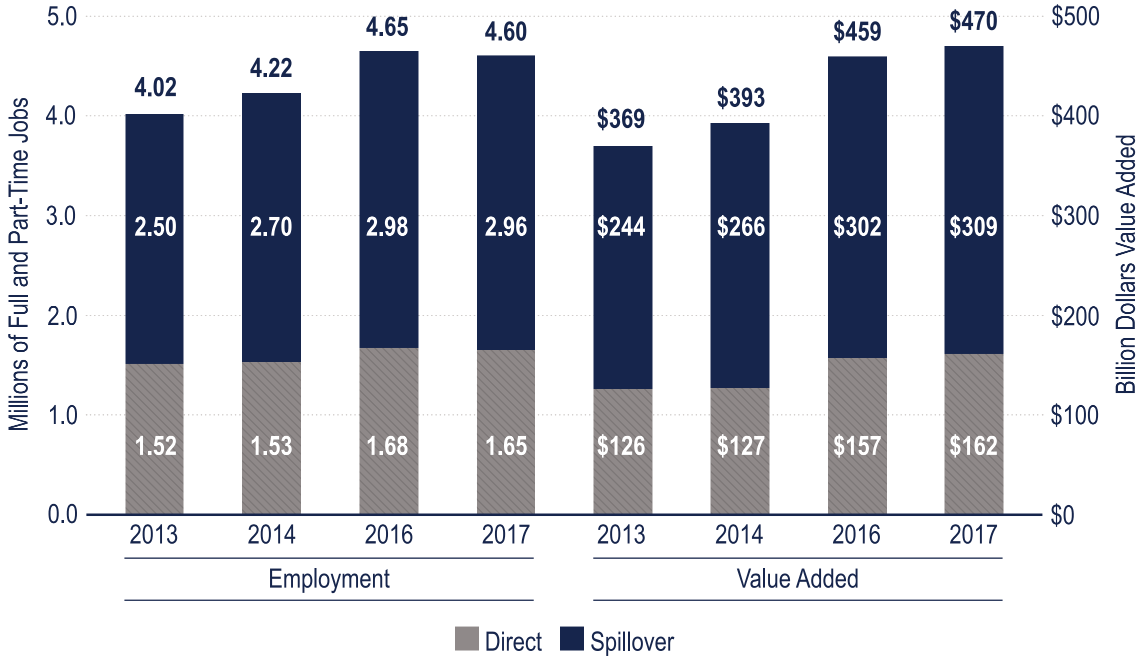


Figure 8a illustrates how the value added produced by the biobased products industry is allocated across each state (using an approximated range), and Figure 9a shows the number of jobs the biobased products industry supports by state. Figures 8b and 9b show how these values have changed over time. An important conclusion from these figures is that the biobased products industry affects every state in the nation and its impact is not just confined to states where agriculture is the main industry. Appendix D shows the direct value added and employment in each state, broken down by the seven major sectors. Appendix E shows maps with these state-level impacts for each of the seven major sectors.

Figure 8a: Direct Value Added Contributed by the Biobased Products Industry in Each State and the District of Columbia in 2017.

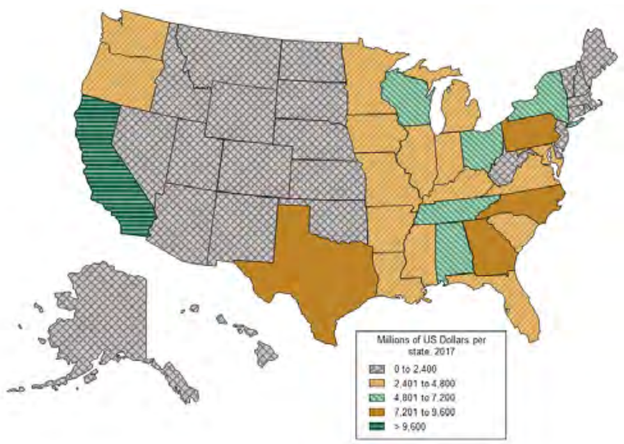


Figure 8b: Percent change (2013 – 2017) of Direct Value Added Contributed by the Biobased Products Industry in Each State and the District of Columbia.

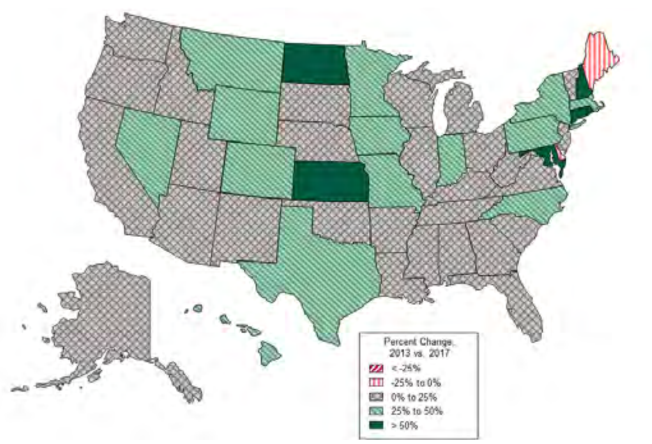


Figure 9a: Direct Jobs Contributed by the Biobased Products Industry in Each State and the District of Columbia in 2017.

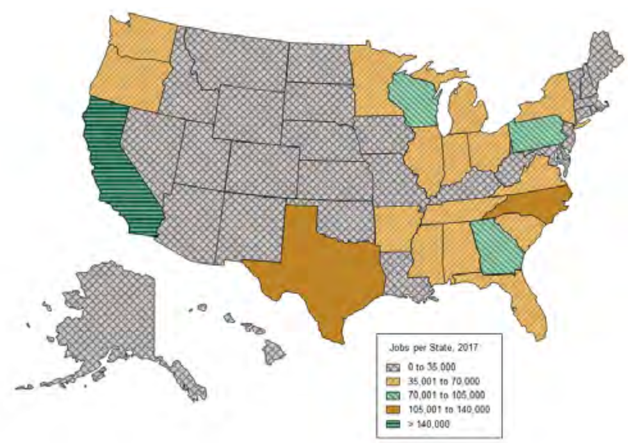


Figure 9b: Percent change (2013 – 2017) of Direct Jobs Contributed by the Biobased Products Industry in Each State and the District of Columbia.

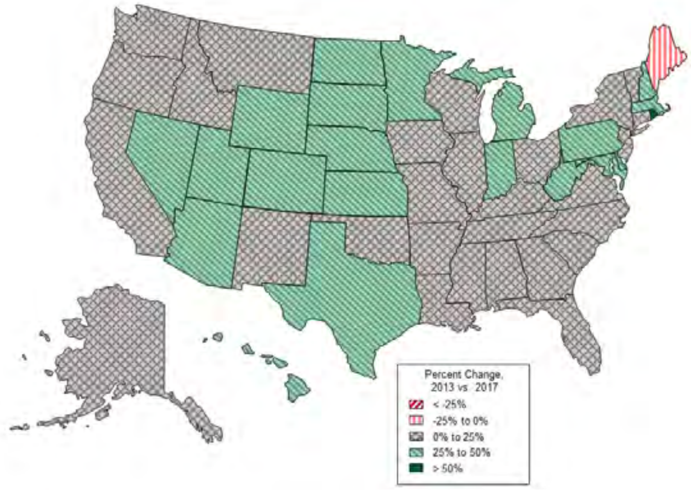


Table 1 lists the top 10 states that contributed to the biobased products industry for the most recent data modeled at the state level (2017) and the percent change between 2013 and 2017.

Table 1: Top 10 States for Direct Value Added to the Biobased Products industry in 2017 and percent change between 2013 and 2017.

Rank	State	Percent Change 2013-2017	Rank	State	Percent Change 2013-2017
1	California	17%	6	Wisconsin	10%
2	North Carolina	32%	7	New York	28%
3	Georgia	12%	8	Ohio	17%
4	Texas	24%	9	Alabama	3%
5	Pennsylvania	23%	10	Tennessee	11%

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."[16] This transition within the U.S. economy also aims to create and maintain 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 established specifically for biobased products. The NAICS is the standard used by Federal agencies in classifying business establishments for the purpose of collecting, analyzing, and publishing statistical data related to U.S. businesses. This limitation is discussed further in the Recommendations section. Despite the lack of specific data on biobased products, the authors developed an extensive database of applicable NAICS codes that represent the associated sectors. For instance, while there is no NAICS code for "biobased chemicals," there is an exhaustive listing of "chemical" sectors, such as paints and adhesives, other basic chemicals, plastics, and artificial fibers. These sectors represent segments of the U.S. economy that include biobased chemicals. A complete listing of all the modeled NAICS codes used is provided 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 comprise of the total chemical sector? To accomplish this task, the authors analyzed the peer-reviewed literature, domestic and international reports, related literature from industry and trade organizations, and market intelligence reports. The authors also conducted interviews with representatives from industry, various organizations, academia, and the government. Table 2 provides the estimated percentage of each sector comprised of biobased products (for example, the estimated percentage of the chemicals industry comprised of biobased chemicals is four percent).

[16] Golden J.S. and Handfield R.B., "Why Biobased? Opportunities in the Emerging Bioeconomy," USDA BioPreferred® Program website, accessed April 2019, http://www.biopreferred.gov/BPResources/files/WhyBiobased.pdf.

Table 2: Percentages of Biobased Products in Each Sector of the U.S. Economy in 2017.
Note: Where conflicting percentages were presented, the authors elected to utilize the lower, more conservative estimates. See the Recommendations section of this report for suggestions on increasing transparency and confidence levels in both Federal statistical reporting programs and voluntary pre-competitive industry initiatives.

Sector	Percent Biobased	Source
Agriculture and Forestry		
Cotton Farming	100	
Forestry, Forest Products, and Timber Tract Production	100	
Commercial Logging	100	
Corn	2.0	USDA Economic Research Service[17]
Oil Seed Farming to Glycerin	0.6	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	2.0	Scaled to include only agriculture biobased products
Processing Soybean and Other Oilseeds	0.6	Scaled on agriculture biobased percentage
Refining and Blending Fats and Oils	0.6	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	51	White Paper on Small and Medium Enterprises and Japan (2012)[19]
Forest Products	100	
Biobased Chemicals	4.0	Current Status of Biobased Chemicals, Biotech Support Service, 2015 (BSS)[20]
Enzymes	100	BCC Research Report (January 2011)[21]
Plastic Packaging and Bottles	0.28	European Bioplastics, Institute for Bioplastics and Biocomposites, nova-Institute (2014)[22]

The following paragraphs discuss the approach the authors used to develop the percentages for three of the seven sectors 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 percent for support activities across all sectors was derived based on the total support activities and the output amount of corn, timber and other products as a percentage of the total agricultural production used to create biobased products. The authors assumed all sectors utilized the same support services equally. Certain subsectors are worth noting here. In 2013, corn biorefineries processed 1.5 billion bushels of corn, the equivalent of about 10 percent of the U.S. corn crop.23 The corn was used to produce starch (17 percent), sweeteners (53 percent), and ethanol (30 percent). About 2 percent of the entire corn crop was used to produce biobased products from starch. The authors have not included the amount of ethanol used to produce biobased products.

[17] USDA Economic Research Service, accessed May 2018. https://www.ers.usda.gov/.

[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] Japan Small Business Research Institute, "2012 White Paper on Small and Medium Enterprises in Japan: Small and Medium Enterprises Moving Forward through Adversity," September 2012, accessed May 2019http://www.chusho.meti.go.jp/pamflet/hakusyo/H24/download/2012hakusho_eng.pdf.

[20] Jogdand, S.N., "Current Status of Bio-Based Chemicals," (India: BioTech Support Services (BSS), 2015), accessed August 2020, https://www.slideshare.net/induniva/current-status-of-biobased-chemicals.

[21] BCC Research, "Enzymes in Industrial Applications: Global Markets," January 2011, accessed May 2019 https://www.bccresearch.com/market-research/biotechnology/enzymes-industrial-applications-bio030f.html.

[22] European Bioplastics, "Bioplastics Facts and Figures," European Bioplastics website, accessed April 2018. http://docs.european-bioplastics.org/2016/publications/EUBP_facts_and_figures.pdf.

[23] Interviews with Greg Keenan, Penford, January 2015, and reference material.

2.2.2 Biorefining

Biorefining accounts for roughly 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 used as input to the refining sector, which includes wet corn milling, soybeans, fats and oils, sugar beets, and sugarcane milling. The Renewable Fuels Association (RFA)24 in 2015 estimated the production of biorefineries was 14.575 billion gallons per year, which is equivalent to approximately 347 million barrels per year. This amount includes fuel from several sources including corn, sorghum, wheat, starch, and cellulosic biomass. The Energy Information Association (EIA)[25] estimated that in January 2015, the refining capacity in the United States was 17,830,000 barrels per day, equivalent to approximately 6.508 billion barrels per year.

2.2.3 Textiles

About 51 percent of textiles, including cotton and rayon, are produced from biobased feedstocks. Cotton, Inc. estimates 75 percent of summer clothing and 60 percent of winter clothing are produced from cotton.[26] U.S. Apparel estimates that the textiles sector accounts for roughly 2.9 million jobs in the United States; mostly in retail sales. In 2012, textile manufacturing accounted for 148,100 jobs.

2.3 Agriculture and Forestry

Figure 10a: Total Value Added Contributed by the Agriculture and Forestry Sector in Each State and the District of Columbia in 2017.

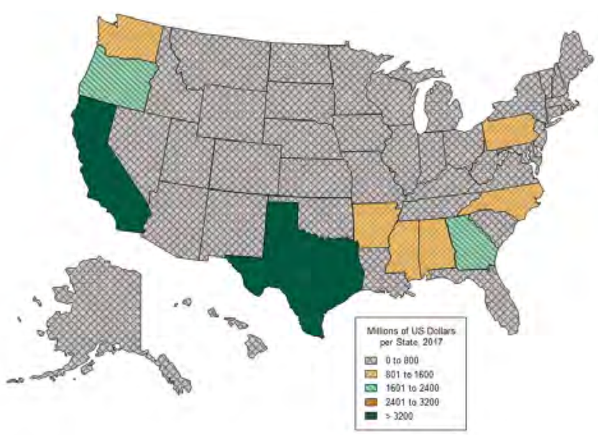


Figure 10b: Percent change (2013 – 2017) of Total Value Added Contributed by the Agriculture and Forestry Sector in Each State and the District of Columbia.

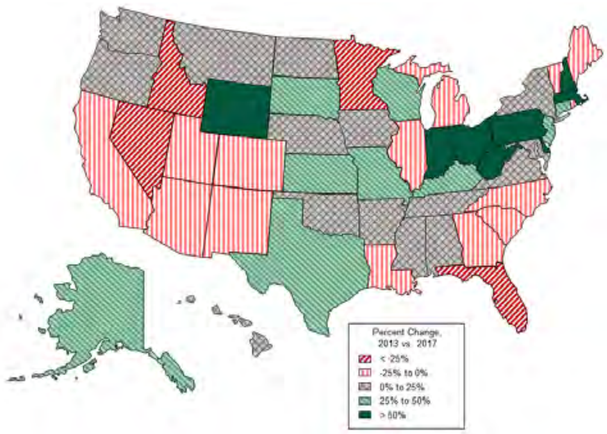


Table 3: Top 10 States for Direct Value Added to the Agriculture and Forestry Sector in 2017 and percent change between 2013 and 2017.

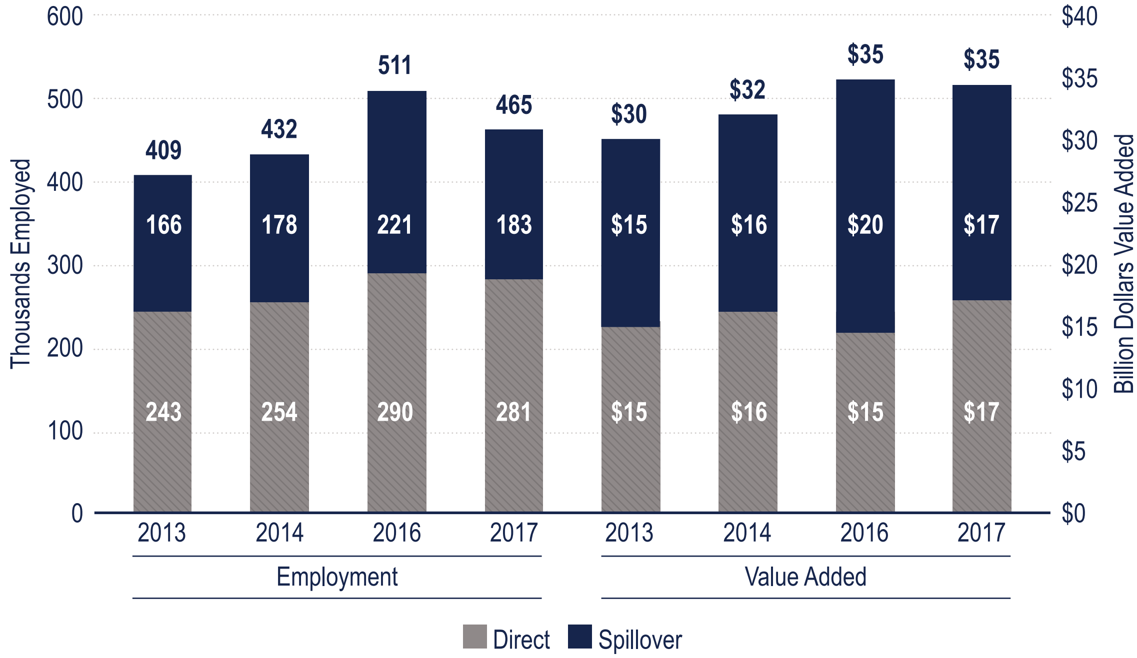
Rank	State	Percent Change 2013-2017	Rank	State	Percent Change 2013-2017
1	Texas	34%	6	Alabama	0%
2	California	-12%	7	Mississippi	3%
3	Georgia	-33%	8	Arkansas	7%
4	Oregon	0%	9	North Carolina	-21%
5	Washington	3%	10	Florida	-43%

24 Renewable Fuels Association, "Biorefinery Locations," accessed April 2015. http://www.ethanolrfa.org/bio-refinery-locations/.

25 U.S. Energy Information Administration (EIA), "Petroleum & Other Liquids Weekly Inputs & Utilization," EIA website, accessed April 2015. http://www.eia.gov/dnav/pet/pet_pnp_wiup_dcu_nus_4.htm.

26 Cotton Incorporated, "Fiber Management Update September 2011," Cotton Incorporated website, accessed April 2015. http://www.cottoninc.com/fiber/quality/Fiber-Management/Fiber-Management-Update/05-Sept-2011/.

Figure 11: Agriculture and Forestry Sector Contribution to Employment and Value Added in 2013, 2014, 2016, and 2017.



Approximately 2.1 million farms contribute to America's rural economy. About 99 percent of U.S. farms are operated by families, i.e., individuals, family partnerships, or family corporations. In many cases, they are suppliers to companies such as the major firms listed below. [27]

Major U.S.-Based Firms[28]
Cargill (Minnesota)
Archer Daniels Midland Company (Illinois)
DuPont Pioneer (seeds) (Iowa)
Land O'Lakes (Minnesota)
Monsanto Company (Missouri)
Ceres (seeds) (California)

Global Firms with Large U.S. Operations
Bayer Crop Science (North Carolina)
BASF Plant Science (North Carolina)
Syngenta (Minnesota and North Carolina)

Economic Statistics
Total value added to the U.S. economy in 2017: **$35 billion**

Exports value added to the U.S. Economy in 2017: **$11.7 billion**

Type SAM Economic Multiplier in 2017: **2.4**

Employment Statistics
Total number of Americans employed due to industry activities in 2017: **511,000**

Total number of Americans employed due to industry activities supporting exports in 2017: **152,000**

Type SAM Employment Multiplier in 2017: **1.65**

[27] American Farm Bureau Federation, "Fast Facts about Agriculture," American Farm Bureau Federation website, accessed April 2018. https://www.fb.org/newsroom/fast-facts.

[28] Forbes, "The World's Biggest Public Companies," Forbes website, accessed April 2015. http://www.forbes.com/global2000/list/.

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

Note: Appendix B shows these results for the top three states by overall direct value added to the biobased products industry (CA, NC, and GA). Appendix C shows these results for the top three states by direct value added in the Agricultural Sector (TX, CA, and GA).

IMPLAN Code	NAICS Codes	Description	Employment	Value Added
16	113310	Commercial logging	127,000	$8,638,000,000
19	11511, 11531	Support activities for agriculture and forestry – animal production has been excluded	87,000	$3,548,000,000
8	111920	Cotton farming	47,000	$3,640,000,000
15	113110, 113210	Forestry, forest products, and timber tract production	14,000	$1,046,000,000
2	111150	Grain farming – only corn included	5,000	$93,000,000
9	111930, 111991	Sugarcane and sugar beet farming	270	$21,000,000
1	11111	Oilseed farming	1,000	$121,000,000
		Totals	**281,270**	**$17,107,000,000**

2.3.1 Overview

The Agriculture and Forestry sector is made up of three main subsectors: crop production, forestry and logging, and support activities for agriculture and forestry. Crop production industries mainly produce crops for fiber and feedstocks (food is excluded). Cotton farming, corn farming, sugarcane harvesting, and oilseed farming are the most important industries. The forestry and logging industry is comprised of two principal industries—timber tract operations and logging—which grow and harvest timber using production cycles of 10 years or more.[29] Support activities for agriculture and forestry provide essential inputs and as well as power, transportation, and other activities that are the foundation for the production process in each respective industry.[30]

Overall, this industry and its subsectors are of paramount importance to the biobased industry since they are 100 percent biobased. Revenue across these industries is estimated at close to $100 billion, and this amount will be surpassed during the five-year period from 2018 to 2022.[31] Corn—and especially cotton—rely heavily on revenue earned through exports. Growth in this sector is expected be modest, with the construction and housing industries playing large roles in the forecast, as well as the continued push for renewable feedstocks.

2.3.2 Crop Production

Cotton Farming

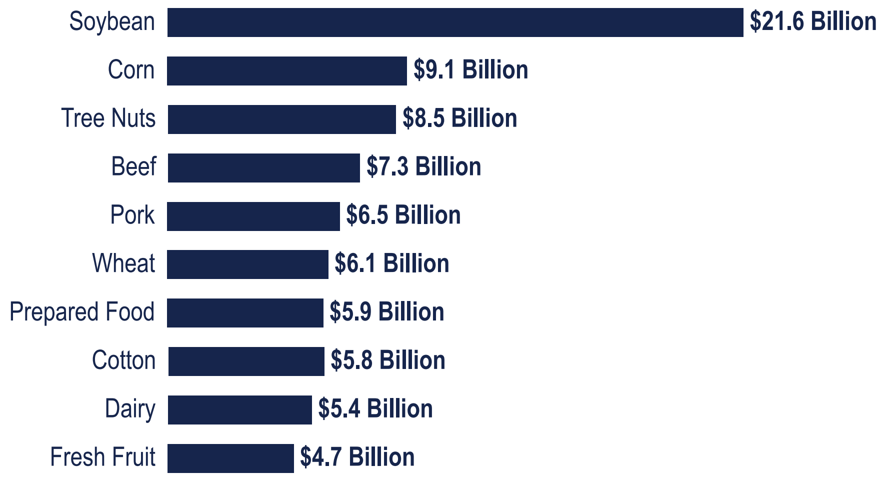
Cotton farming in the United States is almost entirely focused on exports, with roughly 80 percent of its revenue coming from international trade. According to USDA, cotton is the eighth largest agricultural export, as shown in Figure 12.

[29] "About the Forestry and Logging Subsector," U.S. Bureau of Labor Statistics, U.S. Department of Labor website, accessed April 2018, https://www.bls.gov/iag/tgs/iag113.htm.

[30] "About the Crop Production Subsector," U.S. Bureau of Labor Statistics, U.S. Department of Labor website, accessed April 2018, https://www.bls.gov/iag/tgs/iag111.htm.

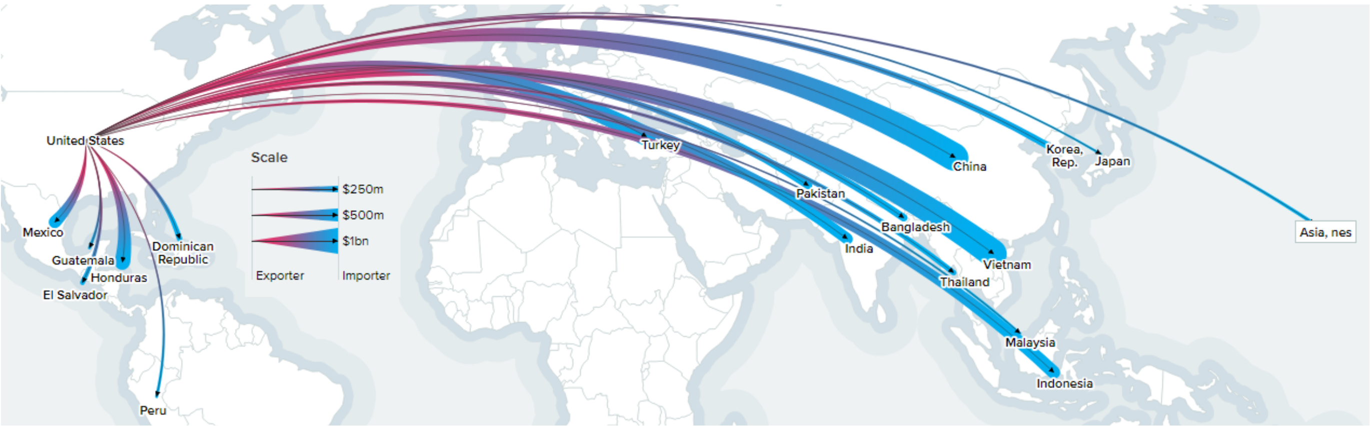
[31] IBISWorld Industry Reports 11112, 11115, 11192, 11193, 11199, 11311, 11331, 11511, 11531 March 2018.

Figure 12: Top U.S. Agriculture Exports in 2017.[32]



Therefore, the industry is highly dependent on the conditions of the global market due to the very small amount of domestic demand. Figure 13 shows the trade flows to the countries that import the most cotton from the United States. Despite declines in exports every year since 2012, IbisWorld predicts revenue will stabilize over the next five-year period, with annual growth of at least 0.1 percent.

Figure 13: United States Cotton Export Flows.[33]



Sugarcane Harvesting

The sugarcane harvesting industry generally is considered to be on the decline due to factors such as consumer demand for healthier food products containing less sugar, and the availability of cheaper imports from Mexico. However, one of the bright spots for this maturing industry is the bioeconomy and, more specifically, the production of biofuels.

Corn Farming

In the five years leading up to 2017, the entire corn industry entire corn industry suffered huge losses as production far surpassed demand because of bumper crops and favorable weather. Fig. 12 shows that corn is the second most abundant product exported from the United States. As renewable energy quotas increase each year and less acreage is being planted to balance the market, revenue is expected to increase at an annualized rate of 1.1 percent over the five-year period from 2018 to 2022. However, export revenues during that same period are expected to increase at an annualized rate of 2.8 percent. The United States is the largest producer and exporter of corn in the world, and demand from Japan, South Korea, and Columbia are expected to help boost exports.

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[32] "Top U.S. Agricultural Exports in 2017," USDA Foreign Agricultural Service website, accessed April 2019. https://www.fas.usda.gov/data/top-us-agricultural-exports-2017.

[33] ResourceTrade.Earth, Chatham House Resource Trade Database, accessed May 2019. https://resourcetrade.earth/data?year=2017&exporter=842&category=90&units=value.

Oilseed Farming

The oilseed farming industry (non-food) produces mainly canola, sunflower, and flaxseed oils, and this industry is overshadowed by other U.S. cash crop industries such as corn, soybeans, and wheat. For this reason, industry revenue can vary widely from year to year. Farmers also can switch easily between crops, which makes this industry even more difficult to predict due to the fluctuation of acres planted, amounts harvested, and market prices. Even though the prices of oilseeds have decreased by 4.4 percent over the past five years, industry revenue is expected to stabilize and then increase over the five-year period from 2018 to 2022. Over this same period, exports are forecast to grow at an annualized rate of 1.3 percent. The demand for high-quality vegetable oils from important foreign markets will boost exports.

2.3.3 Forestry and Logging

Logging

During the past five years, the industry had moderate growth, mainly due to ongoing expansion in the construction and housing markets. However, exports have been slowed by the rising value of the U.S. dollar, making forest products more affordable on the domestic market but less so internationally. The downturn in the paper industry also will affect demand from the logging industry. Over the five years from 2018 to 2022, the logging industry's revenue is expected to increase at an annual rate of 1.3 percent.

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 it is usually harvested young, while the trunks still have small diameters. The trees are chipped to prepare the wood for pulping. Pulpwood-sized stems also are used to manufacture engineered wood products, such as structural wood composites. Wood chips and pulp are used primarily in the production of paper, but they also may be used for the production of fiberboard. Larger-sized trees that meet the minimum size requirements for producing lumber or veneer logs for the production of plywood are classified as sawtimber. Approximately seven percent of global industrial roundwood is produced in the southern region of the United States. The U.S. leads the world in the production of timber for industrial products, accounting for approximately 25 percent of global production.

More than 5,000 products are produced from trees. While lumber and paper are easily recognizable, most of the products are derived from the biobased chemicals within the trees. Historically, these products have included 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. The industry has grown with the resurgence of the housing and construction markets. Demand from the paper manufacturing industry has decreased, and limited growth is expected. Wood-based bioenergy, especially exports to Europe, have helped prevent this industry from losing revenue. Industrial revenue is expected to increase at an annual rate of 1.5 percent over the next five-year period.

Crop Services

This industry is made up of companies that help crop producers with a variety of planting and harvesting activities. The expansion into new markets beyond food is an indicator of new growth. While crop prices are forecast to decrease over the next five years, an increase in production is expected to boost the need for services. Thus, revenue is expected to increase at an annualized rate of 0.7 percent over the next five-year period.

Forest Services

Forest services are hired by both the U.S. Government and private companies, and these services are provided on both public and private land. Services range from forestry consulting to firefighting and reforestation. Increased demand for lumber by the construction and housing industries have helped the industry in recent years, but these industries' demand for services is expected to decrease. Timber and logging operators will respond by opting to integrate the services they need within their own companies.

2.3.4 Case Study: Braskem – A Leader in Green Polyethylene Packaging Innovation

Braskem is one of the world's leading petrochemical producers, but is also one of the biggest producers of biobased feedstocks. The company is collaborating 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 ethanol, a renewable and sustainable resource produced from Brazilian sugarcane. Sugarcane has been an important commodity for Brazil, where Braskem is headquartered. Brazil is the world's largest sugarcane ethanol producer and has been a pioneer in using sugarcane ethanol as a motor vehicle fuel replacement.[34] Along with the use of sugarcane ethanol as a fuel, the plastics industries recognized its value as a feedstock and worked on processes to dehydrate ethanol to produce ethylene. Conversion of ethanol into ethylene began on a large-scale basis, using the same capital assets used to produce petroleum-based ethylene. Biobased PE is used in multiple applications, such as in detergent bottles, synthetic cork, plastic bags, hard hats, and tubes for personal care items.

Braskem, which produces most of Brazil's plastics, manufactures multiple grades of PE that can be used in almost all applications. The company's I'm green™ PE retains the same properties, performance, and application versatility of petroleum-based PE, making it an ideal drop-in replacement for conventional petroleum-based PE. According to Braskem:

> *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 bio 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.*[35]

The authors interviewed Joseph Jankowski, who currently serves as the Commercial Manager for Braskem's Renewables team in North America. Jankowski began his work as an engineer in the petroleum refining industry at Sonoco and moved to a sales role in the polypropylene division that was later sold to Braskem. When he began his career, most of his sales activity involved selling resins or ultrahigh molecular PE resins. He then began to work in the green PE sector, which relies on sugarcane-derived PE. In this position, Jankowski works in many different disciplines, including communications, marketing, and business-to-business account management, as well as engagement with industry, retailers, brands, and traditional clients. Jankowski explained the uses of I'm green™ PE and the importance of this material:

"*Today, an increasing number of companies globally are using I'm green™ PE and converting it to meet specific needs as the image above demonstrates. The following are some examples of how I'm green™ PE is changing the nature of packaging across a number of different retail and industrial product categories, including partnerships with Haldor Topsoe, Scotts, LEGO, Begin Again, and General Mills.*"

[34] Ethanol, SugarCane.org, accessed May 2019, https://sugarcane.org/ethanol/.

[35] "Scotts® Turf Builder® with Root-Trients™ Raises the Bar in Lawn and Garden Sustainability with Braskem's Bio-Based I'm green™ Polyethylene Packaging," Sustainable Brands, May 29, 2018, accessed May 2019, https://sustainablebrands.com/read/press-release/scotts-turf-builder-with-root-trients-raises-the-bar-in-lawn-and-garden-sustainability-with-braskem-s-bio-based-i-m-green-polyethylene-packaging.

Haldor Topsoe - Monoethylene Glycol (MEG)
Braskem has partnered with various companies, most recently including Haldor Topsoe. A press release from Braskem offers more information on this partnership:

> *Braskem, America's largest petrochemical producer and the world's leading biopolymer producer, and Haldor Topsoe, the world leader in catalysts and technology for the chemical and refining industries, announce the commissioning of a pioneering demonstration unit for the development of Monoethylene glycol (MEG) from sugar. Located in Lyngby, Denmark, the pilot plant's operation marks a decisive step in confirming the technical and economic feasibility of producing renewable MEG on an industrial scale.*
>
> *Announced in 2017, the cooperation agreement focuses on developing a new technology for converting sugar into MEG at a single industrial unit, which reduces the initial investment in production and consequently makes the process more competitive. MEG is used to make PET, a resin that is widely used in the textile and packaging industries, especially for making bottles. The global market for MEG currently is at around $25 billion.*
>
> *Starting in 2020, Braskem will send samples of MEG to clients to test in their products. The unit built in Denmark has annual production capacity of hundreds of tons of glycolaldehyde, a substance that is converted into MEG. The goal is for the plant to convert various raw materials, such as sucrose, dextrose and second-generation sugars, into MEG. Currently, MEG is made from fossil-based feedstocks, such as naphtha, gas, or coal.*
>
> *The process for developing renewable MEG in partnership with Haldor Topsoe represents a major advance in competitiveness for Green PET. The partnership strengthens the leading role we play and adds value to our I'm green™ portfolio, which already features Green Polyethylene and Green EVA, both made from sugarcane. It also will further corroborate our vision of using biopolymers as a way to capture carbon, which helps to reduce greenhouse gas emissions," explained Gustavo Sergi, director of Renewable Chemicals at Braskem.*[36]

[36] Braskem and Haldor Topsoe startup demo unit for developing renewable MEG, Braskem, Feb. 6, 2019, accessed May 2019, https://www.braskem.com.br/news-detail/braskem-and-haldor-topsoe-startup-demo-unit-for-developing-renewable-meg.

Scott's Canada

Braskem also partnered with Peel Plastic Product Ltd. and Scotts Canada in May 2018. This partnership created new product packaging for Scotts® Turf Builder® with Root-Trients™ using Braskem's I'm green™ PE. From a Braskem press release:

> *Joseph Jankowski stated that "Braskem is proud to partner with Scotts as the leading provider of lawn and garden growing products in Canada to improve the sustainability of their packaging, in line with Scotts' overall commitment to environmental protection. By utilizing Braskem's I'm green™ PE, Scotts' is aligning their more sustainable approach to the external packaging with the increased organic content inside the package. Overall, consumers are increasingly looking for products that help reduce their environmental footprint, and we are excited to work with Scotts and Peel Plastics to meet that rising demand."*[37]

General Mills' Cascadian Farms

General Mills aims to have all of its packaging be recyclable by 2030. Their Cascadian Farms cereal and granola bar line features a unique box with some unique recycling requirements. The 68 percent biobased bag has now been branded in the sustainable packaging world – and has trademarked the phrase – "we are growing a better package." From the General Mills website:

> *We actively seek more sustainable materials in the early phases of packaging design. For example, we launched a renewable, bio-based plastic film, partially made of plant-based materials, for Cascadian Farm cereal box liners. This change in materials replaces the impacts of about 600,000 pounds (270 metric tonnes) of non-renewable plastic annually. This bio-film increases the sustainability of raw materials, reduces the packaging carbon footprint and does not affect the recyclability of the material in any way.*[38]

LEGO

LEGO's ambitious goal is to achieve 100 percent sustainable biobased materials in their products and packaging by 2030. Converting some of their pieces to I'm green™ PE in Europe represents "the first milestone" in this journey.[39] LEGO began producing some pieces from I'm green™ PE in 2018. They began with pieces like leaves, bushes, and trees orginally made from petroleum-based PE. Polyethylene pieces make up 1-2 percent of all the plastic pieces made by LEGO.[40]

Seventh Generation Detergent

An example of biobased bottling is Seventh Generation, which has been acquired by Unilever. Seventh Generation is a strong supporter of the use of biobased plastic as well as recycled plastics. They focus on biobased products such as their 100-ounce detergent bottle, which now has a version featuring 80 percent recycled content. Due to the mechanical strains that detergent places on a container, the company was unsuccessful in producing a bottle with 100 percent recycled content. However, Seventh Generation was able to utilize I'm Green™ PE provided by Braskem to provide this mechanical strength in place of a virgin petroleum-based resin that had previously been used.[41]

IKEA's ISTAD bag

The ISTAD is a new plastic bag developed by IKEA. The resealable bag is made to keep food fresh and offers multiple other domestic uses. The bag is produced using a biobased plastic that is both a renewable and recyclable material. This is the first large-scale biobased plastic product sold at IKEA and is a move towards IKEA's goal of creating plastic products that are all made with recycled and/or renewable material. IKEA estimates the company will sell 1.4 billion plastic bags this year, saving/displacing 75,000 barrels of oil.[42] Although the bags are not biodegradable, they are recyclable, and can be returned to the store, recycled, and used in other products like plastic decks.

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[37] "Scotts® Turf Builder® with Root-Trients™ Raises the Bar in Lawn and Garden Sustainability with Braskem's Bio-Based I'm green™ Polyethylene Packaging," Sustainable Brands, May 29, 2018, accessed May 2019, https://sustainablebrands.com/read/press-release/scotts-turf-builder-with-root-trients-raises-the-bar-in-lawn-and-garden-sustainability-with-braskem-s-bio-based-i-m-green-polyethylene-packaging.

[38] Packagaing, General Mills, Jan. 24, 2019, accessed May 2019, https://www.generalmills.com/en/Responsibility/Sustainability/packaging-statement.

[39] LEGO® Treehouse Blooming with Sustainable Bricks, The LEGO Group, Aug. 7, 2019, accessed May 2019, https://www.lego.com/en-us/aboutus/news/2019/august/lego-treehouse-blooming-with-sustainable-bricks.

[40] "First Sustainable Lego Bricks will be Launched in 2018," State of Green, March 2, 2018, accessed May 2019, https://stateofgreen.com/en/partners/state-of-green/news/first-sustainable-lego-bricks-will-be-launched-in-2018/.

[41] "Bio-based and PCR HDPE Packaging Redefines the Value-Chain," Braskem, June 7, 2016, accessed May 2019, https://www.braskem.com.br/usa/news-detail/bio-based-and-pcr-hdpe-packaging-redefines-the-value-chain.

[42] "IKEA Switches into Bioplastics in ISTAD Plastic Bag," IKEA Korea, Jan. 8, 2018, accessed May 2019, https://www.ikea.com/kr/en/about_ikea/newsitem/2018-01-08.

Conclusion

Other consumer companies including Estee Lauder, Aveda, and Just Water are moving to use I'm green™ PE in their plastic packaging. These organizations have the awareness and tools necessary to make this sustainable change and have begun using recycled content and I'm green™ PE in their products.

These cases suggest the move towards biobased products is not just occurring in the United States but is moving quickly in other parts of the world. In the United States, the effort is being led by the Ohio State bioplastics team, the Iowa State Center for Bioplastics and Biocomposites initiative, and others in states that grow large quantities of corn and soybeans. Abroad, the European Bioplastics organization is promoting the use of biobased products throughout the rest of the world.

The entire market share today of I'm green™ PE is less than 1 percent, but the growth of the sector is moving at breakneck speed. There are many new sustainable initiatives that use I'm green™ PE, including a John Deere toy truck. Braskem estimates sales targets will grow 100 percent this year. Similar targets have been achieved in each of the previous two years.

2.3.5 Case Study: PepsiCo: Reinventing Sustainable Packaging

As a top producer of consumer-packaged food and beverages, PepsiCo is continuing to innovate and reinvent its packaging to lead the way in sustainable packaging. PepsiCo has been working with many partners, including Danimer Scientific, to develop biobased film resins. In 2019, PepsiCo piloted a biopolymer for snack packaging created principally from a corn-based feedstock that is not part of the human food chain and is industrially compostable. PepsiCo is also working to develop an even more advanced film packaging material. PepsiCo is also concerned that the biobased materials they use in these products come from responsible sources.

From PepsiCo:

> *While using renewable resources for packaging can be a more sustainable alternative to non-renewable resources, these biofeedstocks must be sourced in a responsible and sustainable way, ensuring sufficient land use for food sources and being mindful of environmental impact. To this end, PepsiCo has joined the Bioplastic Feedstock Alliance, a multi-stakeholder alliance convened by the World Wildlife Fund, which aims to improve awareness around the environmental and social impacts of sources for bio plastics.*
>
> *In 2018 PepsiCo joined The NaturALL Bottle Alliance, a research consortium with consumer packaged goods industry leaders and a bio-based materials development company, Origin Materials, to accelerate the development of innovative packaging solutions made with sustainable and renewable resources, including post-consumer cardboard, thus creating additional end market demand for this material.*[43]

As well as being endlessly recyclable without losing the quality of the material, this is a much more resource and carbon-efficient way of making PET than through the use of oil-based polymers.

The PepsiCo "Sustainable Plastics Vision":

> *PepsiCo's sustainable plastics vision is to* ***build a world where plastics need never become waste****. PepsiCo aims to achieve that vision by reducing, recycling, and reinventing our plastic packaging — and leading change through partnerships. The vision is based on three inter-connected strategies:*
>
> 1. Reduce: Reduce plastic that is used.
> 2. Recycle: Support a circular economy for plastics.
> 3. Reinvent: Improve the packaging and plastic that is used.[44]

This case study focuses on the "Reinvent" portion of this vision and the work being done on biobased plastics in this area.

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[43] Packaging, PepsiCo, accessed May 2019, https://www.pepsico.com/sustainability/packaging.

[44] Our Approach, PepsiCo, accessed May 2019, https://www.pepsico.com/sustainability/packaging.

PepsiCo's efforts to develop biobased packaging

Dr. Pak Meng Cham works in the Research and Development lab in a building next to PepsiCo's headquarters in Dallas, TX. Cham has a Ph.D. in material science and, before joining PepsiCo, worked at Dow Chemical in plastics chemical engineering as a material science engineer. After joining PepsiCo, he moved into a packaging research and development role, where he works on material process projects including evaluation and exploration of new technologies and materials to apply to PepsiCo's business. Cham noted he and his team are on the front end of discovery, and eventually those discoveries will move into the implementation, commercialization, and scaling process. Cham is hopeful his discoveries will lead to a global implementation of new packaging technology.

Cham's primary focus has been in sustainability and developing packaging materials that can be environmentally friendly, biobased, compostable, and biodegradable, and also meet current performance requirements demanded by consumers of PepsiCo's products. Cham explained that, recently, he has been focused on biopolymer evaluation developments. His material science and plastic background has aided him in evaluating new materials that can be used to develop new products. Additionally, Cham works with PepsiCo's regulatory team on compostability of bioplastics, which is an important part of the PepsiCo mission.

Cham's research is primarily driven by PepsiCo's corporate goals for 2025.[45] The company set a high goal to reduce its carbon footprint by working to reduce absolute greenhouse gas (GHG) emissions across the company's value chain by at least 20 percent and by doing its part to limit global temperature increases to below 2° Celsius. In addition, the company has pledged to focus on packaging by striving to design 100 percent of its packaging to be recyclable, compostable, or biodegradable; increasing recycled materials in its plastic packaging; reducing packaging's carbon impact; and working to increase recycling rates in partnership with the PepsiCo Foundation.

It is important to note that, when considering PepsiCo's entire production activity, production of packaging has a relatively small impact on the company's overall environmental goals. A majority of the energy consumption that produces GHGs comes from growing and processing food, processing water, and transporting material. However, packaging has a visible and strong impact in other ways. For instance, if plastic packaging finds its way into the environment, it becomes a major problem, especially in terms of the impact on ocean marine life. For that reason, packaging waste is very visible to consumers. Cham's group is looking closely at biopolymers and biodegradable materials that can be used for new packaging solutions. In doing so, the company has gone down many different avenues and pathways.

About ten years ago, PepsiCo piloted a new packaging material—a Sun Chip bag—that was the first compostable packaging ever produced in the market. This was a polylactic acid (PLA)—based material, and PepsiCo became the leader in the industry at that time. The compostable bag was made from more than 90 percent renewable, plant-based materials and was designed to compost in a hot, active home or industrial compost pile in approximately 14 weeks. Cham explained that the team made the difficult decision to discontinue the bag in 2011 because, at the time, composting was a niche activity, and those consumers who did compost were sometimes unable to create the optimal conditions necessary for the bag to break down in a home compost pile. Additionally, some independent municipal green bin programs were unable to accept the bag, which resulted in them ending up in landfills. Moreover, consumer acceptance of the packaging was impacted by complaints that the bag was too noisy.

However, Cham noted PepsiCo is currently engaged in developing an improved PLA material that is compostable in an industrial composting facility.

PepsiCo also has a pilot program to develop new biobased packaging, coming off a successful campaign in the last two years. Throughout 2017 and 2018, PepsiCo launched pilots of biobased plastic bags in three geographic locations. In the United States, they began packaging Tostitos in these bags for certain food service accounts. They also began testing the acceptance of biobased bags with consumers in Chile and India for select lines of Lay's potato chips. The bags are made with renewable resources and are compostable in industrial composting facilities. These were smaller scale pilots within smaller markets. The pilot program goals included testing consumer reaction to the material and its marketing, to evaluate the logistics of the supply chain, and to determine if consumers were disposing of the material at recycling or composting locations. Cham admits there is a lot to learn before biobased packaging can be rolled out on a larger scale.

[45] Our Goals, PepsiCo, accessed May 2019, https://www.pepsico.com/sustainability/performance-with-purpose/our-goals.

Cham also noted that, while PepsiCo's portfolio does not currently include this material, the future is coming, and the company wants to ensure they are ready to roll out production when the market is ready.

Challenges to Reinventing Packaging

Cham pointed out that it takes time to move to biobased packaging, as many challenges exist. There is almost always a performance, productivity, and economical challenge to move to the new generation of flexible packaging. For example, NatureWorks is the largest biobased PLA producer in the world, but PLA is still a small volume material and not a commodity material such as polyethylene and polypropylene. Thus, cost and production challenges are always an issue when talking to resin producers.

As a result, biobased material is more expensive than conventional material. PepsiCo is working on improving the performance issues of biobased materials, but because of the smaller quantities being purchased, producers do not have the scale that would allow them to optimize their operations. Scaling up will come in time and is part of the journey of developing biopolymers. Cham noted that PepsiCo product developers are learning as they go, and he acknowledged that educating consumers to help them understand how to recycle and compost the new materials will be an important part of the product development process. Cham also noted that consumers are still learning what it means for a product to be recyclable, biodegradable, or compostable, and in many cases, consumers use these terms interchangeably. Cham emphasized it is imperative to educate consumers on what is recyclable, how to dispose of materials properly, and why they need to be concerned about this activity.

This is particularly true when it comes to sorting recyclables and ensuring that people do not throw recyclable and compostable materials into the wrong bins. Industrial composters are finding non-compostable elements such as PLA included in compost bins, leading to concerns about "contamination issues" (mixing non-compostable material with compostable material). Contamination issues are problematic because the non-compostable material does not go away, or decompose, which affects the quality of the compost. The composting facility can handle a certain amount of contamination, but too much contamination causes problems with the composting systems. Industrial composters are trying different things to prevent contamination, including changing compost bin labels and colors to distinguish them from recycling or trash bins.

Cham said that PepsiCo is having ongoing conversations with industrial composters to understand what the company can do to help. From a certification standpoint and as a brand owner, Cham says PepsiCo is well aware of the challenges and is working to overcome them.

The Future

Cham reflected on where PepsiCo is on this journey. "We have a lot of internal and external conversations with different partners and parties, and we know that biobased packaging will be part of our packaging mix in the future. We believe we have to be part of the solution to create a world where plastic does not become waste. It is a question of bringing together the right technologies and making these changes as fast as we can."

As a global company, PepsiCo recognizes there is a need for a faster solution in some regions than in others. Cham explained that each region has different regulatory requirements, and he speculated that some regions will simply ban the use of single use plastic in the near future, which may also eventually happen in the United States. Cham said that PepsiCo must be proactive as a company and ensure it is applying all technologies to achieve the goal of zero waste, despite the technical infeasibility at the moment.

From a technical standpoint, PepsiCo recognizes there are some things preventing the company from achieving performance goals. Despite this, Cham is optimistic about the future of sustainable packaging: he fully believes we will eventually get there. He says it is about creating the right environment to help guide the general public in the direction of recycling and composting: "In addition to applications, the waste collection system to support collecting the used material properly, whether recycled or for composting, is critical."

Cham noted the United States has a long way to go in educating consumers and building an infrastructure for plastic recycling and composting. That is why in 2018 PepsiCo committed a $10 million grant to The Recycling Partnership with a goal of improving access to recycling for 25 million households.

As a researcher and a scientist, Cham said, "We can develop the best technology, but the public will play a big part in being successful in this goal."

2.4 Biorefining

Figure 14a: Total Value Added Contributed by the Biorefining Sector in Each State and the District of Columbia in 2017.

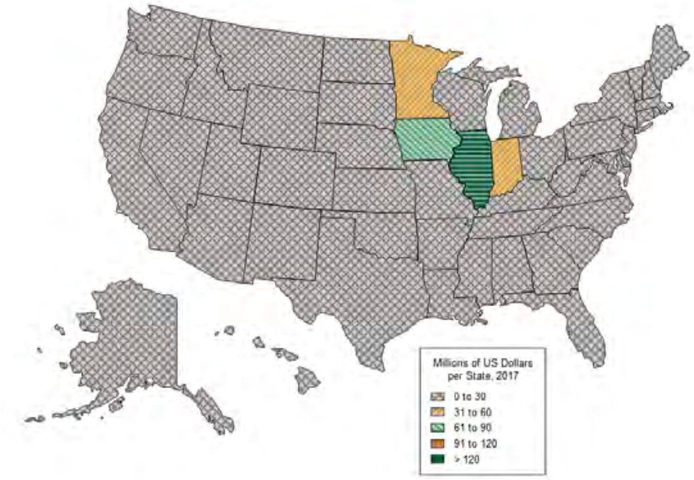


Figure 14b: Percent change (2013 – 2017) of Total Value Added Contributed by the Biorefining Sector in Each State and the District of Columbia.

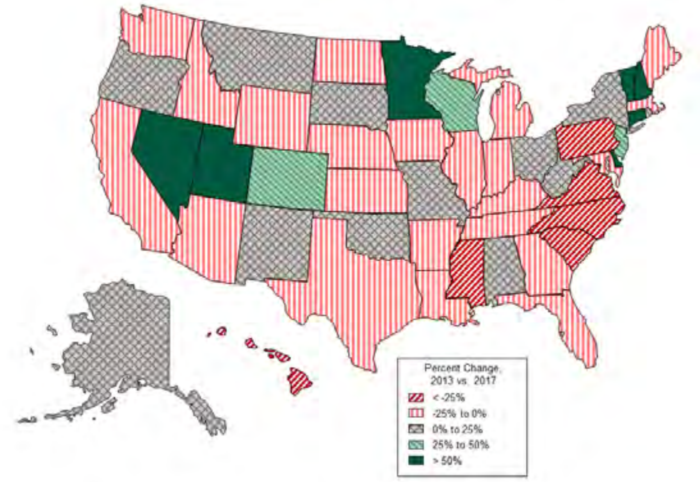
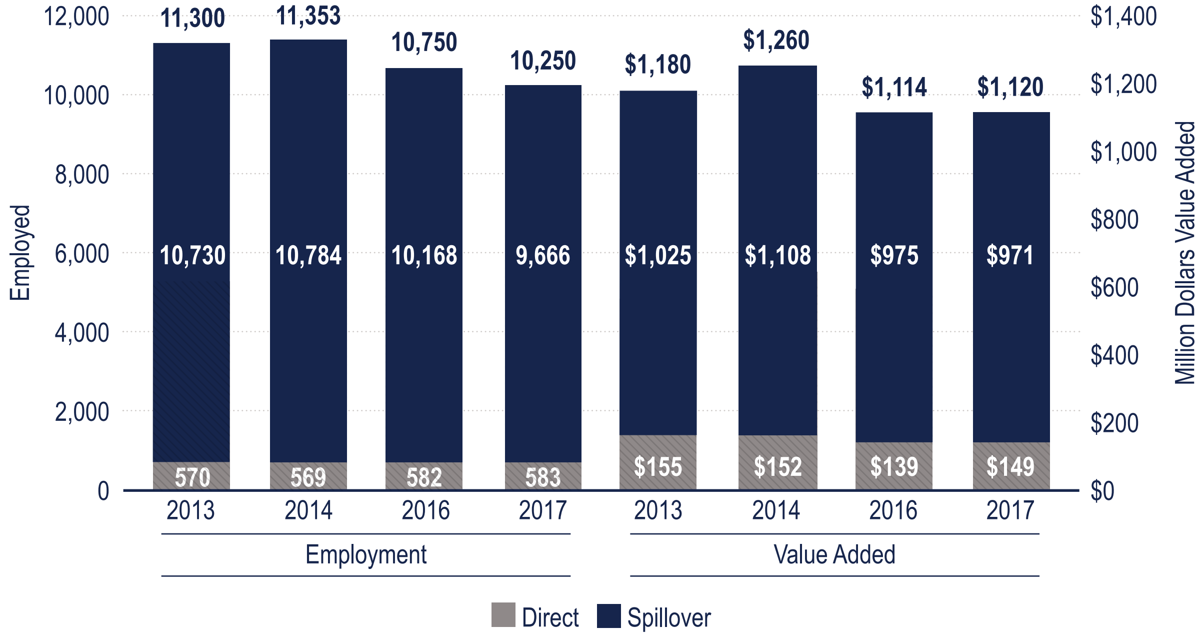


Table 5: Top 10 States for Direct Value Added to the Biorefining Sector in 2017 and percent change between 2013 and 2017.

Rank	State	Percent change 2013-2017	Rank	State	Percent change 2013-2017
1	Illinois	16%	6	Idaho	29%
2	Iowa	13%	7	North Dakota	0%
3	Indiana	19%	8	California	23%
4	Louisiana	12%	9	Florida	31%
5	Minnesota	28%	10	Texas	17%

Figure 15: Biorefining Sector Contribution to Employment and Value Added in 2013, 2014, 2016, and 2017.



As of January 8, 2015, there were 213 biorefineries in the United States with a nameplate capacity of 15,069 million gallons per year, and biorefineries were being constructed or expanded to produce another 100 million gallons per year. Many of these refineries are producing co-products that support the U.S. biobased products industry.[46]

Major U.S.-Based Firms[47]
Cargill (Minnesota)
Archer Daniels Midland Company (Illinois)
Poet, LLC (South Dakota)
Valero (Texas)
Green Plains Renewable Energy (Nebraska)
Flint Hills Resources (Kansas)

Economic Statistics
Total value added to the U.S. economy in 2017: **$1.1 billion**

Value added to the U.S. Economy by exports in 2017: **$172 million**

Type SAM Multiplier: **7.6 in 2017**

Employment Statistics
Total number of Americans employed due to biobased industry activities in 2017: **10,300**

Total number of Americans employed due to industry activities supporting exports of biobased products in 2017: **1,500**

SAM Employment Multiplier: **17.5 in 2017**

[46] 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.

[47] Forbes, "The World's Biggest Public Companies," Forbes website, accessed April 2015. http://www.forbes.com/global2000/list/.

Table 6: Distribution of Direct Value Added and Employment by Biorefining Sub-Sectors.

IMPLAN Code	NAICS Codes	Description	Employment	Value Added
70	311221	Wet corn milling	263	$86,000,000
74	311313	Beet sugar manufacturing	124	$20,000,000
75	311311, 311312	Sugarcane mills and refining	100	$26,000,000
71	311222, 311223	Soybean and other oilseed processing	54	$12,000,000
72	311225	Fats and oils refining and blending	42	$5,000,000
		Totals	**583**	**$149,000,000**

2.4.1 Overview

Biorefining is an innovative alternative to the production of petroleum-based energy, and it is an important part of emerging biobased economies. Over the next five years, the global market for biorefining is expected to increase to almost $717 billion, with a compound annual growth rate (CAGR) of 8.9 percent. North America and Europe lead the world market, but the Asia Pacific market is expected to have the highest growth rate in the coming years. This positive outlook from the industry is largely due to the volatile prices of fossil fuels. Growth in the sector is limited in that major investment and technological costs are required 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 provide an additional base from which they can sell their products.[48] 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.[49]

[48] "The Socio Economic Impact of a Biorefinery on Rural Renaissance," Climate Ethanol Alliance website, November 6, 2017, accessed May 2019, http://ethanolalliance.com/2017/11/06/the-socio-economic-impact-of-a-biorefinery-on-rural-renaissance/.

[49] Valdivia, M., Galan, J.L., Laffarga, J., Ramos, J., *Biofuels 2020: "Biorefineries Based on Lignocellulosic Materials." Microbial Biotechnology*. 2016; 9(5):585-594. doi:10.1111/1751-7915.12387.

2.4.2 Case study: Nanosystems: An Outlier Worth Noting

Dr. John Nanos, the founder and owner of Nanosystems, Inc., creates unique products and is an important player in the biobased products space. Nanos shared with us, "I am sure I am an outlier, but what we do is an important part of the goals established by the BioPreferred® Program, and I am living proof of the success of the program. I have a keen perspective on sustainable markets and on biobased technologies." Nanos believes the future of his company is based in biotechnologies, and given his background and experiences, he has a unique top-to-bottom perspective.

Nanos is an organic polymer chemist with a Ph.D. in organic chemistry from the University of Michigan (UM) and has been working in the area of polyurethane chemistry for more than 20 years. Upon finishing his graduate degree in chemistry, he was only aware of petroleum-based chemical feedstocks, and hence, started his career in the polyurethane world. Polyurethane chemistry is dominated by petroleum-based chemical feedstocks, and so Nanos followed his peers, working with petroleum as the primary (or only) feedstock for chemical developments.

The dominance of petroleum-based plastics was part of his and the chemical world's story, and for many years, biobased alternatives were limited, costly, and underperforming. Nanos stated that much of his work took place in a niche area of polyurethanes—hydrophilic or "water-loving" polyurethanes. This included cosmetic applicators, earplugs, wound dressing for absorbent articles that absorb human blood or fluids, as well as other products produced from this chemistry. Nanos explained that within this space of specialty polyurethanes, his industry was a slave to these 'exhaustible,' finite, petroleum-based feedstocks.

In 2005, while teaching chemistry as an adjunct professor at UM, Nanos launched a start-up company in Ann Arbor called Nanosystems, Inc. after developing an alternative way to make the polyurethane foam used in everything from the cores of surfboards to ear plugs and wound dressings. While Nanos was teaching at UM, he began consulting for companies that wanted to develop more eco-friendly surfboards. When Clark Foam, the dominant manufacturer of petroleum-based liquids used to make surfboard cores, was shut down in 2005, Nanos seized the opportunity to fill the void, and a business was born.

Nanos, who grew up in Dearborn, Michigan as the son of a Ford Motor Company engineer, developed chemicals for foam that are derived from soybeans, corn, and other vegetable oils instead of petroleum. Today, Nanosystems produces these liquid building blocks for foam in Ann Arbor and Texas, shipping them to customers around the globe.

One challenge as explained by Nanos was for the urethane industry to integrate sustainable feedstocks into its supply chain. This was a challenge because naturally-produced polyols were structurally different from the incumbent petroleum systems. Nanos remarked that trying to jam these naturally-produced polyols into potentially big volume products, such as bedding or car seats, was simply not possible. Nanos recalled that the structural differences and resulting application limits made it very difficult to make progress with biobased feedstocks in polyurethane foams early on, despite the fact that there was a large market demand for biobased polyurethanes. Nanos recognized there was a huge pull from the automotive community, as companies like Ford Motor Company were constantly seeking new sustainable materials for their vehicles.

A big stroke of luck occurred when Nanosystems discovered its biobased foam molecule could be made from sugar cane. This discovery came about through a collaboration with The Coca-Cola Company, which is the world's largest producer of polyethylene terephthalate (PET) bottles. The Coca-Cola Company sought a sustainable supply chain for its PET bottles, giving birth to its "Plant Bottle." The Coca-Cola Company gave Nanos access to this biobased supply chain for his specialty hydrophilic polyurethane systems. Nanos described this partnership using a metaphor, "I'm riding on the gorilla's back. Coke blazed the trail, and they allowed their assets to be incorporated into my polyurethane supply chain." Nanos explained this was important because Coke was now producing the same molecules being used by the automotive industry for foam, but now the new technology allowed the molecule to be based on raw materials from sugarcane instead of oil.

He emphasized that Nanosystems was lucky their biobased product was as good as, if not better than, the incumbent petroleum-based product. The challenge today for many biobased products in industries like the automotive industry is that biobased molecules can perform differently than petroleum-based molecules, without adding functional benefits from being biobased. Purchasing managers will not pay more for biobased ingredients if the performance is not as good as the petroleum-based alternatives. As Nanos noted, there must be both a performance and economic benefit. The automotive industry in particular is open to introducing biobased products when both these conditions hold, and Nanos has found a good reception in their development labs.

Patenting his biobased polyurethane technology and gaining the BioPreferred® Program's USDA Certified Biobased Product label has allowed Nanos to license a global partner —one of the largest producers in the United States—which specializes in cosmetic sponges and values a sustainable product life cycle. This partner produces a foam sponge, which is made from Nanos' biobased technology. These sponges are sold nationally in large retail chains. Reflecting on the partnership, Nanos said he is proud of it and what they have accomplished together. He remarked that they acted as a true partner, allowing Nanosystems to grow with them so the supply chain could evolve and become more efficient, which, in turn, allowed Nanosystems to benefit, as well as stabilizing the supply chain.

Another area of targeted expansion for Nanosystems is horticulture and agriculture. Nanos' biobased foams are hydrophilic, meaning that when the material is mixed with wet peat moss, it holds it in place like a binder and yields an ideal growing media with controlled moisture retention and porosity. These biobased foams benefit the plant root system, reduce plant mortality,

and can also be used for reforesting initiatives. Nanos commented that the horticultural industry represents another thriving opportunity for biobased ingredients.

Nanos recalled that in the early days of his career, he had to make a real commitment to biobased chemistry. He explained that he was unable to come to grips with being slave to the petroleum industry, knowing that petroleum is an exhaustible resource, and this realization was a driving factor in his career. He committed to becoming sustainable as a philosophy, and he studied the technology enough to recognize opportunities when they showed up in front of him. Nanos remarked that it is never hard to sell moving to biobased products if the product is as good as a petroleum-based product, and if the sustainable model does not add cost.

Nanos reasoned that the biobased product industry can only catch up to and overtake petroleum products if the biobased industry continues to become more efficient. "And the only way we will do that," Nanos continued, "is if we see more investment to bring more of the biobased supply chain into the United States. The BioPreferred® Program has been a great supporter from the beginning, and the USDA Certified Biobased Product label on my finished goods can be seen every time I walk into a Walmart. USDA helped to blaze the trail for my biobased polyurethanes, and helped support the case that being green and sustainable has a real market benefit, which is a tangible one."

2.5 Biobased Chemicals

Figure 16a: Total Value Added Contributed by the Biobased Chemicals Sector in Each State and the District of Columbia in 2017.

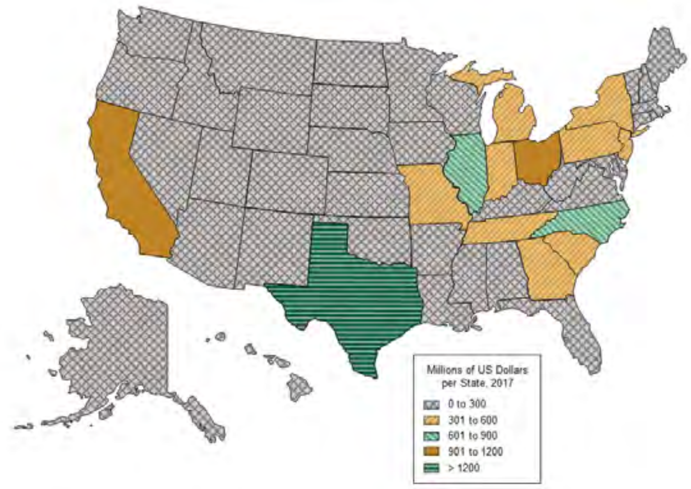


Figure 16b: Percent change (2013 – 2017) of Total Value Added Contributed by the Biobased Chemicals Sector in Each State and the District of Columbia.

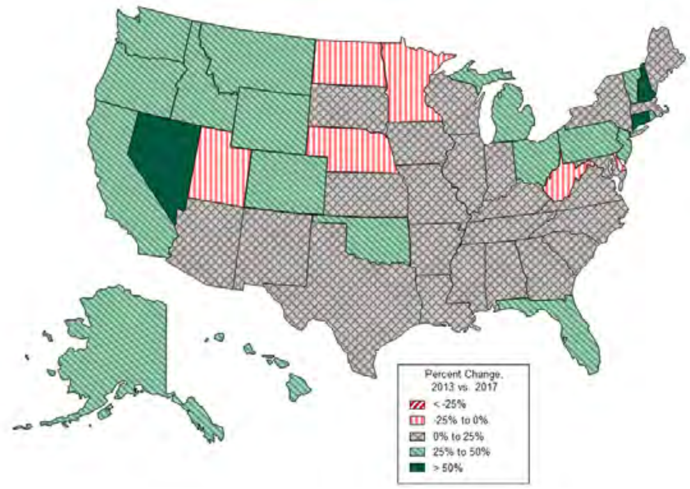
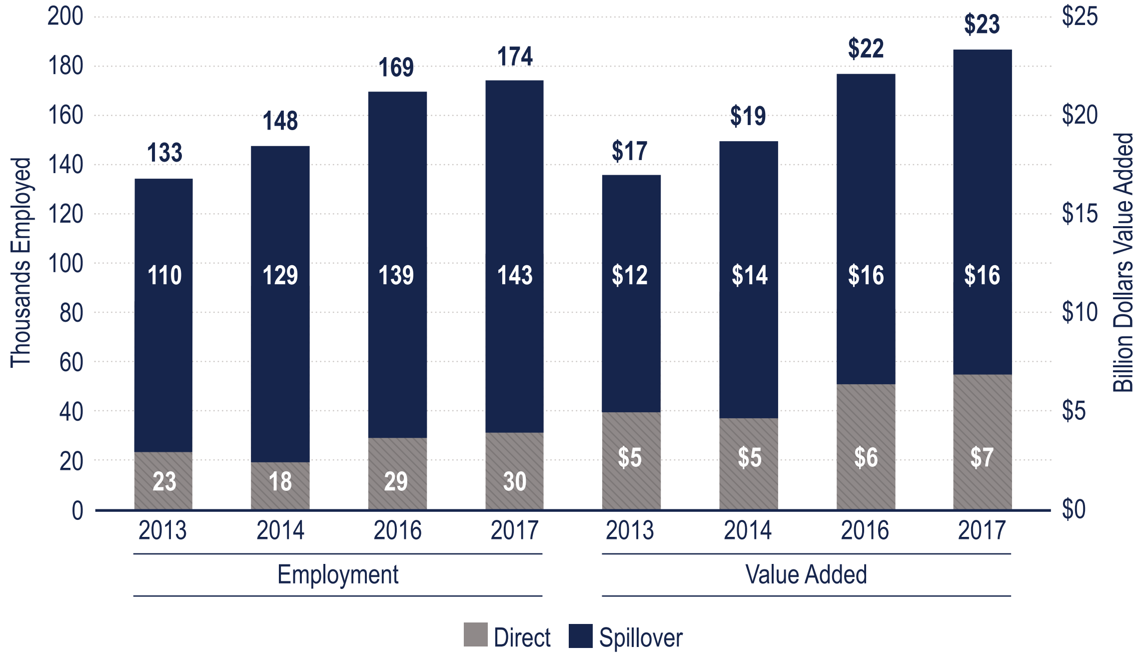


Table 7: Top 10 States for Direct Value Added to the Biobased Chemicals Sector in 2017 and percent change between 2013 and 2017.

Rank	State	Percent change 2013-2017	Rank	State	Percent change 2013-2017
1	Ohio	29%	**6**	Illinois	16%
2	Texas	17%	**7**	New York	15%
3	North Carolina	19%	**8**	Pennsylvania	26%
4	California	23%	**9**	Michigan	24%
5	New Jersey	25%	**10**	Tennessee	20%

Figure 17: Biobased Chemicals Sector Contribution to Employment and Value Added in 2013, 2014, 2016, and 2017.



After struggling for most of the past five years, the industry is expected to rebound over the coming five years and grow at an annual rate of 2.1 percent. Increased demand from downstream consumers, overall part of an expanding economy, signals a return to increased revenue and profits for the industry.[50]

Major U.S.-Based Firms[51]

DuPont (Delaware)
Sherwin-Williams Co. (Ohio)
Myriant (Massachusetts)
NatureWorks, LLC (Minnesota)
Dow Chemical Company (Michigan)
Gemtek (Arizona)
Gevo (Colorado)
Solazyme (California)
Biosynthetic Technologies (California)

Economic Statistics

Total value added to the U.S. economy in 2017: **$23 billion**

Exports value added to the U.S. Economy in 2017: **$4.8 billion**

Type SAM Value Added Economic Multiplier in 2017: **3.4**

Employment Statistics

Total number of Americans employed due to industry activities in 2017: **174,000**

Total number of Americans employed due to industry activities supporting exports in 2017: **36,000**

Type SAM Employment Multiplier in 2017: **5.7**

[50] IBIS report

[51] Forbes, "The World's Biggest Public Companies," Forbes website, accessed April 2015. http://www.forbes.com/global2000/list/.

Table 8: Distribution of Direct Value Added and Employment by Biobased Chemicals Sub-Sectors.

IMPLAN Code	NAICS Code	Description	Employment	Value Added
196	32621	Tire manufacturing	2,790	$345,000,000
182	325620	Toilet preparation manufacturing[52]	2,890	$1,252,000,000
198	32629	Other rubber product manufacturing	2,860	$326,000,000
166	325211	Plastics material and resin manufacturing	2,950	$830,000,000
165	32519	Other basic organic chemical manufacturing	2,740	$611,000,000
177	325510	Paint and coating manufacturing	2,140	$530,000,000
187	325998	Other miscellaneous chemical product manufacturing	2,000	$411,000,000
193	326150	Urethane and other foam product (except polystyrene) manufacturing	1,860	$215,000,000
192	326140	Polystyrene foam product manufacturing	1,700	$199,000,000
168	32522	Artificial and synthetic fibers and filaments manufacturing	1,250	$198,000,000
179	325611	Soap and other detergent manufacturing	1,390	$776,000,000
197	326220	Rubber and plastics hoses and belting manufacturing	1,190	$143,000,000
180	325612	Polish and other sanitation goods manufacturing	1,250	$415,000,000
178	325520	Adhesive manufacturing	1,140	$227,000,000
185	325991	Custom compounding of purchased resins	900	$160,000,000
186	325992	Photographic film and chemical manufacturing	560	$122,000,000
183	325910	Printing ink manufacturing	450	$74,000,000
181	325613	Surface active agent manufacturing	270	$128,000,000
		Totals	**30,330**	**$6,962,000,000**

[52] This industry comprises establishments primarily engaged in preparing, blending, compounding, and packaging toilet preparations, such as perfumes, shaving preparations, hair preparations, face creams, lotions (including sunscreens), and other cosmetic preparations.

2.5.1 Overview

Biochemicals currently make up a very small segment—estimated at less than one percent of the overall revenue—of the chemical industry. This section and the subsequent sections describe the chemical manufacturing industry, not the biochemical manufacturing industry. 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 most of the past five years, the industry is expected to rebound over the coming five years and grow at an annual rate of 2.1 percent. Increased demand from downstream consumers signals a return to increased revenue and profits for the industry.[53]

Consumer spending and manufacturing have a direct effect on chemical demand since 96 percent of all products made in the United States require chemical inputs. Therefore, an increase in the industrial production index, which tracks the mining, manufacturing, electric, and gas industries, directly affects demand for chemicals. The construction industry is also important to chemical manufacturing in that it is a key supplier to the industry and is also a marker of the health of the overall economy.

The current, modest growth in emerging economies abroad is a good sign for industry exports, even as the industry battles against the trade-weighted index. It remains to be seen how strong the dollar will become over the coming years and what kind of detrimental effect this will have on exports. As producers benefit from lower operating costs, revenue is mitigated further by increases in wages and increases in input prices.

Chemical prices over the past five years have been extremely volatile, particularly due to crude oil prices. This volatility occurs because chemicals are the most influential raw materials from the standpoint of what industries must pay to obtain them. The biobased chemical industry offers an alternative model for sourcing raw materials independent of fossil fuels. This provides chemical manufacturers the ability to conduct long-term planning using steadier inputs. Major industry giants such as DowDupont and the Sherwin-Williams Company already have committed themselves to a turn towards the biobased industry. Further, the awareness and demand for green products and sustainable business models will encourage companies, both large and small, to explore and invest in the biochemical industry.

Plastic & Resin Manufacturing

The plastic and resin manufacturing industry produces synthetic rubber, thermoplastics, and thermosetting resins. While demand has been steady, the volatility of the prices of raw materials has caused revenue to decrease over the past five years. Demand from construction and manufacturing industries is a key marker for success in this industry. Over the five-year period from 2018 to 2022, annual growth is expected to increase by 0.3 percent. Exports, during the same period, are expected to increase by 0.4 percent.

Synthetic Fiber Manufacturing

The synthetic fiber industry relies heavily on several key downstream purchasers, from carpet and textile mills to manufacturers of industrial products. As some of these industries slowed in recent years, the synthetic fiber industry also was less profitable. Exports also decreased as the U.S. dollar gained in value, and imports became more affordable, which weakened domestic demand even further. Over the next five years, from 2018 through 2022, revenue is expected to recover somewhat, with an increase of about 1.1 percent. This increase is expected because of a healthier economy, specifically a strong construction market and more disposable income.

Soap & Cleaning Compound Manufacturing

Over the past five years, foreign competition and volatile oil prices have put a strain on the industry's profits. Between now and 2022, manufacturers are expecting to contend with this competition by producing high-quality, brand-name, environmentally-friendly products that capitalize on increased disposable income. Industry leaders will explore products that feature "biodegradability, aquatic toxicity, renewable feedstock, and carbon dioxide emissions." However, as the dollar appreciates, exports in this industry

[53] IBIS report

are expected to decrease sharply to 6 percent over the next five years. Biobased chemicals are an important growth factor in this subsector, because consumers are more concerned about using natural organic and plant-based compounds in their soap.

Cosmetic & Beauty Products Manufacturing

This industry produces a wide range of products, from essentials, such as deodorant and body wash, to discretionary items, such as creams and lotions. Consumer demand for environmentally-friendly products with natural ingredients is helping create a new market that relies on biobased products. As companies in the United States expand their reach globally, exports are expected to increase by 4.6 percent in the period between 2018 and 2022, while overall revenue is expected to produce a modest growth of 0.6 percent.

Ink Manufacturing

Restructuring will continue in the ink manufacturing industry between 2018 and 2022 as it grapples 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 percent. Exports also are set to decrease by 0.9 percent due to increasing competition from foreign producers. The authors estimated that biobased plastic production in the United States was approximately 0.3 percent of the total annual production of plastic, and the authors estimated that the entire chemical sector was 4 percent biobased chemicals.[54] Estimates of the future penetration of the market by commodity chemicals by 2025 vary from as little as vary from as little as 6 - 10 percent to as much as 45 - 50 percent for specialty and fine chemicals.[55, 56]

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[54] BCC Research, “Biorefinery Applications: Global Markets,” March 2014, p. 118.

[55] Bachmann, R. (2003), Cygnus Business Consulting and Research.

[56] Informa Economics, Inc. (2006), “The Emerging Biobased Economy: A Multi-Client Study Assessing the Opportunities and Potential of the Emerging Biobased Economy.” Developed by Informa Economics, Inc. in Participation with MBI International and The Windmill Group.

2.5.2 Case Study: Croda: A Company Steeped in Biobased History Moves Forward to a Successful Future

Croda was founded in 1925 by entrepreneur George Crow and chemist Henry Dawe (hence the "CRODA" name), based on a vision of creating products entirely from natural materials. The first product the company produced was lanolin made from refined wool grease. From this, Croda has grown to become a global specialty chemicals company that creates ingredients and technologies used in formulating everyday products used by industry and consumers. The company's first manufacturing site was opened in the North of England in 1925. Croda still operates there today, but has grown to more than 4,200 employees across manufacturing sites and has offices in more than 36 countries.

Croda's evolution from producing lanolin to exploring a wide range of specialty chemicals made from natural sources took time. World War II brought contracts to supply items such as camouflage oils, insect repellents, and gun cleaning oils, and as the war ended, Croda diversified into new areas; most notably cosmetics. The company established a sales office in New York in the 1950s. This laid the foundation for Croda, Inc., which has two manufacturing sites and sales teams covering all of North America and Canada. In the 70s and 80s, Croda began to acquire new companies and continued diversifying into different markets. This allowed the company to recognize that its core competency was creating specialty ingredients from renewable resources, which then became the focus of all activity. In 1997, Croda acquired Sederma, a world leader in active ingredients for skincare. With this purchase came new capabilities in producing skincare active ingredients. The 2006 acquisition of Uniqema firmly established Croda as a global leader in the personal care products industry.

Today, Croda continues to seek out changing market requirements and create products that anticipate these new needs. The company has three core market sectors: Personal Care / Life Sciences, comprised of Crop Care and Health Care; Performance Technologies comprised of Coatings and Polymers, and finally, Geo Technologies, Home Care, Lubricants, and Polymer Additives. There is also an Industrial Chemicals business area. In all areas of the business, the focus is on developing and delivering innovative ingredients sustainably. In 2013, the company was named among the top 100 most sustainable companies in the world.[57]

Greg Smith, Director of Marketing and Sales for Croda's Performance Products Division, describes the business: "We supply the 1 - 5 percent ingredient that makes the end-use product perform for our customers' customer." Croda makes hundreds of ingredients that are emulsifiers, demulsifiers, wetters, hydrotropes, rheology modifiers, corrosion inhibitors, friction modifiers, anti-stats, polymer slip agents, natural polyols, emollients, excipients, and adjuvants. One of Croda's core business areas is emulsion technology, which involves creating ingredients that can prevent mixtures, such as oil in water, from separating.[58]

One example of the emulsion technology created by Croda is a range of non-ionic surfactants. The non-ionic surfactants can be made up of esters, fatty acids, and fatty alcohols, which are typically hydrophobic and do not dissolve well in water. These chemicals are used as a substrate that is reacted with ethylene oxide to give them water-loving, or hydrophilic, properties. A key characteristic of surfactants is that they contain both hydrophobic and hydrophilic components, which allows them to be soluble in water or oil mixtures. Croda's surfactants serve as ingredients used in a broad range of applications, including personal care, health care, crop care, lubricants, polymer additives, coatings and polymers, home care, and industrial chemicals.

Fatty acids and fatty alcohol are derived from biobased feedstocks, including palm coconut, tallow, fish oil, canola, and other naturally occurring fats and oils. In addition, ethylene oxide can be derived from biobased ethanol. Today, 90 - 95 percent of ethylene oxide is produced using petrochemical processes. Croda produces ethylene oxide from alcohol derived from corn and other biobased sugars, and in the future, the company is seeking to use ethanol as a feedstock. The process for producing ethylene oxide involves taking corn- and sugar-based ethanol and dehydrating the material to produce ethylene. Then, the ethylene passes through a silver catalyst and reacts with oxygen, producing ethylene oxide. Next, Croda refines the ethylene oxide to remove impurities. This purified ethylene oxide is then used to make non-ionic surfactants. Croda uses its ethylene oxide exclusively for surfactants, and all of the ethylene oxide is consumed on-site.

[57] "What We Do," Croda website, accessed August 2019, https://www.croda.com/en-gb/about-us/what-we-do.

[58] "Emulsification," Croda website, accessed August 2019, https://www.crodaindustrialchemicals.com/en-gb/products-and-applications/emulsification#tab-collapse-non-ionic-surfactants.

The surfactants that have 100 percent biobased substrates now combined with 100 percent biobased EO have been tested and certified through the USDA BioPreferred® Program. Croda currently has 85 surfactants qualified to be labeled with the ECO prefix ahead of its products, a designation for its 100 percent biobased line. The company also has a prefix for products with increased renewable content, branded with "EBC" for "Enhanced Biobased Content" products. The USDA's BioPreferred® Program uses an ASTM test method to quantify renewable carbon.

Croda's production facilities are also designed for sustainability, including its facility in Atlas Point, DE where the biobased EO and nonionic surfactant plant is located. Renewable energy supplies 100 percent of the facility's steam and 50 percent of its electricity. Croda's headquarters in Edison, N.J. is 50 percent powered by solar energy. The company's plant in Hull, United Kingdom generates its own wind power, and the site in Gouda, Netherlands generates all of its steam needs through biodigestion of glycerin streams. Croda's Atlas Point surfactants have the lowest carbon footprint in their class, and Croda as a whole continues to look to reduce CO_2 emissions throughout the global manufacturing system.

Smith noted more and more customers say they might pay more for a product if they know it is biobased and it works: "Consumers are becoming more educated. In 2004, only 4 percent cared about the biobased content of their consumer products, and in 2014, 26 percent said they cared about the biobased content in their products. The problem with many biobased options, until now, has been performance. Ethylene oxide has always been the water-soluble tool of choice in chemistry but has not been biobased. Now, with biobased ethylene oxide, performance is as good as petrochemically-derived ethylene oxide. Consumer companies like Seventh Generation, Method, Honest Company, and others are formulating consumer products that are renewable, biobased, readily biodegradable, and low in toxicity."

Croda makes biobased ethylene oxide at their manufacturing facility in Atlas Point, Del. The biobased ethylene oxide will support the manufacture of biobased nonionic surfactants in 2020. Smith said, "We expect to see millions of pounds of biobased products being produced, replacing petrochemical and non-renewable products. We will be making a positive impact on our business, on our customer's business, and on the environment." The company has invested because it believes in sustainability as a core business tenant and biobased feedstocks are the wave of the future. For Croda, the future is now.

2.5.3 Case Study: Biodegradable Products Institute and the Role of Biobased Products

The BPI is the leading certification institute for compostable packaging and products. Its certification program ensures products and packaging displaying the BPI logo have been independently tested and verified according to scientifically-based standards. The BPI also promotes best practices for the diversion and recovery of compostable material through municipal and commercial composting.[59]

A year ago, the California legislature outlawed the use of disposable plastic bags in grocery stores: an important step towards reducing single-use plastic waste. There is still much single-use plastic tossed out every day — including beverage cups and lids, snack wrappings, potato chip bags, water bottles, and take-out food containers. BPI is playing an important role in how this story will play out. Plastic litter is not just ugly to look at; it is a threat to the environment. Plastic is accumulating rapidly in every type of natural environment. Conventional plastic does not biodegrade and instead breaks into smaller and smaller pieces that are showing up in increasing numbers in oceans and lakes and are being eaten by sea birds and fish.

Rhodes Yepsen first got involved with the composting movement more than a decade ago when he became an editor and writer for BioCycle Magazine, the leading magazine on composting, residential food waste programs, and disposable products. Later, he began working as a consultant, then got involved as a board member for BPI. Eventually, he became BPI's Executive Director.

With a comprehensive perspective on the world of composting and biodegradable products, Yepsen has developed insight on the many challenges that exist within this area. "The biggest problems facing composting," Yepsen explained, "are the lack of infrastructure, the small number of composting facilities accepting food waste and packaging, and as the number of programs grow, the lack of access to these facilities. That is the biggest hurdle – there are many commercial organic programs serving stadiums, universities, and sports facilities. However, there are only a few municipalities that offer curbside composting, and until we get that number up to the level of recycling, we will continue to face a major barrier for compostable packaging."

According to the EPA's 2015 data on Municipal Solid Waste (MSW) generation, people in the United States composted 8.9 percent of all the waste they generated. Compare that with 52.5 percent of waste generated going to landfills, 25.8 percent going to recycling, and 12.8 percent going to combustion with energy recovery.[60] In the EPA data, composted material is broken into two main categories: yard trimmings (for example, leaves or cut grass) and food. In 2015, people in the United States generated almost 35 million tons of yard trimmings and composted 61.3 percent of it. This is a sharp contrast to the people in the United States' generation of nearly 40 million tons of food scraps and composting only 5.3 percent of it.

[59] Biodegradable Products Institute, accessed May 2019, https://www.bpiworld.org/.

[60] "Advancing Sustainable Materials Management: 2015 Fact Sheet," EPA, July 2018, accessed May 2019, https://www.epa.gov/sites/production/files/2018-07/documents/2015_smm_msw_factsheet_07242018_fnl_508_002.pdf.

The availability of composting facilities is key to this issue. Even as the volume of compostable packaging is growing, there will be a limit to this growth if packaging cannot be effectively composted at the proper facilities. A 2017 study conducted by BioCycle determined there were 4,713 total compost facilities in the United States. Of those 4,713 facilities, 57 percent accept yard trimmings only, 5 percent accept yard trimmings and food scraps only, and another 13 percent accept "multiple organics," which include yard trimmings and food scraps as well as other industrial organic wastes.[61] The majority of these facilities are not designed to handle compostable packaging or post-consumer waste, which can often be contaminated with other packaging and waste materials that are not compostable. That is where the value proposition comes in.

Studies have shown that the use of compostable packaging in a foodservice environment will increase the amount of food scraps they are able to capture and eventually send to a composter. This makes more sense if you picture a waste station in a foodservice environment that uses takeout packaging. If patrons are able to deposit food scraps and packaging in one bin that accepts both materials, there is actually a chance that the food scrap portion will be diverted from the landfill. Food scraps, such as leftover nachos in a container or a half-eaten pizza in a box—are contaminants to traditional recycling streams, and the two elements (food scraps and packaging) must be separated before being placed in recycling or compost bins. However, many patrons will not take the time to separate their waste, and thus, without the compost part of the waste diversion system, all of the food scraps and packaging are lost to the landfill.

Biodegradability and Biobased Products

It is important to note that biobased is not the equivalent of biodegradable, and vice versa. A biobased product is determined by what feedstocks were used in creating the material. Biodegradability is determined by the way a material decomposes. For example, NatureWorks Ingeo® products are biobased, and they are also compostable and biodegradable. For this reason, if cutlery converters use Ingeo material to produce cups or forks, they advertise the products' composability.

The BPI Label

The BPI label certifies that a product is compostable. Products that are awarded the BPI certification are listed by stock keeping unit in a database. This listing is key to ensuring that products bearing the logo are, in fact, compostable. It is not always easy for the consumer to understand and prioritize ecolabels, so branding is an important component of how marketers view the label.

In general, the concept of consumer product sustainability is a complex situation to navigate, as the product characteristics are often dependent on the types of problems one is seeking to solve. For example, a manufacturer that is trying to reduce non-renewable inputs would focus on biobased products, while a manufacturer that is trying to reduce the amount of the product that is going into landfills will be concerned with compostability. In some cases, both criteria can be met. While consumers are looking for an easy decision that is "green," there is often no single solution that meets all the criteria for sustainable materials.

In fact, Yepsen offered the opinion that not all biobased plastics should be compostable:

"I happen to believe that having recyclable biobased plastics is also important," said Yepsen. "Having a drop-in biobased PET that is used in the PlantBottle® is also critical, even though the entire bottle is not compostable, nor would we want them to be. If we can fit consumer products like the PlantBottle® into the recycling stream, that is a positive trend. We have to recognize that despite the challenges along the way, there is an upwards trend towards sustainable packaging and the issue is getting more consumer attention. There is a rosy future ahead for biobased plastics, durables, and recyclables. What we are experiencing now are bumps in the road, not roadblocks!"

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[61] Goldstein, N., "The State of Organics Recycling in the U.S.," BioCycle, October 2017, accessed May 2019, https://www.biocycle.net/2017/10/04/state-organics-recycling-u-s/.

2.6 Enzymes

Figure 18a: Total Value Added Contributed by the Enzymes Sector in Each State and the District of Columbia in 2017.

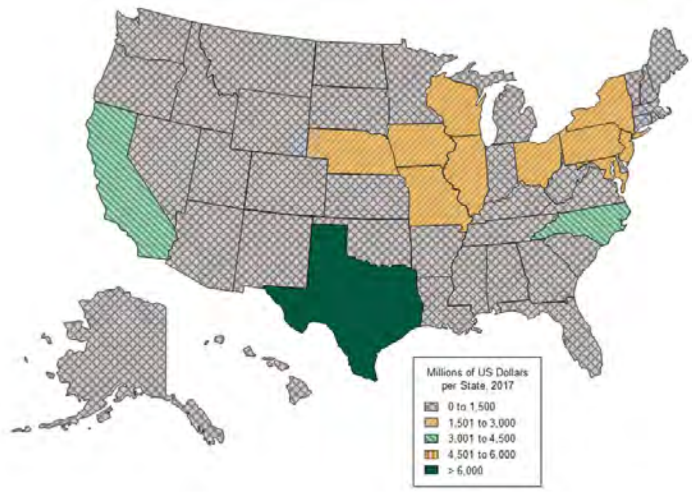


Figure 18b: Percent change (2013 – 2017) of Total Value Added Contributed by the Enzymes Sector in Each State and the District of Columbia.

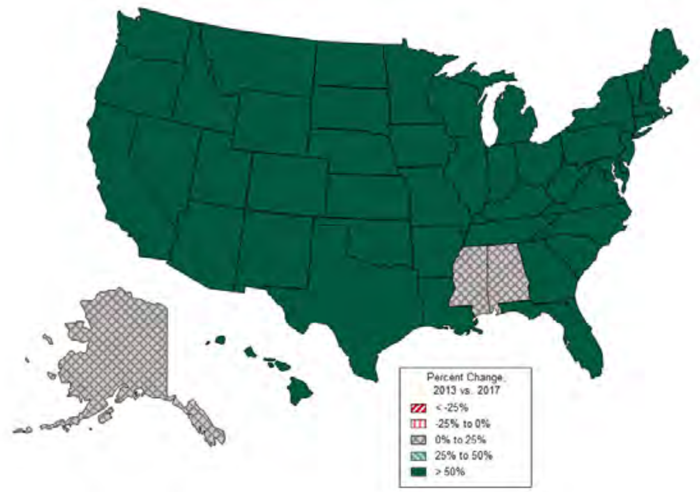
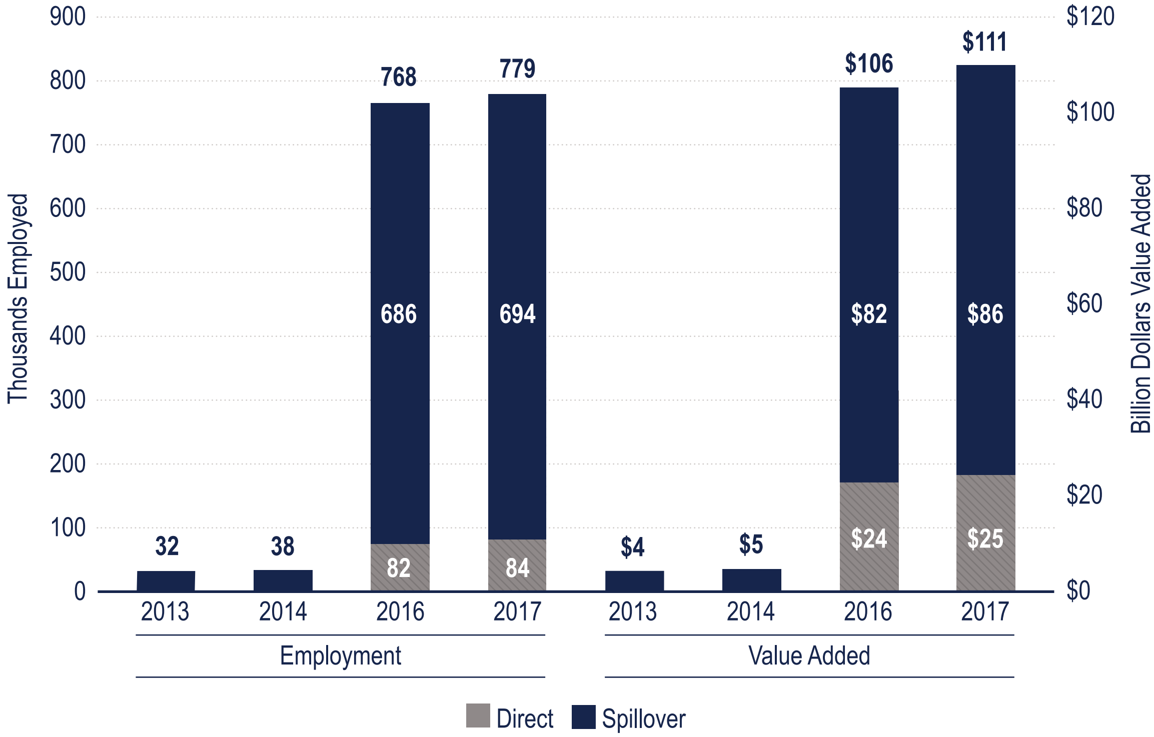


Table 9: Top 10 States for Direct Value Added to the Enzymes Sector in 2017 and percent change between 2013 and 2017.

Rank	State	Percent Change 2013-2017	Rank	State	Percent Change 2013-2017
1	North Carolina	96%	**6**	California	97%
2	Texas	95%	**7**	New York	97%
3	Maryland	97%	**8**	Ohio	95%
4	Pennsylvania	96%	**9**	Nebraska	94%
5	Iowa	95%	**10**	Missouri	96%

Figure 19: Enzymes Sector Contribution to Employment and Value Added in 2013, 2014, 2016, and 2017.[62]



Enzymes are used in a wide range of industrial sectors, including the production of detergents and biobased chemicals. The industrial enzyme market in the United States was estimated at $1.315 billion in 2016 and is expected to increase at a CAGR of 5.6 percent in the period 2017-2022.[63]

Major U.S.-Based Firms

National Enzymes Company (Missouri)
Archer Daniels Midland (Illinois)
Verenium/BASF (California)
Dyadic (Florida)

Global Firms with a Presence in the U.S.

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

Economic Statistics

Total value added to the U.S. economy in 2017: **$111 billion**

Exports value added to the U.S. Economy in 2017: **$32 billion**

Type SAM Economic Multiplier in 2017: **4.5**

Employment Statistics

Total number of Americans employed due to industry activities in 2017: **779,000**

Total number of Americans employed due to industry activities supporting exports in 2017: **225,000**

Type SAM Employment Multiplier in 2017: **9.2**

[62] The 2013-2014 results were calculated using a different methodology than the 2016-2017 results and are thus not directly comparable.

[63] Mordor Intelligence report: "United States Industrial Enzymes Market," 2016, accessed March 2018. https://www.mordorintelligence.com/industry-reports/united-states-industrial-enzymes-market.

Table 10: Distribution of Direct Value Added and Employment by Enzymes Sub-Sectors.

IMPLAN Code	NAICS Codes	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 a very 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, winemaking, brewing, and baking.

Globally, the industrial enzyme market greatly contributes to the annual revenue and is a major driver for innovation across a number of industries. The industrial enzyme market in the United States was estimated at $1,315 million in 2016 and is expected to grow at a CAGR of 5.6 percent in the period encompassing 2017-2022.[64] This positive outlook is owed to a number of factors, ranging from government legislation to growing demand in a number of key industries.[65] 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.[66] New research in forensics and molecular biology will also help drive innovation and meet demand.[67]

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 percent of enzymes yet to be classified, this indicates an enormous possibility for innovation and growth. Industrial enzymes serve a dual function within the biobased industry. By facilitating biochemical reactions, enzymes directly reduce the use of petrochemicals and a 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.

64 Mordor Intelligence report: “United States Industrial Enzymes Market, 2016,” accessed March 2018. https://www.mordorintelligence.com/industry-reports/united-states-industrial-enzymes-market.

65 Grand View Research: “Enzymes Market by Type, Market Research Report,” accessed March 2018. https://www.grandviewresearch.com/industry-analysis/enzymes-industry.

66 Grand View Research: “Enzymes Market by Type, Market Research Report,” accessed March 2018. https://www.grandviewresearch.com/industry-analysis/enzymes-industry.

67 Grand View Research: “Enzymes Market by Type, Market Research Report,” accessed March 2018. https://www.grandviewresearch.com/industry-analysis/enzymes-industry.

2.6.2 Case Study: Sealed Air: Developing Biobased Packaging Solutions

With the explosion in e-commerce, product packaging is becoming a growing industry. The global bubble wrap packaging market is growing at a rate of 7 percent annually due to the growth in online shopping, electronics, and availability in the market, and it is expected to reach $10.73 billion by 2023.[68] From The Atlantic:

> *The biggest market share holder in the American protective-packaging space is Sealed Air, a company with a very literal name that has some historical origins. The company was founded in 1960 by Alfred Fielding and Marc Chavannes, the inventors of bubble wrap. At the time, bubble wrap was invented for use as wallpaper. That trend never caught on, but the material's use as protective packaging took off. Before bubble wrap, the most common options for cushioning goods in transit were sawdust, newspaper, and rubberized horsehair.*
>
> *Sealed Air has since branched out from bubble wrap, which now accounts for only about 15 percent of its $1.6 billion protective-packaging business. But air-cushion sales have been booming. The company's "fill-air" product is used by Amazon, Home Depot, Walmart, UPS, and FedEx. "That product has experienced a real uptick for us. Our sales for fill-air is up about 40 percent versus prior years," said Ken Chrisman, the president of the protective-packaging division of Sealed Air.*[69]

In the last several years, Sealed Air has begun to introduce biobased packaging materials, including a polyethylene foam called EcoPure. The company has also recently announced a partnership with Plantic to introduce a plant-based food packaging film. Additionally the company produces a number of fiber-based solutions such as a paper-based insulative product called TempGuard, which is proving to be popular among e-commerce grocers such as SunBasket.

As Vice President of Corporate Innovation and Sustainability at Sealed Air, Dr. Ron Cotterman is excited about the possibilities in the sustainable packaging industry. Cotterman is a chemical engineer by training with more than 30 years of experience working in research and development in the industry, and he has spent the last 10 of those years in a sustainability-focused role, searching for alternative packaging solutions. He leads a number of teams working with Sealed Air's corporate strategy team to champion new goals for the company to employ sustainable materials in packaging systems.

When discussing his early work in the sustainability field, Cotterman noted his job was to identify mergers involving biobased products to fill Sealed Air's portfolio (the company would execute the mergers and see if the biobased products had advantages). Cotterman stated that, in general, they found most biobased packaging was more expensive than traditional packaging, and the performance tradeoffs were unacceptable. As a result, the company experimented with a lot of new technology, including a polystyrene foam tray produced from polylactic acid, but they were unable to make it feasible with the competitive market, and therefore, exited those businesses.

Sealed Air has two primary product lines. The first, Cryovac, is for food packaging; the second, bubble wrap, is for fulfillment and e-commerce. Sealed Air is headquartered in Charlotte, with operations providing multiple products to industry outside of packaging products, including films, laminates, bags, and equipment. As a systems provider, Sealed Air develops the systems, equipment, and materials to produce its packaging products, and they also provide training for their customers on how to use their packaging technology.

Sealed Air has a number of sustainable product initiatives underway. First, the company produces several biodegradable, fiber-based materials used to create mailers for e-commerce. Additionally, the company produces paper-based systems used as insulation in meal kits. The recent rise in popularity of convenience foods like meal kits and ready meals has expanded the market for insulating materials. Demand for sustainable packaging is growing due to requests from consumers, as well as major e-commerce retailers like Amazon, who are establishing sustainability goals for their materials.

[68] "Bubble Wrap Packaging Market to Grow at 7.04 percent," Packaging Technology Today, Jan. 10, 2018, accessed May 2019, http://www.packagingtechtoday.com/news-headlines/bubble-wrap-packaging-market-to-grow-at-7-04/.

[69] Lam, B., "About Those Air Cushions In Amazon Packages Everywhere," The Atlantic, Dec. 22, 2016, accessed May 2019, https://www.theatlantic.com/business/archive/2016/12/air-cushions/511487/.

Second, Sealed Air is working on a new polyethylene foam produced from biobased polyethylene derived from sugarcane. The biobased foam option is being explored by package delivery companies like UPS, who are concerned with weight, safety, and transportation efficiency. While the biobased foam is identical to the petroleum-derived foam, the biobased foam has a 40-60 percent price premium disadvantage, which can be offset by other materials. However, the market has not provided clarity on how much of a premium consumers are willing to pay, and if there is no performance advantage, then it can be difficult to justify a biobased foam. In almost all cases, the cost differential is purely an effect of what raw materials cost, not manufacturing efficiency, which puts the emphasis on deriving lower-cost materials.

Third, Sealed Air is releasing a new biobased food packaging material made from Plantic™ biobased plastic resin. Through a cooperation formed in 2018 with a Japanese chemical company, Kuraray, Sealed Air is offering biobased food packaging materials made from Plantic™ biobased resins. The Plantic™ packaging material, derived from corn, will be used to package perishable foods such as poultry, beef, and seafood. The Plantic™ material has a special feature developed for food applications:

Plantic's barrier trays are made from recycled PET, with a thin layer of Plantic's renewable barrier material which helps keeps the meat fresh. During the recycling process, the thin Plantic plant starch layer uniquely washes away, allowing the PET tray to be recycled.[70]

The product is a great example of a biobased material that is competitive, has performance advantages. It provides a highly effective oxygen barrier and it is also cost competitive with traditional rollstock barrier films.[71] Sealed Air is now in the process of building a new plant in Houston to scale-up production of this new product.

[70] Coles Plantic Joint Press Release, Plantic™, July 24, 2018, accessed May 2019, http://www.plantic.com.au/Latest_News/coles-plantic-joint-press-release.

[71] Sealed Air to offer Plantic™ bio-based food packaging in the United States, Canada and Mexico, Sealed Air®, June 5, 2018, accessed May 2019, https://sealedair.com/media-center/news/sealed-air-offer-plantic-bio-based-food-packaging-united-states-canada-and-mexico.

2.7 Biobased Plastic Bottles and Packaging

Figure 20a: Total Value Added Contributed by the Biobased Plastic Bottles and Packaging Sector in Each State and the District of Columbia in 2017.

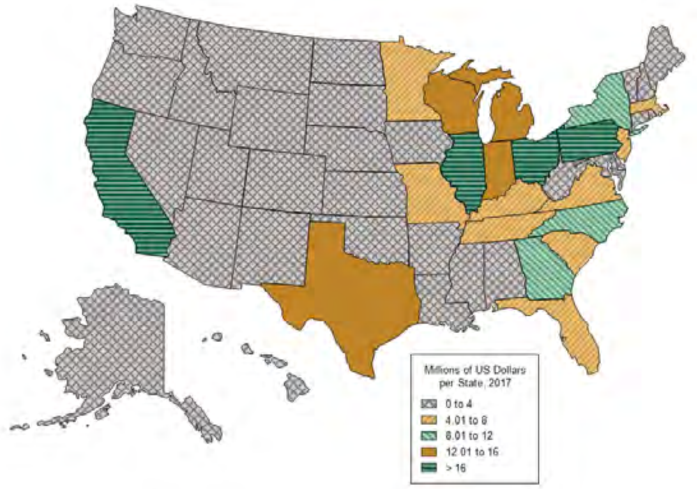


Figure 20b: Percent change (2013 – 2017) of Total Value Added Contributed by the Biobased Plastic Bottles and Packaging Sector in Each State and the District of Columbia.

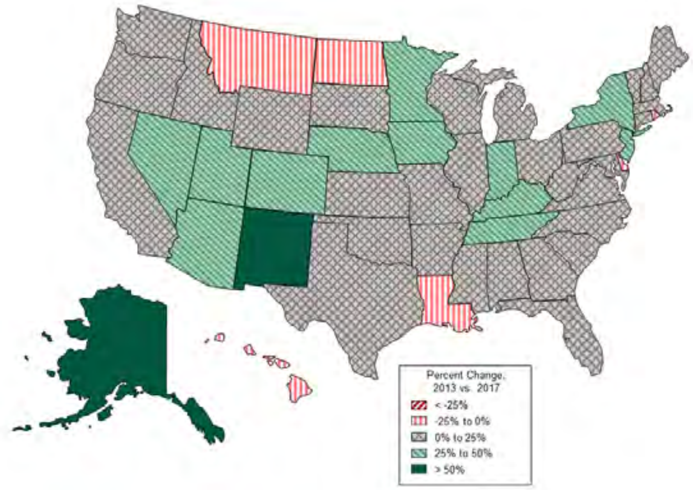
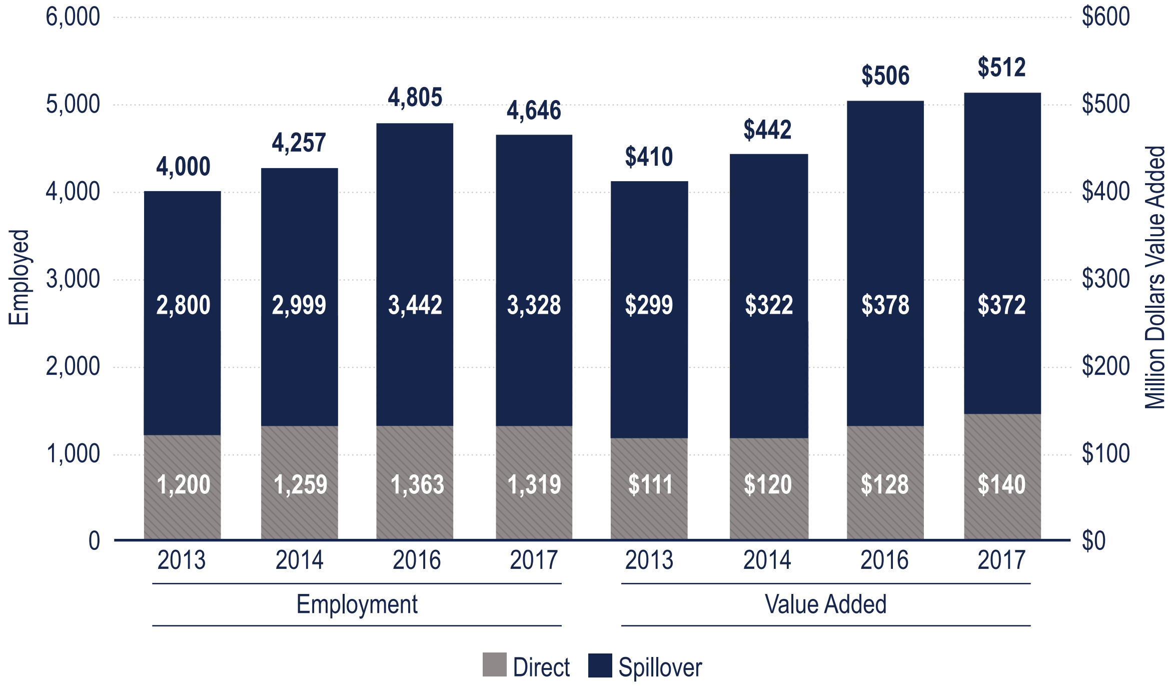


Table 11: Top 10 States for Direct Value Added to the Biobased Plastic Bottles and Packaging Sector in 2017 and percent change between 2013 and 2017.

Rank	State	Percent Change 2013-2017	Rank	State	Percent Change 2013-2017
1	Illinois	15%	**6**	Michigan	18%
2	Ohio	14%	**7**	Indiana	20%
3	California	12%	**8**	Texas	13%
4	Pennsylvania	18%	**9**	New York	24%
5	Wisconsin	14%	**10**	Georgia	15%

Figure 21: Biobased Plastic Bottles and Packaging Sector Contribution to Employment and Value Added in 2013, 2014, 2016, and 2017.



The biobased plastics manufacturing industry is relatively young and has a positive growth forecast estimated at 4.5 percent to 2023. Drop-in solutions represent the single largest sector of global biobased plastics production. They are (partly) biobased, non-biodegradable commodity plastics, such as PE, PET, and PP, and they can be recycled easily along with their conventional counterparts.[72]

Major U.S.-Based Biobased Plastics Producers

DuPont (Delaware)
Jamplast (Missouri)
Metabolix (Massachusetts)
NatureWorks, LLC (Minnesota)
Teknor Apex (Rhode Island)
Gevo (Colorado)
Virent (Wisconsin)

Major U.S.-Based Biobased Plastics Users

Coca-Cola (Georgia)
Ford Motor Company (Michigan)
Heinz Company (Pennsylvania)
Nike (Oregon)
Procter & Gamble (Ohio)

Economic Statistics

Total value added to the U.S. economy in 2017: **$512 million**
Exports value added to the U.S. Economy in 2017: **$59 million**
Type SAM Economic Multiplier in 2017: **3.7**

Employment Statistics

Total number of Americans employed due to industry activities in 2017: **4,800**
Total number of Americans employed due to industry activities supporting exports in 2017: **540**
Type SAM Employment Multiplier in 2017: **3.5**

[72] 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.

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

IMPLAN Code	NAICS Codes	Description	Employment	Value Added
195	32619	Other plastics product manufacturing	890	$76,000,000
188	32611	Plastics packaging materials and unlamented film and sheet manufacturing	270	$39,000,000
194	326160	Plastics bottle manufacturing	90	$14,000,000
189	326121	Unlamented plastics profile shape manufacturing	70	$11,000,000
		Totals	**1,320**	**$140,000,000**

2.7.1 Overview

Among the seven biobased product sectors, biobased plastics is the one in which new technologies and changes will be most recognizable by consumers.

The biobased plastics manufacturing sector is relatively young and has a positive growth forecast estimated at 4.5 percent to 2023. New manufacturers, new products, and new markets all contribute to this growth. In addition, the increasing awareness of sustainability, both on the part of producers and consumers, helps drive innovation and demand. Exports account for about 5 percent of total revenue, which is $177.9 million annually.

Support from the U.S. government, specifically the BioPreferred® Program, helps provide the framework required for the expansion of the sector. Additional favorable legislation would further benefit the industry since it is part of a competitive market. Strong economic conditions worldwide are key markers for growth. Typically, as consumers spend more money, the demand for packaged products increases accordingly. Volatility in the price of crude oil is another indicator for growth in biobased plastics. When oil prices fluctuate, companies turn to biobased plastics as an alternative to petroleum-based plastics to obtain more stable pricing. As environmental awareness expands worldwide, consumer demand will encourage manufacturers to explore renewable resources further. Voluntary steps toward environmentally-preferable packaging by industry leaders, such as Coca-Cola and PepsiCo, create market opportunities while setting a precedent for change across sectors. As biobased plastics become more mainstream, consumers will expect more companies to follow suit. This will create further innovation and technological advances that will help manufacturers expand into other sectors beyond packaging, such as construction and medical supplies.

Exports

Exports in the biobased plastics sector have been decreasing slowly as global production catches up with production in the United States. Currently, Asia is producing more than half of the world's biobased plastics. Biobased plastics exports from the United States are destined primarily for China (39.4 percent), Taiwan (27.6 percent), Japan (9.8 percent), and Hong Kong (6.3 percent). Exports are expected to account for about 5 percent of total revenue.

Products

Biobased plastics are plastics manufactured from renewable biomass, such as vegetable oil, cornstarch, pea starch, and microbiota. Generally, biobased plastics are assigned to four categories: cellulose-based, glucose-based, starch-based, and synthetic-based biobased plastics.

Cellulose-based biobased plastics represent about 15 percent of the sector's revenue. Cellulose materials, such as acetate, are modified from sources such as cotton, hemp, and wood pulp. These plastics are used in a wide range of applications, from packing confectionaries to DVDs. The use of cellulose polymer materials, such as cellulose film, has been decreasing as other polymers, such as propylene, have become more popular. Overall, cellulose-based biobased plastics have been losing market share.

Glucose-based biobased plastics are produced from polyhydroxibutyrate, which is derived from sucrose through bacterial fermentation. The bacterial component makes the end product alterable for different uses. Polylactides (lactic acid polymers or PLA) are another glucose-based plastic that is composed of lactose derived from beet sugar, potatoes, or wheat. These biobased plastics are water-resistant, and used to make food packaging, cups, bottles, carpets, and clothing. These plastics account for 10 percent of the sector's revenue.

The sale of starch-based biobased plastics contributes an estimated 55 percent of the sector's revenue, which is the largest share of any of the biobased plastics. These plastics are used mainly for food service tableware. They can be manufactured from raw or modified starch or what is known as thermoplastic starch (TPS), as well as by fermenting starch-derived sugars, known as PLA. Cassava, potatoes, and wheat are common sources of starch.

Synthetic-based plastics are unique polymers that include lignin-based biobased plastics, which use byproducts from the paper-milling industry. Synthetic-based plastics make up about 20 percent of the industry's revenue.

Markets

The biobased plastics sector manufactures products for several industries that can be categorized into three primary groupings: packaging, bottles, and transportation.

Packaging comprises the largest share of the market for biobased plastics, accounting for 36.5 percent of total revenue. Packaging is used for food, electronics, and toys. Demand in this market reflects the overall status of the economy since a growing economy and the resulting increases in consumer spending increase the demand for packaging.

Plastic bottles account for about 32.3 percent of the industry, with industry leaders, such as The Coca-Cola Company, providing the largest markets. The main drivers of growth in this market are increasing awareness of global environmental issues and the desire to appeal to consumers' concerns. Unease about petroleum-based plastics emitting toxins into drinking water and increasing prices for oil also benefits this sector. Volatile oil prices make plant-based bottles more appealing to manufacturers. It is expected that the market share of plastic bottles will continue to increase.

The use of biobased plastics in the transportation industry is a relatively new innovation. Automakers are replacing traditional plastics with biobased plastics, primarily due to their lighter weight. This sector also depends heavily on a strong economy since sales of cars increase and decrease depending on the state of the economy. This sector accounts for about 9.3 percent of total revenue.

Labor and Research

This industry continues to expand as new research produces additional innovations. Legislative support and funding for university-level research are important for the future biobased plastics, as is the case for the entire biobased industry. Because the biobased industry relies on the results of ongoing research, labor costs in this industry, at 17.8 percent of revenue, are much higher than labor costs in other manufacturing industries. The industry requires highly-skilled labor, with the majority being scientists and engineers who specialize in renewable resources. The average salary in this industry is approximately $70,000 per year.

2.7.2 Case Study: Ecovative Design: Mushroom-based Innovation

Based in upstate New York, Ecovative Design is a biomaterials company founded by Eben Bayer and Gavin McIntyre. The company's mission is "to grow better materials that are compatible with the Earth,"[73] in part by providing sustainable alternatives to plastics and foams commonly used in packaging and building materials. The company evolved from a university project for which the founders developed an innovative technology to use mycelium derived from mushrooms as a natural adhesive in place of fossil fuel-based chemicals. As mechanical engineers, both students recognized the potential to use this technology to create a sustainable replacement for plastic foam, and they began working to assess using the mushroom-based adhesive to bond agricultural byproducts such as corn stover to create a replacement foam material.[74]

McIntyre reflected that, from there they used mycelium strains, including those from gourmet mushrooms, to assess various materials, and they discovered they could produce a material that had the same performance as conventional plastics. After that, the company progressed rapidly, using its findings to develop and commercialize products such as protective packaging and insulation. The company has received a number of awards and established numerous partnerships; past and present partners include Dell, IKEA, and Sealed Air.

Tunable Characteristics

Mushroom materials are a novel class of renewable biomaterial grown from fungal mycelium and low-value, non-food agricultural agricultural materials—often agricultural waste such as corn stover or cotton hulls—using the patented process developed by Ecovative Design. The fungal mycelium grows in the dark and binds the non-food agricultural materials mixture together to fill the mold over the course of about five days.

[73] We Grow Materials, Ecovative Design, accessed May 2019, https://ecovativedesign.com/.

[74] Ecovative Design, accessed May 2019, https://www.sbir.gov/sites/default/files/SBA_Success_Ecovative.pdf.

McIntyre described the process, saying, "We are in the process industry, as mycelium is like the cement that is in concrete, while the residue (corn stover, etc.) is the aggregate in the concrete. We take a mixture of residue, steam pasteurize it, and introduce a trace of the mycelium – and over 4-6 days it grows and creates a composite material that comes out white. We dry it in an oven, which renders it biologically inactive and removes the water, and results in a product with aesthetic and mechanical properties similar to foam." The resulting material is light, organic, and compostable, and it can be used in many products, including protective packaging, building materials, thermal insulation panels, car bumpers, apparel, and surfboards.

This process allows Ecovative to grow high performance structures rather than producing individual components that need to be assembled into a functional material. Additionally, the process allows for tuning of the structure based on the desired performance characteristics, such as porosity, texture, strength, resilience, and fiber orientation. As a result, Ecovative can design and create materials tailored to a specific customer's needs.[75] Mycelium products are not certified for direct food contact, but there are many other areas where the foam can be used, including areas in the home such as light shades, acoustical tiles, and higher-value products, which require performance attributes such as light weight or heat resistance.

The environmental footprint of the resulting products is minimized during production due to the use of agricultural waste and reliance on natural and non-controlled growth environments, and after their intended product life cycle, the products are backyard compostable. The founders' intention is that this technology can replace polystyrene and other petroleum-based products that never decompose, or take many years to do so.

The company has two biobased product platforms: MycoFlex™ and MycoComposite™. The company's patented MycoFlex™ platform produces 100 percent pure mycelium structures, which can be used for a wide range of applications, from high-performance footwear to leather alternatives. The MycoComposite™ platform binds together organic material like agricultural byproducts and wood chips to produce durable, biodegradable, and 100 percent vegan composite materials.

The Innovation Journey

Over time, Ecovative recognized that it needed to target its product applications to align with the scale and scope of the business. McIntyre recalled that when they began creating building construction materials, they recognized they did not have the capacity required to produce the volume of material volume of material necessary. With that in mind, McIntyre said they instead moved into protective packaging, which they recognized as one of the single greatest uses of plastic products. This led them to begin prototyping mushroom packaging in 2011.

Since then, they have developed another form of mycelium, which, when grown on wood residue, can be used to produce MycoComposite™ acoustic panels and board insulation, and MycoFlex™, which is an alternative to polyurethane. As part of the MycoComposite™ platform, Ecovative has created Mushroom® Packaging, a high-performing packaging solution that is cost competitive with conventional foams. Additionally, Ecovative partnered with Dell to design high performance, biodegradable packaging components to replace EPE-polyethylene foam parts that provide cushioning and bracing in large packages for Dell servers. Dell's packages weigh more than 200 pounds (90kg) each, and their sensitive servers require ample protection. Ecovative's packaging design team worked with Dell's packaging engineers to create a shape that would protect the hard drives from damage in the event of a drop.[76] In 2011, the two founders opened a full-scale, 40,000-square-foot manufacturing plant. This year, they launched Ecovative Interiors, crafting wood furniture and wall tiles.

McIntyre commented that through the company's innovation journey, they have recognized that organizations are very cost conscious, and they have learned to develop various solutions with that in mind. For example, McIntyre explained shipping costs often constrain Ecovative's ability to ship to customers outside of a certain radius. Moreover, volume constraints related to shipping drive the cost up, and shipping protective packaging involves shipping a lot of volume, even though it is mostly air. Therefore, Ecovative has adopted a distributed approach that allows it to work with partners who are close in location to the target customers. "For instance," remarked McIntyre, "we have a new partner on the West Coast who is producing product for the West Coast exclusively, thus reducing shipping and burdening costs."

[75] Our Foundry, Ecovative Design, accessed May 2019, https://ecovativedesign.com/ourfoundry.

[76] Mushroom® Packaging, accessed May 2019, https://mushroompackaging.com/.

Another issue that drives cost is the type of geometries involved. McIntyre commented that custom-molded geometries often require a lot of labor to produce using traditional fossil fuel-based polyurethane and polyethylene foams. He noted Ecovative's technology is able to produce these geometries much more efficiently, and as a result, the company is able to create custom-molded geometrics that are more cost effective than when using traditional foams.

Additional cost constraints include the cost of oil, as oil is a feedstock for traditional plastics, and the consumer demands for certain types of alternative products. McIntyre noted that as the price of oil fluctuates, the company has had to carve out a niche for itself, and European legislation on single use plastic products has driven that niche. Ecovative is now developing more construction products in areas like Germany and the Netherlands, where there is a growing market for sustainably-produced products. The company has established licensing partners in Europe and is seeing much more growth there than in the United States. This is likely due to better legislative drivers for sustainable products and greater consumer awareness around the environmental impact of single-use plastics. McIntyre remarked that this increased consumer awareness and demand has led to an increase in from other packaging companies looking for innovative solutions.

McIntyre reflected on Ecovative's journey, saying, "We have seen a lot of growth in our product. When we first started, we were focused on industrial products including furniture, industrial equipment, and large computer server packaging. We have recognized that these markets are high volume and very cost sensitive, which may not be a great fit for our technology." In continuing, McIntyre emphasized that it is important for Ecovative to continue developing alternative uses and markets for its products.

He noted they are seeing a lot of demand for their MycoFlex material. In the last year, Ecovative has seen increased demand for sustainable products in the personal care products industry, which will allow the company to explore developing new products such as cosmetic applicators and sponges. Additionally, McIntyre noted that, in certain markets, customized sustainable packaging is important because consumer marketers believe the story behind their product is important.

McIntyre concluded by noting that Ecovative is continually looking for additional partners and opportunities for innovation. He believes Ecovative will continue to perform competitively as consumer demand continues to shift toward focusing more on sustainable products. "Our story involves biobased ingredients and has a great sustainability story behind it," said McIntyre. "The future is exciting!"

2.7.3 Case Study: Green Dot Bioplastics: The Search for Compostable Plastics

Green Dot Bioplastics makes a biobased plastic elastomer product that has been verified to meet U.S. (ASTM D6400) and E.U. (EN 13432) standards for composting in an industrial composting facility. The biobased plastic will decompose in a backyard-composting environment as well. A brand associated with the company is Terratek®, a line of biodegradable, biobased plastic created from starch-based materials or wood-plastic composites.

The company's CEO, Mark Remmert, shared the compelling story that led him to pursue innovative approaches to creating compostable plastics. Prior to founding Green Dot Bioplastics, Remmert spent 30 years at Dow Chemical, mostly working in traditional petroleum-based plastic and polymer businesses, including a number of overseas assignments. Remmert left Dow in 2010 and moved back to the United States. His time overseas, particularly in Europe, made him increasingly aware of the problems associated with petroleum-based plastic materials. With such a long career in traditional plastics, moving into a role that sought to employ biobased inputs into plastic was a significant change.

Despite his awareness of problems associated with traditional plastics, Remmert noted that in many ways, there is no material better than plastic. It has valuable properties that represent tremendous benefits for health, hygiene, and safety applications. However, Remmert commented that the plastic industry over the last 50 years has ignored the problems of plastics. He explained that, for much of his traditional plastics career, many of the concerns surrounding plastics that arose in the 1980s, 1990s, and 2000s were toxicology and hygiene-related, and plastics companies were often involved in protracted battles with non-governmental organizations fighting on the toxicology front.[77] The focus was on plastic-leaching chemicals that are harmful to human, plant, and animal life, and on plastic litter gathering in various environmental habitats.

Remmert noted that the concerns surrounding plastics have shifted somewhat. In the last 20 years, a lot of the concern over the damage caused by plastics has switched from toxicology to the manufacturing and distribution of plastic. Environmental issues facing our planet, such as CO_2 accumulation adding to global climate change, air/water discharge, etc., is much more prominent in public discussions. Nonetheless, Remmert noted the problems centered around plastic waste remain; no one has a solution about what to do with the billions of pounds of plastic waste that are either buried in landfills or are released uncontrolled into the environment. This is a major concern because many plastics are designed to last forever, and rather than biodegrading, simply break down into smaller and smaller pieces that remain in the environment for many years.

As he retired from a career in traditional plastics, Remmert had all of those things on his mind when he moved back to the United States to a small ranch in Kansas. He was unsure about what he wanted to do next, but was intrigued with environmental issues concerning greenhouse gases, rain forests, carbon sequestration, and shifting ecosystems. Remmert recalled that, through a series of timely meetings, he was introduced to some people at the Kansas Bioscience Authority, executives at some of the top bioscience enterprises, and a group of investment bankers and financiers in New York City who wanted to start an eco-friendly plastics company, but who had no knowledge of polymer science. At first, Remmert thought that the idea for an eco-friendly plastic company was far-fetched, but eventually, they were able to obtain grants from the Kansas Bioscience Authority to adopt technology acquired from Europe and start an R&D company focused on biobased plastics. Remmert explained their idea at first was to develop biodegradable rubber for the footwear industry. He was offered the chance to become the founding CEO of the new company, and that was the start of Green Dot Bioplastics.

[77] "Why is Plastic Harmful?", Plastic Pollution Coalition, accessed May 2019, https://plasticpollutioncoalition.zendesk.com/hc/en-us/articles/222813127-Why-is-plastic-harmful-.

The entrepreneurs' first effort was to file a patent for an engineered biobased, biodegradable material they called Terratek® Flex. Remmert indicated that this led to receiving a round of funding from private investors, which then allowed them to purchase the biobased plastic division of a publicly-traded company, followed by receiving additional funding, and all of a sudden, they had a start-up company! Remmert emphasized that the focus of Green Dot Bioplastics from the beginning was about reducing the impact of plastics, using more recycled materials, and adding value through the use of biodegradable materials and their own biodegradable polymers.

Today, Green Dot has a large lab and manufacturing facility in Kansas. Remmert noted that the company is a formulator and compounder, and the company works with suppliers, such as Braskem, who are producing molecules by converting ethanol to ethylene to polyethylene. Remmert indicated that Green Dot takes plastic polymer materials from its suppliers and produces a compound by combining the polymer with different organic materials, such as organic acids and proteins, and fibers and fillers, such as agricultural waste products. After being in business for six years, Green Dot has some 50 commercial customers that buy its materials. Some of Green Dot's customers include Kencove Farm Fence Supplies, which uses Green Dot's materials to develop wood-composite fencing; SelfEco, which worked with Green Dot to develop biodegradable plant pots; and Futures Fins, which uses Green Dot's materials in its surfboards and paddleboards. Remmert emphasized that one of the reasons for the company's success has been the fact that its material costs are competitive with traditional plastics, and the materials also work well with existing molding and extrusion equipment in most cases.

However, Remmert is quick to point out there is a lot of work to do before biobased plastics become more prevalent. The two primary reasons for this are that biobased plastics often cost more than traditional petrochemical-derived plastics, and they do not always perform as well. Remmert reasoned that there need to be strong reasons for people to use biobased plastic in order for it to become more prevalent. Regulation will play an important role in helping drive people to use more biobased plastics that are biodegradable.

Remmert believes that plastic manufacturers should be held accountable, through introduction of a mandate or regulation, for their share of the environmental problems being caused. A recent article in *National Geographic* found that crustaceans on the ocean floor are eating plastic, and 80 percent of them were found to have plastic fibers in their digestive systems.[78] Despite the increase in ocean pollution as well as outcry from consumers, producers are not being held accountable. Remmert remarked that if manufactures were held accountable for the environmental impacts of their products, the behavior would change, and introduction of more biobased plastics would be a plausible solution. Remmert predicted that the next century will belong to new biobased feedstocks, and companies will all begin working with new molecules that are biologically-derived.

[78] Gibbens, S., Parker, L., "Creatures in the Deepest Trenches of the Sea are Eating Plastic," National Geographic, Feb. 28, 2019, accessed May 2019, https://www.nationalgeographic.com/environment/2019/02/deep-sea-creatures-mariana-trench-eat-plastic/.

2.8 Forest Products

Figure 22a: Total Value Added Contributed by the Forest Products Sector in Each State and the District of Columbia in 2017.

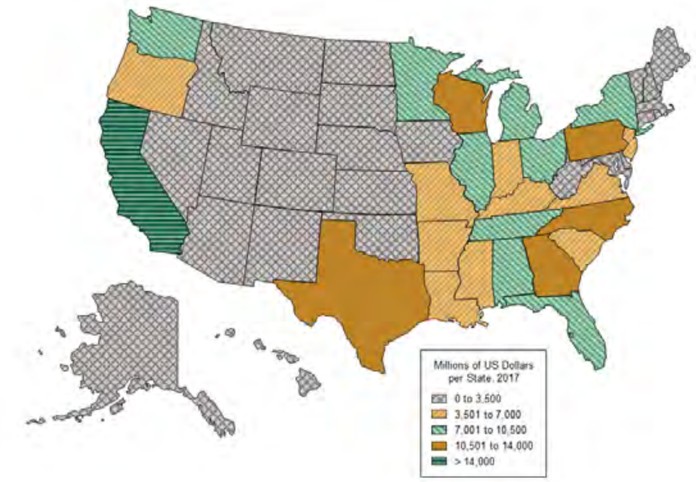


Figure 22b: Percent change (2013 – 2017) of Total Value Added Contributed by the Forest Products Sector in Each State and the District of Columbia.

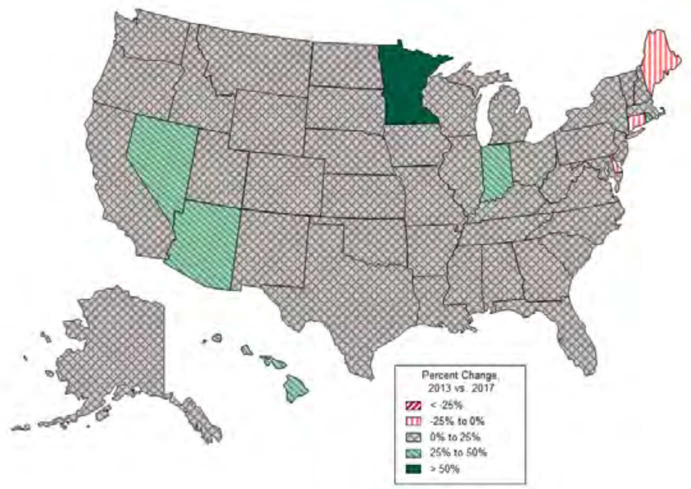
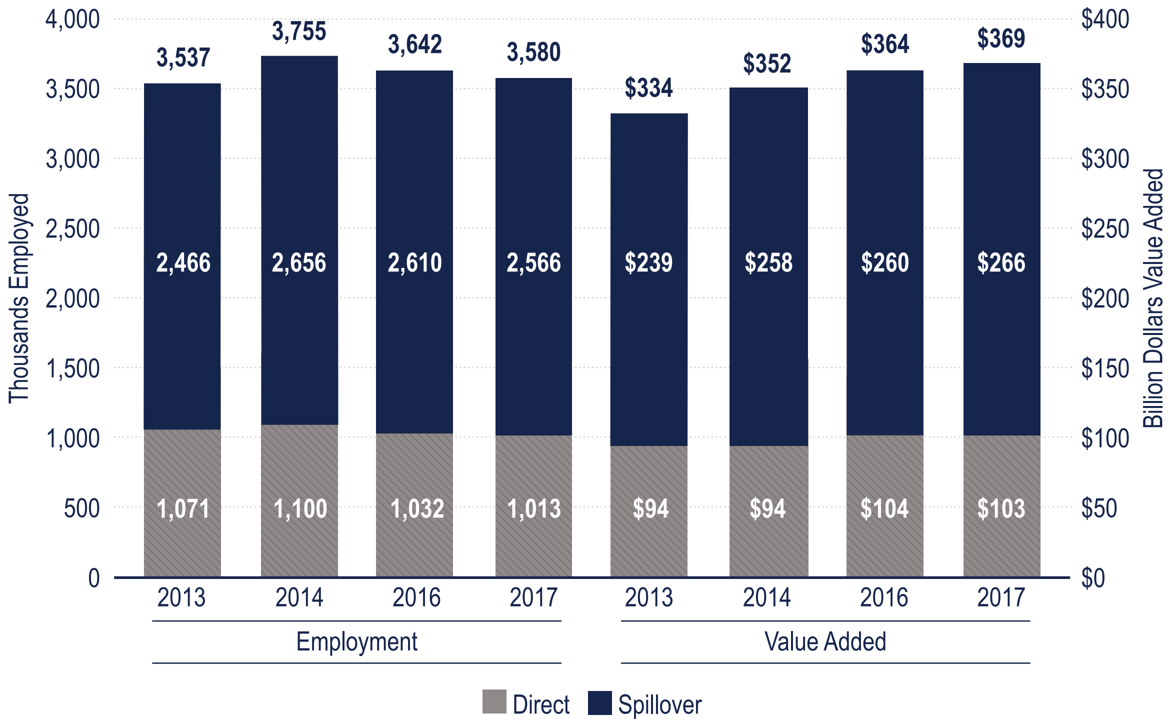


Table 13: Top 10 States for Direct Value Added to the Forest Products Sector in 2017 and percent change between 2013 and 2017.

Rank	State	Percent change 2013-2017	Rank	State	Percent change 2013-2017
1	California	15%	**6**	North Carolina	15%
2	Pennsylvania	6%	**7**	Tennessee	10%
3	Wisconsin	3%	**8**	Ohio	13%
4	Georgia	13%	**9**	Alabama	0%
5	Texas	15%	**10**	Illinois	7%

Figure 23: Forest Products Sector Contribution to Employment and Value Added in 2013, 2014, 2016, and 2017.



A third of the United States - 760 million acres - is forested. Privately-owned forests supply 91 percent of the wood harvested in the U.S.; state and tribal forests account for about 6 percent, and Federal forests, only 2 percent.[79]

Major U.S.-Based Firms[80]

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

Economic Statistics

Total value added to the U.S. economy in 2017: **$369 billion**

Exports value added to the U.S. Economy in 2017: **35 billion**

Type SAM Economic Multiplier in 2017: **3.6**

Employment Statistics

Total number of Americans employed due to industry activities in 2017: **$3.6 million**

Total number of Americans employed due to industry activities supporting exports in 2017: **300,000**

Type SAM Employment Multiplier in 2017: **3.53**

[79] American Forest and Paper Association (AF&PA), Fun Facts, AF&PA website, accessed April 2015. http://www.afandpa.org/our-industry/fun-facts.

[80] Forbes, "The World's Biggest Public Companies," Forbes website, accessed April 2015. http://www.forbes.com/global2000/list/.

Table 14: Distribution of Direct Value Added and Employment by Forest Products Sub-Sectors.

IMPLAN Code	NAICS Codes	Description	Employment	Value Added
149	32221	Paperboard container manufacturing	139,260	$15,534,000,000
368	337110	Wood kitchen cabinet and countertop manufacturing	110,690	$6,238,000,000
134	321113	Sawmills	89,570	$6,249,000,000
147	32212	Paper mills	66,310	$14,861,000,000
142	321920	Wood container and pallet manufacturing	56,710	$3,134,000,000
150	32222	Paper bag and coated and treated paper manufacturing	61,670	$8,039,000,000
369	337121	Upholstered household furniture manufacturing	54,480	$3,053,000,000
139	321911	Wood windows and door manufacturing	43,630	$3,437,000,000
141	321918	Other millwork, including flooring	37,360	$2,618,000,000
370	337122	Non-upholstered wood household furniture manufacturing	39,130	$2,263,000,000
136	321211, 321212	Veneer and plywood manufacturing	29,520	$2,233,000,000
137	321213, 321214	Engineered wood member and truss manufacturing	29,000	$1,712,000,000
152	322291	Sanitary paper product manufacturing	30,770	$8,512,000,000
148	322130	Paperboard mills	29,630	$7,139,000,000
145	321999	All other miscellaneous wood product manufacturing	28,260	$1,852,000,000
372	337127	Institutional furniture manufacturing	20,900	$1,514,000,000
143	321991	Manufactured home (mobile home) manufacturing	16,310	$1,416,000,000
151	32223	Stationery product manufacturing	19,270	$2,216,000,000
374	337212	Custom architectural woodwork and millwork	18,700	$1,419,000,000
373	337211	Wood office furniture manufacturing	16,480	$1,521,000,000
153	322299	All other converted paper product manufacturing	16,690	$1,723,000,000
138	321219	Reconstituted wood product manufacturing	13,660	$2,014,000,000
144	321992	Prefabricated wood building manufacturing	16,850	$1,042,000,000
140	321912	Cut stock, re-sawing lumber, and planing	14,590	$1,162,000,000
371	337125	Other household non-upholstered furniture manufacturing	140	$11,000,000
135	321114	Wood preservation	9,150	$1,323,000,000
146	322110	Pulp mills	4,820	$900,000,000
		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.

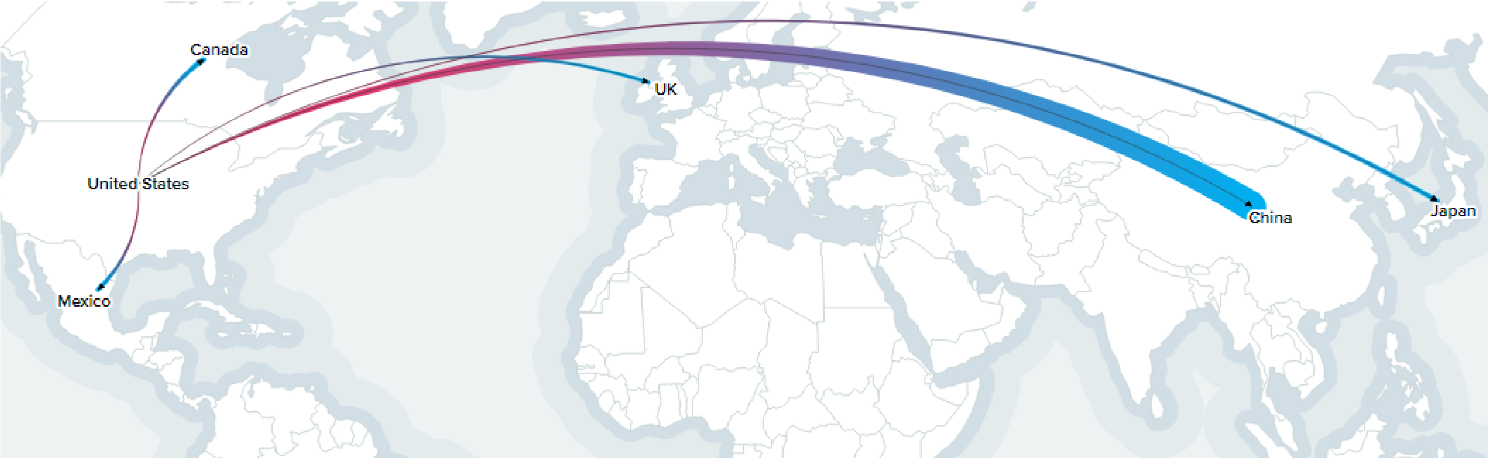
There are approximately 760 million acres—more than a million square miles—covered by forests in the United States. Almost 70 percent of the forested acreage in the United States is timberland that produces wood that is suitable for industrial and commercial use. About 90 percent of this land is privately owned. The southern region of the United States has about 40 percent of this timberland, and the northern and western regions have about 32 percent and 28 percent, respectively.

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 considered a valuable offset for greenhouse gas emissions. The USDA Forest Service estimates these systems offset 15 percent of all emissions.[81]

The U.S. forest products industry employs approximately one million people, making the sector one of the top 10 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 North American countries, and European countries, as shown in Figure 24.

Figure 24: The United States' Forest Product Global Trade Flows in 2017.[82]



Cardboard Box and Container Manufacturing

This is the largest paper-converting industry in the United States, and it is also the largest industry in the biobased forest products sector. This industry is a large consumer of all types of paper and serves every sector of the economy. Manufacturers produce packaging products, cardboard boxes, and containers. This industry has grown significantly over the five-year period ending in 2017. Over the current five-year period that ends in 2022, growth is expected to continue at a rate of about 1.4 percent. The increase in online commerce has helped boost this industry, and nearly half of all products are used by food, beverage, and agriculture companies. While exports have slowly increased to about 1.7 percent, exports are not a huge factor, and manufacturing is moving offshore, thus pushing for consolidation within the industry.

[81] "U.S. Forest Products Industry – Statistics & Facts," Statista website, accessed July 2018. https://www.statista.com/topics/1316/forest-products-industry/.

[82] ResourceTrade.Earth, Chatham House Resource Trade Database, accessed May 2019. https://resourcetrade.earth/data?year=2017&exporter=842&category=3&units=value.

Paper Mills

Between competition from foreign paper mills and the overall decrease in demand for paper, this industry has struggled over the past five years, with annual growth estimated at –2.8 percent. The outlook over the next five years is about the same, with a continued annual growth rate of -2.5 percent. Since China has overtaken the United States and has become the largest producer of paper in the world, competition in the industry has intensified significantly, especially with developing countries entering the market. As the value of the U.S. dollar increases, exports continue to decrease, slowing to a projected rate of only 0.4 percent growth in the period from 2018 to 2022.

Sawmills and Wood Preservation

This industry relies primarily on both residential and non-residential construction markets, and has experienced strong growth over the last five years. Over the next five-year period from 2018 to 2022, interest rates are expected to continue to increase slowly, which will slow the housing market and temper annual growth at an estimated 1.9 percent. Exports increased at an annual rate of 4.4 percent over the previous five-year period, but as the dollar gets stronger, exports become less competitive on the world market. Lumber prices also are expected to increase since they depend on supply, trade, and tariffs with Canada.

Paperboard Mills

Paperboard is used in the production of cardboard boxes, so the industry is closely linked to consumer demand in that industry. As imports penetrated the U.S. market over the five-year period that ended in 2017, the growth of the paperboard industry slowed to about 0.4 percent. As the economy strengthens and with the influence of online shopping, the outlook for this industry is slightly better over the next five years with a forecast annual growth rate of 1.3 percent. Recycled paperboard will be the fastest growing and most exciting aspect of the industry in the next five years. Exports do not represent a large part of this industry.

Millwork

This industry produces wooden floors, window frames, and doors, and it is linked closely to the residential construction market. Current trends in interior design have made these products popular, which has boosted the market. The biggest challenge in this market is substitute products made from alternative materials. Over the five-year period ending at the end of 2022, revenue is expected to grow at an annual rate of 1.3 percent. Exports are not of major importance to this industry.

Wood Paneling Manufacturing

This subsector primarily is linked to the construction of homes, and it had strong growth of 6.2 percent in the previous five-year period. Over the next five-year period through 2022, revenue is expected to continue to increase due to support provided by vertical integration within the industry, but the rate will likely be lower at about 2.2 percent. Export revenue decreased by 3.8 percent during the last five-year period, mainly due to the increase in the value of the U.S. dollar.

2.8.2 Case Study: Okabashi – A Uniquely American Biobased Footwear Company

Okabashi Brands is a family-owned and operated shoe company located in Buford, Georgia. Since 1984, the company has been focused on creating comfortable, stylish, and sustainable footwear. As a family-owned company, Okabashi incorporates its values, including stewardship and care for the environment, into every aspect of their operation. The company does this in part by operating in a closed-loop manufacturing system and incorporating both recycled and biobased materials into their products.[83]

Okabashi's CEO Sara Irvani is a third generation shoemaker, following in the footsteps of her father, Bahman Irvani, and grandfather, Rahim Irvani. The Irvani family got its start in Iran, and Rahim Irvani ran the leading shoe manufacturing business in the 1970s. After the company was nationalized during the Iranian Revolution in 1979, the family decided to its love of shoes to the United States, drawn by the country's business-friendly reputation. This led to the start of Okabashi in 1981. [84]

The company's approach to designing shoes incorporates Japanese concepts of reflexology and design to create shoes that promote foot health and comfort. [85] In addition to environmental stewardship and foot wellness, the company also places a high value on keeping its manufacturing operations in the USA and collaborating with local vendors whenever possible.

The authors received the opportunity to talk with Zach Myers, who has been working at Okabashi for about three years. He graduated with an Industrial Engineering (IE) degree from the University of West Virginia and worked first at Sears, Kmart, and Simmons Mattresses in Atlanta.

On coming to work at Okabashi, Myers explained that he knew he wanted to get into injection molding, and while there were many job opportunities available in the industry, he knew Okabashi would be a good fit with their warm and welcoming environment as soon as he interviewed there. Myers noted that he started out working in research and development at Okabashi. Drawing on his prior experience in adhesives, Myers joined the company's product development area in adhesives, where he was able to improve production. Myers remarked that there are many areas of Okabashi's manufacturing process that he is able to help make a big difference and real improvements using his background in supply chain management and manufacturing, with the help of his IE degree.

Okabashi has three brands: 1) Okabashi, the Legacy brand; 2) Oka-B, a brand focused on boutique styles for women, introduced in 2005; and 3) Third Oak, the company's latest brand, which is designed using a simple, clean, earthy design and is marketed for people who want to be more environmentally friendly. Myers noted that each brand uses different material blends, but all three brand utilize the same base material, which is a polyvinyl chloride (PVC) compound that employs 44 percent biobased soy material. According to Myers, the soy material is what prompted Okabashi to consider the USDA Certified Biobased Product certification. Okabashi now has more than 20 USDA Certified Biobased products.

In addition, Myers noted all of Okabashi's shoes (except for the adornments for the Oka-B) are completely recyclable, and the company has instituted an in-house recycling program. Myers explained that customers who purchase a pair of Okabashi shoes automatically receive a fifteen percent discount on their next order if they return their old sandals to Okabashi. The company takes the old sandals, grinds them up, and recycles the material into new shoes, and this process can be repeated. Myers emphasized that this recycling ability is what is great about Okabashi's manufacturing process. He explained that in most injection molding processes result in a lot of unusable scrap material. The process produces "runners"—stringy bands of PVC that branch out of the path of the material going into the mold, which often becomes scrap (and, thus, waste). However, Myers explained that Okabashi's process and material allows them to grind up the runners and use the recycled material to make new shoes. Myers continued by noting that this process is good for the company on multiple fronts—it saves them money, and it prevents the material from reaching a landfill.

[83] "The Okabashi Story," Okabashi, accessed May 2019, https://www.okabashi.com/pages/about-us.

[84] "Okabashi: Sustainable Family Footware," Tharawat Magazine, Jan. 1, 2019, accessed May 2019, https://www.tharawat-magazine.com/online-magazine/okabashi-sustainable-family-footwear/#gs.3agk4u.

[85] "The Okabashi Story," Okabashi, accessed May 2019, https://www.okabashi.com/pages/about-us.

"Today, each of our styles can be run with virgin material that we purchase from a vendor in the Unites States," explained Myers, "but in fact, many of our styles use around 25 percent to 45 percent recycled material." Myers noted that the amount of recycled material used during production changes depending on the materials that are on hand each day. For example, when there is a lack of regrind material on hand, the company utilizes virgin material. Conversely, when there is an abundance of regrind, the company utilizes the regrind material to produce shoes that day, which allows them to save money. Myers noted each of the company's styles can be produced using regrinds.

Okabashi shoes are molded from a proprietary, recyclable material that is 45 percent soy by weight and is also BPA, latex, phthalate free, and made in the United States. Okabashi's focus on keeping production located in the United States adds another facet to the company's focus on environmental stewardship. As reported by Myers, Okabashi conducted a carbon footprint study in conjunction with Georgia Institute of Technology, asking the question of how the company's carbon footprint would be impacted if manufacturing were conducted overseas in Asia. The results of the study showed that the carbon footprint would be much greater. Myers noted the company's shoes are manufactured in Buford, Georgia, which means that each pair travels only 7 percent as far as the average shoe imported to the United States. This prevents 10,000 miles of carbon emissions from the ships, planes and trucks required to transport shoes produced in Asia to the United States.[86] Okabashi's website indicates that today, more than 99 percent of shoes worn in the USA are imported, and the company is proud to be in the 1 percent that has chosen to keep its manufacturing in the United States.[87]

Additionally, the company believes durability is key for sustainability. Okabashi guarantees the quality of each pair of shoes for two years. The company's two-year guarantee contrasts with typical disposable flip-flops that are cut out of sheets of foam and eventually end up in landfills or oceans. The shoes have garnered a loyal following with over 35 million pairs of shoes sold.

According to Myers, Okabashi's typical annual production is one million pairs of shoes. All of the company's shoes now use the soy-based material as a replacement for the petroleum-based component of the materials—a fact that shows that the company is living up to its environmental values. Myers commented that Okabashi is continuing to explore pushing the boundaries of its R&D, and the company is always looking to make its story even more attractive to customers. The company has been accepted by Target for a complete nationwide program, and as a result, they will be increasing capacity by 50 percent or more. Myers noted that they are in the process of increasing capacity, buying new machinery, improving their pick and pack line, and working on improving their assembly area. "Our CEO Sara Irvani regularly comes out on the floor to understand the distribution and fulfillment side to ensure that people have what they need," said Myers. "That is the sign of a good leader – someone who is constantly where the action is and is always learning new things."

[86] "The Okabashi Story," Okabashi, accessed May 2019, https://www.okabashi.com/pages/about-us.

[87] "The Okabashi Story," Okabashi, accessed May 2019, https://www.okabashi.com/pages/about-us.

2.9 Textiles

Figure 25a: Total Value Added Contributed by the Fabrics, Apparel, and Textiles Products Sector in Each State and the District of Columbia in 2017.

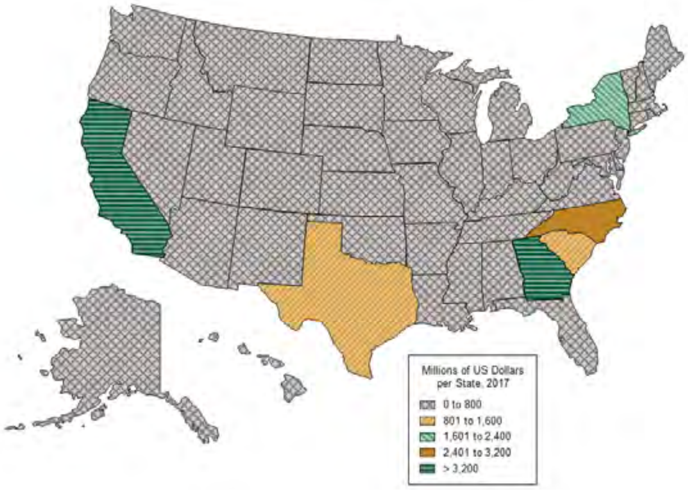


Figure 25b: Percent change (2013 – 2017) of Total Value Added Contributed by the Fabrics, Apparel, and Textiles Products Sector in Each State and the District of Columbia.

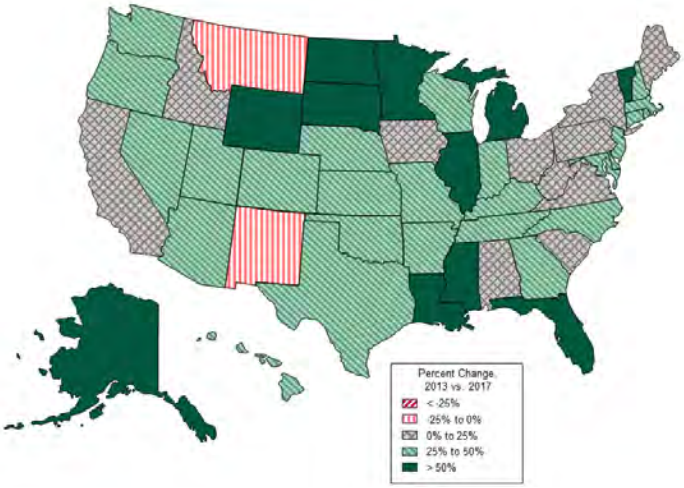
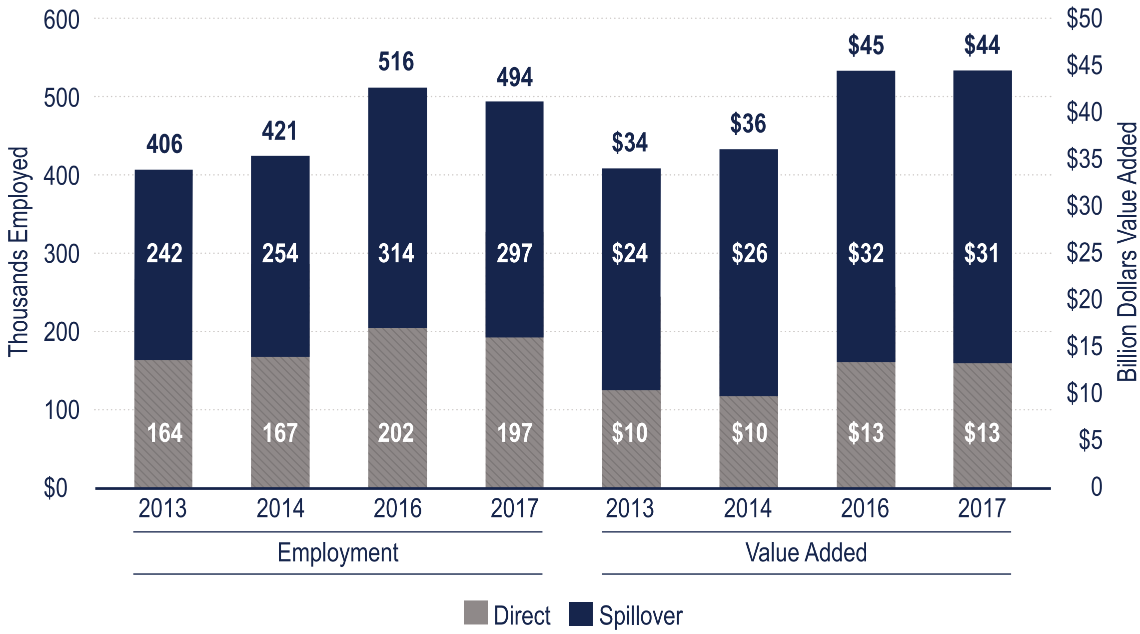


Table 15: Top 10 States for Direct Value Added to the Fabrics, Apparel, and Textiles Products Sector in 2017 and percent change between 2013 and 2017.

Rank	State	Percent change 2013-2017	Rank	State	Percent change 2013-2017
1	Georgia	27%	**6**	Virginia	2%
2	California	8%	**7**	Texas	24%
3	North Carolina	20%	**8**	Pennsylvania	18%
4	New York	15%	**9**	Tennessee	26%
5	South Carolina	20%	**10**	New Jersey	27%

Figure 26: Biobased Textile Sector Contribution to Employment and Value Added in 2013, 2014, 2016, and 2017.



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

Major U.S.-Based Firms[88]

V. F. Corporation (North Carolina)
Levi Strauss & Co. (California)
W. L. Gore & Associates (Delaware)
Milliken & Company (South Carolina)
Hanesbrands, Inc. (North Carolina)
Ralph Lauren (New York)
Nike (Oregon)

Economic Statistics

Total value added to the U.S. economy in 2017: **$44 billion**

Exports value added to the U.S. Economy in 2017: **$9.0 billion**

Type SAM Economic Multiplier in 2017: **3.5**

Employment Statistics

Total number of Americans employed due to industry activities in 2017: **494,000**

Total number of Americans employed due to industry activities supporting exports in 2017: **103,000**

Type SAM Employment Multiplier in 2017: **2.5**

[88] Forbes, "The World's Biggest Public Companies," Forbes website, accessed April 2015. http://www.forbes.com/global2000/list/.

Table 16: Distribution of Direct Value Added and Employment by Textiles Sub-Sectors.

IMPLAN Code	NAICS Codes	Description	Employment	Value Added
126	31521	Cut and sew apparel contractors	24,300	$713,000,000
119	314110	Carpet and rug mills	16,700	$1,453,000,000
123	314999	Other textile product mills	19,100	$1,035,000,000
128	31523	Women's and girls' cut and sew apparel manufacturing	13,400	$1,099,000,000
112	31311	Fiber, yarn, and thread mills	15,400	$941,000,000
113	313210	Broadwoven fabric mills	14,000	$1,081,000,000
127	31522	Men's and boys' cut and sew apparel manufacturing	13,400	$793,000,000
117	31331	Textile and fabric finishing mills	13,000	$1,033,000,000
121	31491	Textile bag and canvas mills	13,900	$859,000,000
120	31412	Curtain and linen mills	11,200	$885,000,000
129	31529	Other cut and sew apparel manufacturing	7,600	$386,000,000
115	313230	Nonwoven fabric mills	7,600	$1,072,000,000
130	31599	Apparel accessories and other apparel manufacturing	7,600	$374,000,000
124	31511	Hosiery and sock mills	3,800	$156,000,000
114	31322	Narrow fabric mills and schiffli machine embroidery	3,600	$201,000,000
118	313320	Fabric coating mills	4,000	$435,000,000
116	31324	Knit fabric mills	3,200	$219,000,000
122	314991, 314992	Rope, cordage, twine, tire cord and tire fabric mills	3,400	$345,000,000
125	31519	Other apparel knitting mills	2,000	$100,000,000
		Totals	**197,200**	**$13,180,000,000**

2.9.1 Overview

According to *2016 Top Market Reports, Technical Textiles*, global demand for U.S. textiles will increase annually by four percent. Increasing incomes, improved standards of living, and the growth of new markets in both the developed and developing countries contribute to this demand. Canada and Mexico are the largest markets for U.S. textile exports, accounting for 55 percent of total trade (2016 report). China, Germany, and the United Kingdom round out the top five markets for U.S. exports.

Textiles in the United States span a number of large industries, from apparel to carpet mills. Some of these industries, such as cut and sew manufacturing, will have decreased profits as companies move abroad in search of more affordable labor. However, textile mills will have profits that increase slightly over the next five years at an annualized rate of about 0.2 percent. Compared to foreign competitors, U.S. manufacturers are more willing to make large investments in heavy machinery, such as spinning and weaving mills that can cost upwards of $70 million. These investments, coupled with growth into new markets, such as automobiles and home furnishings, create a positive outlook for these mills.

The EPA estimates that 25.5 billion pounds of usable textiles are thrown away each year in the United States, which is equivalent to 70 pounds per person.[89] As a result of consumer practices and, in particular, modern fashion trends, the textile industry is a major user of natural resources, especially fresh water. Growing awareness surrounding environmental impacts and sustainability have caused both consumers' expectations and the textile industry to shift. At this time, 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 biodegraded.

[89] Snyder, G., "Don't Trash Your Old Clothes," The EPA Blog, Feb 3, 2019, accessed May 2019, https://blog.epa.gov/2014/02/03/dont-trash-your-old-clothes/.

2.9.2 Case Study: Guest Supply: Providing Biobased Products in the Hotel Bathroom

Guest Supply is a division of Sysco Corporation that produces a variety of amenities for hotels. One branch of Guest Supply is focused on personal care products such as shampoo, conditioner, body lotion, mouthwash, and other toiletries that are typically found in a hotel bathroom

Rawia Amer has been working at Guest Supply for more than 14 years. As the manager responsible for formulation of products in the personal care division, Amer knows there are several hurdles that have to be passed for a product—biobased or otherwise—before it can be distributed in hotels. First, because personal care products fall under the category of hygiene, all products must meet strict guidelines imposed by the FDA. Second, products must be in compliance with the region in which they will be distributed. For example, California has a list of ingredients that cannot be included in cosmetics. In fact, many other regions, including the European Union and Canada, have regional requirements. Part of Amer's job as is to ensure the product is in compliance with the laws of the region where it is going to be distributed.

At the moment, Guest Supply is marketing two biobased brands: Bath and Body Works, and Essential Elements. Ensuring its products are biobased is an important part of Guest Supply's corporate social responsibility program. For some product lines, Guest Supply worked with manufacturers to ensure the initial formula included biobased ingredients in the raw materials going into the product. As the company examined other lines, they discovered many other products were already using biobased ingredients and did not require significant changes in the formula to be labeled through the USDA BioPreferred® Program.

Amer noted that Guest Supply saw an area where they could obtain a competitive advantage when hotels began to request biobased products. Amer explained, "Our leadership recognized the value of the USDA BioPreferred® Program, as it certified our products as having natural sources. Many of our competitors are claiming their products are 'natural,' but the consumer would not know this by reading the list of ingredients. By showing the percentage of the product that is from biobased materials on the label, Guest Supply saw this as a more accurate and honest way of educating the customer on the percentage of natural ingredients we have in the product. This is important in educating consumers on what makes our products biobased."

Guest Supply has not yet begun to market its USDA Certified Biobased Product labels extensively. The labels have been tested with consumer panels, but one concern is that some customers are asking why a product might be 60-80 percent biobased and not 95 or 100 percent. These types of questions may be a challenge for Guest Supply, as they need to think about how to inform the customer that some of the inputs are still petrochemical-based because biobased substitutes do not yet exist for some chemicals. Guest Supply recognizes this as a challenge to overcome.

Guest Supply is also working on a number of other sustainability initiatives. For example, Guest Supply is working on sustainable bottling and packing and using innovative ways to ensure the packaging is recyclable. In addition, Guest Supply is working to consider the full life cycle of its products in their day-to-day operations, including product disposal. Working along with their customers, Guest Supply has partnered with Clean the World, a global enterprise dedicated to reducing infection and disease in impoverished countries, on an ambitious soap recycling initiative. In North America alone, the hospitality industry discards more than one million bars of soap every day. Yet, due to limited access to soap, millions of people in developing countries die each year from acute respiratory infection and diarrheal disease, the top two killers of children under the age of five. The solution to combat both illnesses is simple: hand washing with bar soap.

Through the soap recycling initiative, Guest Supply collects discarded hand soap and liquids from lodging partners and remanufactures and distributes the products to those in need, helping to combat hygiene-related illnesses and save lives. More than 30 million bars of soap have been distributed in more than 100 countries by Clean the World. Through sustainability efforts such as incorporating biobased ingredients in their personal care products and the soap recycling initiative, Guest Supply and its partners are positively affecting the health and well-being of countless individuals around the globe.

3 Environmental Benefits

3.1 Environmental Benefits

A broad analysis of the biobased products industry was performed using Economic Input-Output Life Cycle Assessment (EIO-LCA) modeling to estimate the savings in petroleum use and the reductions in GHG emissions that resulted from the production and use of biobased products. Using the EIO-LCA methodology, calculated sector sales, and the literature, the reductions in GHG emissions were estimated to be as much as 12.7 million metric tons of CO_2 equivalents in 2017. The estimated petroleum savings from the production and use of biobased products were up to 9.4 million barrels of oil in 2017. Other environmental impact categories that are not estimated in this report could have higher or lower impacts for biobased products compared to petroleum-based products. Further analysis should include modeling of additional impact categories and the implications of other parameters, such as changes in land use.

3.2 Economic Input-Output LCA

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 of industries, to estimate the total emissions throughout the supply chain.[90]

The EIO-LCA methodology builds upon the economic impact modeling methods developed by Nobel Prize winner, Dr. Wassily Leontief. 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.

3.3 Objectives and Methodology

The production and use of biobased products have the potential to reduce GHG emissions and the use of petroleum.[91] The reductions in environmental impacts and the use of resources depend on both types of products and 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 feasible for this report. As a way of estimating the potential GHG emissions and reductions in the use of petroleum, a a zero- to 100 percent-range of the reductions of GHG emission and petroleum use was used and compared to the petroleum-based alternatives. A zero-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 a zero and a 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.[92]

[90] Carnegie Mellon University Green Design Institute, "About the EIO-LCA Method," Carnegie Mellon University Green Design Institute, http://www.eiolca.net/Method/index.html.

[91] Cherubini, F., and Ulgiati, S., "Crop Residues as Raw Materials for Biorefinery Systems–A LCA Case Study," Applied Energy 87, no. 1, (2010): 47-57.

[92] 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.

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 the peer-reviewed literature that describes reductions in environmental impacts. The values used to determine 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.[93] The economic data used in the environmental analysis were based on 2017 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 9.4 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 12.7 million metric tons of CO_2 equivalents. The GHG emissions and petroleum use that are avoided due to the direct replacement of petroleum-based products with biobased products are shown in Figure 27 and 28, respectively. The results of the EIO-LCA model were generated in terms of kg CO_2 equivalents and terajoules of petroleum, but the petroleum use was converted to barrels of oil using a heating value of 6.077 MMBTU per barrel of oil. For both impact measures, the plots show the impacts that potentially are avoided as a function of percent reduction compared to the petroleum-based alternative. In addition to the range of impacts avoided, percentage reductions from the peer-reviewed literature also were applied to the EIO-LCA output and reported in the following sections.

3.5 Petroleum Use Avoided

The use of petroleum that was avoided by using biobased products amounted to a petroleum savings up to 9.4 million barrels of oil. 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. Cherubini and Ulgiati determined that biobased chemicals produced at a biorefinery using a switchgrass feedstock reduced fossil fuel usage well beyond 80 percent compared to the use of petroleum-based chemical production methods, which corresponds to 9.4 million barrels of oil.[94]

The biorefining industry that produces biobased chemicals is reported to use 80 percent less petroleum than traditional refineries, resulting in a petroleum savings of as much as 462,700 barrels of oil.[95] 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. 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 85,000 and 113,000 barrels of oil, respectively.[96, 97]

The first economic report on the economic impact estimated a reduction in petroleum use equivalent to the use by 200,000 average passenger cars for a year.[98] This previous estimate corresponds to a 26 percent reduction in petroleum use when biobased products are used instead of petroleum-based products. Given the data from the literature shown in this analysis, 26 percent appears to be a reasonable and conservative number.

[93] Carnegie Mellon University Green Design Institute, "Economic Input-Output Life Cycle Assessment (EIO-LCA) U.S. 1997 Industry Benchmark Model," *Carnegie Mellon University Green Design Institute*, accessed May 2019, http://www.eiolca.net/Models/index.html.

[94] Cherubini, F., and Ulgiati, S., "Crop Residues as Raw Materials for Biorefinery Systems–A LCA Case Study," *Applied Energy* 87, no. 1, (2010): 47-57.

[95] Cherubini, F., and Ulgiati, S., "Crop Residues as Raw Materials for Biorefinery Systems–A LCA Case Study," Applied Energy 87, no. 1, (2010): 47-57.

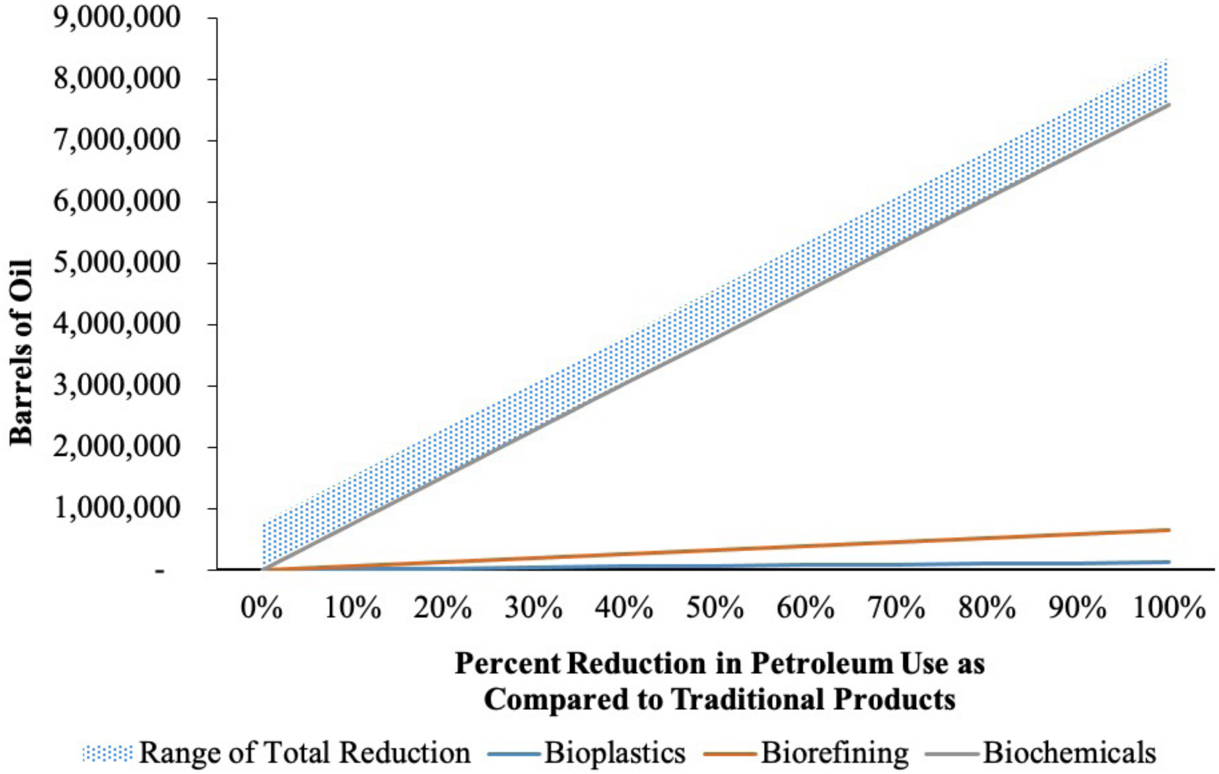
[96] Yu, J., and Chen, L.X.L., "The Greenhouse Gas Emissions and Fossil Energy Requirement of Bioplastics from Cradle to Gate of a Biomass Refinery," Environmental Science & Technology 42, no. 18, (2008): 6961-6966, doi: 10.1021/es7032235.

[97] Harding, K. G., Dennis, J. S., Von Blottnitz, H., and Harrison, S.T.L., "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, (2007): 57-66.

[98] 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.

Figure 27: Potential Petroleum Use Reductions by Biobased Products Manufactured in the United States with a Range of Zero- to 100 percent Reduction in Petroleum Use as Compared to Non-Biobased Product Alternatives.

Note: assuming a heating value of 6.077 MMBTU per barrel of oil.



3.6 Avoided GHG Emissions

The production and use of biobased products to replace petroleum-based products had the potential to reduce GHG emissions by as much as 11.6 million metric tons of CO_2 equivalents in 2017 assuming a conservative 60 percent reduction of fossil fuel use. The potential avoided GHG emissions for each sector grouping are shown in Figure 28. 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 percent compared to petroleum-based chemicals, which corresponds to approximately 7.4 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 percent, biorefining has the potential to offset as many as 1.2 million metric tons of GHG emissions per year.[99]

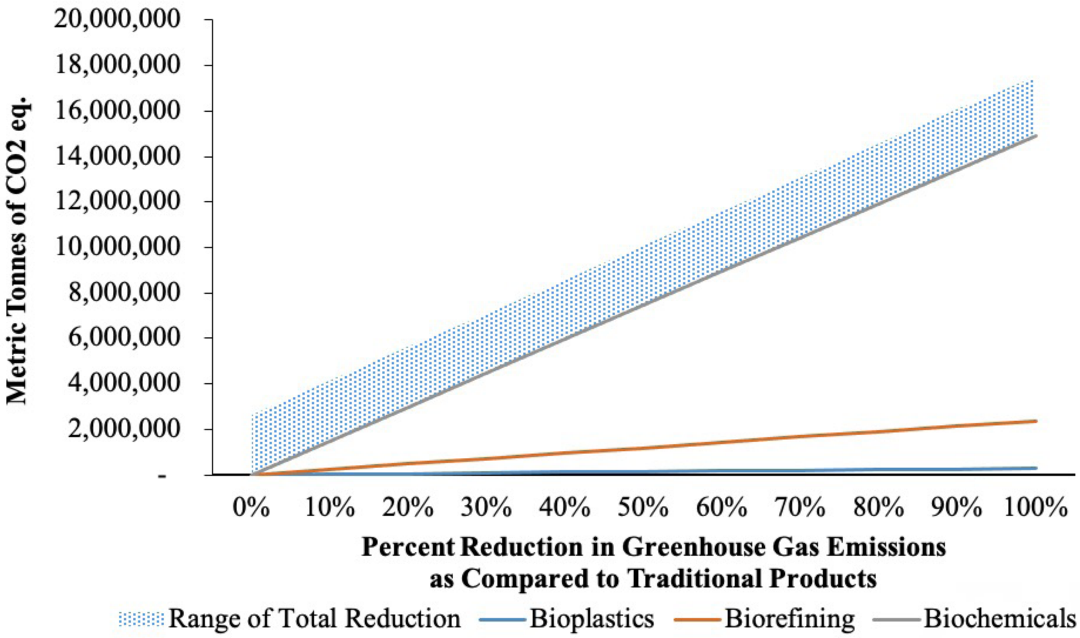
In terms of sales, the biobased plastic bottles and packaging sector was the smallest of the three sectors examined, but it had the highest reduction in GHG emissions reported in the literature. Yu and Chen reported an 80 percent percent decrease in GHG emissions compared to petroleum-based plastics, and Harding et al. reported a 65 percent decrease compared to petroleum-based plastics.[100, 101] When considering these two percentage reductions in GHG emissions, the reductions from biobased plastics could correspond to 170,000 and 210,000 metric tons of CO_2 equivalents for the 65 percent and 80 percent reductions, respectively. This reduction is shown with the dark blue line in Figure 28.

[99] Cherubini, F., and Ulgiati, S., “Crop Residues as Raw Materials for Biorefinery Systems–A LCA Case Study,” *Applied Energy* 87, no. 1, (2010): 47-57.

[100] Yu, J., and Chen, L.X.L., “The Greenhouse Gas Emissions and Fossil Energy Requirement of Bioplastics from Cradle to Gate of a Biomass Refinery,” *Environmental Science & Technology* 42, no. 18, (2008): 6961-6966, doi: 10.1021/es7032235.

[101] Harding, K. G., Dennis, J. S., Von Blottnitz, H., and Harrison, S.T.L., “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, (2007): 57-66.

Figure 28: Potential Reductions in Greenhouse Gas Emissions by Biobased Products Manufactured in the United States with a Range of Zero- to 100 percent Reduction in GHG Emissions Compared to Non-Biobased Product Alternatives.



3.7 Limitations

While the EIO-LCA model is useful in many regards, it is an older model and has some limitations. 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 likely have changed due to increased regulations of emissions and changing energy production systems. For this study, the authors used the U.S. 2002 (428-sector) Producer model, and the adjusted industry output was deflated from 2013 dollars to 2002 dollars. 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 provide a range of estimates for GHG emissions and the reductions in the use of petroleum.

3.8 Other Environmental Aspects of Biobased Products

Biobased products are an important part of human history, from providing the first forms of tools to advancing education by providing media for written communication. Many of these original uses of biobased products are still very important to many economies and society in general; however, many new biobased products have been developed in the last 150 years. Cellulose nitrate (1860), cellulose hydrate films or cellophane (1912), and soy-based plastics (1930s) are three examples of biobased materials that were developed prior to the development of the petrochemical industry in the 1950s.[102, 103, 104] With the increased use of petrochemical-based polymers and products, certain biobased materials were supplanted by petroleum-based feedstocks for the production of polymers and other materials.

With renewed interest in the environment, fluctuating oil prices, and developments in biotechnology, scientists in the 1980s developed biodegradable biobased plastics, such as PLA and PHAs. These biobased plastics, based on renewable polymers, have the potential to reduce the use of

[102] Man - Made Cellulosic Fibres (1968). Monopolies and Mergers Commission (UK).

[103] Ralston, B. E., and Osswald, T.A. (2008). "Viscosity of Soy Protein Plastics Determined by Screw-Driven Capillary Theometry;" Journal of Polymers and the Environment. July 2008, Volume 16, Issue 3, Pages 169-176.

[104] Shen et al. (2009). Li Shen, Juliane Haufe, Martin K.Patel, 2009, Product Overview and Market Projection of Emerging Biobased Plastics, Universiteit Utrecht

fossil fuels and the associated greenhouse gas emissions.[105] The lifecycle assessment (LCA) framework defined in the ISO 14044 standard can be used to understand and quantify the environmental impacts of these biobased products. This framework has previously been used to examine the lifecycles of various biobased products and to compare them to the fossil fuel-based products they could replace.[106, 107, 108]

The ISO 14044 standard has been beneficial in normalizing LCA methods and in providing a common standard that has increased the comparability and rigor of various studies. However, within this framework, there is no guidance on how to deal with the important issues that are unique to biobased products. The environmental analyses of biobased products have been shown to be sensitive to assumptions concerning the storage of biogenic carbon, the timing of emissions, direct and indirect changes in land use, and the methodologies used for accounting for carbon. The lack of commonly used, extensively shared, and scientifically-sound methodologies to address these topics has been noted by OECD (2010), Nowicki et al. (2008), Pawelzik et al. (2013), and Daystar (2015.).[109, 110, 111, 112]

3.8.1 Environmental Performance

There is extensive literature that deals with the role of biobased feedstocks as a renewable resource and their enhanced environmental performance compared to non-renewable resources. LCAs are available in the literature that compares biobased polymers and various petrochemical polymers; however, the results can be disparate because of the lack of consistent LCA methodologies needed to address biobased products. One example that has been the subject of extensive research is the role of petrochemical-based plastics, such as PE and PET, with regard to global warming potential (GWP) compared to biobased alternatives.[113, 114] The majority of studies focused only on the consumption of non-renewable energy and GWP, and they often found biobased polymers to be superior to petrochemical-derived polymers. Other studies that considered these and other environmental impact categories were inconclusive. It also is valuable to note that maturing technologies, future optimizations, and improvements in the efficiencies of biobased industrial processes are expected as the authors learn more about these processes and products.

Yates and Barlow undertook a critical review of biobased polymers to address the assumption that biobased polymers are an environmentally-preferable alternative to petrochemical polymers because they are produced using a renewable feedstock and because they potentially are biodegradable.[115] The research they examined in the literature consistently identified that the farming practices used to grow biobased feedstocks may produce varying levels of environmental burdens. In addition, the energy required to produce these biobased feedstocks may, at times, be greater than the energy required to produce petrochemical polymers.[116]

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[105] 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.

[106] Shen and Patel, 2010. "Present and Future Development in Plastics from Biomass. Biofuels, Bioproducts and Biorefining," Volume 4, Issue 1, pages 25-40, January/February 2010.

[107] Groot, W. J., & Borén, T. (2010). "Life Cycle Assessment of the Manufacture of Lactide and PLA Biopolymers from Sugarcane in Thailand." The International Journal of Life Cycle Assessment, 15(9), 970-984. doi: 10.1007/s11367-010-0225-y.

[108] Weiss M, Haufe J, Carus M, Brandão M, Bringezu S, Hermann B, et al. (2012). "A Review of the Environmental Impacts of Biobased Materials." Journal of Industrial Ecology; 16(S1):S169–81.

[109] OECD (2010). OECD, 2009, "The Bioeconomy to 2030, Designing a Policy Agenda." www.oecd.org/publishing/corrigenda

[110] Nowicki, P., Banse, M., Bolck, C., Bos, H., Scott, E., "Biobased Economy: State-of-the-Art Assessment," The Agricultural Economics Research Institute, February 2008.

[111] Pawelzik, P., Carus, M., Hotchkiss, J., Narayan, R., Selke, S., Wellisch, M., Weiss, M., Wicke, B., and 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.

[112] Daystar, J., Treasure, T., Reeb, C., Venditti, R., Gonzalez, R. and S. Kelley. (2015). "Environmental Impacts of Bioethanol Using the NREL Biochemical Conversion Route: Multivariate Analysis and Single Score Results." *Biofuels, Bioproducts and Biorefining*. DOI: 10.1002/bbb.1553

[113] Song, J.H., Murphy, R.J., Narayan, R., Davies, G.B.H. (2009). "Biodegradable and compostable alternatives to conventional plastics." *Philosophical Transaction of the Royal Society*. B 2009; 364:2127-39

[114] Shen, L., Haufe, J., Patel, M.K. "Product Overview and Market Projection of Emerging Bio-Based Plastics." Group Science, Technology and Society, Copernicus Institute for Sustainable Development and Innovation, Utrecht University.

[115] Yates, M. and C.Y. Barlow (2013). "Life Cycle Assessments of Biodegradable, Commercial Biopolymers-A Critical Review." *Resources, Conservation and Recycling* 78. Pp:54-66

[116] Yates, M. and C.Y. Barlow (2013). "Life Cycle Assessments of Biodegradable, Commercial Biopolymers-A Critical Review." *Resources, Conservation and Recycling* 78. Pp:54-66 (2013)

3.8.2 Carbon Storage in Biobased Products

Biogenic 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 biogenic 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 biogenic emissions are carbon neutral and are excluded from life cycle inventories.

The benefits and issues related to temporary carbon storage and biogenic 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 GWP within a given analytical time period.[117]

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 biogenic carbon, and it has released a draft regulation setting guidelines for accounting for biogenic carbon emissions.

3.8.3 Land Use Change

With the world's rapidly increasing population, additional land or improvements in agricultural yield will be required to support people's needs. 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, the 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.

In general, increased demand of agriculture products will result in converting forest land into cropland. When land is converted from forest land to cropland, a release of substantial forest carbon occurs. Beyond increased carbon emissions associated with LUC, changing from forest land to cropland impacts biodiversity, soil loss, and water quality. It is worth noting that the majority of the biobased products produced in the United States are from forest lands. In recent history, U.S. forest land area has been increasing, and these biobased forest products have not resulted in forest land converting to cropland.

3.8.4 Disposal

Biobased materials often are inherently biodegradable, or they are 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.[118] End-of-life LCA modeling is also sensitive to the biogenic accounting methodologies that are used, as discussed earlier.

[117] Levasseur, A., Lesage, P., Margni, M., Deschênes, L., and Samson, R. "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.

[118] 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.

3.8.5 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.

3.8.6 Microplastic Pollution

Characteristics

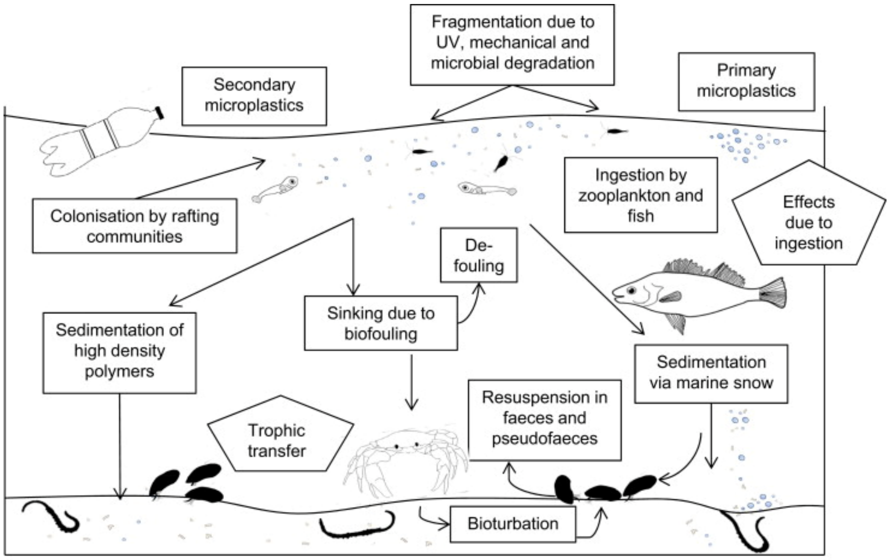
In recent years, there has been growing concern for the environmental and health impacts of microplastics pollution and its abundance in the natural environment. It should be noted that biobased materials such as biobased plastics and cotton are often biodegradable and do not create microplastics particles 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.[119] (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 identifiable by the unaided eye, microplastics are the most abundant form of plastic debris. Microplastics are transported through several pathways (Figure 32) 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.[120]

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.[121] Ingested microplastic particles have been shown to transfer up trophic levels and translocate to tissues and organs of organisms.[122]

Figure 29: Potential Pathways for the Transport of Microplastics and its Biological Interactions[123]



[119] Wright, S., Thompson, R. and Galloway, T. "The Physical Impacts of Microplastics on Marine Organisms: A Review." Environmental Pollution 178 (2013) 483-492.

[120] Andrady, A. "The Plastic in Microplastics: A Review." Marine Pollution Bulletin 119 (2017) 12–22

[121] Rehse, Saskia, Kloas, Werner, Zarfl, Christiane. "Short-term Exposure With High Concentrations of Pristine Microplastic Particles Leads to Immobilisation of Daphnia Magna." *Chemosphere 153 (2016) 91e99*

[122] Andrady, A. "The Plastic in Microplastics: A Review." Marine Pollution Bulletin 119 (2017) 12–22

[123] Wright, S., Thompson, R. and Galloway, T. "The Physical Impacts of Microplastics on Marine Organisms: A Review." Environmental Pollution 178 (2013) 483-492

4 Tracking Biobased Procurement

4.1 Relevant Federal Requirements

The 2018 Farm Bill includes new requirements and programs that will benefit the biobased products industry. The farm bill also continued funding for the BioPreferred® Program and moved the program to USDA Rural Development.

The 2018 Farm Bill also requires USDA to educate agencies on how to navigate voluntary labeling programs in Federal purchasing to ensure the value of biobased products are understood and these products are prioritized.[124]

In another positive requirement, the 2018 Farm Bill directs the Secretary of Agriculture and the Secretary of Commerce to jointly develop NAICS codes for renewable chemicals and biobased products manufacturers. Biobased product specific codes would greatly enhance the ability to track and report on the biobased products industry.

4.2 Current Reporting Activity

While there is no single, centralized Federal reporting system for collecting data on Federal biobased product procurement the requirement for the development of standardized NAICS codes for biobased products will provide a unique opportunity for standardizing reporting.

Until then, and as presented below in our 2018 report, the following tracking programs are currently in place.

Office of Management and Budget (OMB) Scorecard Contract Action Reviews: The OMB Scorecard on Sustainability/Energy, which is an annual performance scorecard, is used in part to assess agencies' progress on sustainable acquisitions. For OMB's sustainability scorecard, agencies select five percent of applicable contract actions from the previous two calendar quarters and review those actions to demonstrate compliance with biobased and other sustainable product acquisition requirements. The previous year's contract action review data are assessed to determine where biobased product requirements have been included, particularly in relation to janitorial, food services, facilities maintenance, vehicle maintenance, construction, and landscaping services contracts where there generally are several requirements to purchase biobased products if the contractors are purchasing their own supplies.

Strategic Sustainability Performance Plans (SSPPs) and Sustainability Report and Implementation Plan (SRIP): Federal agencies develop, implement, and annually update their SSSPs and SRIP, which describe how they will achieve environmental, economic, and energy goals, including sustainable acquisition. Agencies must establish a target for the number of contracts to be awarded with biobased criteria and the dollar value of biobased products to be delivered in the following fiscal year in their SSPPs.

System for Award Management (SAM): The SAM is a Federal Government owned-and-operated website that consolidates construction and services contractors' capabilities of the Central Contractor Registration Database, and Online Representations and Certifications database. It also contains a biobased purchases reporting portal. In accordance with FAR 52.223-2, vendors that have been awarded services or construction contracts issued after May 18, 2012 are required to report their biobased product purchases under their Federal contracts annually through SAM.

[124] Lane, J., New Year, New Farm Bill: "BIO Celebrates Legislation's Role in Strengthening America's Bio-based Economy," Biofuels Digest, Dec. 12, 2013, accessed May 2019, https://www.biofuelsdigest.com/bdigest/2018/12/13/new-year-new-farm-bill-bio-celebrates-legislations-role-in-strengthening-americas-bio-based-economy/.

Federal Procurement Data System – Next Generation (FPDS-NG): The FPDS-NG is a repository data system for procurements in the Federal Government. Agencies can acquire data from FPDS-NG on their previous year's acquisitions of products and services that could have included biobased product requirements.

FPDS-NG Element 8L is used as a filter for biobased reporting in the SAM. The lists of applicable contract actions are generated from FPDS-NG data and made available to the SAM for contractors to provide their biobased product purchasing information. For a contract action to be accessed from FPDS-NG, the contracting officials must have properly coded the action as having included biobased product requirements, the FAR clause for biobased product certification (52.223-1), and the FAR clause for reporting (52.223-2) by construction and services contractors. Currently, because of FPDS-NG data quality, not all applicable contract actions are transferred to the SAM from FPDS-NG. In addition, contract actions issued prior to May 18, 2012 – the effective date of the FAR reporting clause – do not contain the clause and are not available in the SAM for biobased purchase reporting.

Agency Contract Forecasts: An agency's annual contracting forecast can be used to obtain some data on planned contract actions. In general, the forecasts can provide information about recurring requirements, such as janitorial services.

Agency Tracking Systems: If an agency uses a tracking system for internal purchasing or a tracking system for the purchases of biobased products, the historical data on the acquisitions of biobased products can be obtained from these systems. For example, the National Aeronautics and Space Administration (NASA) uses an internal tracking system, NASA Environmental Tracking System that can be used to track expenditures on biobased products.

Office of Federal Procurement Policy's Report: On January 19, 2017, OMB's Office of Federal Procurement Policy (OFPP) submitted a report entitled "*Report to Congress on Implementation of Section 6002 of the Resource Conservation and Recovery Act; Section 9002 of the Farm Security and Rural Investment Act of 2002; and Section 9002 of the Agricultural Act of 2014*." The report was submitted to Congressman Jason Chaffetz and other members of Congress.[125] In the report, which covers FY 2014 FY 2016, OFPP provides information on the compliance activities associated with sustainable acquisition purchasing (See p. 9.); usage of sustainable acquisition clauses (pp. 10 and 11); procurement dollars with sustainability clauses (p. 12); Federal agency commitments to purchase biobased products in FY 17 (p. 13), and other relevant data.

4.2.1 Resources Available to Federal Agencies

Many resources are available for contracting officers and purchase card holders to help them meet the biobased product requirements of Section 6002. These resources include various training and informational tools offered by the Federal Acquisition Institute, Defense Acquisition University, the USDA, DoD, NASA, GSA, and the DOE. These resources include example contract language, example source selection evaluation factors, example FedBizOpps language, and example purchase card information to ensure purchases include biobased products. They also include guidance for small business vendors who sell biobased products; training for purchase card holders on biobased product requirements; training for contracting officers and contract specialists on biobased products and options; training for technical personnel on biobased product requirements and options; training for Service and Construction Contractors who provide biobased products; and awards for government and contrator personnel who are leaders in biobased product procurement.

The GSA has an online tool, the Green Procurement Compilation (GPC) website[126] that consolidates Federal purchasing requirements including requirements for purchasing biobased products, to help Federal buyers in their sustainable acquisition efforts. The GPC provides information on the purchasing options available under GSA contracts (e.g., by Multiple Award Schedule) and provides links to pre-populated searches within GSA Advantage! to help customer agencies identify the companies that offer sustainable products and services, including biobased products. The authors identified targets for biobased purchases that the Federal agencies identified in their 2017 planning process in Table 17.

[125] "Report to Congress on Implementation of Section 6002 of the Resource Conservation and Recovery Act (RCRA); Section 9002 of the Farm Security and Rural Investment Act of 2002; and Section 9002 of the Agricultural Act of 2014," prepared by Office of Federal Procurement Policy, Office of Management and Budget, January 19, 2017, accessed May 2019. https://www.whitehouse.gov/sites/whitehouse.gov/files/omb/procurement/reports/2017_rcra_report.pdf.).

[126] "Green Procurement Compilation," Sustainable Facilities Tool website, accessed May 2019. https://sftool.gov/greenprocurement.

Table 17: Federal Agency Commitments to Purchase Biobased Products in Fiscal Year 2017.[127]
Note: this is the most recent year data is available.

Agency	Target Contracts	Product Value
Department of Homeland Security	340	$500,000
Department of Commerce	86	$31,657
Department of Defense	60,391	$139,686,772
Department of Energy	300	$50,000,000
Department of the Interior	1,000	$30,000,000
Department of Justice	200	$4,950,000
Department of Labor	20	$1,400,000
Department of Transportation	25	$21,000,000
Department of Education		None
Environmental Protection Agency	149	$5,272,000
General Services Administration	9,504	$45,783,579
Department of Health and Human Services	274	$1,100,005
Department of Housing and Urban Development	3	$6,100,000
National Archives and Records Administration	217	$17,000,000
National Aeronautics and Space Administration	1,100	$1,000,000
Office of Personnel Management	14	$6,299,155
Smithsonian Institution		None
Social Security Administration	10	$10,561,000
Department of State	400	$40,000,000
Department of the Treasury	9,000	$4,750,000
Tennessee Valley Authority	200	$800,000
U.S. Army Corps of Engineers	1,000	$64,916,000
U.S. Department of Agriculture	200	$2,000,000
U.S. Post Office		None
Department of Veterans Affairs		None
Government Wide	**84,433**	**$453,150,168**

[127] "Report to Congress on Implementation of Section 6002 of the Resource Conservation and Recovery Act (RCRA); Section 9002 of the Farm Security and Rural Investment Act of 2002; and Section 9002 of the Agricultural Act of 2014," prepared by Office of Federal Procurement Policy, Office of Management and Budget, January 19, 2017, accessed May 2019. https://www.whitehouse.gov/sites/whitehouse.gov/files/omb/procurement/reports/2017_rcra_report.pdf.).

4.3 State & Local Biobased Procurement Programs

This partial listing provided presents a broad spectrum of established state and local procurement programs that promote the purchasing of biobased products. Portions of this information have been used with the consent of the United soybean Board. Their listing[128] is a valuable resource for the biobased products industry.

Nationally, the Urban Sustainability Directors Network (USDN) and the Responsible Purchasing Network (RPN) jointly developed a "Sustainable Procurement Playbook for Cities" in 2016. The document provides multiple recommendations for the use of biobased products. Chicago served as the lead USDN city for the project, and was joined by the following cities: Ann Arbor (MI), Austin, Houston and San Antonio (TX), Boston and Somerville (MA), Burlington (VT), Fairfax (VA), Lakewood, Orlando and Sarasota (FL), Oklahoma City (OK), Palo Alto and San Francisco (CA), Salt Lake City (UT), Washington, D.C., Vancouver (BC, Canada), and Winnipeg (MB, Canada).

ARIZONA-CITY OF PHOENIX

Phoenix, Arizona has an established Environmentally Preferable Purchasing (EPP) Policy. The policy applies to all commodity purchases made through a purchase order or city contractual agreement, as well as non-professional service contracts and purchases related to capital improvement projects. Departments will evaluate the potential for EPP attributes including biobased content.

ARIZONA STATE UNIVERSITY

Representative of the purchasing powers of major higher education institutions, ASU has a "Green Purchasing" policy (PUR 210) revised in 2015. The policy has a specific Biobased Products section (4) that defines: Biobased plastic products that are biodegradable and compostable, such as bags, film, food and beverage containers, and cutlery, shall be acquired by the university and/or used by our contracted suppliers.

1. Compostable plastic products purchased shall meet ASTM standards as found in ASTM D6400-04. Biodegradable plastics used as coatings on paper and other compostable substrates shall meet ASTM D6868-03 standards.
2. Vehicle fuels made from non-wood, plant-based contents such as vegetable oils are encouraged.
3. Paper, paper products, and construction products made from non-wood, plant-based contents such as agricultural crops and residues are encouraged.

ARKANSAS

Biobased Products Act (AR Code 25-37-101 & 102)

This act was established in 2005. It is similar to Federal programs in that it requires each state agency to give preference in making procurement decisions to items composed of the highest percentage of biobased products if they are: 1) practicable, and 2) consistent with maintaining a satisfactory level of competition.

Key elements include:

- The program must be developed using Federal guidelines that designate biobased products that qualify for preferred procurement under USDA's BioPreferred® Program.
- Provide direct or indirect access to information regarding items identified or certified by Federal rules, as they existed on January 1, 2005, that are or can be produced with biobased products and whose procurement by procuring agencies will carry out the objectives of this section;
- Set forth recommended practices with respect to the procurement of biobased products and items containing biobased materials; and provide direct or indirect access to information on availability, relative price, performance, and environmental and public health benefits of biobased materials and items.

CALIFORNIA

Environmentally Preferable Purchasing

This law, formerly known as AB 498 (Chan, Chapter 575, Statutes of 2002), addresses environmentally preferable purchasing, and became California law in September 2002. It directs the Department of General Services, in consultation with the California EPA, members of the public, industry, and public health and environmental organizations, to provide state agencies with information and assistance regarding environmentally preferable purchasing.

The California Department of General Services has developed an "Environmentally Preferable Purchasing Best Practices Manual" which has numerous references to biobased product purchasing practices.

[128] "State and Local Activities," United Soybean Board website, accessed May 2019, https://www.soybiobased.org/resources/state-local-activities/.

ORANGE COUNTY, CALIFORNIA

The Orange County Environmentally Preferable Purchasing Policy User Guide provides specific preferences for the use of biobased products. This user guide was established in support of the county's Environmentally Preferable Purchasing Policy first enacted on 09/09/2008 and revised in 2012.

COLORADO

Environmentally Preferable Purchasing (EPP)
Colorado developed an EPP policy in compliance with state Executive Order D2015-013. One of the specific strategies stated in the policy is the use of "agricultural biobased products," including use in fuels for vehicles and construction products made from plant-based materials.

CONNECTICUT

Connecticut's statewide contract for painting supplies requires that specialty-cleaning products must meet at least one environmental standard (e.g., USDA's BioPreferred® Program, EPA Design for the Environment (Safer Choice), Green Seal™ certifications).

ILLINOIS

Biobased products may be given preference over other bidders unable to do so, provided that the cost included in the bid of biobased products is not more than five percent greater than the cost of products that are not biobased. A biobased product is defined as a product designated under USDA's BioPreferred® Program.

INDIANA

Indiana statute requires state governmental bodies and educational institutions to purchase biobased products under certain conditions. A biobased product is defined as, "an item designated by the U.S. Department of Agriculture as a biobased product for Federal procurement under Section 9002 of the Federal Farm Security and Rural Investment Act of 2002."

- Biobased products must be available at the time of the purchase
- It must be economically feasible to purchase the biobased product
- The purchase of biobased products is not inappropriate because of 1) Federal regulations or policy in matters involving the Federal Government, or 2) the special requirements of scientific uses.

IOWA

State Purchase of Designated Biobased Products (IA Code 8A.317)

Iowa's law requires state agencies to give preference to purchasing designated biobased products. Purchases of designated biobased products must be made from the seller whose designated biobased product contains the greatest percentage of biobased materials. The preference program must be set up for procuring the maximum content of biobased materials in biobased products.

State Purchase of Biobased Hydraulic Fluids, Greases and Other Industrial Lubricants (IA Code 8A.316)

This law requires Iowa state agencies, when purchasing hydraulic fluids, greases, and other industrial lubricants, to give preference to purchasing biobased hydraulic fluids, greases, and other industrial lubricants as provided in section 8A.316-317 of the Iowa Code.

Renewable Chemical Tax Credit Program

This program allocates $100 million in tax credits over 10 years to be applied to the manufacturing of 40 key building block chemicals. For each pound of biobased chemicals produced in a given year, a company can receive a $0.05 tax credit.

MAINE

Environmentally Preferable Procurement Program

Maine established its EPP program in November 2004. The program has several strategies, including considering several environmental factors in making best value (as defined in statute) determinations on purchases.

MARYLAND

Environmentally Preferable Products and Services

The Maryland Green Purchasing Committee has statutory authority to establish specifications for environmentally preferable products or services (EPP), to be adopted by state agencies. Biobased products are included in the statutory definition of environmentally preferable. There are certain exceptions to the law. State agencies are required to report annually on their purchases of EPP as a percentage of their gross purchases.

MASSACHUSETTS

Massachusetts' Environmentally Preferable Products (EPP) program was established by Executive Order 509 and encourages and prioritizes the procurement of goods that are grown, manufactured, transported, and handled in a sustainable manner.

MICHIGAN

Michigan established a purchasing preference program to give preference to biobased products whose content was sourced in Michigan when making purchases. A biobased product is defined as a "product granted the US Department of Agriculture certified biobased product label under USDA's BioPreferred® Program."

MINNESOTA

For companies to take advantage of the Renewable Chemical Production Incentive Program, chemicals must be at least 51 percent biobased. Manufacturing facilities must also (a) be located within Minnesota, (b) source 80 percent of their raw materials from Minnesota, and (c) produce a minimum of 750,000 pounds of chemicals per quarter to enter the program. Production payments range from $0.03 per pound of chemical produced from sugar, cellulosic sugar, or starch, to $0.06 per pound of chemical produced from cellulosic biomass.

NEW JERSEY

New Jersey Executive Order 76, issued in January 2006, directs state agencies to purchase environmentally preferable cleaning products. Green cleaning products are identified as having biobased ingredients instead of petroleum-based ingredients and their use is encouraged whenever possible. A number of state contracts call for the use of green products or services.

Sustainable Jersey, a nonprofit organization that works with local municipalities in support of their sustainability programs, offers a certification program that gives points for the implementation of a variety of sustainable practices, including the use of biobased products in municipal contracts for goods and services.

NEW YORK

New York has established some environmental and sustainability programs, including a "Green Cleaning Program." The program establishes policies, approves green cleaning products and best practices for green cleaning products procured by the state.

Executive Order No. 4 establishes the basis for green procurement lists and specifications for purchasing by state agencies of New York. It also establishes requirements for developing sustainability and environmental stewardship programs by state agencies.

NORTH DAKOTA

State Purchasing Practices (ND Century Code 54-4.4-07)

North Dakota encourages state agencies and institutions of higher learning to purchase environmentally preferable products. The state's Century Code says, "Where practicable, biobased products should be specified." In 2014, the state's Office of Management & Budget, in conjunction with the state's Board of Higher Education, developed guidelines for a biobased procurement program.

OHIO

Ohio's law requires the state Department of Administrative Services (DAS) and other state agencies give preference to and purchase biobased products. It requires the DAS to establish a biobased product preference program. Some of the key elements of the program include:

- References the USDA's BioPreferred® Program in its definition of a biobased product. The state statue defines a biobased product as, "a product determined by the U.S. Secretary of Agriculture to be a commercial or industrial product, other than food or feed, that is composed, in whole or significant part, of biological products, renewable domestic agricultural materials, or forestry materials or is an intermediate ingredient or feedstock."
- The law generally requires DAS and other state agencies, when purchasing equipment, material, or supplies, to purchase biobased products in accordance with USDA's BioPreferred® Program, and requires the Director of Transportation and educational institutions of the state to comply with the program, even though those entities have purchasing authority separate from DAS under continuing law.

- Exceptions: If the DAS director finds the product: (1) is not available within a reasonable period of time, (2) fails to meet certain performance standards, or (3) is available only at an unreasonable price ("unreasonable price" is defined in statute).
- For any biobased product offered under the program, a vendor is required to certify that the product meets the biobased content requirements for the designated item.
- Requires a state institution of higher education to purchase designated items in accordance with procedures established by the institution.
- Exempts the purchase of motor vehicle fuel, heating oil, or electricity from the program's requirements.

OREGON

This Executive Order, issued April 2012, established the Oregon Green Chemistry Innovation Initiative. It directed state agencies to build awareness of the benefits of the use of green chemistry; to develop best practices for environmentally preferable purchasing of goods and services; to consider new or existing programs for state investment funds and loan and grant programs; to revise state purchasing and procurement practice to include specific guidelines designed to establish preferences for products designed and manufactured in a manner that is consistent with the principles of green chemistry. This EO led to the development of the state's Green Chemistry Procurement Guidelines.

There are a number of sustainability policies and activities in place in Oregon designed to meet the state's sustainability goals. These include guidelines for green building and sustainable construction, resources for drought conditions, and agency sustainability plans.

PENNSYLVANIA

This Management Directive, effective since 2014, requires state agencies that purchase goods and services to, within one year after a product is placed on the USDA Bio-Based Products List (USDA's BioPreferred® Program) and each year thereafter, estimate agency purchases of products on the list and report agency purchases of such products to the state Department of General Services.

SOUTH DAKOTA

State Biobased Purchasing (SD Statute 5-18A-30)

South Dakota allows a state purchasing agency to give preference to the purchase of supplies manufactured from recycled or biobased materials if the bids are within five percent of the lowest bid offering nonrecycled or non-biobased materials. The state defines biobased as, "any materials composed wholly or in a significant part of biological products including renewable agricultural materials or forestry materials."

VERMONT

Custodial Cleaning Chemicals

As part of its Environmental Safety and Occupational Health Criteria for custodial cleaning chemicals, Vermont lists the purchase of biobased products as desirable product criteria.

VIRGINIA

Green Jobs Tax Credit

For taxable years beginning on or after January 1, 2010, but before January 1, 2021, a taxpayer is allowed a credit for each new green job created within the Commonwealth by the taxpayer. The amount of the annual credit for each new green job is $500 for each annual salary that is $50,000 or more. Each taxpayer qualifying under this section is allowed the credit for up to 350 green jobs.

"Green job" means employment in industries relating to the field of renewable, alternative energies, including the manufacture and operation of products used to generate electricity and other forms of energy from alternative sources that include hydrogen and fuel cell technology, landfill gas, geothermal heating systems, solar heating systems, hydropower systems, wind systems, and biomass and biofuel systems.

5 Recommendations

5.1 Challenges Facing the Biobased Products Industry

The biobased products industry has grown significantly since our first economic analysis was conducted using data from 2013. In 2017 (the most current data available), the value added to the U.S. economy by biobased products was $470 billion, up from $459 billion in 2016. This estimate compares favorably with the National Research Council's estimate of $353 billion for 2012. This is good news, but the overall size of the biobased products industry is still small compared to the size of the industry that uses non-renewable feedstocks, indicating there is a lot of room for growth. For the biobased products industry to grow, the significant challenges the authors have identified during the course of this research must be addressed. Many of these challenges were discussed in the USDA's Billion Ton Bioeconomy Initiative report[129], which was discussed during a series of listening sessions. Some of the challenges that were identified are listed below.

- *Major technical hurdles exist for development and scale*. Before investments can be made in large-scale biorefineries, investors must be confident that the technology is sound and the supply chain is economically and environmentally sustainable.

- *There is intense competition from traditional petroleum-derived products*. For more than 20 years, the variability of the cost of petroleum has resulted in variability in the cost competitiveness of biobased products. This variability limits the financial investments needed to scale up the technology and validate its performance. It also limits the ultimate availability of biobased products and raises their prices. Biobased products must be cost competitive to promote the growth of the industry.

- *A lack of necessary infrastructure prevents growth.* Many biobased product sectors rely on biobased feedstocks, but a lack of infrastructure presents problems with respect to the availability of the required supply chain. Drop-in biobased products need to meet pre-existing performance standards and require extensive testing.

- *Access to capital for large financial investments is lagging.* The biobased products industry received some significant investments a few years ago, but this has decreased due to the technical, logistical, and market risks that have arisen. It is essential to re-energize the financial community to invest in the biobased products industry. Publicly supported loan guarantee programs and mandated incentives, including the renewable fuel standard (RFS), have led to increased financial investments, but the results are lower than what is required for growth.

- *Uncertainties exist about environmental, social, and economic outcomes.* Concerns still exist about impacts on the environment, soil quality, water quality, biodiversity, GHG emissions, net energy values, and direct/indirect changes in land use. Economic concerns include food and financial security and the ability to verify outcomes from biobased product processes. The public and policy makers must be successfully educated on the benefits of biobased products.

- *Policy uncertainty is causing instability and increased investment risk in the biobased products industry.* Changes in the Farm Bills can have major impacts on the biobased products industry. It is risky to make long-term plans based on policies that may change with each Farm Bill.

- *A strong and capable workforce is needed.* New training is required to help the American workforce to meet the evolving demands of the bioeconomy.

In addressing these challenges, the authors have identified several recommendations which are discussed on the following pages.

[129] "USDA and the EPA," Biomass Research & Development Board, "*The Billion Ton Bioeconomy Initiative: Challenges and Opportunities* (2016)," https://www.usda.gov/energy/maps/resources/TheBillionTonBioeconomyInitiativeChallengesandOpportunities/$file/TheBioeconomyInitiative_20161109.pdf.

5.2 Recommendations for Increasing the Growth of the Biobased Products Industry

5.2.1 Recommendation 1: Improve the Ease of Tracking Biobased Products in Federal Acquisition Systems

In its current form, Federal acquisition systems provide no way to access a centralized report for tracking purchases of biobased products. Section 23.103 of the FAR mandates Federal agencies ensure 95 percent of new contract actions for the supply of products and for the acquisition of services require biobased and other sustainable products, including energy efficient and water efficient products.[130]

Contract Officers (COs) are required to take training on sustainable acquisition, but the training varies by agency. In addition, there is a Green Procurement Compilation website[131] that provides a comprehensive green purchasing resource designed for Federal contracting personnel and program managers. Several locations on this site provide specific descriptions of Required Green Products that include biobased products identified by the BioPreferred® Program. For example, the link on the BioPreferred® Program under Cafeteria Services includes cutlery (such as SelfEco and NatureWorks products), dishwashing products, and food cleaners.

A major problem with this system of compliance is that there is no centralized reporting system for tracking the usage of biobased products. GSA representatives indicated CO involvement in promoting biobased purchases and ensuring compliance with biobased purchasing requirements varies by CO and agency. Generally, agencies such as USDA, NASA, GSA, and DoD do a good job of ensuring the biobased products clause is included in contracts. However, the ability to actually track compliance across all agencies is severely hindered by the current forms of tracking provided in the Federal Procurement Data System Next Generation (FPDS-NG).

The FPDS-NG is a repository data system for procurements in the Federal Government. Agencies can obtain data from FPDS-NG related to the previous year's acquisitions of products and services that could have included requirements for the purchase and use of biobased products.

FPDS-NG Data Element 8L is used as a filter for biobased reporting in the System for Award Management (SAM). SAM is a Federally owned-and-operated website that consolidates construction and service contractors' capabilities. It also contains a portal for reporting biobased product purchases. In accordance with FAR 52. 223-2, vendors awarded service or construction contracts after May 18, 2012 are required to annually report the biobased product purchases under their Federal contracts through SAM.[132] The lists of applicable contract actions are generated from FPDS-NG data and made available to SAM for contractors to provide their biobased product purchasing information. For a contract action to be obtained from FPDS-NG, the COs must have properly coded the action as including biobased product requirements, the FAR clause for biobased product certification (52.223-1), and the FAR clause for reporting (52.223-2) by construction and services contractors. Currently, not all applicable contract actions are pulled into SAM from FPDS-NG because of the poor quality of FPDS-NG data.

The most serious problem with these systems is that neither can provide aggregated spending data on all categories of biobased products. It appears that each agency handles the level of compliance differently. FPDS-NG allows determination of whether biobased products purchasing clauses are included in awarded contracts, but there is no method for tracking the total value of biobased products sold against these contracts using a reliable analytical tracking method. It is also possible to look into FPDS-NG for supply contracts that require biobased products, but again, there is no simple and consistent way to track this.

Therefore, while annual targets are established for biobased product purchasing, to date, there is no sustainable method for monitoring whether these targets are being met. Several recommendations were developed in conjunction with personnel on the United Soybean Board during the preparation of this report concerning government acquisition systems, some of which are presented below. These recommendations only represent suggested improvements.

[130] "Federal Acquisition Regulation," *Code of Federal Regulations*, title 48 (2018): § 23.103, https://www.acquisition.gov/sites/default/files/current/far/html/Subpart%2023_1.html.

[131] "Green Procurement Compilation," U.S. GSA, accessed July 11, 2018, https://sftool.gov/greenprocurement.

[132] "Federal Acquisition Regulation," *Code of Federal Regulations*, title 48 (2018): § 52.223-2, https://www.acquisition.gov/far/html/52_223_226.html.

- Consolidating, as soon as possible, current data elements in the FPDS-NG Data Element 8L, "Recovered Materials/Sustainability," and Data Element 8K, "Use of EPA Designated Products" into a new data field called simply "Sustainability Requirements." This field can provide concise, well-defined selections for sustainable purchasing requirements. Reducing the number of fields to one and clarifying the selections by aligning them with FAR language would allow more efficient data entry on sustainable requirements contained in contract actions captured via FPDS-NG.
- Providing training to the acquisition workforce on using the new FPDS-NG data field. Personnel in the field must have training on how to understand the biobased product purchasing criteria and how to fill out the data element correctly.
- Using SAM to collect biobased product purchasing data. Currently, FPDS-NG Data Element 8L is used as a filter for SAM's biobased purchases reporting portal. Lists of applicable contract actions are generated from FPDS-NG data and made available to SAM for contractors to provide information concerning their purchases of biobased products. If the data being transferred into SAM data were to improve, SAM could be the best option for collecting historical information on service and construction contracts. The improvements in FPDS-NG and SAM data would greatly enhance the ability of agencies to establish and ensure compliance with biobased product purchasing targets.
- Providing outreach information on SAM reporting to Federal contractors concerning how to properly and accurately report information on SAM.
- Collecting data on contract actions with strategic sourcing contract vehicles, whether internal (e.g., Department of Homeland Security's strategic sourcing vehicles) or those managed by the GSA (e.g., janitorial/sanitation products; maintenance, repair, and operation products; or building maintenance operations services).
- Reviewing construction or service contracts initiated before May 18, 2012, the effective date of the FAR's biobased products reporting clause (52.223-2). Reporting requirements for biobased product purchases can be added to solicitations for recurring contracts.
- Examining agency purchase card data. The dollar value of agency purchase card data is high and includes the purchases of many biobased products.
- Collecting automated biobased purchasing data from the AbilityOne Program, since many Federal employees purchase biobased products through the AbilityOne electronic catalog.
- Increasing awareness of COs and Federal contractors on the benefits of biobased products and the BioPreferred® Program.
- Increasing the number and proper identification of biobased products in government electronic catalogs, such as GSA Advantage and DoD EMALL, to expedite direct purchases.
- Ensuring that biobased products are clearly identified in electronic catalogs.
- Collecting automated biobased product purchasing data on biobased products purchased through the GSA and the Defense Logistics Agency (DLA).

5.2.2 Recommendation 2: Increase Incentives for Biobased Research and Market Growth

Multiple discussions during interviews with executives from biobased product companies indicated that significant barriers exist in two areas: 1) Federal compliance with biobased product purchasing requirements and 2) tax benefits supporting increased research across the wide range of biobased product categories.

As noted in the prior section, the Federal Government supports the use of biobased products in GSA and other agency contracts, but it lacks the "teeth" to ensure compliance with these requirements. Fully compliant purchasing of biobased products is unlikely to occur without a full-scale revision of the FPDS-NG system, so other incentives or penalties should be applied.

The second component is related to creating tax benefit-based incentives for biobased product research that leads to innovations. A good example of such is a bill currently in review. This bill would create a renewable chemicals production tax credit and provide credits against taxes imposed under the Income Tax Act for eligible businesses producing a renewable chemical in the same state as the biomass feedstocks are derived. This bill seeks to establish a short-term tax credit to support the production of renewable chemicals or investments in renewable chemical production facilities. The Department of Commerce and Economic Opportunity could issue tax credits up to $25 million. Eligible businesses would be able to claim a tax credit equal to the product of $0.05 multiplied by the number of pounds of renewable chemicals produced in the state from biomass feedstock.[133]

It is also worthwhile to investigate how other global regions are trying to implement strategies to increase the biobased products industry that may put them ahead of the United States in terms of innovation in this increasingly important industry. For instance, as part of its broader Bioeconomy Strategy launched in 2012, the EU is working to enhance the production and conversion of biobased feedstocks.[134] Their strategy also seeks to focus and direct Europe's common efforts in this diverse and fast-changing part of the economy. Its main purpose is to streamline existing policy approaches related to the biobased products industry.

The EU's Bioeconomy Strategy is structured around three important activities:

- *Investments in research, innovation, and skills;*
- *Reinforced policy interactions and stakeholder engagement; and*
- *Enhancement of markets and competitiveness.*[135]

The strategy proposes answers to challenges that Europe and the rest of the world are facing, i.e.

- Increasing populations that must be fed
- Depletion of natural resources
- Impacts of ever-increasing environmental pressures
- Climate change

On May 6, 2014, the EU implemented Regulation (EU) No. 560/2014,[136] which established the Bio-based Industries (BBI) Joint Undertaking, a more than $4 billion public-private partnership between the EU and the Bio-based Industries Consortium.[137] According to the European Commission:

> *The objective of the BBI Joint Undertaking is to implement a program of research and innovation activities in Europe that will assess the availability of renewable biological resources and the development of new bio-refining technologies to sustainably transform these resources into biobased products, materials, and fuels.*
>
> *It is believed that this initiative will yield important breakthroughs in biobased innovation. The partnership is designed to involve multiple industries and participants through collaboration between stakeholders along the entire biobased value chains, including primary production and processing industries, consumer brands, small and medium-sized enterprises, and research and technology centers and universities.*[138]

These programs are beginning to produce results. For example, the Zernike Advanced Processing (ZAP) facility is opening an innovation lab in the Netherlands to provide facilities for experimental biobased research.

> *The ZAP facility is a semi-industrial environment in which academic institutions and businesses can collaborate on innovative solutions for the biobased economy. The facility is designed so that potential entrepreneurs can present applied research questions to the team, leading to the development and marketing of new biobased products or making chemical processes more sustainable. Within ZAP, biomass residues, such as sugar beets, potatoes, grass, pruning waste, lupine, hemp, and others, are used to generate energy for use in multiple industries, such as pharmaceuticals and cosmetics.*[139]

[133] Renewable Chemicals Act of 2017, H.R.3149, 115th Congress (2017-2018).

[134] European Commission, "*Innovating for Sustainable Growth: A Bioeconomy for Europe*" (2012), http://bookshop.europa.eu/en/innovating-for-sustainable-growth-pbKI3212262/.

[135] European Commission, "*Innovating for Sustainable Growth: A Bioeconomy for Europe*" (2012), http://bookshop.europa.eu/en/innovating-for-sustainable-growth-pbKI3212262/.

[136] "Establishing the Bio-based Industries Joint Undertaking," *The Council of the European Union*, EU No 560/2014 (2014),http://eur-lex.europa.eu/legal-content/EN/TXT/PDF/?uri=CELEX:32014R0560&from=EN.

[137] Biobased Industries Consortium website, accessed July 2018. http://biconsortium.eu/.

[138] "Bio-based Products and Processing," The European Commission, accessed July 12, 2018, https://ec.europa.eu/research/bioeconomy/index.cfm?pg=policy&lib=bbpp.

[139] "ZAP Biobased Research will be Changing Society," University of Groningen, accessed July 12, 2018, https://www.rug.nl/news/2018/03/_zap-biobased-research-will-be-changing-society_.

Europe is also at the forefront of shifting consumer behaviors via public policies that provide incentives for biobased products. Analytical group FMI Corporation ties the increase in the use of biobased plastics in the EU to regulatory schemes that support bio-applications and to consumers' awareness and acceptance of green products and policies. For instance, consumers in Italy and Germany have been shifting away from the traditional bags used in shopping for groceries to biodegradable plastic bags. Also, early in 2018, the EU approved new provisional waste reduction agreements on targets for recycling and reduction of landfilling, which was a boost for biobased plastics because it "acknowledges that biobased feedstock for plastic packaging as well as compostable plastics for separate biowaste collection contribute to more efficient waste management and help to reduce the impacts of plastic packaging on the environment."[140]

In China, significant progress and investment are going into scaling up several industries that make biobased products, e.g., biobased chemicals, such as lactic acid, 1,3-propanediol, and succinic acid; biodegradable biobased polymers, such as co-polyester of diacid and diol, polylactic acid; and non-biodegradable biobased polymers, such as bio-based polyamide, polytrimethylene terephthalate, biobased polyurethane, and biobased fibers.[141]

In both cases, it is important to recognize the interdependency of parties in the biobased supply chain. Until recently, first-mover risks held back a lot of investment, as described in previous reports. During this period, there were also significant industry challenges because the volume of biobased products demanded was smaller than the volume of biobased products needed to support a large-scale biorefinery as a source of feedstocks. This presented a "chicken and egg" dilemma, because the benefits of large-scale biorefineries could not be attained unless there was a demand for the output. Unless there is significant demand for biomass value chains, in terms of demand for biobased feedstocks and support from farmers, foresters, and waste management authorities, there is not enough demand to support a biorefinery. The interdependency and complex value chains that span a wide range of products and sectors require a coordinated approach, similar to what is happening in the EU. As an example, the Ford and Reebok case studies provide convergent examples of challenges that exist in terms of lack of product availability in very diverse industries. The key challenges that lie ahead include:

- Sustainable biomass supply
- Market pull from Federal acquisition and state public procurement
- Market pull from consumers
- Incentives for the private sector to invest
- Increased standardization and labeling of products to increase consumer awareness
- Educating retailers and consumers concerning what biobased content means and how it is measured

Many of these measures cannot be addressed simply at the Federal level; they will require community-level collaboratives supported by a Farm Bill aligned with Federal incentives for growth. The focus should include:

- Feedstocks – creating a sustainable biomass supply with improved productivity and logistics value chains for transportation to consumer markets
- Biorefineries that optimize efficient processing through continuous improvement, R&D, and upscaling of flagship pilots and demonstrations.
- Development of national and regional clusters through tax incentives to provide support for emerging industries to co-locate near feedstock sources, which can help bring jobs to rural areas. This can help drive efficiency in logistics and reduce costs.
- Support of entrepreneurial small and medium enterprises to get access to capital markets through pooled funds and support for market growth in order to access global markets.

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[140] "Bio-based Products and Processing," The European Commission, accessed July 12, 2018, https://ec.europa.eu/research/bioeconomy/index.cfm?pg=policy&lib=bbpp.

[141] Yan Xiaoqian, et al., "Development Status of Domestic Bio-Based Materials Industry." *Chinese Journal of Biotechnology* 32, no. 6 (2016): 715-725. http://journals.im.ac.cn/cjbcn/ch/reader/view_abstract.aspx?file_no=gc16060715&flag=1.

5.2.3 Recommendation 3: Increase Opportunities for Private Sector and University Collaboration Through Ongoing NSF, USDA, and DOE Funding Support

One of the most important catalysts for innovation in the biobased products industry involves the cooperation of industry and academia to increase biobased product innovation. There are multiple examples of collaboration between universities and the private sector that have resulted in significant breakthroughs and new technologies. An older example of this is George Washington Carver:

> *One of the most well-regarded universities for biobased research is Iowa State University (ISU). George Washington Carver, a pioneer of biobased product innovation, began his botanical studies in Ames in 1891, as the first African-American student at ISU. Upon completion of his Bachelor of Science degree, Carver's professors, Joseph Budd and Louis Pammel, persuaded him to enter the master's degree program. His graduate studies included intensive work in plant pathology at the Iowa Experiment Station. In these years, Carver established his reputation as a brilliant botanist and began the work that he would pursue for the remainder of his career. After graduating from ISU, Carver embarked on a career of teaching and research. Booker T. Washington, the principal of the African-American Tuskegee Institute, hired Carver to head the Institute's Agricultural Department in 1896. Carver conducted groundbreaking research on plant biology, much of which was focused on the development of new uses for crops, including peanuts, sweet potatoes, soybeans, and pecans. Carver invented hundreds of products: more than 300 products from peanuts, including milk, plastics, paints, dyes, cosmetics, medicinal oils, soap, ink, and wood stains; 118 products from sweet potatoes, including molasses, glue for postage stamps, flour, vinegar, synthetic rubber; and even a type of gasoline.* [142]

A more recent example of collaboration is the Center for Bioplastics and Biocomposites (CB^2). CB^2 focuses on "developing high-value, biobased products from agricultural and forestry feedstocks." [143] It is a NSF Industry & University Cooperative Research Center (I/UCRC) made up of the collaborative efforts of the Biopolymers & Biocomposites Research Team at ISU, the Composite Materials and Engineering Center at Washington State University (WSU), and industry members. ISU has unique biobased products expertise, and WSU has been researching natural fiber polymer composites for over 60 years. CB^2 hopes the combined efforts of ISU and WSU will lead to the U.S. plastics industry adopting new biobased product technologies and ideas.

As CB^2's website describes, this center has three goals:

> *(1) to improve the basic understanding of the synthesis, processing, properties, and compounding of bioplastic and biocomposite materials; (2) to develop reliable data concerning the characteristics of the materials for industrial partners; and (3) to support large-scale implementation of renewable materials. In order to achieve these goals, the activities will be:*
>
> - Collaboration with industry to develop fundamental knowledge related to bioplastics and biocomposites
> - Dissemination of this knowledge through publications, workshops, and tradeshows
> - Education of future researchers, engineers, and scientists[144]

David Grewell, the Director of CB^2, shared how such collaboration typically occurs. The center has several industrial partners, including 3M, Branson, Diageo, Dukane, Archer Daniels Midland, John Deere, Ford, Hyundai, and Myriant. These partners identify a problem they wish to have solved, and seek solutions involving the development of a new biobased material for a specific function with defined performance requirements. Once a problem is identified, CB^2 sends requests for proposals to the 27 professors at ISU and WSU, and these professors vote once a year on which projects to pursue. Faculty members can submit proposals, and they are encouraged to work with industry partners in exploring their solution. Proposals are reviewed and presented at a fall event. This is an engaging program that encourages frequent interactions between faculty and industrial experts. All intellectual property from funded proposals belongs to the sponsoring partners, but some royalties may be paid as well.

[142] "George Washington Carver Biography," A&E Television Networks, accessed July 12, 2018, https://www.biography.com/people/george-washington-carver-9240299.

[143] "About," The Center for Bioplastics and Biocomposites, accessed July 12, 2018, http://www.cb2.iastate.edu/about.html.

[144] "About," The Center for Bioplastics and Biocomposites, accessed July 12, 2018, http://www.cb2.iastate.edu/about.html.

A key to the success of this program is the funding provided by the National Science Foundation. According to CB2's website,

> *The Center for Bioplastics and Biocomposites is an NSF Industry & University Cooperative Research Center (I/UCRC) that brings together industry partners and university researchers who have a common interest in biobased plastics and composites.*
>
> *The I/UCRC program helps build partnerships between industry, universities, and policymakers. An I/UCRC center is supported primarily by industry partners, and it conducts research that is relevant to industry's interests. NSF has a supporting role and supplies the Center with matching funds for the first five years with declining grant support thereafter.*[145]

The ongoing support of NSF and other organizations for industry-university research is fundamentally important for the development and production of new biobased materials. Several universities and private sector companies have invested in centers, faculty members, and initiatives that are exploring different technologies to use biobased materials in new products.

5.2.4 Recommendation 4: Expand Marketing of and Education Related to the BioPreferred® Program's USDA Certified Biobased Product Label

Several people the authors interviewed recognized that government spending is getting tighter, and government programs are likely to be under budget pressure. To ensure the BioPreferred® Program is properly funded, USDA must become more proactive in marketing its benefits to stakeholders. Although the biobased product industry is still in a nascent stage, the potential to growth is significant, and growth can be supported by establishing greater credibility, which occurs through positive recognition of the benefits of accreditation. It is not just about getting a greater number of products certified as USDA Certified Biobased Products; it also must involve ongoing marketing and recognition by both commercial and retail brands, consumers, and distributors. The Biopreferred® Program has grown to a point at which further growth can occur more rapidly if current brands participating in the BioPreferred® Program expand their footprint.

What can be done to enhance and market the BioPreferred® Program? In response to that question, several suggestions emerged from our discussions:

- Create a market pavilion and invite all brands participating in the BioPreferred® Program to be showcased and featured to potential retailers, Federal and state contractors, and commercial procurement managers.
- Promote the BioPreferred® Program's brand through targeted education at community forums, retailer shows, and supplier events sponsored by the DoD Supply Officer events and GSA.
- Collaborate with groups worldwide that support biobased products and could help promote exports to these regions.
- Partner with other agencies and organizations such as the DOE, Cotton, Inc., and the Foodservices Packaging Institute to promote mutual goals.
- Link the USDA Certified Biobased Product label to tangible sustainability metrics that are meaningful to consumers (e.g., volume of hydrocarbons reduced, jobs supported in the USA, volume of landfill waste avoided, or other metrics that support consumer awareness).
- Create market pull factors that create specific incentives for growth. Discuss current operational procedures with stakeholders and adapt. For example, the EPA had a "Design for the Environment" program and label that it renamed "Safer Choice" and released a new label after more than a year of discussions with stakeholders.
- There also are variations of the Safer Choice label that can be used for business, industrial, and institutional products, as well as fragrance-free products for consumers who prefer these products. In addition, EPA presents Safer Choice Partner of the Year Awards, which recognize the leadership contributions of Safer Choice partners and stakeholders who have shown outstanding achievements in the design, manufacture, promotion, and use of Safer Choice-certified products. These types of promotions could enhance the visibility of the BioPreferred® Program's brand.

[145] "About," The Center for Bioplastics and Biocomposites, accessed July 12, 2018, http://www.cb2.iastate.edu/about.html.

5.2.5 Recommendation 5: Leverage Biobased Product Goals with the DOE and other Federal Agencies

Biobased product promotion began as a result of the 2002 Farm Bill, which sought to identify alternative uses for agricultural resources that would increase the demand for biobased products and support market prices for farmers.

From a supply chain perspective, there are clear synergies between the objectives of the BioPreferred® Program and the objectives of the DOE's Bioenergy Technologies Office (BETO). BETO works to develop technologies for domestically-produced biofuels and biobased products. Scientists and engineers with BETO are focused on discovering new and more efficient ways to convert biomass to biofuels and developing commercially-viable biobased products; working with various parts of the government, industrial, academic, agricultural, and nonprofit partners. Biomass and biofuels are two of the main feedstocks used to make many biobased products, including products identified by the BioPreferred® Program.

The Feedstock Supply and Logistics Technology area within BETO focuses on developing technologies to ensure a reliable, affordable, and sustainable supply of terrestrial biomass feedstock. The DOE website goes into more depth:

> *Ensuring a sustainable supply of high-quality biomass feedstock requires research and development to streamline all elements of the biomass feedstock supply chain, including plant breeding and genomics, crop production and harvesting practices, and biomass preprocessing, transport, and storage systems. Sustainable feedstock production includes all of the steps required to produce biomass feedstocks to the point where they are ready to be collected or harvested from the field or forest. Feedstock Logistics encompasses all the unit operations necessary to harvest the biomass and move it from the field or forest to the conversion process at the biorefinery, while ensuring that the delivered feedstock meets the biorefinery physical and chemical quality specifications.*[146]

The alignment and partnership of BETO and the BioPreferred® Program could be linked under USDA's Rural Development (RD) initiative.[147] A goal of RD is to promote economic development by supporting loans to businesses through banks, credit unions, and community-managed lending pools. RD offers technical assistance and information to help agricultural producers and cooperatives get started and improve the effectiveness of their operations.

Another important and much broader Federal initiative is the Bioeconomy Initiative. It involves multiple agencies with the goal of developing and coordinating innovative approaches for expanding the use of the country's abundant biomass resources to maximize economic, social, and environmental benefits.[148] Their report released in 2016, "The Billion Ton Bioeconomy Initiative," identified many of the challenges to expanding the bioeconomy.[149] The Bioeconomy Initiative created a sustainability framework that considers multi-dimensional impacts and benefits to prioritize the most promising pathways. This effort is a product of interagency collaboration under the Biomass Research and Development Board and does not establish any new policies, nor does it explicitly reflect U.S. Government policy. The agencies involved in this effort have some distinct, yet overlapping, objectives to advance the growth of the biobased products industry that benefit from coordination:

- DOE funds research, development, and demonstration of advanced biofuels to lower production costs.
- USDA supports the sustainable production of high quality, non-food feedstocks for conversion into biobased products, bioenergy, and bioheat.
- EPA implements the Renewable Fuel Standard and regulates the processes and safety of biobased products.
- The U.S. Department of the Navy supports the use of alternative fuels for its maritime fleet and national security.
- DOT funds research to develop alternative energy pathways for the U.S. transportation sector.

146 "Biomass Feedstocks," The Office of Energy Efficiency and Renewable Energy, U.S. Department of Energy, accessed July 12, 2018, https://www.energy.gov/eere/bioenergy/biomass-feedstocks.

147 "Rural," USDA, accessed July 12, 2018, https://www.usda.gov/topics/rural.

148 USDA, EPA, Biomass Research & Development Board, *The Billion Ton Bioeconomy Initiative: Challenges and Opportunities* (2016), https://www.usda.gov/energy/maps/resources/TheBillionTonBioeconomyInitiativeChallengesandOpportunities/$file/TheBioeconomyInitiative_20161109.pdf.

149 USDA, EPA, Biomass Research & Development Board, *The Billion Ton Bioeconomy Initiative: Challenges and Opportunities* (2016), https://www.usda.gov/energy/maps/resources/TheBillionTonBioeconomyInitiativeChallengesandOpportunities/$file/TheBioeconomyInitiative_20161109.pdf.

- Department of the Interior (DOI) manages and conserves the public lands for the use and enjoyment of present and future generations under its mandate of multiple-use and sustained yield.
- The NSF funds research and education in engineering and areas that involve transformation and/or transport of matter and energy by chemical, thermal, or mechanical means.
- The Executive Office of the President's Office of Science and Technology Policy ensures that the scientific and technical work of the Executive Brand regarding biobased products is coordinated properly in order to provide the greatest benefit to society.

These recommendations all have a common theme of increasing collaboration between multiple industry partners, public sector organizations, academic institutions, consumer marketing consultancies, and others. The goal is that by working together, the many challenges that exist in growing the biobased products industry can be addressed through alternative and innovative approaches that promote consumer awareness, utilize existing market and supply chain channels in different ways, and develop technologies that promote renewable resources in new and different ways. Biobased products still represent a very small percentage of the existing market across multiple product categories, but the authors are seeing increased growth, which is projected to continue in the years ahead.

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 USDA 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, N.C.

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).[150] 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:

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

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 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.[151]

Employment in IMPLAN is represented as the number of the number of both full- 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[152]. 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.

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

[151] USA. U.S. Department of Commerce. Bureau of Economic Analysis. "Concepts and Methods of the U.S. Input-Output Accounts." By Karen J. Horowitz and Mark A. Planting. September 2006, updated March 2009. Accessed May 2018. http://www.bea.gov/index.php/system/files/papers/WP2006-6.pdf.

[152] IMPLAN refers to value added in this context as "total value added."

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.[153] 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 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 2013 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 for 2013 at a local purchase percentage of 100 percent. 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.

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

$$\frac{\text{Direct Effect + Indirect Effect}}{\text{Direct Effect}} = \textbf{Type I Multiplier}$$

153 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.

Appendix B:
Direct Value Added and Employment by Agriculture and Forestry Subsectors in CA, NC, and GA

Distribution of Direct Value Added and Employment by Agriculture and Forestry Subsectors for the top three states in the U.S. by direct value added to the U.S. Biobased Products Industry

Distribution of Direct Value Added and Employment by Agriculture and Forestry Subsectors in California.

IMPLAN Code	NAICS Codes	Description	Employment	Value Added
16	113310	Commercial logging	3,700	$289,000,000
19	11511, 11531	Support activities for agriculture and forestry – Animal production has been excluded	34,400	$1,410,000,000
8	111920	Cotton farming	1,300	$342,000,000
15	113110, 113210	Forestry, forest products, and timber tract production	500	$61,000,000
2	111150	Grain farming – only corn included	50	<$1,000,000
9	111930, 111991	Sugarcane and sugar beet farming	<50	<$1,000,000
1	11111	Oilseed farming	<50	<$1,000,000
		Totals	**39,950**	**$2,102,000,000**

Distribution of Direct Value Added and Employment by Agriculture and Forestry Subsectors in North Carolina.

IMPLAN Code	NAICS Codes	Description	Employment	Value Added
16	113310	Commercial logging	4,500	$243,000,000
19	11511, 11531	Support activities for agriculture and forestry – Animal production has been excluded	2,600	$88,000,000
8	111920	Cotton farming	700	$162,000,000
15	113110, 113210	Forestry, forest products, and timber tract production	200	$23,000,000
2	111150	Grain farming – only corn included	<50	<$1,000,000
9	111930, 111991	Sugarcane and sugar beet farming	0	$-
1	11111	Oilseed farming	<50	$2,674,000
		Totals	**8,000**	**$519,000,000**

Distribution of Direct Value Added and Employment by Agriculture and Forestry Subsectors in Georgia.

IMPLAN Code	NAICS Codes	Description	Employment	Value Added
16	113310	Commercial logging	6,800	$404,000,000
19	11511, 11531	Support activities for agriculture and forestry – Animal production has been excluded	4,300	$126,000,000
8	111920	Cotton farming	3,500	$533,000,000
15	113110, 113210	Forestry, forest products, and timber tract production	400	$84,000,000
2	111150	Grain farming – only corn included	<50	<$1,000,000
9	111930, 111991	Sugarcane and sugar beet farming	0	$–
1	11111	Oilseed farming	<50	<$1,000,000
		Totals	**15,000**	**$1,147,000,000**

Appendix C: Direct Value Added and Employment by Agriculture and Forestry Subsectors in TX, CA, and GA

Distribution of Direct Value Added and Employment by Agriculture and Forestry Subsectors for the top three states in the U.S. by direct value added in the Agriculture and Forestry Sector

Distribution of Direct Value Added and Employment by Agriculture and Forestry Subsectors in Texas.

IMPLAN Code	NAICS Codes	Description	Employment	Value Added
16	113310	Commercial logging	2,100	$130,000,000
19	11511, 11531	Support activities for agriculture and forestry – Animal production has been excluded	12,600	$321,000,000
8	111920	Cotton farming	18,400	$2,095,000,000
15	113110, 113210	Forestry, forest products, and timber tract production	300	$20,000,000
2	111150	Grain farming – only corn included	300	<$1,000,000
9	111930, 111991	Sugarcane and sugar beet farming	<50	<$1,000,000
1	11111	Oilseed farming	<50	<$1,000,000
		Totals	**33,700**	**$2,566,000,000**

Distribution of Direct Value Added and Employment by Agriculture and Forestry Subsectors in California.

IMPLAN Code	NAICS Codes	Description	Employment	Value Added
16	113310	Commercial logging	3,700	$289,000,000
19	11511, 11531	Support activities for agriculture and forestry – Animal production has been excluded	34,400	$1,410,000,000
8	111920	Cotton farming	1,300	$342,000,000
15	113110, 113210	Forestry, forest products, and timber tract production	500	$61,000,000
2	111150	Grain farming – only corn included	50	<$1,000,000
9	111930, 111991	Sugarcane and sugar beet farming	<50	<$1,000,000
1	11111	Oilseed farming	<50	<$1,000,000
		Totals	**39,950**	**$2,102,000,000**

Distribution of Direct Value Added and Employment by Agriculture and Forestry Subsectors in Georgia.

IMPLAN Code	NAICS Codes	Description	Employment	Value Added
16	113310	Commercial logging	6,800	$404,000,000
19	11511, 11531	Support activities for agriculture and forestry – Animal production has been excluded	4,300	$126,000,000
8	111920	Cotton farming	3,500	$533,000,000
15	113110, 113210	Forestry, forest products, and timber tract production	400	$84,000,000
2	111150	Grain farming – only corn included	<50	<$1,000,000
9	111930, 111991	Sugarcane and sugar beet farming	0	$–
1	11111	Oilseed farming	<50	<$1,000,000
		Totals	**15,000**	**$1,147,000,000**

Appendix D:
Direct Value Added and Employment at the State Level, by Sector (2017)

Direct Value Added and Employment in each State by each of the Seven Major Sectors in the U.S. Biobased Products Industry.

State	Direct Employment	Direct Value Added
AK	**1,740**	**79,943,900**
Agriculture and Forestry	710	58,867,500
Biobased Chemicals	10	598,600
Biorefining	<10	<100
Enzymes	<10	<100
Forest Products	930	15,656,400
Biobased Plastic Bottles and Packaging	<10	12,300
Textiles	100	4,819,100
AL	**55,450**	**5,158,412,400**
Agriculture and Forestry	10,740	776,454,300
Biobased Chemicals	260	82,578,800
Biorefining	<10	744,900
Enzymes	50	14,214,000
Forest Products	33,420	3,924,597,100
Biobased Plastic Bottles and Packaging	20	1,659,000
Textiles	5,840	265,981,100
AR	**35,090**	**3,290,103,500**
Agriculture and Forestry	7,520	550,410,800
Biobased Chemicals	210	66,667,100
Biorefining	<10	491,900
Enzymes	810	128,037,900
Forest Products	26,420	2,638,522,400
Biobased Plastic Bottles and Packaging	10	1,455,100
Textiles	1,120	54,125,100

State	Direct Employment	Direct Value Added
AZ	**19,150**	**1,129,651,100**
Agriculture and Forestry	3,120	231,245,200
Biobased Chemicals	150	34,435,300
Biorefining	<10	82,000
Enzymes	380	111,074,000
Forest Products	14,420	767,545,800
Biobased Plastic Bottles and Packaging	10	1,041,600
Textiles	1,410	43,398,700
CA	**165,260**	**11,903,185,700**
Agriculture and Forestry	39,910	2,102,817,100
Biobased Chemicals	1,710	422,568,700
Biorefining	20	4,443,700
Enzymes	5,280	1,336,822,800
Forest Products	86,930	6,722,129,100
Biobased Plastic Bottles and Packaging	100	8,591,900
Textiles	33,860	1,657,479,000
CO	**14,690**	**863,864,600**
Agriculture and Forestry	1,690	55,946,700
Biobased Chemicals	150	40,458,300
Biorefining	<10	320,500
Enzymes	390	110,533,600
Forest Products	10,870	589,096,400
Biobased Plastic Bottles and Packaging	10	854,600
Textiles	1,720	95,137,100
CT	**10,920**	**1,392,525,700**
Agriculture and Forestry	960	26,655,600
Biobased Chemicals	380	93,664,400
Biorefining	<10	27,200
Enzymes	1,400	608,670,000
Forest Products	7,340	612,763,600
Biobased Plastic Bottles and Packaging	10	1,168,700
Textiles	1,240	139,790,200

State	Direct Employment	Direct Value Added
DC	**170**	**11,088,100**
Agriculture and Forestry	<10	<100
Biobased Chemicals	<10	90,100
Biorefining	<10	<100
Enzymes	<10	<100
Forest Products	110	9,633,500
Biobased Plastic Bottles and Packaging	<10	5,800
Textiles	50	1,358,400
DE	**2,760**	**301,662,500**
Agriculture and Forestry	720	21,854,600
Biobased Chemicals	60	29,842,800
Biorefining	<10	195,700
Enzymes	260	138,852,800
Forest Products	1,530	223,931,600
Biobased Plastic Bottles and Packaging	<10	598,600
Textiles	440	19,816,800
FL	**55,470**	**4,162,249,800**
Agriculture and Forestry	11,290	503,693,000
Biobased Chemicals	610	115,331,000
Biorefining	20	4,429,200
Enzymes	800	114,500,300
Forest Products	37,600	3,290,503,400
Biobased Plastic Bottles and Packaging	30	2,203,400
Textiles	6,160	259,769,900
GA	**98,620**	**9,357,121,200**
Agriculture and Forestry	14,980	1,147,049,800
Biobased Chemicals	780	202,353,700
Biorefining	10	1,918,700
Enzymes	1,280	292,283,200
Forest Products	54,610	5,821,833,700
Biobased Plastic Bottles and Packaging	40	5,114,400
Textiles	28,610	2,161,122,600

State	Direct Employment	Direct Value Added
HI	**2,450**	**84,592,600**
Agriculture and Forestry	500	10,320,300
Biobased Chemicals	10	1,547,100
Biorefining	<10	8,800
Enzymes	20	2,806,000
Forest Products	1,290	51,842,400
Biobased Plastic Bottles and Packaging	<10	53,500
Textiles	660	21,129,600
IA	**24,180**	**2,505,078,700**
Agriculture and Forestry	1,720	63,628,500
Biobased Chemicals	270	140,918,200
Biorefining	60	17,197,600
Enzymes	2,930	1,350,403,800
Forest Products	20,150	1,663,454,700
Biobased Plastic Bottles and Packaging	20	1,948,900
Textiles	870	51,168,400
ID	**16,060**	**1,040,954,600**
Agriculture and Forestry	2,670	155,815,700
Biobased Chemicals	80	12,719,800
Biorefining	20	4,679,800
Enzymes	230	32,868,400
Forest Products	12,660	826,763,600
Biobased Plastic Bottles and Packaging	<10	312,200
Textiles	470	13,804,800
IL	**46,020**	**4,062,901,300**
Agriculture and Forestry	2,020	71,461,000
Biobased Chemicals	1,210	281,134,800
Biorefining	120	43,762,600
Enzymes	2,640	468,923,900
Forest Products	37,750	3,340,058,300
Biobased Plastic Bottles and Packaging	100	10,868,200
Textiles	4,750	238,845,500

State	Direct Employment	Direct Value Added
IN	**63,140**	**3,786,585,900**
Agriculture and Forestry	4,610	173,242,600
Biobased Chemicals	630	195,177,400
Biorefining	30	10,216,400
Enzymes	1,390	322,430,000
Forest Products	54,870	3,264,656,500
Biobased Plastic Bottles and Packaging	90	6,691,300
Textiles	2,910	136,697,700
KS	**11,570**	**782,304,300**
Agriculture and Forestry	1,020	79,901,700
Biobased Chemicals	180	58,765,600
Biorefining	<10	544,600
Enzymes	1,270	328,426,800
Forest Products	8,440	445,070,500
Biobased Plastic Bottles and Packaging	10	1,076,800
Textiles	1,360	47,971,200
KY	**33,950**	**2,407,534,200**
Agriculture and Forestry	4,510	147,122,300
Biobased Chemicals	510	124,692,500
Biorefining	<10	485,300
Enzymes	1,080	225,387,900
Forest Products	26,440	2,035,071,100
Biobased Plastic Bottles and Packaging	30	2,717,600
Textiles	2,440	102,235,200
LA	**26,030**	**2,954,961,700**
Agriculture and Forestry	6,370	419,948,200
Biobased Chemicals	360	172,857,600
Biorefining	30	7,208,300
Enzymes	1,430	593,626,800
Forest Products	18,100	2,324,309,600
Biobased Plastic Bottles and Packaging	10	515,300
Textiles	1,270	41,703,600

State	Direct Employment	Direct Value Added
MA	**24,320**	**1,991,309,800**
Agriculture and Forestry	2,990	92,026,100
Biobased Chemicals	360	81,861,300
Biorefining	<10	50,300
Enzymes	1,420	488,653,100
Forest Products	15,410	1,147,556,600
Biobased Plastic Bottles and Packaging	30	3,215,700
Textiles	4,590	243,002,000
MD	**13,690**	**2,722,778,100**
Agriculture and Forestry	1,040	40,076,300
Biobased Chemicals	190	73,444,600
Biorefining	10	2,284,500
Enzymes	2,190	1,871,253,300
Forest Products	8,600	643,060,500
Biobased Plastic Bottles and Packaging	20	2,108,200
Textiles	1,760	109,143,900
ME	**18,910**	**1,311,119,500**
Agriculture and Forestry	5,540	246,969,000
Biobased Chemicals	30	4,172,800
Biorefining	<10	164,400
Enzymes	190	18,127,500
Forest Products	11,840	983,061,900
Biobased Plastic Bottles and Packaging	<10	434,700
Textiles	1,310	58,150,600
MI	**48,300**	**3,589,706,100**
Agriculture and Forestry	4,860	215,093,200
Biobased Chemicals	1,280	223,058,200
Biorefining	10	3,012,500
Enzymes	970	124,675,500
Forest Products	39,150	2,954,492,600
Biobased Plastic Bottles and Packaging	80	6,706,700
Textiles	3,020	177,559,300

State	Direct Employment	Direct Value Added
MN	39,840	3,715,375,200
Agriculture and Forestry	2,590	116,081,000
Biobased Chemicals	390	103,581,600
Biorefining	30	6,476,400
Enzymes	1,260	255,076,800
Forest Products	33,990	3,307,456,900
Biobased Plastic Bottles and Packaging	40	3,321,200
Textiles	2,760	131,586,200
MO	**33,850**	**3,186,973,200**
Agriculture and Forestry	5,480	334,419,700
Biobased Chemicals	550	152,919,100
Biorefining	<10	712,300
Enzymes	3,340	767,161,500
Forest Products	23,970	2,138,632,400
Biobased Plastic Bottles and Packaging	30	3,217,300
Textiles	2,430	104,769,000
MS	**47,040**	**3,140,885,900**
Agriculture and Forestry	9,020	627,566,900
Biobased Chemicals	210	54,481,100
Biorefining	<10	82,400
Enzymes	<10	<100
Forest Products	35,330	2,313,538,800
Biobased Plastic Bottles and Packaging	10	819,100
Textiles	2,430	137,324,700
MT	**6,920**	**489,457,600**
Agriculture and Forestry	2,130	110,000,900
Biobased Chemicals	20	1,796,900
Biorefining	10	1,005,700
Enzymes	150	23,766,500
Forest Products	4,090	335,905,000
Biobased Plastic Bottles and Packaging	<10	39,200
Textiles	200	4,257,100

State	Direct Employment	Direct Value Added
NC	**109,970**	**9,507,653,500**
Agriculture and Forestry	8,090	519,427,300
Biobased Chemicals	1,140	434,004,300
Biorefining	<10	431,000
Enzymes	4,950	2,439,397,100
Forest Products	75,190	5,042,784,900
Biobased Plastic Bottles and Packaging	50	4,805,300
Textiles	21,550	1,349,550,600
ND	**4,230**	**366,016,000**
Agriculture and Forestry	590	26,566,600
Biobased Chemicals	10	5,091,300
Biorefining	20	4,526,200
Enzymes	310	132,004,400
Forest Products	3,330	249,604,000
Biobased Plastic Bottles and Packaging	<10	163,200
Textiles	180	9,714,500
NE	**8,130**	**819,106,200**
Agriculture and Forestry	1,160	39,801,000
Biobased Chemicals	120	55,221,400
Biorefining	10	934,200
Enzymes	1,990	839,592,400
Forest Products	5,700	351,509,100
Biobased Plastic Bottles and Packaging	10	695,500
Textiles	500	23,832,000
NH	**10,360**	**649,174,300**
Agriculture and Forestry	3,400	156,072,500
Biobased Chemicals	60	12,060,100
Biorefining	<10	149,100
Enzymes	840	123,415,800
Forest Products	4,550	261,957,600
Biobased Plastic Bottles and Packaging	10	976,100
Textiles	1,500	97,425,200

State	Direct Employment	Direct Value Added
NJ	**27,000**	**2,319,977,600**
Agriculture and Forestry	1,630	49,898,700
Biobased Chemicals	1,020	286,593,600
Biorefining	<10	808,100
Enzymes	2,940	706,606,700
Forest Products	19,230	1,543,611,200
Biobased Plastic Bottles and Packaging	40	3,940,600
Textiles	4,860	281,940,600
NM	**4,810**	**230,743,500**
Agriculture and Forestry	1,160	52,489,300
Biobased Chemicals	30	3,369,000
Biorefining	<10	<100
Enzymes	30	3,698,100
Forest Products	3,280	164,950,700
Biobased Plastic Bottles and Packaging	<10	65,200
Textiles	320	9,488,000
NV	**5,250**	**296,890,700**
Agriculture and Forestry	150	3,009,400
Biobased Chemicals	60	9,277,800
Biorefining	<10	37,800
Enzymes	20	2,017,000
Forest Products	4,330	253,346,000
Biobased Plastic Bottles and Packaging	10	601,400
Textiles	700	30,387,500
NY	**60,730**	**5,353,209,300**
Agriculture and Forestry	4,670	177,507,300
Biobased Chemicals	790	281,127,100
Biorefining	10	1,123,500
Enzymes	3,980	1,305,047,500
Forest Products	39,770	2,823,406,600
Biobased Plastic Bottles and Packaging	60	5,195,300
Textiles	12,600	973,039,000

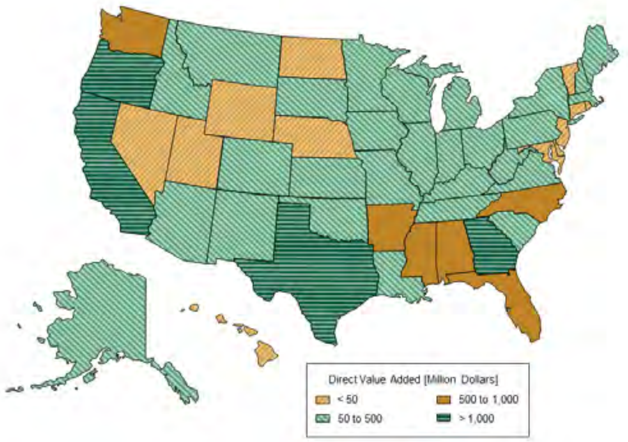
State	Direct Employment	Direct Value Added
OH	**65,560**	**5,167,738,300**
Agriculture and Forestry	6,500	324,182,800
Biobased Chemicals	1,740	629,064,200
Biorefining	10	2,936,900
Enzymes	3,670	916,901,800
Forest Products	53,750	3,995,292,400
Biobased Plastic Bottles and Packaging	110	9,943,500
Textiles	3,700	219,994,400
OK	**10,680**	**1,046,137,000**
Agriculture and Forestry	2,780	138,127,800
Biobased Chemicals	120	50,596,600
Biorefining	<10	360,700
Enzymes	130	39,300,600
Forest Products	6,990	773,246,900
Biobased Plastic Bottles and Packaging	10	591,000
Textiles	920	79,355,900
OR	**46,940**	**4,210,854,000**
Agriculture and Forestry	13,460	1,112,351,000
Biobased Chemicals	120	21,926,400
Biorefining	<10	43,100
Enzymes	490	96,848,500
Forest Products	31,700	2,979,992,500
Biobased Plastic Bottles and Packaging	10	930,600
Textiles	1,530	63,355,700
PA	**90,380**	**8,420,451,700**
Agriculture and Forestry	10,850	483,107,800
Biobased Chemicals	1,110	230,228,100
Biorefining	<10	83,700
Enzymes	5,030	1,502,424,800
Forest Products	68,480	6,128,075,500
Biobased Plastic Bottles and Packaging	80	8,021,000
Textiles	6,670	327,652,500

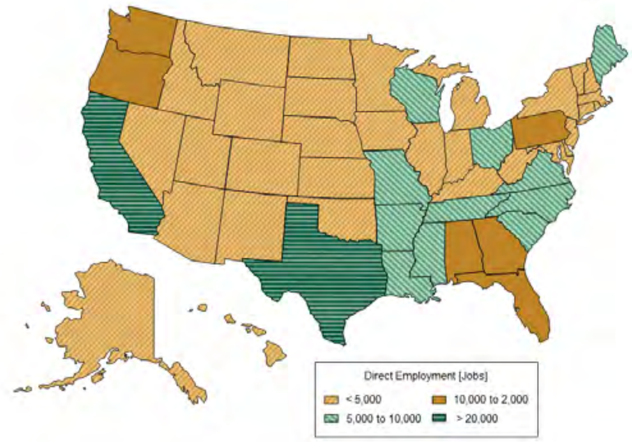
State	Direct Employment	Direct Value Added
RI	**11,790**	**733,745,900**
Agriculture and Forestry	140	3,422,500
Biobased Chemicals	90	14,118,600
Biorefining	<10	<100
Enzymes	80	8,537,000
Forest Products	2,680	187,272,500
Biobased Plastic Bottles and Packaging	<10	518,100
Textiles	1,500	76,529,200
SC	**42,910**	**4,578,210,100**
Agriculture and Forestry	5,380	348,960,000
Biobased Chemicals	690	176,429,600
Biorefining	<10	196,800
Enzymes	930	148,052,100
Forest Products	26,660	3,295,172,900
Biobased Plastic Bottles and Packaging	30	3,762,000
Textiles	10,390	797,229,600
SD	**7,750**	**403,865,300**
Agriculture and Forestry	1,040	57,033,100
Biobased Chemicals	60	15,121,900
Biorefining	<10	103,200
Enzymes	630	194,458,900
Forest Products	6,270	317,686,100
Biobased Plastic Bottles and Packaging	<10	255,000
Textiles	420	16,446,500
TN	**54,470**	**4,968,736,600**
Agriculture and Forestry	6,060	336,104,100
Biobased Chemicals	880	217,653,000
Biorefining	10	4,134,000
Enzymes	710	106,339,400
Forest Products	41,580	4,130,803,400
Biobased Plastic Bottles and Packaging	40	2,535,300
Textiles	5,790	299,549,800

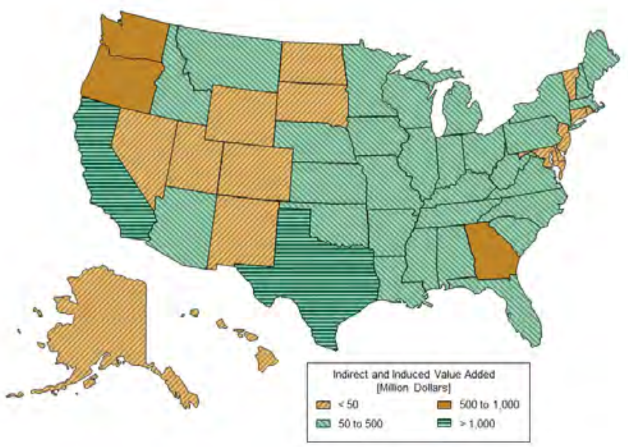
State	Direct Employment	Direct Value Added
TX	**115,830**	**8,928,712,500**
Agriculture and Forestry	33,620	2,567,280,400
Biobased Chemicals	2,140	567,545,900
Biorefining	10	4,278,700
Enzymes	7,160	2,075,290,700
Forest Products	71,020	5,227,052,300
Biobased Plastic Bottles and Packaging	70	6,452,300
Textiles	9,020	332,998,700
UT	**13,630**	**1,035,959,600**
Agriculture and Forestry	530	11,311,600
Biobased Chemicals	90	26,595,900
Biorefining	<10	13,900
Enzymes	10	2,149,100
Forest Products	11,550	959,475,900
Biobased Plastic Bottles and Packaging	10	807,200
Textiles	1,480	42,002,200
VA	**46,240**	**3,648,421,500**
Agriculture and Forestry	6,530	349,493,200
Biobased Chemicals	490	145,812,900
Biorefining	<10	163,600
Enzymes	980	303,643,400
Forest Products	35,180	2,712,624,300
Biobased Plastic Bottles and Packaging	30	3,462,100
Textiles	4,130	408,126,400
VT	**6,520**	**280,261,100**
Agriculture and Forestry	1,630	48,513,500
Biobased Chemicals	50	3,820,400
Biorefining	<10	11,800
Enzymes	50	3,297,500
Forest Products	4,440	216,732,800
Biobased Plastic Bottles and Packaging	<10	269,600
Textiles	410	11,330,100

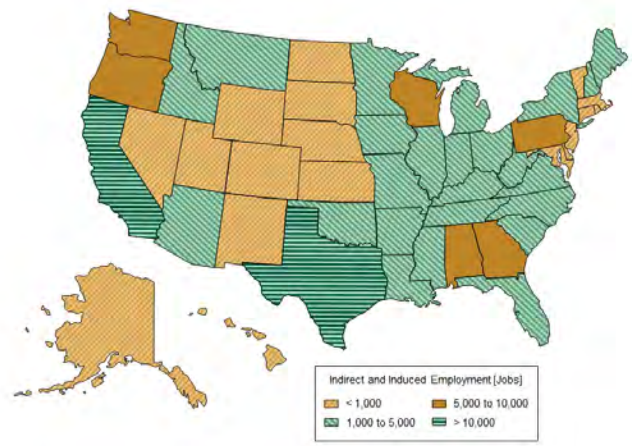
State	Direct Employment	Direct Value Added
WA	**47,670**	**4,128,580,700**
Agriculture and Forestry	12,530	919,387,400
Biobased Chemicals	190	35,525,100
Biorefining	<10	577,200
Enzymes	1,320	210,217,900
Forest Products	31,060	2,901,454,000
Biobased Plastic Bottles and Packaging	20	1,699,400
Textiles	2,980	121,585,600
WI	**79,400**	**6,957,465,400**
Agriculture and Forestry	7,570	292,321,200
Biobased Chemicals	550	150,709,200
Biorefining	<10	84,200
Enzymes	3,390	683,161,800
Forest Products	67,390	5,952,205,000
Biobased Plastic Bottles and Packaging	90	7,712,500
Textiles	2,280	143,154,800
WV	**12,890**	**730,583,700**
Agriculture and Forestry	4,340	200,864,100
Biobased Chemicals	200	44,462,500
Biorefining	<10	<100
Enzymes	700	123,056,100
Forest Products	8,170	480,872,300
Biobased Plastic Bottles and Packaging	10	535,600
Textiles	200	6,159,400
WY	**2,120**	**78,835,100**
Agriculture and Forestry	880	28,339,000
Biobased Chemicals	20	5,004,700
Biorefining	10	485,000
Enzymes	30	3,056,500
Forest Products	1,080	37,773,900
Biobased Plastic Bottles and Packaging	<10	42,800
Textiles	140	7,213,400

Agriculture and Forestry Sector

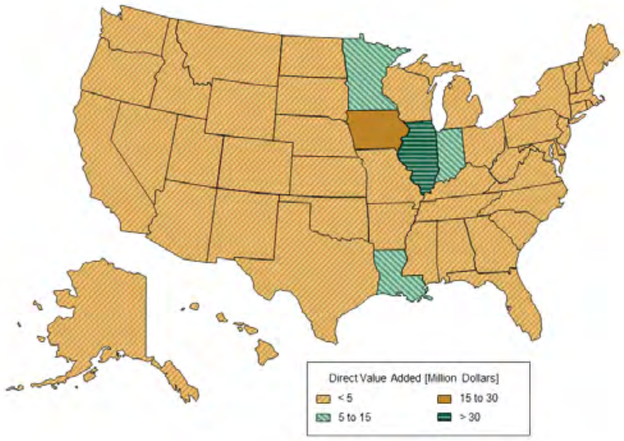


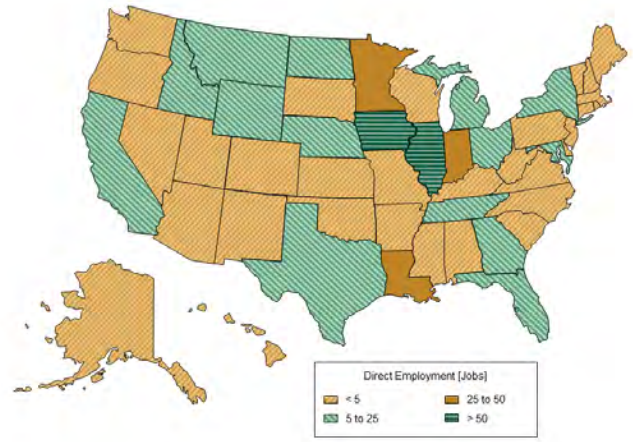


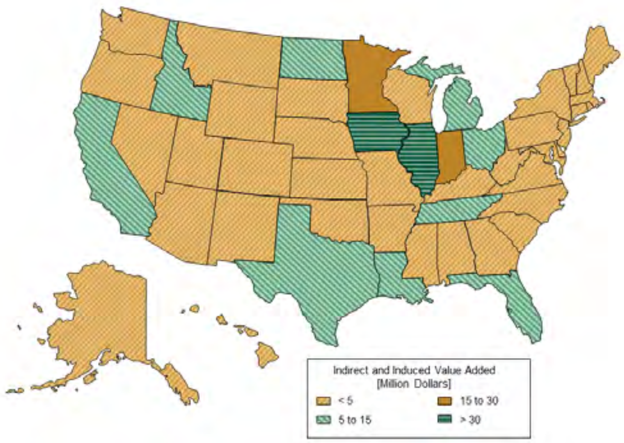


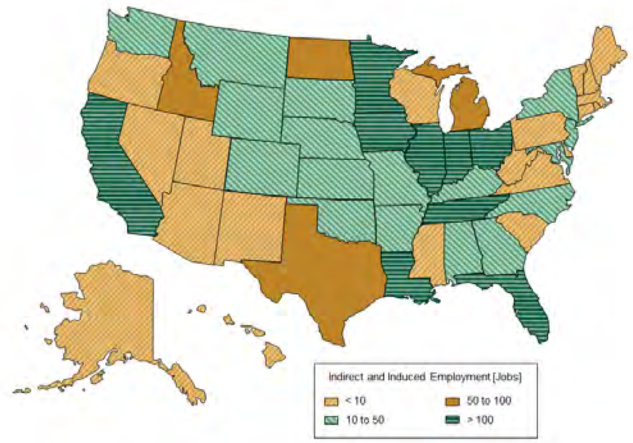


Biorefining Sector

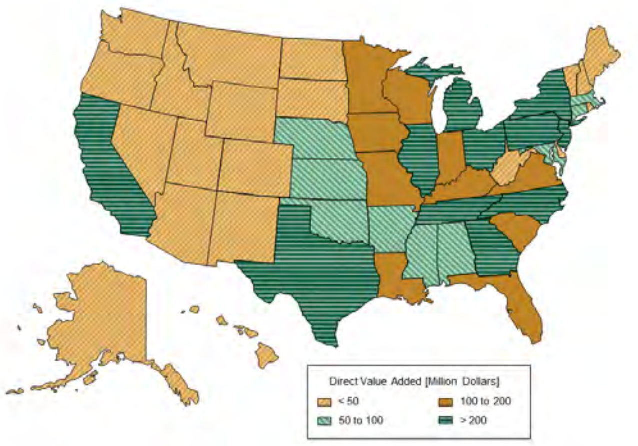


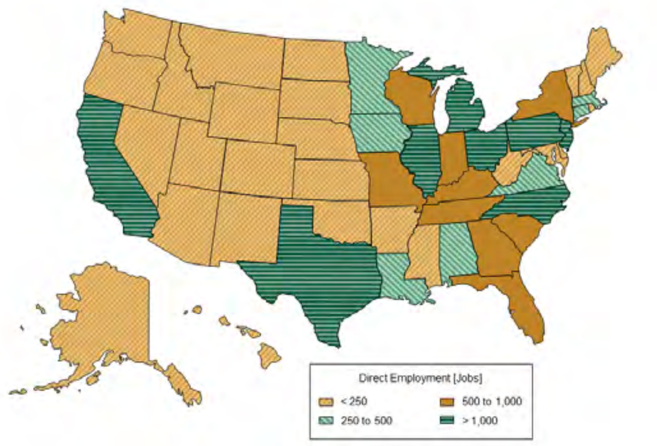


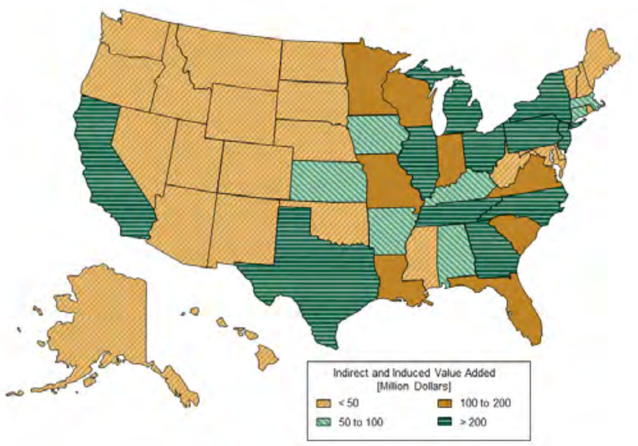


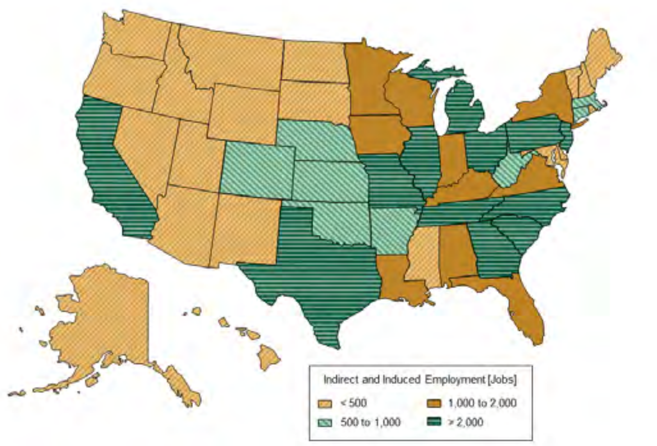


Biobased Chemicals Sector

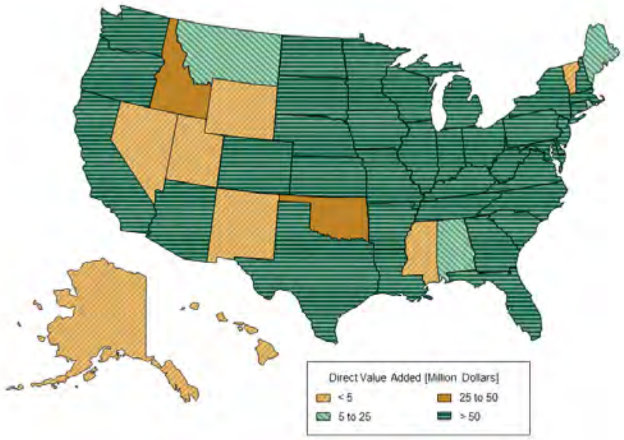


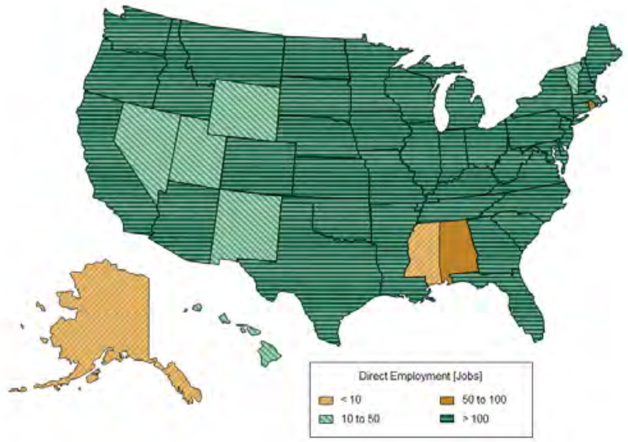


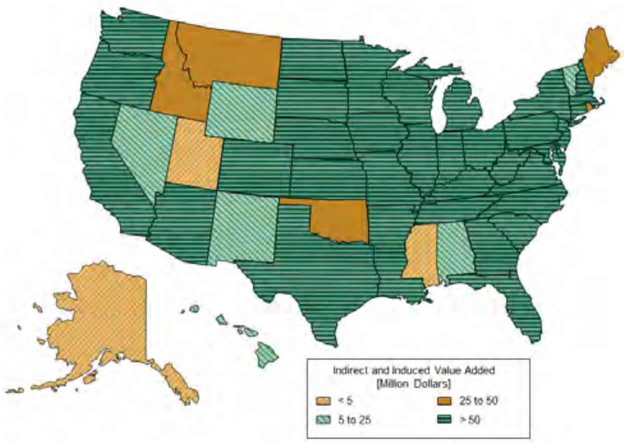


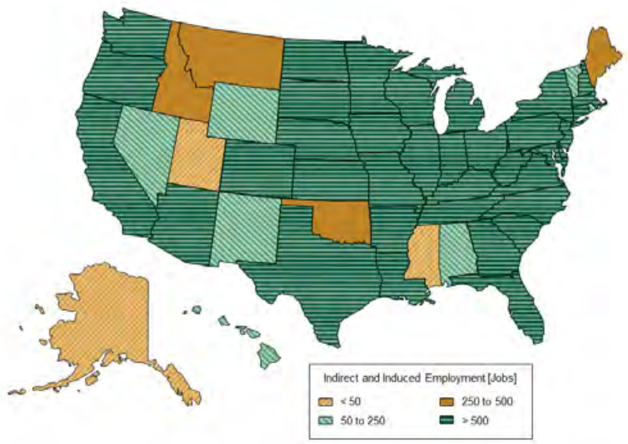


Enzymes Sector

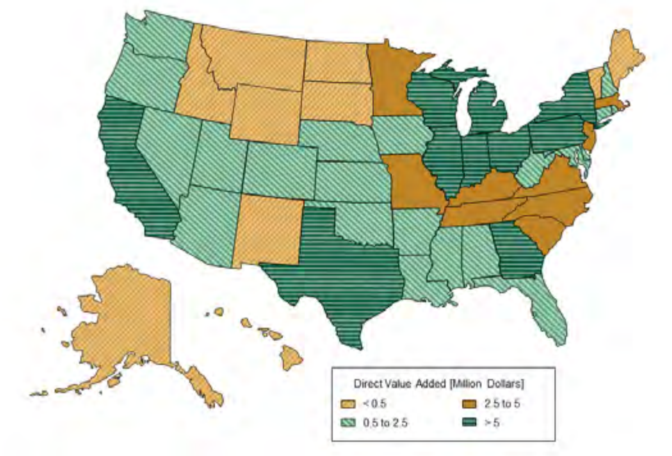


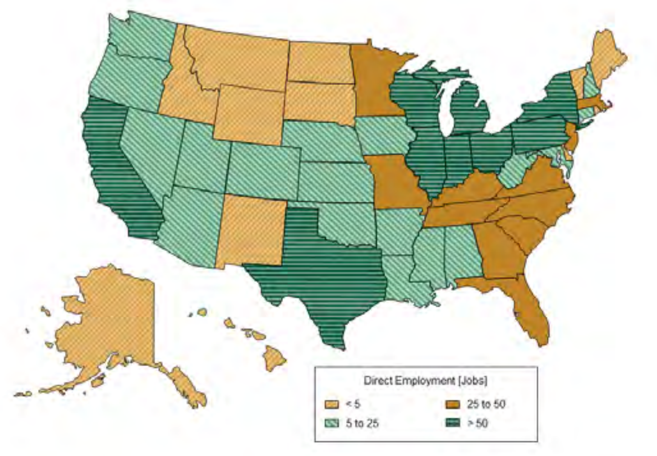


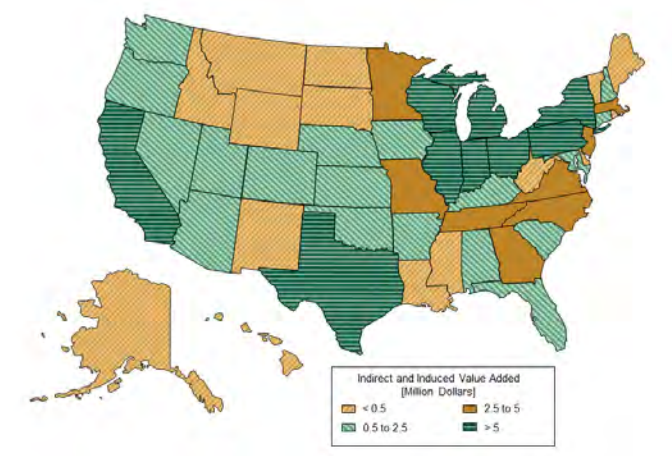


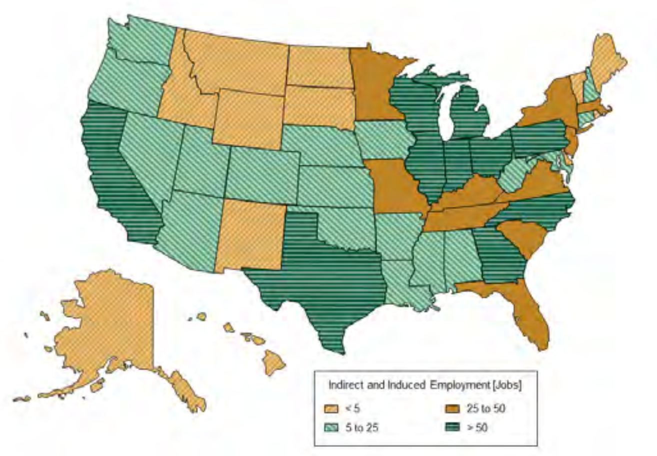


Biobased Plastic Bottles and Packaging Sector

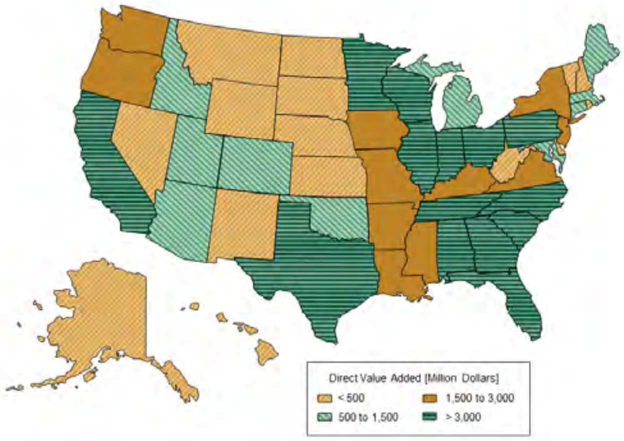


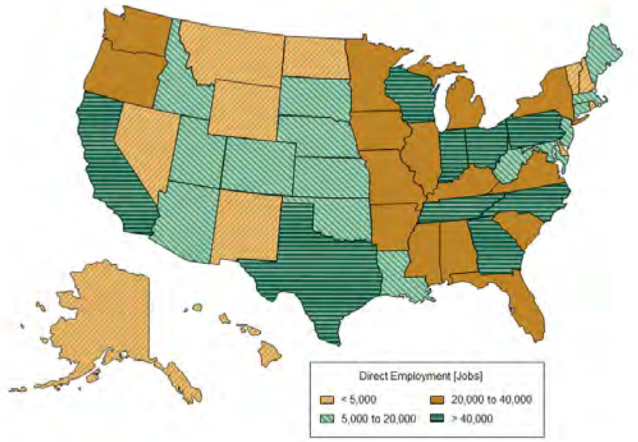


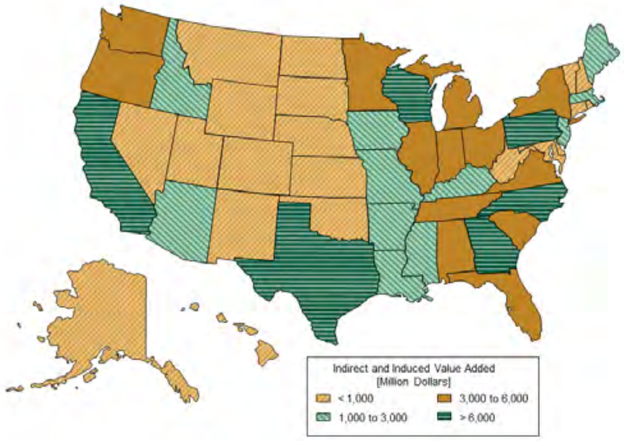


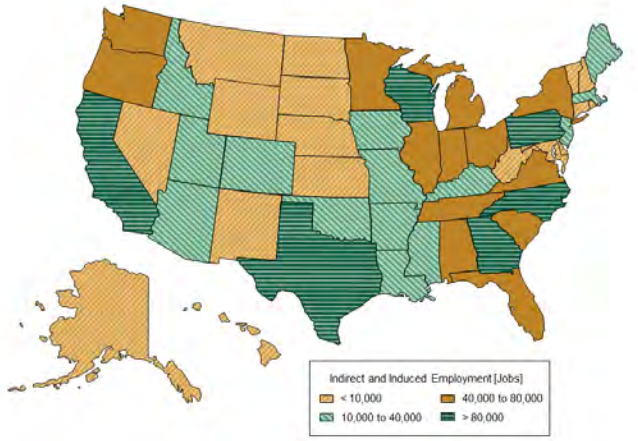


Forest Products Sector









Textiles Sector